MTC200 / MT-CNC

NC Programming Instructions

17VRS

Application Manual

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Purpose of the document This document describes the software version 005-17VRS.

In earlier software versions (Docu. No. 109-0668-4183-xx), some of the functions that are described here are not contained at all, or in a restricted version only.

Configuration control

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1 General Information

1.1 General Information

A CNC (Computer Numerical Control) is a special computer used to control a machine tool, robot or transfer system. Like a personal computer, the CNC control has its own operating system, which is specifically designed for numerical applications, as well as so-called control software installed on this operating system.

The controller software translates the CNC-program into a language which the controller can understand.

Details relating to a particular CNC machine tool, robot, or transfer system may be found in the machine builder's manual. The machine builder's information takes precedence over the information provided in this Programming Manual.

The programming examples are based on DIN 66025/ISO Draft 6983/2 along with the additional features implemented by INDRAMAT GmbH.

All geometric volumes are metric.

Combinations in the NC syntax and other functions which are not described in this programming manual may also execute on the controller. However, we make no warranties as to the proper functioning of these combinations and functions upon initial shipment and in the event of service.

We reserve the right to make changes based on technical advancements.

This Programming Manual is valid for the CNC having:

Graphical user interface effective version:	05.17/VRS
Operating software effective version:	03.17/VRS

Note Boxes identified by this symbol describe a specific functional behavior which is dependent on parameter settings.

1.2 Program and Data Organization

Data structure of the CNC with user interface on an IBM-PC and an SOT (stations operator terminal).

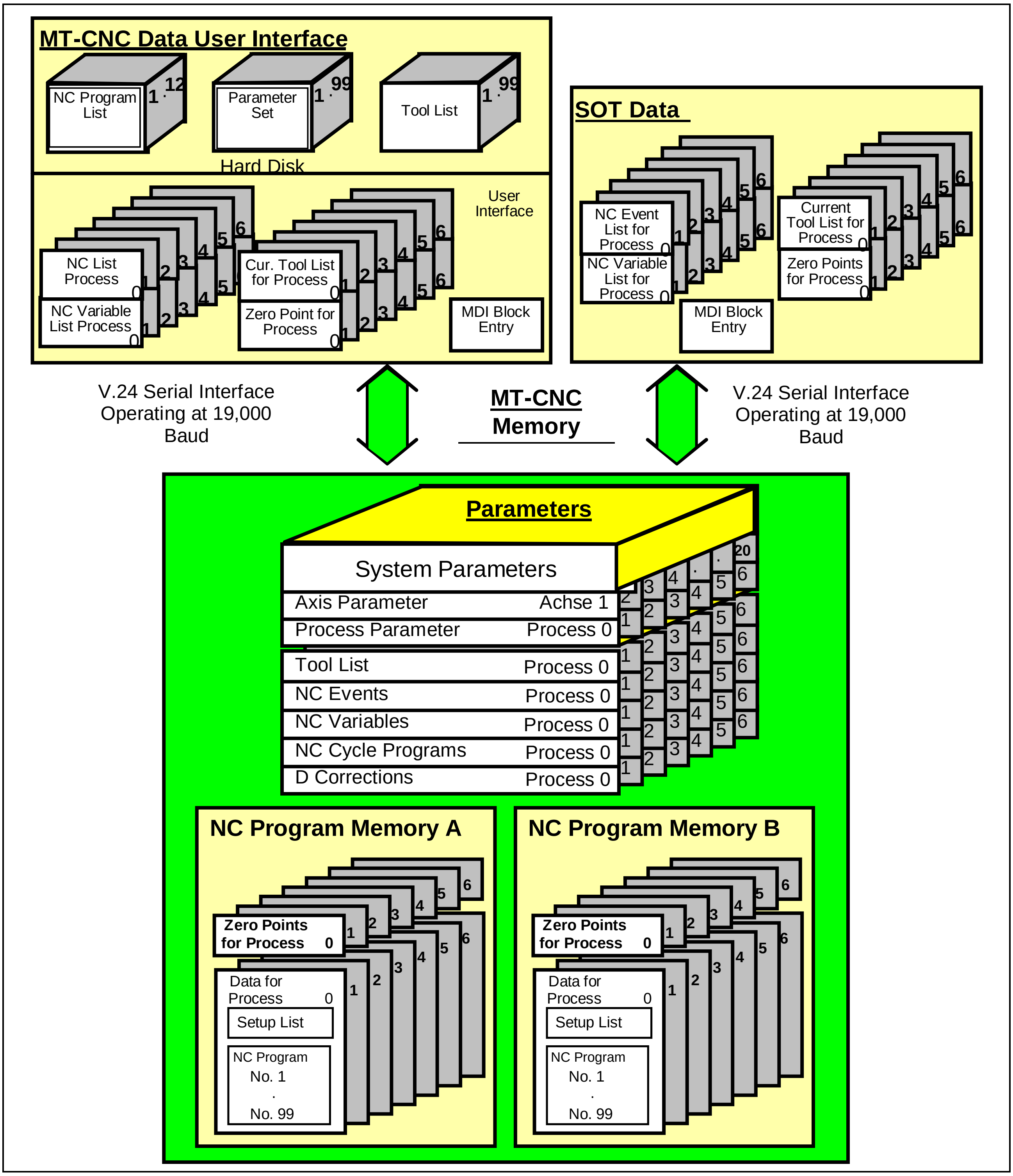


Fig. 1-1: CNC data organization

Approximately 400KB available memory is present on the basic version of the CNC. As shown in Figure 1-1, the CNC-memory is divided into several areas. The individual areas are described briefly in the following sections.

The CNC controller is adapted to the given machine or system by means of parameters. Up to 99 different parameter sets can be managed on the user interface.

The parameters are divided into the following areas:

System parameters The system parameters define how many processes and axes need to be managed by the CNC controller as well as what type of tool management system is present.

Process parameters The process-specific data, for example the default plane, programmable and maximum displayable places to the right of the decimal point, maximum speed for contour mode, etc. are specified in the process parameters.

Axis parameters The axis is assigned to specific processes in the axis parameters; and the corresponding axis limit data—for example, maximum axis speed, travel limits—are defined here.

A detailed description of the system, process and axis parameters may be found in the *System Parameter Reference Manual* document.

Tools list The tool list for a process contains the actual tool data for all tools assigned to the process, and it therefore represents an image of the magazine which is present at the station. Up to 99 different tool lists can be managed on the user interface. The NC commands for tool handling are described in Chapter 8 "*Commands for Tool Management*." A complete description of all data and functions relating to tools is provided in the sections on *"Tool Management"* and *"Tool Data Management."*

NC events NC events are binary variables which can be used by the NC-program. A detailed description of NC-events and event-dependent functions is provided in Chapter 7, "NC Events".

NC-Variable An NC variable represents a numerical value which is capable of changing. A total of 1792 NC-variables are available in the CNC (256 NC-variables for each process). Chapter 10, "*Programming Subroutines and Cycles*," provides a detailed description of what can be accomplished with NC-variables.

NC cycle programs A specific memory area is available in the CNC for NC cycle programs supplied by the machine builder and INDRAMAT GmbH. Additional information on NC cycle programs is provided in the manual on "*NC Cycles*."

D corrections The D-corrections are additive relative to the tool geometry data registers. The D-corrections act in an additive manner relative to the existing geometry registers L1, L2, L3 and R. 99 D-corrections are available for each of the 7 processes. Each D-correction contains the L1, L2, L3 and R registers. The assignment of values in the D-correction register can be accomplished using the CNC operator interface or the SOT.

NC program package An NC-program package contains all necessary Tool Setup Lists (tool specifications data) and NC-programs of all processes used in the machining work. Up to 12 different NC-program packages can be managed on the user interface. Dividing the NC-memory into two areas, A and B, permits two NC-program packages to be managed simultaneously in the CNC. The decision as to which of the two NC-program packages is to be run is made by the operator via the user interface or via the SPS. While one NC-program package is already running, a second NC-program package can be loaded into the controller's memory. This will overwrite any NC-program package that may already be present in the controller.

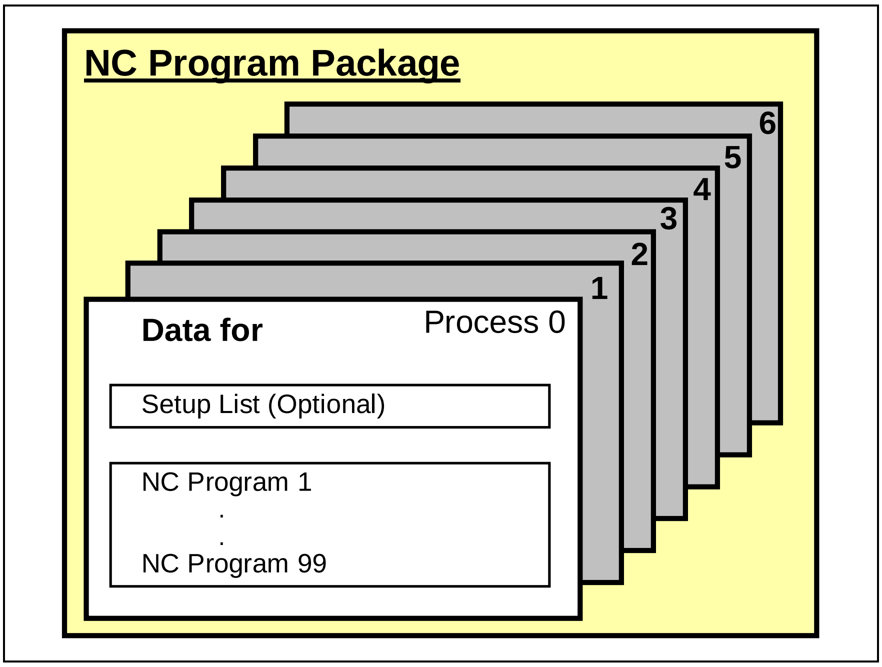


Fig. 1-2: NC program package

Tool setup list

The tool setup list contains a tool data set for each T number used in the NC-program. This tool data set defines which tool is to be used and which specifications this tool must meet. If the machine tool builder determines that a setup list is not required, the T number together with its corresponding data set is used in the tool list. The setup list should be entered before creating the program, however no later than during creation of the program. Additional information on the setup list is provided in the manuals on "*Tool Management*" and "*Tool Data Management*."

The CNC provides up to 60 zero points (10 *(G54..G59)) for each process. The zero points are assigned to the currently active 'A' or 'B' NC-program memory in the CNC-memory. Entries in the zero point table on the operator interface are always assigned to the currently active NC-program memory.

2 NC Program

2.1 Organization of the Tool Setup Lists

A tool setup list can be created for any process which uses tool. This list allows any given tool names or tool numbers to be assigned to the T numbers used in the NC-program. The Setup List also contains the tool specification data. Setup Lists can be organized to be *station-specific* or *program-specific*.

Station-specific organization

up to 7 tool setup lists (1 per process) are possible.

Program-specific organization

up to 693 tool setup lists (7 processes * 99 tool setup lists) are possible.

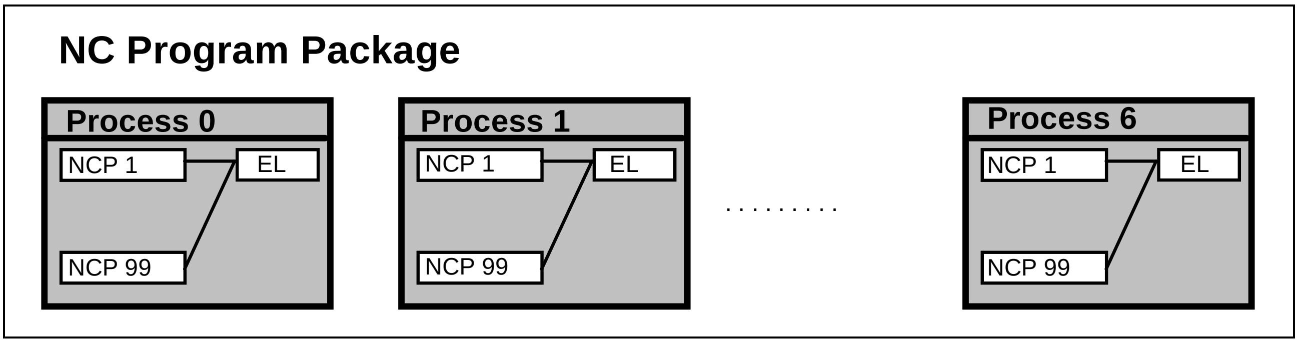


Fig. 2-1:Setup Lists with station-specific organization

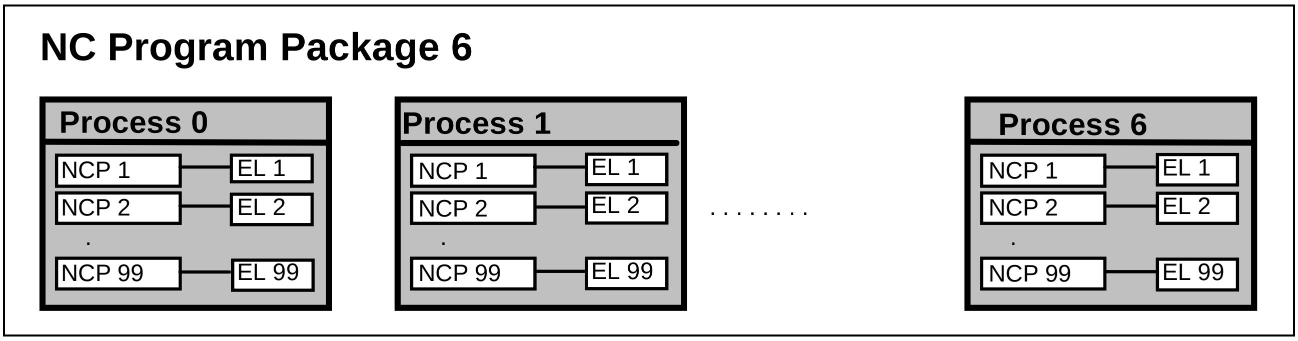


Fig. 2-2: Setup Lists with program-specific organization

When program-specific organization of Setup Lists is used, the size of the program memory available to NC-programs is decreased!

Note: The station- or program-specific Setup Lists are defined in the system parameters.
The machine builder must declare in the SPS program whether the CNC will work with or without Setup Lists!

The setup list should be completed when the NC-program is written, however no later than when the NC-program is transferred into the system. This is the only way that names referencing T numbers in the NC-program can be meaningful. The final assignment of the tools located in the tool magazine to the T numbers used in the program is made when the program is initiated (optional Tool Check).

2.2 Program Organization

The NC-program and its command set is based on DIN 66025 / ISO Draft 6983/2 together with specific INDRAMAT enhancements. 99 NC-program packages can be managed on the user interface. Each NC-program package can contain up to 99 NC-programs for each process. Thus, an NC-program package can consist of 693 NC-programs (7 processes * 99 NC-programs).

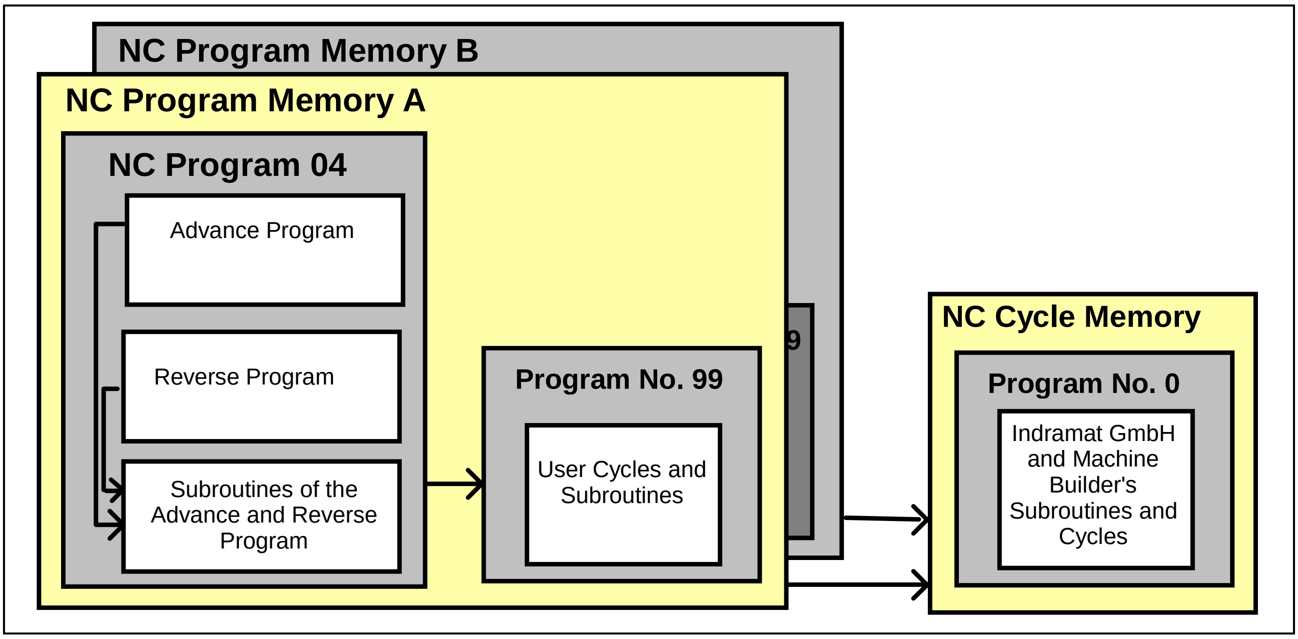


Fig. 2-3: NC program organization

An NC-program can contain both

- the *forward* and
- the *reverse program* for an operation.

If subroutines for the reverse program are not found in the current NC-program, a search using the number 99 is automatically performed in the NC-program. If the subroutine for the cycle is not located in program number 99, a search is performed in program number 0.

Program No. 99

Program number 99 is suitable for frequently used program modules such as user cycles, the tool change subroutine, or the reverse program.

Program No. 0

Program number 0 is reserved for the INDRAMAT machining cycles and for the machine builder's cycles. A detailed description of the INDRAMAT machining cycles is provided in the documentation on "NC-cycles."

NC-programs are assigned to a given process.

- The NC-program assigned to process number 0 (management process) is called a part program.
- The NC-programs for processes 1 to 6 are called process programs. From this point on they are referred to as **NC-program**

If a system consists of a number of processes, the part program in process 0 handles the coordination of all the other processes.

Advance program

An advance program consists of a complete sequence of NC-blocks needed to produce a workpiece. In addition to the path information needed for machining, the advance program also contains all additional auxiliary functions and branch/jump commands for subroutines and cycles.

The advance program ends with the NC-block in which RET (end of program with reset) is programmed.

Example

T4 BSR .M6	Tool change SF D50
T8 MTP	Next machining tool
G00 G90 G54 X0 Y0 Z50 S5000 M03	Home position
G01 X46 Y144 Z2	Pos. at safety distance
.	
.	
RET	

Reverse Program

A reverse program consists of a complete series of NC-blocks which describe an operation sequence which is to be performed to establish the reference or home position of a station, regardless of how complicated the traverse moves required for it might be. As a rule, a reverse program is programmed in program number 0 or number 99 so that it can be used as a subroutine to establish the reference point or home position of a station or machine.

The reverse program begins with the NC-block in which the label .HOME is programmed. Other entry points for the reverse program can be defined in the advance program with the aid of reverse vectors (see Chapter 9 "Commands for Controlling Processes and Programs ").

When reverse programming is done in a systematic manner without any omissions, the operator can extract the station(s) or the machine from the most complicated machining situations and return to the initial position in the event of errors or malfunctions or in any given EMERGENCY STOP situation. This is done safely and without the risk of collision.

Example

.HOME	Global Homing
MRF	Go to tool magazine reference point
D0	Cancel D-corrections
G40 G47 G53 G90	Cancel overrides
G74 Z0 F1000	Go to Z axis reference point
G74 X0 Y0 F1000	Go to X and Y axis reference point
RET	

Note: It is not necessary to program a reverse program unless the machine builder has specified in the process parameters that a reverse program must be programmed.

2.3 Process-Specific Programming

The CNC is organized into a maximum of 7 processes. Each process has its own NC-block preparation which combines the data from the NC-program with data such as zero points, Setup Lists, etc.

The number of processes is declared in the system parameters. Or if more than 2 processes are declared, process 0 is generally used to synchronize the other processes.

Example

Use of a number of processes on a double-slide single-spindle lathe with a milling head:

- Process 0
  Synchronization of processes 1 and 2, coordinates whether the processes are working simultaneously and asynchronously or synchronously.
- Process 1
  Process 1 contains the X and Z axes for the upper turret head.
- Process 2
  Process 2 contains the X and Z axes for the lower turret head, the main spindle S1, the C axis, and spindle S2 as the driven tool spindle.

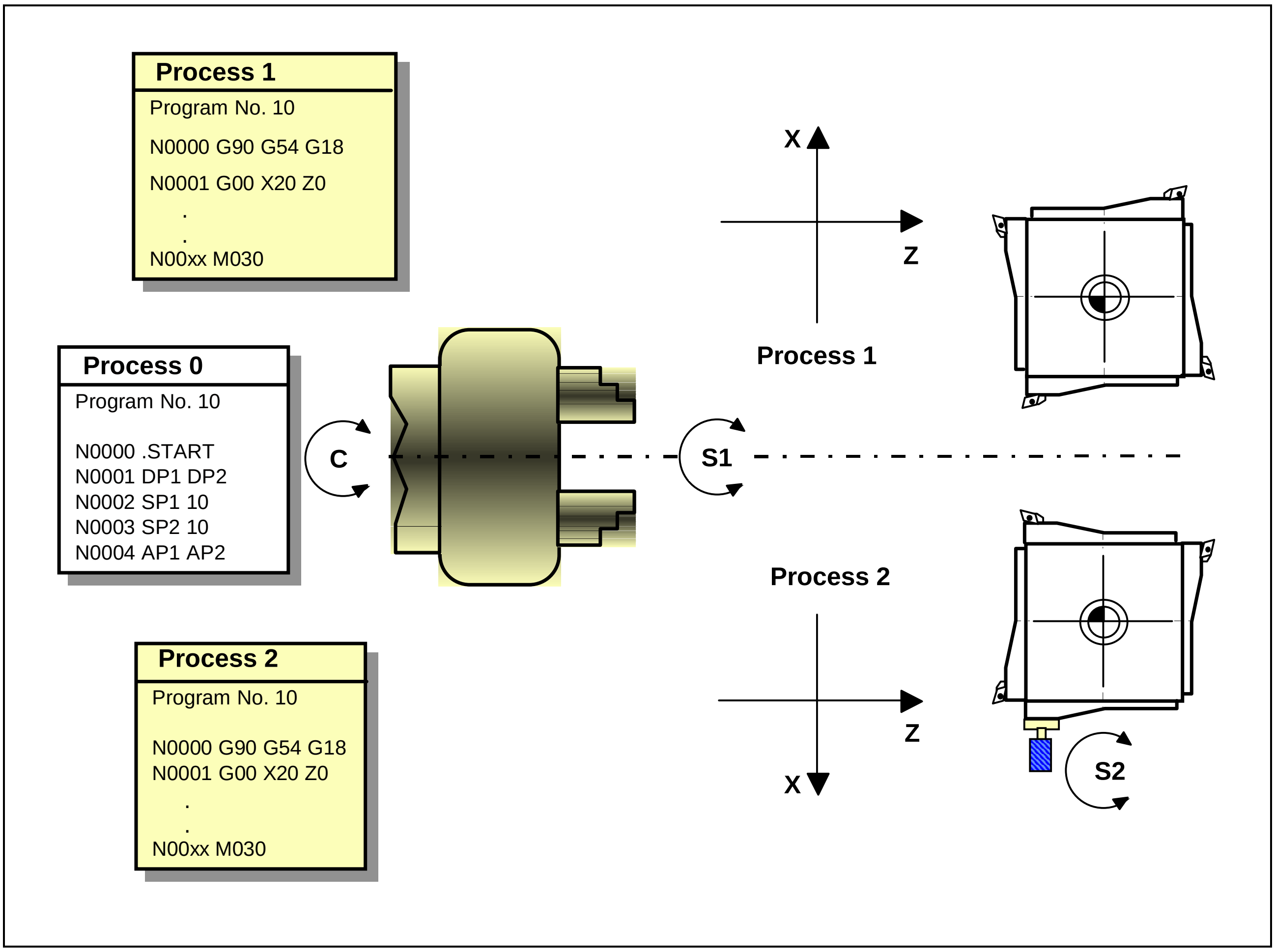


Fig. 2-4: Double-slide single-spindle lathe for milling work

2.4 Elements of an NC Block

An NC-block contains data for performing an operating step. The NC-block consists of one or more words as well as the NC control commands. The NC-block length must not exceed 240 characters, and it can be split among no more than four lines.

An NC-block is comprised of the following elements:

- NC-block number
- Branch label
- NC-words (NC control command(s))
- Message
- Remark in the program
- Remark in the source program

Structure of an NC-block

N0020	G54	G01	X50 Y60	F2000 S1500	M03
Program control command	Correction call	Traverse statement	Geometry statement	Technology statement	Auxiliary function
Block no.	**NC words (NC control commands)**				

CAUTION

All the elements of an NC-block except for function assignments must be separated by at least one space.

The priority for processing an NC-block in the NC-memory is as follows:

NC-block number	Label	Aux. function before motion	G codes	NC variables	Axis Values	Inter-polation para-meters	F values	S value	Aux. function after motion	Palette com-mands	Tool com-mands	Events	Pro-cess com-mands	Program control com-mands
N1234	**.ENDE**	**M03**	**G01**	**@100=x**	**X100 Y100**	**I0 J50**	**F1000**	**S800**	**M03**	**SEL 1**	**MTP T6**	**SE 5**	**DP 1**	**HLT**

NC Block Numbers

Syntax **N××××** **× = 0..9**

Each NC-block begins with the letter *N* followed by a 4-digit decimal integer number as the NC-block number. The numbering of NC-blocks in an NC-program always starts at N0000. The numbering of NC-blocks is automatically generated by the user interface when programming in 1-step intervals.

When NC-blocks are inserted via the user interface, all subsequent NC-blocks are automatically renumbered.

NC blocks that can be skipped

In an NC-controlled machine tool, a simple way must be provided to skip NC-blocks so that certain functions such as gaging operations, part loading and unloading and the corresponding program NC-blocks can be allowed to proceed in a controlled manner or can be skipped.

Blocks in a part program which are not to be processed each time the program is executed must be identified by a slash "/" at the beginning of the NC-block. These NC-blocks are only processed when the user activates the skip function by pressing the Skip NC-block machine control key.

Example

```
N0100 G01 X20 F400
;Additional gaging cut
N0101 / G00 X300 M03 S6500
N0102 / G01 Z45 F100
N0103 / G00 X370 M05
N0104 / HLT
```

In cyclical mode, the CNC skips a series of NC-blocks if the operator activates the skip function before the first NC-block in this sequence is processed. If the user presses the Skip NC-block machine control key while a sequence of NC-blocks containing the skip marks is processing, this will have no effect on processing in cyclical mode. The CNC continues to process regardless of this action.

During single-block processing mode, the CNC checks whether the skip function is active at the beginning of each NC-block. In contrast to cyclical mode, this gives the user the opportunity to control which individual NC-blocks are skipped.

CAUTION

The slash marks used to mark NC-blocks to be skipped, stop lookahead NC-block processing. Thus, contour mode is not possible with NC-blocks marked to be skipped.

2.5 NC Word

The NC-word contains the DIN 66025 instructions and various specific INDRAMAT enhanced commands.

The NC-word is divided into:

- geometric instructions ⇨ Axis positions X__ Y__
- technology instructions ⇨ Spindle speed, feed S__ F__
- Traverse instructions ⇨ Rapid traverse, circular interpolation G__ G__
- Auxiliary functions ⇨ Coolants, tools M__ T__
- Override calls ⇨ Tool overrides, zero points G__ G__
- Enhanced functions ⇨ Conditional branch, calculations

A word is comprised of the address letter and the numerical value with which specific machine moves and auxiliary functions are initiated.

Address letter

The address letter is generally a text character.

Numerical value

The numerical value can have signs and decimal points. The sign is located between the address letter and the numerical value. A positive sign does not need to be entered.

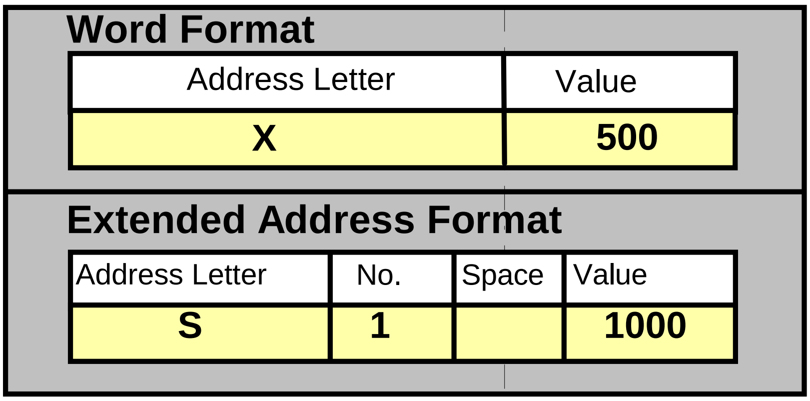


Fig. 2-5: Word syntax

Example

; Enhanced address structure for an X1 and Y1 axis	
G01 X1 50.45 Y1 35.456 F1000	Thread position 1
Z10	Z to safety distance
M103 S1 1000	1st spindle 1000 RPM

Note: There must be a blank between the address and the numeric value that is to be assigned.

The decimal point is fixed to achieved the resolutions shown below:

X0.00001	=	0.01 µm
X0.0001	=	0.1 µm
X0.001	=	1 µm

etc.

Leading or following zeros can be ignored in the decimal point format.

Decimal point entry is possible in the following addresses:

Address letters: I, J, K, P, S, F, contents of @xxx

Note: The maximum number of places to the right of the decimal point which can be programmed is set in the process parameters.

Branch Label

Syntax

.xxxxxx   **x = 0..9 , A..Z , a..z**

A branch label points to a branch-to label in a destination NC-block. A branch label is always present two times, once in the NC-block in which the branch occurs and once in the destination NC-block to which the branch is to be performed. A label always marks a program branch, regardless of whether the branch is conditional or unconditional.

The branch-to address (destination label) can be in the same NC-program. If the branch-to address is not found, a search is performed for the branch-to address in program no. 99 or program no. 0.

NOTE

Certain labels are reserved by their names for the INDRAMAT canned cycles and for those of the machine builder.

In terms of syntax, the label begins with a decimal point followed by at least one and no more than six legal characters. The syntax is not case sensitive. The * sign following the decimal point is reserved for INDRAMAT canned cycles. When a label is programmed in a NC-block, the label must be the first element in the NC-block after the number. A branch command using a label is considered to be a program control command, and, based on its priority, it is performed last.

Example

```
G54 G90 G00 X0 Z0
G04 F5
BSR .ENDE
RET
.ENDE
M05
G04 F1
RTS
```

Message

Syntax **[Text]**

Each NC-block can contain a message which will be displayed in the diagnostic menu (station window) in the user interface at the end of NC-block processing. The message in the diagnostics line remains active until it is overwritten by a new message. A so-called empty message must be programmed in order to clear the current message in the NC-diagnostics line. The message is also cleared from the NC-diagnostic line when a program initiates. An NC-block cannot contain more than one message.

A message is written in square brackets. It must not exceed a length of 48 characters. All ASCII characters may be used. The message can be inserted at any location in the NC-block; however, with the exception of the comment it is always the last function to execute.

Example

```
N1234 G01 G54, G90 [ Traverse X to safety distance ] F1000
N1235 X500
N1236 [ Traverse Z to safety distance ] G01 G51 G90 F1000
N1237 Z100
```

Hint

Syntax **(Text)**

Each NC-block can contain a hint. A hint is written in parentheses. It must not exceed a length of 80 characters. All ASCII characters may be used. The hint can be inserted at any desired location in the NC-block. The hint is transferred to the controller memory and is shown in the current NC-block display.

An NC-block cannot contain more than one hint and one message.

Example

```
N1234 G00 ( Traverse X to starting position ) X150
N1235 ( Traverse Z to starting position) G01 Z10
```

Limitation: Messages and hints must n o t be programmed between individual Preparatory G-functions.

Comment in the Source Program

Syntax **; Text**

Each NC-block can contain one comment in the source program which is introduced by a semicolon. All characters following the semicolon are interpreted as a comment. The term comment in the source program means that the comment is only present in the source program—that is, on the user interface—and not in the controller memory. Compared to messages and hints, this type offers the advantage of saving memory space in the controller.

If a semicolon is used at the very beginning of a NC-block, the entire NC-block is marked as a comment and a NC-block number is not assigned.

Example

```
N0050 G01 X250 Y100 F1000        6th drilling position
; Call centered drilling cycle
N0051 BSR .*ZENBO
```

Limitation: Comments in the source program must n o t be programmed between individual NC-words.

2.6 Available Addresses

Available address letters in the CNC:

A	Reserved for axis name	**P**	Angle
B	Reserved for axis name	**Q**	Auxiliary Q-function
C	Reserved for axis name	**R**	Radius
D	D-corrections	**S**	Spindle speed / position
E	Edge number	**T**	Tool number
F	Feed	**U**	Reserved for axis name
G	Preparatory G-functions	**V**	Reserved for axis name
H	Unassigned	**W**	Reserved for axis name
I	Interpolation parameter	**X**	Reserved for axis name
J	Interpolation parameter	**Y**	Reserved for axis name
K	Interpolation parameter	**Z**	Reserved for axis name
L	Unassigned	**@**	Variable
M	Auxiliary M-function	**RX**	Nominal radius around X
N	NC-block number	**RY**	Nominal radius around Y
O	Zero point database	**RZ**	Nominal radius around Z

An expanded address syntax is provided for the following addresses:

A(1..3)	Reserved for axis name	**B(1..3)**	Reserved for axis name
C(1..3)	Reserved for axis name	**U(1..3)**	Reserved for axis name
V(1..3)	Reserved for axis name	**W(1..3)**	Reserved for axis name
X(1..3)	Reserved for axis name	**Y(1..3)**	Reserved for axis name
Z(1..3)	Reserved for axis name	**S(1..3)**	Spindle speed / position

The NC syntax is not case sensitive; no distinction is made between upper and lower case. This means that "x400" can be used instead of "X400" when programming an axis position. However, for the sake of legibility, it is generally a good idea to write NC commands in upper case characters.

The full ASCII character set may be used for hints and messages.

3 Motion Commands, Dimension Inputs

3.1 Coordinate System

The coordinate system defines the location of a point or series of points in a plane or in space relative to two or three NC axes.

As a rule, the right-hand, orthogonal Cartesian coordinate system having axes X, Y and Z is used in NC technology. This system is defined relative to the main axes of the machine.

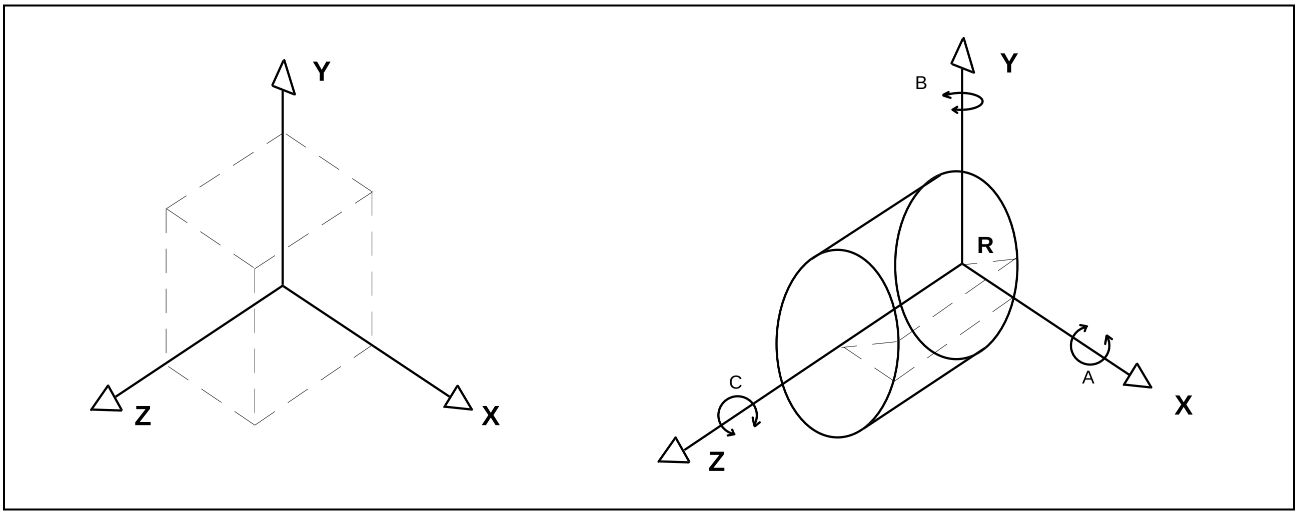


Fig. 3-1: Coordinate system

All other axes are defined relative to these 3 main axes. A, B and C are rotary or pivoting axes having X, Y or Z as their center axes.

The A axis rotates about the X axis, the B axis rotates about the Y axis, and the C axis rotates about the Z axis. The positive direction of rotation of rotary axes corresponds to clockwise rotation when viewed in the positive axis direction.

With milling machines, the main axes are generally named X, Y and Z. With lathes the names are defined as Z and X.

Note: The axis names can be freely defined via the axis parameters.

3.2 Motion Commands

The motion command or traverse instruction causes an axis to move or traverse. The motion command consists of the address letter of the axis address (for example, X, Y or Z) followed by the sign (+, -) to indicate the direction of motion, and the distance to be traversed, the coordinate value.

Syntax

Syntax:

Address Letter	Coordinate Value
Z	**100.5**

Address Letter	Equal Sign	Variable
X	**=**	**@120**

Address Letter	Space	Coordinate Value
X1		**245.65**

The coordinate value is comprised of:

- the sign,
- 6 or 5 places to the left of the decimal point,
- the decimal point
- 4 or 5 places to the right of the decimal point.

If no sign is programmed, the coordinate value is considered to be positive. If the coordinate value only has places to the left of the decimal point, the decimal point need not be entered. Leading or following zeros can be ignored.

If a decimal point is programmed, at least one place to the right of the decimal point must be stated.

The number of places to the left and right of the decimal point must not exceed 10 places.

In the notation using four places to the right of the decimal point, the maximum value range for coordinates is:

-214748.3648 to **+214748.3647**

or with five places to the right of the decimal point:

-21474.83648 to **+21474.83647**

3.3 Dimension Input

The motion commands for the axes can be entered in two different ways:

- As an absolute dimension input (G90) or
- as an incremental dimension input (G91).

Input Data as Absolute Dimensions 'G90'

With absolute dimension input all dimensions are stated relative to a fixed zero point. When the CNC-program boots, the initial setting is G90. G90 remains in effect until it is written over with G91. In the NC-program, G90 only needs to be programmed if one wishes to cancel G91.

Example

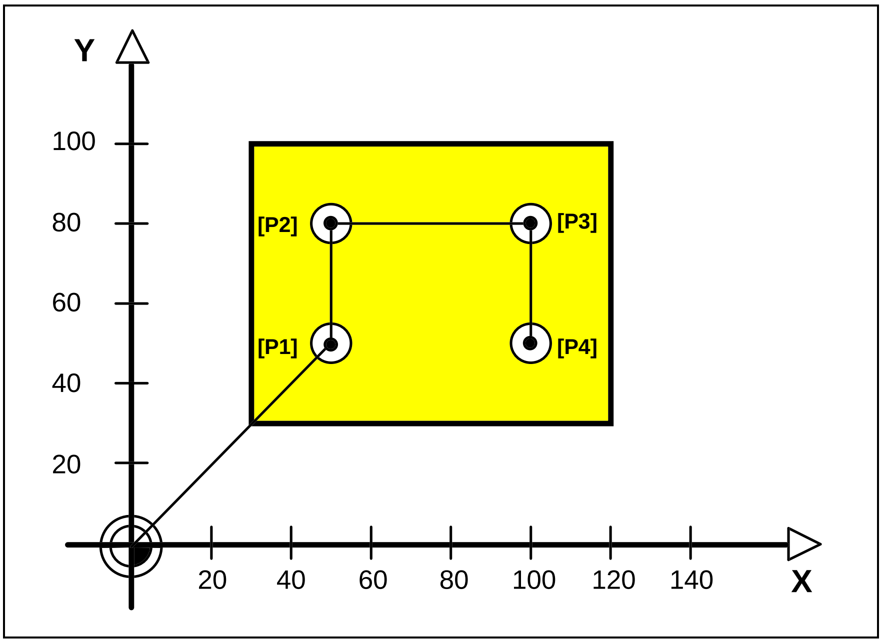


Fig. 3-2: Absolute dimension input

G00 G90 G54 X0 Y0 Z10 S1000 M03	Starting position
G01 X50 Y50 F500	[P1]
BSR .DRILL	Branch to drilling subroutine
Y80	[P2]
BSR .DRILL	Branch to drilling subroutine
X100	[P3]
BSR .DRILL	Branch to drilling subroutine
Y50	[P4]
BSR .DRILL	Branch to drilling subroutine
M05	Spindle OFF
RET	End of program
.DRILL	Drilling subroutine
G01 Z-10 F300	Drill to depth Z
G04 F2	Dwell time 2 seconds
Z3	Drill to safety distance
RTS	Return from subroutine

Input Data as Incremental Values 'G91'

Incremental positioning defines all subsequent dimensional entries as differences relative to the NC-block starting position.

G91 remains in effect until the end of the program or until it is overwritten by G90.

Example

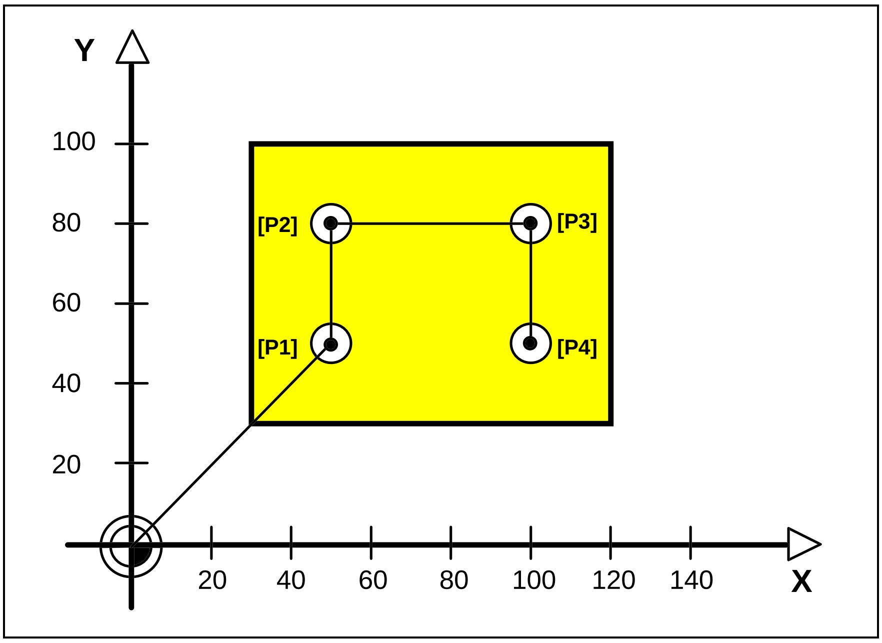


Fig. 3-3: Input data as incremental values

G00 G90 G54 X0 Y0 Z3 S1000 M03	Starting position
G01 G91 X50 Y50 F500	[P1]
BSR .DRILL	Branch to drilling subroutine
Y30	[P2]
BSR .DRILL	Branch to drilling subroutine
X50	[P3]
BSR .DRILL	Branch to drilling subroutine
Y-30	[P4]
BSR .DRILL	Branch to drilling subroutine
M05	Spindle OFF
RET	End of program
.DRILL	Drilling subroutine
G01 Z-13 F300	Drill to depth Z
G04 F2	Delay 2 seconds
Z13	Return to safety clearance
RTS	Return of subroutine

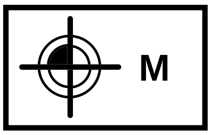
3.4 Zero Points

Zero points and various reference points used to establish workpiece geometry are defined on all numerically controlled machines.

Machine zero point

The machine zero point is located in a fixed position at the origin of the machine coordinate system, and it cannot be moved.

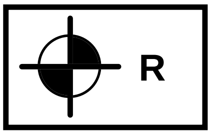
Icon for the machine zero point



Machine reference point

The machine reference point is a defined point located within the working range of the machine. It is used to establish a defined initial position after the machine is powered on. The machine reference point is established by the machine builder in each axis in which incremental positioning is used.

Icon for the reference point

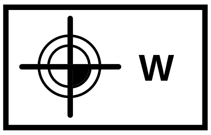


Note: The reference dimensions are set in the drive parameters

Workpiece zero point

The workpiece zero point is the origin of the workpiece coordinate system. The programmer establishes it as the program zero point which is used as the basis for all workpiece dimensions. The reference to the machine zero point is established by the zero offset value when the machine is set up.

Icon for the workpiece zero point



Examples

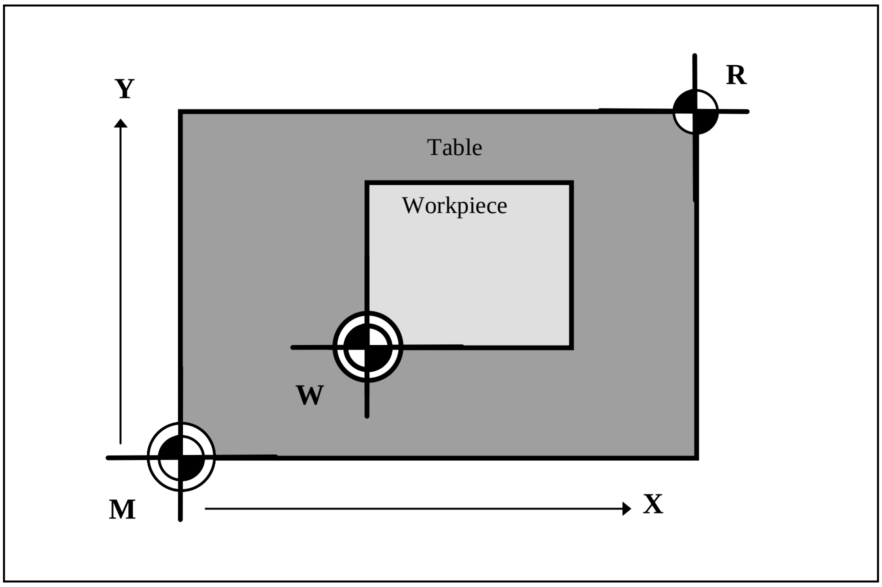


Fig. 3-4: Zero points—drilling/milling machine

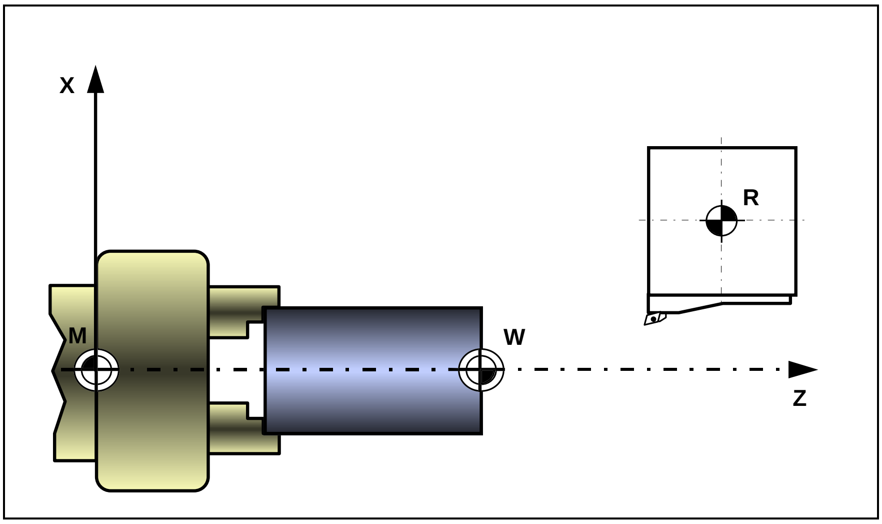


Fig. 3-5: Zero points—lathe (machining ahead of the center of rotation)

3.5 Zero Offsets

The zero offsets permit the origin of a coordinate axis to be offset by a given value relative to the machine zero point. The position of the machine zero point is permanently stored in the CNC-memory and is not changed by the zero offset.

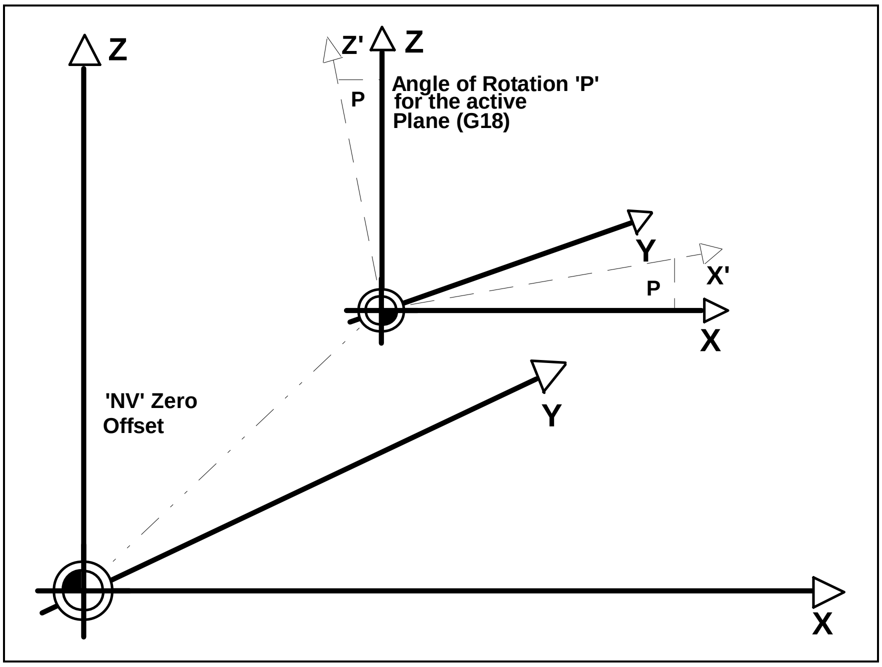


Fig. 3-6: Zero offset

The following zero offsets are provided in the CNC:

- Programmable absolute zero offset G50,
- Programmable incremental zero offset G51,
- Programmable workpiece zero point G52,
- Adjustable zero offsets G54 to G59 and
- adjustable general offset in the zero offset table.

The coordinate zero point of each NC axis can be placed at any desired coordinate position inside or even outside the respective traverse range with the aid of the zero offsets, G50, G51 and G54 to G59 and the workpiece zero point G52. This allows an identical NC-program to be processed at various machine positions.

The position of the machine zero point of each axis is declared in the drive parameters as the difference relative to the reference point. The value entered in the drive parameters corresponds to the coordinate value of the reference point in the machine coordinate system.

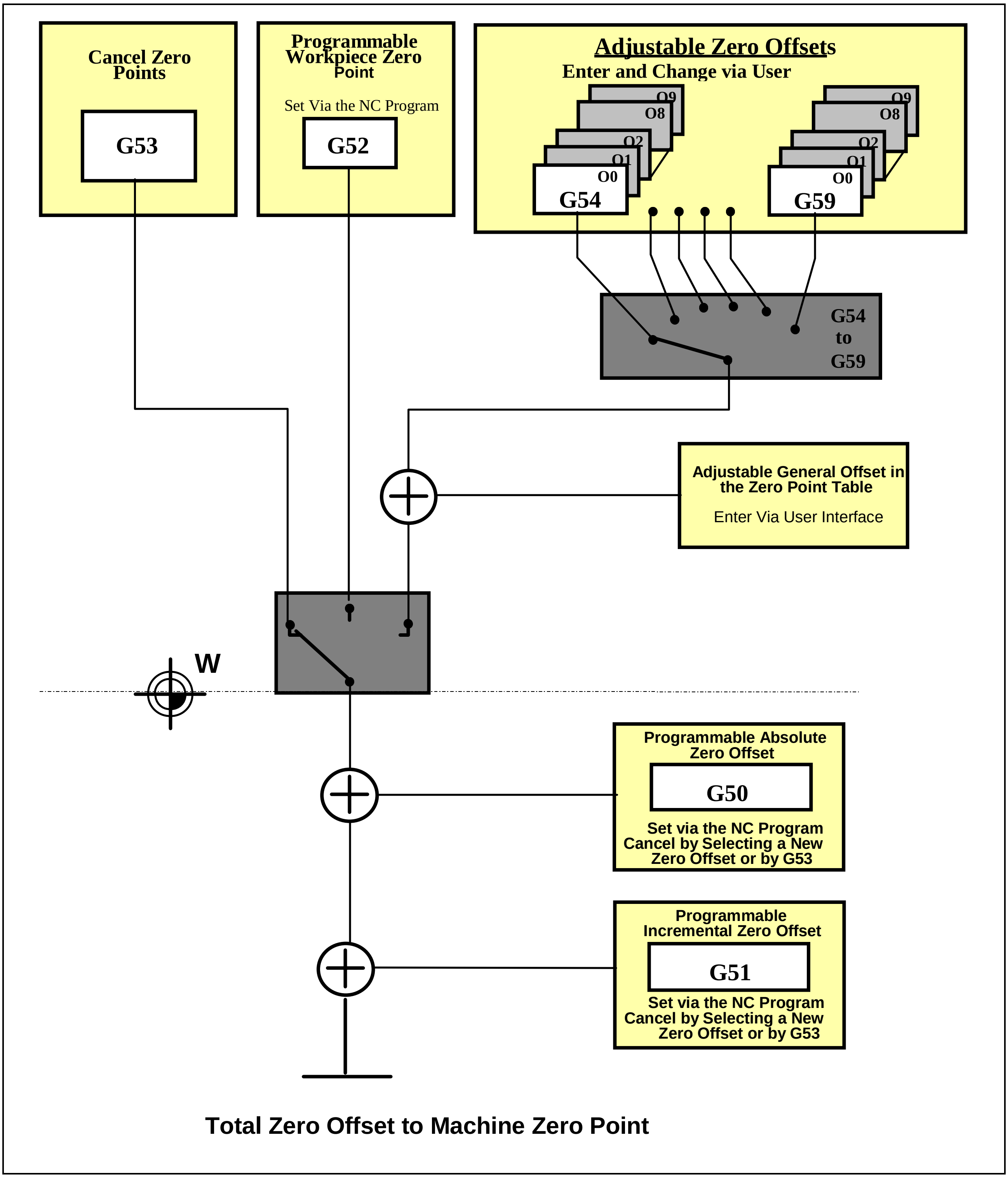


Fig. 3-7: Total of zero offsets

The total value of the zero offsets are comprised of:

the *adjustable zero offsets G54 … G59* or the *programmable workpiece zero point G52* and the *programmable zero offsets G50, G51* as well as the adjustable general offset in the zero offset table.

CAUTION

The programmable zero offsets G50 and G51 become inactive when G52, G53, G54 ... G59 are programmed.

Adjustable Zero Offsets 'G54 ... G59'

The adjustable zero offsets are entered in the zero offset table for those axes which are present using the user interface.

The entered values function as an absolute offset relative to the machine zero point. The calculation is performed after programming G54 …G59 in the same NC NC-block if the respective axis is programmed. G54 ... G59 is canceled by G53 or G52.

- Depending on the setting in the process parameters, the adjustable zero offsets G54 …G59 can be the power-on default and the initial setting when the NC-program boots.

Example

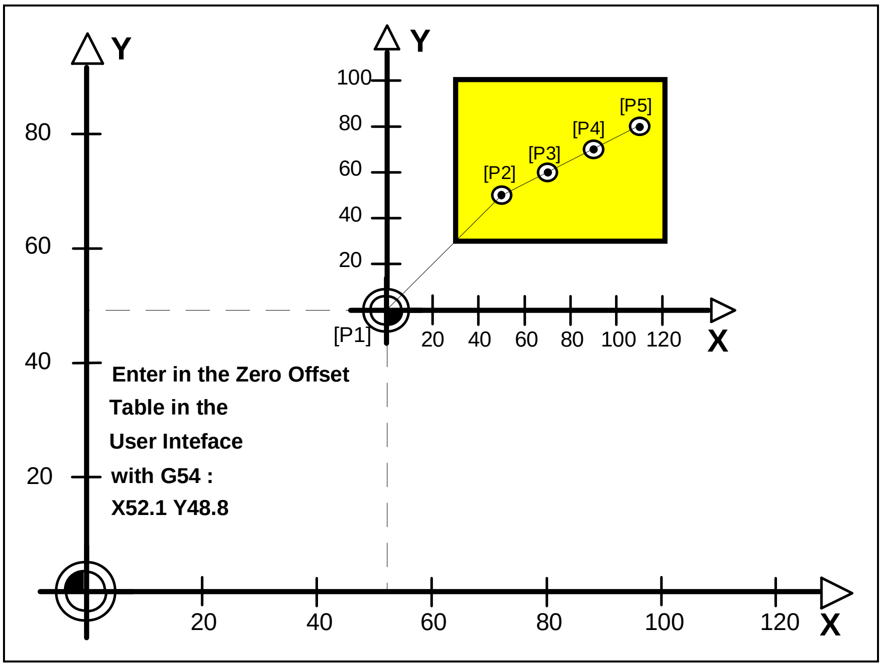


Fig. 3-8: Adjustable zero offset G54

G00 G90 G54 X0 Y0 Z10 S1000 M03	Starting position [P1]
G01 X50 Y50 F1000	[P2]
BSR .DRILL	Branch to drilling subroutine
X70 Y60	[P3]
BSR .DRILL	Branch to drilling subroutine
X90 Y70	[P4]
BSR .DRILL	Branch to drilling subroutine
X110 Y80	[P5]
BSR .DRILL	Branch to drilling subroutine
M05	Spindle OFF
RET	End of program
.DRILL	Drilling subroutine
G01 Z-10 F300	Drill to depth Z
G04 F2	Dwell time 2 seconds
Z3	Return to safety distance
RTS	Return of subroutine

Coordinate Plane Rotation by Angle of Rotation 'P'

Coordinate plane rotation is used to adapt the coordinate system of the workpiece to the coordinate system of the machine. The angle of rotation P is assigned to the individual zero offsets G54 … G59, G50, G51 and the adjustable general offset. Coordinate rotation is always active in the active plane (for example G17).

With the adjustable zero offsets G54 …G59 and with the adjustable general offset, the angle of rotation is entered as PHI in the zero offset table.

The angle of rotation is programmed using the address Pxxx with the programmable zero offsets G50 and G51.

- The total of all active rotational angles is subject to the same conditions as with the zero offsets.
- As a rule, the angle of rotation is not active until the next active NC NC-block.
- The angle of rotation is calculated in the controller as a modulo value from 0° to 360°. This means that a programmed angle of, for example 540°, is calculated as 180°.
- Coordinate rotation cannot be programmed with the programmable workpiece zero point G52.

Example

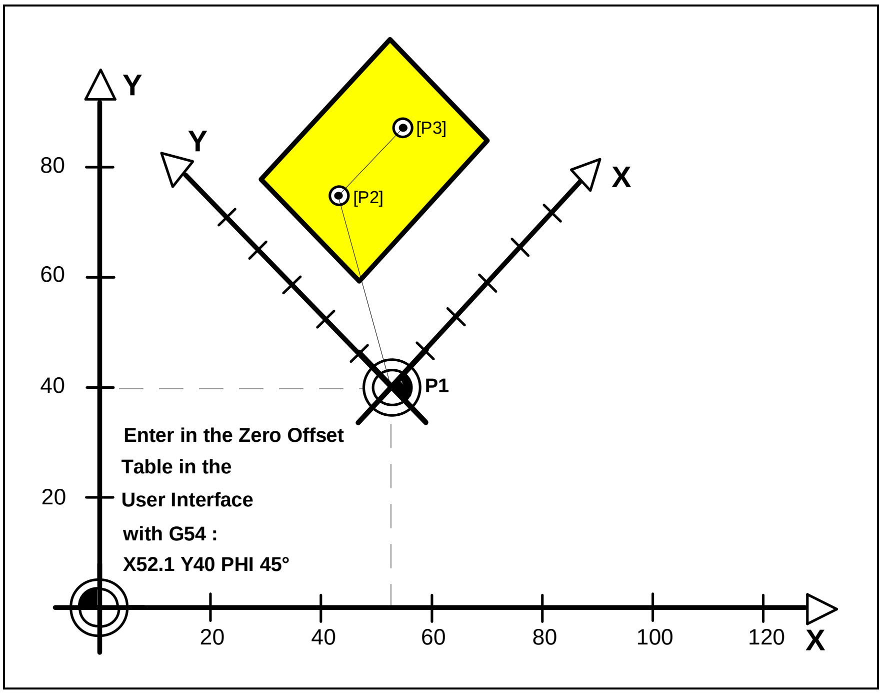


Fig. 3-9: Adjustable zero offset G54 with coordinate rotation

G00 G90 G54 X0 Y0 Z10 S1000 M03	Starting position [P1]
G01 X40 Y70 F800	[P2]
BSR .DRILL	Branch to drilling subroutine
X80	[P3]
BSR .DRILL	Branch to drilling subroutine
M05	Spindle OFF
RET	
.DRILL	Drilling subroutine
RTS	Return of subroutine

Zero Offset Tables 'O'

The CNC allows the adjustable zero offsets, G54 …G59 to be addressed up to ten times using different coordinate values.

The zero offset table can be present up to ten times in the CNC. The designation for each zero offset table is zero offset table.

Note: The number of zero point databases is specified by the machine builder in the process parameters.

The selection criterion in the NC-program is the NC command O[0..9] which, together with a single-digit number—the zero offset table number—addresses one of up to ten zero offset tables.

- The initial setting is zero offset table number 0.
- If only zero offset table number 0 is to be used, or if this number is the first to be active in the NC-program, the number 0 will not need to be programmed separately.
- If the zero offset table is changed in the NC-program, G53 automatically becomes active.
- Selection of a zero offset table remains modally active until the end of the program. The zero offset table selection is reset by the commands RET and BST.
- The NC-command O should be programmed in a separate NC NC-block. It must be activated at least on NC NC-block prior to the selection of a new zero offset.

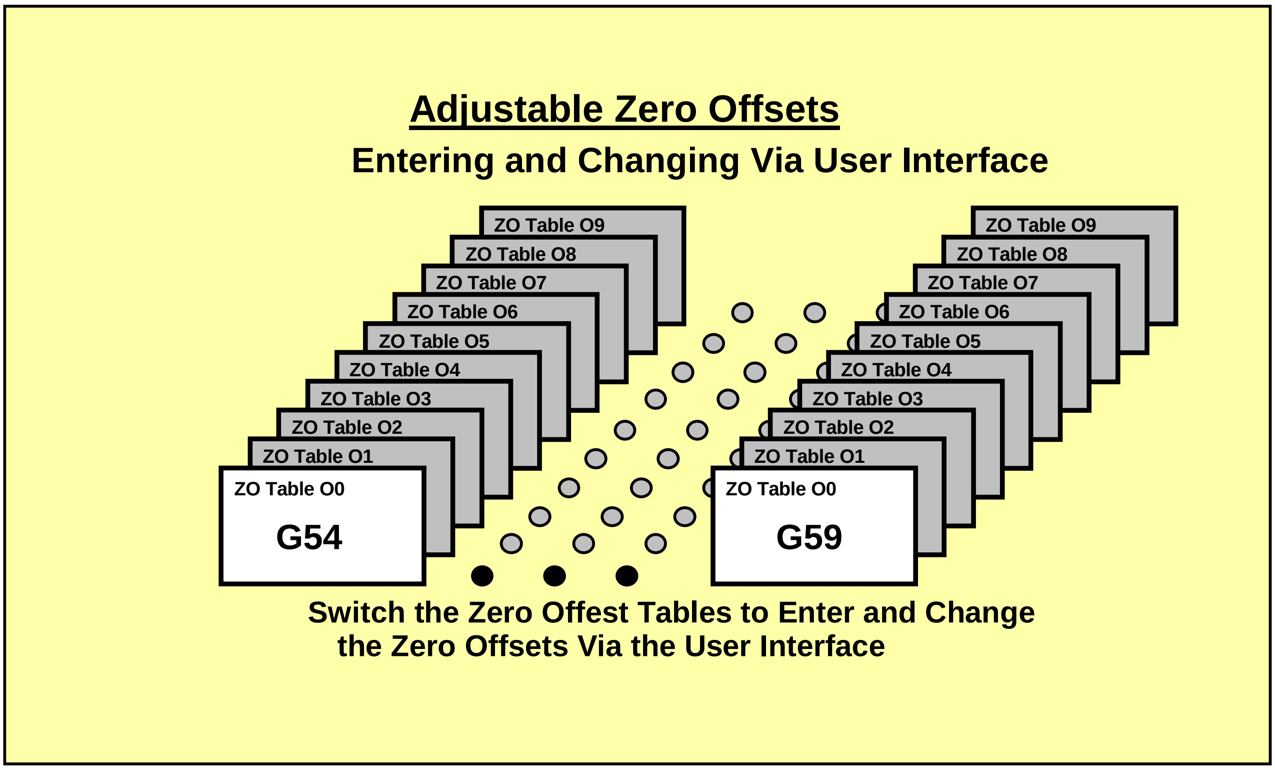


Fig. 3-10: Available zero point tables

Example

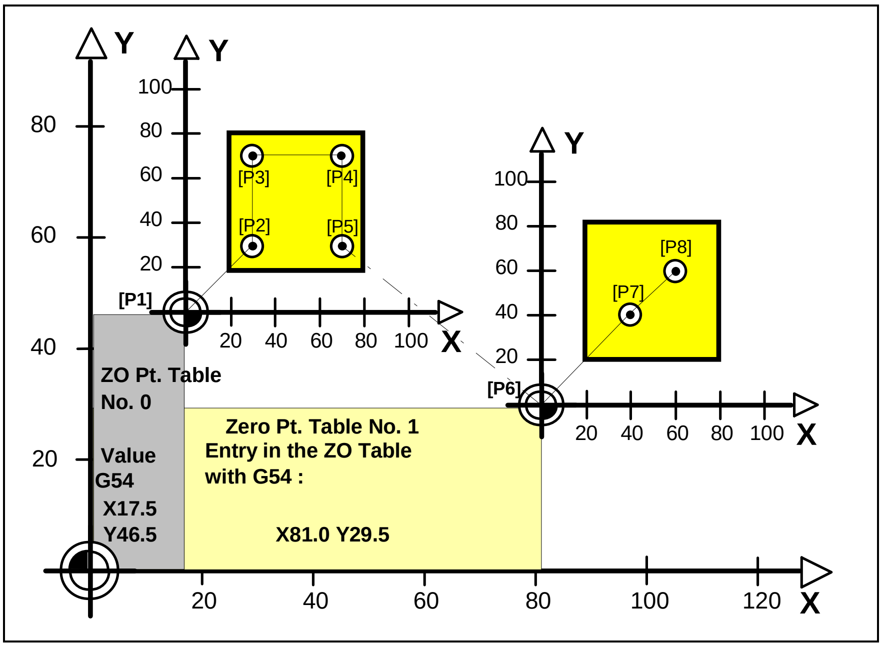


Fig. 3-11: Calling 2 zero offset tables using G54

[Zero offset table no. 0 is active]	
G00 G90 G54 X0 Y0 Z10 S1000 M03	Starting position [P1]
G01 X30 Y30 F1000	[P2]
BSR .DRILL	Branch to drilling subroutine
Y70	[P3]
BSR .DRILL	Branch to drilling subroutine
X70	[P4]
BSR .DRILL	Branch to drilling subroutine
Y30	[P5]
BSR .DRILL	Branch to drilling subroutine
[activate zero offset table no. 1]	
O1	
G00 G54 X0 Y0	Starting position [P6]
G01 X40 Y40 F1000	[P7]
BSR .DRILL	Branch to drilling subroutine
X60 Y60	[P8]
BSR .DRILL	Branch to drilling subroutine
M05	Spindle OFF
RET	End of program
.DRILL	Drilling subroutine
G01 Z-10 F300	Drill to depth Z
G04 F2	Dwell time 2 seconds
Z3 F1000	Return to safety distance
RTS	Return of subroutine

Programmed Absolute Zero Offset 'G50' Programmed incremental zero offset 'G51'

The programmed zero offsets G50 and G51 move the machining zero point with

- G50 absolute or
- G51 incremental

to the most recently selected workpiece zero point by the offset values which were declared together with the address letters.

In addition, the machining coordinate system can be moved using G50 absolute or using G51 incremental to the most recently selected work-piece coordinate system in order to rotate the active plane using the ad-dress letter P.

- The programmed zero offsets G50 and G51 are NC-block active. The offset remains in effect until the next change of the zero offset or of the coordinate system.
- No further functions may be programmed in a NC-block containing G50 or G51.

Example

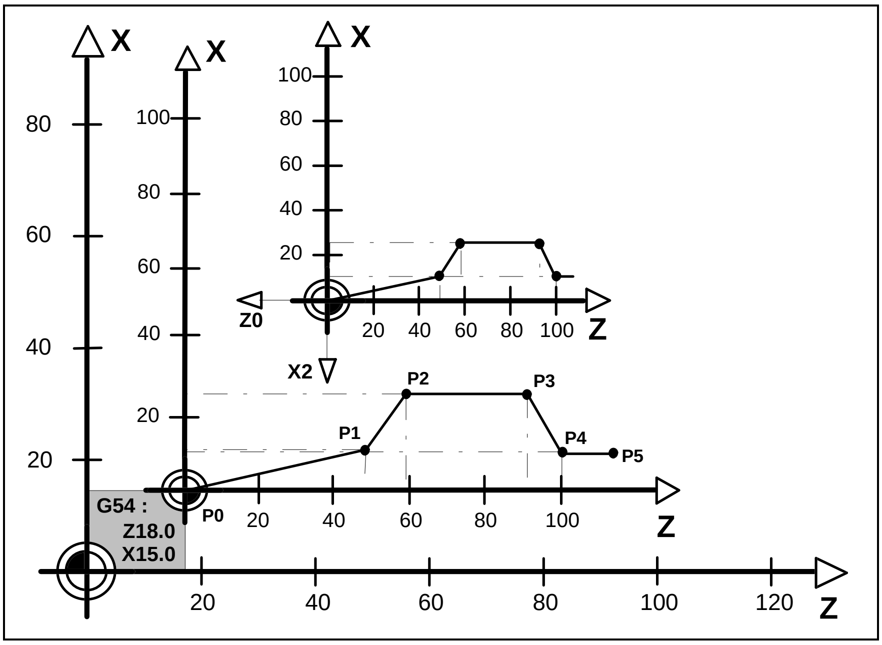


Fig. 3-12: Programmed zero offset G50

G00 G90 G54 X0 Z0	[P0]
BSR .CONT	Branch to the contour subroutine
G50 X2	Zero offset X by 2 mm
BSR .CONT	2nd call of the contour subroutine
RET	
.CONT	Contour subroutine
G01 X10 Z48 F750	[P1]
X25 Z59	[P2]
Z92 F1500	[P3]
X11 Z100 F600	[P4]
Z113 F1000	[P5]
G00 X40	Return to safety distance
Z0	
X0	[P0]
RTS	Return to main program

Programmed Workpiece Zero Point 'G52'

A workpiece zero point can be programmed as the axis position for all axes which are present using programmed workpiece zero point G52. When G52 is performed, the coordinate values to which the G52 command applies are assigned to the current position. This corresponds to the definition of the workpiece zero point relative to the current position.

- Axes which are not programmed using G52 work in the machine coordinate system.
- Programming G52 produces a G53 when the change occurs. All zero offsets which are already active are canceled.
- No further functions may be programmed in a NC-block containing G50.
- Coordinate rotation P cannot be programmed in combination with G52.

Example

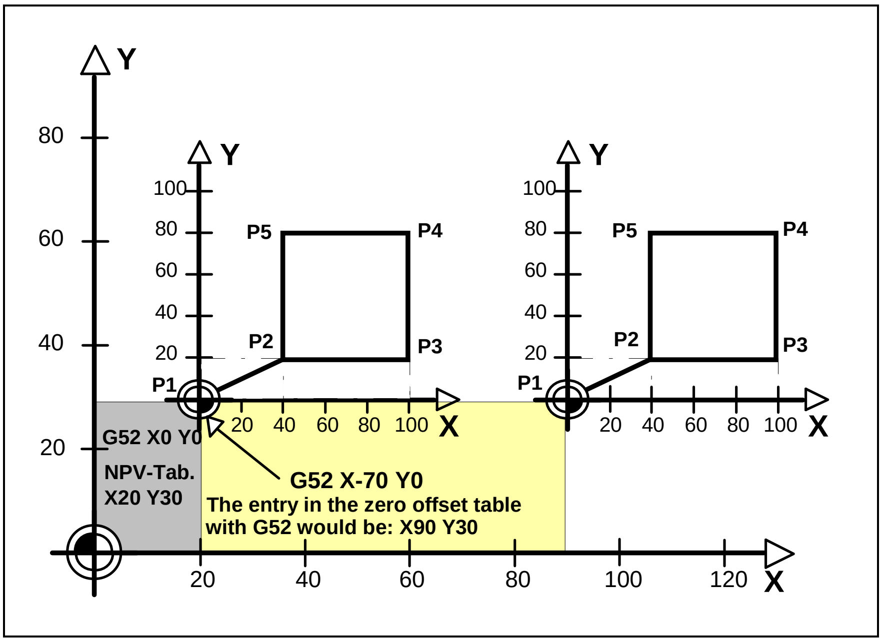


Fig. 3-13: Call G52

G90 G53 G00 X20 Y30	
G52 X0 Y0	Call G52
BSR .CONT	Branch to the subroutine
G52 X-70 Y0	Call G52
BSR .CONT	Branch to the subroutine
RET	
.CONT	Subroutine
G00 X0 Y0	[P1]
G01 X40 Y20 F1000	[P2]
X100	[P3]
Y80	[P4]
X40	[P5]
Y20	[P2]
G00 X0 Y0	
RTS	Return to main program

Cancel Zero Offsets 'G53'

All zero offsets are canceled by programming G53. This causes the workpiece coordinate system to be switched to the machine coordinate system.

- Depending on the setting in the process parameters, G53 can be the power-on default and the initial setting when the NC-program starts.
- If G53 is placed in a NC-block containing G91 only the position display is switched to the machine’s actual system.
- If the active zero offsets are canceled using G53 when tool path correction is active (G41, G42), a G40 (no tool path correction) is issued internally. The tool correction is rebuilt for the following parameters NC-blocks.

Adjustable General Offset in the Zero Offset Table

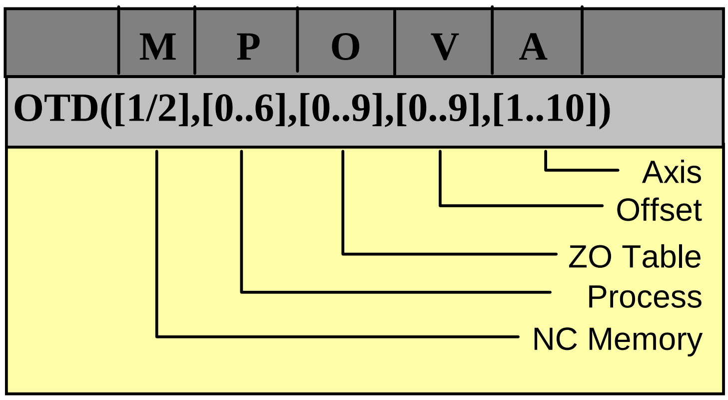
By having an adjustable general offset in the zero offset table, the CNC can also offset the workpiece zero point in addition to the adjustable and programmable zero offsets. The adjustable general offset functions in an additive manner relative to the adjustable and programmable zero offsets. This means that the adjustable general offset does not become active until one of the adjustable or programmable zero offsets has been activated.

- The adjustable general offset is canceled using G53 and is not calculated in until the next time a zero offset is selected.
- An angle of rotation can be entered in the address phi in the zero offset table. This angle is added onto the already active angles of rotation.
- The adjustable general offset can never be active alone due to the conditions described above.

Reading and Writing Zero Offset Data from the NC Program via OTD

The OTD command (Offset Table Data) can be used to read and write the data in the zero offset table and the zero offsets which have been activated in the NC-program from the NC-program.

Syntax



Please refer to the chapter „Reading and Writing ZO Data from the OTD Program“ for a detailed description of the OTD command.

3.6 Plane Selection

Plane selection is an important requirement for correctly performing all motion commands in an NC-program. It informs the controller of the plane on which machining is performed in order to permit a correct calculation of the tool correction values. It also plays a role in circle programming.

Plane Selection 'G17', 'G18', 'G19'

The three planes XY, ZX and YZ are formed by the coordinate axes X, Y and Z of the three-axis coordinate system.

G17	**Plane selection**	**XY**
G18	**Plane selection**	**ZX**
G19	**Plane selection**	**YZ**

The three main axes X, Y and Z form a Cartesian coordinate system which spans the three planes XY, ZX and YZ; the third of these axes is always normal to the corresponding plane.

Note: The meaning of the axes in the coordinate system is specified by the machine builder in the axis parameters.

The preparatory commands G17, G18 or G19 are used to communicate the desired machining plane to the NC controller, whereby the tool axis is always normal to the machining plane. If the position of the tool axis can be changed for design-related reasons, this also defines the machining plane.

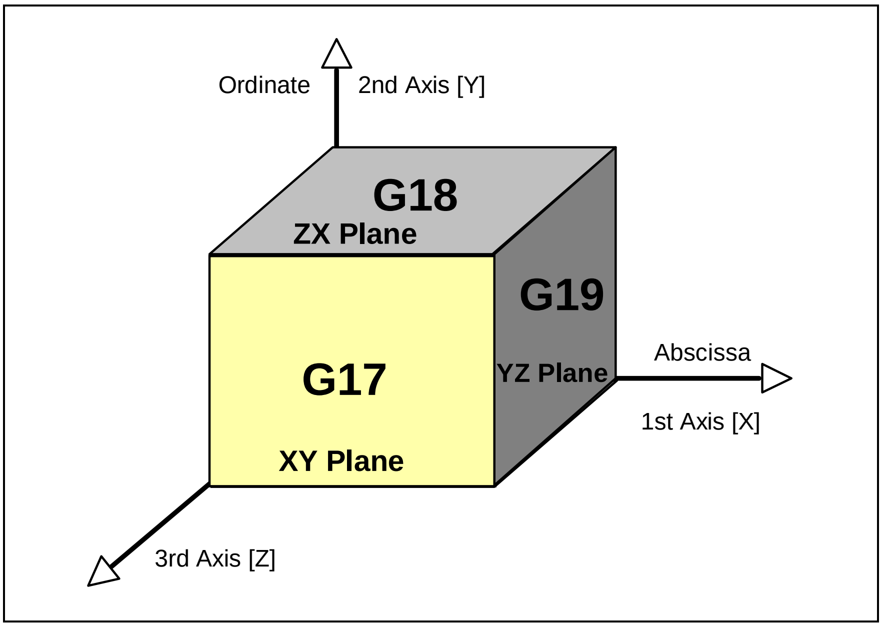


Fig. 3-14: Machining planes

Tool length correction

The tool length correction is always performed in the direction of the tool axis, which means that the override is normal to the selected machining plane.

Tool path correction

The tool path correction is always generated for the active machining plane. Canceling the tool path correction causes the machining plane to be changed. The tool path correction is generated for the new plane following the change.

Circular interpolations

Circular interpolation is only possible in the active machining plane. Helical interpolations superimpose linear movement in the direction of the tool axis onto the circular interpolation taking place in the machining plane.

Note: The default plane is specified by the machine builder in the process parameters.

A change in the selected plane overwrites the previous plane selection and remains modally active. The default plane is selected at the end of the program and upon 'Control Reset'.

Free Plane Selection 'G20'

Free plane selection permits

- the axes that span the Cartesian coordinate system to be selected, and
- the working plane inside the spanned coordinate system and the axis that is perpendicular to the working plane to be defined.

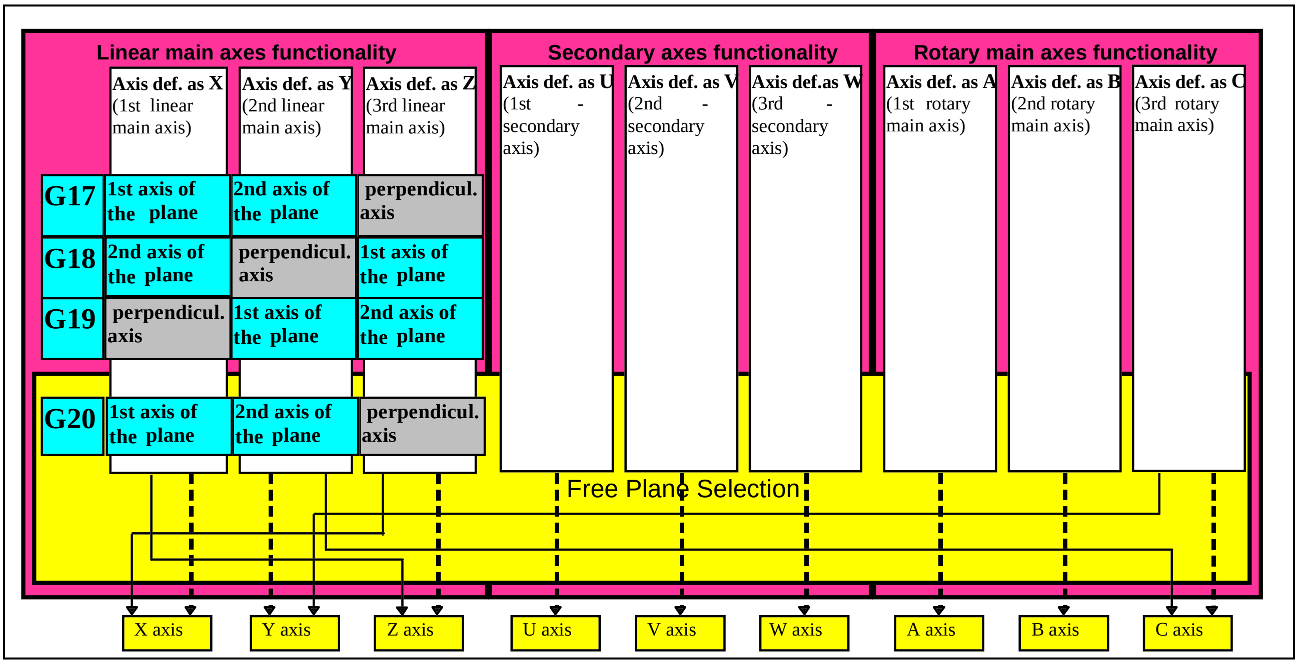


Fig. 3-15: Basic operation of the free plane selection (example: lateral cylinder surface machining using G20 Z0 C0 X0)

Programming

Free plane selection is performed with G20. The user can, in succession, specify the axes that shall obtain the functionality of the 1st axis of the working plane, of the 2nd axis of the working plane, and of the axis that is perpendicular to the working plane.

Syntax

G20 [1st axis of the plane] [2nd axis of the plane] {perpendic. axis}

[ ]: Mandatory parameter of free plane selection

{ }: optional parameter

Boundary conditions

- An axis (axis designation) may only occur once within a G20 command.
- Tool magazine axes and spindles are excluded.
- With G20, the user may program two or three axes.
- The working plane may be spanned by a maximum of two rotary axes.
- The third axis (that is perpendicular to the plane) must be a linear axis.
- If an NC block contains a G20 command, the only additional axis designators that may be programmed are the ones used for free plane selection.
- The NC automatically retains the currently used axis if a specification is not made for the axis that is perpendicular to the working plane.
- A 0 must be added to each axis designation.

- The G17 ... G20 commands form a group (G code group 2).
- A change in the plane selection overwrites the previous plane selection and has a modal effect.
- At the end of the program (BST, RET, JMP, M02 and M30), upon a control-reset, and upon a transition to manual mode (if the process parameter „Manual axis jogging causes reset“ has been set), the NC selects the base coordinate system (Cxx.053 axis parameter, Axis defined in tight hand coord. system as ...) and selects the working plane that is saved there (Bxx.004 process parameter, Default interpolation plane).
- In the axis meaning (axis functionality) axis parameters, the machine manufacturer must (for safety reasons) allocate the necessary axis functionality to the axes that follow the G20 command.

NC functions

- In circle programming and with active G20, the interpolation parameters I, J and K are allocated in the same way as with G17. The interpolation parameter (of the axis that is perpendicular to the working plane) must not be used.
- The constant surface speed function is related to the axis with axis meaning X. This fact must be taken into account during free plane selection if the axis meaning X is assigned via G20 to another axis.
- Thread cutting (G33), tapping (G63, G64 and G65) and feed per revolution (G95) are functions of the linear primary axis. Any axis - except a rotary axis - with the axis meaning X, Y or Z may perform them.
- The NC always processes the tool and D corrections in the axes with axis meaning X, Y or Z.

NOTE

- When free plane selection is activated via G20, the controller cancels the constant surface speed function (G96) and activates the spindle speed in rpm function (G97)
- Furthermore, the controller activates straight line interpolation (G01) when free plane selection is activated.

Detailed description

Please refer to the description „Free plane selection and lateral cylinder surface machining“ in Folder 5 for further information about free plane selection.

Example

A turning center possesses the following axes within a process (axes within the turning center (process 0)):

Axis designation	Axis meaning	Comment
X1	X	Turning slide
X2	W	Milling slide
Y	Y	for milling
Z	Z	for turning and milling
C	C	for machining on the lateral surface
B	B	swivel axis for the milling slide
U	U	tailstock
S1	S1	main spindle
S2	S2	tool spindle for milling

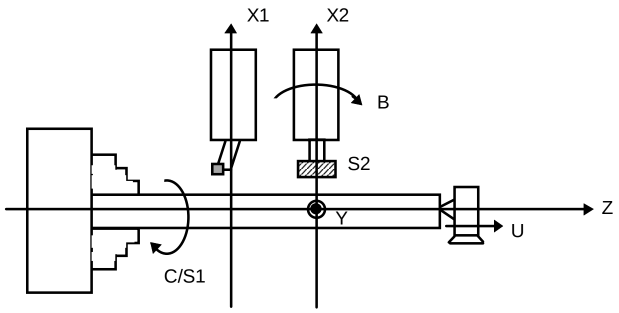


Fig. 3-16: Location of the axes within the turning center

Selection and axis allocation:

To perform the different machining tasks, the following planes are selected during machine operation:

G code	Linear main axes			Secondary axes			Rotary main axes			Wor-king plane	Perp. axis	Comment
	Axis m. X	Axis m. Y	Axis m. Z	Axis m. U	Axis m. V	Axis m. W	Axis m. A	Axis m. B	Axis m. C			
G18	X1	Y	Z	U	-	X2	-	B	C	Z X1	Y	Turning (=power-on state)
G20 X2=0 Y0 Z0	X2	Y	Z	U	-	X1	-	B	C	X2 Y	Z	Milling (corr. to G17 with X2)
G20 Z0 X2=0 Y0	Z	X2	Y	U	-	X1	-	B	C	Z X2	Y	Milling (corr. to. G18 with X2)
G20 Y0 Z0 X2=0	Y	Z	X2	U	-	X1	-	B	C	Y Z	X2	Milling (corr. to G19 with X2)
G20 Z0 C0 X2=0 G32 RI=80	Z	C	X2	U	-	X1	-	B	C	C Z	X2	Lateral cylinder surface ma-chining

When ‘G20 Z0 C0 X2=0‘ is used for selecting the coordinate system of the subsequent lateral cylinder surface machining process, the axis meanings are allocated as follows (example):

- Starting from the allocations that have been defined in the axis parameters, the axis Z obtains the axis meaning X, and the axis X1 the axis meaning Z.
- In a second step, axis C obtains axis meaning Y and axis Y obtains axis meaning C.
- In a third step, the NC assigns the axis meaning Z to the axis X2 and the axis meaning W to the axis X1.

3.7 Diameter and Radius Programming 'G15' / 'G16'

Workpieces which are machined on lathes generally have a circular cross section. The CNC permits the workpiece dimensions to be entered in two ways upon programming:

- as diameter dimensions and/or
- as radius dimensions

The names of the preparatory G-functions are as follows:

G15 Radius programming

G16 Diameter programming

Note: The power-on default for radius and diameter programming is set by the machine builder in the process parameters.

Diameter programming relates exclusively to the X axis.

Example with diameter programming

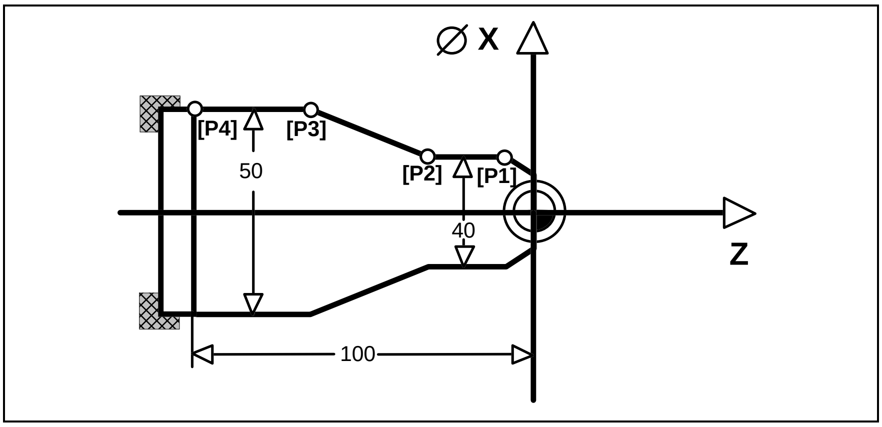


Fig. 3-17: Example of diameter programming

```
; Lathe, G16 is set as the default position through process parameters
G01 G90 X40 Z-8 F1000          [P1]
Z-30                           [P2]
X50 Z-63 F500                  [P3]
Z-100 F1000                    [P4]
RET
```

The following conditions apply for diameter programming:

- With absolute positioning (G90) the programmed X value is interpreted as a diameter; negative X values (diameters) are permitted. With circles, the center points of the circles as well as the end points are to be specified as diameters.
- With incremental position statements (G91) the difference in diameter relative to the previous position is stated. Beginning with the old diameter, the tool traverses the stated traverse difference to the new

position. With circles the circle center points and end points are to be stated as a difference in diameter relative to the starting point.

- The thread lead is interpreted as a radius dimension when machining face threads on a lathe.
- Functions like constant surface speed and feed per revolution in the X direction are not affected by diameter programming.
- If position data are read into a NC-variable for the diameter axis, this is the diameter value.
- The zero offsets for the X axis are programmed in radius.
- The tool corrections in the X axis are interpreted as radius values.
- The diameter symbol ∅ is used in the position display to indicate the axis in which diameter programming is active.

3.8 Dimensional Units

Upon setup, machine tools are specified for a certain basic programming unit (mm or inches). To produce workpieces which are dimensioned in a different dimensioning unit on this machine, the dimensional units can be changed for coordinate values, speed values, and programmable offsets by using Preparatory G-functions.

Note: The basic unit to be used in programming is specified by the machine builder in the process parameters.

Inch Programming Input 'G70'

If millimeters is set in the process parameters as the basic programming unit, the subsequent values are interpreted as inch data and are converted to inches internally after G70 has been programmed.

- Motion commands (coordinate values); for example X5.5 inches is converted to X139.7 mm.
- Interpolation parameters I, J and K and radius R;
- Feed data F and G95 F; for example, F20 inch/min is internally converted to F508 mm/min;
- Programmed offsets G50, G51 and G52;
- Motion commands assigned by means of NC-variables (X=@050), interpolation parameters (I=@051), feedrate information (F=@052) and programmable offsets (G50 X=@053).

G70 remains in effect until the end of the program or until it is overwritten by G71.

Metric (mm) Programming Input 'G71'

If 'inches is set in the process parameters as the basic programming unit, the subsequent values are interpreted as millimeter data and are converted to inches internally after G71 has been programmed.

- Motion commands (coordinate values); for example X127mm is converted to X5 inches.
- Interpolation parameters I, J and K and radius R;
- Feed data F and G95 F; for example, F1500 mm/min is internally converted to F59.05 inches/min;
- Programmable offsets G50, G51 and G52;
- Motion commands assigned by means of NC-variables (X=@050), interpolation parameters (I=@051), feedrate information (F=@052) and programmed offsets (G50 X=@053).

G71 remains in effect until the end of the program or until it is overwritten by G70.

Example

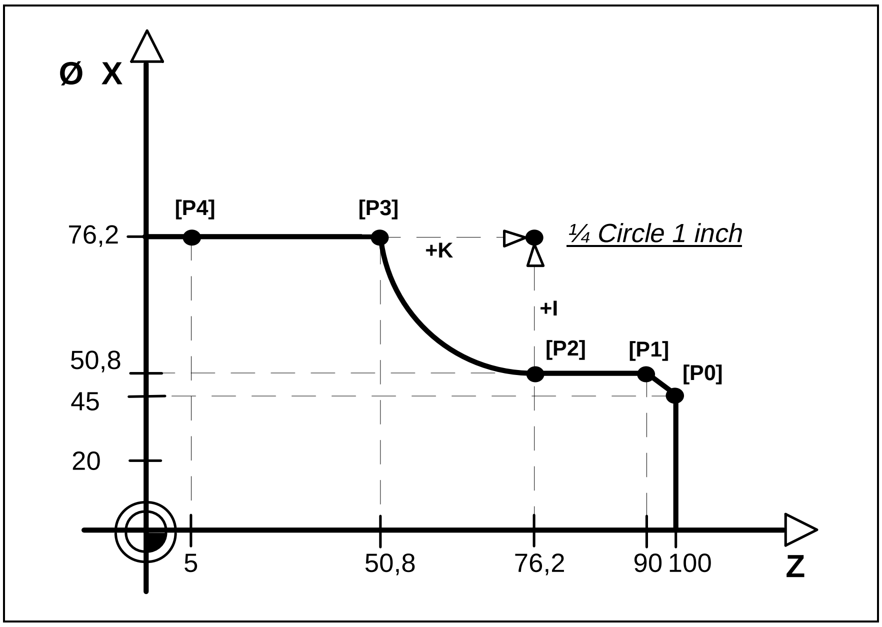


Fig. 3-18: Millimeters as the basic programming unit, and change to inches G70

G00 G90 G54 X45 Z100	[P0]
G01 X50,8 Z90 F800	[P1]
G70	Change to inches
Z3 F35	[P2]
G02 X3 Z2 I3 K3	[P3]
G71	Change to mm
G01 Z5	[P4]

•

RET

3.9 Mirror Imaging of Coordinate Axes 'G72' / 'G73'

The programmable mirror function permits the mirror imaging of any desired coordinate axes within a machining program. When a coordinate axis is mirror imaged, the original contour is machined symmetrically opposite in the same size and at the same distance on the other side of the mirror imaging axis.

The activation and deactivation of mirror imaging preparatory G-function is programmed using the Preparatory G-functions in the part program.

The mirror function can be activated via G73. It remains latched until it is canceled by G72 or until it is automatically reset at the end of the program (RET, M002/M030) or by BST. G72 sets all mirror imaging axes back to the default position.

Syntax

G73 <axis name>-1	Mirror function ON
G72	Cancel mirror function for all axes

Mirroring one axis

The following rule applies to the mirror imaging of an axis:

- The signs of the coordinates of the mirror imaged axis are interchanged.
- In the case of circular interpolation the direction of rotation is switched. (G02→G03, G03→G02)
- The machining direction of the path correction is reversed (G41→G42, G42→G41)

Mirroring two axes

The following rules apply to mirror imaging two axes in a single plane:

- The signs of both mirror-imaged coordinates are interchanged (X-Y, Z-X, Y-Z)
- In the case of circular interpolation the direction of rotation remains the same.
- The machining direction of the path correction remains the same.

The zero offsets G54...G59, G52 and the adjustable offset are not mirror imaged. The programmable zero offsets G50 and G51 are also mirror imaged in programming after the mirror image function has been selected.

- The Preparatory G-functions for mirror imaging are assigned to Preparatory G-function group 18.
- Selecting mirror imaging does not result in any axis movement. The tool path correction and NC-block lookahead are terminated when mirror imaging is selected. Tool lengths are not mirror imaged.
- When main axes are mirror imaged, the workpiece is always mirror imaged.
- The position display shows the corresponding workpiece coordinates.

Example Mirror Imaging

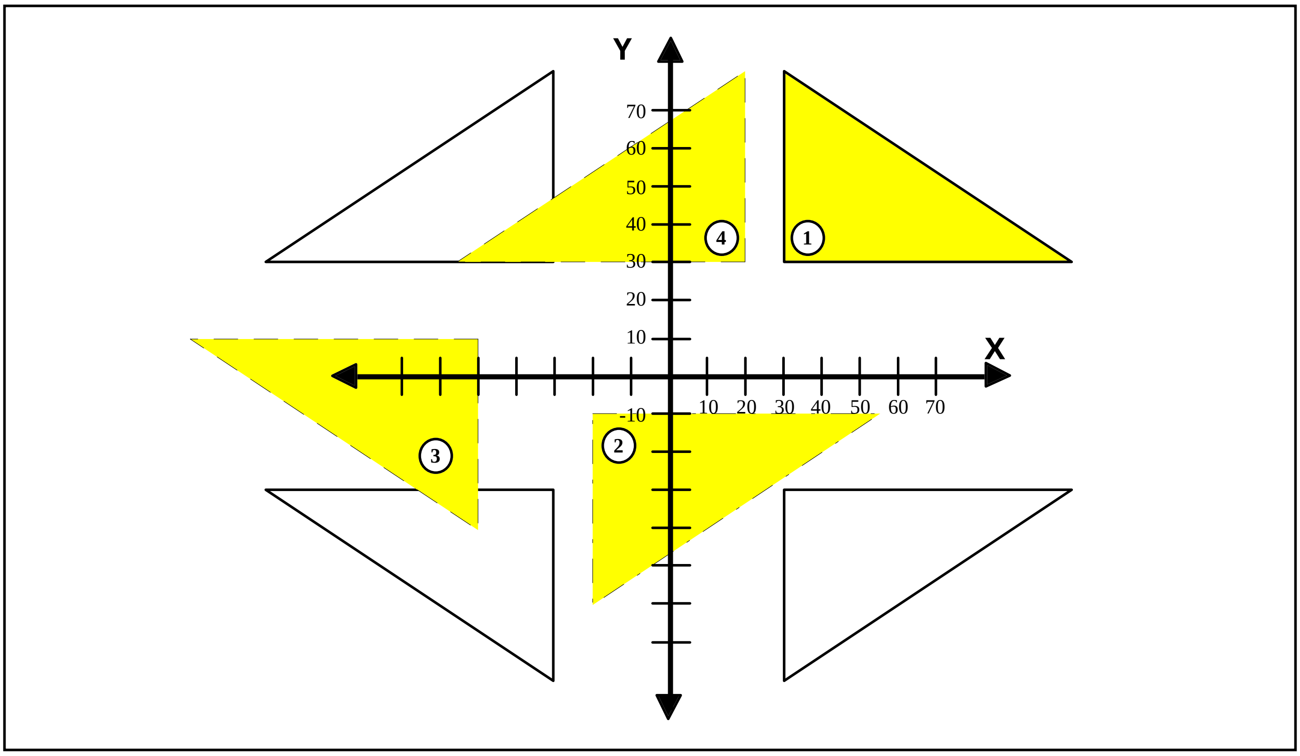


Fig. 3-19: Correlation when mirror imaging one or more coordinate axes

NC program

G00 G54 G90 X0 Y0 BSR .TRIA	① No axis mirror imaged
G50 X50 G73 X-1 BSR .TRIA G72	④X axis is mirror imaged
G50 X-20 Y40 G73 X-1 Y-1 BSR .TRIA G72	③ X and Y axes are mirror imaged
G50 X-50 Y20 G73 Y-1 BSR .TRIA G72 RET	② Y axis is mirror imaged
.TRIA	Subroutine for the triangle
G90 G01 X30 Y30 F1000	Triangle starting point
X130 X30 Y90	
Y30	Endpoint = starting point
G00 G54 X0 Y0 RTS	

3.10 Scaling 'G78' / 'G79'

The scaling function provides programmable scaling factors to change the scale used for the distance to be traversed on all machine axes.

The activation and deactivation of the scaling preparatory G-function is programmed using the Preparatory G-functions in the part program.

Scaling can be activated via G79. It remains modally active until it is canceled by G78 or until it is automatically reset at the end of the program (RET,M002/M030) or by BST. G78 resets all scaled axes back to the default state.

Syntax	**G79** <**axis name**><**scaling factor**>	Scaling ON
	G78	Scaling OFF for all axes

The following values are recalculated for scaling:

- Axis coordinates
- Interpolation parameters
- Radius
- Programmable zero offsets G50 and G51
- Thread lead
- Effective clearances

The zero offsets G54...G59, G52 and the adjustable offset are not scaled. The programmed zero offsets G50 and G51 are also scaled in programming after the scaling preparatory G-function has been selected.

- The Preparatory G-functions for scaling are assigned to Preparatory G-function group 19.
- The scaling factors must always be positive values.
- For circle radius programming with R using G02/G03 or with the nominal radii RX, RY and RZ, the scaling factors used in the active machining plane must always be quantitatively identical.
- Selecting scaling does not result in any axis movement. The tool path correction and NC-block lookahead are terminated when scaling is selected. Tool lengths are not scaled.
- With circular interpolation an error message will be issued if the scaling factors have different absolute values. The same applies to rotary axis programming using nominal radii.
- The numerical value which results after recalculation using the scaling factor appears in the position display. The actual value and the distance-to-go correspond to the real axis positions.
- If the scale factor is > 1, the original component is enlarged.
- If the scale factor is < 1, the original component is reduced in size.
- In the internal calculation definition, mirror imaging is performed first followed by scaling.

Example Scaling

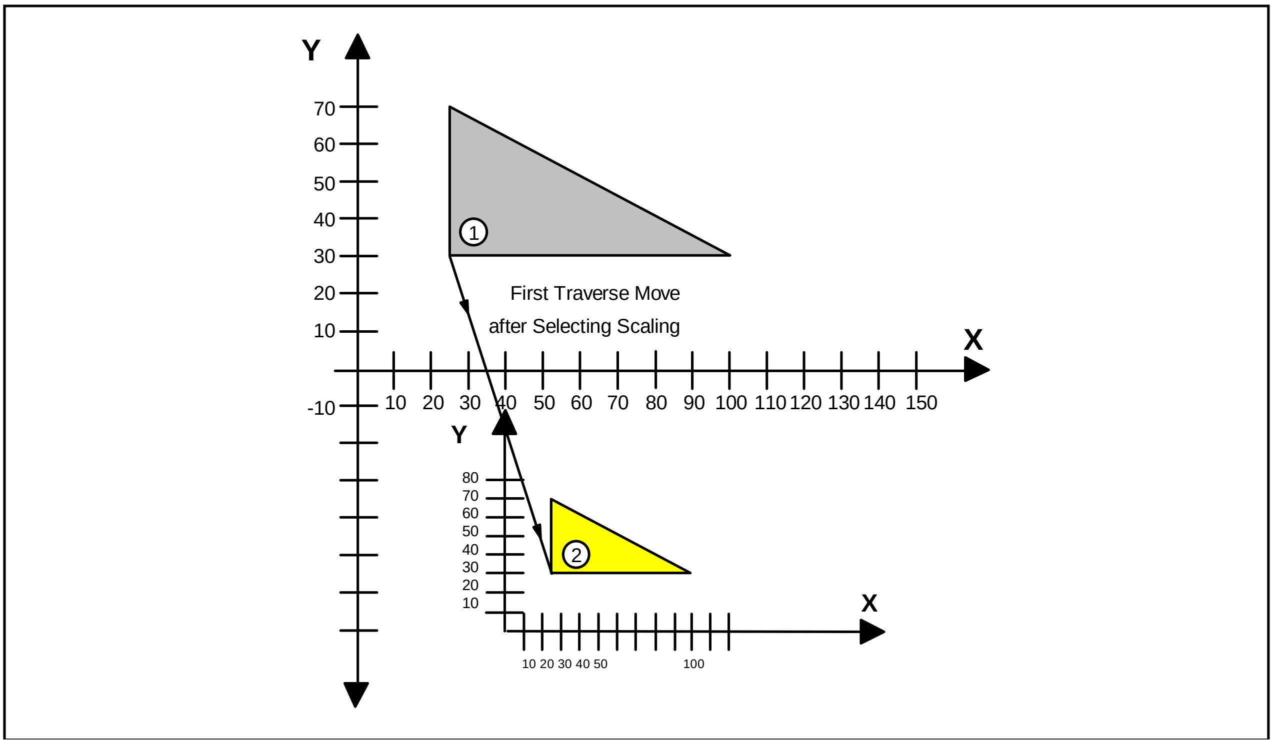


Fig. 3-20: Example of programming using the scaling preparatory G-function

NC program

G00 G54 G90 X0 Y0	
BSR .TRIA	① Triangle without scaling
G50 X40 Y-70	Move zero point
G79 X0.5 Y0.5	Set the scaling factors
BSR .TRIA	② Triangle with scaling
G78	Cancel scaling
G00 G54 G90 X0 Y0	
RET	
.TRIA	Subroutine for the triangle
G90 G01 X25 Y30 F1000	Starting position
X100	
X25 Y70	
Y30	Final position = starting position
RTS	

3.11 Axis Homing Cycle 'G74'

The preparatory function G74 axis homing cycle allows traversing to the reference point along one or more axes in an NC-program or via MDI NC-block entry.

Syntax **G74 <[Axis Name][CoordinateValue=0]> <Feed>**

Example	G74 X0 Z0 F10000

G74 is non-modal. In the homing cycle, each programmed axis is moved at the homing velocity that has been entered in the axis parameters.

Notes on programming G74

- G74 deactivates the tool path and tool length correction using G40, sets the machine zero point (G53), switches to feed programming (G94) and to absolute dimension input (G90).
- The coordinate values of the programmed axes in a G74 NC-block must be declared to be zero.
- If a number of axes are programmed in a G74 NC-block, the axis movement of the axes is not performed with interpolation.
- A feedrate programmed in a G74 NC-block will also remain active for other types of interpolation.

Note: The reference dimensions and the homing cycle traversing speed are set by the machine builder in the drive parameters.

3.12 Traverse to Positive Stop

The function Feed to Positive stop allows one or more axes to feed to a mechanical stop without causing a drive error. Possible applications are: to preload an axis slide at this stop position during machining, or to use the axis position at the stop as a reference position for further machining.

Feed to Positive Stop 'G75'

The preparatory function G75 feed to positive stop causes the axes which are programmed together with the preparation function in the NC NC-block to traverse in the direction of the programmed coordinate value.

Syntax **G75 <[Axis Name][Coordinate Value]> <Feed>**

Example	G75 X100 Z50 F500

G75 is active only for the NC-block in which it is located. The axes are traversed in the direction of the programmed coordinate value using the feed which is programmed in the G75 NC-block. If a mechanical resistance—for example, a mechanical stop—is detected during this distance, the torque which is defined by the axis parameter Cxx.044 Reduced Torque at Positive Stop is limited based on a percentage of the peak current. The command value is not increased further; the distance-to-go and the torque preload are maintained.

Notes on feed to positive stop

- If a feed value is not programmed in the G75 NC-block, traversing is performed at the speed entered in the axis parameter ‘Max. Feed to Positive Stop’.
- If the programmed final axis position value is reached, the error message:
  `„Positive Stop not within programmed move (@-axis)”`
  is issued.
- If the stop yields and wanders during operation, or if the axis slide is forced out of position by a strong opposing force, the axis position is updated. If this causes the initial position for the NC-block not to be reached or the final position for the NC-block to be exceeded, the error message:
  `„Positive Stop not within programmed move (@-axis)”`
  is issued.
- The dimensional information in a G75 NC-block can be entered in absolute mode (G90) or incremental mode (G91).
- If a number of axes are programmed in a G75 NC-block, the axis movement of the axes is not performed with interpolation.

Note: The parameters ‘Reduced Torque at Positive Stop’ and ‘Max. Feed to Positive Stop’ are set by the machine builder in the axis parameters.

Example

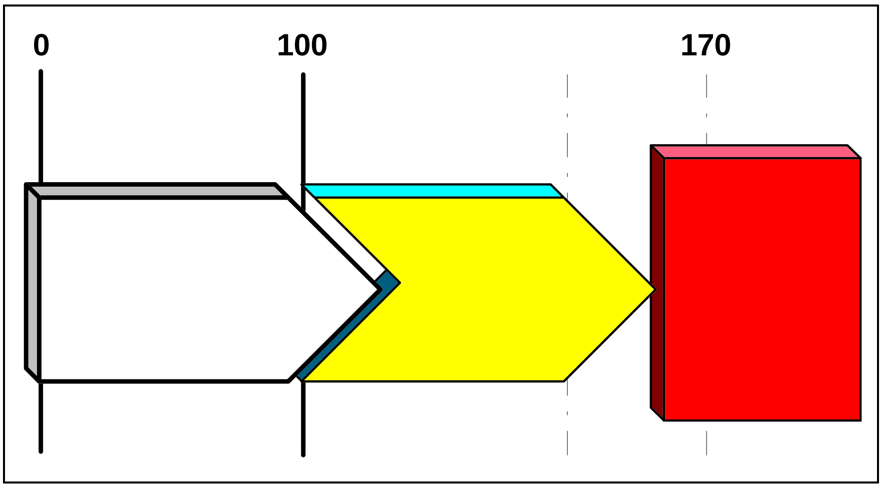


Fig. 3-21: Feed to Positive stop

G00 Z100 M3 S1250	Z axis to starting position
G75 Z170 F200	Feed to positive stop
•	
•	
G76	Cancel axis preload
G01 Z100 F1000	Z axis to starting position
G00 Z0 M5	Z axis to reference point
RET	

Cancel All Feeds to Positive Stop 'G76'

The preparatory command G76 cancel all axes at positive stop causes the pre-loads on all pre-loaded axes to be canceled. The actual position value is used as the position command value so that the axis positions can be used as reference positions for further traverse moves. The distance-to-go is ignored.

Syntax **G76**

Notes on programming G76

- G76 is active only for the NC-block in which it is located.
- The preparatory command G76 cannot be programmed together with axis data. G76 cancels the axis pre-loads on all axes which are pre-loaded using G75 Feed to Positive stop.
- If a program is terminated by the NC command RET, by a branch with stop BST, when the NC-program is manually reset via Control-Reset, or if there is a power failure, all axis preloads are automatically canceled.

3.13 Reposition and NC Block Restart

The functions

- reposition and
- NC-block restart

automate traversing back to the contour following a program interruption.

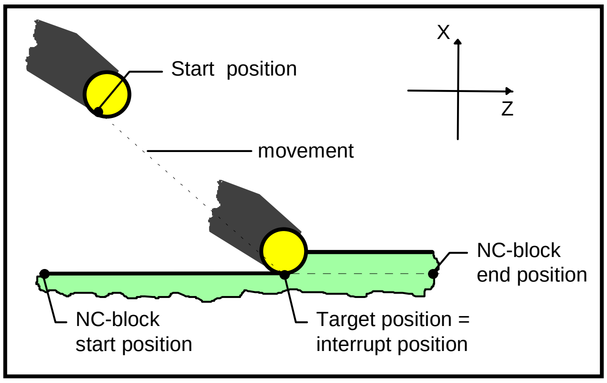
After program interruptions in which the operator withdrew the tool from the contour in manual mode—to check and replace the inserts on the tool, for example—the reposition function allows the operator to return to the point of interruption, and the NC-block restart function allows him to traverse back to the starting point of the NC-block.

Both functions are available in the manual and program-driven modes. In manual mode the controller compensates for the difference between the target position and the actual position in the order in which the user presses the jog keys. In the program-driven modes, the axis are traversed to their destination positions in the order which is programmed by the machine builder in an NC subroutine.

Reposition and NC Block Restart in the Automatic Operating Modes

Operators frequently use reposition and return to NC-block in manual mode only in order to return the axes to the vicinity of the contour. Once the possibility of collisions occurring is eliminated, the operators change to one of the automatic operating modes, Automatic, Semiautomatic or Execute Program in Manual Mode, and there they continue repositioning or NC-block restart by pressing the Start key.

By changing to a programmed-controlled operating mode well enough in advance, tool racing and tool racing marks on the workpiece can be avoided. Following repositioning or NC-block restart, the NC resumes program execution without performing a new NC start.



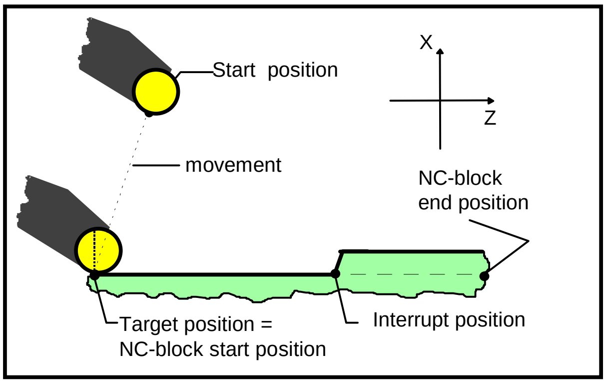


Fig. 3-22: Repositioning in the program operating modes

Fig. 3-23: Repositioning in the program-controlled operating modes

The desired function is selected by pressing the machine operating keys Reposition or NC-block restart. Repositioning or NC-block restart is started by pressing the Start PB", and the NC axes are moved to the destination position in a specified order.

- The machine builder can specify the order in which the NC axes are traversed to the contour. This order can be adapted to the given machine configuration. This is especially necessary when additional rotary main axes are present in addition to the spindles and the linear main axes.
- Program execution resumes without an additional NC start as soon as the NC has reached the destination point.

Repositioning and NC Block Restart 'G77'

G77 causes the NC to traverse to the destination position for the programmed feed axes, and in the case of spindles, to restore the status which existed prior to the interruption. With G77 the NC traverses the existing distance-to-go between the destination position and the current position for feed axes (axis meanings: X, Y, Z, U, V, W, A, B, C) by performing an interpolation operation similar to the G00 interpolation. It uses the destination position in machine coordinates that was determined at the beginning of the repositioning or NC NC-block restart operation as the destination position for the axes.

Syntax **G77 <[AxisName][CoordinateValue=0]> <Feed>**

Example	G77 X0 Y0 Z0 F1000

Notes on programming G77

- G77 is active only for the NC-block in which it is located.
- G77 S[x] 0 ([x]=1..3) causes the NC to restore the most recently active RPM for the spindles or it causes the NC to traverse to the specified destination position. The NC uses the positioning speed which was previously parameterized for spindle positioning to traverse to the destination position. An additional S value is not needed for specifying the positioning speed.
- With rotary-axis-capable main spindles (C-axis), the state upon interruption (main spindle/rotary axis mode) must be stored in the SPS. With repositioning or NC NC-block restart, the rotary-axis capable main spindle must be traversed to completion in the corresponding interruption state (main spindle/rotary axis mode).

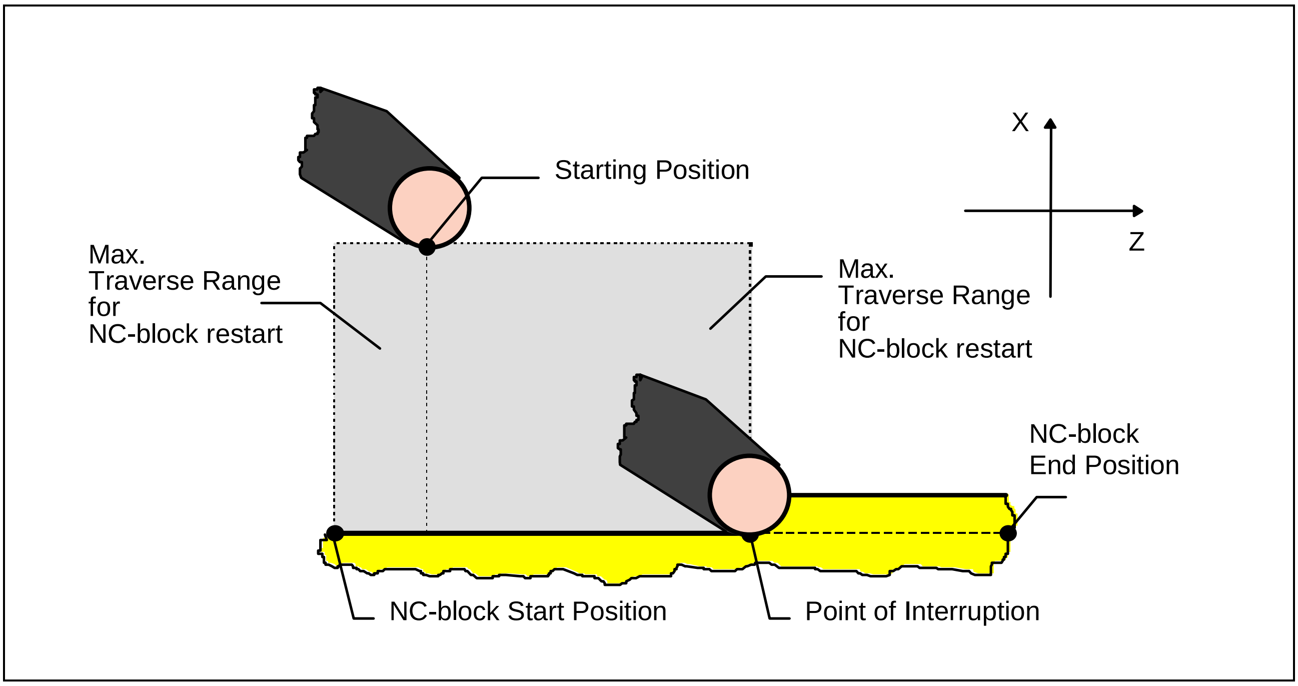


Fig. 3-24: Repositioning and NC-block restart

4 Motion Blocks

4.1 Axes

Linear Main Axes

The linear main axes span a Cartesian coordinate system.

They are identified by means of axis names:

- 1st linear main axis (symbol: X)
- 2nd linear main axis (symbol: Y)
- 3rd linear main axis (symbol: Z)

The axis name (address of the axis as it is to be addressed in the NC-program) is freely configurable; however, the *meaning* of the axis is defined by the position of the axis in the coordinate system (see Fig. 4-1). In the CNC the axes are permanently assigned to specific processes; however, they can be switched to other processes (see chapter 11, "NC Special Functions"). An axis cannot be addressed simultaneously in more than one process.

Circular interpolations and the tool radius path correction can only be performed within the machining planes spanned by the linear main axes (G17, G18, G19).

Rotary Main Axes

Rotary main axes rotate about the linear main axes.

The axis meanings:

- 1st rotary main axis (symbol: A)
- 2nd rotary main axis (symbol: B)
- 3rd rotary main axis (symbol: C)

indicate which coordinate axis the respective rotary main axis rotates about (*see Fig. 4-1*). The axis name (the address of the axis) is freely configurable; however, the axis meaning is defined by the position of the axis in the coordinate system. With absolute positioning (G90) the traverse range is ± 360.000 degrees. With absolute positioning (G90) the position which is programmed in an absolute statement is traversed to over the shortest possible path. With incremental positioning (G91) the traverse range is ±999999.9999 degrees or ±99999.99999 degrees (depending on the parameter setting). The sign indicates the traverse direction.

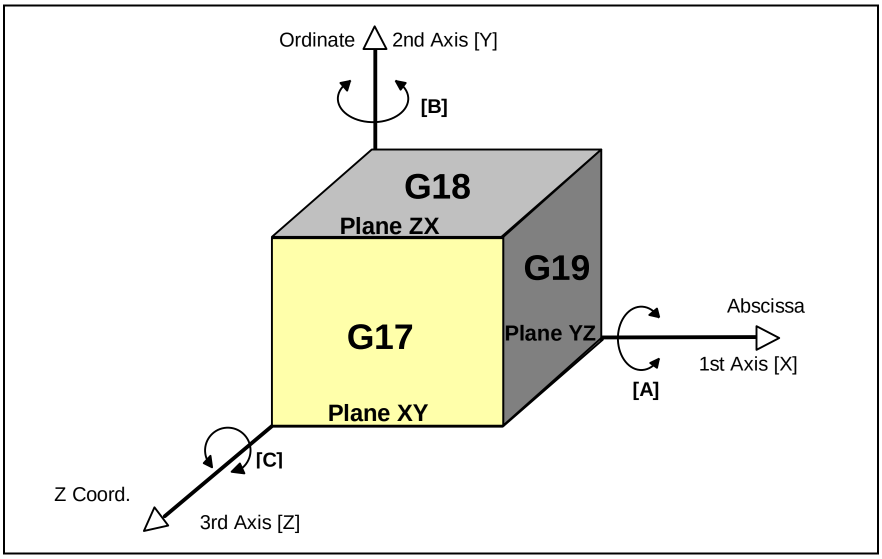


Fig. 4-1: Linear main axes (X, Y, Z) and rotary main axes (A, B, C) in a reference coordinate system

Linear and Rotary Auxiliary Axes

Linear and rotary auxiliary axes can occupy any given position in space.

- 1st auxiliary axis (symbol: U)
- 2nd auxiliary axis (symbol: V)
- 3rd auxiliary axis (symbol: W)

identify this type of axis.

The axis meanings U, V and W are completely equivalent. They can be selected for linear and rotary axes, as well as rotary-axis capable main spindles.

Like the other axes, auxiliary axes take part in positioning operations and interpolation moves, and like them they reach their programmed final value simultaneously. The path feedrate (F value) specified in the NC-program, however, does not apply to the auxiliary axes, but only to the linear and rotary main axes if they are programmed within a NC-block.

4.2 Interpolation Conditions

Minimized Following-Error Mode 'G06'

A Minimized Following-error mode is activated for the axis moves using the interpolation condition G06. All subsequent moves along the path are almost completely true to the path. The NC-block transitions are not rounded, and they are processed free of interruptions. The path velocity is reduced to nearly zero in the vicinity of contour corners (bends in the path). The Minimized Following-error mode is implemented by means of a dynamic feed forward system. A following error occurs only within the 2-ms limits of the interpolation clock.

- Virtually lag-free operation can only be achieved when INDRAMAT digital drives are used. With analog drives, G06 results in reduced-following-error operation.
- After it is selected, G06 remains modal active until it is canceled by G07 or until it is automatically reset at the end of the program or by BST, M02, M30.
- This function permits the gain factor to be increased to the machine's maximum mechanical load limits. A higher gain factor produces better dynamic characteristics in the axis moves.

Examples

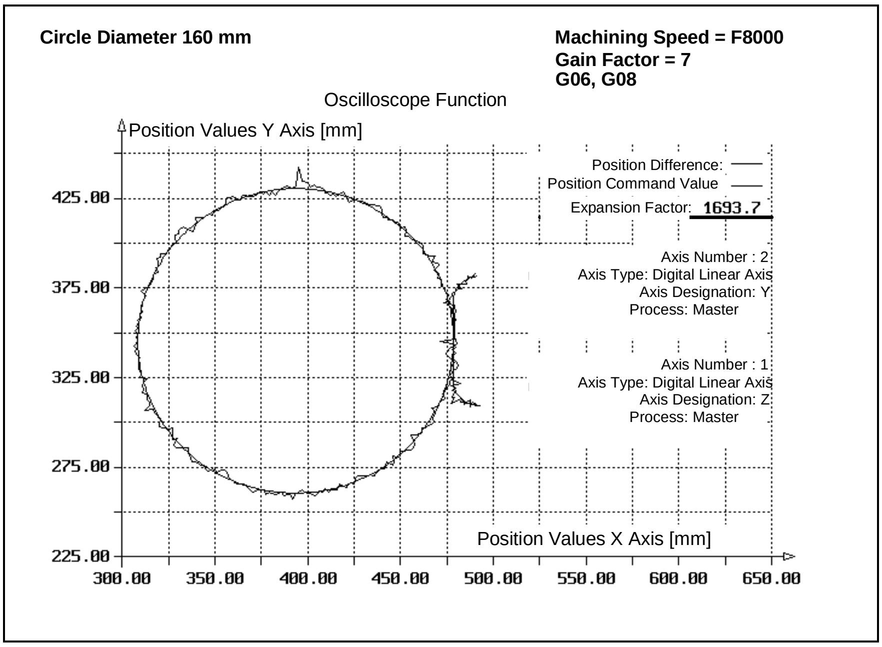


Fig. 4-2: Circular interpolation with F8000 mm/min and Minimized Following-Error Mode

In the circle shown in Fig. 4-2 the following-error is multiplied by an expansion factor of 1693.7. Here is the part program for the circle plot (Figs. 4-2 to 4-5).

T11 BSR .M6	Tool change SF D10
G00 G90 G54 G06 G08 X199 Y136 Z5	Starting position
S5000 M03	Spindle ON
G01 Z-5 F1000	Lower cutter into material
G41 X199 Y141 F8000 [or. F1000]	Start point for circular machining
G03 X180 Y122 I199 J122	Insertion circle
G01 X180 Y100	Transition element
G02 X180 Y100 I100 J100	Full circle ∅160
G01 X180 Y77	Transition element
G03 X198 Y59 I198 J77	Withdrawal circle
G00 Z5	Withdraw tool to safety distance
T0 BSR .M6	Tool change
RET	Return to start of program

The actual contour is nearly ideal on the NC control end due to the compensated following error. A position deviation of 0.002 mm occurred only at the transition between the squares. The position deviation at the transition between the quadrants can be compensated for almost completely by programming in addition friction compensation (see Chapter 11, "Special Functions, AXD Command").

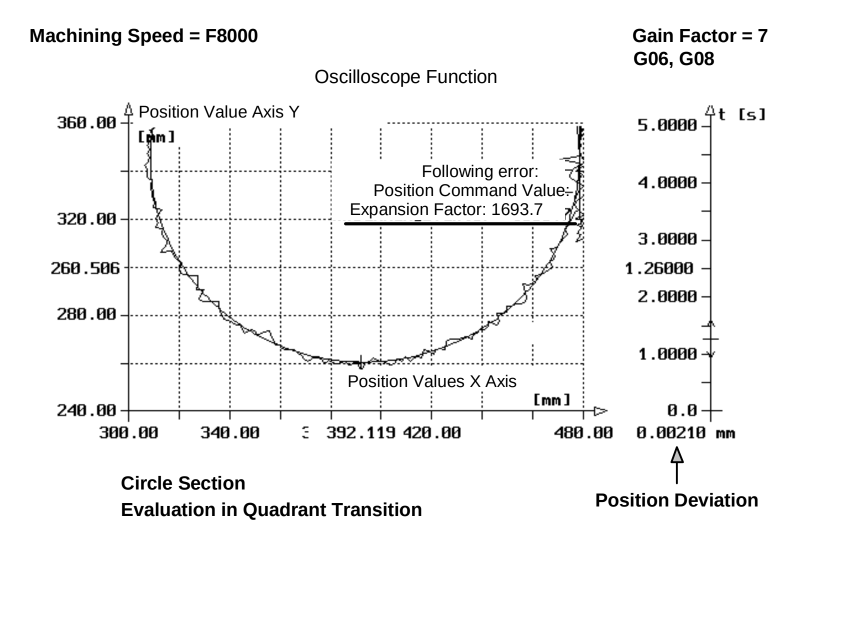


Fig. 4-3: Circular interpolation with Minimized Following-Error Mode, partial view

The next figure shows, by way of comparison, the same circle at a path feedrate of F1000 mm/min.

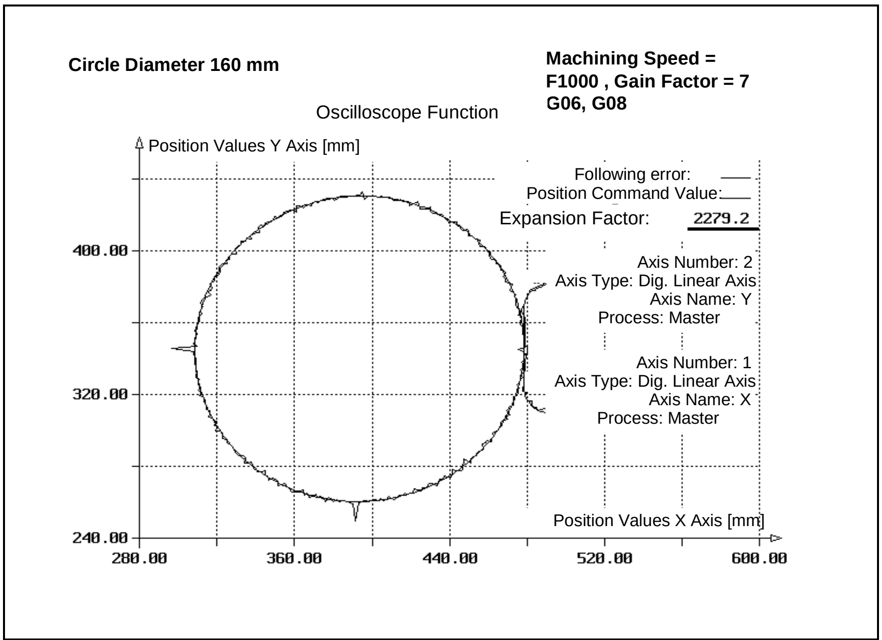


Fig. 4-4: Circular interpolation with F1000 mm/min and Minimized Following-Error Mode

The figure below shows an evaluation of the position deviation in the quadrant transition.

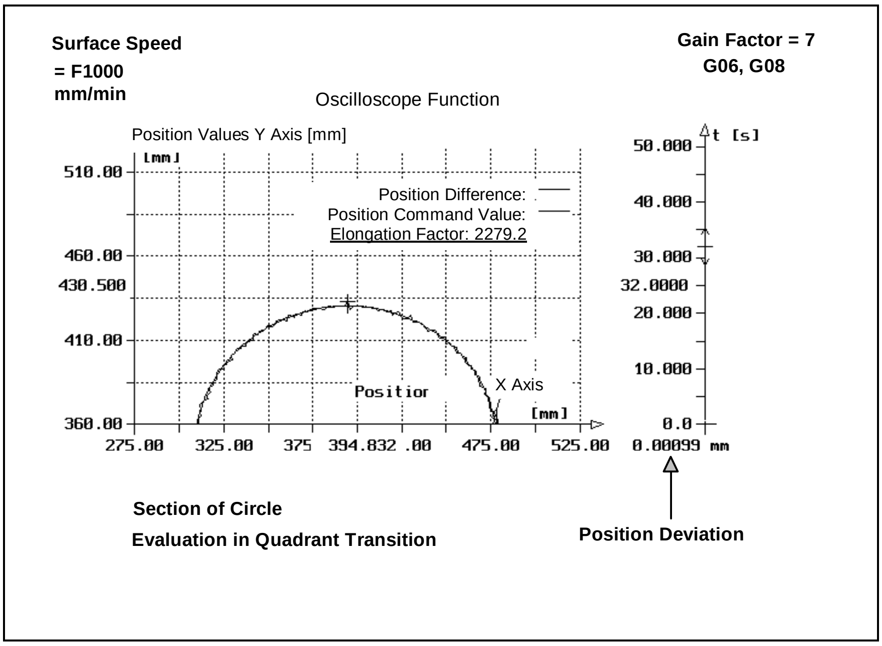


Fig. 4-5: Circular interpolation with Minimized Following-Error Mode, partial view F1000

Interpolation with Following Error 'G07'

A following-error-containing algorithm is activated for the axis moves using the interpolation condition G07. G07 is the power-on state. It is active and latched until it is overwritten by a G06. G07 is reset automatically at the end of the program (RET) or by the BST, M02, M30 command. NC-block transitions which are not tangential will be rounded.

Example

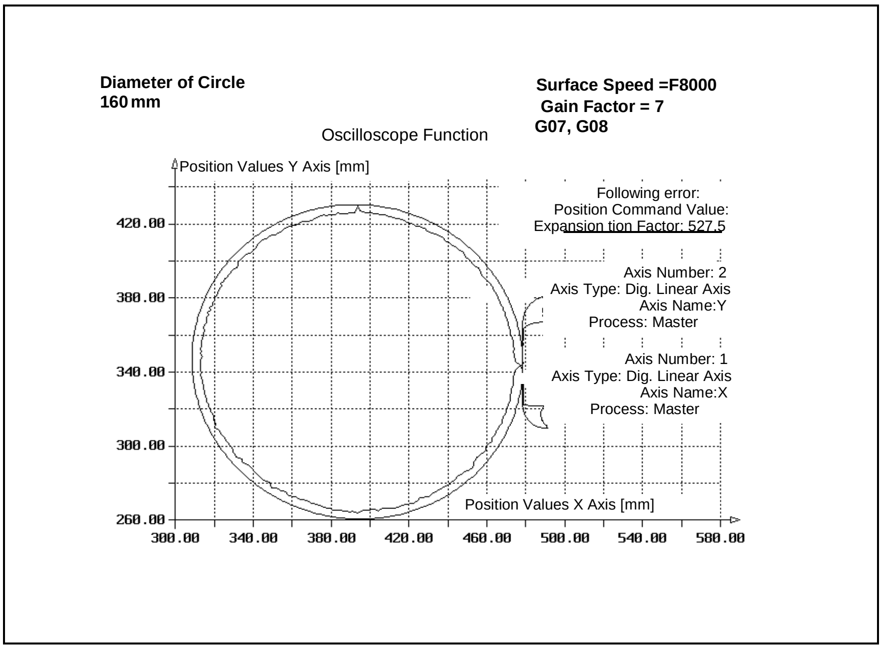


Fig. 4-6: Circular interpolation with F8000 mm/min and G07

In the circle shown here (Fig. 4-6) the actual contour is multiplied by an expansion factor of 527.5. By contrast, the expansion factor with G06 was a multiplier of 1693.7—more than three times the value—which explains the variation in the position deviation. Here is the part program for the circle plots (Figs. 4-6 to 4-9).

T11 BSR .M6	Tool change SF D10
G00 G90 G54 G07 G08 X199 Y136 Z5	Starting position
S5000 M03	Spindle ON
G01 Z-5 F1000	Lower cutter into material
G41 X199 Y141 F8000 [or. F1000]	Start point of circular machining
G03 X180 Y122 I199 J122	Insertion circle
G01 X180 Y100	Transition element
G02 X180 Y100 I100 J100	Full circle ∅160
G01 X180 Y77	Transition element
G03 X198 Y59 I198 J77	Withdrawal circle
G00 Z5	Withdraw tool to safety clearance
T0 BSR .M6	Tool change
RET	Return to start of program

The diameter of the programmed circle becomes smaller according to the programmed speed and the selected gain factor. The programmed contour will be maintained with increasing accuracy as the programmed speed becomes smaller and the selected gain factor becomes larger.

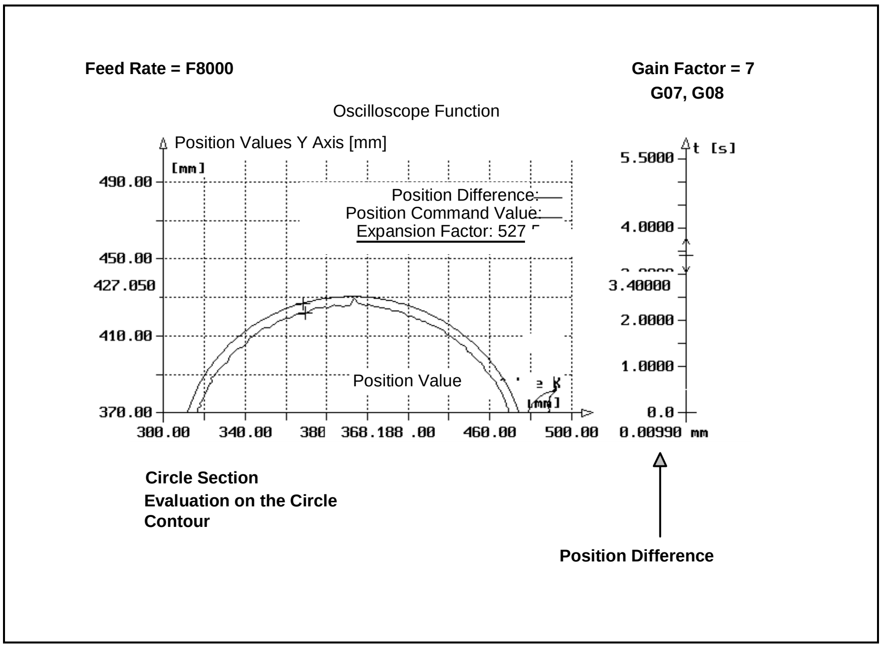


Fig. 4-7: Circular interpolation with G07, partial view,

The next figure shows, by way of comparison, the same circle at a path feedrate of F1000 mm/min.

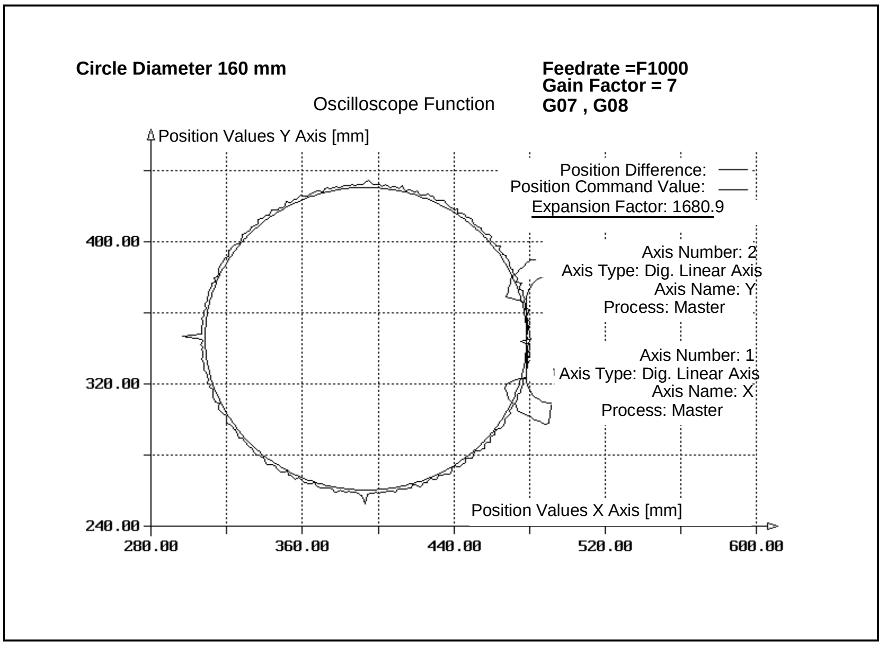


Fig. 4-8: Circular interpolation with F1000 mm/min and G07

The figure below shows an evaluation of the position deviation in the rectangular transition.

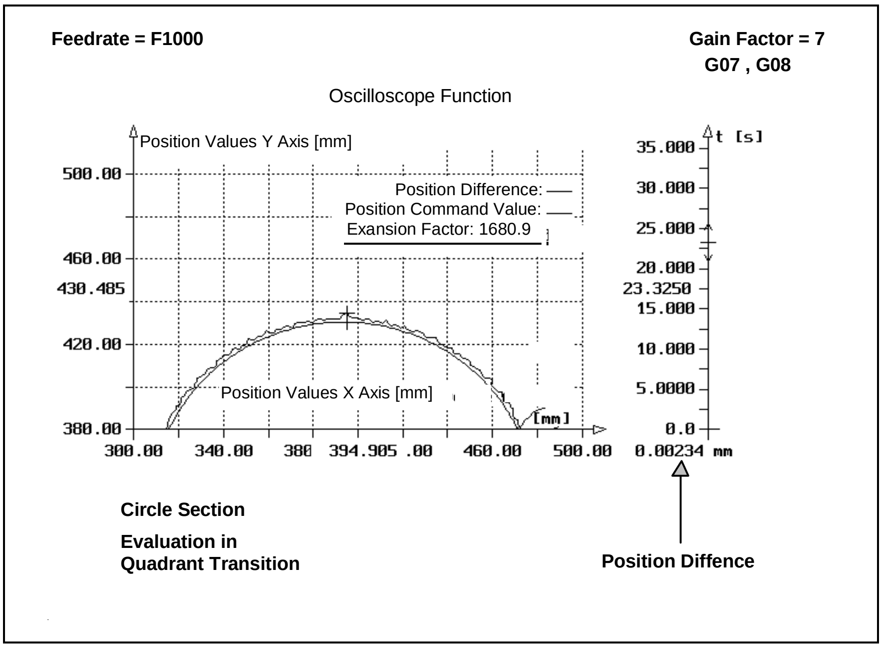


Fig. 4-9: Circular interpolation with G07, partial view with F1000 mm/min

Contouring Mode (Acceleration) 'G08'

The interpolation function G08 is used to adjust the final velocity at the end of the NC-block to ensure that the transition to the next NC-block occurs at the highest possible velocity. The crucial factor is the maximum velocity jump which is defined in the axis parameters. In the case of a tangential NC-block transition with the same contour velocity, the transition is made at the same velocity. The result is that workpiece surfaces are more uniform; no free-cutting marks are produced.

- With a tangential transition and with G06 active, for example in a transition from a straight line to a small circle, the velocity is reduced to the calculated starting velocity of the next NC-block.
- When G08 contouring mode (acceleration), G61 exact stop before NC-block transition is programmed, G09 contouring mode (decele-

ration) is activated automatically. G08 cannot be programmed again until G61 has been canceled.

- The G08 function is active with feedrate overrides of 1%–100%. If the feedrate override is set for more than 100%, the velocity is reduced to 100% in the NC-block transitions.
- The M-functions stop NC-block execution until an acknowledgment is received; thus, G08 does not work in NC-blocks in which an M-function is programmed.
- After it has been selected, G08 remains active modally until it is canceled by G09 or until it is automatically reset at the end of the program or by BST, M02, M30.
- Interposed NC-blocks in which no interpolation moves occur do not cause a velocity change. For example: Interposing a NC-block containing G01 F7000 would cause a speed change.

Note: The Maximum Feedrate Change w/o Ramp is specified by the machine builder in the axis parameter Cxx.017.

Examples

The velocity diagram (Fig. 4-10) clearly shows how the NC-block transition from the first to the second area is traversed at unreduced velocity. The NC-block transition cannot be detected. In the NC-block transition to the third section, the feedrate is reduced to F7000. The velocity is reduced in an optimal manner to the NC-block starting velocity without overshooting.

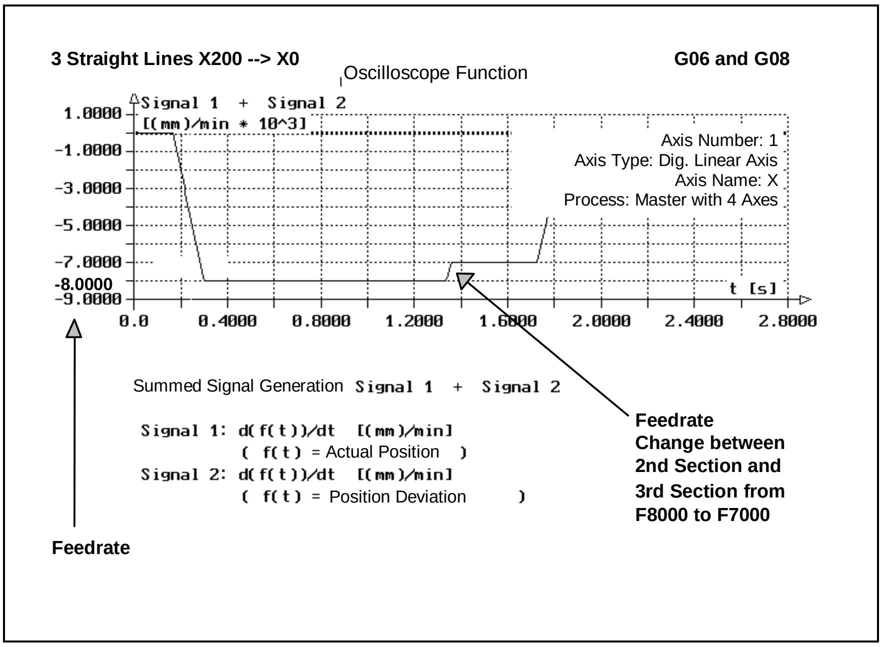


Fig. 4-10: NC-block transition with G08 and F8000

Example of a program for the velocity diagrams shown in Figs. 4-10 and 4-11:

G54 G90 G00 G06 G08 X200	Starting point of the X axis
G01 F8000	Feedrate
X150	1st area
X50	2nd area
X0 F7000	3rd area with new F-value
RET	Return to program beginning

In the following velocity diagram (Fig. 4-11), the change in velocity between the second area with F8000 and the third area with F7000 has been magnified using a zoom function. Here one can clearly see the contouring mode (acceleration) occurring between the two areas.

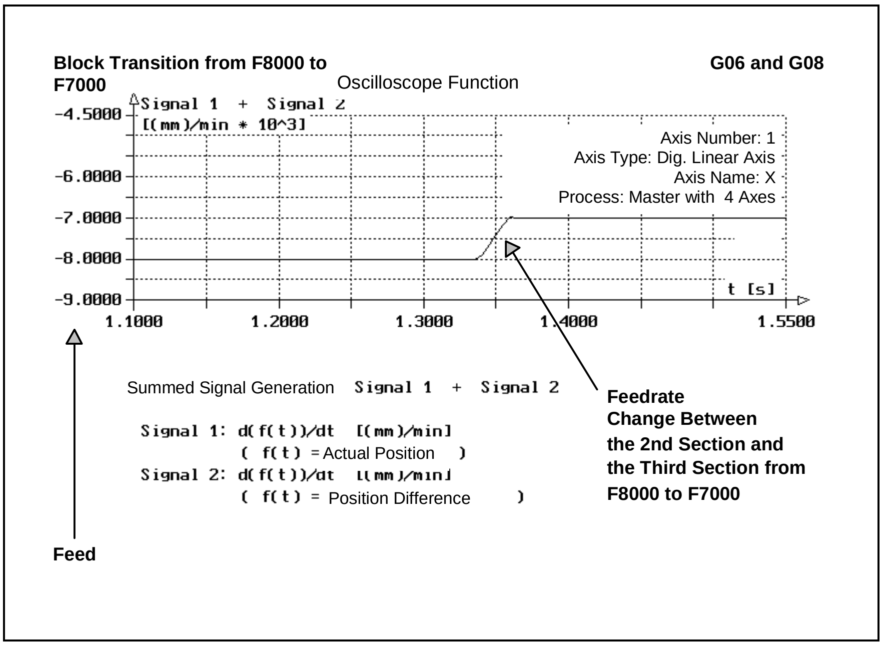


Fig. 4-11: NC-block transition via G08 from F8000 to F7000

Contouring Mode (Deceleration) 'G09'

The interpolation condition G09 is used to adjust the end-of-block velocity in such a way that as stop could be performed using the maximum velocity change without ramp defined in the axis parameters.

- Position deviations can be reduced at NC-block transitions by using the interpolation condition G09.
- Machining using G09 requires more time, and the surface quality can be adversely affected by the free cutting marks.
- G09 is the power-on default. It is active and latched until it is overwritten by a G08. G09 is reset automatically at the end of the program (RET) or by the BST, M02, M30 command.

Note: The Maximum Feedrate Change w/o Ramp is specified by the machine builder in the axis parameter Cxx.017.

Examples

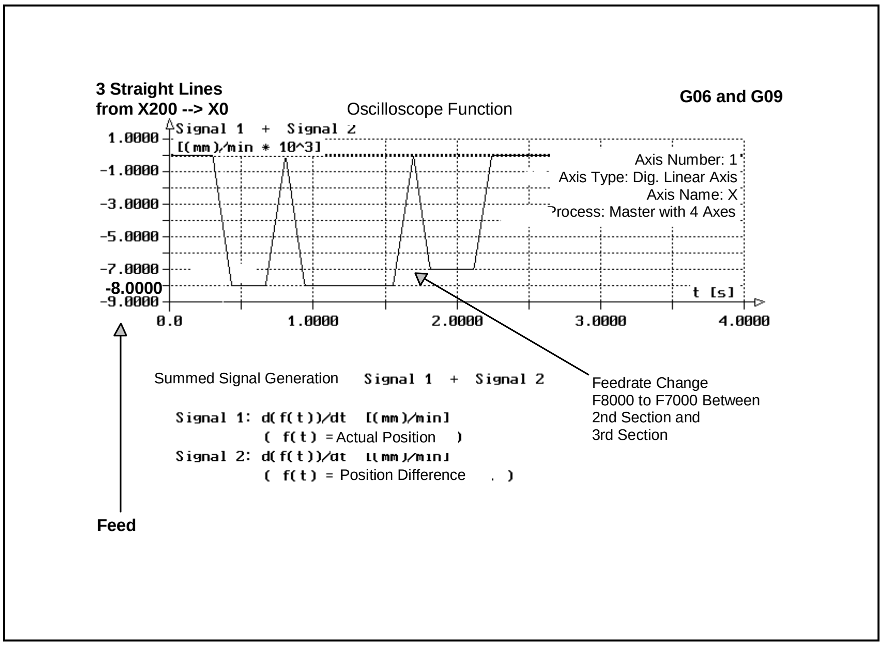


Fig. 4-12: NC-block transitions with G09 and F8000

The velocity diagram (Fig. 4-12) clearly shows how the velocity of the axis is reduced to almost 0 between the workpiece areas. The remaining velocity at which the transition to the next NC-block occurs is derived from the axis parameter Cxx.017 Maximum Feedrate Change w/o Ramp.

Example of a program for the velocity diagrams shown in Figs. 4-12 and 4-13:

G54 G90 G00 G06 G09 X200	Starting point of the X axis
G01 F8000	Feedrate
X150	1st area
X50	2nd area
X0 F7000	3rd area with new F-value
RET	Return to program beginning

In the following velocity diagram (Fig. 4-13), the change in velocity between the second area with F8000 and the third area with F7000 has been magnified using a zoom function.

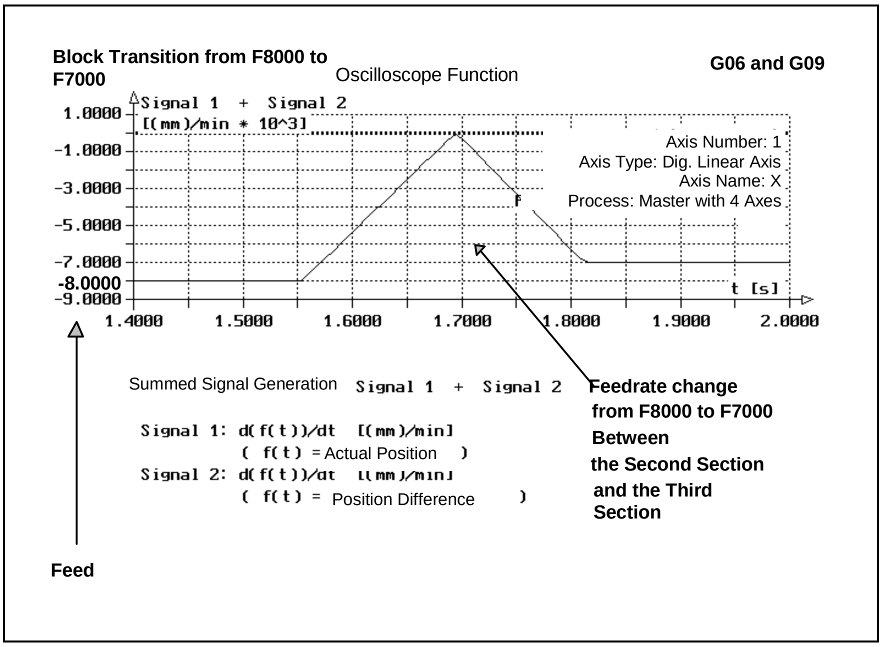


Fig. 4-13: NC-block transition via G09 from F8000 to F7000

Exact Stop Before NC-block Transition (with Lag Finishing) 'G61'

The programmed destination position is traversed to within a preset exact-stop limit with the interpolation condition G61. The *exact-stop limit* is defined in the axis parameters by a positioning window. When the positioning window is reached, processing switches to the next NC-block and the next axis move starts.

- G61 exact stop before NC-block transition (with lag finishing) is automatically activated when G00, linear interpolation at rapid traverse, is programmed.
- If G61 is programmed, the interpolation condition G08 is reset. G08 cannot be reactivated until G61 has been canceled.
- It is recommended that G61 be selected for machining sharp contour corners and not for tangential transitions.
- After it has been selected, G61 remains modally active until it is canceled by G62 or until it is automatically reset at the end of the program or by BST, M02, M30.

Note: The positioning window is specified by the machine builder in the axis parameter Cxx.023 In-Position Windows.

Examples

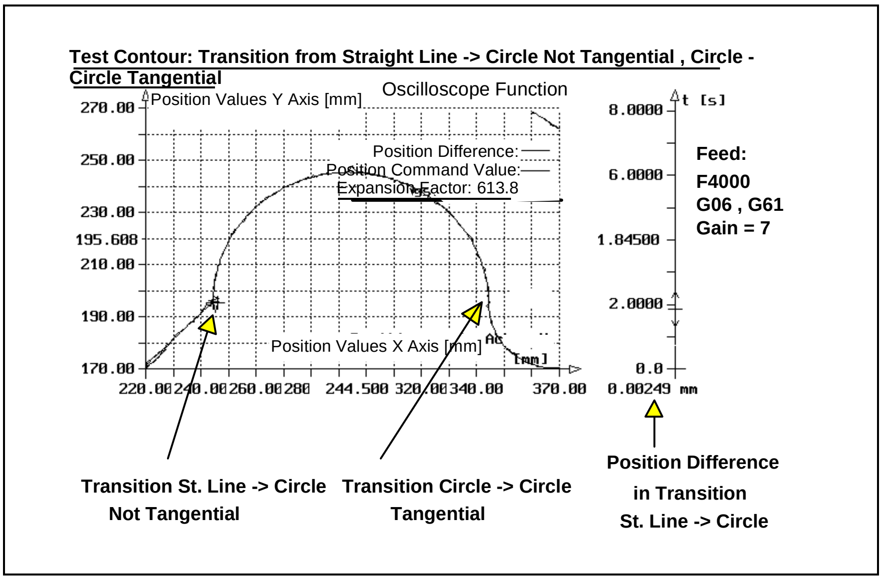


Fig. 4-14: Contour diagram with G61

The contour diagram shown here (Fig. 4-14) illustrates how the contour is accurately maintained by G61 in the transition from the straight line → to the circle and from the circle → to the circle. The positioning window for the examples shown here is specified as 0.010 mm in the axis parameters. The position deviation in the non-tangential transition from the straight line → circle is 0.00249 mm. If the positioning window in the axis parameters were increased in size, the transition would be made with correspondingly higher accuracy. The position deviation is less than 0.001 mm in the tangential transition circle → circle.

Example of a program for the diagrams shown in Figs. 4-14 and 4-15:

G00 G54 G90 G06 G08 X-100 Y-100	Starting point
G01 G61 X-50 Y-50 F4000	1st straight line
G02 X50 Y-50 I0 J-50	1st semicircle
G03 X100 Y-50 I75 J-50	2nd semicircle
RET	Return to program beginning

The following velocity diagram (Fig. 4-15) shows how the velocity is reduced until the positioning window is reached. When the positioning window is reached, processing switches to the next NC-block and the next axis move starts.

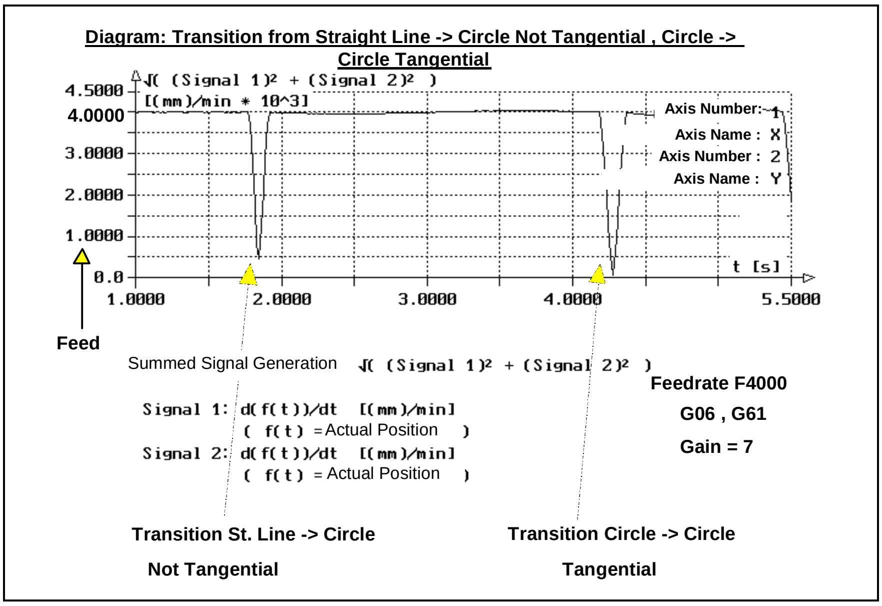


Fig. 4-15: Velocity diagram with G61

Block Transition with Lag Present 'G62'

With interpolation condition G62 processing switches to the next NC-block as soon as the command values for all axes programmed in the NC-block that are issued by the interpolator have reached their programmed final values. The system does not wait until the actual values have reached their final position. Any lag (following error) which may be present is not reduced as the final position is approached.

- G62 NC-block transition with lag present is suppressed when G00 linear interpolation at rapid traverse is programmed.
- Sudden contour changes and non-tangential transitions are rounded off by programming G62.
- G62 is the power-on default. It is active and latched until it is overwritten by a G61. G62 is reset automatically at the end of the program (RET) or by the BST, M02, M30 command.
- Machining time is reduced when G62 and G08 are programmed.

Examples

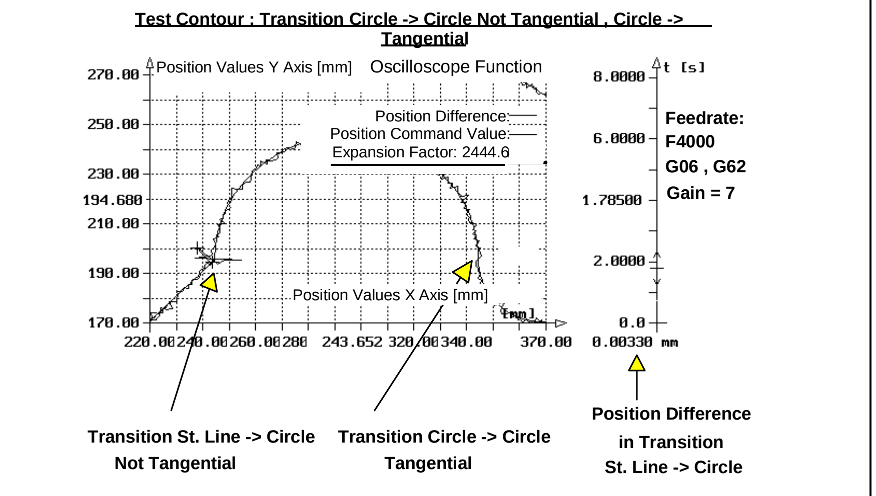


Fig. 4-16: Contour diagram with G62

The contour diagram shown here (Fig. 4-16) illustrates how the non-tangential transitions (straight line → circle) are slurred as a consequence of G62. The contour is traversed at optimal velocity (via G08). At the contour itself, the machining quality is identical to that achieved with G61. When one compares the contour diagrams in Figs. 4-14 (G61) and 4-16 (G62), one sees that the expansion factor for the position deviation is four times as high in Fig. 4-16.

Example of a program for the diagrams shown in Figs. 4-16 and 4-17:

G00 G54 G90 G06 G08 X-100 Y-100	Starting point
G01 G62 X-50 Y-50 F4000	1st straight line
G02 X50 Y-50 I0 J-50	1st semicircle
G03 X100 Y-50 I75 J-50	2nd semicircle
RET	Return to program beginning

In the following velocity diagram (Fig. 4-17), one can see how the path velocity in the non-tangential transition straight line → circle is reduced by the change of direction. The tangential transition circle → circle is traversed at a constant path velocity as a consequence of conditions G62 and G08.

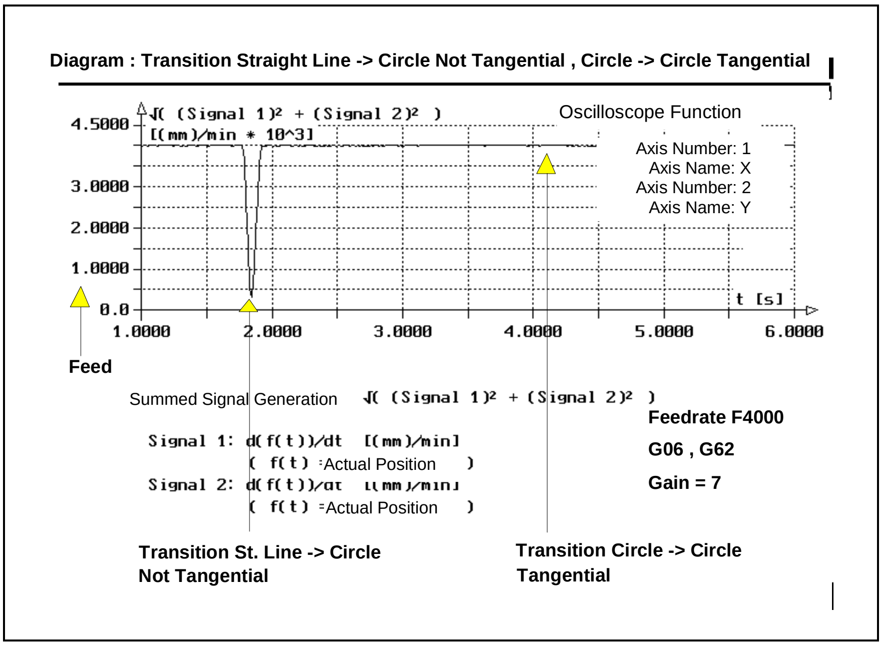


Fig. 4-17: Velocity diagram with G62

Acceleration 'ACC'

An acceleration limit can be programmed in an NC-program using the function ACC: programmable acceleration. This function is used, for example, to reposition the workpiece holder axes according to the weight of the workpiece. The programmable acceleration limits the maximum path acceleration specified in the parameters. The acceleration therefore is programmed as a percentage of the path acceleration defined in the parameters; it is applied to all axes programmed in the NC-block.

- The value range for the acceleration therefore is from 1% to 100%.
- An acceleration factor which is outside the value range will produce an error message when the program is executed.
- The acceleration factor can be programmed as a constant as well as a mathematical expression. If the acceleration factor is declared as a constant, it is not possible to program places to the right of the decimal point. If it is declared as a mathematical expression, the value is automatically rounded to an integer.
- An acceleration factor programmed using the ACC command remains modally active until it is overwritten by a new programmed value or is automatically reset to 100% at the end of the program or by the command BST, M02, M30.
- If the maximum path acceleration parameter was set to a very high value which is disproportionate to the maximum possible path acceleration, the ACC command may not take effect.

Note: The maximum Path Acceleration is specified by the machine builder in the process parameter Bxx.007.

Example

Syntax		
Syntax	**G01 ACC 50 X100**	**ACC as constant**
	G01 ACC=@10 X100	**ACC as variable**
	G01 ACC=10*@10+30 X100	**ACC as math. expression**

NC-program	G00 G54 G90 G61 G06 X200	Starting point
	G01 X150 F8000	1st straight line
	ACC 40 X50	2nd straight line acceleration factor 40%
	ACC 15 X-50	3rd straight line acceleration factor 15%
	RET	Return to program beginning

The process parameter for maximum acceleration was set to 500 mm/sec^2 for the velocity diagram shown here. Thus, the acceleration for the NC-block containing ACC 40 X50 was 200 mm/sec^2, and that for the NC-block containing ACC 15 X-50 was 75 mm/sec^2.

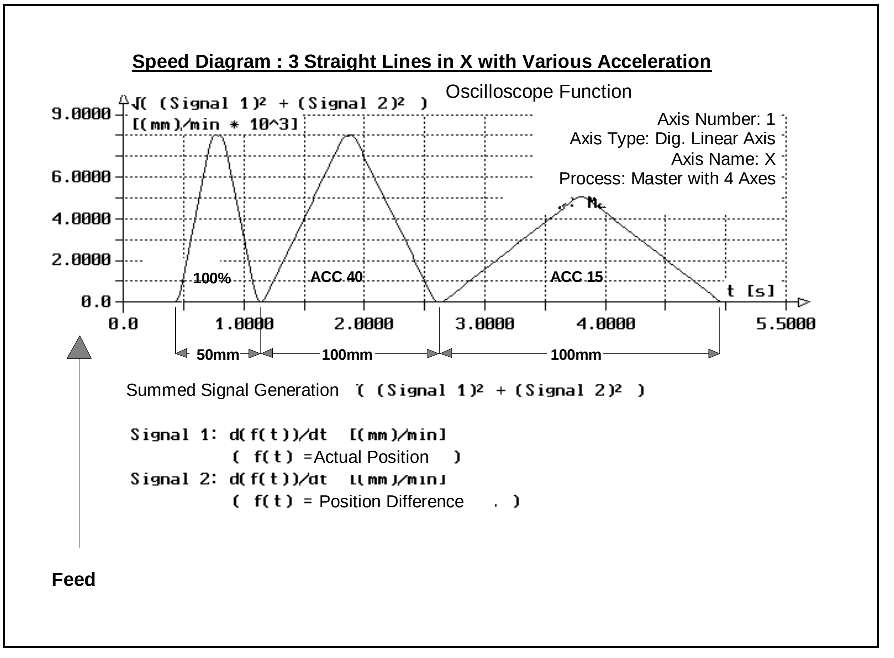


Fig. 4-18: Acceleration diagram for programmable acceleration

4.3 Interpolation Functions

Linear Interpolation, Rapid Traverse, 'G00'

The coordinate values programmed using the preparatory code G00 are traversed to at maximum path velocity. If G00 applies to more than one axis, the traverse move is performed with interpolation.

A feedrate can be programmed with G00 using an F-word. If a feedrate (F value) is not programmed in the NC-block, the motion occurs at the maximum path velocity entered in the process parameter (Bxx.007). The path velocity is limited to the maximum axis velocity entered in the axis parameters, so that linear interpolation is always performed. The F-value programmed with G00 remains active for all subsequent traverse moves and interpolation types until it is overwritten by a new F-value.

Block transition with lag present (G62) is suppressed in combination with G00. The transition to the next NC-block does not occur until all the programmed axes lie within the position window for the programmed coordinate value which is specified in the axis parameters.

If contouring mode (acceleration) is active (G08), a change to contouring mode (acceleration) (G09) is already made in the previous NC-block. If G00 is overwritten by a different type of interpolation, G08 is automatically activated.

G00 remains modally active until it is overwritten by a different preparatory code in the same G group (G01, G02, G03).

Example

G00 G54 G90 X40 Y40	[P1] rapid traverse at maximum path velocity
X120 Y60 F8000	[P2] rapid traverse with F-word

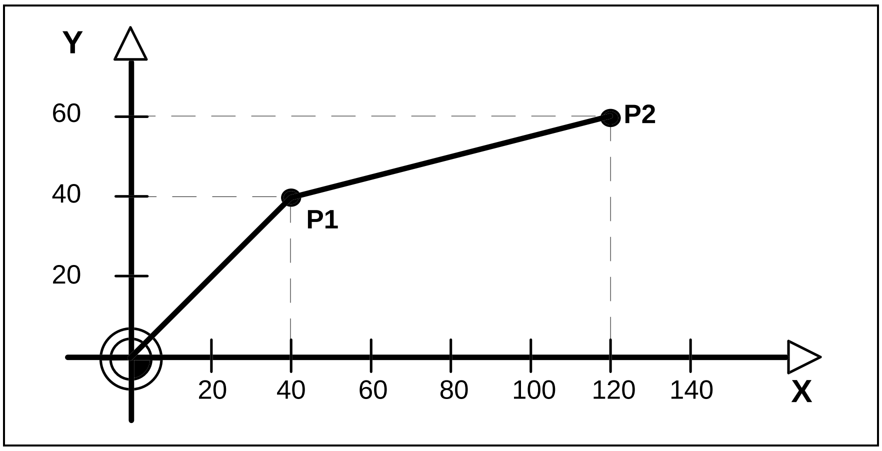


Fig. 4-19: Linear interpolation, rapid traverse G00

Linear Interpolation, Feedrate 'G01'

The axes programmed using the preparatory code G01 are traversed to their programmed coordinate value on a straight line relative to the current coordinate system using the current feedrate. The programmed axes are started simultaneously, and they all reach their programmed end point at the same time.

If a new feedrate (F value) is programmed using preparatory code G01, the most recently active F-value is overwritten. The programmed F-value functions as a path feedrate. Thus, when a number of axes are being traversed, the velocity component of each individual axis is less than the programmed path feedrate. If a F-word was not yet active when the controller was powered on, G01 must be used to program an F-value.

G01 remains modally active until it is overwritten by a different preparatory code in the same G group (G00, G02, G03).

Example Linear interpolation in 2 axes

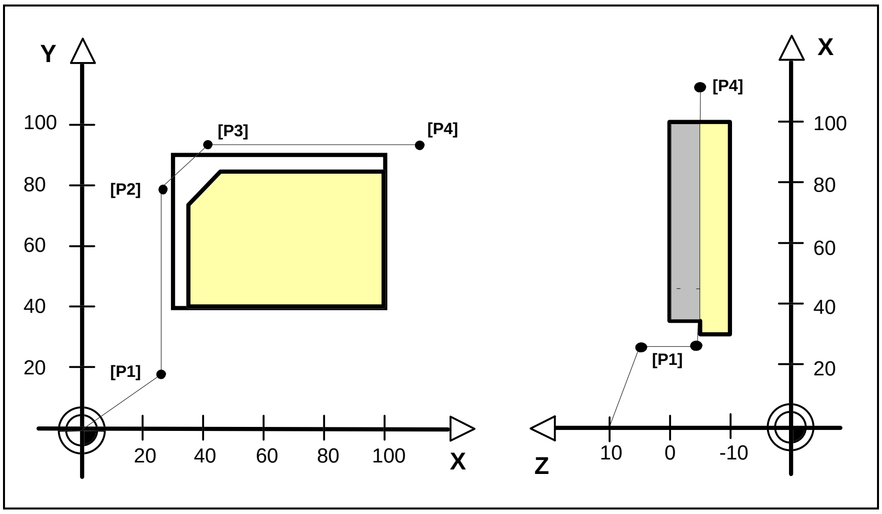


Fig. 4-20: Linear interpolation, feedrate G01 with 2 axes

G00 G90 G54 G06 G08	Motion commands, interpolation conditions
X0 Y0 Z10 S3000 M03	Starting position, spindle ON
G01 X26.26 Y18 Z5 F2000	[P1] start machining position
Z-5	Infeed Z axis
Y80 F1200	[P2] linear interpolation, 1 axis
X41 Y93.5	[P3] linear interpolation, 2 axes
X111	[P4] linear interpolation, 1 axis
G00 Z10 M05	Z axis to safety distance
RET	

Example Linear interpolation in 3 axes

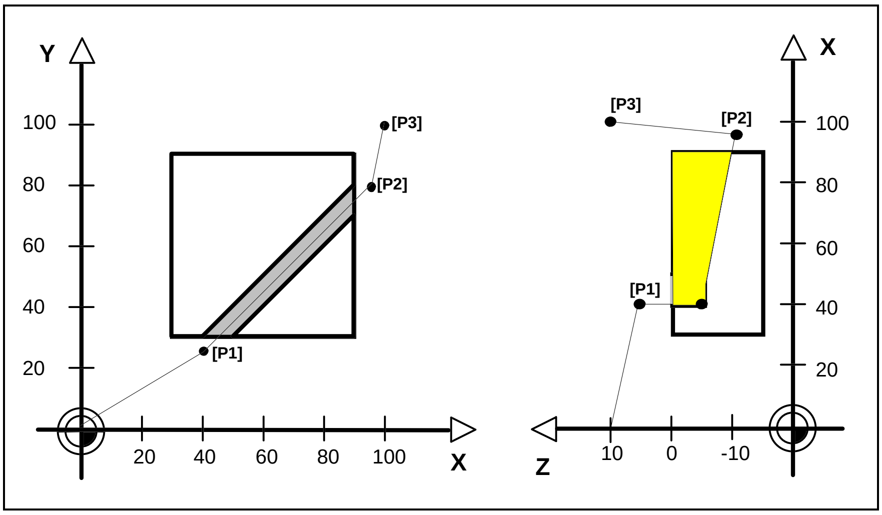


Fig. 4-21: Linear interpolation, feedrate G01 with 3 axes

G00 G90 G54 G06 G08	Motion commands, interpolation conditions
X0 Y0 Z10 S3000 M03	Starting position, spindle ON
G01 X40 Y25.5 Z5 F2000	[P1] start machining position
Z-5	Infeed Z axis
X95.74 Y80 Z-10 F1200	[P2] linear interpolation, 3 axes
X100 Y100 Z10 F2000	[P3] Z axis to safety distance
M05	Spindle OFF
G00 X0 Y0	Return to starting point
RET	Return to program begin

Circular Interpolation 'G02' / 'G03'

The tool programmed with G02 or G03 is moved along a circular path to the programmed end point using the effective or programmed feedrate (F-value). The programmed axes are started simultaneously, and they all reach their programmed end point at the same time.

The circular motion in the direction of the programmed end point is produced:

- in the clockwise direction with G02 and
- in the counter-clockwise direction with G03 (see Fig. 4-22).

The tool is moved about the programmed center point of the circle.

A circular motion can be performed in each plane when the corresponding G-codes are selected (G17, G18, G19). The programmed center of the circle and the end points must lie on the same machining plane as the starting point.

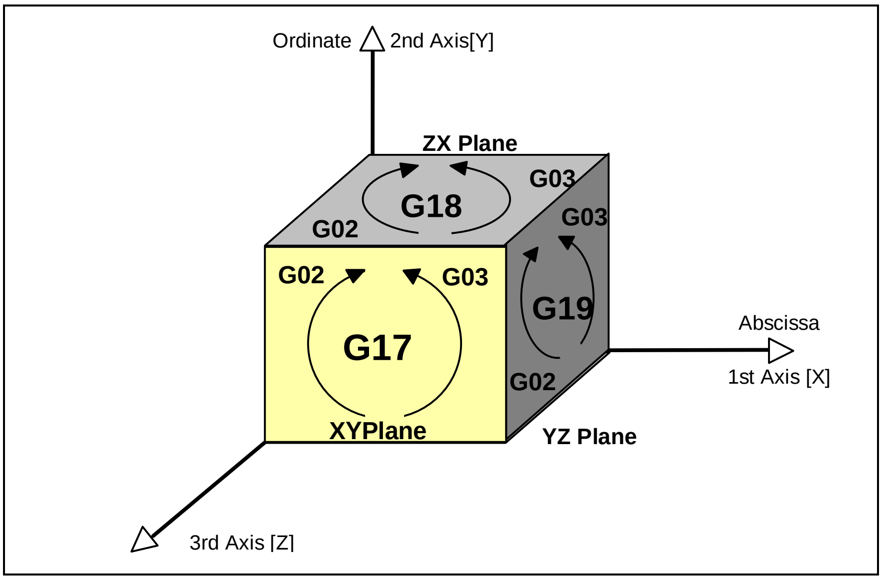


Fig. 4-22: Circular programming according to planes

The radius and the starting angle of the arc is calculated from the starting point and the center point. Any radius which is determined based on the end point and the center point and is different is ignored. This means that the end point can only be used to calculate the final angle. Thus, the programmed end point may not always lie on the arc. The programmed end point can therefore differ from the traversed end point.

With incremental data input (G91), the center point and the end point are expressed relative to the starting point; with absolute input (G90), they are expressed relative to the current zero point.

When programming uses absolute data input, the value of the starting point is assigned to the coordinate value of a not programmed address letter (X, Y, Z, I, J, K); with incremental input, the value 0 is assigned.

If a full circle is programmed, only the center point needs to be entered since the starting points and end points are identical with a full circle.

The circle or arc is defined by the programmed axis commands and the interpolation parameters. The starting point of the circle is defined by the previous NC-block. The end point of the circle is defined by the axis value data X, Y and Z in the G02/G03 NC-block. The center point of the circle is defined by entered the interpolation parameters I, J and K or directly via radius R.

Interpolation parameters I, J, K

Interpolation parameters are assigned to the axes which are used in a circular interpolation. These parameters are parallel to the axes, and their signs depend on the direction in which they are oriented relative to the center point of the circle. Based on DIN 66 025, the interpolation parameters I, J and K are assigned to axes X, Y and Z.

If coordinate values are not programmed using addresses I, J and K, the corresponding starting point is assigned with absolute dimension programming. With incremental dimension programming, the default value is 0.

With G91 programming, the interpolation parameters define the distance from the starting point of the circle to the center point; with G90 programming they define the distance from the current zero point to the center point.

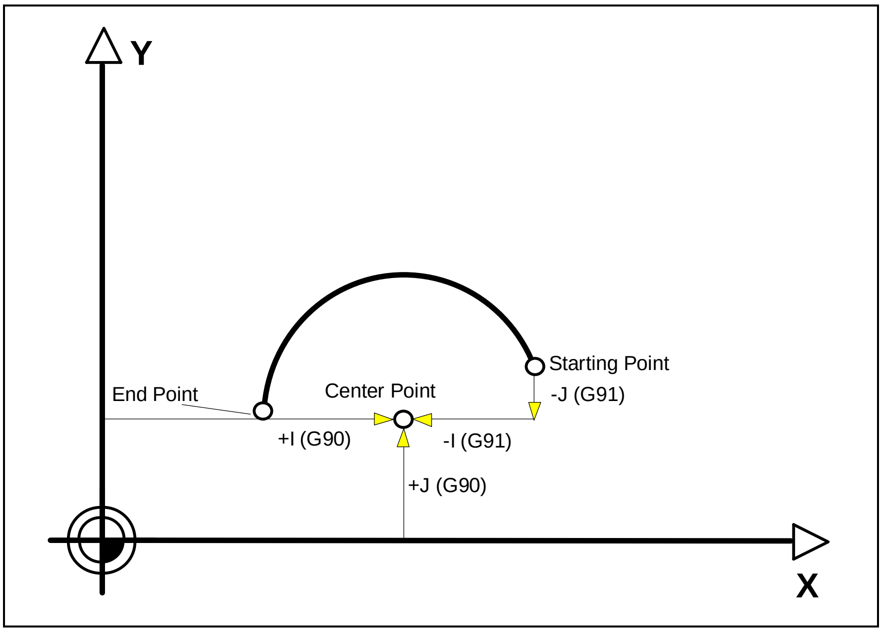


Fig. 4-23: Circular interpolation with interpolation parameters

Example Full circle in the X-Y plane with G90

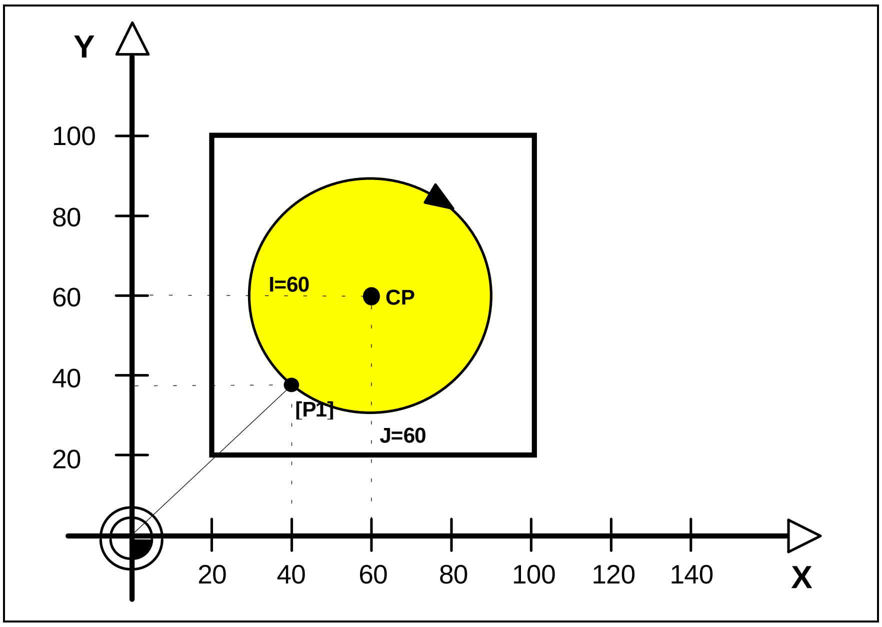


Fig. 4-24: Full circle with G90

G00 G90 G54 G06 G08	Motion commands, interpolation conditions
X0 Y0 Z10 S3000 M03	Starting position, spindle ON
G01 X40 Y37.24 F2000	Starting point of circle
Z-10 F500	Infeed the Z axis
G02 X40 Y37.24 I60 J60	Full circle in clockwise direction
Alternatively: G02 I60 J60	With full circle, without circle end point
G00 Z10	Z axis to safety distance
M05	Spindle OFF
X0 Y0	Return to starting point
RET	Return to program beginning

Example Full circle in the X-Y plane with G91

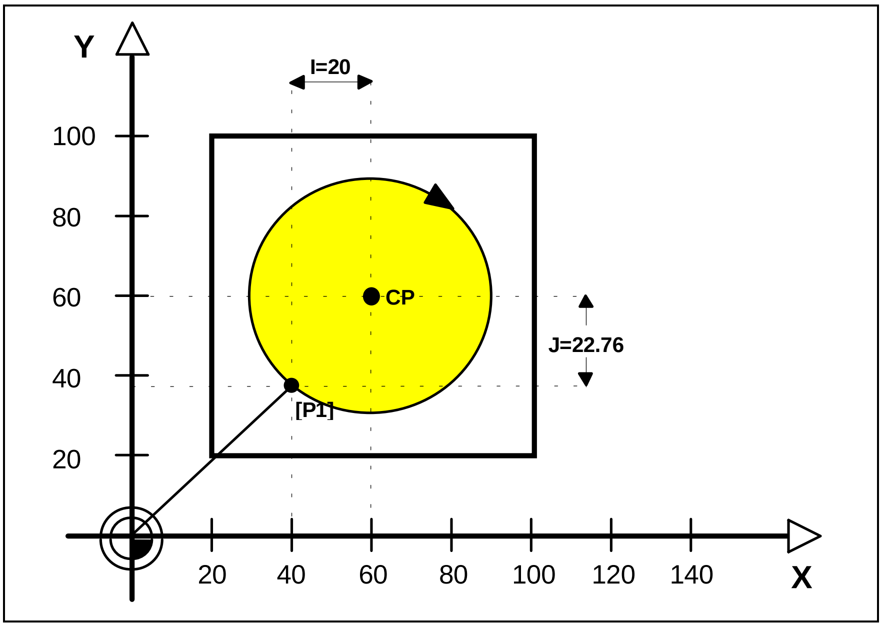


Fig. 4-25: Full circle with G91

G00 G90 G54 G06 G08	Motion commands, interpolation conditions
X0 Y0 Z10 S3000 M03	Starting position, spindle ON
G91 G01 X40 Y37.24 F2000	Circle starting point with incr. data input
Z-20 F500	Infeed the Z axis
G02 X0 Y0 I20 J22.76	Full circle in clockwise direction
Alternatively: G02 I20 J22.76	With full circle, without circle end point
G00 G90 Z10	Z axis to safety distance (G90)
M05	Spindle OFF
X0 Y0	Return to starting point
RET	Return to program beginning

Example Machining on lathe in Z-Y plane

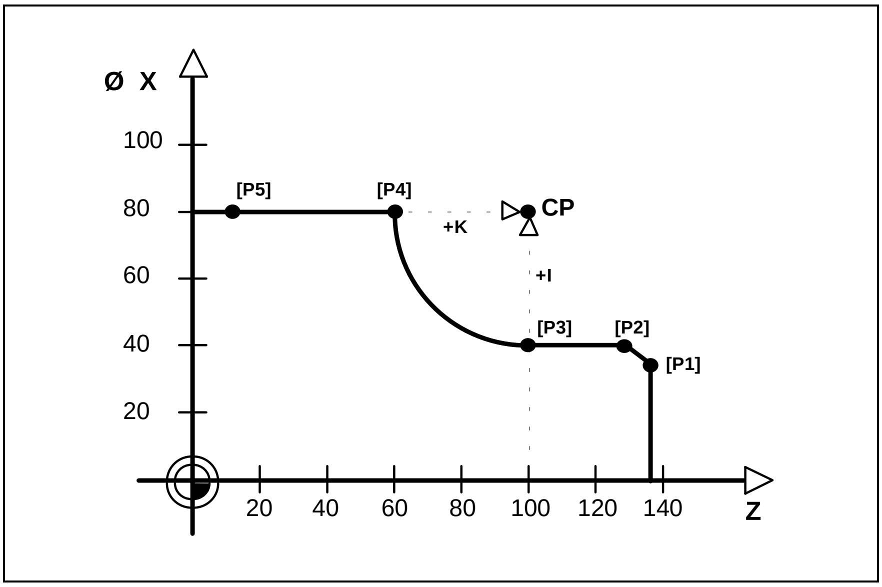


Fig. 4-26: Circle programming on lathe, behind center of rotation

Example of Programming Using Absolute Dimension Input (G90)

G00 G90 G54 G06 G08	Motion commands, interpolation conditions
M03 S2000	Spindle ON
X34.5 Z136.5	[P1] Starting position
G01 X40 Z128.5 F500	[P2] linear interpolation
Z100	[P3] circle starting point
G02 X80 Z60 I80 K100	[P4] quarter circle in clockwise direction
G01 Z10	[P5] machining end point
G00 X100	X axis to safety distance
M05	Spindle OFF
RET	Return to program beginning

Example of Programming Using Incremental Dimension Input (G91)

G00 G90 G54 G06 G08	Motion commands, interpolation conditions
M03 S2000	Spindle ON
X34.5 Z136.5	[P1] Starting position
G01 G91 X5.5 Z-8 F500	[P2] linear interpolation
Z-28.5	[P3] circle starting point
G02 X40 Z-40 I40 K0	[P4] quarter circle in clockwise direction
G01 Z-50	[P5] machining end point
G90 G00 X100	X axis to safety distance
M05	Spindle OFF
RET	Return to program beginning

Circle Radius Programming

In order to allow dimensions to be taken directly off workpiece drawings, an option is provided for circular paths to be declared directly in the NC-program by stating the radius.

A distinct circular path is only produced within a semicircle (180°) when G02 or G03 programming is used (*see Fig. 4-27).* For this reason, it is important to indicate whether the traversing angle will be greater or less than 180°. For arcs whose angle exceeds 180°, the radius must be entered preceded by a minus sign.

Syntax for circle radius programming in the G17 plane

G02	X ... Y ...	**R+ ... with a traverse angle to 180°**
G03		**R- ... with a traverse angle > 180°**

Example Defining the arc

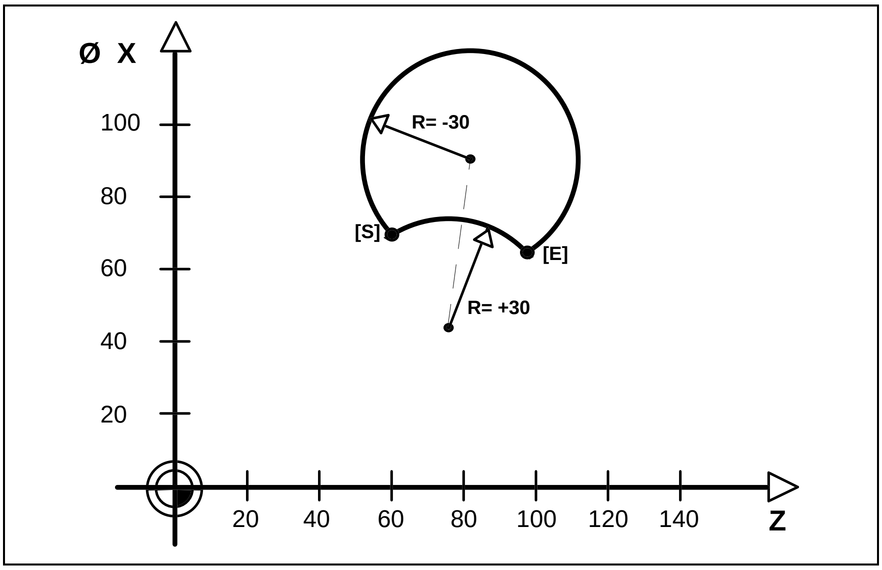


Fig. 4-27: Circle radius programming, determining the sign to be used for the radius

G01 X... Z...
G02 X... Z... R±30

As can be seen from the above example, two possibilities would result for this programmed circle. Selecting the sign (R+30 or R-30) determines which circle is traversed.

- The direction of motion relative to the circle end point is determined by G02 or G03.
- Circle radius programming is not permissible with a traverse angle of 0° or 360°. The axes will remain at their starting points.
- If the circle end point is missing, the axis will remain at their starting points. No traversing takes place.
- The programmed radius is active in the current machining plane (G17, G18, G19).

Example Circle radius programming in the Z-X plane

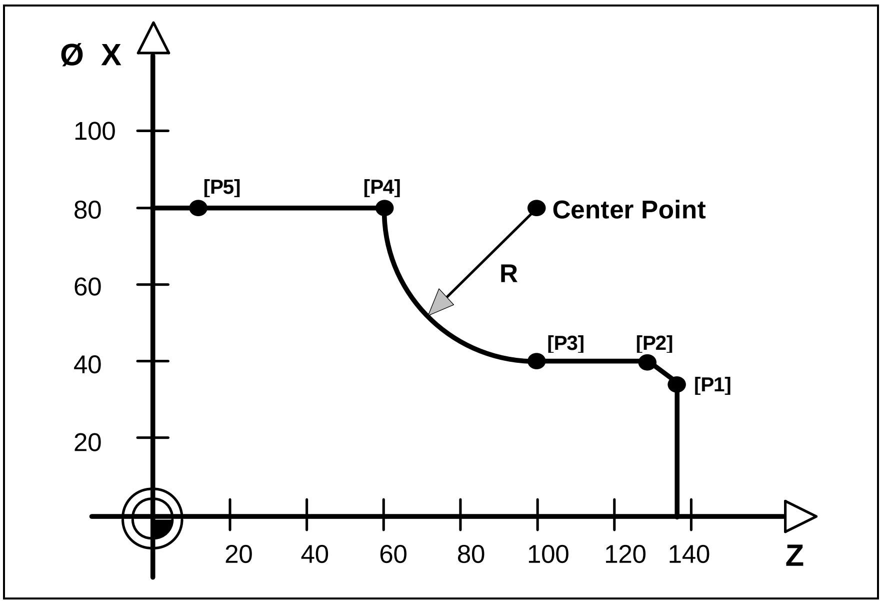


Fig. 4-28: Circle radius programming on lathe, behind center of rotation

NC program

G00 G90 G54 G06 G08	Motion commands, interpolation conditions
M03 S2000	Spindle ON
X34.5 Z136.5	[P1] Starting position
G01 X40 Z128.5 F500	[P2] linear interpolation
Z100	[P3] circle starting point
G02 X80 Z60 R40	[P4] quarter circle in clockwise direction
G01 Z10	[P5] machining end point
G00 X100	X axis to safety distance
M05	Spindle OFF
RET	Return to program beginning

Helical Interpolation

Helical interpolation is a combination of circular and linear interpolation which is used to produce a spiraling tool path. The circular interpolation takes place in the selected plane (G17, G18, G19) while linear interpolation is simultaneously occurring in a third axis which is perpendicular to the plane of circular interpolation.

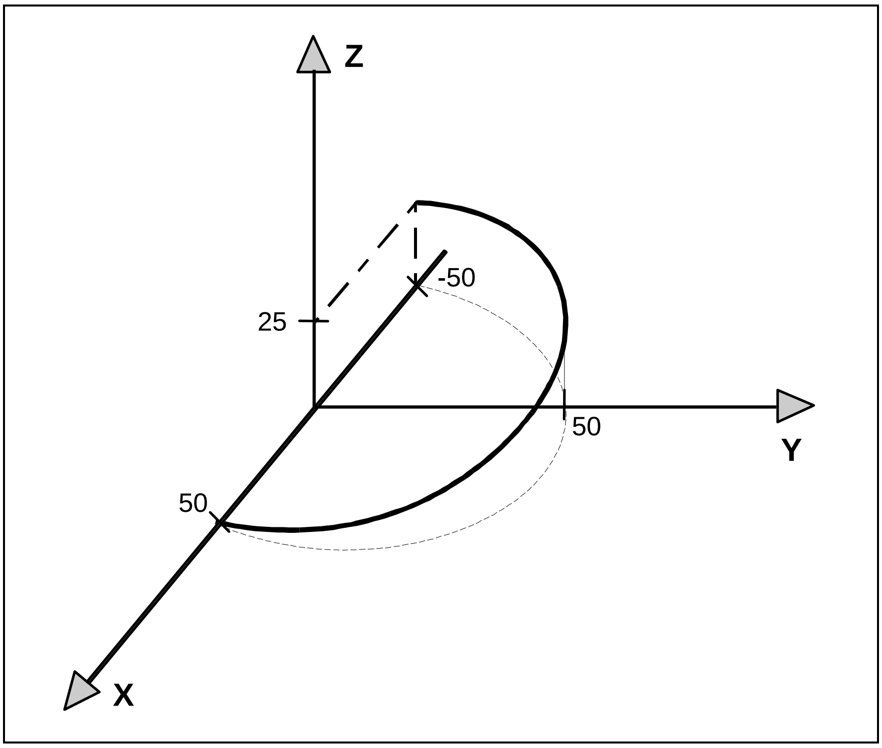


Fig. 4-29: Helical interpolation

With helical interpolation an arc and a straight line erected perpendicular to the end point of the arc are both programmed in the same NC-block. The axis feeds are coordinated in such a way that the tool describes a helix which has a constant pitch.

No more than one coil (corresponding to a full circle) can be programmed in an NC-block. A number of coils in sequence can only be produced by programming a corresponding number of individual coils.

The programmed feedrate (F-value) relates to the actual tool path.

All other conditions are the same as in circular interpolation.

Example Helical interpolation in the X-Y plane with G90

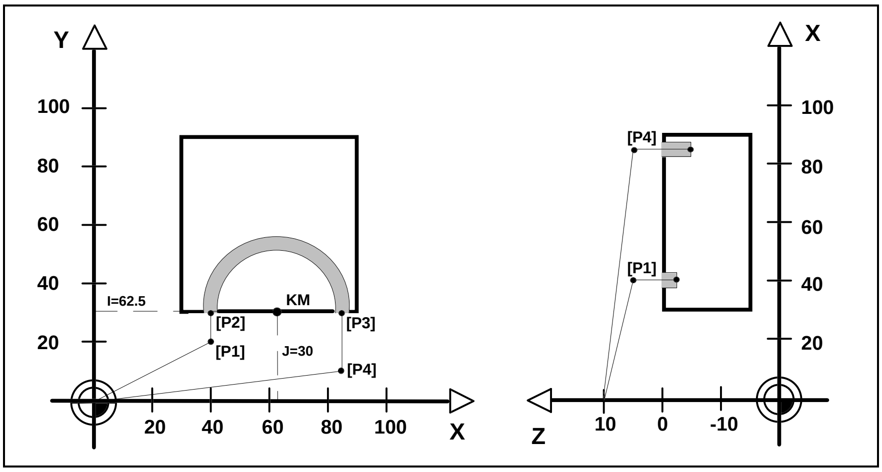


Fig. 4-30: Helical interpolation with G90

Example of Programming Using Absolute Dimension Input (G90)

G00 G90 G54 G06 G08	Motion commands, interpolation conditions
X0 Y0 Z10 S5000 M03	Starting position, spindle ON
G01 X40 Y20 Z5 F2000	[P1] Z axis to safety distance
Z-2.5	Z axis to machining depth
X40 Y30	[P2] starting point of half coil
G02 X85 Y30 I62.5 J30 Z-5	[P3] helix in clockwise direction
G01 X85 Y10	[P4] traverse X and Y until clear
G00 Z5	Z axis to safety distance
M05	Spindle OFF
X0 Y0 Z10	Return to starting position
RET	Return to program beginning

Example Helical interpolation in the X-Y plane with G91

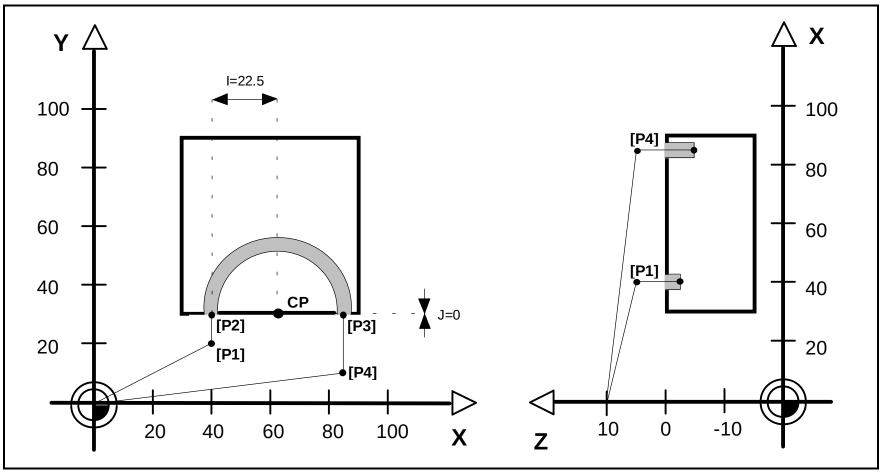


Fig. 4-31: Helical interpolation with G91

Example of Programming Using Absolute Dimension Input (G91)

G00 G90 G54 G06 G08	Motion commands, interpol. conditions
X0 Y0 Z10 S5000 M03	Starting position, spindle ON
G91 G01 X40 Y20 Z-5 F2000	[P1] Z axis to safety distance
Z-7.5	Z axis to machining depth
Y10	[P2] starting point of half coil
G02 X45 I22.5 J0 Z-2.5	[P3] helix in clockwise direction
G01 Y-20	[P4] traverse X and Y until clear
G00 Z10	Z axis to safety distance
M05	Spindle OFF
X-85 Y-10 Z5	Return to starting position
RET	Return to program beginning

Thread Cutting 'G33'

The G33 function thread cutting can be used to cut

- single or multiple point longitudinal threads,
- face threads and
- taper threads with a constant lead.

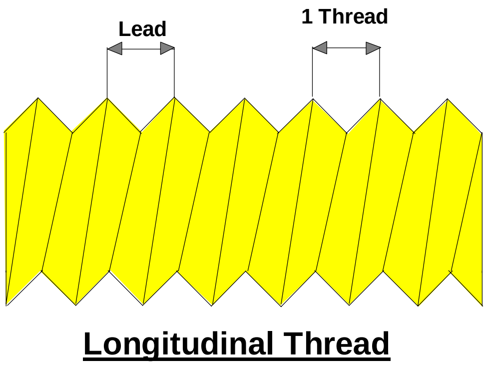


Fig. 4-32: Longitudinal threads

Syntax **G33 <end point [X,Y,Z]> <lead [I,J,K]> <starting angle [P]>**

The thread length is the difference between the starting point and the end point that is programmed in the G33 NC-block. The thread entry length and exit length in which the feedrate will be accelerated or reduced must be taken into account. The coordinate values can be programmed using absolute (G90) or incremental (G91) positioning data.

The thread lead is entered in addresses I, J and K; however, no more than one interpolation parameter can be programmed in a single thread NC-block. The interpolation parameters I, J and K are programmed as unsigned incremental values. The interpolation parameters I, J and K are assigned to axes X, Y and Z.

The thread starting angle may be programmed as a value from 0° to 360° in address P. Programming a thread starting angle allows multiple threads to be cut without offsetting the starting point. If a starting angle is not programmed at address P, it is assumed that the starting angle is 0°.

Clockwise or counterclockwise threads are produced by stating the direction of spindle rotation: M03 or M04. If a different spindle is selected for thread cutting using G33, the spindle must be activated by means of the SPF <spindle number> command prior to the G33 NC-block. The spindle number 1 (S/S1) is always active in the power-on state. The spindle must be starting at the desired RPM prior to or in the G33 NC-block.

In any event, positioning with minimized lag G06 must always be used for thread cutting with G33 since this function improves thread quality.

G33 is one of the G-codes which are active only for one NC-block at a time so that it stops being active after the NC-block is completed. The thread is cut from the cutting starting point up to the programmed end point of the NC-block; motion is possible in several axes (taper threads).

- No more than 500 threads can be cut per thread NC-block. If more than 500 threads are required, they can be machined using thread NC-block sequences.
- The maximum spindle speed in the thread NC-block is 13,500 rpm: The necessary approach distance increases as the spindle speed and thread lead increase.
- The constant surface speed, G96, is ignored with thread cutting via G33. The spindle speed which was last programmed under G97 is set.

- If the thread is cut using positioning with minimized lag G06, the spindle speed can be changed during thread cutting by using the spindle override. The feedrate will adjust accordingly. The feedrate override will not be active.
- The immediate stop (emergency off, stop in setup mode), the spindle speed and the feedrate are reduced in synch with one another and are increased in synch following a restart.
- With taper threads, the thread lead is stated with respect to the main axis. If the desired thread lead is to be expressed relative to the Z axis, the lead must be declared in interpolation parameter K. If the thread pitch applies to the X axis, it must be programmed in interpolation parameter I.
- The thread lead is interpreted as a radius dimension when machining face threads on a lathe using diameter programming.
- Depending on the parameter setting, the thread lead can be entered using 3 or 4 places to the left of the decimal point and, correspondingly 5 or 4 places to the right of the decimal point.

NOTE

The G33 function is only available when APRB04 (axis processor) is present.

Example NC-program for longitudinal thread

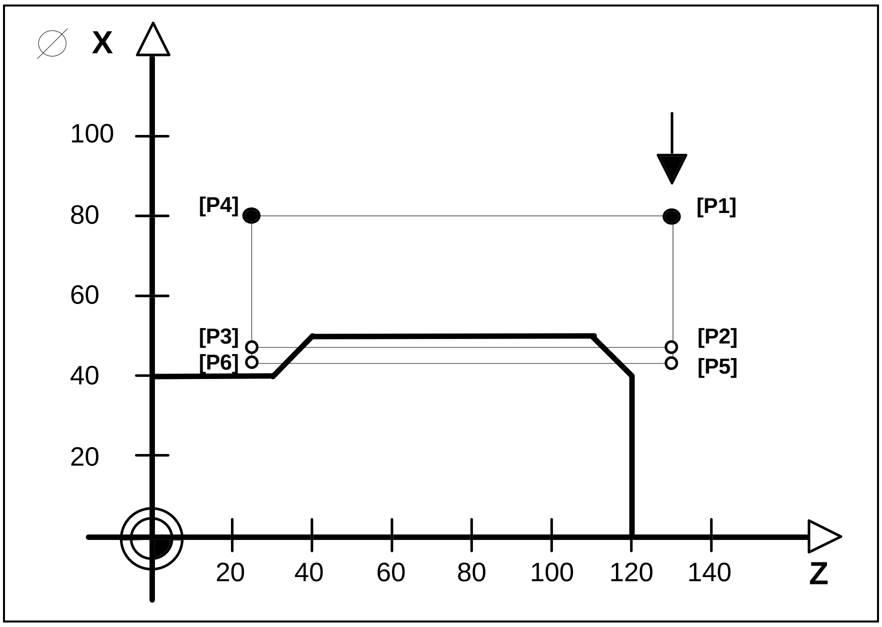


Fig. 4-33: Thread cutting—longitudinal thread

Thread lead	3 mm		
Thread depth:	4 mm	Thread depths per cut:	2 mm

NC-program

G00 G54 G90 G06 G08 X80 Z130 S2000 M03	[P1] Starting conditions
G01 X45.5 F1500	[P2] infeed for first cut
G33 Z30 K3 P180	[P3] 1st thread pass
G00 X80	[P4] Withdraw X axis
Z130	[P1] Starting point
G01 X43.5 F1500	[P5] Infeed for 2nd cut
G33 Z30 K3 P180	[P6] Second thread pass
G00 X80	[P4] Withdraw X axis
M05	Spindle OFF
RET	Return to start of prog.

Example NC-program for taper thread

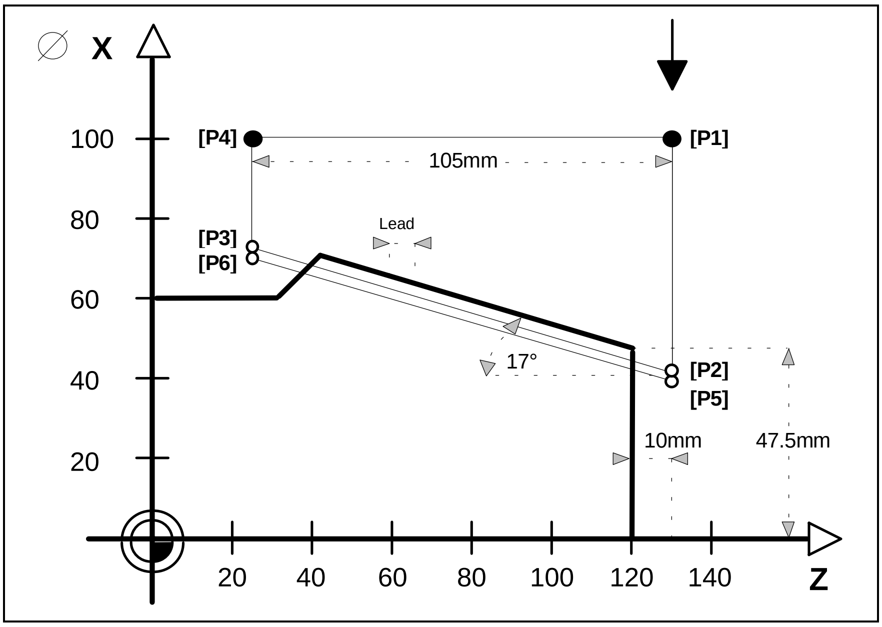


Fig. 4-34: Thread cutting—taper thread

Thread lead	2.5 mm	
Thread depth:	3 mm	Thread depths per cut: 1.5 mm

NC program

G00 G54 G90 G06 G08 X100 Z130 S2000 M03	[P1] Starting conditions
G01 X39.89 F1500	[P2] infeed for first cut
G33 X71.99 Z25 K2.5 P90	[P3] 1st thread pass
G00 X100	[P4] Withdraw X axis
Z130	[P1] Starting point
G01 X38.39 F1500	[P5] Infeed for 2nd cut
G33 X70.49 Z25 K2.5 P90	[P6] 2nd thread pass
G00 X100	[P4] Withdraw X axis
M05	Spindle OFF
RET	Return to start of prog.

Calculation of the thread starting point and end point coordinates for the X axis:

$$P5 = 47.5 - 3 = 44.5$$
$$P5 = 44.5 - 2 * (10 * TAN17°) = 38.39$$
$$P6 = 38.39 + (105 * TAN17°) = 70.49$$

$$P2 = 47.5 - 1.5 = 46$$
$$P2 = 46 - 2 * (10 * TAN17°) = 39.89$$
$$P3 = 39.89 + (105 * TAN17°) = 71.99$$

Example NC-program for face thread

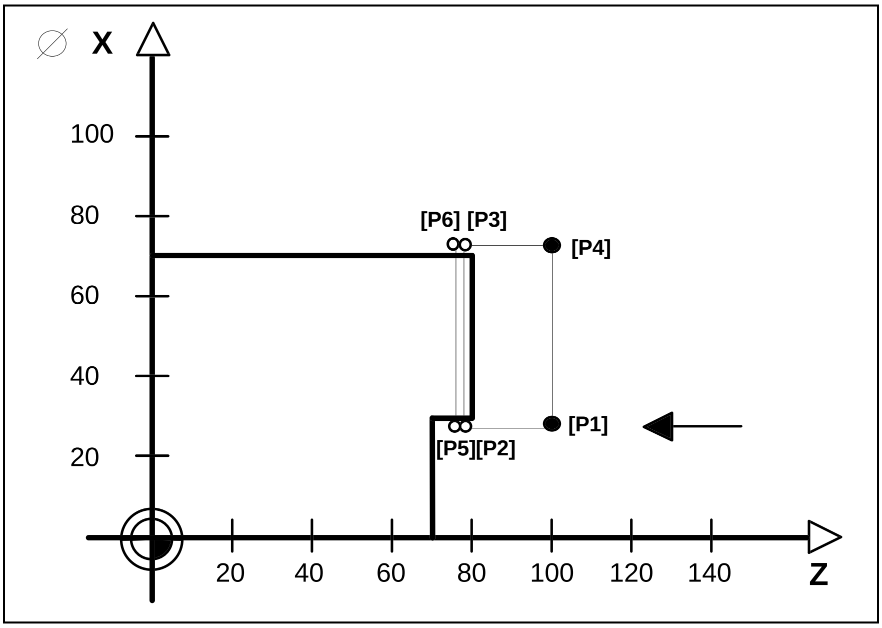


Fig. 4-35: Thread cutting—face thread

Thread lead: 2 mm
Thread depth: 3 mm Thread depth per cut: 1.5 mm

NC program:

G00 G54 G90 G06 G08 X27.5 Z100 S2500 M03	[P1] Starting conditions
G01 Z78 F1500	[P2] Infeed for first cut
G33 X72.5 I2 P180	[P3] 1st thread pass
G00 Z100	[P4] Withdraw Z axis
X27.5	[P1] Starting point
G01 Z76.5 F1500	[P5] Infeed for 2nd cut
G33 X72.5 I2 P180	[P6] 2nd thread pass
G00 Z100	[P4] Withdraw Z axis
M05	Spindle OFF
RET	Return to start of prog.

Sequences of Thread-Cutting NC Blocks Using 'G33'

The G33 function can be used to program consecutive chains of thread-cutting NC-blocks containing different leads. A thread sequence can consist of

- single- or multiple-thread longitudinal threads,
- face threads, or
- taper threads

in any desired order, provided that the lead during each section of the thread remains constant.

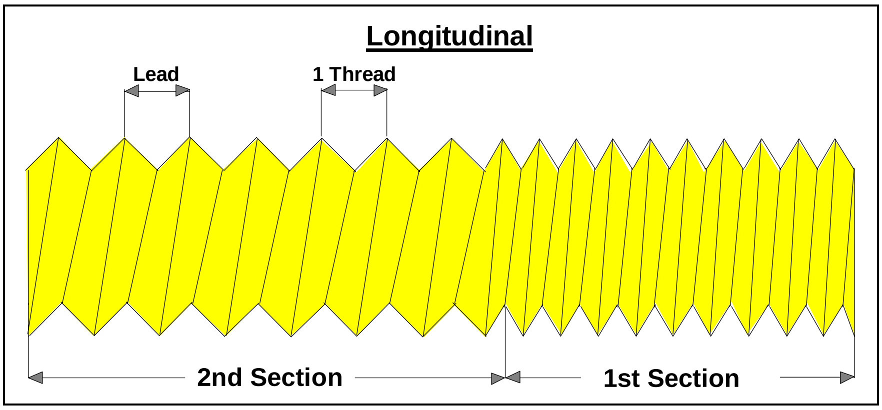


Fig. 4-36: Longitudinal thread having two sections of thread each with a different lead

Syntax

G33 <endpoint [X,Y,Z]> <lead [I,J,K]> <starting angle [P]>
G33 <endpoint [X,Y,Z]> <lead [I,J,K]> <starting angle [P]>

Thread sequences are programmed as consecutive series of thread-cutting NC-blocks. A transition distance is calculated between two thread-cutting NC-blocks for each axis experiencing a velocity change. The thread change is performed at the maximum permissible acceleration, so that transition parabola result.

- G08 contouring mode (acceleration) must be active during thread-cutting sequences. G06 positioning with minimized lag should be activated to ensure that the transition parabola between the thread NC-blocks are as small as possible.
- There must not be any function programmed between and in the individual thread blocks of a thread-cutting sequence that interrupts block preparation (such as auxiliary functions, computations, etc.).
- If the single-block operating mode is active, each thread-cutting NC-block is processed individually. In this case, a new starting distance is required for each thread-cutting NC-block. Thus, thread-cutting sequences are not possible in the single-block operating mode.

All other conditions are the same as in thread cutting.

Example	NC-program for thread-cutting sequences

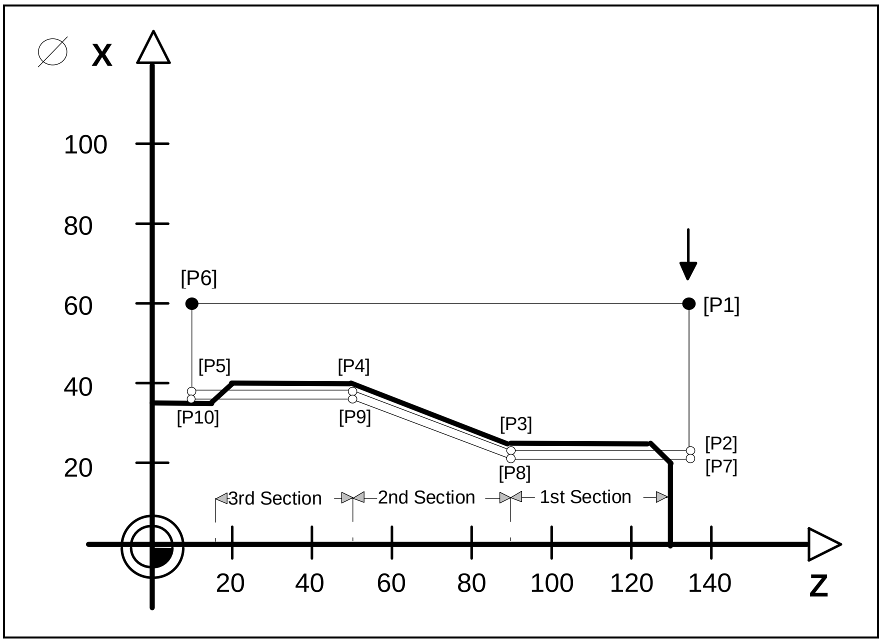


Fig. 4-37: Thread-cutting sequence

Thread lead:	1: 3 mm	2: 5 mm	3: 1 mm
Thread depth:	4 mm	Thread depth per cut:	2 mm

NC program:

G00 G54 G90 G06 G08 X60 Z135 S2000 M03	[P1] Starting conditions
G01 X23 F1500	[P2] Infeed for first cut
G33 Z90 K3 P180	[P3] 1st thread section / 1st pass
G33 X38 Z50 K5	[P4] 2nd thread section / 1st pass
G33 Z10 K1	[P5] 3rd thread section / 1st pass
G00 X60	[P6] Withdraw X axis
Z135	[P1] Starting point
G01 X21 F1500	[P7] Infeed for 2nd cut
G33 Z90 K3 P180	[P8] 1st thread section / 2nd pass
G33 X36 Z50 K5	[P9] 2nd thread section / 2nd pass
G33 Z10 K1	[P10] 3rd thread section / 2nd pass
G00 X60	[P6] Withdraw X axis
M05	Spindle OFF
RET	Return to start of prog.

Rigid Tapping 'G63' / 'G64'

Threads can be tapped without a compensating chuck using the function G63. With thread tapping without compensating chuck the spindle alignment is controlled and not, as would be the case in normal tapping, the spindle rpm. The spindle motion and the infeed motion of the axis which is programmed together with G63 are interpreted linearly. A positionable main spindle is needed for tapping without compensating chuck. The spindle must be driven directly (slip), and the position encoder should be located directly on the spindle.

The CNC supplies two preparatory functions for tapping without compensating chuck. These functions are only active for the duration of the NC-block containing them.

- G63 - Spindle stops at end of motion

The functions G63 and G64 differ only with respect to the end of motion.

Syntax

G63 <end point [X,Y,Z]> <feed per spindle revolution [F]>
G64 <end point [X,Y,Z]> <feed per spindle revolution [F]>

Two cases are possible when the feed/spindle link is established:

- The spindle is stopped (n=0)
- The spindle is already rotating (n=S)

If the spindle is stopped when the feed/spindle link is established, the link can be activated at the start of the common acceleration phase so that the spindle and the feed axis are already interpolating upon acceleration. Which acceleration is selected will depend on which axis is the weakest (main spindle or feed axis).

If the spindle is already rotating when the feed/spindle link is established, the feed axis is accelerated to the required speed at its maximum acceleration, and then the link is activated, so that the main spindle and the feed axis do not interpolate until the constant-speed range is reached.

- Clockwise or counter-clockwise thread tapping is achieved by stating the direction of spindle rotation: M03 or M04.
- If a different spindle is to be selected for thread tapping using G63/64, the spindle must be activated by means of the SPF <spindle number> command prior to the G63 NC-block. The first spindle (S/S1) is always active in the power-on state.
- Tapping should be performed using the preparatory function G06 positioning with minimized lag. If G06 is not active with tapping without compensating chuck or if analog axis cards are installed, the same gain factor must be set for the spindle and for the infeed axis for G63/G64.
- The functions G08 contouring mode (acceleration) and G61 exact stop before NC-block transition are meaningless for tapping.
- A main spindle which is stopped at the end of motion (G63) can be reactivated using the spindle control commands M03/M04 and by programming the rpm value (S value).
- If the tap is turned out of the thread using G64, the spindle stops briefly at the end point of the NC-block in order to change from position-controlled to rpm-controlled mode.
- Except for time-based dwell G04 and the auxiliary functions, no NC commands can be programmed between the G63 command tap to depth <X, Y or Z> and the G63/G64 command withdraw tap.
- With digital drives, if the spindle is activated prior to the NC-block containing G63 tapping, the spindle will stop briefly in the G63 NC-block in order to switch from rpm-controlled mode to position-controlled mode.

- The lead factor *feed per spindle revolution* must be programmed in a single NC-block containing G63 and G64 by using the F-word.
- Depending on the parameter setting, the thread lead can be entered using 3 or 4 places to the left of the decimal point and, correspondingly 5 or 4 places to the right of the decimal point.

Example NC-program - tapping with G63

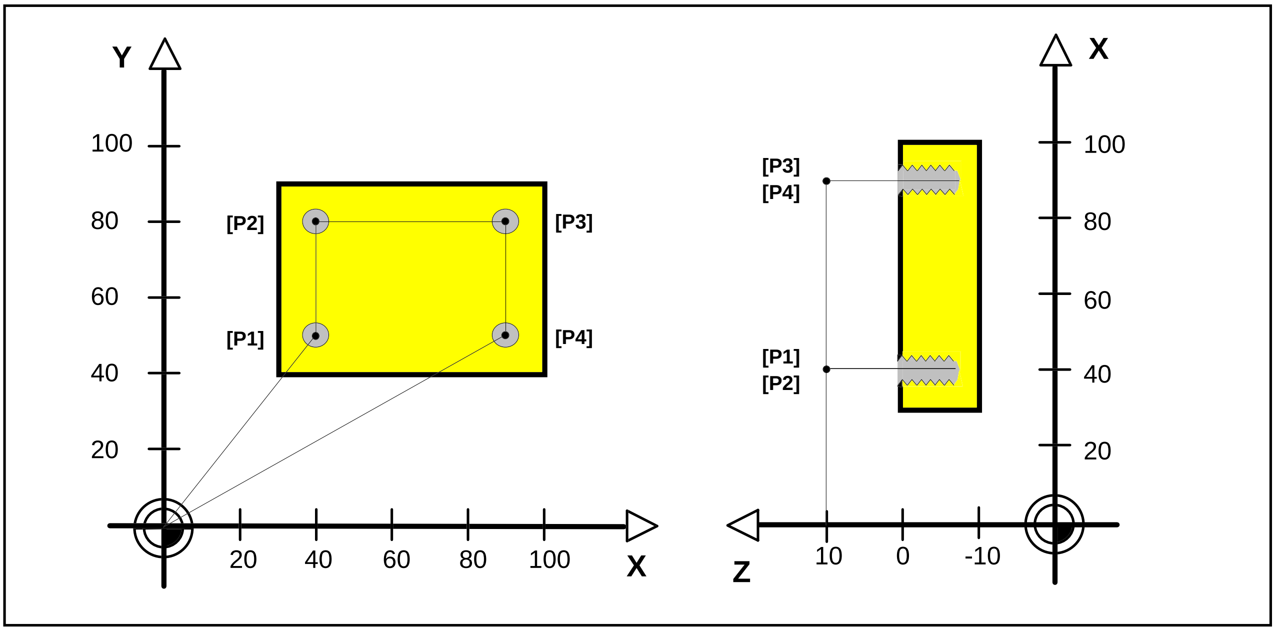


Fig. 4-38: Tapping with G63

NC program with G63:
Spindle stopped at the beginning of the G63 NC-block
Spindle stopped when motion is terminated

G00 G54 G90 G06 G08 X0 Y0 Z10	Motion commands, interpolation conditions
G01 X40 Y50 F2000	[P1] 1st tapping position
BSR .GEBO	Branch to tapping subroutine
Y80	[P2] 2nd tapping position
BSR .GEBO	Branch to tapping subroutine
X90	[P3] 3rd tapping position
BSR .GEBO	Branch to tapping subroutine
Y50	[P4] 4th tapping position
BSR .GEBO	Branch to tapping subroutine
G00 X0 Y0	Return to starting point
RET	Return to program beginning
.GEBO	Tapping subroutine
G63 Z-7.5 F2 S1000 M03	Tap to depth Z
G63 Z10 F2 S750 M04	Back out tap
RTS	Return from subroutine

Spindle already stopped at the beginning of the G63 NC-block
Spindle stopped when motion is terminated

G00 G54 G90 G06 G08 X0 Y0 Z10	Motion commands, interpolation conditions
G01 X40 Y50 F2000 M03 S1000	[P1] 1st tapping position, spindle ON
BSR .GEBO	Branch to tapping subroutine
Y80 M03 S1000	[P2] 2nd tapping pos., spindle ON
BSR .GEBO	Branch to tapping subroutine
X90 M03 S1000	[P3] 3rd tapping position, spindle ON
BSR .GEBO	Branch to tapping subroutine
Y50 M03 S1000	[P4] 4th tapping position, spindle ON
BSR .GEBO	Branch to tapping subroutine
G00 X0 Y0	Return to starting point
RET	Return to program beginning
.GEBO	Tapping subroutine
G63 Z-7.5 F2	Tap to depth Z
G63 Z10 F2 S750 M04	Back out tap
RTS	Return from subroutine

Example NC-program - tapping with G63 and G64

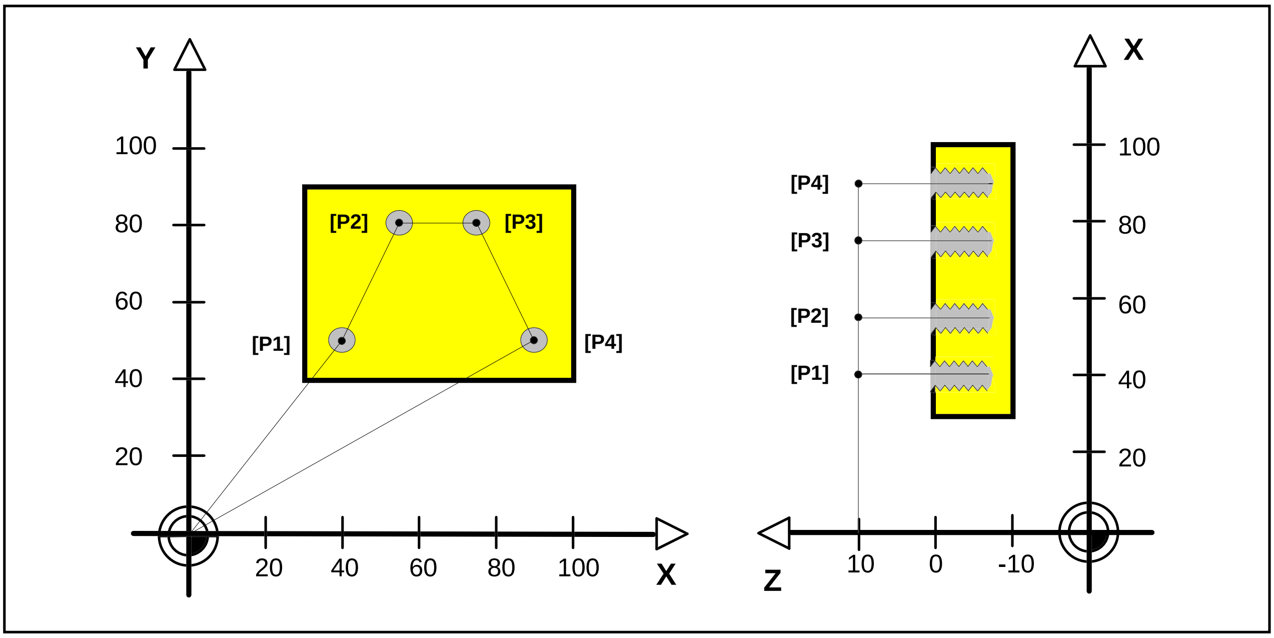


Fig. 4-39: Tapping with G63 and G64

NC-program using G63 and G64:
Spindle stopped at the beginning of the G63 NC-block
Spindle continues to turn after end of motion

G00 G54 G90 G06 G08 X0 Y0 Z10	Motion commands, interpolation conditions
G01 X40 Y50 F2000	[P1] 1st tapping position
BSR .GEBO	Branch to tapping subroutine
X55 Y80	[P2] 2nd tapping position
BSR .GEBO	Branch to tapping subroutine
X75	[P3] 3rd tapping position
BSR .GEBO	Branch to tapping subroutine
X90 Y50	[P4] 4th tapping position
BSR .GEBO	Branch to tapping subroutine
M05	Spindle OFF
G00 X0 Y0	Return to starting point
RET	Return to program beginning
.GEBO	Tapping subroutine
G63 Z-7.5 F2 S1000 M03	Tap to depth Z
G64 Z10 F2 S800 M04	Back out tap
RTS	Return from subroutine

Spindle already stopped at the beginning of the G63 NC-block
Spindle continues to turn after end of motion

G00 G54 G90 G06 G08 X0 Y0 Z10	Motion commands, interpolation conditions
G01 X40 Y50 F2000 M03 S1000	[P1] 1st tapping position, spindle ON
BSR .GEBO	Branch to tapping subroutine
X55 Y80 M03 S1000	[P2] 2nd tapping pos., spindle ON
BSR .GEBO	Branch to tapping subroutine
X75 M03 S1000	[P3] 3rd tapping position, spindle ON
BSR .GEBO	Branch to tapping subroutine
X90 Y50 M03 S1000	[P4] 4th tapping position, spindle ON
BSR .GEBO	Branch to tapping subroutine
M05	Spindle OFF
G00 X0 Y0	Return to starting point
RET	Return to program beginning
.GEBO	Tapping subroutine
G63 Z-7.5 F2	Tap to depth Z
G64 Z10 F2 S800 M04	Back out tap
RTS	Return from subroutine

Floating Tapping 'G65' - Spindle as Lead Axis

The function G65 can be used to tap threads with main spindles which can be positioned but cannot interpolate under position control. In addition, G65 is used on main spindles which are driven indirectly and in cases which the position encoders are not located directly on the spindle. A compensating chuck is usually used with tapping per G65. The feed distance which is programmed in conjunction with G65 is dependent on the main spindle position. However, because of the inherent system-related delay, the feed will always lag behind the main spindle. This delay is twice as long when there is a change in the direction of rotation. It is always preferable to use the functions G63/G64 for tapping without compensating chuck.

Syntax	**M05**	**Spindle STOP**
	G65 <feed distance per spindle rotation [F]>	**Activate tapping**
	S500 M03	**RPM and direction of rotation**
	Z-10	**Tap to depth Z**
	Z10 S800 M04	**Back out tap**

A positionable main spindle is needed for the G65 tapping function.

- The main spindle must be stopped using M05 before activating G65 tapping.
- When G65 is active, it is not possible to traverse using G00; no circular and helical interpolation G02/G03 is performed, and no axis referencing G74 is performed. Feed functions relating to the NC-block transition (G08, G09, G61, G62) are suppressed.
- No axis moves can be programmed in a G65 NC-block.
- The spindle must be activated after the G65 NC-block; whether tapping is clockwise or counter-clockwise depends on the spindle direction declaration M03 or M04. The spindle remains inactive unless activated by a traverse command in a main axis.
- The linking factor feed per spindle revolution must be programmed in a single NC-block containing G65 by using the F-word.
- Tapping should be performed using the preparatory function G06 positioning with minimized lag.
- With main spindles which are driven directly and in which the position encoder is located directly on the spindle, the G65 function can also be used to tap threads without using a compensating chuck, provided that the speed is moderate.
- If a different spindle is selected for thread tapping via G65, the spindle must be activated by means of the SPF <spindle number> command prior to the G65 NC-block. The first spindle (S/S1) is always active in the power-on state.
- G65 is overlaid by G93 or overwritten by G94 or G95, which automatically stops the spindle.
- Depending on the parameter setting, the thread lead can be entered using 3 or 4 places to the left of the decimal point and, correspondingly 5 or 4 places to the right of the decimal point.

NOTE

If G65 is active, only the linear main axes, X, Y and Z may be programmed. Other axis letters will result in an error message.

Example NC-program - tapping with G65

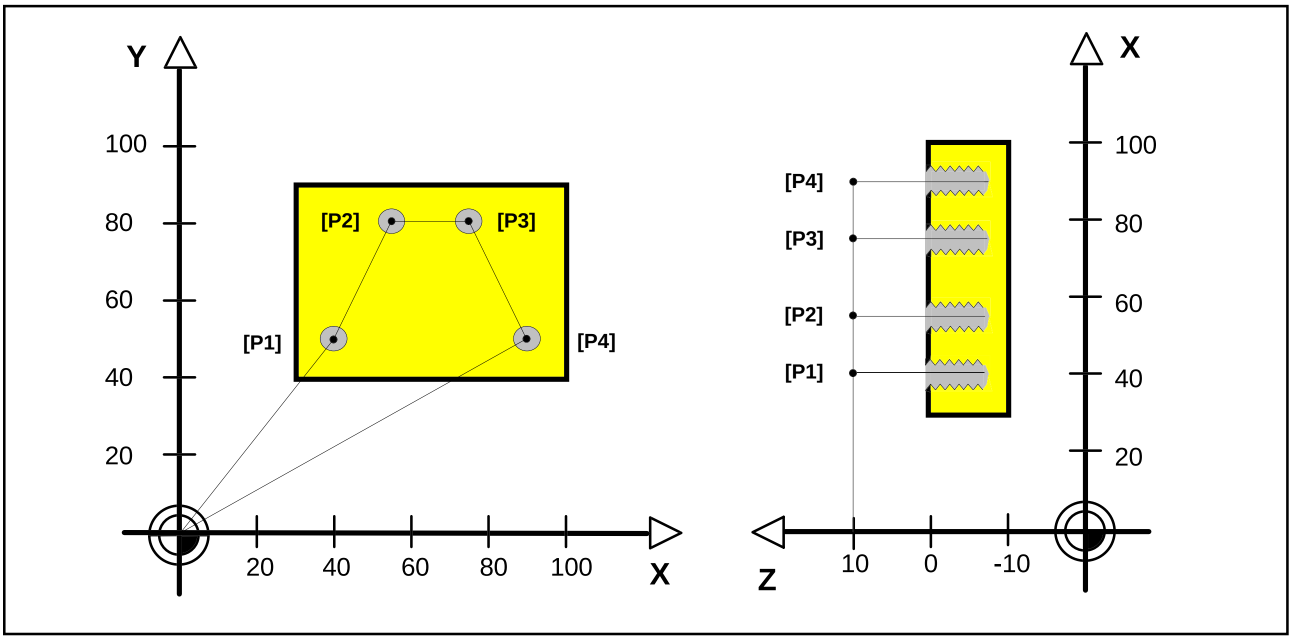


Fig. 4-40: Tapping with G65

NC-program using G65:

G00 G54 G90 G06 G08 X0 Y0 Z10	Motion commands, interpolation conditions
G01 X40 Y50 F2000	[P1] 1st tapping position
BSR .GEBO	Branch to tapping subroutine
X55 Y80	[P2] 2nd tapping position
BSR .GEBO	Branch to tapping subroutine
X75	[P3] 3rd tapping position
BSR .GEBO	Branch to tapping subroutine
X90 Y50	[P4] 4th tapping position
BSR .GEBO	Branch to tapping subroutine
M05	Spindle OFF
G00 X0 Y0	Return to starting point
RET	Return to program beginning
.GEBO	Tapping subroutine
M05	Spindle STOP
G65 F2	Activate tapping
S500 M03	Spindle speed and direction of rotation
Z-7.5	Tap to depth Z
Z10 S400 M04	Back out tap
G94	Cancel G65
RTS	Return from subroutine

4.4 Feed

F Word

The feedrate in an NC-program is expressed by a feed which uses the address letters F and a feedrate which is stated directly as a constant or by means on an expression. The programmed feedrate determines the processing speed for each type of interpolation. The feedrate is restricted so that the limits entered in the parameters are not exceeded. If the F-word is programmed in conjunction with a preparatory function, the meaning can change. The corresponding type of operation is defined in the corresponding preparatory functions (G00, G04, G93, G95).

Syntax

F<Konstante> ⇨ **F1000**

F<Ausdruck> ⇨ **F=@50**

If the F-word is programmed as the feedrate, is becomes the command value for the machining speed.

The F-word interacts with the associated G-code as follows:

Meaning	G code	Active	Format		Comments
Speed programming	G94	modal	To left of dec. point 6 5	To right of dec.point 1 2	Canceled by G95. The most recent G94 F-value is reactivated the next time G94 is called.
Feed per revolution	G95	modal	To left of decimal 4 3	To right of decimal 4 5	Canceled by G94. If G95 is repeated, the most recent G95 F-value is reactivated.
	G63, G64	per NC-block	4 3	4 5	The F-value is reactivated when G63 and G64 are renewed. This has no effect of the F-values of G94.
	G65	modal			Condition as with G95
Time in seconds	G04	per NC-blocks	3	2	
Inverse Time Feed	G93	per NC-block	5	2	

If the F-word appears alone in the NC-block, it is assigned to the memory of the modally active preparatory conditions of the feed declarations group. If the F-word appears in a NC-block together with one of these preparatory functions, the corresponding feed is activated first, and then the F-value is placed in the appropriate memory.

- When G94 is active (feedrate programming), the units mm/min. or inch/min. are used for the feedrate.
- With G63, G64, G65, tapping and with G95, feed per revolution the unit used for the feedrate is mm/spindle revolution or inch/spindle revolution.
- With G04 time-based dwell and with G93 input feedrate as inverse time value the time in seconds is entered in the F-word.
- The programmed feedrate can be changed via the feedrate override from 0% to 255%. The 100% position corresponds to the programmed value.

The feed values are reset after the controller has been powered on, the program is loaded into the controller, and after a NC-command BST, M02, M30, RET or Control-Reset. At the beginning of an NC-program feed values must be programmed before or together with the first motion command.

Note: The maximum path velocity and the maximum axis velocity are set by the machine builder in the parameters.

Input Feedrate as Inverse Time Value 'G93'

The machining time for a programmed workpiece can be defined by the function G93 input feedrate as inverse time value. The machining time is determined via the F-word. With the specified machining time, the controller calculates the required path velocity depending on the limit values.

Syntax **G93 F<time in seconds>**

G93 is active on a NC-block-by-block basis and must be programmed in combination with an F-word.

- In the programmed NC-block, G93 overlays G94 or G95.
- The F-value which is programmed with G93 does not affect the F-values which were programmed with G94 or G95.
- The F-value programmed together with G93 can be programmed with five places to the left of the decimal point and two places to the right.

Example NC-program using G93

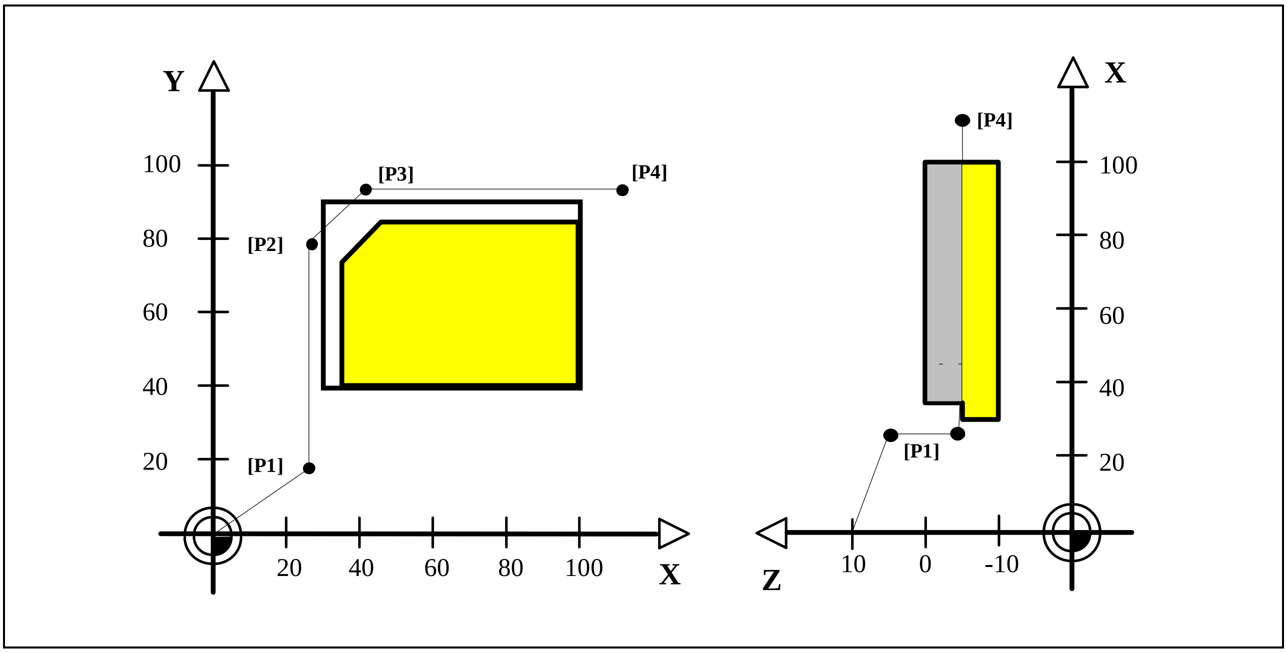


Fig. 4-41: Linear interpolation, G01 with 2 axes and input feedrate as inverse time value

G00 G90 G54 G06 G08	Motion commands, interpolation conditions
X0 Y0 Z10 S3000 M03	Starting position, spindle ON
G93 G01 X26.26 Y18 Z5 F0.97	[P1] starting position, input feedrate as inverse time value
G93 Z-5 F0.3	Infeed Z axis
G93 Y80 F1.86	[P2] linear interpolation, 1 axis
G93 X41 Y93.5 F0.6	[P3] linear interpolation, 2 axes
G93 X111 F2.1	[P4] linear interpolation, 1 axis
G00 Z10 M05	Z axis to safety distance
RET	Return to program beginning

Input Feedrate in mm or inch per Minute 'G94'

The programmed F-value is interpreted as the feedrate per min with the function G94 Input feedrate in mm/inch per min. G94 input feedrate in mm/min is the power-on state if set in the process parameters and G71 is active. The input feedrate is inch/min if G70 is active. The feed distance is programmed for linear axes in the active unit (mm/inch). The feed distance with rotary axes is programmed in units of the feed constant which is programmed in the axis parameters.

- Depending on the settings in the process parameters (Bxx.041 Spindle Speed Programming Default), G94 may be the power-on default. G94 is modal active and is canceled by G95, G96 or G65.
- After the controller is turned on, after an NC-program is loaded, after a BST, M02, M30, RET or control reset, G94 is set automatically depending on the setting in the process parameter (Bxx.041), and the feed values (F values) are reset.
- The special requirements that apply to the path feedrate depending on the nominal radii when machining with the C-axis are described in section 4.6 "Rotary Axis Programming" on page 4-47.

Input Feedrate in Inches or mm per Spindle Revolution 'G95'

The function G95, input feedrate in inches or mm per spindle revolution causes the programmed F-word to be interpreted in mm or inches per spindle revolution. The contour feedrate depends on the value of the actual spindle speed. If a position encoder is not located on the main spindle, the contour feedrate depends on the spindle RPM command value.

Syntax **G95 F<input feedrate in inches or mm per spindle revolution>**

G95 input feedrate in inches or mm per spindle revolution remains modally active until it is canceled by G94 or G65 or until a reset is performed at the end of the program (RET) or an automatic reset is performed via BST, M02, M30. G93 input feedrate as inverse time value active on top of G95

- In the power-on state, G95 always applies to the first spindle (S/S1). If G95 is to be applied to a different spindle, the desired spindle must be selected prior to the G95 NC-block by using the SPF <spindle number> command.
- Depending on the settings in the process parameter (Bxx.041), G95 may be the power-on default. G95 input feedrate in inches or mm per spindle revolution remains modally active until it is canceled by G94 or G65. G93 input feedrate as inverse time value active on top of G95.
- After the controller is turned on, after an NC-program is loaded, after a BST, M02, M30, RET or control reset, G95 is set automatically depending on the setting in the process parameter (Bxx.041), and the feed values (F values) are reset.
- G95 is activated automatically when G96 is selected. If G95 was not previously active, an error message is issued due to the fact that the F-value is missing.
- When G95 is active, axis moves which were commanded via G01, G02 or G03 are not performed unless the spindle is turning.
- Axis moves in rapid traverse (G00) superimpose G94 on G95 and are performed at the feedrate entered in the parameters (Bxx.005 Max. Path Velocity) or at the feedrate programmed with G00 in the NC-block.
- Programmed axis moves occurring when the spindle is off or with S0 prevent further program execution and result in an error message.
- The programmed F-values for the functions G94 and G95 do not interact with one another.
- The spindle override affects the spindle rpm and the feedrate when G95 is active.

Time-Based Dwell 'G04'

The G04 function can be used to program a delay time in the NC-program for functions such as relief cutting, machine control functions, etc.

Syntax **G04 F<time in seconds>**

G04 time-based dwell is active on a NC-block-by-block basis and must be programmed in combination with an F-word. The F-word will then correspond to a dwell time in seconds.

- The maximum directly programmed time-based dwell is 600 seconds (10 minutes) and the maximum resolution is 0.01 seconds.
- The F-value programmed together with G04 can be programmed with three places to the left of the decimal point and two places to the right.
- In an NC-block in which a time-based dwell is programmed, the only other items which can be programmed are M, S and Q functions.
- The time-based dwell programmed in the F-value using G04 does not affect the modally active F-values (feedrate).

Example	NC-program using G04
G00 G90 G54 G06 G08	Motion commands, interpolation conditions
X0 Y0 Z10 S3000 M03	Starting position, spindle ON
G04 F3.5	Delay of 3.5 sec for spindle ramp-up
G01 X26.26 Y18 Z5 F2000	Machining
•	
•	
RET	Return to program beginning

Basic Connections Between Programmed Path Velocity (F) and Axis Velocities

Under interpolation conditions, the CNC computes the path velocity as follows:

Path velocity equation

$$F = \sqrt{\dot{X}^2 + \dot{Y}^2 + \dot{Z}^2 + \left(\dot{A} * R_X\right)^2 + \left(\dot{B} * R_Y\right)^2 + \left(\dot{C} * R_Z\right)^2}$$

Example Path velocity for thread cutting

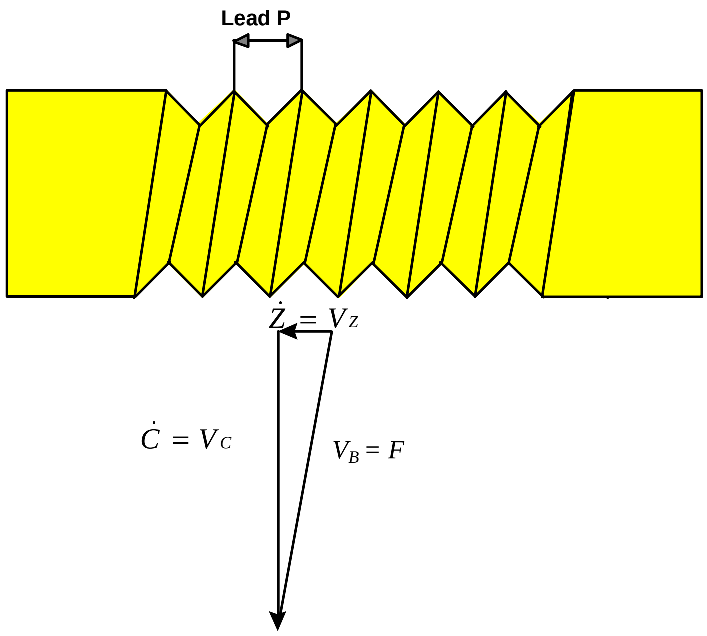


Fig. 4-42: Path velocity for thread cutting

In this example, the following equation results for computing the path velocity:

$$F = \sqrt{\dot{Z}^2 + \left(\dot{C} * R_Z\right)^2}$$

Basically, we can consider two possibilities of F value programming.

Without R_Z

The CNC interprets the F value as a velocity in the direction Z.

NC program: G01 Z... C... F...

Computation:

$$F = \sqrt{\dot{Z}^2} = P * n_W$$

n_W: speed
P: thread pitch

Effect:

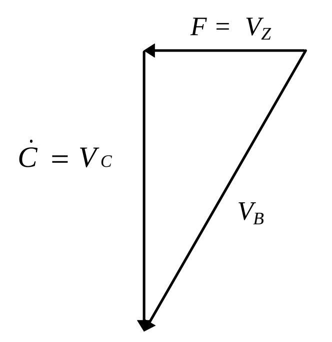


Fig. 4-43: Feed rate (F) without R_Z

Here, the C axis is interpolated simultaneously.

With R_Z The CNC interprets the F value as the resulting path velocity.
NC program: G01 Z... C... RZ... F...

Computation:

$$F = \sqrt{\dot{Z}^2 + \left(\dot{C} * R_Z\right)^2}$$

$$mit \qquad \dot{Z} = P * n_W$$

$$und \quad \dot{C} * R_Z = 2\pi * R_Z * n_W$$

$$\Rightarrow F = \sqrt{P^2 + \left(2\pi * R_Z\right)^2} * n_W$$

Effect:

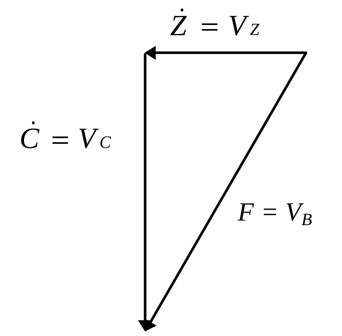


Fig. 4-44: Feed rate (F) with R_Z

4.5 Spindle Speed

S-Word for the Spindle RPM Statement

The spindle RPM in an NC-program is expressed by a speed word which uses the address letters S and an rpm speed which is stated directly as a constant or by means on an expression. A spindle code can also be added to the speed word if a number of spindles are present. The spindle speed is restricted so that the limits entered in the parameters are not exceeded. When G97 spindle speed in rpm is active, the S-word is interpreted as the spindle RPM value. G97 is the power-on state on the CNC. The following sections describe how the S-word functions in conjunction with the various spindle functions (G92, G96, G97, M19).

Syntax

S<Konstante> ⇨ **S5000**

S<Ausdruck> ⇨ **S=@55-100**

with enhanced address format:

S<Index> <Constant> ⇨ **S2 3500**

S<Index> <Expression> ⇨ **S3=@150**

The spindle speed value range extends from 0 to the maximum value entered in the spindle parameters.

The S value works with the associated spindle functions as follows:

Meaning	**G / M code**	**Active**	**Format**		**Comments**
Spindle speed in RPM	G97 with M03/M04 Mx03 / Mx04	modal	Integer part 5	Fractional part 2	If G97 is programmed after G96 is active, the most recently active RPM is taken over as the new RPM command value.
(x = Index [1 ... 3])	M19 Mx19	per NC block	3	2	Spindle positioned in degrees
Constant surface speed	G96	modal	5	2	Canceled by G97.
Upper spindle speed limit	G92	Only active with G96 Modally active to G97	5	2	Canceled by G97, the G92 value is reactivated the next time G96 is used again.

If the S-word appears alone in the NC-block, it is assigned to the memory of the modally active spindle functions. If the S-word appears in a NC-block together with one of the spindle functions, the corresponding spindle function is activated first, and then the S value is placed in the appropriate memory.

Up to 3 spindles can be used in a process. Thus, the spindle ID extension is limited to from 1 to 3. If the spindle extension is left out when there is more than one spindle in the process, the spindle statement will apply to the first spindle (S/S1). Each spindle has its own memory for the S-values. This prevents the S-values from modifying one another.

- The programmed spindle speed can be changed via the spindle override from 0% to 255%. The 100% position corresponds to the programmed S value.
- The S-value can be entered with 5 digits to the left of the decimal point and 2 to the right.

- The spindle speed values are reset after the controller has been powered on, the program loaded into the controller, and after a BST, M02, M30, RET or Control-Reset.
- If the spindle extension is left out when there is more than one spindle in the process, the spindle statement will apply to the first spindle (S/S1).
- The spindle direction used in the main spindle is determined by the M-functions: M03 *spindle clockwise* and M04 *spindle counterclockwise*. If more than one spindle is present in a process,
  - M103 / M104 for the first spindle,
  - M203 / M204 for the second spindle, and
  - M303 / M304 for the third spindle,

  must be programmed, based on the respective spindle numbers.

Each spindle can be called once in a single NC-block.

Example	M103 S1 1500 M203 S2 2500 M303 S3 3500

Note: The maximum spindle speed is set by the machine builder in the axis parameters (Cxx.049 Maximum Programmable Spindle Speed).

Select Main Spindle for Feed Programming 'SPF'

If several spindles are being used in a process, certain functions such as G96, constant surface speed, must be allowed to act on another spindle in addition to the first spindle.

Syntax **SPF <Spindle Number>**

The following functions are dependent on the selected main spindle:

- G33 thread cutting
- G63/G64 floating tapping
- G65 floating tapping; spindle as lead axis
- G95 feed per revolution
- G96 constant surface speed

The first spindle (S/S1) is always active in the power-on state. If one of the above function is to act upon a spindle other than the first spindle, the reference spindle must first be selected using SPF <spindle number>SPF.

- The reference spindle must be selected at least one NC-block prior to one of the above function calls.
- SPF <spindle number> remains modally active until it is overwritten with a different spindle number or is automatically set to the first spindle at the end of the program (RET) or by BST, M02, M30.
- The programming of G 97 spindle speed in rpm is active for all spindles present in the process. The reference spindle for one of the functions referred to above must therefore be reset after G97 has been programmed.
- SPF <spindle number> may only be used for main spindles which are in the spindle mode. A main spindle which is in the rotary axis mode cannot be selected as a reference spindle.

Example NC-program—longitudinal thread machining with the 2nd spindle

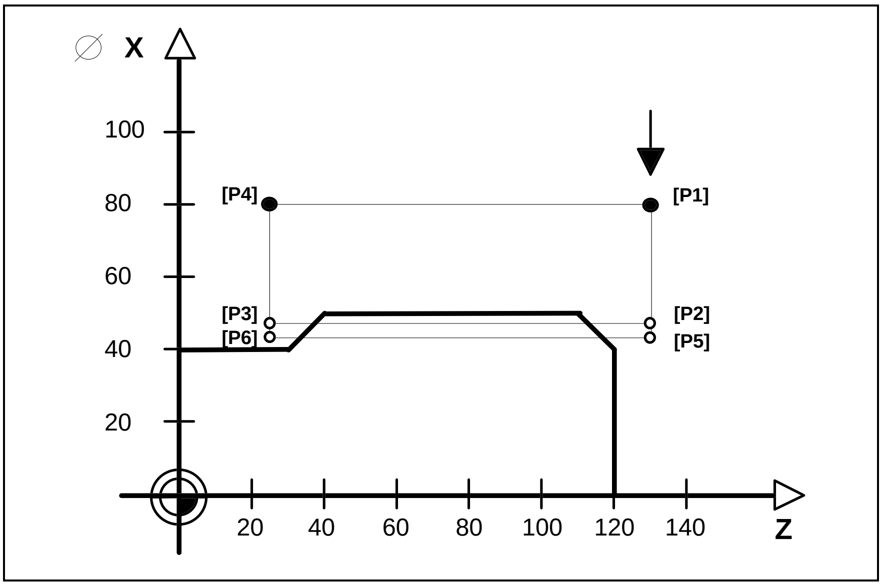


Fig. 4-45: Thread cutting—longitudinal thread with the second spindle

Thread lead:	3mm		
Thread depth:	4mm	Thread depth per cut:	2mm

NC program

G00 G54 G90 G06 G08 X80 Z130	[P1] Starting conditions
SPF 2	Select reference spindle
S2 2000 M203	Spindle 2 ON
G01 X45.5 F1500	[P2] Infeed for first cut
G33 Z30 K3 P180	[P3] 1st thread thru hole
G00 X80	[P4] Withdraw X axis
Z130	[P1] Starting point
G01 X43.5 F1500	[P5] Infeed for second cut
G33 Z30 K3 P180	[P6] Second thread thru hole
G00 X80	[P4] Withdraw X axis
M205	Spindle 2 OFF
RET	Return to program beginning

Constant Grinding Wheel Peripheral Speed (SUG) 'G66'

With G66, the programmed value in m/s or feet/s brings about a constant grinding wheel peripheral speed with automatic adjustment of the spindle speed to the individual grinding wheel diameters.

Syntax

G66 S<Constant grinding wheel peripheral speed>

G66 is allocated to the G code group 8. Consequently, G96 or G97 may be used for de-selecting it.
G66 is related to the current spindle. A preceding SPF<spindle number> permits the SUG to be selected for any spindle.

Boundary conditions

- After the SUG has been selected with G66, all programmed speed command values for the addressed spindle are interpreted as m/s or feet/s in all modes.
- The grinding wheel peripheral speed remains in effect until the tool data record is removed from the corresponding spindle or until the spindle is stopped by control-reset in response to the AxxCSPRST SPS signal.
- The required spindle speed is calculated after the SUG has been selected.
- The corresponding tool data elements of the addressed spindle are used for calculating and monitoring the speed.

- When the SUG is selected with G66, the corresponding spindle must contain a valid tool data record (tool codes 1, 2 and 3 [correction type ≥ 3]). An error message will be generated if this is not the case.
- When the SUG is selected with G66, the corresponding length registers for the wheel diameter must be > 0. An error message will be generated if this is not the case.
- A new speed calculation is performed if a new S value is programmed, or in the next NC block if there is a change in a geometry register that is relevant to the wheel diameter.
- The data elements of the D correction are currently excluded from the speed calculation.
- G96 or G97 or RET, BST, M30 de-selects G66.

Calculation formula:

$$S_{[min^{-1}]} = \frac{SUG_{[m/s]} * 60000}{d_{AKT\,[mm]} * \pi} \qquad S_{[min^{-1}]} = \frac{SUG_{[ft/s]} * 720}{d_{AKT\,[inch]} * \pi}$$

S: spindle speed [1/min]
SUG: grinding wheel peripheral speed [m/s or feet/s]
d_{AKT}: grinding wheel diameter [mm or inch]

CAUTION

The data elements „tool code and representation type“ of the base tool data that are necessary for grinding, and the selection of the SUG with G66 only become active if the „Technology“ data item in the system parameters has been set to „grinding“.

Constant Surface Speed 'G96'

The CNC controller uses the G96 constant surface speed function to determine the correct spindle speed to match the current turning diameter. G96 constant surface speed is a typical lathe function and face turning is the most frequent application. The infeed axis 4 G96 is derived from the typical G18 (ZX) axis allocation of a lathe, so that the X axis is defined as an infeed axis. The spindle speed is inversely proportional to the distance of the tool trip from the axis of rotation when G96 is active so that the spindle speed increases as the distance becomes smaller.

Syntax **G96 S<Constant Surface Speed in m/min>**

When G00 is active, the spindle speed is set independent of the current X position to the rpm which results at the end of the NC-block. G96 continues to remain active; however, the link to the feed move is temporarily broken. The NC-block is considered to be over when the spindle has reached its command rpm and the feed axes have reached their end point.
G95 is activated automatically when G96 is selected. If G95 was not previously active, an error message is issued due to the fact that the F-value is missing.
Since the spindle speed would become too great with very small X values, the spindle speed is limited to the maximum spindle speed set in the parameters.
When G96 is active, the S value is interpreted as surface speed in m/min. The spindle speed is calculated from the relationship:

$$S = \frac{vc}{(2 * r * PI)}$$

S: spindle speed [1/min]
vc: surface speed [mm/min]
r: effective radius [mm], distance to turning axis

- In the power-on state, G96 always applies to the first spindle (S/S1). If G96 is to be applied to a different spindle, the desired spindle must be selected prior to the G96 NC-block by using the SPF <spindle number> command.
- Depending on the settings in the process parameter Bxx.041 (Spindle Speed Programming Default), G96 may be the power-on default. G96 constant surface speed (CSS) remains modally active until it is canceled by G97.
- After the controller is turned on, after an NC-program is loaded, after a BST, M02, M30, RET or control reset, G96 is set automatically depending on the setting in the process parameter Bxx.041, and the spindle speed values (S values) are reset.
- If the S value is changed when G96 is active, this S value change must be programmed together with G96.
- When G96 is active, the maximum spindle speed can be limited by the command G92 S <spindle speed>.
- The spindle override is limited to 100% when G96 is active. Reducing the spindle override to less than 100% results in a reduction of the surface speed.
- If G96 is canceled by G97, the most recently active spindle speed is taken over as the new spindle speed command value.

Example NC program - face turning with G96

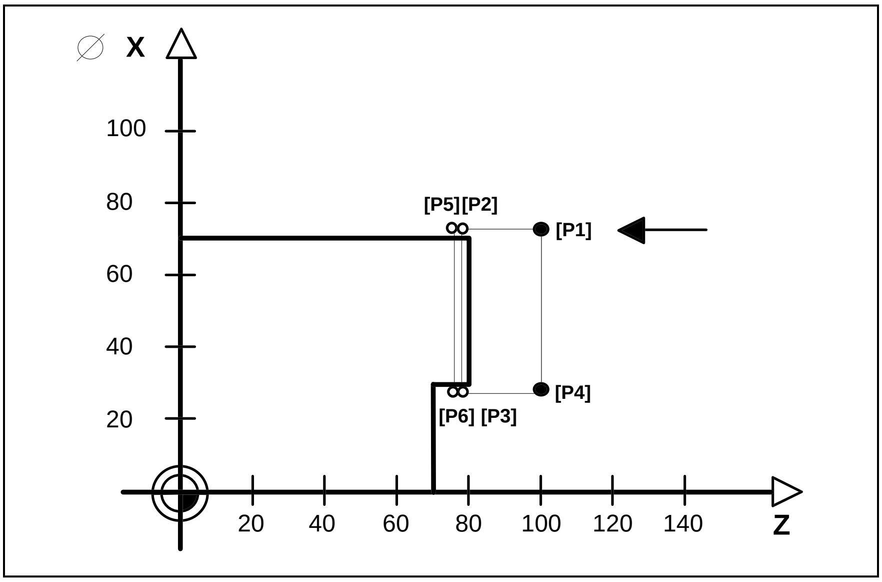


Fig. 4-46: Face turning

NC-program

G00 G54 G90 G06 G08 X72.5 Z100	[P1] Starting conditions
S1 2500 M103	Spindle ON
G00 Z78	[P2] Infeed for first cut
G96 X27.5 S1 400	[P3] 1st face turning operation
G00 Z100	[P4] Withdraw Z axis
X72.5	[P1] Starting point
G00 Z76.5	[P5] Infeed for second cut
G96 X27.5 S1 400	[P6] 2nd face turning operation
G00 Z100	[P4] Withdraw Z axis
M105	Spindle OFF
RET	Return to program beginning

Upper Spindle Speed Limit 'G92'

The G92 function can be used to set an upper spindle speed limit when G96 is active. When G96 is active, the surface speed is kept constant. This can lead to a spindle speed which theoretically is of infinite magnitude in the case of face turning or cutting down to the center of rotation. For reasons relating to machining technology, it may be necessary to limit the maximum spindle speed to a value which is less than the maximum spindle speed set in the parameters. G92 is used to set a maximum upper limit for the spindle speed when G96 is active.

Syntax **G92 S <Upper Spindle Speed Limit>**

G92 is active only for the NC-block in which it is located. The limit set for the spindle speed remains modally active until it is overwritten with a new speed limit by new programming of G92 or is reset by programming G92 S0.

- A speed limit programmed using G92 remains modally active until it is canceled by programming G92 S0 or is automatically reset at the end of the program RET or by BST, M02, M30.
- The spindle speed limit set using G92 is deactivated by programming G97; it is reactivated the next time G96 is programmed.
- No further functions may be programmed in an NC-block containing G92.

Spindle Speed in RPM 'G97'

The programmed S-value is interpreted in rpm when the function G97 spindle speed in rpm is used. G97 is the power-on state on the CNC if set in process parameter Bxx.041; it remains modally active until it is overwritten by a G96.

- Depending on the settings in the process parameter Bxx.004, G97 may be the power-on default. G97 spindle speed in rpm remains modally active until it is canceled by G96.
- After the controller is turned on, after an NC-program is loaded, after a BST, M02, M30, RET or control reset, G97 is set automatically depending on the setting in the process parameter Bxx.041, and the spindle speed values (S values) are reset.
- If G96 is canceled by G97 is active, the most recently active spindle speed is taken over as the new spindle speed command value.
- The programming of G 97 spindle speed in rpm is active for all spindles present in the process. The selection of the reference spindle using SPF must therefore be reset after G 97 has been programmed.

4.6 Rotary Axis Programming

Effective Radii 'RX', 'RY', 'RZ'

With all interpolation moves using G00 and G01, the components of the local vector are assumed to be constant during an NC-block. The translational and rotational moves are performed at constant speed. The speed, inflection-point speed, and acceleration components of all axes involved in the move are calculated using the same method as before, however the rotary main axes are taken into account. The effective distances for the actual distances to the respective main axes are indicated by the designations RX, RY, and RZ. The CNC only takes the fact components caused by the rotations of the rotary main axes into account when the corresponding effective distances RX, RY and RZ are specified with respect to the respective linear main axis about which the rotation occurs.

- The effective distances RX, RY and RZ give the absolute distance to the respective linear main axis. They therefore must not be programmed using a sign in the NC-program.
- Effective distances having an absolute value of 0 are not programmed.
- The programming of the effective distances in the NC-program is active for a single NC-block and must be programmed in the NC-block in which it is to be active.
- The effective distances can be programmed in any desired order in the NC-program and without reference to the rotary axes.
- Unreasonable entries for effective distances can cause the rotary main axes to turn too fast or too slow, or they can result in no speed components at all.

CAUTION

In conjunction with the KDA main spindle drive, it is absolutely essential to perform the C-axis movement with the minimized lag function G6 active.

Example NC program - spiral groove

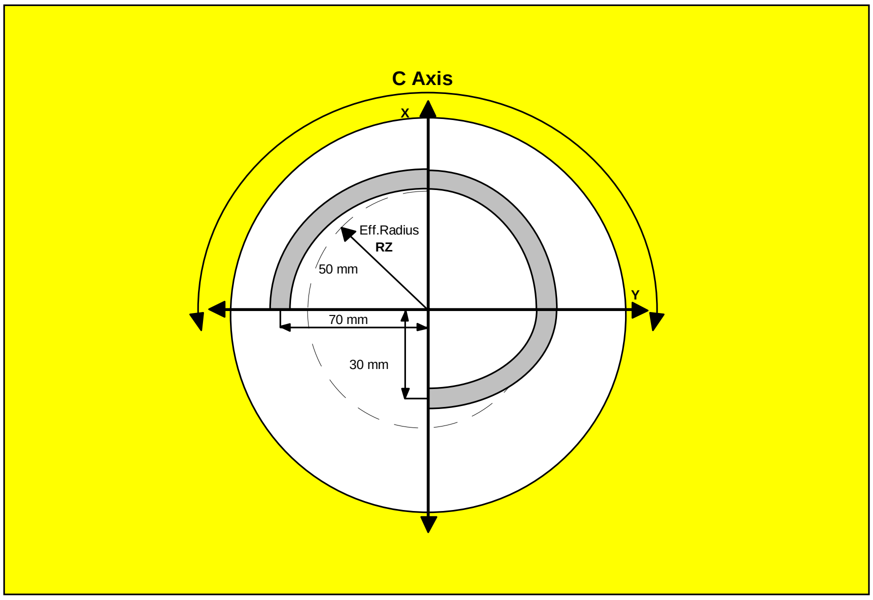


Fig. 4-47: Machining a spiral groove on a face surface

NC program

G90 G06 G17	Process (machining plane) XY, end
•	
•	
•	
G00 X-30 Y0 Z501 C90	Approach; positioning of C-axis
G01 Z497 F500	Lowering the cutter
[spiral groove machining]	
G01 G91 X-40 C-270 RZ50 F1200	Spiral groove on the end surface
•	
•	
RET	Return to program beginning

NC-program Changeover Between Spindle and C Axis

The changeover between C axis mode and main spindle mode is performed in terms of the NC syntax by programming the C-axis (Cxxx.xxx) or the main spindle (M03 Sxxxx). If the C-axis is programmed in the following NC-block when the main spindle mode is active, the CNC performs the changeover with the help of the SPS. NC-block preparation and NC-block processing are stopped until the changeover operation is completed.

The same mechanism is active as is used in the changeover from C axis mode to main spindle mode.

- After the changeover from the main spindle mode to C-axis mode, all the spindles active in the process must be traversed one time with G90 absolute input data as absolute dimensions, before G91 input data as incremental values can be used.

Changeover with a rotary-axis capable main spindle drive

M19 S0	Orient main spindle
G00 G54 G90 X100 Z200 M03 S1000	Base position, spindle mode
•	Machining
G00 G17 G06 X100 Z250 C90	Base position, C-axis mode
•	
G01 G91 X-40 C-270 RZ50 F1200	Machining
•	
G00 G18 G54 G90 X120 Z200 M03 S1200	Base position, spindle mode
•	
RET	Return to program beginning

Approach Logic for Endlessly Rotating Rotary Axes

Modulo calculation

Modulo calculation is used for positioning endlessly rotating rotary axes.

Possible positioning methods:

- Shortest way G36
- Positive direction G37
- Negative direction G38

NOTE

Modulo calculation can only be used with absolute coordinate programming (G90).

It does not have an effect on incremental coordinate programming (G91).

The G36, G37, and G38 commands form the G code group „Rotary axis approach logic“ (no. 21).

Shortest way

In the modulo calculation „shortest distance“, G36, the command position is approached via the shortest way.

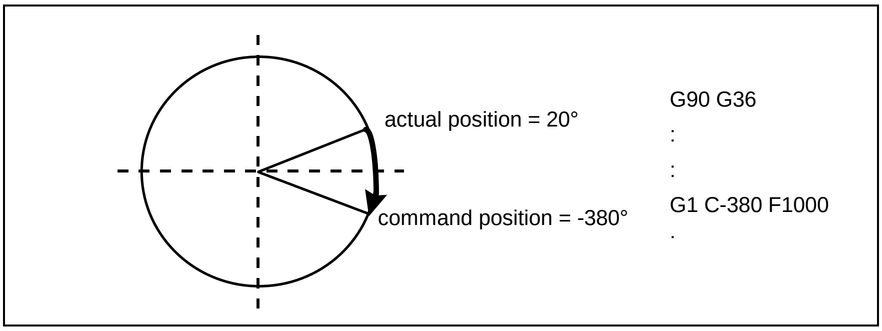


Fig. 4-48: Positioning using Modulo calculation „shortest way“(G36)

- G36 is the power-on state; it may be de-selected by G37 or G38.
- The power-on state G36 is restored at the end of the program (BST, RET, JMP, M02, M30).

Positive direction

In the modulo calculation „positive direction“, G37, the command position is approached in the positive direction.

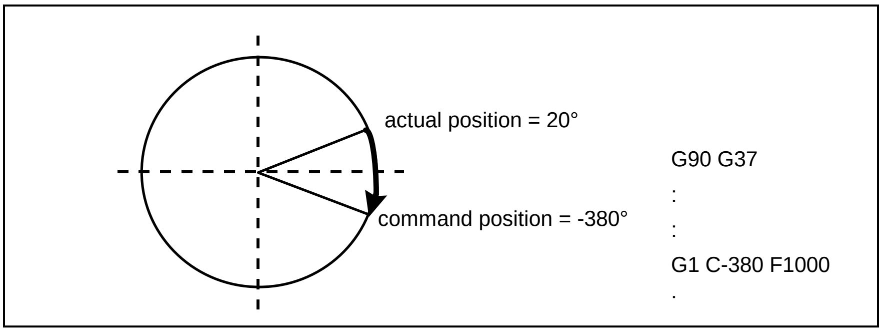


Fig. 4-49: Positioning using Modulo calculation „positive direction“ (G37)

- G37 may be de-selected by G36 or G38.
- The power-on state G36 is restored at the end of the program (BST, RET, JMP, M02, M30).

Negative direction

In the modulo calculation „negative direction“, G38, the command position is approached in the negative direction.

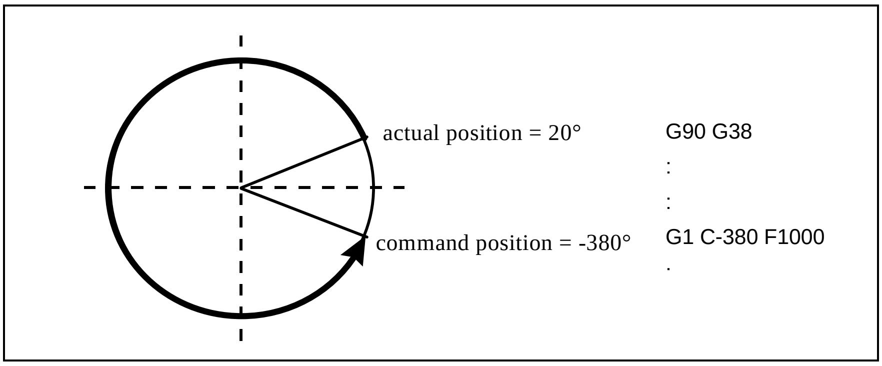


Fig. 4-50: Positioning using Modulo calculation „negative direction“ (G38)

- G38 may be de-selected by G36 or G37.
- The power-on state G36 is restored at the end of the program (BST, RET, JMP, M02, M30).

Note: The machine manufacturer may change the default setting in the Bxx.056 process parameters.

4.7 Coordinate Transformation

Coordinate transformation is available for:

- Face machining, and
- lateral cylinder surface machining

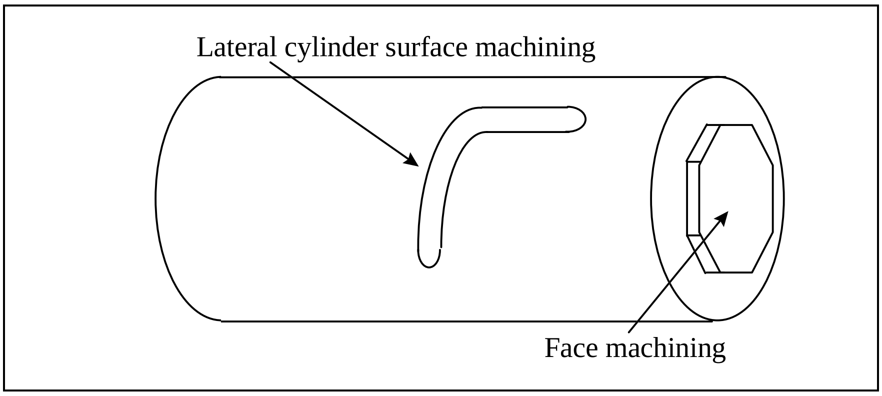


Fig. 4-51: Lateral cylinder surface and face machining

The commands G30 (de-selecting coordinate transformation), G31 (face coordinate transformation), and G32 (lateral cylinder surface coordinate transformation) form the G code group „transformation functions“ (no. 17).

Selection of Face Machining ‘G31’

The function G31 „select face machining“ is used to switch the CNC to a fictive Cartesian coordinate system. The defined fictive linear axis are used in the interpolation instead of the assigned real main axes. The path feedrate with the transformation function must be specific, as with milling, as a relative speed between the tool and the workpiece using the F-value. The programmed path feedrate is reduced in such a way that the maximum rpm of the rotary axis is not exceeded. This is especially true with movement near the center of rotation.

Syntax **G31**

Boundary conditions

- The CNC supports the transformation function for the XY plane (G17). The real axes involved in the transformation must have the axis meaning X and C.
- The real Y axis (if present) becomes an auxiliary axis which has the meaning V. When the transformation is deactivated, the NC reestablishes the original status.
- The zero offsets are canceled (G53) when coordinate transformation is selected (G31); tool path compensation and tool length correction are deactivated (G40, G47). The CNC switches to radius programming (G15).
- The X axis must be in the positive area when the change to coordinate transformation occurs.
- After the changeover to coordinate transformation, the zero offsets for the fictive axes become active, depending on which ones are set. The zero offsets of the real main axes assigned to the fictive axes are not in effect.
- After the change to coordinate transformation, it is possible to program directly using absolute (G90) or incremental (G91) dimensional input.
- It is possible to open a new program during coordinate transformation by using NC-block search; however, coordinate transformation (G31) <u>must</u> be set with the basic settings for this function (G54, G48, etc.) in MDI <u>before</u> starting the program.
- The fictive axes cannot be passed on to other processes (FAX, GAX).

- The reference spindle for feed programming with floating tapping (G63, G64, G65) must be set using the SPF command.
- In the power-on state, the coordinate transformation always applies to the first spindle. If the transformation is to be applied to a different spindle, the desired spindle must be selected prior to coordinate transformation by using the SPC <spindle number> command.
- The real main axes which are assigned to the fictive axes must not be programmed during the transformation.
- G31 coordinate transformation remains modally active until it is canceled by G30 or G32, or until it is reset automatically via BST or at the end of the program (RET).

Note: When coordinate transformation is active, the CNC employs axis designation 2 for the two fictitious axes that span the current working plane, instead of axis designation 1 which is stored in the machine parameters.
The machine manufacturer defines the axis designation of the fictitious axes in the axis parameters.

NOTE

The coordinate transformation function is an option that requires a special hardware configuration.
All axes that are involved in the coordinate transformation must be on an APR card.
The real primary axes that are allocated to the fictitious axes must not be programmed during coordinate transformation.

CAUTION

When the coordinate transformation function is executed in a machine with a real Y axis, the corresponding process must not contain an axis of the axis meaning V.
When the coordinate transformation function is activated, the CNC automatically triggers a changeover to rotary axis mode.
When face machining is activated and de-activated, the CNC de-activates all zero offsets, and sets G53.
If diameter programming (G16) is selected while face machining is active, the CNC interprets all position values of the fictitious axis with axis meaning X as a diameter specification.

Detailed description

Please refer to the „Coordinate transformation function“ description in Folder 5 for further and supplementary information about face machining.

Example NC program - face machining

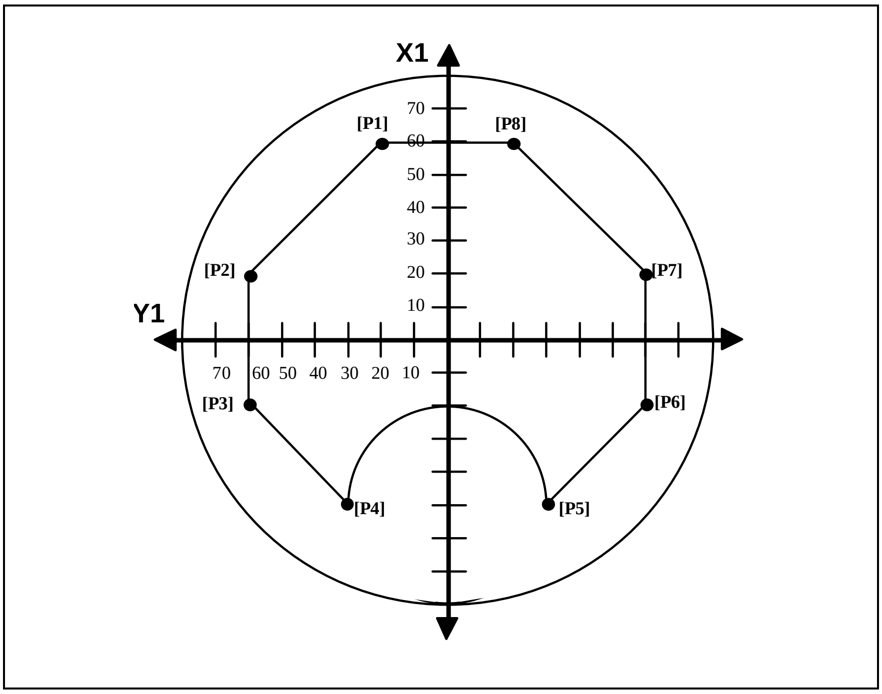


Fig. 4-52: Face machining with coordinate transformation

NC program

```
T12 M6                        ;Tool change of driven tool
M89                           ;Engage driven tool
S2 3500 M203                  ;Driven tool ON
G00 G17 G54 G48 Z100
X140 C0                       ;Home position for the change
G31                           ;Activate coordinate transformation
G54 G90 G06 G08 G48           ;Home position
G00 G42 G94 X1 60 Y1 20       ;[P1] starting point of machining
G01 Z-0.5 F500                ;Infeed Z axis
X1 20 Y1 60 F400              ;[P2] 1st straight line
X1 -20                        ;[P3] 2nd straight line
X1 -50 Y1 30                  ;[P4] 3rd straight line
G02 X1 -50 Y1 -30 I-50 J0     ;[P5] Semicircle in CW direction
G01 X1 -20 Y1 -60             ;[P6] 4th straight line
X1 20                         ;[P7] 5th straight line
X1 60 Y1 -20                  ;[P8] 6th straight line
Y1 20                         ;[P1] 7th straight line
G00 Z10                       ;Z axis to safety distance
G30                           ;Cancel coordinate transformation
G54 G48 G00 X140              ;Home position
Z200                          ;Withdraw Z axis
M90                           ;Disengage driven tool
M30                           ;Return to program beginning
```

Selection of Lateral Cylinder Surface Machining 'G32'

With lateral cylinder surface machining G32, the CNC produces straight lines and circles on the lateral cylinder surface according to the G00, G01, G02 und G03 blocks that are specified in the NC program. The straight lines and circles on the lateral cylinder surface can be programmed on the plane of the developed lateral cylinder surface that is spanned by a linear axis and a rotary axis.

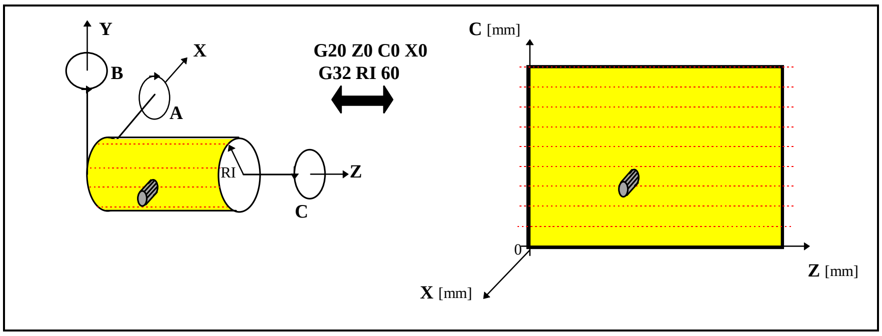


Fig. 4-53: Lateral cylinder surface machining

Programming

The rotary axis that is involved in lateral cylinder surface machining can be programmed like a linear axis in[mm] or in [inch] (by specifying positions on the lateral cylinder surface).

Syntax

G32 RI=w or **G32 RI w**

w: Value of the effective radius

Effective radius

- Specifying the effective radius RI is mandatory.
- Specifying an effective radius RI ≤ 0 is <u>not permitted</u>.
- The effective radius RI must not be altered when lateral cylinder surface machining is active. (G30 must first be used for de-activation).
- If the machining plane is spanned by two rotary axes, the CNC takes the effective radius RI of both rotary axes into account.
- The effective radius RI has a modal effect. The CNC retains the effective radius until lateral cylinder surface machining is de-activated.

Plane selection

Before lateral cylinder surface machining is activated, the plane must usually be selected with G20, free plane selection.

G20 ...

Boundary conditions

- During lateral cylinder surface machining, the involved rotary axis obtains the functionality of a linear primary axis. Functions such as tool radius path correction and zero offsets, including rotations, may also be used in the course of lateral cylinder surface machining.
- During lateral cylinder surface machining, the CNC monitors the limited rotary axes (travel range limits) in the same way as during normal operation.
- During lateral cylinder surface machining, rotary axes must be programmed in [mm] or [inch].
- When lateral cylinder surface machining is activated, the CNC automatically switches over to radius programming (G15).
- Upon de-selection, the CNC restores the programming type (radius programming, G15, or diameter programming, G16) that has been stored in the process parameters.
- G32 - coordinate transformation - remains modally in effect until it is canceled by G30 or G31, or until it is automatically reset at the end of the program (BST, RET, JMP, M02, M03).

NOTE

Before lateral cylinder surface machining is activated, the activated machining plane must be spanned by at least one rotary axis. This is possible using G20, free plane selection.

CAUTION

When lateral cylinder surface machining is activated or de-activated, the CNC de-activates all zero offsets and sets G53.
If diameter programming (G16) is selected during lateral cylinder surface machining, the CNC interprets all position values of the axis with axis meaning X as diameter specifications.

Detailed description

Please refer to the „Free plane selection and lateral cylinder surface machining“ description in Folder 5 for further and supplementary information about lateral cylinder surface machining.

Example NC program - lateral cylinder surface machining

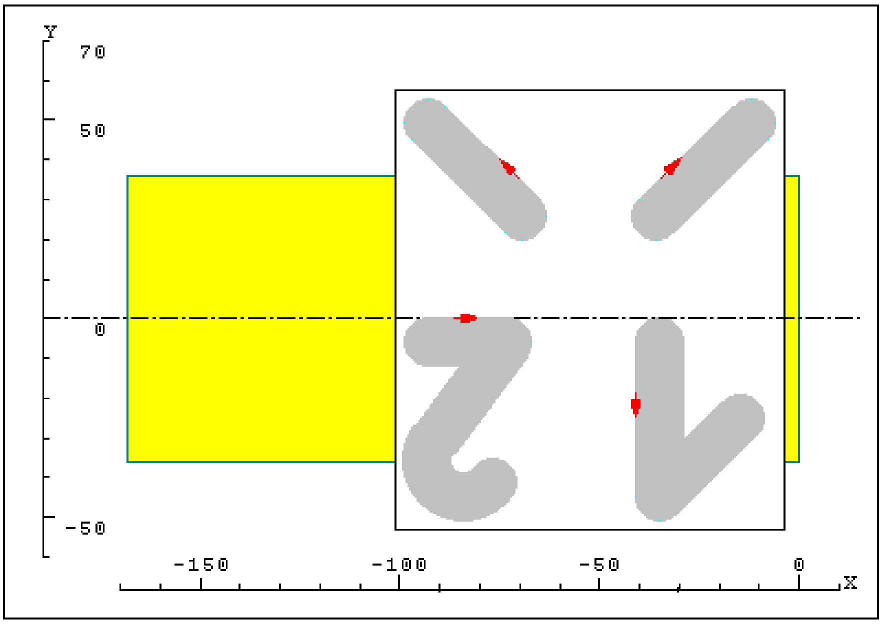


Fig. 4-54: Lateral cylinder surface machining with coordinate transformation

NC program

```
:
Milling  contour 'letter 1'
N0008 G55 G15 G94 G97 G6 G8 S2 3000 M203
N0009 G0 C0
N0010 G20 Z0 C0 X0                  Free plane selection
N0011 G32 RI 36.5                   Lateral cyl. surface machining ON
N0012 G55 G48 Z1-36.15
N0013 Y1 25 Z1-36.15
N0014 X38
N0015 G1 X36 F150
N0016 G42 Y1 25 Z1-42 F297
N0017 Y1 50 Z1-42
N0018 G2 Y1 54.2426 Z1-30.7574 I-35 J50
N0019 G1 Y1 34.2426 Z1-10.7574
N0020 G2 Y1 25.7574 Z1-19.2426 I-15 J30
N0021 G1 Y1 36.5147 Z1-30
N0022 Y1 5 Z1-30
N0023 G2 Y1 5 Z1-42 I-36 J5
N0024 G1 Y1 25 Z1-42
N0025 G0 X38
N0026 G30                           Lateral cyl. surface machining OFF
:
```

De-Selection of Coordinate Transformation 'G30'

The CNC employs the G30 function - de-selection of coordinate transformation - to de-select an existing coordinate transformation (G31, G32).

When the coordinate transformation is de-selected (G30), the zero offsets (G53) are de-selected, and tool path correction and tool length correction are de-activated (G40, G47).

G30 is the power-on state; it has a modal effect. G30 is canceled by G31 or G32. G30 is set automatically after an NC program has been loaded and after a BST, RET, or Control-Reset.

De-selection of face coordinate transformation G31

The fictitious Cartesian coordinate system is de-selected and the coordinate system is selected that has been defined in the process parameters. The fictitious axes are de-selected and may consequently no longer be programmed.

The plane that has been specified in the process parameters is selected as the current machining plane; and the CNC switches over to the workpiece programming mode (radius/diameter) that has been stored in the process parameters.

After coordinate transformation has been de-activated, programming can be performed directly in absolute (G90) or incremental (G91) dimensions.

CAUTION

The fictitious axes may no longer be programmed.
The zero offsets for the real axes have already been set.
The zero offsets of the fictitious axes that are allocated to the real axes are without effect.

De-selection of the lateral cylinder surface coordinate transformation G32

Upon de-selection, the CNC restores the programming mode (radius programming, G15, or diameter programming, G16) that has been stored in the process parameters.

CAUTION

The CNC de-activates all zero offsets and sets G53.

Select Main Spindle for Transformation G-Codes ‘SPC’

If a number of spindles in which a coordinate transformation could be performed are present in a process, there must be some way to select the main spindle for the coordinate transformation.

Syntax

SPC <Spindle number>

The first spindle is always active in the power-on state. If the transformation is to apply to a spindle other than the first spindle, the correct main spindle must be selected by using SPC <spindle number> before using G31 or G32 to select coordinate transformation.

Select main spindle for coordinate transformation must be performed when the main spindle mode is active. It cannot be selected during C-axis mode.

SPC <spindle number> remains modally active until it is overwritten with a different spindle number or is automatically set to the first spindle at the end of the program (RET) or by BST, M02, M30.

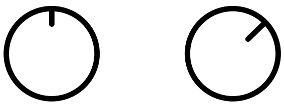
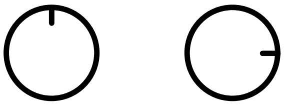
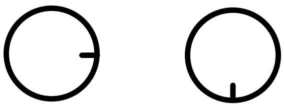
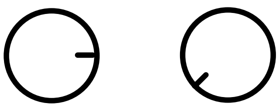
4.8 Main Spindle Synchronization

Use of Main Spindle Synchronization

Main spindle synchronization is primarily used on lathes to transfer parts, to recess parts, to machine shafts, for polygon turning, and for non-round turning.

Functionality of Main Spindle Synchronization

Up to 3 spindles can be operated in sync within a process on the CNC. One spindle is used as the master spindle, while the other two spindles are operated as synchronized spindles. The CNC always traverses the master and synchronized spindles such that they remain angularly in sync. The following example illustrates the relationship with angular synchronization between a master spindle and a synchronized spindle.

	Angular Position of the Spindles	**Remark**
Prior to Synchronization	Master spindle / Synchronized spindle 	Each spindle is located in any given random position
After synchronization step	Master spindle / Synchronized spindle 	The synchronized spindle moves to the specified angular offset position (= 90°) (translation ratio = 1).
After rotation of 90°	Master spindle / Synchronized spindle 	The synchronized spindle has rotated 90° in synch with the master spindle.
After a change in the position offset of 45°	Master spindle / Synchronized spindle 	The synchronized spindle has rotated 45° with respect to the master spindle.

The advantage of the absolute angular synchronization mode is that the angular offset between the master and the synchronized spindles can be set in a defined manner at any point in time.

Permissible Configurations

The rules which define the permissible spindle configurations for the main spindle synchronization are listed below. If one of these rules is violated at the beginning of synchronization or during synchronization, the NC interrupts the process and generates an error message.

- Only one master spindle can be used in a main spindle synchronization.
- All spindles used in a main spindle synchronization must belong to one process.
  - If the spindles of a different process are to participate in the main spindle synchronization, this must be declared to the respective process using the axis transfer commands (GAX/FAX).

- All spindles used in a main spindle synchronization must be controlled by the same APRB card.
- No more than two synchronized spindles can belong to a synchronization group aside from the master spindle.
- The master spindle must have a lower drive number than the synchronized spindles within the SERCOS drive loop.
- A single spindle cannot be both a master and a synchronized spindle at the same time.

NOTE

Only digital main spindle drives equipped with the SERCOS interface and digital DDS 2.2 feed drives equipped with main spindle functions and with the SERCOS interface can be used in main spindle synchronization.

Sequence of a Synchronization Operation

Activate main spindle synchronization

The main spindle synchronization is activated in NC-program-controlled mode from the NC-program by means of an auxiliary function. In manual mode, the synchronization can be activated by means of a machine control key or by any other key. An interface signal between the SPS and the NC allows main spindle synchronization to be activated in any operating mode.

The following must be specified from the user interface, the NC-program, or the SPS program before starting main spindle synchronization:

- The master spindle assigned to the synchronized spindle
- The translation ratio between the master spindle and the synchronized spindle
- The direction of rotation of the synchronized spindle
- The effective angular offset and position offset between both spindles
- The tolerance limits for monitoring the actual-position-value differences between the master and the synchronized spindle

Auxiliary Functions for Selecting and Canceling Main Spindle Synchronization

Effective with version 15VRS, Q-functions Q9000 - Q9999 are reserved for INDRAMAT-specific functions. The Q-functions Q9700 - Q9764 are provided for main spindle synchronization. We recommend that the auxiliary functions be assigned as follows for main spindle synchronization:

	9 reserved for INDRAMAT	**7 reserved for Main Spindle Synchronizing**	**Process number x = 0...6**	**Function**	**Remarks**
Q	9	7	x	0	Main Spindle synchron. groups 1 & 2 OFF
Q	9	7	x	1	Main Spindle synchron. group 1 ON
Q	9	7	x	2	Main Spindle synchron. group 2 ON
Q	9	7	x	3	Main Spindle synchron. group 1 OFF
Q	9	7	x	4	Main Spindle synchron. group 2 OFF

Synchronization Operation

If the spindles are rotating at different speeds (stopped = 0 rpm) when spindle synchronization is activated, the NC accelerates or decelerates the synchronized spindle at maximum acceleration/deceleration until it reaches the synchronization speed. As soon as it reaches the synchronization speed, the NC switches to position control and rotates the synchronized spindle to the set position within one revolution using the shortest direction. If the master spindle and the synchronized spindle are stopped, the synchronized spindle simply traverses to its command position taking the existing translation ratio and the existing angular offset and position offset into account.

The NC switches all spindles involved in the synchronization to position control. If functions such as M03, M04 or G95 are active when main spindle synchronization is activated, the NC continues position control mode for these spindles. The changeover operation does not have any negative effects on the surface of the workpiece.

Cancel Synchronization

Main spindle synchronization can be canceled without regard for the operating mode by resetting the activation interface signal. All spindles involved in the synchronization retain their speeds after cancellation. If the spindles must stop after cancellation, this must be programmed by means of M05 or M19 after synchronization has been canceled. When the synchronization is deactivated, the NC switches the spindles which were involved in the synchronization back to speed (rpm) control if a function which normally runs under rpm control is active at this time.

NC Programming

None of the synchronized spindles which participate in main spindle synchronization may be programmed during synchronized operation. However, if an attempt is made to do this, the NC terminates program execution and issues an error message.

Furthermore, the master and synchronized spindles must not be operated in the rotary axis mode and a gear change must not be performed during synchronized operation. Any attempt to do so will result in the termination of the program and the issuance of an appropriate error message.

- Synchronized operation remains active at the end of the program (BST, RET, M02 and M30), with control reset or with jog in manual mode if the SPS does not cancel the synchronized spindles which are involved in synchronized operation.
- The master spindle must be the main spindle during synchronized operation. In synchronized operation, the functions G33, thread cutting, G95 feed per revolution and G96 constant surface speed, apply exclusively to the master spindle. For this reason, the master spindle must be selected as the main spindle as soon as main spindle synchronization is activated.
- During synchronized operation, the user must not switch the spindles which are involved in the main spindle synchronization from one process to another. The use of the axis transfer commands GAX/FAX with the spindles which are engaged in synchronized operation will cause the program to terminate and an error message to be issued. Thus, spindles which are part of the synchronized operation and belong to a different primary process must be transferred to the respective process before synchronized mode is activated, and they must not be returned to the primary process until synchronized mode is canceled.

NOTE

The spindle which is engaged in tapping, G63, G63 or G65, must not be a master spindle or a synchronized spindle.

Machine Data for Main Spindle Synchronization

The machine data for the main spindle synchronization occupy a page 50 named main spindle synchronization. The following data structure is present in the page for each process:

No.	Name	Value Range	Description
001	Synchron. Synch. spindle 1 ok	0/1	0: synchronized operation not OK 1: Synch. operation OK
002	Synchron. Synch. spindle 2 ok	0/1	0: synchronized operation not OK 1: Synch. operation OK
003	Lead spindle in Coord. Sys.	0, 10, 11, 12	0: no master spindle present; 10: Spindle S1; 11: Spindle S2; 12: Spindle S3
004	Synch.spdl.1 in Coord.Sys.	0, 10, 11, 12	0: no synch. spindle present; 10: Spindle S1; 11: Spindle S2; 12: Spindle S3
005	Angle offset Synch.spdl.1	0.0000°-359.9999°	Angular offset between master spindle and synchronized spindle 1
006	Position offset Synch.sp.1	0.0000°-359.9999°	Position offset between master spindle and synchronized spindle 1
007	Lead spindle RPM i_LS/SS1	1 - 65536	The translation ratio is calculated by dividing the master spindle revolutions by the synchronized spindle revolutions.
008	Synch.spdl.1 RPM i_LS/SS1	1 - 65536	The translation ratio is calculated by dividing the master spindle revolutions by the synchronized spindle revolutions.
009	Direction Synch.spdl.1	0/1	0: no change in direction 1: opposite direction
010	Synch.run window Synch.sp1	0.0000°-359.9999°	Synchronized operation window for the interface signal AxxS.SS1OK
011	Error limit Synch.spdl.1	0.0000°-359.9999°	Error limit window for the interface signal AxxS.SS1ER
012	Synch.spdl.2 in Coord.Sys.	0, 10, 11, 12	0: no synch. spindle present; 10: Spindle S1; 11: Spindle S2; 12: Spindle S3
013	Angle offset Synch.spdl.2	0.0000°-359.9999°	Angular offset between master spindle and synchronized spindle 2
014	Position offset Synch.sp.2	0.0000°-359.9999°	Position offset between master spindle and synchronized spindle 2
015	Lead spindle RPM i_LS/SS2	1 - 65536	The translation ratio is calculated by dividing the master spindle revolutions by the synchronized spindle revolutions.
016	Synch.spdl.2 RPM i_LS/SS2	1 - 65536	The translation ratio is calculated by dividing the master spindle revolutions by the synchronized spindle revolutions.
017	Direction Synch.spdl.2	0/1	0: no change in direction 1: opposite direction
018	Synch.run window Synch.sp2	0.0000°-359.9999°	Synchronized operation window for the interface signal AxxSSS2OK
019	Error limit Synch.spdl.2	0.0000°-359.9999°	Error limit window for the interface signal AxxSSS2ER

The individual data elements can be reconfigured from the SPS via the user interface or from the NC-program provided that the corresponding master spindle or synchronized spindle is not active. If the user accesses the data for a spindle which is engaged in synchronized operation from the SPS or from the user interface, an error message will be issued. If the user attempts to do this in the NC-program using the MTD command, an error message will be issued, and the NC will stop processing. Some exceptions are the data elements 005 angular offset and 006 position offset of synchronized spindles 1 and 2. The user can modify them at any time during synchronized operation, either from the SPS via the user interface or from the NC-program.

4.9 Follower and Gantry Axes

Uses of Follower and Gantry Axes

The function Follower axis groups or gantry axis referred to below as synchronized axis group allows up to four feed axes to be operated in synchronization.

Each feed axis can be declared a master axis, and up to 3 synchronized slave axes can be assigned to it. The master axis and the slave axes together comprise a synchronized axis group. Such groups can be activated or deactivated depending on the operating mode, or they can be kept active during the entire operation of the machine, including homing operations. When they are in the inactive state, they can be reconfigured during machine operation from the SPS and the NC as well as by means of the user interface. Up to 4 different synchronized axis groups can be simultaneously active after for each process.

During synchronized operation, all the slave axes in the group follow the path traveled by the master axis, taking into account their respective translation ratios and their directions of rotation.

Permissible Configurations

The following rules describe the configurations which are permissible for synchronized operation. If the NC detects a violation of these rules, it interrupts processing and generates an error message.

- One master axis and at least one slave axes must be present in each synchronized axis group.
- A synchronized axis group must not contain more than one master axis.
- A maximum of three slave axes may be present in each synchronized axis group.
- All axes in a synchronized axis group must belong in the same process.
  - If the axis of a different process is to participate as a master or slave axis in the synchronized axis group, this fact must be declared to the respective process using default axis transfer commands (FAX/GAX).
- All axes in a synchronized axis group must be located on a single APRB card.
- The master axis must have a lower drive number than the slave axes on the SERCOS loop.
- A single axis cannot be both a master axis and at the same time a slave axis.
- All axes in a synchronized axis group must be of the same axis type (linear, modulo rotating rotary, or limited rotating rotary axes).
- Tool storage axes must not be part of a synchronized axis group, either as master axes or as slave axes.
- If rotary axes form a synchronized axis group, they must be programmed using the same number of divisions per revolution.

- The master and slave axes in an active synchronized axis group must not be present as master or slave axes in a different synchronized axis group.

Steps in a Follower Operation

A synchronized axis group can be activated during program-controlled operation from the NC-program by means of an auxiliary function. In manual mode, the user can activate synchronized operation by means of a machine control key or some other key. An interface signal between the SPS and the NC allows follower axis synchronization to be activated in any operating mode. It is important to be certain that the master and slave axes are placed in their starting position before activating synchronized operation and that the corresponding machine data are entered properly.

Synchronized operation can be canceled without regard for the operating mode by resetting the activation interface signal. All axes in the synchronized axis group retain their position without any change after being deactivated.

Auxiliary Functions for Synchronized Operation

Effective version 15VRS, Q-functions Q9000 - Q9999 are reserved for INDRAMAT-specific functions. The Q-functions Q9800 - Q9868 are provided for synchronized axis operation. We recommend that the auxiliary functions be assigned as follows for synchronized operation:

	9 reserved for INDRAMAT	**8 reserved for synchronized axis operation**	**Process number x = 0...6**	**Function**	**Remarks**
Q	9	8	x	0	Synchronous axis groups 1 - 4 OFF
Q	9	8	x	1	Synchronous axis group 1 ON
Q	9	8	x	2	Synchronous axis group 2 ON
Q	9	8	x	3	Synchronous axis group 3 ON
Q	9	8	x	4	Synchronous axis group 4 ON
Q	9	8	x	5	Synchronous axis group 1 OFF
Q	9	8	x	6	Synchronous axis group 2 OFF
Q	9	8	x	7	Synchronous axis group 3 OFF
Q	9	8	x	8	Synchronous axis group 4 OFF

NC Programming

During synchronized operation, the user must not program any axis other than the master axis of an active synchronized axis group. All other slave axes are not programmed during synchronized mode. If the user attempts to do this by, for example, mirror imaging or scaling a slave axes, the NC interrupts program execution and issues an error message.

Zero offsets and tool corrections (including D-corrections) are only taken into account by the NC for the master axis. The slave axes of a synchronized axis group receive only command values considering their translation ratio and direction specified in the machine data page 40.

- The synchronized axis groups remain active at the end of the program (BST, RET, M02 and M30), with control reset or with jog in manual mode if the SPS does not cancel the active synchronized axis.
- During synchronized operation, the user must not switch the axis in the synchronized axis group from one process to another. The use of the axis transfer commands with the axes which are engaged in synchronized operation will cause the program to terminate and an error message to be issued. Thus, axes which are operated in synchronized

mode and belong to a different primary process must be transferred to the respective process before the synchronized axis group is activated, and they must not be returned to the primary process until synchronized mode is canceled.

- Feed to positive stop (G75) cannot be used with synchronized mode.
- When coordinate transformation is active (G31), the axes which are involved in the transformation (axes whose meanings are X and C) must not be part of any active synchronized axis group.

Machine Data for the Synchronized Axis Groups

The machine data for the Follower and gantry axes occupy a page 40 named Follower and gantry axes. The following data structure is present in the page for each process and for each synchronized axis group:

No.	Name	Value Range	Description
001	Axis group switched on	0/1	0: synchronized axis group not active 1: Synchronized axis group is active
002	Lead axis in coord. sys.	0 - 9	0: no master spindle present; 1,2,3,4,5,6,7,8,9: Axis meaning X,Y,Z,U,V,W,A,B,C
003	Follower axis 1 in coord. sys 1	0 - 9	0: no slave axis present; 1,2,3,4,5,6,7,8,9: Axis meaning X,Y,Z,U,V,W,A,B,C
004	RPM lead axis 1 i_LA/FA1	1 - 65536	The translation ratio is calculated by dividing the lead axis revolutions by the follower axis 1 revolutions.
005	RPM follower axis 1 i_LA/FA1	1 - 65536	The translation ratio is calculated by dividing the lead axis revolutions by the follower axis 1 revolutions
006	Direction follower axis 1	0/1	0: no change in direction 1: opposite direction
007	Follower axis 1 = gantry axis	0/1	This data element currently is not evaluated.
008	Follower axis 2 in coord. sys	0 -9	0: no slave axis present; 1,2,3,4,5,6,7,8,9: Axis meaning X,Y,Z,U,V,W,A,B,C
009	RPM lead axis 2 i_LA/FA2	1 - 65536	The translation ratio is calculated by dividing the lead axis revolutions by the follower axis 2 revolutions.
010	RPM follower axis 2 i_LA/FA2	1 - 65536	The translation ratio is calculated by dividing the lead axis revolutions by the follower axis 2 revolutions
011	Direction follower axis 2	0/1	0: no change in direction 1: opposite direction
012	Follower axis 2 = gantry axis	0/1	This data element currently is not evaluated.
013	Follower axis 3 in coord. sys	0 - 9	0: no slave axis present; 1,2,3,4,5,6,7,8,9: Axis meaning X,Y,Z,U,V,W,A,B,C
014	RPM lead axis 3 i_LA/FA3	1 - 65536	The translation ratio is calculated by dividing the lead axis revolutions by the follower axis 3 revolutions.
015	RPM follower axis 3 i_LA/FA3	1 - 65536	The translation ratio is calculated by dividing the lead axis revolutions by the follower axis 3 revolutions
016	Direction follower axis 3	0/1	0: no change in direction 1: opposite direction
017	Follower axis 3 = gantry axis	0/1	This data element currently is not evaluated.

The individual data elements can be reconfigured from the SPS via the user interface or from the NC-program provided that the corresponding synchronized axis group is not active. If the user accesses the data for an active synchronized axis group from the SPS or from the user interface, an error message will be issued. If the user attempts to do this in the NC-program using the MTD command, an error message will be issued, and the NC will stop processing.

5 Tool Corrections

5.1 Data Structure Used with Tool Data

In order to perform the automatic tool check of which tools are installed, the tool management system needs to use the setup-list-specific tool specification data and the tool-list-specific tool actual data.

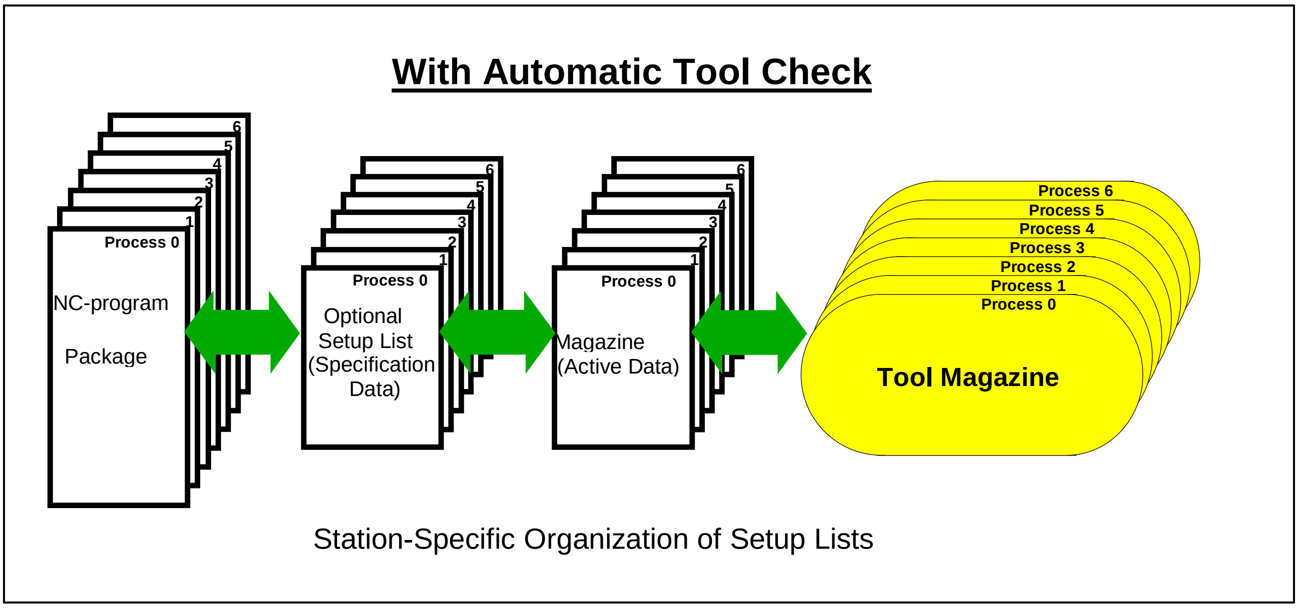


Fig. 5-1: Basic principle of automatic tool check

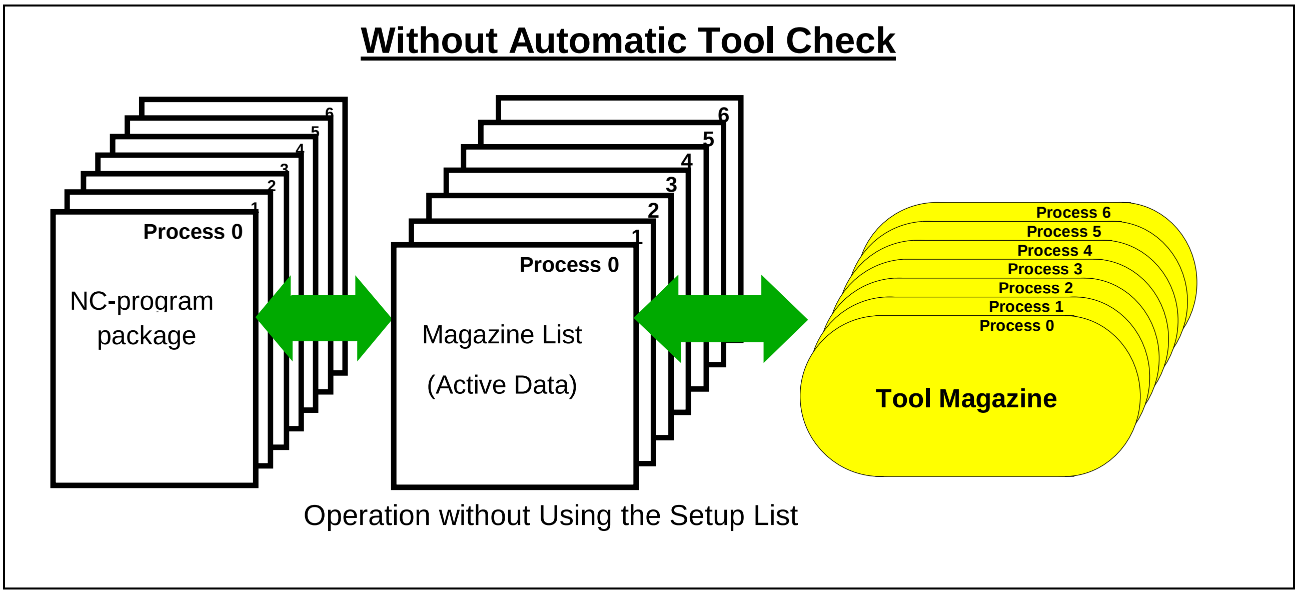


Fig. 5-2: Basic operation without automatic tool check

The following comparison of the setup list and the tool list illustrates how they are used.

	Setup List	Active Tool List
Purpose	Brings together the specification data of all tools required for the machining work.	Prepares and stores the actual data of all tools present in the physical tool storage.
Contents	*Basic tool data* ⇨ Tool Ids *Edge data* ⇨ Edge ID ⇨ Geometry limits (option)	*Basic tool data* ⇨ Tool Ids ⇨ Location Data ⇨ Units ⇨ User data (option) *Edge data* ⇨ Edge ID ⇨ Tool life data (option) ⇨ Geometry data (option) ⇨ User data (option)
Identification	The individual tools are identified based on the tool number and the tool ID.	The individual tools are identified based on the location and the tool ID.
Modification(possible from the PC; SOT, SPS program or NC-program)	The setup lists cannot be changed within the controller.	The active tool list data can be modified in the controller, even when the program is executing.
Modification by the controller	The controller does not perform modification.	Within the controller, the remaining tool life and the wear condition are updated at specified times.
General organization	Setup lists are always included in an NC-program package.	Each tool list is handled separate from other tool lists or data.
Organization on the user interface	*Station-specific setup lists:* A setup list can be established for each process (station) within an NC-program package. *NC-program specific setup lists:* A setup list can be established for each program within an NC-program package.	Up to 99 different tool lists can be managed for each process on the PC, one in the control as the Active Tool List.
Loading into the controller	The setup lists which are present in an NC-program package are all loaded together into the NC-programs.	Each tool list is loaded independently of other tool lists or data.
Activation	Setup lists are loaded with the NC-program package into memory A or B, and they are selected for use from this memory.	A prepared tool list is loaded in the controller for each process which uses a tool management.
Archiving	Backup is performed automatically with the NC-program package.	Tool lists are archived individually.

5.2 Setup Lists

Purpose of the Setup Lists

The setup list is used to define the presence of all tools required for the machining operation as well as whether and how they can be used for the machining steps which are to be performed. The setup list is also used with the automatic tool check to ensure that the tools are available and ready to use.

Thus, a setup list must be created when the NC-program is written for each process which has a tool management and which uses tools to perform a machining operation (see also Tool Data Management in the user interface description).

A setup list is not necessary unless the machine builder specifies that it is necessary in the SPS program.

Data in the Setup List

A setup list includes all the required tools. Each tool used in an NC-program must be entered in the appropriate setup list.

Each tool entry contains

- the basic tool data and
- the edge data

which means that the number of edge records which need to be filled out is equal to the number of edges declared in the basic tool data.

The table below shows the value ranges for the individual data in the setup list and the corresponding units.

NAME	RANGE	DATA TYPE	UNIT	DATA ELEMENT	OPTION	EL	WL
Base tool data	(per tool)						
Tool ID							
Index address	hexadecimal long word with 32 Bits (read only)		-	01			
ID (tool name)	up to any 28 characters	STRING28	-	02		X	X
Storage	0 - 2 (0: magazine/turret, 1: spindle, 2: gripper)		-	03			X
Location	0 - 999		-	04			X
Tool number	1 - 9999999	DINT	-	05		X	X
Index number	1 - 999	INT		06			X
Correction type	1 - 4	USINT	-	07		X	X
Number of edges	1 - 9	USINT	-	08		X	X
Tool status	0/1 (32 status bits)		-	09			X
Location data							
free half-locations	0 - 4	USINT	-	10			X
old location	1 - 999	INT	-	11			X
Storage of next tool	0 - 2 (0: magazine/turret, 1: spindle, 2: gripper)	INT	-	12			
Location of next tool	1 - 999	INT	-	13			
Storage of prev. tool	0 - 2 (0: magazine/turret, 1: spindle, 2: gripper)	INT	-	14			
Location of prev. tool	1 -999	INT	-	15			
Units							
Time unit	0/1 (0: min, 1: cycle.)	USINT	-	16			X
Length unit	0/1 (0: mm, 1: inch)	USINT	-	17			X
Technology data							
Tool code	1 - 9	USINT	-	18		X	X
Representation type	0 - 999	INT	-	19		X	X
User data							
User data 1	+/- $1.2 * 10^{-38}$ - +/- $3.4 * 10^{+38}$ and 0 (current input via MUI, as for geometry data)	REAL	any	20	X		X
. . .	. . .	. . .	. . .	. . .	. . .		. . .
User data 9	+/- $1.2 * 10^{-38}$ - +/- $3.4 * 10^{+38}$ and 0 (current input via MUI, as for geometry data)	REAL	any	28	X		X
Comment	up to any 5 x 76 characters		-		X	X	
Edge data	(per edge)						
Edge ID							
Edge orientation	0 - 8	USINT	-	01		X	X
Edge status	0/1 (16 status bits)	WORD	-	02			X
Tool life data							
Remaining tool life	0.0 - 100.00	REAL	%	03	X		X
Warning limit	0.1 - 100.00	REAL	%	04	X		X
max. tool life	0 - 9999999 (0: tool life measurement inactive)	REAL	min or cycles	05	X		X
Utilization time	0 - 9999.999	REAL	min or cycles	06	X	X	
Geometry data							
Length L1	-9999.9999 - +9999.9999 or -999.99999 - +999.99999	DINT	mm or inch	07			X
Length L2	-9999.9999 - +9999.9999 or -999.99999 - +999.99999	DINT	mm or inch	08			X
Length L3	-9999.9999 - +9999.9999 or -999.99999 - +999.99999	DINT	mm or inch	09			X
Radius R	-9999.9999 - +9999.9999 or -999.99999 - +999.99999	DINT	mm or inch	10			X
Wear L1	-9999.9999 - +9999.9999 or -999.99999 - +999.99999	DINT	mm or inch	11	X		X
Wear L2	-9999.9999 - +9999.9999 or -999.99999 - +999.99999	DINT	mm or inch	12	X		X
Wear L3	-9999.9999 - +9999.9999 or -999.99999 - +999.99999	DINT	mm or inch	13	X		X
Wear R	-9999.9999 - +9999.9999 or -999.99999 - +999.99999	DINT	mm or inch	14	X		X
Offset L1	-9999.9999 - +9999.9999 or -999.99999 - +999.99999	DINT	mm or inch	15	X		X
Offset L2	-9999.9999 - +9999.9999 or -999.99999 - +999.99999	DINT	mm or inch	16	X		X
Offset L3	-9999.9999 - +9999.9999 or -999.99999 - +999.99999	DINT	mm or inch	17	X		X
Offset R	-9999.9999 - +9999.9999 or -999.99999 - +999.99999	DINT	mm or inch	18	X		X
Geometry limits							
L1_min	-9999.9999 - +9999.9999 or -999.99999 - +999.99999	DINT	mm or inch	19	X	X	
L1_max	-9999.9999 - +9999.9999 or -999.99999 - +999.99999	DINT	mm or inch	20	X	X	
L2_min	-9999.9999 - +9999.9999 or -999.99999 - +999.99999	DINT	mm or inch	21	X	X	
L2_max	-9999.9999 - +9999.9999 or -999.99999 - +999.99999	DINT	mm or inch	22	X	X	
L3_min	-9999.9999 - +9999.9999 or -999.99999 - +999.99999	DINT	mm or inch	23	X	X	
L3_max	-9999.9999 - +9999.9999 or -999.99999 - +999.99999	DINT	mm or inch	24	X	X	
R_min	-9999.9999 - +9999.9999 or -999.99999 - +999.99999	DINT	mm or inch	25	X	X	
R_max	-9999.9999 - +9999.9999 or -999.99999 - +999.99999	DINT	mm or inch	26	X	X	
Wear factors							
Wear factor L1	-9999.9999 - +9999.9999 or -999.99999 - +999.99999	DINT	mm or inch/ min or cycles	27	X		X
Wear factor L2	-9999.9999 - +9999.9999 or -999.99999 - +999.99999	DINT	mm or inch/ min or cycles	28	X		X
Wear factor L3	-9999.9999 - +9999.9999 or -999.99999 - +999.99999	DINT	mm or inch/ min. or cycles	29	X		X
Wear factor R	-9999.9999 - +9999.9999 or -999.99999 - +999.99999	DINT	mm or inch/ min. or cycles	30	X		X

Legend **EL**: = setup-list-related data item **WL**: = tool-list-related data item

Tool Identification

Tool name (ID)

The tool name, which consists of up to 28 characters of any type, is used to uniquely identify each tool used. It is displayed within the controller system, both on the user interface as well as on the SOT (Station Operator Terminal).

Any tools which are used must be uniquely named so that they can be clearly identified. Tools which can replace on another (spare tools) are listed under a single tool name. An additional tool index number is then used to differentiate them.

The extended tool name allows each operation-specific tool identification system to be retained on the controller level.

Tool number

Within an NC-program, it is possible to access a tool or a location by using the T word, which is comprised of the initial address letter T and a tool number (up to 7 digits) or a location number (up to 3 digits). A programmed tool number causes the tool management system to determine the current location of the tool based on the tool number and name contained in the setup list and based on the tool name and location number contained in the active tool list. A tool can be accessed from the NC-program based on the correlation between the tool number (as used in the NC-program) and the tool (operation-specific tool ID) that is assigned in the setup list.

Correction type

The Correction Type establishes the number of corrections used on a tool and their orientations (see also Fig. 5-3).

Correction Type 1 (Drilling Tool)	**Correction Type 2 (Milling Tool)**	**Correction Type 3 (Turning Tool)**	**Correction Type 4 (Angle Attachment Tool)**
An Correction Type 1 tool has only 1 length correction (L3), and this correction is always perpendicular to the given machining plane.	An Correction Type 2 tool has—in addition to the length correction (L3), which is always perpendicular to the machining plane—a radius correction (R), which lies within the machining plane.	This type of tool has 2 length corrections (L1, L2) and a radius correction (R), which lies within the machining plane.	Tools of this type have a length correction (L1, L2, L3) in all three main axes (X, Y, Z) and a radius correction (R) in the current machining plane. The length L3 Is always perpendicular to the active machining plane; while lengths L1 and L2 always form the active machining plane.

The correction type of the corresponding tool in the storage must correspond to the type specified in the setup list so that it can be used for the intended machining operation.

If the letter N is entered as the correction type, the user interface will display the data for L1, L2, L3 and R in the following edge data corresponding to the settings in the system parameters. When the tool check is performed, only those geometry limits which are required for the Correction Type are taken from the setup list to check tool geometry.

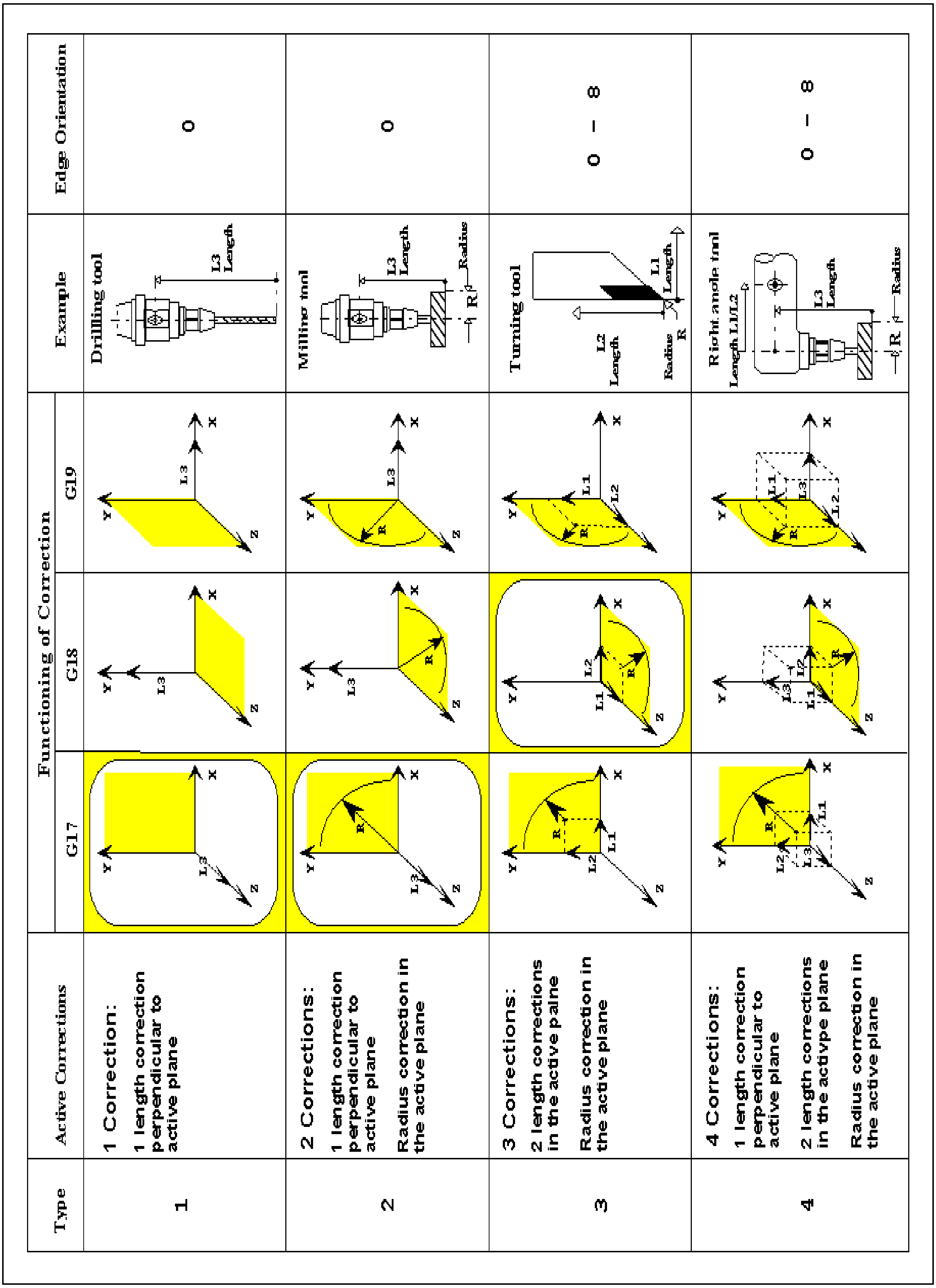


Fig. 5-3: Defining the correction type

Number of edges

Up to nine edge data sets can be assigned to each tool, even though the tool may not possess this many edges. In order to not waste memory, the maximum number of edges can be reduced to one edge per tool by setting the system parameter A00.54.

The number of edges specified in the setup list must be met by the given tool before it can be used for the intended machining operation.

Entering the letter *N* in the number of edges will cause the user interface to subsequently display the same number of edges as are defined in the maximum number of edges system parameter. When the tool check is performed, the only edge data sets in the setup list which will be used are the ones which are also present in the tool list.

Units

Time unit

- Minutes [min] or
- cycles [cycle]

can be used as the unit of duration.

All tool life data for the tool, for the spare tools (with the exception of the remaining tool life expressed as a percentage and the warning limit expressed as a percentage) are handled and updated in the unit of duration selected here.

Beginning with Version 4.14, the data field for the unit of time is fully present in the tool list and is no longer displayed in the setup list.

Unit of Length

All tool geometry data can be entered either in

- Millimeter [mm] or
- Inch [inch]

The unit of length in the setup list does not need to conform to that in the tool list since during the loading operation into the controller all the geometry data are converted to the basic programming unit which applies to the process.

User Data in the Setup List

Comment

A comment of up to 5 lines of 76 characters each can be supplied for each entry in the setup list, provided that this option is set in the system parameters.

By using this comment, any desired information can be provided for each group of companion tools—for example, assembly specifications and instructions.

Note: The comment is only shown on the PC.

Edge ID

Edge orientation

The edge orientation permits correction type 3 tools (turning tools) and type 4 tools (angle attachment tools) to be measured with respect to the theoretical edge point *P* without causing inaccuracies in subsequent machining.

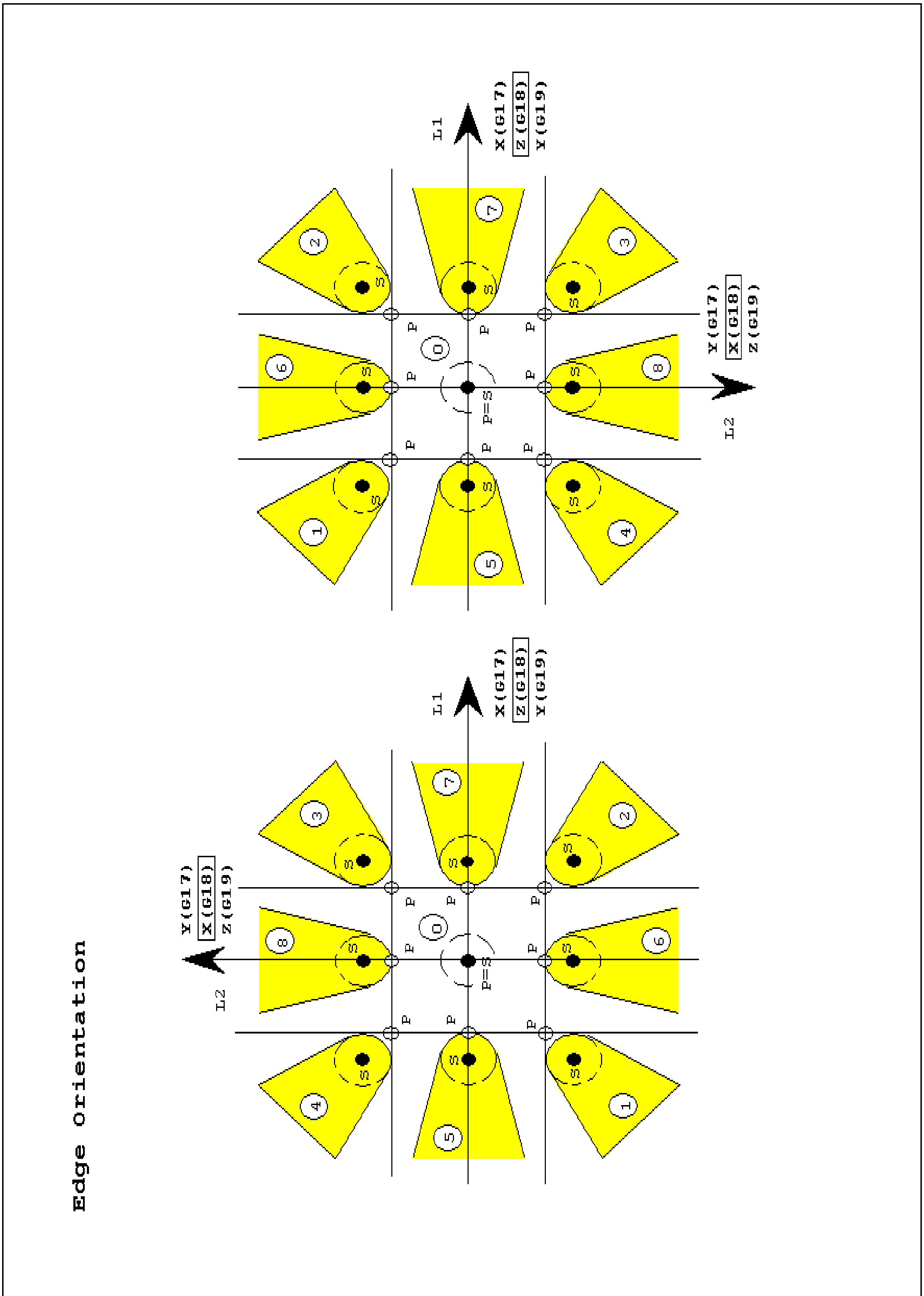


Fig. 5-4: Possible tool edge orientations

Tool life data

Maximum tool life

The maximum tool life is the machining time in

- minutes or
- cycles

which the tool can be used for to perform material-removal work from initial use until it becomes unusable under similar cutting conditions and for a given tool/material combination.

- Entering a value of 0 as the maximum tool life turns off tool life monitoring for the given tool.

Beginning with Version 4.14, the data field for the tool life is only present in the tool list and is no longer displayed in the setup list.

Tool life time

The tool life time is the time the tool was engaged in machining the given part. If needed, the tool life time can be used with user-specific SPS and CNC-programs to perform certain tests — for example to determine whether the current tool life of all tools present in the tool storage system will be adequate to manufacture a given lot size.

Geometry limits

The geometry limits allow the tools present in the storage system to be checked to see whether they can be used for the upcoming machining process.

The check of whether the length and radius of the respective tool will permit the planned machining operation is conducted during the automatic tool check when a NC-program is started. This prevents interruptions during machining. Aside from ensuring that suitable tools are ready for use, entering useful geometry limits in the program writing stage will prevent subsequent collisions.

- The geometry limits in the setup list are ignored in the Tool corrections.

Maximum and minimum lengths

- The maximum lengths:
  L1_max, L2_max and *L3_max*, and
- the minimum lengths:
  L1_min, *L2_min* and *L3_min*

specify the limits for the linear distance within which the intended machining operations can still be performed.

Maximum and minimum radius

- The maximum radius:
  R_max and
- the minimum radius:
  R_min

specify the tool radius limits within which the intended machining operations can still be performed.

Wear factors

Wear-induced tool length or tool radius changes can be compensated for by means of wear factors.

Beginning with Version 4.14, the data fields for the wear factors are only present in the tool list and are no longer displayed in the setup list.

Length wear factors (L1, L2 and L3)

Length wear compensation is activated when tool length correction is activated via G48 or G49. The compensation value used to adjust for tool length wear is calculated in the tool management system by multiplying the duration of tool machining time by the length wear factor. If the length wear factor is entered in mm/min or inch/min, the tool management system uses the total time in which the tool was active while working motion was being carried out (all moves with the exception of G00) as the machining time.

However, if the tool wear factor is entered in mm/cycle or inch/cycle, the tool management system uses one cycle as the machining time. Thus, the compensation value for tool length corresponds to the tool wear factor.

The tool management system automatically updates the machining time and, thus, the compensation value for length wear.

- upon a transition to a different edge
- when an edge is called again
- when the tool is placed back in the magazine (tool storage = magazine)
- when the tool is rotated out of the machining position (tool storage = turret)
- when a tool is canceled using TO (tool storage = turret or no tool storage present).

Radius wear factor (R)

Radius wear compensation is activated when tool path compensation is activated via G41 or G42. The compensation value used to adjust for tool radius wear is calculated in the tool management system by multiplying the duration of tool machining time by the radius wear factor. If the radius wear factor is entered in mm/min or inch/min, the tool management system uses the total time in which the tool was active while working motion was being carried out (all moves with the exception of G00) as the machining time.

However, if the radius wear factor is entered in mm/cycle or inch/cycle, the tool management system uses one cycle as the machining time. Thus, the compensation value for tool radius corresponds to the radius wear factor.

The tool management system automatically updates the machining time and, thus, the compensation value for radius wear.

- upon a transition to a different edge
- when an edge is called again
- when the tool is placed back in the magazine (tool storage = magazine)
- when the tool is rotated out of the machining position (tool storage = turret)
- when a tool is canceled using TO (tool storage = turret or no tool storage present).

5.3 Tool Lists

Purpose of the Tool List

Tool lists are used exclusively to prepare and save tool data. They can be created, modified and saved with the aid of the PC user interface while machining is taking place. This allows the user to prepare tool storage configurations for upcoming work.

In this way, the time to install new tools in the tool storage system can be kept to a minimum. The operator loads the tool lists prepared in this manner into the controller and equips the tool magazine to match the tool list. As soon as machining starts, the tool list which is still present on the PC is ignored and the tool list that is currently located in the CNC reflects the current status of the tools in the magazine.

In addition to the basic tool data, the tool list contains the data needed for the edges (edge number, geometry, life data and user-defined data) for all tools which have been entered.

- Changes which relate to the current tool configuration, such as the insertion, removal or change of a tool or changes in the tool data, should be made directly in the active tool data.

Data in the Tool List

A tool list is comprised of all the entries for the tools which are present in the magazine.

The available value ranges for the individual data in the tool list as well as the units in which they may be expressed are shown in the table on the next page.

NAME	RANGE	DATA TYPE	UNIT	DATA ELEMENT	OPTION	EL	WL
Base tool data	(per tool)						
Tool ID							
Index address	hexadecimal long word with 32 Bits (read only)		-	01			
ID (tool name)	up to any 28 characters	STRING28	-	02		X	X
Storage	0 - 2 (0: magazine/turret, 1: spindle, 2: gripper)		-	03			X
Location	0 - 999		-	04			X
Tool number	1 - 9999999	DINT	-	05		X	**X**
Index number	1 - 999	INT		06			X
Correction type	1 - 4	USINT	-	07		X	X
Number of edges	1 - 9	USINT	-	08		X	X
Tool status	0/1 (32 status bits)		-	09			X
Location data							
free half-locations	0 - 4	USINT	-	10			X
old location	1 - 999	INT	-	11			X
Storage of next tool	0 - 2 (0: magazine/turret, 1: spindle, 2: gripper)	INT	-	12			
Location of next tool	1 - 999	INT	-	13			
Storage of prev. tool	0 - 2 (0: magazine/turret, 1: spindle, 2: gripper)	INT	-	14			
Location of prev. tool	1 -999	INT	-	15			
Units							
Time unit	0/1 (0: min, 1: cycle.)	USINT	-	16			X
Length unit	0/1 (0: mm, 1: inch)	USINT	-	17			X
Technology data							
Tool code	1 - 9	USINT	-	18		X	X
Representation type	0 - 999	INT	-	19		X	X
User data							
User data 1	+/- 1.2 * 10^{-38} - +/- 3.4 * 10^{+38} and 0 (current input via MUI, as for geometry data)	REAL	any	20	X		X
. . .	. . .	. . .	. . .	. . .	. . .		. . .
User data 9	+/- 1.2 * 10^{-38} - +/- 3.4 * 10^{+38} and 0 (current input via MUI, as for geometry data)	REAL	any	28	**X**		X
Comment	up to any 5 x 76 characters		**-**		**X**	X	
Edge data	(per edge)						
Edge ID							
Edge orientation	0 - 8	USINT	-	01		X	X
Edge status	0/1 (16 status bits)	WORD	-	02			X
Tool life data							
Remaining tool life	0.0 - 100.00	REAL	%	03	X		X
Warning limit	0.1 - 100.00	REAL	%	04	X		X
max. tool life	0 - 9999999 (0: tool life measurement inactive)	REAL	min or cycles	05	X		X
Utilization time	0 - 9999.999	REAL	min or cycles	06	X	X	
Geometry data							
Length L1	-9999.9999 - +9999.9999 or -999.99999 - +999.99999	DINT	mm or inch	07			X
Length L2	-9999.9999 - +9999.9999 or -999.99999 - +999.99999	DINT	mm or inch	08			X
Length L3	-9999.9999 - +9999.9999 or -999.99999 - +999.99999	DINT	mm or inch	09			X
Radius R	-9999.9999 - +9999.9999 or -999.99999 - +999.99999	DINT	mm or inch	10			X
Wear L1	-9999.9999 - +9999.9999 or -999.99999 - +999.99999	DINT	mm or inch	11	X		X
Wear L2	-9999.9999 - +9999.9999 or -999.99999 - +999.99999	DINT	mm or inch	12	X		X
Wear L3	-9999.9999 - +9999.9999 or -999.99999 - +999.99999	DINT	mm or inch	13	X		X
Wear R	-9999.9999 - +9999.9999 or -999.99999 - +999.99999	DINT	mm or inch	14	X		X
Offset L1	-9999.9999 - +9999.9999 or -999.99999 - +999.99999	DINT	mm or inch	15	X		X
Offset L2	-9999.9999 - +9999.9999 or -999.99999 - +999.99999	DINT	mm or inch	16	X		X
Offset L3	-9999.9999 - +9999.9999 or -999.99999 - +999.99999	DINT	mm or inch	17	X		X
Offset R	-9999.9999 - +9999.9999 or -999.99999 - +999.99999	DINT	mm or inch	18	X		X
Geometry limits							
L1_min	-9999.9999 - +9999.9999 or -999.99999 - +999.99999	DINT	mm or inch	19	X	X	
L1_max	-9999.9999 - +9999.9999 or -999.99999 - +999.99999	DINT	mm or inch	20	X	X	
L2_min	-9999.9999 - +9999.9999 or -999.99999 - +999.99999	DINT	mm or inch	21	X	X	
L2_max	-9999.9999 - +9999.9999 or -999.99999 - +999.99999	DINT	mm or inch	22	X	X	
L3_min	-9999.9999 - +9999.9999 or -999.99999 - +999.99999	DINT	mm or inch	23	X	X	
L3_max	-9999.9999 - +9999.9999 or -999.99999 - +999.99999	DINT	mm or inch	24	X	X	
R_min	-9999.9999 - +9999.9999 or -999.99999 - +999.99999	DINT	mm or inch	25	X	X	
R_max	-9999.9999 - +9999.9999 or -999.99999 - +999.99999	DINT	mm or inch	26	X	X	
Wear factors							
Wear factor L1	-9999.9999 - +9999.9999 or -999.99999 - +999.99999	DINT	mm or inch/ min or cycles	27	X		X
Wear factor L2	-9999.9999 - +9999.9999 or -999.99999 - +999.99999	DINT	mm or inch/ min or cycles	28	X		X
Wear factor L3	-9999.9999 - +9999.9999 or -999.99999 - +999.99999	DINT	mm or inch/ min. or cycles	29	X		X
Wear factor R	-9999.9999 - +9999.9999 or -999.99999 - +999.99999	DINT	mm or inch/ min. or cycles	30	X		X
User data							
User data 1	+/- 1.2 * 10^{-38} - +/- 3.4 * 10^{+38} and 0 (current input via MUI, as for geometry data)	REAL	any	31	X		X
. . .	. . .	. . .	. . .	. . .	. . .		. . .
User data 5	+/- 1.2 * 10^{-38} - +/- 3.4 * 10^{+38} and 0 (current input via MUI, as for geometry data)	REAL	any	35	X		X
User data 6	-9999.9999 - +9999.9999 or -999.99999 - +999.99999	DINT	any	36	X		X
. . .	. . .	. . .	. . .	. . .	. . .		. . .
User data 10	-9999.9999 - +9999.9999 or -999.99999 - +999.99999	DINT	any	40	X		X

Legend **EL**: = setup-list-related data item **WL**: = tool-list-related data item

Tool Identification

Tool name (ID)

The tool name (ID), which consists of up to 28 characters of any type, is used to uniquely identify each tool used. It is displayed within the controller system, both on the user interface as well as on the SOT (Station Operator Terminal).

Any tools which are used must be uniquely named so that they can be clearly identified. Tools which can replace one another (spare tools) are listed under a single tool name (ID). An additional tool index number (see section below) is then used to differentiate such tools.

The extended tool name (ID) allows each operation-specific tool identification system to be retained on the controller level.

Storage

The storage datum does not appear directly in the tool list since the tool list only includes the spindles in addition to the tool storage system (storage = 0). The spindles are indicated by an Sx (x = 1..4) placed in front of the location number in the tool list.

Location

The location datum defines the tool storage location in the tool storage system; and, with spindles, it defines the spindle on which the tool is located. All tool storage locations as well as all spindles which are present can be configured with data using the tool list.

CAUTION

After a tool list has been loaded into the controller, it is important to make certain that the tools actually located in the magazine match those in the tool list. If a tool magazine is incorrectly loaded, the workpiece and the machine itself may be damaged.

Tool number

Within an NC-program, it is possible to access a tool or a location by using the T word, which is comprised of the initial address letter T and a tool number (up to 7 digits) or a location number (up to 3 digits). A programmed tool number causes the tool management system to determine the current location of the tool based on the tool number contained in the active tool list.

NOTE

Effective Version 4.14, the data element of the tool number is contained in the setup list and in the tool list. If automatic tool checking is set, the tool numbers in the setup list take precedence and overwrite any assignments which may be present in the tool list.

Tool index number

The tool index number is used:

- to uniquely identify spare tools (tools which have the same tool name (ID) and the same T-number)
- and to specify the order in which spare tool will be used in machining work.

Spare tools are used based on their tool index number; spare tools which have a low index number are given preference over tools which have a higher index number if they are not completely worn or locked.

Spare tools are addressed from the NC-program using the same T-number.

The controller does not change to a new spare tool until the same T-number is called again and the previously used tool (i.e. a tool having the same tool number and name (ID) and the next lower index number) is worn or locked.

Correction type

The Correction Type establishes the number of corrections used on a tool and their orientation (see Fig. 5-5).

Correction Type 1 (Drilling Tool)	Correction Type 2 (Milling Tool)	Correction Type 3 (Turning Tool)	Correction Type 4 (Angle Attachment Tool)
An Correction Type 1 tool has only 1 length correction (L3), and this correction is always perpendicular to the given machining plane.	An Correction Type 2 tool has—in addition to the length correction (L3), which is always perpendicular to the machining plane—a radius correction (R), which lies within the machining plane.	This type of tool has 2 length corrections (L1, L2) and a radius correction (R), which lies within the machining plane.	Tools of this type have a length correction (L1, L2, L3) in all three main axes (X, Y, Z) and a radius correction (R) in the current machining plane. The length L3 Is always perpendicular to the active machining plane; while lengths L1 and L2 always form the active machining plane.

The correction type of the corresponding tool in the storage must correspond to the type specified in the setup list so that it can be used for the intended machining operation.

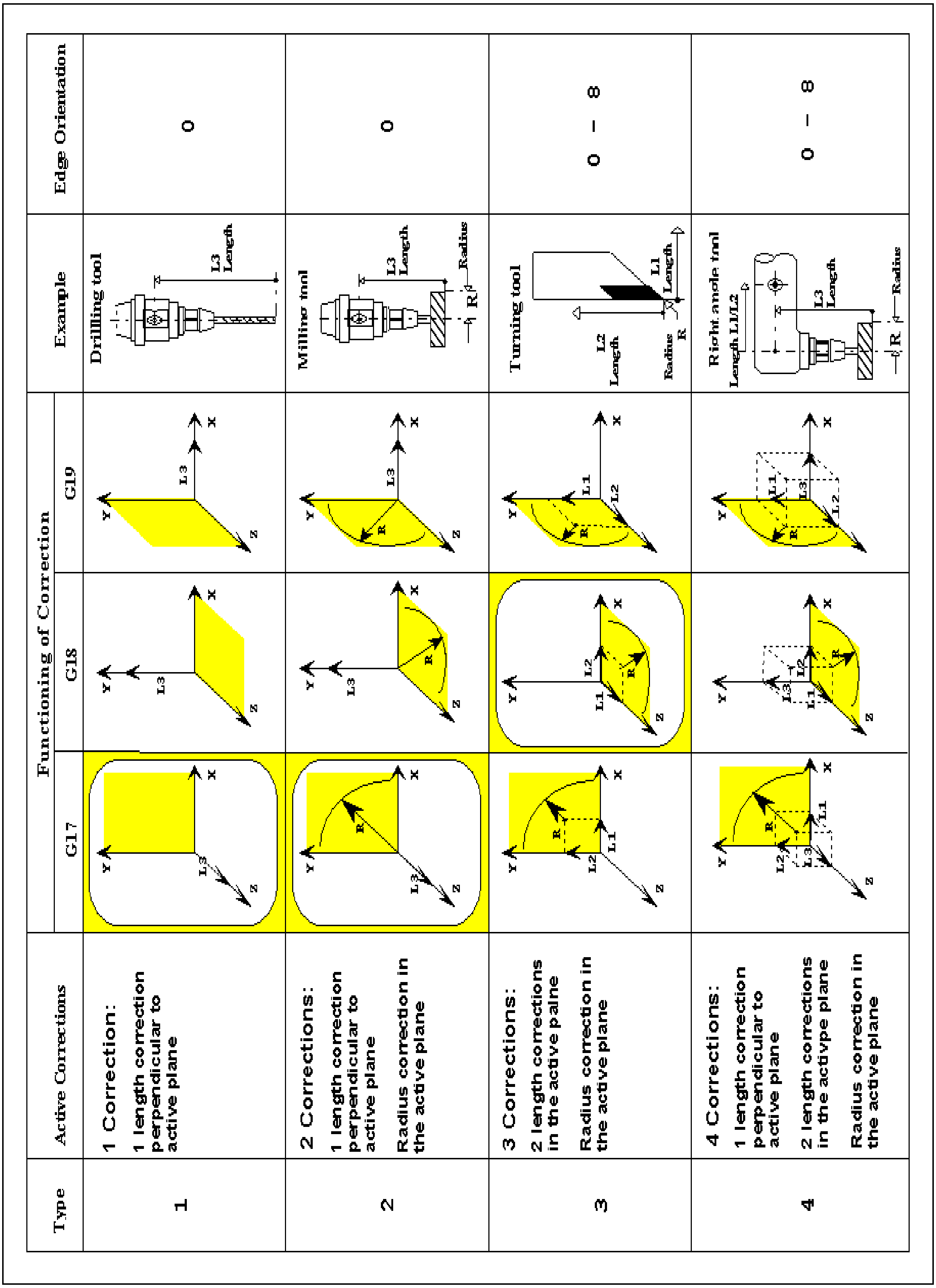


Fig. 5-5: Defining the Correction Type

Number of edges

Up to nine edge data sets can be assigned to each tool, even though the tool may not possess this many edges. In order to not waste memory, the maximum number of edges can be reduced to one edge per tool by setting the appropriate parameter in the system parameters.

The number of edges specified in the setup list must be met by the given tool in the tool storage system before it can be used for the intended machining operation.

Tool status

The tool status bits provide information on the status of the tool location and the status of the tool if one is present in the tool location. The following table shows the tool status bits used in the tool list.

Group	Status Bits	Symbol	Remark
Location lock	Location locked	L	in preparation
	Upper half location for fixed location-coded tool is locked		in preparation
	Lower half location for fixed location-coded tool is locked		in preparation
Location reserve	Upper half location is reserved		in preparation
	Lower half location is reserved		in preparation
Location in use	Upper half location is covered		in preparation
	Lower half location is covered		in preparation
	Location in use		Value auto-updated
Wear status	Tool worn	d	Value cannot be changed
	Warning limit reached	w	Value cannot be changed
Spare tool identification	Machining tool	p	Value cannot be changed
	Spare tool	s	Value cannot be changed
Fixed-location coding	Fixed-location-coded tool	C	in preparation
Tool status	Tool locked	L	Value can be changed
User tool status 1	User tool status bit 1	as desired	Value can be changed
User tool status 2	User tool status bit 2	as desired	Value can be changed
User tool status 3	User tool status bit 3	as desired	Value can be changed
User tool status 4	User tool status bit 4	as desired	Value can be changed
User tool status 5	User tool status bit 5	as desired	Value can be changed
User tool status 6	User tool status bit 6	as desired	Value can be changed
User tool status 7	User tool status bit 7	as desired	Value can be changed
User tool status 8	User tool status bit 8	as desired	Value can be changed

The operator can lock or unlock tools using the tool locked status bit in the tool list. In addition, up to eight application-specific status bits can be assigned to the basic tool data of each tool. Preset them in the tool list.

The remaining tool-specific status bits such as:

- tool done (worn out) (d)
- warning limit reached (w)
- tool used as primary tool (p) and
- spare tool (s)

cannot be changed in the tool list. The only status bits which can be reset via a reset function are „tool done“ and „warning limit reached" (see description of user interface "Tool Data Management").

Location data

Free half locations

Overly wide tools are identified by the datum free half locations:

0: This is a normal width tool which does not required any additional location beyond the actual location.

1: The tool overlaps an additional half location to the right and left of the actual location.

2: The tool overlaps two additional half locations to the right and left of the actual location.

3: The tool overlaps three additional half locations to the right and left of the actual location.

4: The tool overlaps four additional half locations to the right and left of the actual location.

The overlapped half locations are indicated by dashed lines on the user interface of the PC and SOT.

Old location

The old location data is not declared in the tool list. However, it is included in the data set so the fixed location for fixed-location-coded tools located in a spindle can be saved with the other data.

Units

Time unit

- Minutes [min] or
- cycles [cycle]

can be used as the unit of time.

All tool life data for the tool for the spare tools (with the exception of the remaining tool life expressed as a percentage and the warning limit expressed as a percentage) are handled and updated in the unit of duration selected here.

Beginning with Version 4.14, the data field for the unit of duration fully present in the tool list and is no longer displayed in the setup list.

Unit of length

All tool geometry data can be entered either in

- millimeter [mm] or
- inch [inch]

The unit of length in the setup list does not need to conform to that in the tool list since during the loading operation into the controller all the geometry data are converted to the basic programming unit which applies to the process.

Tool user data

Tool user data 1-9

The tool user data 1–9 in the basic tool data allow any desired user-specific data to be included for the tool. When the desired name is entered in the system parameters, the user data are placed in the tool data set and tool list and are displayed in the current tool list (see also Description of Parameters). The user data, as well as the other data, can be prepared in the tool list.

Typical example of user data in the basic tool data are:

- Weight of the tool (affects how fast the tool change is made)
- Maximum tool rpm
- Maximum tool dimensions (for collision tests)

Edge ID

Edge orientation

The edge orientation permits correction-type-3 tools (turning tools) and type-4 tools (angle attachment tools) to be measured with respect to the theoretical edge point P without causing inaccuracies in subsequent machining.

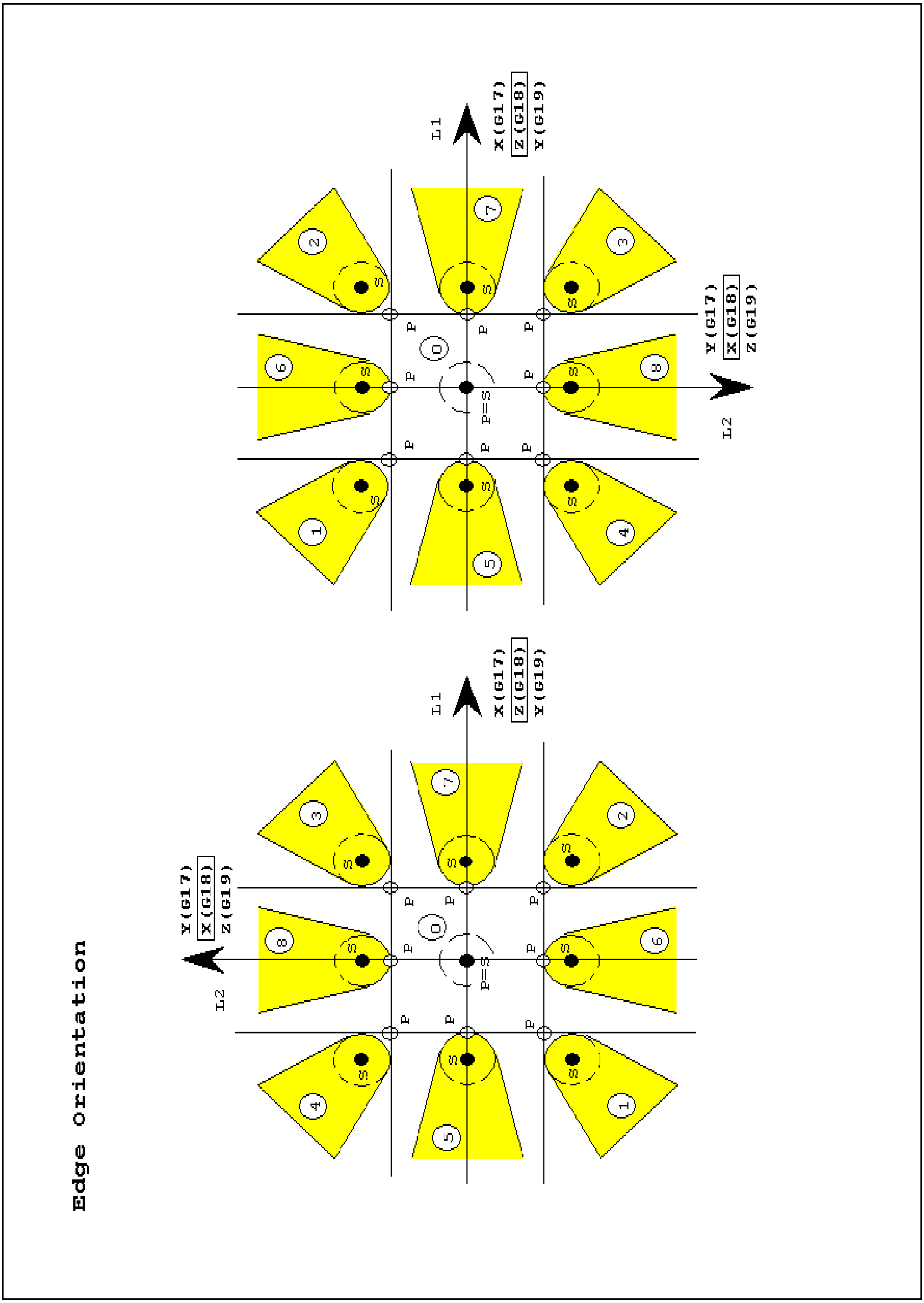


Fig. 5-6: Possible tool edge positions

Edge status

The edge status bits provide information on the status of a given edge. The following table shows the edge status bits used in the tool list.

Group	Status Bits	Symbol	Remark
Wear status	Edge done	d	Value cannot be changed
	Warning limit reached	w	Value cannot be changed
User edge status 1	User edge status bit 1	as desired	Value can be changed
User edge status 2	User edge status bit 2	as desired	Value can be changed
User edge status 3	User edge status bit 3	as desired	Value can be changed
User edge status 4	User edge status bit 4	as desired	Value can be changed

Up to four different user-specific status bits can be assigned to each edge. They can be preset in the tool list.

The two edge status bits:

- „Edge done" (d) and
- „warning limit reached" (w)

cannot be modified directly in the tool list. However, they can be reset with the aid of a reset function (see Tool Data Management) in the description of the user interface.

Tool life data

Remaining tool life in percent

The remaining tool life in percent indicates the wear condition of a tool without taking the tool/workpiece material combination or process data into account.

$$\textit{remaining tool life [\%]} = \frac{\textit{remaining tool life [min] or [cycles]}}{\textit{maximum tool life [min] or [cycles]}} * 100\ [\%]$$

A new or reground tool has a remaining tool life in percent of 100%, while a completely worn tool has a remaining tool life in percent of 0%. The tool management system manages and monitors the wear status of the tools based on the remaining tool life in percent and ignoring the tool/workpiece material combinations of the current machining operations.

The remaining tool life in percent is updated:

- during the automatic tool check
- upon a transition to a different edge
- when an edge is called again
- when the tool is placed back in the magazine (tool storage = magazine) or
- when the tool is rotated out of the machining position (tool storage = turret)
- when a tool is canceled using TO (tool storage = turret or no tool storage present).

The remaining tool life in percent is calculated using the following calculation specifications:

$$\textit{\% rem. tool life}_{after} = \textit{\% rem. tool life}_{before} - \frac{\textit{utilization time [min] or [cycles]}}{\textit{max. tool life [min] or [cycles]}} * 100\ \%$$

At the time of each update the tool management system checks the remaining tool life and sets the interface signal 'PxxS.MGTWO' for the SPS if the remaining tool life of a tool indicates that the tool is fully worn and that a useable spare tool is not present.

Warning limit in percent

The warning limit in percent defines the remaining tool life percent value at which the status warming „limit reached“ will be displayed.

At the time of each update the tool management system checks the remaining tool life and sets the interface signal 'PxxS.MGWRN' for the SPS if the remaining tool life of a tool has reached the warning limit and if a useable spare tool is not present.

Maximum tool life

The maximum tool life is the machining time in

- minutes or
- cycles

which the tool can be used for to perform material-removal work from initial use until it becomes unusable under similar cutting conditions and for a given tool/stock pair.

NOTE

Entering a value of 0 as the maximum tool life turns off tool life monitoring for the given tool.

Note: Beginning with Version 4.14, the data field for the tool life is only present in the tool list and is no longer displayed in the setup list.

Geometry data

If a correction function is active, the tool dimensions are automatically compensated with the aid of the geometry data.

The geometry data is organized as follows:

Geometry	Wear	Offset
Length L1	Wear L1	Offset L1
Length L2	Wear L2	Offset L2
Length L3	Wear L3	Offset L3
Radius R	Wear R	Offset R

The wear and offset registers can be selected as options by means of the system parameters.

The geometry registers serve as program-independent memories that are used to add corrections to the tool dimensions.

The wear registers are used by the CNC to compensate for tool wear at any given time based on the wear factors.

To accomplish this, the CNC calculates the wear at the given time at then adds it to the values which are already present in the wear registers. If the wear factors are not selected in the system parameters or if they are set to zero in the data sets, the wear registers are available exclusively to the user.

The wear registers can be changed by the reset function. The reset function changes the remaining tool life in percent to 100% and also clears all the wear registers belonging to the tool.

The offset registers are not affected by the CNC. Like the wear registers, they can be used to compensate for dimensional changes which are determined by the user or by a dimensional control system. However, they can also be used as memory areas for additional offsets, for example to compensate for adapter dimensions.

Length corrections (L1, L2, L3)

The length corrections L1, L2, L3 of a tool edge are calculated as follows:

$$\textit{Length corretions } L1 = \textit{length } L1 + \textit{wear } L1 + \textit{offset } L1$$
$$\textit{Length corretions } L2 = \textit{length } L2 + \textit{wear } L2 + \textit{offset } L2$$
$$\textit{Length corretions } L3 = \textit{length } L3 + \textit{wear } L3 + \textit{offset } L3$$

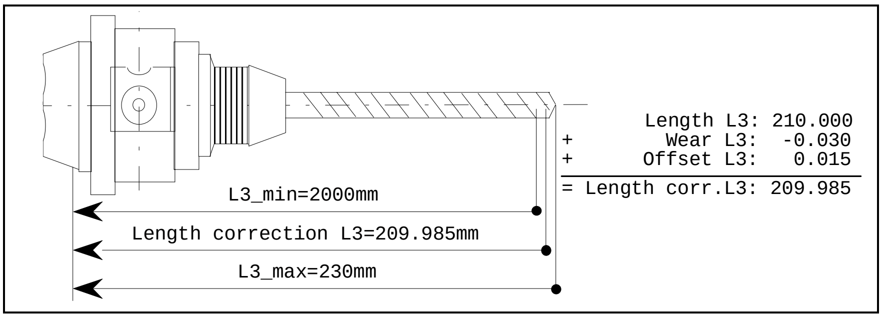


Fig. 5-7: Length correction L3 using a drill bit as an example

The geometry data which apply to the tool with the selected correction type are displayed on the PC and SOT user interfaces and are used in the calculations in the controller

Radius correction (R)

The radius correction *R* of a tool edge is calculated as follows:

$$\textit{Radius correction } R = \textit{radius } R + \textit{wear } R + \textit{offset } R$$

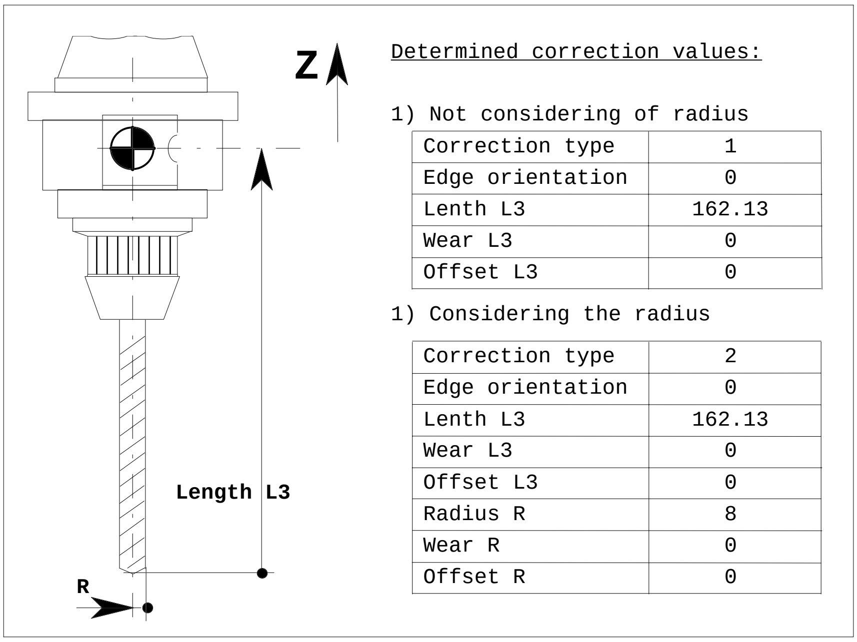
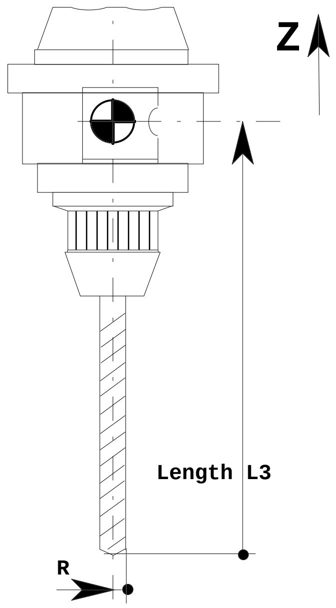


Fig. 5-8: Radius correction R using a roughing cutter as an example

Examples For tool measurement



Determined correction values:

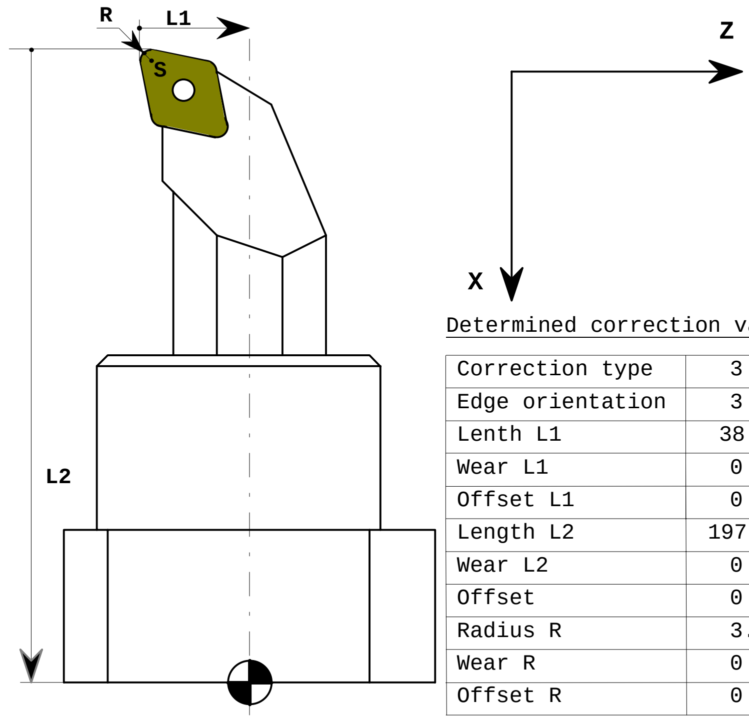
1) Not considering of radius

Correction type	1
Edge orientation	0
Lenth L3	162.13
Wear L3	0
Offset L3	0

1) Considering the radius

Correction type	2
Edge orientation	0
Lenth L3	162.13
Wear L3	0
Offset L3	0
Radius R	8
Wear R	0
Offset R	0

Abb. 5-9: Example: measuring a turning tool



Determined correction values:

Correction type	3
Edge orientation	3
Lenth L1	38.322
Wear L1	0
Offset L1	0
Length L2	197.827
Wear L2	0
Offset	0
Radius R	3.2
Wear R	0
Offset R	0

Abb. 5-10: Example: measuring a drilling tool

Wear factors

Wear-induced tool length or tool radius changes can be compensated for by means of wear factors.

Beginning with Version 4.14, the data fields for the wear factors are only present in the tool list and are no longer displayed in the setup list.

Length wear factors (L1, L2 and L3)

Length wear compensation is activated when tool length correction is activated via G48 or G49. The compensation value used to adjust for tool length wear is calculated in the tool management system by multiplying the duration of tool machining time by the length wear factor. If the length wear factor is entered in mm/min or inch/min, the tool management system uses the total time in which the tool was active while working motion was being carried out (all moves with the exception of G00) as the machining time.

However, if the tool wear factor is entered in mm/cycle or inch/cycle, the tool management system uses one cycle as the machining time. Thus, the compensation value for tool length corresponds to the tool wear factor.

The tool management system automatically updates the machining time and, thus, the compensation value for length wear.

- upon a transition to a different edge
- when an edge is called again
- when the tool is placed back in the magazine (tool storage = magazine)
- when the tool is rotated out of the machining position (tool storage = turret)
- when a tool is canceled using TO (tool storage = turret or no tool storage present).

Radius wear factor (R)

Radius wear compensation is activated when tool path compensation is activated via G41 or G42. The compensation value used to adjust for tool radius wear is calculated in the tool management system by multiplying the duration of tool machining time by the radius wear factor. If the radius wear factor is entered in mm/min or inch/min, the tool management system uses the total time in which the tool was active while working motion was being carried out (all moves with the exception of G00) as the machining time.
However, if the radius wear factor is entered in mm/cycle or inch/cycle, the tool management system uses one cycle as the machining time. Thus, the compensation value for tool radius corresponds to the radius wear factor.
The tool management system automatically updates the machining time and, thus, the compensation value for radius wear.

- upon a transition to a different edge
- when an edge is called again
- when the tool is placed back in the magazine (tool storage = magazine)
- when the tool is rotated out of the machining position (tool storage = turret)
- when a tool is canceled using TO (tool storage = turret or no tool storage present).

User data for edges

User Data 1–5 for edges

User data 1–5 in the basic tool data allow any desired user-specific data to be included for each edge.
When the desired name is entered in the system parameters, the user data are placed in each edge set and tool list and are displayed in the active tool list (see also Description of Parameters).
The user data, as well as the other data, can be prepared in the tool list.

Typical example of user data in the edge data are:

- Surface speed
- Feed per tooth
- Spindle speed
- Machining feedrate
- Temporary measurement buffer
- Average value
- Empirical value

User data 6-10 for edges

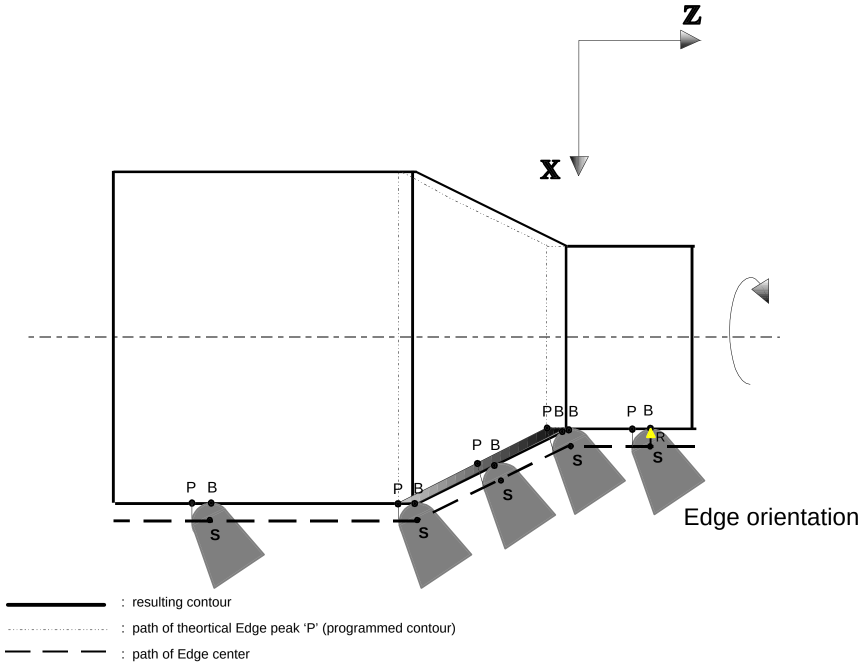
The user data 6-10 for edges enable the machine manufacturer to define additional data elements in the tool data record by specifying a corresponding designation. Numbers with up to 8 significant digits (32-bit values without exponent) can be stored in the user data 6-10 for edges (of the DINT type with 32-bit values without exponent).

5.4 Tool Path Compensation

Inactive Tool Path Compensation

If no edge radius/cutter radius path compensation is active, the theoretical edge tip *P* is used as the reference point for the controller. The theoretical edge tip *P* will always move on the programmed contour in this case.

However, this will lead to errors if the movements are not parallel to the axes.



P theoretical edge tip
S edge center
B actual touch point

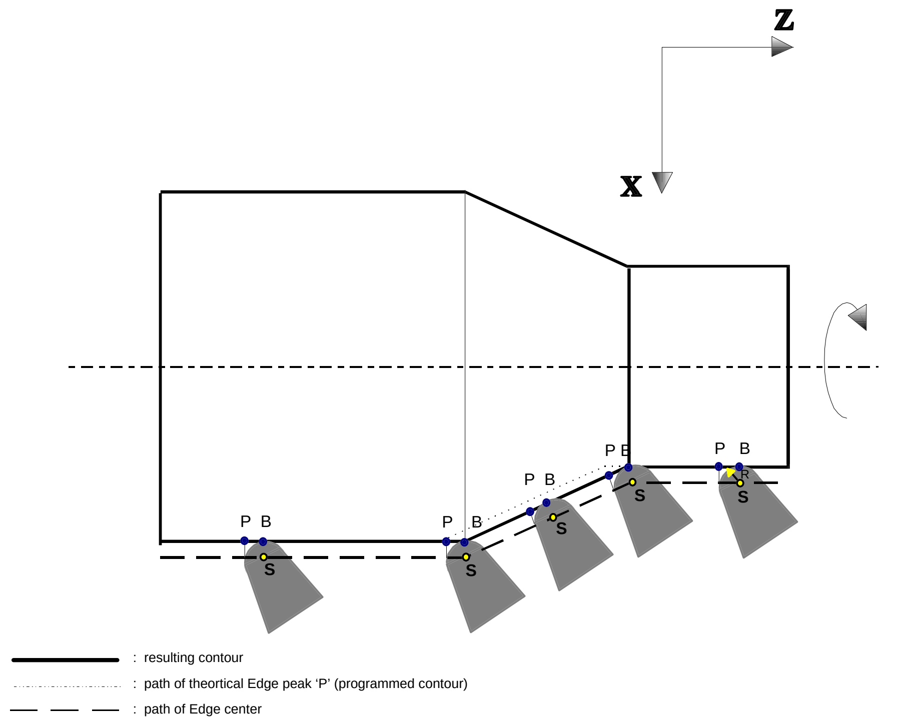
Fig. 5-11: Errors which will result if machining is performed without using tool edge radius path compensation

The shaded area in the drawing will not be removed since the controller is using the theoretical edge tip P as its point of reference.

If edge radius / cutter radius path compensation is on, the CNC automatically places the actual point of contact B on the programmed contour. Thus, the resulting contour is identical to the programmed contour.

Active Tool Path Compensation

If edge radius / cutter radius path compensation is active (G41/G42), the CNC automatically calculates the length corrections which are active in the working plane with respect to the center point of the edge S by adding/subtracting the correct radius to/from the theoretical edge tip based on the current position of the cutting edge.



P theoretical edge tip
S edge center
B actual touch point

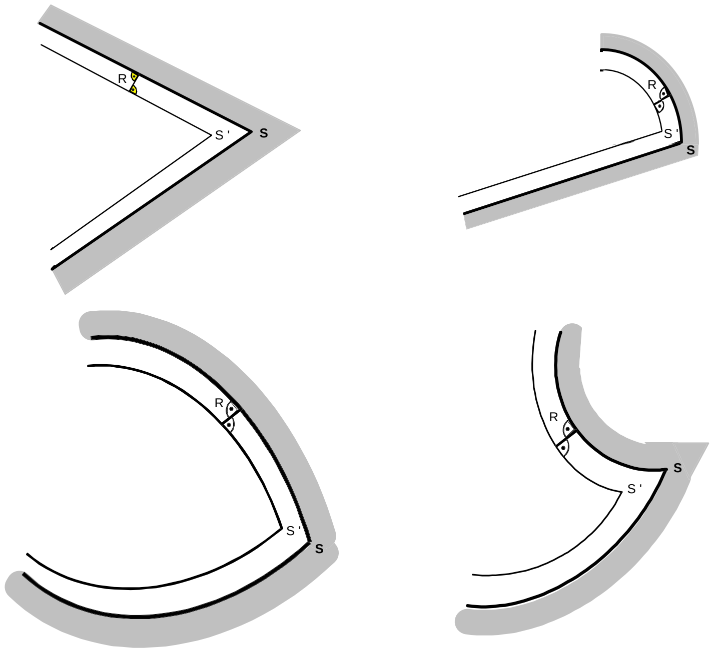
Fig. 5-12: Error-free machining with tool edge radius path compensation active.

With tool path compensation active the center point of the tool travels along a path which is parallel to the programmed contour and is offset by the tool radius.

Contour Transitions

Inside corners

With inside corners, the corrected NC-block transition point is based on the point at which the lines parallel to the contours intersect.



R theoretical edge tip
S edge center
S ' actual touch point

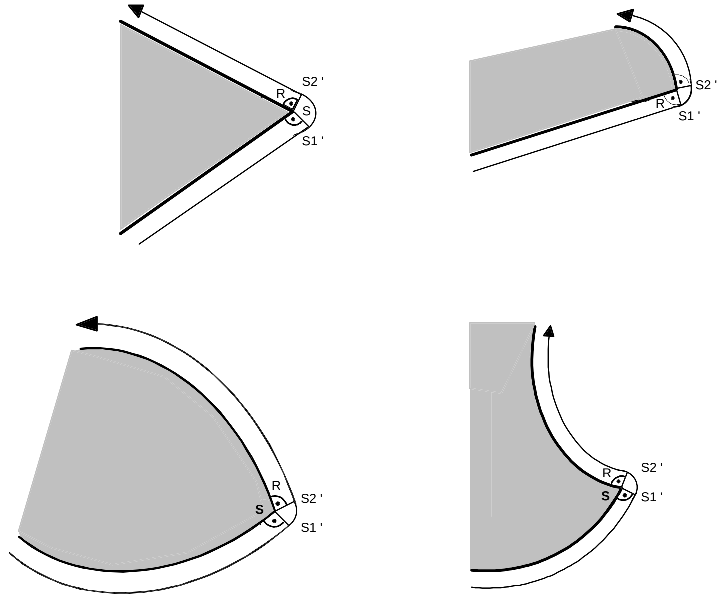
Fig. 5-13: Inside corners

Outside corners

The tool center point must travel around outside corners so that they are not damaged.

Two methods can be used to accomplish this:

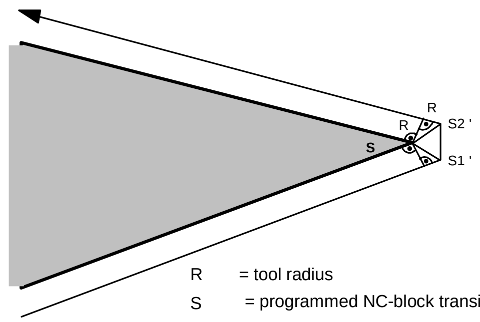
1. Insertion of an arc as the transition element by using NC-command G43, and
2. Insertion of a chamfer as the transition element by using NC-command G44. A chamfer cannot be inserted unless the transition is straight line ↔ straight line. A chamfer is used as the transition element when the transition angle between the two straight lines is greater than 90°. If the transition angle is less than 90°, the NC-block transition point is recalculated based on the intersection point of the lines parallel to the contour.



R	tool radius
S	programmed NC-block transition point
S1 '	corrected NC-block transition point 1
S2 '	corrected NC-block transition point 2

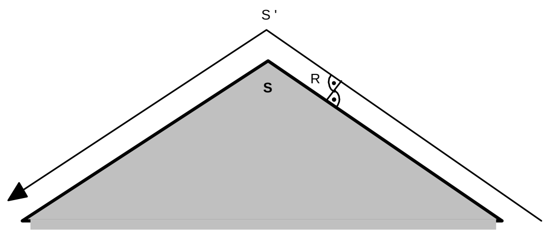
Fig. 5-14: Arc as contour transition using G43

Transition Angle > 90°



R	= tool radius
S	= programmed NC-block transition point
S1 '	= corrected NC-block transition point 1
S2 '	= corrected NC-block transition point 2

Transition Angle Less Than or Equal to 90°



R	= tool radius
S	= programmed NC-block transition point
S '	= corrected NC-block transition point

Fig. 5-15: Chamfer as contour transition and corrected NC-block transition point

When arcs or chamfers are inserted as contour transitions, the CNC automatically generates an additional transition NC-block. This NC-block is considered to be an independent NC-block, and as such it must be started separately in single-block processing mode.

CAUTION

With lookahead calculation of the corrected tool center point path, only the transition angle relative to the contour element of the following motion NC-block is used in the calculation and not the length of the contour element. The cases indicated in Fig. 5-16 are not recognized.

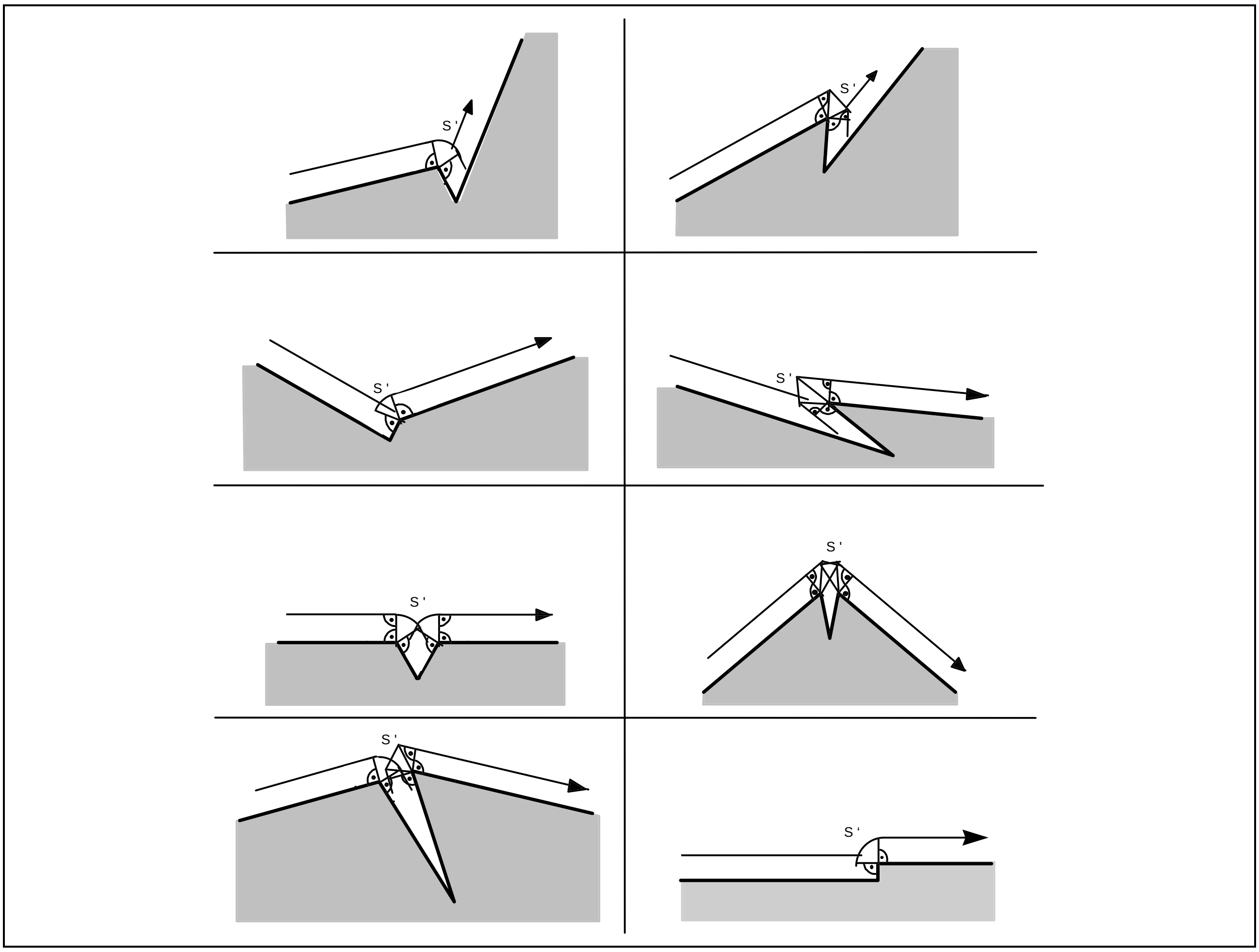


Fig. 5-16: Limitations with contour transition elements

The contour elements which are represented as straight lines can, of course, be replaced by arcs. Any overlaps with elements other than the next contour element are ignored.

With concave arcs (Fig. 5-17), the case shown here is recognized and program execution is terminated and an error message is generated.

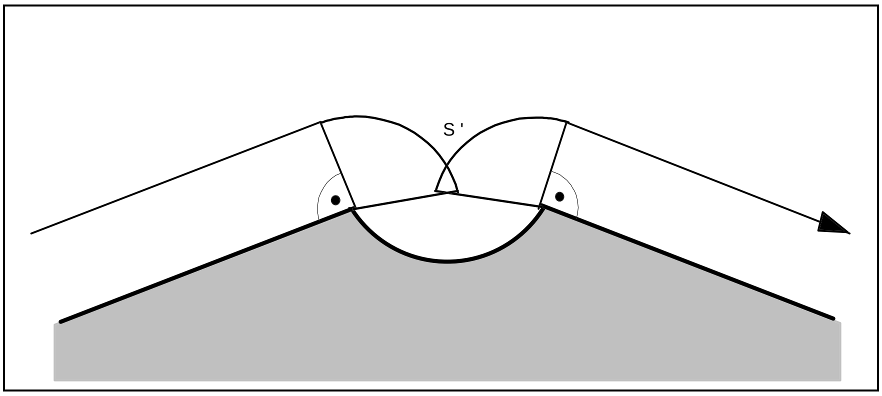


Fig. 5-17: Concave arc 1 element

The case shown below results in contour violations with concave arcs.

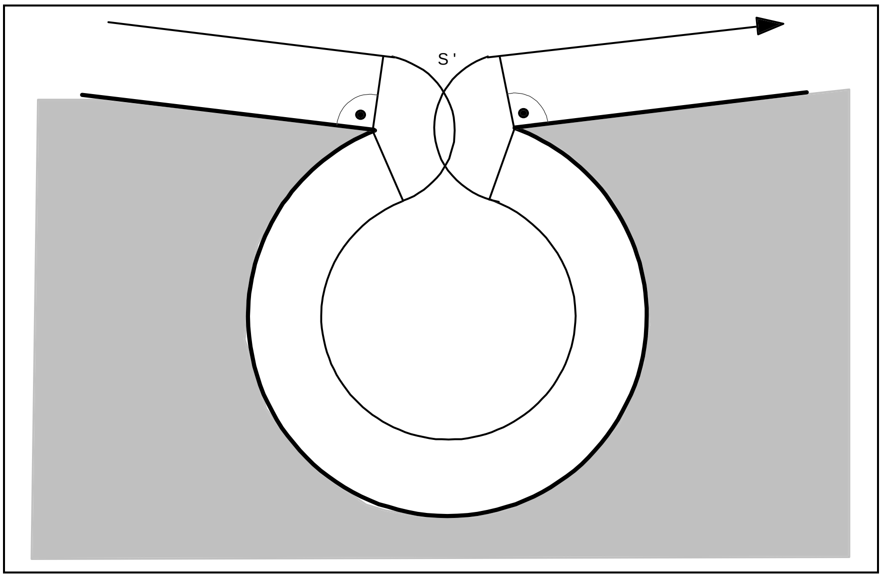
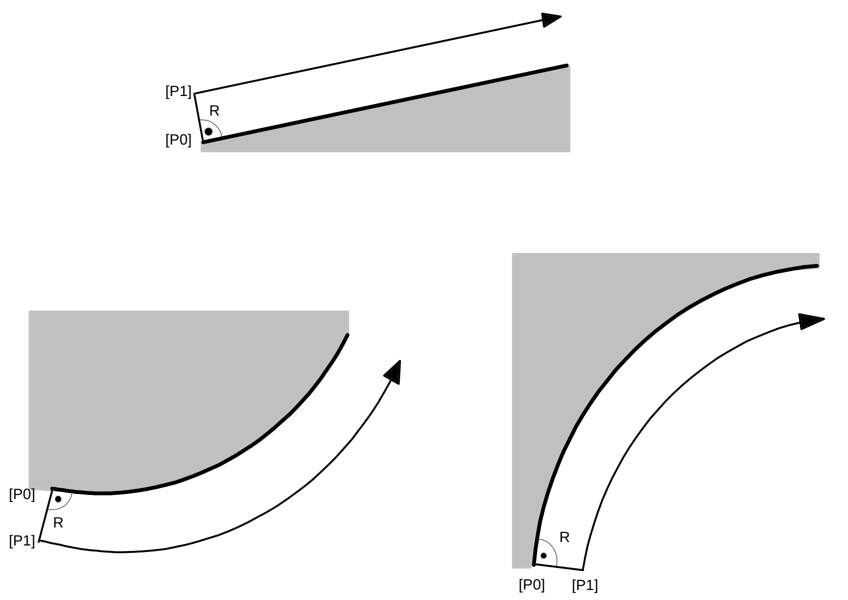


Fig. 5-18: Concave arc, several contour elements

Since as a general rule no more than four NC-blocks can be prepared in advance, one of the next three NC-blocks must be a motion NC-block including at least a change of one axis coordinate in an axis which belongs to the selected working plane. If this is not the case, the contour move is considered to be completed, and the next contour transition will not be calculated. Lookahead NC-block processing will be interrupted with calculations in the NC-program which led to the completion of a contour move. Thus, a coherent contour move cannot be programmed in a NC-variable manner.

Establishing Tool Path Compensation at the Contour Beginning

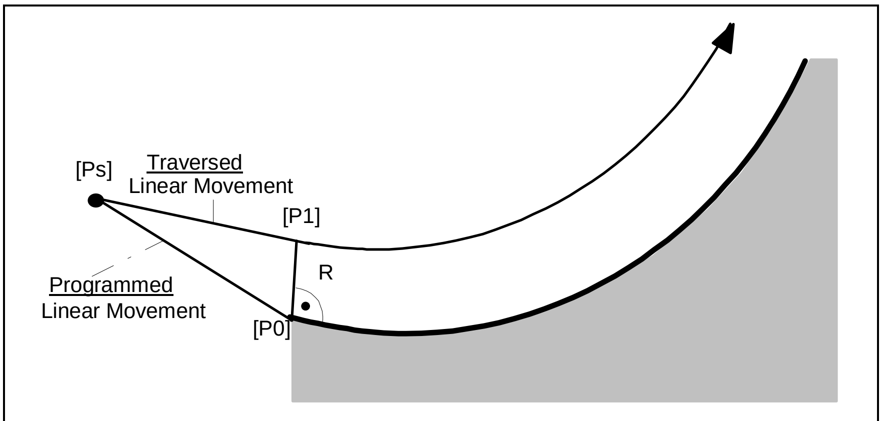
The starting point of the contour [P1] which will be corrected with tool path compensation is located above the starting point [P0] of the programmed contour perpendicular to the subsequent direction of motion.



R	tool radius
[P0]	programmed starting point of the contour
[P1]	corrected starting point of the contour

Fig. 5-19: Starting point of tool path compensation

The establishment of tool path compensation requires an additional move in the working plane which is performed only in conjunction with a programmed linear movement.



R	tool radius
[Ps]	starting point of tool path compensation
[P0]	programmed starting point of the contour
[P1]	corrected starting point of the contour

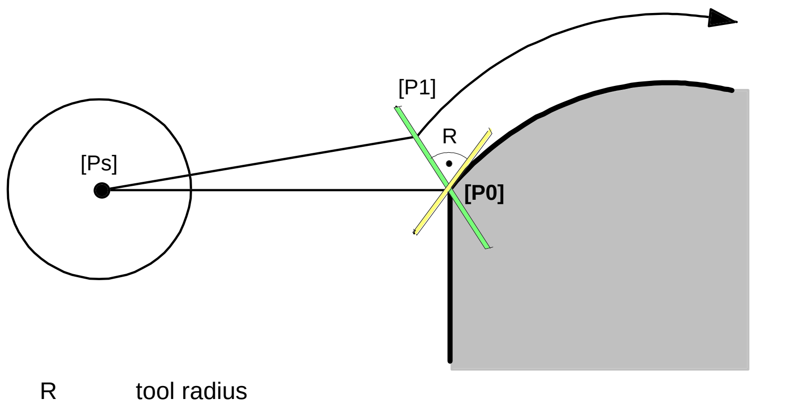
Fig. 5-20: Establishing tool path compensation

If an attempt is made to perform the tool path compensation by means of a circular movement, an error will be issued.

```
"*G41/G42 activated with circular interpolation"
```

and the NC-program will terminate.

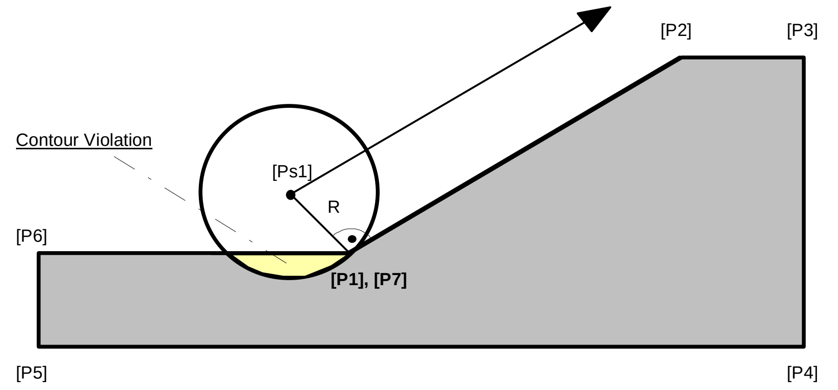
To avoid violations of the contour starting point, the starting point of tool path compensation must be selected in such a way that the tool is located completely within the quadrant which is opposite the contour corner.



R	tool radius
[Ps]	starting point of tool path compensation
[P0]	programmed starting point of the contour
[P1]	corrected starting point of the contour

Fig. 5-21: Contour starting point of tool path compensation

If the starting point of the tool path compensation is moved to an inside corner with closed contours, a contour violation would result at the end of the contour (see Fig. 5-22).

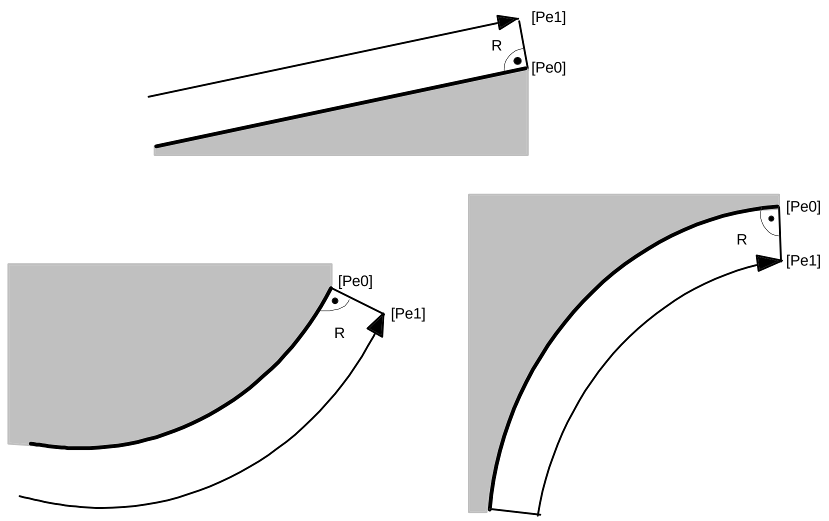


R	tool radius
[P0]	programmed starting point of the contour
[P1]	corrected starting point of the contour

Fig. 5-22: Tool path compensation with closed contours

Removing Tool Path Compensation at the End of the Contour

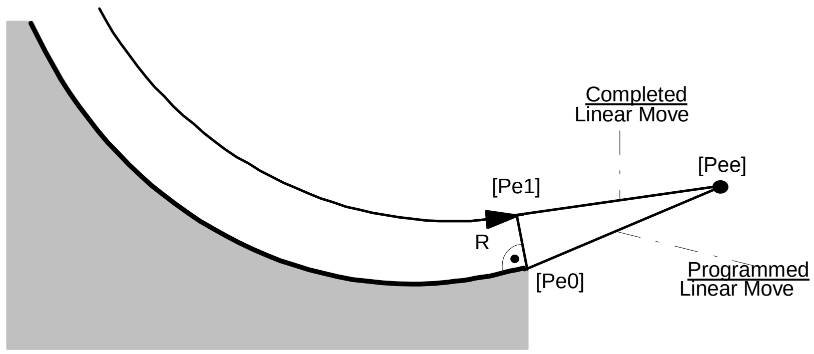
The end point of the contour [Pe1] which was corrected with tool path compensation is located above the end point [Pe0] of the programmed contour perpendicular to the prior direction of motion.



R	tool radius
[Pe0]	programmed end point of the contour
[Pe1]	corrected end point of the contour

Fig. 5-23: End point of tool path compensation

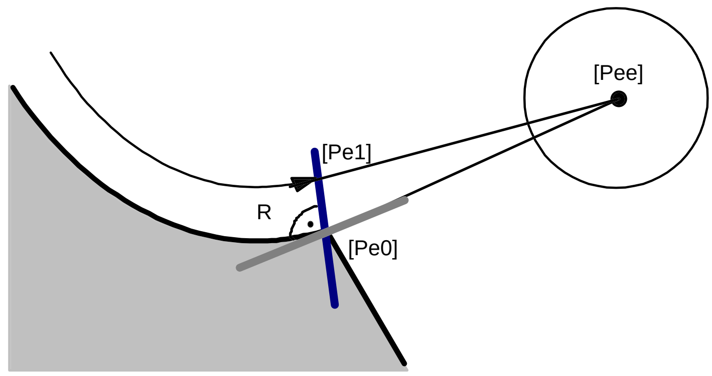
The cancellation of tool path compensation requires an additional move in the working plane which can only be performed in conjunction with a programmed linear movement (see Fig. 5-24).



R	tool radius
[Pee]	end point of tool path compensation
[Pe0]	programmed end point of the contour
[Pe1]	corrected end point of the contour

Fig. 5-24: Removing tool path compensation

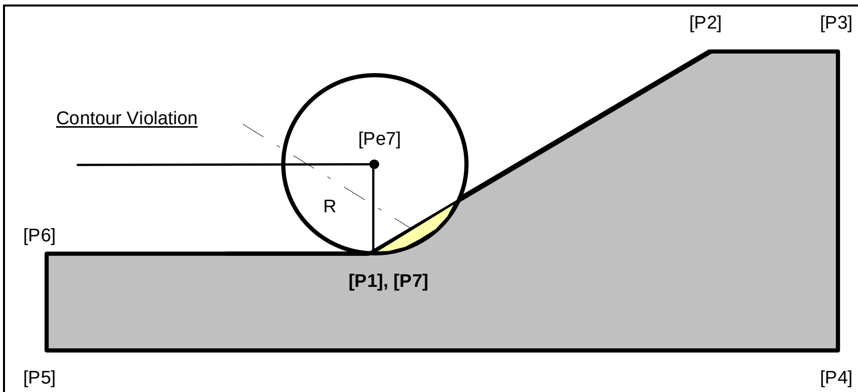
Removing tool path compensation on an arc will not cause an error to be issued, but it will cause unpredictable contour errors. To avoid violations of the contour end point, the end point of tool path compensation must be selected in such a way that the tool is located completely within the quadrant which is opposite the contour corner.



R	tool radius
[Pee]	end point of tool path compensation
[Pe0]	programmed end point of the contour
[Pe1]	corrected end point of the contour

Fig. 5-25: Contour end with tool path compensation

If the end point of the tool path compensation is moved into an inside corner with closed contours, a contour violation would result at the start of the contour (see Fig. 5-26).

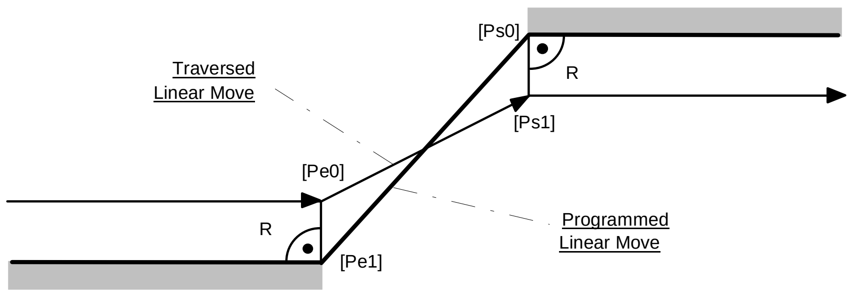


R	tool radius
[P7]	programmed end point of the contour
[Pe7]	corrected end point of the contour

Fig. 5-26: Tool path compensation with closed contours

Change in Direction of Compensation

A change in direction of compensation functions as if it were the removal and then re-establishment of tool path compensation.



R	tool radius
[Pe0]	programmed end point of the first contour
[Pe1]	corrected end point of the first contour
[Ps0]	programmed starting point of the second contour
[Ps1]	corrected starting point of the second contour

Fig. 5-27: Change in direction of compensation

The change in direction of tool path compensation requires an additional move in the working plane which is performed only in conjunction with a programmed linear movement.

CAUTION

If an attempt is made to perform the tool path compensation by means of a circular movement, an error message will be issued:

`“G41/G42 activated with circular interpolation”`

and the NC-program will terminate.

The conditions described in the Chapters „Establishing Tool Path Compensation at the Contour Beginning“, page 5-29 and „Removing Tool Path Compensation at the End of the Contour“, page 5-31 regarding the possibility of violating the starting point and end point of the contour also apply here.

5.5 Activating and Canceling Tool Path Compensation

Canceling Tool Path Compensation 'G40'

The function G40 is used to cancel an already active tool path compensation. With tool path compensation canceled the center point of the tool travels on the programmed path.

If an active tool path compensation (G41 or G42) is canceled by a G41, the next anticipated move is a linear move on the process plane. The axis values of both main axis must be programmed in the NC-block so that the tool path compensation can be removed.

- G40 is the power-on state; it is modally active. G40 is canceled by G41 or G42.
- G40 is automatically set after the controller has been powered on, after an NC-program is loaded and after a BST, M02, M30, RET or Control-Reset.

Tool Path Compensation, Left of Workpiece Contour 'G41'

Tool path compensation, left of workpiece contour is activated by the G41 function command.

When tool path compensation on the left of the contour is active, the tool center point moves on the left of the programmed contour when viewed in the direction of movement. It moves on a path which is parallel to the contour and which is offset from this contour by the tool radius value.

If G41 is programmed after an active G40 or G42, the next anticipated move is a linear move in the process plane. The axis values of both main axis must be programmed in the NC-block in order for the tool path compensation to be reestablished or changed.

- G41 tool path compensation, left of workpiece contour remains modally active until it is canceled by G90 or G42 or until a reset is performed at the end of the program (RET) or BST, M02, M30.
- When tool path compensation is active, no more than two NC-blocks can be programmed without programming a move in the current process plane. If more than two NC-blocks are programmed without a move, the tool path compensation is canceled with G40.

CAUTION

If an attempt is made to perform the tool path compensation by means of a circular movement, an error will be issued:

`“G41/G42 activated with circular interpolation”`

and the NC-program will terminate.

Tool Path Compensation, Right of Workpiece Contour 'G42'

Tool path compensation, right of workpiece contour is activated by the G42 function command.

When tool path compensation on the right of the contour is active, the tool center point moves on the right of the programmed contour when viewed in the direction of movement. It moves on a path which is parallel to the contour and which is offset from this contour by the tool radius value.

If an active tool path compensation (G41 or G42) is canceled by a G41, the next anticipated move is a linear move on the process plane. The axis values of both main axis must be programmed in the NC-block so that the tool path compensation can be removed.

- G42 tool path compensation, right of workpiece contour remains modally active until it is canceled by G40 or G41 or until a reset is performed at the end of the program (RET) or BST, M02, M30.
- When tool path compensation is active, no more than two NC-blocks can be programmed without programming a move in the current process plane. If more than two NC-blocks are programmed without a move, the tool path compensation is canceled with G40.

CAUTION

If an attempt is made to perform the tool path compensation by means of a circular movement, an error will be issued:

`“G41/G42 activated with circular interpolation”`

and the NC-program will terminate.

Example NC program - tool path compensation with G42

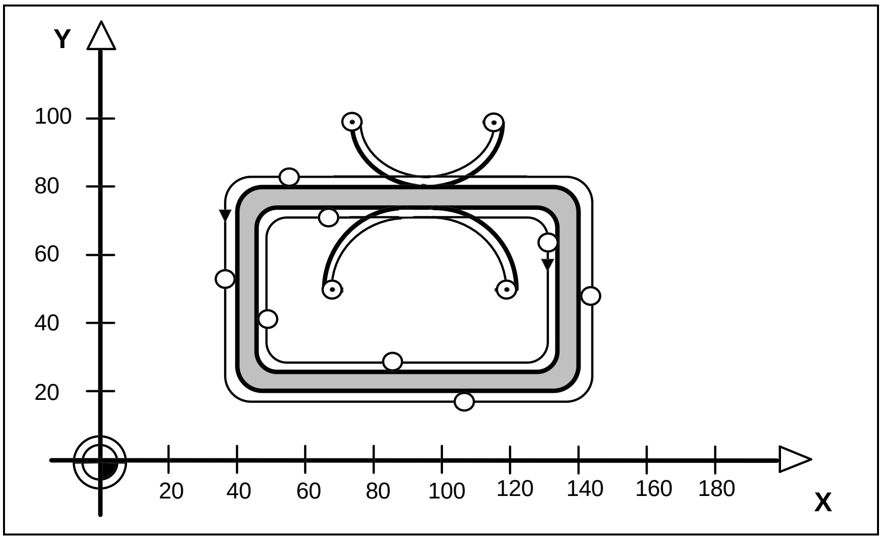


Fig. 5-28: Tool path compensation, right of contour (G42)

NC program using G42

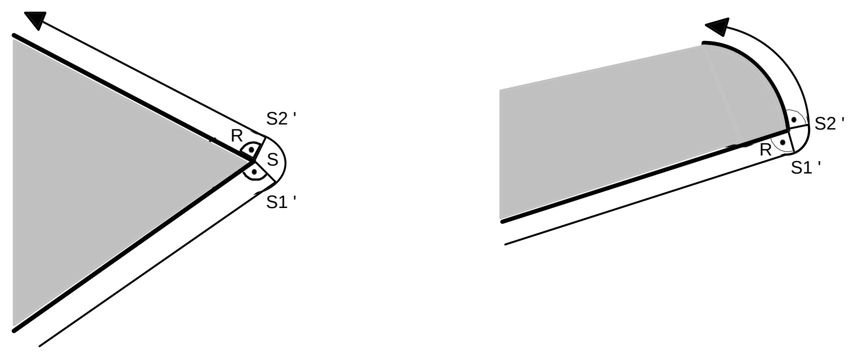
(TOOL CHANGE: IDENT=SF D5)	
T4 BSR .M6	
G00 G54 G06 G08 X115 Y99.5 Z5	Motion commands, interpolation conditions
G01 Z2 F1000 S2000 M03	1st starting position
Z-10 F1200	Lower cutter into material
G42 X117.5 Y99.5 F1500	Establish tool path compensation
G02 X98 Y80 I98 J99.5	Traverse to contour with ¼ circle
G01 X45 Y80	Machine 1st section
G03 X40 Y75 I45 J75	Machine 1st ¼ circle
G01 X40 Y25	Machine 2nd section
G03 X45 Y20 I45 J25	Machine 2nd ¼ circle
G01 X135 Y20	Machine 3rd section
G03 X140 Y25 I135 J25	Machine 3rd ¼ circle
G01 X140 Y75	Machine 4th section
G03 X135 Y80 I135 J75	Machine 4th ¼ circle
G01 X90 Y80	Machine 5th section
G02 X73.5 Y96.5 I90 J96.5	Withdraw from contour with ¼ circle
G01 X73.5 Y99.5	End position of outer contour
G00 Z2	Z axis to safety distance
G40 X68 Y49.5	Starting position inside contour
G01 Z-10 F1000	Lower cutter into material
G42 X65.5 Y49.5 F1500	Establish tool path compensation
X65.5 Y50.5	Linear motion
G02 X90 Y75 I90 J50,5	Traverse to contour with ¼ circle
G01 X130 Y75	Machine 1st section
G02 X135 Y70 I130 J70	Machine 1st ¼ circle
G01 X135 Y30	Machine 2nd section
G02 X130 Y25 I130 J30	Machine 2nd ¼ circle
G01 X50 Y25	Machine 3rd section
G02 X45 Y30 I50 J30	Machine 3rd ¼ circle
G01 X45 Y70	Machine 4th section
G02 X50 Y75 I50 J70	Machine 4th ¼ circle
G01 X98 Y75	Machine 5th section
G02 X119.5 Y53.5 I98 J53.5	Withdraw from contour with ¼ circle
G01 X119.5 Y49.5	End position inside contour
G00 Z2	Z axis to safety distance
(TOOL CHANGE: Store last tool)	
T0 BSR .M6	
RET	End of program

Insert Contour Transition Arc 'G43'

When tool path compensation is active (G41 or G42) G43 inserts an arc as the contour transition element for outside corners.

The tool center point must travel around outside corners so that they are not damaged. An arc should always be inserted for circle ↔ straight line or circle ↔ circle contour transitions.

- G43 is the power-on state. It is modally active until it is overwritten by a G44.
- G43 can only be activated via G41 or G42. If tool path compensation is canceled (G40), G43 has no effect. G43 is reset automatically at the end of the program (RET) or by the BST, M02, M30.
- When an arc is inserted as the contour transition via G43, the CNC automatically generates an additional transition NC-block. This NC-block is considered to be an independent NC-block, and as such it must be started separately in single-block processing mode.
- The conditions which must be met when transition elements are inserted are described in section „Contour Transitions“ on page 5-26.



R	tool radius
S	programmed NC-block transition point
S1 '	corrected NC-block transition point 1
S2 '	corrected NC-block transition point 2

Fig. 5-29: Inserting an arc as the contour transition

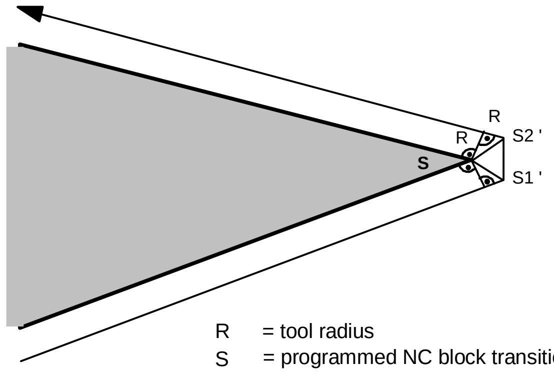
Inserting Contour Transition Chamfer 'G44'

When tool path compensation (G41 or G42) is active, G44 can be used to insert a chamfer as the contour transition with outside corners whose transition angle exceeds 90°.

With outside corners having a transition angle greater than or equal to 90°, the corrected transition point is defined as the intersection of the lines parallel to the contour.

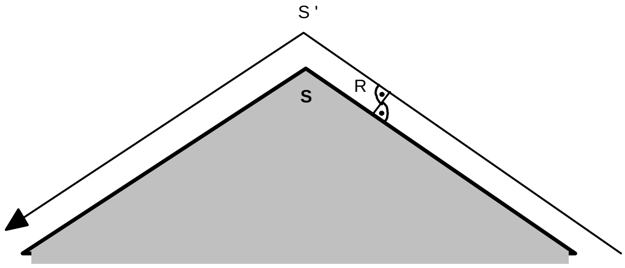
- A chamfer as contour transition can only be used for transitions between two straight lines. With all other transition pairs, an arc is automatically used as the transition element, even if G44 is active.
- After it is selected, G44 remains modally active until it is canceled by G43 or until it is automatically reset at the end of the program or by BST, M02, M30. G44 can only be activated via G41 or G42. If tool path compensation is canceled (G40), G44 has no effect.
- When a chamfer is inserted as the contour transition via G44, the CNC automatically generates an additional transition NC-block. This NC-block is considered to be an independent NC-block, and as such it must be started separately in single-block processing mode.
- The conditions which must be met when transition elements are inserted are described in section „Contour Transitions“ on page 5-26

transition angle > 90°



R = tool radius
S = programmed NC block transition point
S1 ' = corrected NCblock transition point 1
S2 ' = corrected NC blocktransition point 2

transition angle < 90°



R = tool radius
S = programmed NC block point
S ' = corrected block transition point

Fig. 5-30: Inserting a chamfer as the contour transition

Constant Feed on Tool Center Line 'G98'

When tool path compensation is active (G41 or G42), no path feedrate correction is performed for arcs when G98 is programmed. Thus, the programmed path feedrate applies to the tool center line and not the workpiece contour.

In the case of convex arcs (outside circle) this results in a reduction of the path feedrate at the contour; with concave arcs (inside circle) it results in an increase.

- G98 is the power-on state. It is modally active until it is overwritten by a G99. G98 can only be activated via G41 or G42. If tool path compensation is canceled (G40), G98 has no effect. G98 is reset automatically at the end of the program (RET) or by the BST, M02, M30 command.

Constant Feed at the Contour 'G99'

When tool path compensation is active (G41 or G42), path feedrate correction is performed for arcs when G99 is programmed. The path feedrate at the contour corresponds to the programmed value when G99 is active.

In the case of convex arcs (outside circle) this results in an increase of the path feedrate on the tool center line path; with concave arcs (inside circle) it results in a decrease.

- After it is selected, G99 remains modally active until it is canceled by G98 or until it is automatically reset at the end of the program (RET) or by BST, M02, M30. G99 can only be activated via G41 or G42. If tool path compensation is canceled (G40), G99 has no effect.

5.6 Tool Length Compensation

When movements are being performed in the direction of the tool axis and tool length compensation inactive is set, all position data relates to the position of the nose of the spindle.

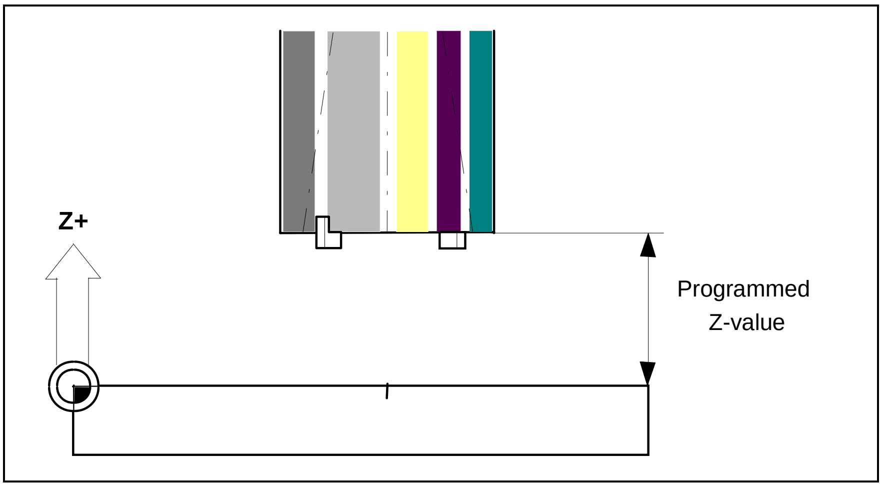


Fig. 5-31: Tool length compensation inactive

When there is motion in the direction of the tool axis and tool length compensation active is also present, the actual tool lengths entered in the magazine list are automatically used for calculations by the controller, so that all position data now applies to the position of the tool tip.

In order to establish or remove tool length compensation, it is necessary to perform a programmed move in the direction of the tool axis such that the spindle nose stops on the programmed position when the end point is approached.

The direction of the tool axis is assumed to be the direction of the main axis which is perpendicular to the process (machining) plane. The position of the tool axis must be changed if the process plane is changed (G17, G18, G19).

The tool length compensation (G47) must be canceled and activation of tool length compensation (G48) must be programmed in the tool change program.

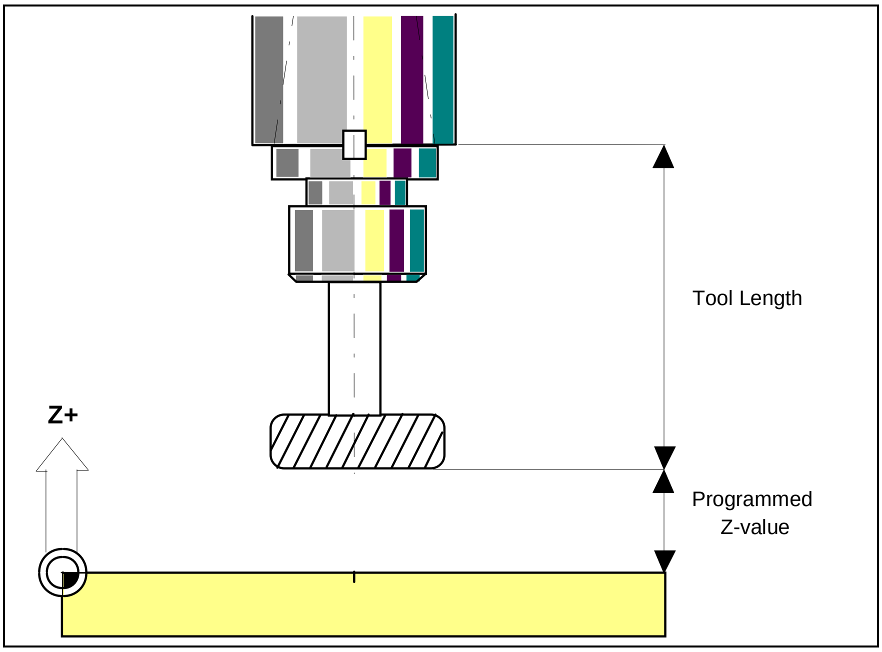


Fig. 5-32: Tool length compensation active

Tool Length Correction, Cancel 'G47'

The function G47 is used to cancel an already active tool length correction. When movements are being performed in the direction of the tool, all position data relates to the position of spindle nose.

If an active tool length correction (G48 or G49) is canceled with G47, a programmed move in the direction of the existing main axes is expected. Moves which do not involve the removal of material from the workpiece, a tool change for example, are generally performed without tool length correction.

- Depending on the settings in the process parameter Bxx.038, G47 may be the power-on default, G47 remains modally active until it is canceled by G48 or G49.
- After the controller is turned on, after an NC-program is loaded, after a BST, RET, M02, M30, or Control Reset, G47 is set automatically depending on the setting in the process parameter Bxx.038.

Tool Length Correction, Positive 'G48'

After tool length correction has been activated by a G48, the CNC compensates the tool lengths entered in the magazine list in the positive axis direction beginning with the next programmed move in the direction of the existing main axes.

- Depending on the settings in the process parameter Bxx.038, G48 may be the power-on default. G48 remains modally active until it is canceled by G47 or G49.
- After the controller is turned on, after an NC-program is loaded, after a BST, RET, M02, M30, or Control Reset, G48 is set automatically depending on the setting in the process parameter Bxx.038.

Tool Length Correction, Negative 'G49'

After tool length correction has been activated by a G49, the CNC compensates the tool lengths entered in the magazine list in the negative axis direction beginning with the next programmed move in the direction of the existing main axes.

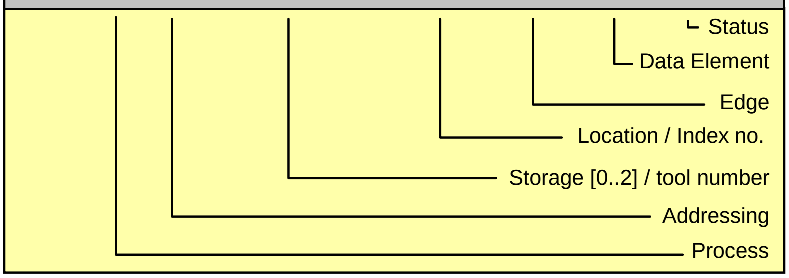
- G49 remains modally active until it is canceled by G47 or G49, or until it is automatically reset at the program end (RET) or by BST.

5.7 Read/Write Tool Data from the NC Program 'TLD'

The TLD command (tool data) can be used to read the tool data from the NC-program and to write them, however some restrictions apply to writing.

Syntax

	P	A	S/T	L/D	E	D	S	
TLD(	[0..6],	[0],	[0..2]	,[1...999],	[0..9],	[1..35],	[1..32])	
TLD(	[0..6],	[1],	[1..9999999],	[1...999],	[0..9],	[1..35],	[1..32])	



All data present in the tool list can be read. The individual data elements are addressed by means of codes. A detailed description of the TLD command is contained in Chapter 11 „NC Special Functions“.

Value Range and Meaning of the Parameters

Name	**Sym**	**Value Range**	**Meaning**		
Process	P	0..6		Process No.	
Addressing	A	0	**1**	0: storage / location addressing	**1: Addressing via tool and index no.**
Storage	S	0..2		S=0 : Magazine/turret S=1 : Spindle S=2 : Gripper	
Location	L	S=0 : 1..999 S=1 : 1..4 S=2 : 1..4		S=0 : Mag.-/turret loc. S=1 : Tool spindle no. S=2: Gripper number	
Tool number(T)	**T**		**1..9999999**		**Tool number**
Tool Index No.	**D**		**1..999**		**Tool index number**
Edge	E	0..9		E=0 : E = 1..9	Basic tool data Edge data
Data Element	D	E=0 : E=1..9 :	3..26 1..35	E=0 : E=1..9 :	Access basic tool data Access edge data
Status	S	E=0 : E=1..9 :	1..32 1..16	E=0 : E=1..9 :	Access tool status bits Access edge status bits

Addres

5.8 D Corrections

The D-corrections are additive relative to the tool geometry data registers. The D-corrections act in an additive manner relative to the existing geometry registers L1, L2, L3 and R. 99 D-corrections are available for each of the 7 processes. Each D-correction contains the L1, L2, L3 and R registers. The assignment of values in the D-correction register can be accomplished using the CNC operator interface or the SOT.

Syntax

D0 ⇨ **Cancel D-corrections**

D<D-correction No. [1..99]> ⇨ **Select a D-correction**

The D-corrections act like the geometry data in the tool management system. The D-corrections can be used when tool management is present, for example as tool reference point offset registers. If tool management is not defined with an CNC process, the D-corrections themselves can be used in place of tool management for simple applications. The D-corrections function like Correction Type 4 in tool management. An edge orientation cannot be defined in the D-corrections.

How the D corrections work

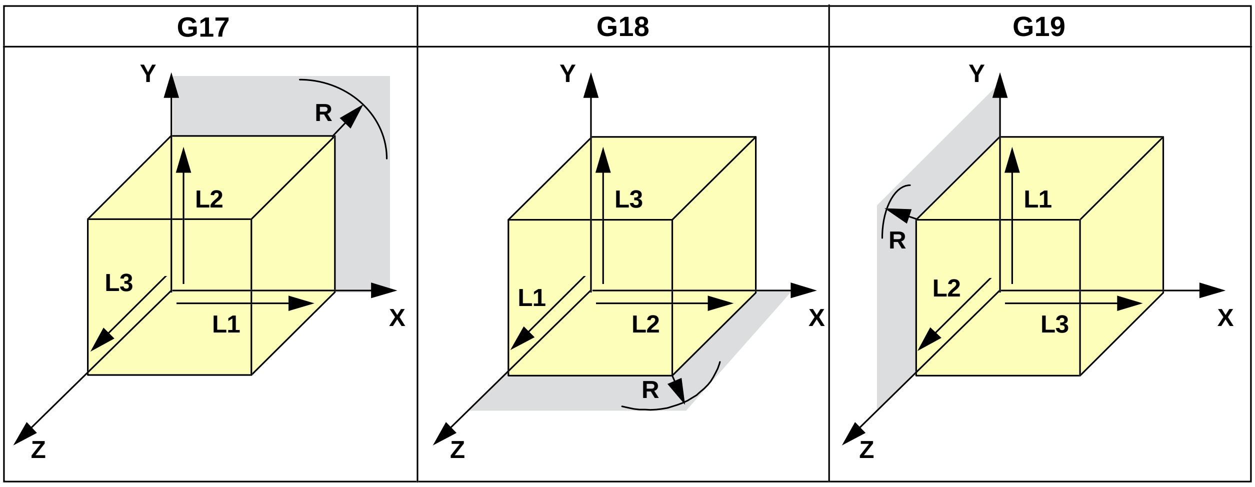


Fig. 5-33: How the D-corrections work in the process plane

Geometry registers L1, L2 and L3 are not used for compensation unless tool length correction G48/G49 is active. Geometry register R is only used for compensation when tool path compensation G41/G42 is active.

When tool management is active for a selected tool and a D-correction is also active, the tool lengths and radius are calculated as follows:

Length correction L1 = Length L1 + Wear L1 + Offset L1 + L1 of the D correction
Length correction L2 = Length L2 + Wear L2 + Offset L2 + L2 of the D correction
Length correction L3 = Length L3 + Wear L3 + Offset L3 + L3 of the D correction
Radius correction R = Radius R + Wear R + Offset R + R of the D correction

Using D corrections

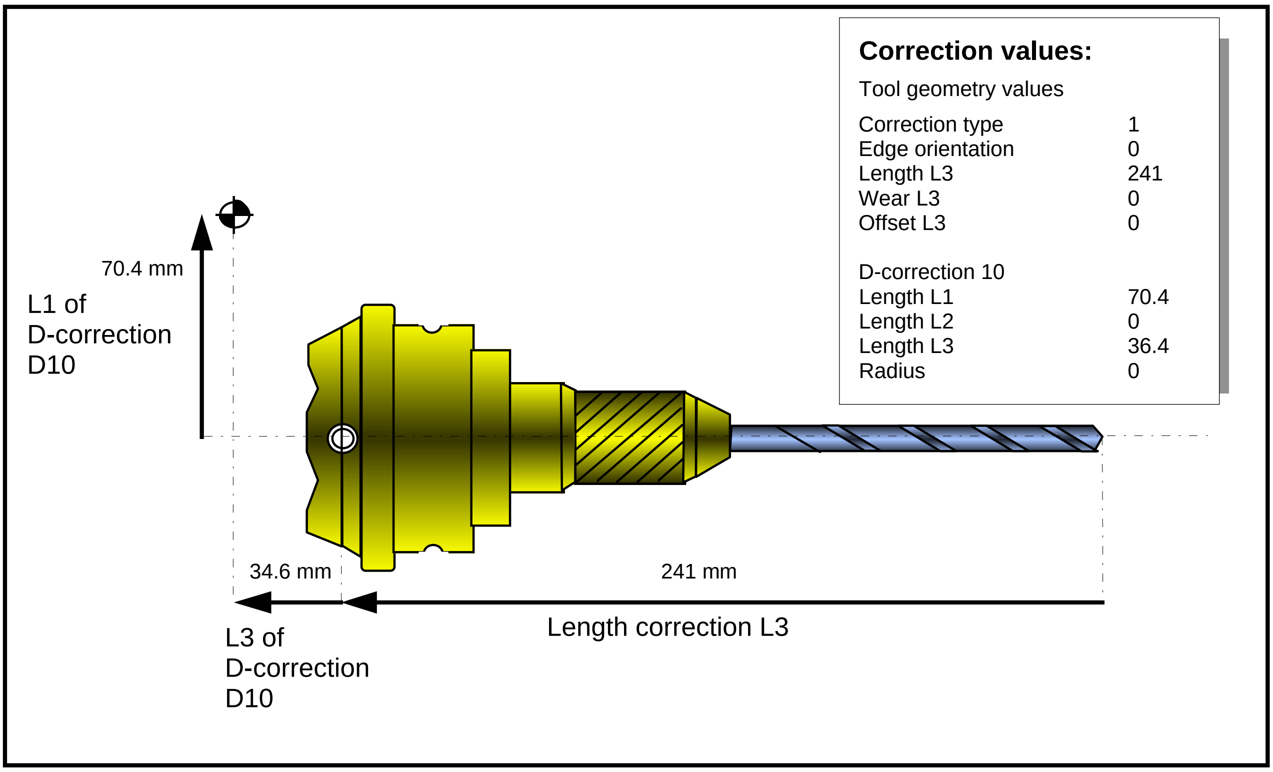


Fig. 5-34: Definition of the tool reference point with the aid of D-corrections

- Geometry registers L1, L2, L3 and R of the selected D-correction are not active unless tool length correction (G48/G49) or tool radius correction (G41/G42) is active.

- D0 is active in the power-on state; thus, the D-corrections do not perform compensation.
- A programmed D-correction is modally active. The programmed D-correction is canceled when D0 is programmed. D0 is automatically active after an NC-program is loaded and after a BST, RET, M02, M30, or Control-Reset.
- If the tool length correction or the tool radius correction are deactivated when a D-correction is active, the geometries of the corresponding D-correction once again become active when the tool length/radius correction is reactivated.
- Geometry registers L1, L2 and L3 act in the direction of the 3 main axes (X, Y, Z) depending on which process plane is selected. Length L3 is always perpendicular to the current machining plane; while lengths L1 and L2 always lie within the current machining plane.

Note: The D-corrections are not available in an NC process unless the machine builder has specified that they are available in the process parameters.
The maximum value which can be entered for geometry registers L1, L2, L3 and R is entered in the process parameters.

6 Auxiliary Functions (S, M, Q)

6.1 General Information

Auxiliary functions are passed to the SPS and are then executed and acknowledged by the SPS. For this to happen, the switch functions needed in the SPS must be defined.

NOTE

- If an auxiliary function has been output to the SPS, block processing stops until the function is acknowledged. Thus, programming an auxiliary function which is not defined in the SPS program will block further program execution.
- Programming auxiliary functions temporarily stops block processing. This interrupt S-functions like G08 contouring mode (acceleration).
- The auxiliary functions are processed in the following order in the NC-block: S, M, Q.

6.2 Auxiliary Functions ‘M’

The M-functions are instructions which are primarily used to program machine or controller switching functions (for example, spindle on/off, cutting fluid on/off, gear change, etc.). An auxiliary function is programmed with a code number which may be up to three digits long and which uses M as the address letter. The codes for the auxiliary functions are defined in part in DIN 66 025 Part 2 and in part by the machine builder.

Organization of the M functions in function groups

1	Program control commands		M000, M001, M002, M030
2	Spindle control commands	Spindle 1	M003, M004, M005, M013, M014
2	Spindle control commands	Spindle 1	M103, M104, M105, M113, M114
3	Spindle control commands	Spindle 2	M203, M204, M205, M213, M214
4	Spindle control commands	Spindle 3	M303, M304, M305, M313, M314
5	Coolant and lubricant	Spindle 1	M007, M008, M009
5	Coolant and lubricant	Spindle 1	M107, M108, M109
6	Coolant and lubricant	Spindle 2	M207, M208, M209
7	Coolant and lubricant	Spindle 3	M307, M308, M309
8	Clamp and unclamp	Spindle 1	M010, M011
8	Clamp and unclamp	Spindle 1	M110, M111
9	Clamp and unclamp	Spindle 2	M210, M211
10	Clamp and unclamp	Spindle 3	M310, M311
11	Gear range selection	Spindle 1	M040, .., M045
11	Gear range selection	Spindle 1	M140, .., M145
12	Gear range selection	Spindle 2	M240, .., M245
13	Gear range selection	Spindle 3	M340, .., M345
14	Spindle override		M046, M047
15	Feed override		M048, M049
16	Block-active M-functions as well as all M-functions defined by the machine builder		M019, M119, M219, M319 Mxxx

All M-functions with the exception of the spindle control commands Mx03, Mx04, Mx05, Mx13, Mx14, the program control commands Mx00, Mx01, Mx02, Mx30, and the block-active M-function Mx19 (x = 1...3) can be used as desired by the machine builder since they do not trigger any internal functions in the controller.

- In a given NC-block, only one M-function can be programmed from each function group.
- M-functions from M000 to M399 can be programmed with the CNC.
- No more than four M-functions can be programmed in a single NC-block.
- The M-functions overwrite one another.

Note: If more than one gear range is activated in the axis parameters, the M-functions will no longer be available for general use.

Program Control Commands

Programmed stop (unconditional) M000

M000 allows a defined NC-program stop to be performed—for example, to inspect a tool. After the tool has been checked, the program can be continued by pressing the start key.

In all program-controlled modes M000, like the HLT command, produces a program stop in the NC. However, in contrast to HLT, and the end of the motion, the NC sends the M000 auxiliary function to the SPS.

Conditional Stop M001

M001 acts like M000 when the interface signal conditional stop (PxxC.M01) is set by means of a machine control key. The NC evaluates the interface signal conditional stop after acknowledging the auxiliary function.

End of NC program M002 / M030

M002/M030 act like the RET command. In addition, the NC sends the currently programmed auxiliary function to the SPS. Both auxiliary functions communicate the end of program to the SPS by resetting the NC-program to the start of the program. The NC thus establishes the power-on state. After M002 or M030 are performed, all subroutine levels and all reverse vectors are cleared and the NC controller is in the initial state in the main program level.

Spindle Control Commands

The spindle is turned on or off using the spindle control commands M003, M004, M005, M013, M014. The first digit in the M-functions is evaluated as the spindle index number. If the spindle index is 0 or 1 (M003 or M103), the M-function is applied to the first spindle; if the spindle index is 2 (M203), the M-function is applied to the second spindle, if 3 (M303) to the third spindle.

- The spindle control commands Mx03, Mx04, Mx13 and Mx14 take effect as soon as an axis move is programmed in the NC-block. However, they are not output to the SPS until the motion command is completed.

Mx03 Spindle in clockwise direction

Activate spindle rotation in clockwise direction.

Mx04 Spindle in counterclockwise direction

Activate spindle rotation in counterclockwise direction.

Mx05 Spindle stop

Shut off spindle and shut off supply of coolant/lubricant.

Mx13 Spindle in clockwise direction and coolant/lubricant ON

Turn on spindle rotation in the clockwise direction and turn on coolant/lubricant supply if the required switching functions are defined in the SPS program.

Mx14 Spindle in counterclockwise direction and coolant/lubricant ON

Turn on spindle rotation in the counterclockwise direction and turn on coolant/lubricant supply if the required switching functions are defined in the SPS program.

Spindle positioning

The function M19 S... allows the main spindle to be stopped in a defined position. The angular position is programmed in degrees at address S

Positioning the main spindle can be accomplished from the stopped state and when the main spindle is still turning.

Once the SPS acknowledges Mx19, the NC-block is still considered to be processing until the spindle reaches its final position.

If Mx19 is programmed without an S word, an error will be issued when the program is executed.

The M19 function can only be used with positionable main spindles (with position feedback).

Syntax

M19 S<constant>	⇨	**M19 S180**
M19 S=<expression>	⇨	**M19 S=@070**
M<spindle index>19 S<spindle index><constant>	⇨	**M219 S2 90**
M<spindle index>19 S<spindle index>=<expression>	⇨	**M319 S3=@060**

Gear Range Selection

If the number of gear ranges for one of the spindles is greater than 1 in the CNC axis parameters, M-function groups 11-13 will be reserved for the controller-internal functions of the CNC.

M-functions for gear selection with corresponding function groups:

11	Gear selection	spindle 1	Mx40, .., Mx44 (x=0 or 1)
12	Gear selection	spindle 2	M240, .., M244
13	Gear selection	spindle 3	M340, .., M344

Meaning of the M-functions:

Mx40	Automatic gear selection for spindle X
Mx41	1st gear range for spindle x
Mx42	2nd gear range for spindle x
Mx43	3rd gear range for spindle x
Mx44	4th gear range for spindle x

- Automatic gear selection (Mx40) is dependent on the corresponding axis parameter set by the machine builder.
- If a multiple-range gear is not present, the M-functions can be used for other purposes.

6.3 S Word as Auxiliary Function

If a process was defined without a spindle in the process parameters, the S-word has the meaning of an auxiliary function. This means that the user has an additional address letter which he can define for auxiliary functions in the SPS program. The S-function can be entered as an unsigned integer constant having up to 4 digits. The numerical range for this constant is 0 to 9999.

Syntax **S<constant>** ⇨ **S1234**

There may be an expression instead of the constant.

S=<expression> ⇨ **S=@123+@124**

6.4 Q Function

An auxiliary functions defined by the user in the SPS program can be called using the address letter Q and an unsigned integer constant having up to 4 digits. The numerical range for this constant is 0 to 9999.

Syntax **Q<constant>** ⇨ **Q1234**

Q-functions Q9000 to Q9999 are reserved for INDRAMAT-specific functions.

7 NC Events

7.1 Definition of NC Events

Which can be used by the NC-program and which, like flags in the SPS program, represent any desired state defined by the programmer. NC-events can be set and reset as desired in the NC and SPS programs. Processes can be synchronized by waiting for a defined state in an NC-event.

Up to 224 NC-events are available in the CNC. Thirty-two (32) local NC-events are allocated to each process. When the process numbers are used for addressing, all 224 NC-events can be used in a process, regardless of whether the process itself is defined. An NC-event is identified by the process to which it belongs and by the NC-event number. If the process to which the NC-event belongs is not programmed, the process defaults to the process in which the NC-event is programmed.

Interrupt-controlled program branches can be performed with the aid of NC-events. This is described in section 7.4 Asynchronous Handling of NC-events.

- If an "*" is declared instead of the NC-event number, all the NC-events in the given process are addressed.
- NC-events can also be changed by the SPS program. Therefore please refer to the machine builder's information since the builder may have used various NC-events for synchronization purposes.
- The status of the NC-events is retained after control power deactivation. Before NC-events are used in an NC-program, they should be placed in a defined state.
- NC-events 0 to 7 are reserved for interrupt-controlled program branches; in general, they should be kept open for such functions.
- Various NC-events are used by the INDRAMAT standard/optional NC-cycles. The numbers of these NC-events are stated in the corresponding description.
- No more than four different NC-event commands and only one NC-event branch command may be programmed in one NC-block.

7.2 Influencing NC Events

Set NC Event ‘SE’

The NC-event defined in the command parameter is set using the command SE. If the NC-event is already set, this command will be ignored. The NC-event continues to be set until it is reset by the RE reset NC-event command, the SPS program or via the MUI/GUI/SOT interface tools.

Syntax **SE <Process number[0..6]>:<Event number[0..31]>** ⇨ **SE 1:15**

SE <Event number[0..31]> ⇨ **SE 9**

- If the symbol "*" is declared instead of the NC-event number, all the NC-events in the given process are addressed.
- NC-events can also be changed by the SPS program. Therefore please refer to the machine builder's information since the builder may have used various NC-events for synchronization purposes.
- Even though it is theoretically possible to set NC-events in other processes, it is a good idea to only change NC-event status in the process to which the NC-event belongs and to only scan NC-events from other processes.

Reset NC Event 'RE'

The NC-event defined in the command parameter is reset using the command RE. If the NC-event is already reset, this command will be ignored. The NC-event continues to be reset until it is set by the SE set NC-event command, the SPS program or via the MUI/GUI/SOT interface tools.

Syntax

RE <Process number[0..6]>:<Event number[0..31]> ⇨ **RE 1:15**

RE <Event number[0..31]> ⇨ **RE 9**

- If the symbol "*" is declared instead of the NC-event number, all the NC-events in the given process are addressed.
- NC-events can also be changed by the SPS program. Therefore please refer to the machine builder's information since the builder may have used various NC-events for synchronization purposes.
- Even though it is theoretically possible to reset NC-events in other processes, it is a good idea to only change NC-event status in the process to which the NC-event belongs and to only scan NC-events from other processes.

Wait until NC Event is Set 'WES'

The WES command wait until NC NC-event is set is used in the process in which WES is set to stop program processing until the NC-event defined in the command parameter is set. If the NC-event is already set, the block continues to process without interruption.

Syntax

WES <Process number[0..6]>:<Event number[0..31]> ⇨ **WES 1:15**

WES <Event number[0..31]> ⇨ **WES 9**

- If the symbol "*" is declared instead of the NC-event number, processing waits until at least one NC-event in the specified process is set.
- NC-events can also be changed by the SPS program. Therefore please refer to the machine builder's information since the builder may have used various NC-events for synchronization purposes.
- Since a process which is waiting for an NC-event cannot set the same NC-event, it is only possible to wait for one NC-event whose status is changed by a different process, SPS or user interface.
- The WES command should not be programmed in a portion of a program in which tool path compensation is active. If this proves to be unavoidable, be certain the WES is only programmed between linear block transitions.

Wait until NC Event Is Reset ‘WER’

The WER command wait until NC NC-event is reset is used in the process in which WER is programmed to stop program processing until the NC-event defined in the command parameter is reset. If the NC-event is already reset, the block continues to process without interruption.

Syntax

WER <Process number[0..6]>:<Event number[0..31]>	⇨	**WER 1:15**
WER <Event number[0..31]>	⇨	**WER 9**

- If the symbol "*" is declared instead of the NC-event number, processing waits until at least one NC-event in the specified process is reset.
- NC-events can also be changed by the SPS program. Therefore please refer to the machine builder's information since the builder may have used various NC-events for synchronization purposes.
- Since a process which is waiting for an NC-event cannot reset the same NC-event, it is only possible to wait for one NC-event whose status is changed by a different process, SPS or user interface.
- The WER command should not be programmed in a portion of a program in which tool path compensation is active. If this proves to be unavoidable, be certain the WES is only programmed between linear block transitions.

Example NC program - Influencing NC events

At the begin of both part programs, all NC-events for the given process are reset. The NC-program in process 2 stops block processing in the third line until NC-event no. 1 is set in the sixth line in NC program in process 1.

NC program process 1		NC program process 2	
RE 1:*	;Reset all NC events in process 1	RE 2:*	;Reset all NC events in process 2
T1 BSR .M6	;Tool change	T1	;Tool change
M03 S150	;Spindle ON	WES 1:1	;Wait for NC event 1 of process 1
G04 F15	;Dwell time	M03 S150	;Spindle ON
M05	;Spindle OFF	G04 F15	;Dwell time
SE 1:1	;Set NC event in process 1	M05	;Spindle OFF
RET	;End of program	RET	;End of program

7.3 Conditional Branches Upon NC Events

Branch If NC Event Set ‘BES’

The BES command branch if NC-event set is used to continued program processing at the declared branch label if the NC-event defined in the command parameter is set.

Syntax

BES <Branch label> <Process number[0..6]>:<Event number[0..31]> ⇨ **BES .LABEL 1:15**

BES <Branch label> <Event number[0..31]> ⇨ **BES .LABEL 9**

- If the symbol "*" is declared instead of the NC-event number, processing to the addressed branch label if at least one NC-event in the specified process is set.
- NC-events can also be changed by the SPS program and via the MUI/GUI/SOT menu. Therefore please refer to the machine builder's information since the builder may have used various NC-events for synchronization purposes.

Branch If NC Event Reset ‘BER’

The BER command branch if NC NC-event reset is used to continued program processing at the declared branch label if the NC-event defined in the command parameter is reset.

Syntax

BER <Branch label> <Process number[0..6]>:<Event number[0..31]> ⇨ **BER .LABEL 1:15**

BER <Branch label> <Event number[0..31]> ⇨ **BER .LABEL 9**

If the symbol "*" is declared instead of the NC-event number, processing branches to the addressed branch label if all the NC-events in the specified process are reset.

NC-events can also be changed by the SPS program and via the MUI/GUI/SOT menu. Therefore please refer to the machine builder's information since the builder may have used various NC-events for synchronization purposes.

Example NC program - Branches conditional on NC events

At the begin of both NC-programs, all NC-events for the given process are reset. If NC-event 15 in process 1 is set before process 2 reaches line 3, then process 2 continues processing at the branch label ".WAIT" in line 7. If it is not set, the process continues to execute in line 4.

NC program process 1		NC program process 2	
RE 1:*	;Reset all NC events in process 1	RE 2:*	;Reset all NC events in process 2
T1 BSR .M6	;Tool change	T1	;Tool change
SE 1:15	;Set NC event 15 in process 1	BES .WARTEN 1:15	;Branch to .label WAIT if NC event 15 of process 1 status is 1
M03 S150	;Spindle ON	M03 S150	;Spindle ON
G04 F15	;Dwell time	G04 F15	;Dwell time
M05	;Spindle OFF	M05	;Spindle OFF
RET	;End of program	RET	;End of program

7.4 Interrupting NC Events

The CNC can use NC-events to influence the NC-program execution at any desired time. Since the status of NC-events can be changed by the SPS and by other processes, the NC-program can be made to branch conditional upon certain signal changes.

The control of NC-program flow consists of being able to interrupt the execution of the active NC-block including the current axis moves and to call a subroutine and then to return to the interrupted NC-block or to make a complete branch and to continue the NC-program at a different location.

The interrupting NC-events permit, for example, a move to a position, which is scanned for, (limit switch), gaging cycles (probe) or joining operations (force sensor). All manner of other conditions used to trigger the interruption of a move or simply to modify the NC-program flow are conceivable.

The response time to an external NC-event typically is 50 milliseconds with the CNC.

NC-events from 0 .. 7 of each process are reserved for the interrupt-controlled program branches. If a condition is met, the corresponding NC-event assumes the 1 state. The priority of NC-events increases with their number. NC-event "1" has a higher priority than NC-event "0," and NC-event "7" has the highest priority. This permits a response to an external NC-event while the handling of a previously detected low-priority NC-event is not yet completed.

The first action taken to handle an external NC-event is that all axis moves in the process are brought to a stop as soon as possible. Spindles are not stopped when an NC-event is called. The position of the stop is then calculated back into the program coordinate system so that it can be used as the starting position for the following move. In addition, the previously prepared motion blocks are cleared, and block processing begins a new starting at the point in the program which was defined as the start of NC-event handling. The start of NC-event handling is identified by the branch label switch was programmed with the NC-event.

- The supervision of NC-events and the appropriate response only takes place when an advance NC-program is running. All NC-event supervision activities are deactivated at the end of the program, when an axis is jogged, or when the program is reset by means of a Control Reset.
- NC-event commands are processed to completion at the end of the NC-block. No more than one command for asynchronous handling of NC-events can be programmed in an NC-block.
- NC-events can also be changed by the SPS program. Therefore please refer to the machine builder's information since the builder may have used various NC-events for synchronization purposes.

Branch on NC Event to NC Subroutine (Interrupt) ‘BEV’

The BEV command branch on NC NC-event to NC subroutine (interrupt) is used to activate monitoring of the NC-event specified in the command parameter. If the NC-event assumes the status "1", processing branches to the subroutine which is parameterized in the branch label of the BEV command. A change of the status of low-parity NC-events or of the triggering NC-event is ignored until the end of the subroutine. However, the program may be interrupted by higher-priority NC-events.

Syntax **BEV <Branch label> <Event number[0..7]>** ⇨ **BEV .LABEL 4**

After the branch from the subroutine, block preparation is resumed at the beginning of the interrupted NC-block so that this block is now completely processed to insure that all the functions of the interrupted block are performed. This can lead to unexpected results with incremental programming and incremental variable programming (@01=@01+3).

- The portion of the NC-program which is processed as a subroutine must be terminated upon the branch back from the subroutine. Monitoring of the triggering NC-event and lower-priority NC-events is resumed automatically.
- Repeating the assignment of a branch label to an NC-event using the BEV command overwrites the previous assignment as well as any different branching behavior defined using the command JEV Jump on NC NC-event.
- NC-events can also be changed by the SPS program. Therefore please refer to the machine builder's information since the builder may have used various NC-events for synchronization purposes.

Jump on NC Event (Interrupt) ‘JEV’

The JEV command jump on NC NC-event (interrupt)is used to activate monitoring of the NC-event specified in the command parameter. If the NC-event assumes the status "1", processing branches to the point in the NC-program which is parameterized in the jump label of the JEV command. A change of the status of low-parity NC-events or of the triggering NC-event is ignored. However, the program may be interrupted by higher-priority NC-events.

Syntax **JEV <Branch label> <Event number[0..7]>** ⇨ **JEV .LABEL 4**

After the interruption is triggered by the NC-event, the program is continued at a defined location and it cannot be reset, as is for the case with the BEV command, by a jump back from a subroutine (RTS) into the interrupted NC-block.

Repeating the assignment of a jump label to an NC-event using the JEV command overwrites the previous assignment as well as any different branching behavior defined using the command BEV branch on NC-event to NC-subroutine (interrupt).

NC-events can also be changed by the SPS program. Therefore please refer to the machine builder's information since the builder may have used various NC-events for synchronization purposes.

Cancel NC Event Supervision (Interrupt) ‘CEV’

The command CEV cancel NC-event supervision (interrupt) can be used to cancel NC-event supervision when NC-event supervision is activated by means of BEV or JEV. The NC-event supervision is canceled for the NC-event declared in the command parameter.

Syntax **CEV <Event number[0..7]>** ⇨ **CEV 5**

Disable NC Event Supervision (Interrupt) ‘DEV’

The command DEV disable NC-event supervision (interrupt) can be used when NC-event supervision has been activated by a BEV or JEV to disable this NC-event supervision for a certain portion of the NC-program until the NC-event supervision is re-enabled via EEV enable NC-event supervision. The NC-event supervision is disabled for the NC-event declared in the command parameter.

Syntax **DEV**

Enable NC Event Supervision ‘EEV’

The EEV command enable NC-event supervision is used to re-enable NC-event supervision which was disabled by means of DEV. The NC-event supervision is enabled for the NC-event declared in the command parameter.

Syntax **EEV**

Example NC program - Interrupting NC-event handling

Two types appear in a prepared portion. In the first type, the holes shown in Fig. 7-1 are present, and a thread must be tapped. The number of holes can vary between 1 and 5; however, they are specified by their position. The given tapping position is selected via ZO (G54..G58). In the second type, normal processing is performed; the holes are ignored. An initiator located in the Z axis checks for the presence of holes. The initiator is connected to the SPS as an input. If the 0 state is present at the given input, the SPS sets NC-event no. 6 in process "0."

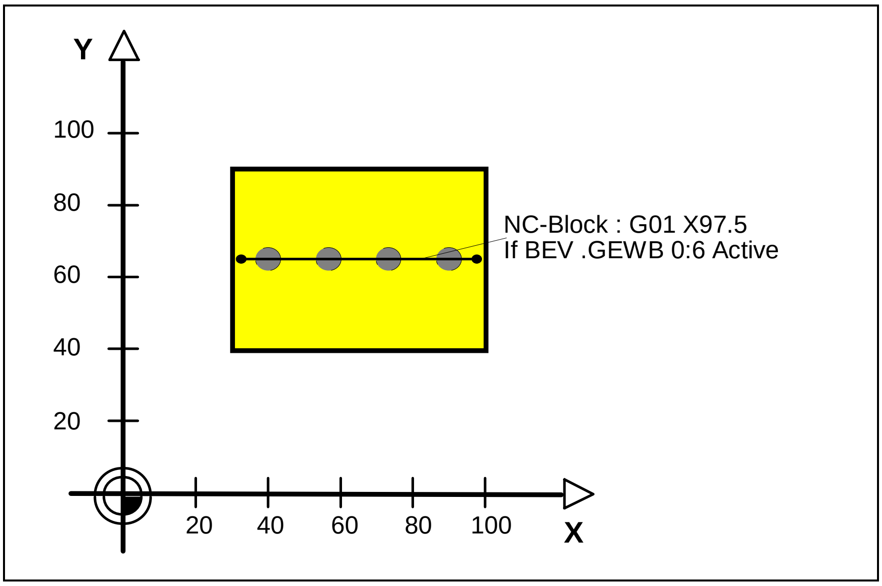


Fig. 7-1: Tapping depending an NC event

NC program

; normal processing	
CEV	Disable NC event supervision
T1 BSR .M6	Tool change of first tool
G00 G90 G54 G06 G08	Motion commands, interpolation conditions
X0 Y0 Z10 S3000 M03	Starting position for process
•	
•	Machining
•	
T0 BSR .M6	
@50=0	Initialize variables for the ZOs
O1	Select the 2nd zero offset table
M52	Swing out initiator
G00 G90 G59 G06 G08	Home position, ZO for initiator
X32.5 Y65	Starting position
G01 Z2 F500 M54	Z axis to scan, activate initiator
BEV .GEWB 6	Activate NC event supervision
G01 X97.5 F700	Check for holes
M55 M53	Deactivate initiator and swing back in
O0	Select the first zero offset table
RET	
.GEWB	
DEV	Deactivate NC event supervision
M55 M53	Deactivate initiator and swing back in
@51=X-OTD(,,,,1) @52=Y-OTD(,,,,2)	
@53=Z-OTD(,,,,3)	Note current position
T15 BSR .M6	Change tap
G90 G=54+@50 G06 G08	ZO establishes the tapping position
G01 X40 Y65 Z10 F2000 M03 S1000	Tapping position
G63 Z-7.5 F2	Tap to depth Z
G63 Z10 F2 S1200 M04	Back out tap
T0 BSR .M6	
@50=@50+1	ZO for next hole
M52	Swing out initiator
G00 G90 G59 G06 G08	Home position, ZO for initiator
X=@51+5 Y=@52 Z=@53	Return to position when interruption occurred X axis + 5 mm as safety distance
M54	Activate initiator
EEV	Activate NC event supervision
RTS	Return to point of interruption

8 Tool Management Commands

8.1 Preparing Tools and Tool Data

The preparation of tools and tool data makes a distinction between the magazine and the turret in the sense that both a physical and a logical tool transfer between the spindle and the magazine (in some cases also using grippers) is necessary and in the sense that with most magazines it is necessary to pre-select the tool so that the magazine can be rotated asynchronously to NC-program execution.

When a magazine is used, a theoretical distinction is made between a pre-selected tool and an active tool in a tool spindle.

The pre-selection of a tool initiated by the NC-program causes the pre-selected tool to be placed in the specified tool change position. The data for this tool is not changed until the time of tool transfer, which is also initiated from the NC-program. The tool management system does not supply the data needed for the subsequent process until the transfer command is performed. When this command is performed, the pre-selected tool becomes the active tool and tool edge 1 becomes the default active cutting edge.

During the process, the correction and tool life data for the active edge are used for the length correction and for the edge radius/cutter radius path compensation as well as for evaluating tool life.

With a turret, the tool which has been placed in the working position with the aid of a tool call is referred to as the active tool.

A tool call initiated from the NC-program causes the pre-selected tool to be placed in the specified working position. The tool management system simultaneously supplies the tool data needed for the subsequent process. Tool edge 1 automatically becomes the active edge.

During the process, the correction and tool life data for the active edge are used for the length correction and for the edge radius/cutter radius path compensation as well as for evaluating tool life.

Tool Selection and Tool Call ‘T’

The numerical value assigned to the address letter T by means of a constant or a mathematical expression indicates the tool number or the tool pocket number. The numerical value must be an integer between 0 and 9999999.

Syntax	**T<Constant>**	⇨	**T1234**
	T=<Expression>	⇨	**T=@50**

In a magazine, the T word works in combination with the NC-commands MTP and MMP (see section 8.2 Tool Storage Motion Commands) solely for the purpose of magazine positioning. The corresponding data are not prepared until the next tool transfer by means of NC-commands TCH and TMS (see also section 8.3 Tool Change Commands).

If a turret is used, the T word is used in combination with the NC-commands MTP and MMP to bring the respective tool into the working position and to activate the corresponding tool data.

The T0 call is used in combination with the MTP motion command to bring an unused magazine pocket into the change position. The corresponding tool data are canceled the next time a transfer is called. With a revolver, the "T0" call works together with "MTP" not to produce a motion but simply to cancel the corresponding tool data.

Select Tool Spindle ‘SPT’

If several tool spindles are being used in a process, certain functions such as select edge E must be allowed to act on another tool spindle in addition to the first tool spindle.

Syntax **SPT <Spindle number[1..4]>**

The first tool spindle is always active in the power-on state. If the tool edge is to apply to a tool spindle other than the first tool spindle, the tool spindle must first be selected using SPT <spindle number>.

- The tool spindle must be selected at least one NC-block prior to a function call.
- SPT <spindle number> remains modally active until it is overwritten with a different spindle number or is automatically set to the first tool spindle at the end of the program (RET) or by BST, M02, M30.
- Tool life surveillance, wear factors, tool path compensation, and tool length compensation are valid for the tool of the selected tool spindle.

Tool Edge Selection ‘E’

The numerical value which is assigned to address letter *E* directly by means of a single-digit decimal number (1–9) selects the active tool edge.

Syntax **E<Constant[1..9]>** ⇨ **E1**

E=<Expression> ⇨ **E=@20**

The edge call causes the corresponding correction and tool life data to be prepared internally so that the tool management system can access it during the next process.

Each tool transfer to a given tool spindle causes the tool data to be prepared and edge 1 to become the active edge. Correspondingly, with a turret, a tool call causes the tool data to be prepared and edge 1 to become the active edge.

Since edge 1 is the edge which is most frequently used in processing, it is not necessary to make a separate edge selection in these cases.

8.2 Tool Storage Motion Commands

All tool storage unit motion is performed asynchronously relative to the motions on the other NC axes. The NC motion commands only initiate tool storage unit motion and do not wait until the tool storage unit has completed the motion. In the meantime, the NC-program—and thus the process—can be continued.

A command can be used to scan signals to determine whether the motion which was initiated is finished. In this way, the NC-program is halted and synchronized with the tool storage unit.

Tool Storage to Reference Position ‘MRF’

The MRF command directs the tool storage axis to return to the reference position.

Syntax **MRF**

This command is comparable to G74 for the NC axes of a process. After the controller is powered on, are reference position must be established for the tool storage system before it can traverse to a particular position.

For this reason, the MRF command must be programmed in the reverse program of a process which uses the tool storage system. This must be accomplished in a way which does not depend on the type of axis or type of storage system.

Before performing the MRF command, it is important to be certain that the tool storage motion does not prevent other NC axes from referencing.

Tool Storage to Home Position ‘MHP’

The MHP command causes the tool storage system to traverse to its home position. In this way, the tool management system ensures that the storage system is traversed to position 1 regardless of the type of axis or storage unit.

Syntax

MHP(<Direction[0..2]>)	⇨	**MHP(1)**
MHP(<Variable>)	⇨	**MHP(@120)**

Direction = 0: any given direction
Direction = 1: positive direction
Direction = 2: negative direction

Optionally, the direction of motion can be stated as being in the direction of the home position. If no direction is stated, the controller follows the shortest path.

When traversing to the home position, the tool management system passes position 1 to the SPS if the storage system is SPS-controlled. The SPS must then traverse to the home position by using position 1 as the reference point.

The CNC does not wait until the tool storage unit has reached the home position. It continues to process the NC-program while the tool storage move is being carried out. If this is not desirable, the MRY command tool storage ready? can be used to halt execution of the NC-program until the tool storage motion is completed.

Note: The home position of the NC-controlled tool axis is declared by the machine builder in the axis parameters.

Move Tool into Position ‘MTP’

The MTP command initiates a tool storage move which places the tool selected via the T-word in the NC-program in the specified position (change, installation or processing position).

Syntax

MTP

MTP(<Position[1..4]>)	⇨	**MTP(3)**
MTP(<Position[1..4]>,<Direction[0..2]>)	⇨	**MTP(1,2)**
MTP(<Variable>,<Variable>)	⇨	**MTP(@110,@90)**

Position = 1: move selected tool to change position 1
Position = 2: move selected tool to change position 2
Position = 3: move selected tool to change position 3
Position = 4: move selected tool to change position 4

Direction = 0: any given direction
Direction = 1: positive direction
Direction = 2: negative directing

Optionally, the position into which the selected tool is to be brought and the direction to be taken when the tool is moved to the specified change position can also be declared. If no direction or position is stated, tool management selects the shortest distance and change position 1.

If a number of tools having the name ID and the same T-number are located in the tool storage unit—so-called spare tools—the tool which has the status of process/machining, p tool is automatically selected by tool management.

With machines which have a tool magazine that can be pre-positioned during processing, the MTP command is often used to pre-rotate the magazine. MTP is usually programmed together with tool selection T... in the NC-program immediately after the change of the previously required tool. In this way, the next tool is already moved to the tool change position while machining work continues.

This command is used in particular on tool changers which have double-arm grippers when the previous tool is to be placed in the magazine pocket from which the new tool is being taken.

- Like MFP the T0 MTP command moves the next free pocket into position.
- The CNC does not wait until the tool storage unit has completed its motion. It continues to process the NC-program while the move is being carried out. If this is not desirable, the MRY command tool storage ready? can be used to halt execution of the NC-program until the tool storage motion is completed.

Move Location into Position ‘MMP’

The MMP command initiates a tool storage move which places the location selected via the T word in the specified position (change, installation or processing position).

Syntax

MMP

MMP(<Position[1..4]>)	⇨	**MMP(2)**
MMP(<Position[1..4]>,<direction[0..2]>)	⇨	**MMP(3,1)**
MMP(<Variable>,<Variable>)	⇨	**MMP(@56,@55)**

Position = 1: move selected location to change position 1
Position = 2: move selected location to change position 2
Position = 3: move selected location to change position 3
Position = 4: move selected location to change position 4

Direction = 0: any given direction
Direction = 1: positive direction
Direction = 2: negative direction

Optionally, the position into which the selected location is to be brought and the direction to be taken when the tool is moved to the specified position can also be declared.

If no direction or position is specified, tool management selects the shortest distance and change position 1.

The MMP command is generally used for sorting work and for adding or removing tools.

- When used with the T-word the MMP command refers exclusively to locations and not to tools. For this reason, if tools are called according to the position using MMP, any spare tools which are present are ignored during a process unless they are explicitly programmed in the NC-program with the aid of the T-word and the corresponding location number.
- The CNC does not wait until the tool storage unit has completed its motion. It continues to process the NC-program while the move is being carried out. If this is not desirable, the MRY command tool storage ready? can be used to halt execution of the NC-program until the tool storage motion is completed.

Move Free Pocket into Position ‘MFP’

The MFP command initiates a tool storage motion to move the closest empty pocket to the specified position.

Syntax

MFP

MFP(<Position[1..4]>)	⇨	**MFP(1)**
MFP(<Position[1..4]>,<Direction[0..2]>)	⇨	**MFP(3,1)**
MFP(<Variable>,<Variable>)	⇨	**MFP(@56,@55)**

Position = 1: move closest empty pocket to change position 1
Position = 2: move closest empty pocket to change position 2
Position = 3: move closest empty pocket to change position 3
Position = 4: move closest empty pocket to change position 4

Direction = 0: any given direction
Direction = 1: positive direction
Direction = 2: negative direction

Optionally, the position into which the closest empty pocket is to be brought and the direction to be taken when the tool is moved to the specified position can also be declared. If no direction or position is specified, tool management selects the shortest distance and position 1.

This command is used to place the tool located in the tool spindle or in the gripper in the closest empty pocket in the magazine. This is especially necessary with tool changers which do not have grippers or which use single-arm systems when the old tool needs to be stored before a new tool can be used.

- The CNC does not wait until the tool storage unit has completed its motion. It continues to process the NC-program while the move is being carried out. If this is not desirable, the MRY command tool storage ready? can be used to halt execution of the NC-program until the tool storage motion is completed.

Move Old Pocket into Position ‘MOP’

The MOP command initiates a tool storage motion which moves the old pocket of the tool located in the tool spindle to the position from which the tool was removed.

Syntax

MOP

MOP(<Position[1..4]>)	⇨	**MOP(2)**
MOP(<Position[1..4]>,<Direction[0..2]>,<Spindle>)	⇨	**MOP(2,1,2)**
MOP(<Variable>,<Variable>,<Variable>)	⇨	**MOP(@56,@55,@54)**

Position = 1: move old pocket to change position 1
Position = 2: move old pocket to change position 2
Position = 3: move old pocket to change position 3
Position = 4: move old pocket to change position 4

Direction = 0: any given direction
Direction = 1: positive direction
Direction = 2: negative direction

Spindle = 1: old pocket of tool in spindle 1
Spindle = 2: old pocket of tool in spindle 2
Spindle = 3: old pocket of tool in spindle 3

Optionally, the position, direction of rotation and the tool spindle can be declared. If the position, direction or tool spindle are not entered, the tool management system selects the old pocket for the tool which is active tool spindle 1 and places it in change position 1 using the shortest distance.

If this command is used consistently, all tools will be returned to the pockets in which they were located before they were used in the machining process. This keeps the tool storage unit in an orderly condition. This is desirable, for example, when extra-wide tools always have to be stored in the same magazine pocket.

- The CNC does not wait until the tool storage unit has completed its motion. It continues to process the NC-program while the move is being carried out. If this is not desirable, the MRY command tool storage ready? can be used to halt execution of the NC-program until the tool storage motion is completed.

Tool Storage Ready? 'MRY'

If the last tool storage motion command has not finished processing, the MRY command temporarily interrupts processing of the NC-program.

Syntax **MRY**

The NC-program does not resume processing until the programmed position has been reached. This permits the tool storage axis to be synchronized with the NC-program.

Tool Storage Enable for Manual Mode 'MEN'

The MEN command allows a tool magazine to be traversed manually while automatic mode is active. For example, this allows a worn tool to be changed while production continues.

Syntax **MEN**

In order for the tool magazine to run in manual mode, the MEN command must be active in the NC-program and the SPS must have selected manual mode for the tool storage. If the tool storage mode is changed to manual after an MEN command has been performed, the CNC continues to execute the program for this process until the next tool storage motion or tool change command is encountered. It then issues the corresponding status message:

```
"*Waiting for tool storage move cmd to be completed"
```

When the system changes back to program-controlled mode, the status message in the diagnostic box is cleared and the remaining commands are processed to completion.

- All motion and tool change commands programmed in the NC-program (generally located in a tool change subroutine) request the tool storage.
- If a further motion or tool change command follows before the change to manual mode and after the tool storage system was enabled via MEM in the NC-program, the tool storage unit cannot be traversed manually while the program is executing and continuing to the next MEN, BST, RET or Control-Reset.

8.3 Tool Change Commands

The tool changer commands should only be used when a magazine is used as the tool storage unit and tools need to be moved between the magazine and the spindle (in some cases via grippers).

Complete Tool Change ‘TCH’

The TCH command initiates a tool change between the spindle and the magazine pocket in the change position.

Syntax **TCH**

TCH(<Position[1..4]>)	⇨	**TCH(1)**
TCH(<Position[1..4]>,<Spindle[1..3]>)	⇨	**TCH(2,1)**
TCH(<Variable>,<Variable>)	⇨	**TCH(@70,@71)**

Position = 1: move selected location to change position 1
Position = 2: move selected location to change position 2
Position = 3: move selected location to change position 3
Position = 4: move selected location to change position 4

Spindle = 1: Tool change in spindle 1
Spindle = 2: Tool change in spindle 2
Spindle = 3: Tool change in spindle 3

The CNC stops program execution while the tool change operation is proceeding under SPS control.

Optionally, the change position and tool spindle can be declared. If no data are declared for the change position or tool spindle, tool management selects change position 1 and tool spindle 1.

- The magazine must be correctly positioned before TCH is called.
- The TCH command is used in particular with double-arm gripper systems.

Change Tool from Magazine to Spindle ‘TMS’

The TMS command initiates a tool transfer between the magazine pocket in change position and the tool spindle.

Syntax **TMS**

TMS(<Position[1..4]>)	⇨	**TMS(3)**
TMS(<Position[1..4]>,<Spindle[1..3]>)	⇨	**TMS(2,2)**
TMS(<Variable>,<Variable>)	⇨	**TMS(@80,@81)**

Position = 1: move selected location to change position 1
Position = 2: move selected location to change position 2
Position = 3: move selected location to change position 3
Position = 4: move selected location to change position 4

Spindle = 1: Tool change in spindle 1
Spindle = 2: Tool change in spindle 2
Spindle = 3: Tool change in spindle 3

The CNC stops program execution while the tool change operation is proceeding under SPS control.

Optionally, the change position and tool spindle can be declared. If no data are declared for the change position or tool spindle, tool management selects position 1 and spindle 1.

- Even before TMS is called, the magazine pocket containing the tool which is to be exchanged must already be in the specified change position, and a tool must not be present in the tool spindle.

- This command is needed for single-arm gripper systems or for grip-perless tool changers if the change operation has to be divided into a pick and place sequence.

Change Tool from Spindle to Magazine ‘TSM’

The TSM command initiates a tool transfer between the spindle and the magazine pocket in change position.

Syntax	**TSM**		
	TSM(<Position[1..4]>)	⇨	**TSM(4)**
	TSM(<Position[1..4]>,<Spindle[1..3]>)	⇨	**TSM(4,2)**
	TSM(<Variable>,<Variable>)	⇨	**TSM(@90,@91)**

Position = 1: move selected location to change position 1
Position = 2: move selected location to change position 2
Position = 3: move selected location to change position 3
Position = 4: move selected location to change position 4

Spindle = 1: Tool change from spindle 1
Spindle = 2: Tool change from spindle 2
Spindle = 3: Tool change from spindle 3

The CNC stops program execution while the tool change operation is proceeding under SPS control. Optionally, the change position and tool spindle can be declared. If no data are declared for the change position or tool spindle, tool management selects change position 1 and tool spindle 1.

- Before TSM is called, a tool must be present in the tool spindle and the magazine must have an empty pocket at the specified change position.
- This command is needed for single-arm gripper systems or for grip-perless tool changers if the change operation has to be divided into a pick and place sequence.

Branch with Spindle Empty ‘BSE’

The BSE branch command permits an empty spindle to be detected.

Syntax	**BSE <Branch label>**	⇨	**BSE .SPLE**

If the spindle is empty, the program execution is continued at the branch label that is specified in the command parameter.

Branch If Tool T0 Selected ‘BTE’

The BTE command can be used to determine whether T0 was last selected, in other words: whether the tool must be removed from the tool spindle without loading a new tool into the tool spindle.

Syntax	**BTE <Branch label>**	⇨	**BTE .PRT0**

If T0 was programmed, program execution continues at the branch label defined in the command parameter.

9 Commands for Controlling Processes and Programs

9.1 Process Control Commands

The multiple-process structure of the CNC makes it necessary to coordinate the individual processes used in the CNC. If more than two processes are present on the CNC, the process whose number is "0" is generally used for program coordination. The number "0" process thus handles the management function used to coordinate all processes which are involved in the work. The process control commands are passed to the CNC ↔ SPS interface.

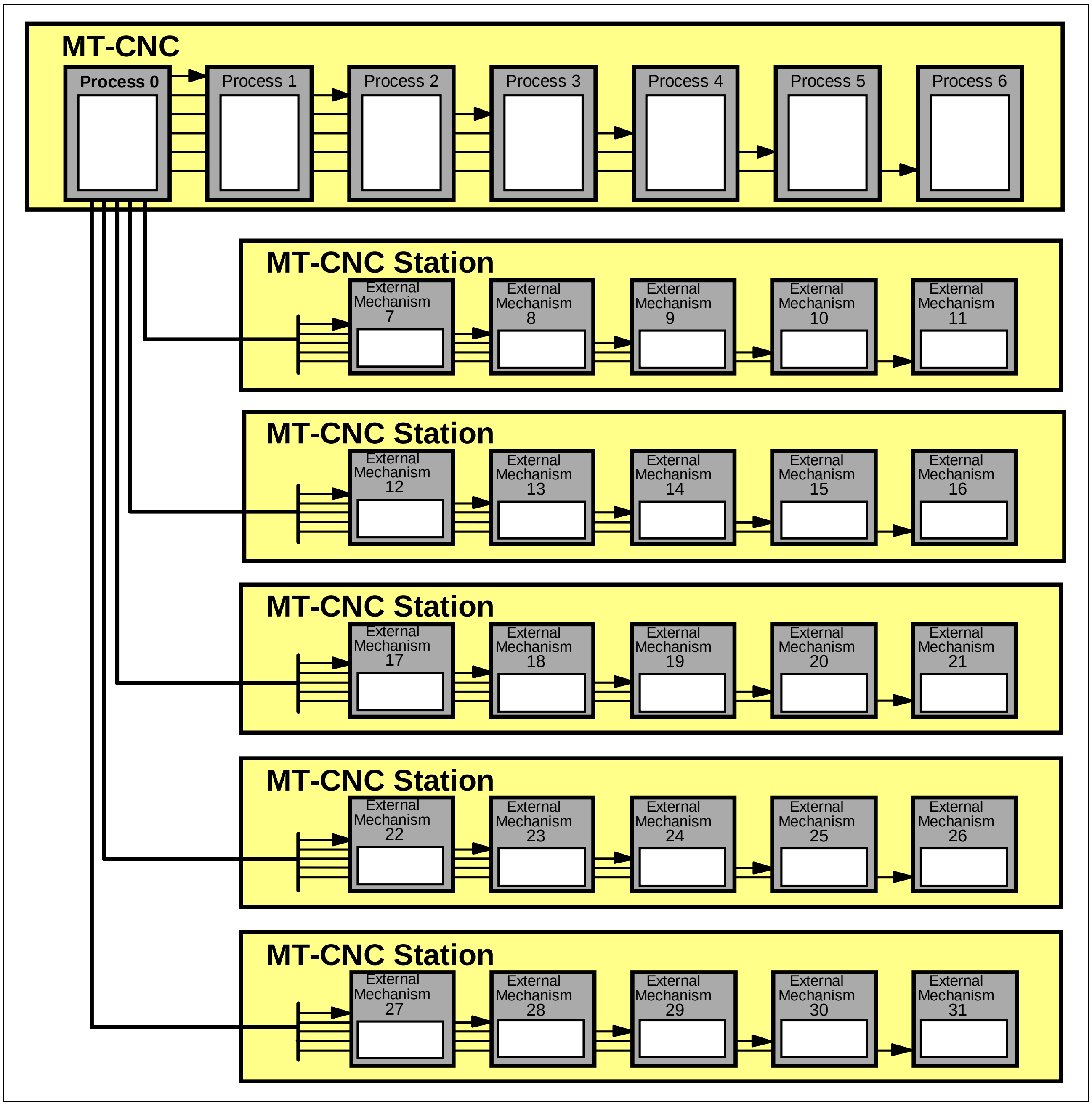


Fig. 9-1: CNC processes and external mechanisms

In addition to the management process, the CNC can control six additional processes and up to 25 external mechanisms.

A management process (process 0) must always be present. This process is responsible for synchronizing the existing processes and external mechanisms, assuming this is necessary. If the system consists of a single station, the coordination task and the axes are assigned directly to the management process.

Note: The number and organization of the processes and external mechanisms is set by the machine builder in the system parameters.

Define Process ‘DP’

The "DP" command uses an internal signal to inform the SPS that the process is needed during NC-program execution. The SPS uses this information to initialize process-specific signals.

Syntax **DP <process>** ⇨ **DP 2**

DP <variable>

Process[0..6] internal processes
Process[7..31] external mechanisms

All other process control commands will not be accepted unless the corresponding process was previously defined using "DP."

- The "DP" command can be used more than once in the NC-block and a number of processes can be defined simultaneously in one NC-block.
- The definition of a process using "DP" is canceled at the end of the program.

Select NC Program for Process ‘SP’

The "SP" command selects the program having the specified program number from the active NC program package for the specified process. The program number corresponds to the number which is stated in the program directory for the given process.

Syntax **SP <process> <program number>** ⇨ **SP 3 25**

SP <variable> <variable>

Process[0..6] internal processes

Process[7..31] external mechanisms

NC program number [1..99] **NC program number in active program package**

The NC program number for the next program which is to be processed can be selected while a process is still active. The selected program is not activated until the next reboot.

- The SP command must not be used more than once in an NC block.

Reverse Process ‘RP’

The "RP" command starts the subprogram which is addressed by the reverse vector in the declared process. Any active forward program which may be present is interrupted and the currently valid reverse vector addresses the branch-to location in the reverse program.

Syntax **RP <process>** ⇨ **RP 4**

RP <variable>

Process[0..6] internal processes
Process[7..31] external mechanisms

- The subroutine addressed by the reverse vector must be located in the program in which the reverse vector was programmed.
- The RP command can be used more than once in the NC block, and a number of reverse programs can be started simultaneously in one NC block.

Advance Program ‘AP’

The "AP" command starts the selected forward program in an inactive process. If the process was already active, NC block processing in the process in which the "AP" command was programmed is stopped until the process which is to be started again has finished. The declared process is then started, and NC block processing of the interrupted process is continued.

Syntax **AP <process>** ⇨ **AP 1**

AP <variable>

Process[0..6] internal processes
Process[7..31] external mechanisms

- The AP command can be used more than once in an NC block. A number of forward programs can be started simultaneously in a single NC block.

Wait for Process ‘WP’

NC block processing of the program from which the call is made is held in the NC block in which "WP" is programmed until the process selected in the command parameter has finished processing.

Syntax **WP <process>** ⇨ **WP 5**

WP <variable>

Process[0..6] internal processes
Process[7..31] external mechanisms

Once the process selected in the command parameter is finished, execution of the NC program from which the call was made can continue.

- The process control command "WP" can be programmed more than once in a single NC block.
- The "WP" command should not be programmed in a portion of a program in which tool path compensation is active. If this proves to be unavoidable, be certain the WP is only programmed between *linear* NC block transitions.

Lock Process ‘LP’

The "LP" command specifies which processes must be in a defined state for the NC program to be completed. This state must remain intact until the NC program is completed.

Syntax **LP <process>** ⇨ **LP 4**

LP <variable>

Process[0..6] internal processes
Process[7..31] external mechanisms

This command can be used, for example, to specify that a station which is not needed for the work can be turned off or that it must be in a specific position so as not to endanger ongoing work.

- Stations which are locked using "LP" cannot be operated manually (if proper SPS interlocks), even though they might not be involved in the programmed work.
- The process control command "LP" is reset and the end of the program by "RET," "BST," “M02,” “M30,” or by Control-Reset.

Example NC program - Process control commands

If a reverse vector is not programmed in any of the processes, the given process jumps to the .HOME label.

Management program	Process 0 program number 15
.START	Label for BST .START
DP 1 DP 2	Definition of process 1 and process 2
SP 1 15	Select program, program 15 in process 1
SP 2 15	Select program, program 15 in process 2
AP 1 AP 2	Start forward program in processes 1 & 2
WP1 WP 2	Wait until both processes have finished their program
SP 1 16	Select program, program 16 in process 1
SP 2 16	Select program, program 15 in process 2
AP 1 AP 2	Start forward program in processes 1 & 2
WP1 WP 2	Wait until both processes have finished their program
BST .START	Branch with stop to .START label
.HOME	Label for .HOME program
DP 1 DP 2	Definition of processes 1 & 2
SP 1 15	Select program, program 15 in process 1
SP 2 15	Select program, program 15 in process 2
RP 1 RP 2	Start reverse program in processes 1 & 2
WP1 WP 2	Wait until both processes have finished their program
BST .START	Branch with stop to .START label
End of Program	

NC program 15 process 1

```
G00 G90 G54 G06 G08     ;Motion commands
G00 Y0 Z50              ;Start position
M03 S1500               ;Spindle ON
G01 X50 Y100 F1000      ;1st mach. position
.                       ;Machining
M05                     ;Spindle OFF
RET                     ;End of program
```

NC program 15 process 2

```
G18 G90 G54 G06 G08     ;Motion commands
G00 X0 Z0 Y70           ;Start position
M03 S1500               ;Spindle ON
G01 X50 Z40 F1500       ;1st mach. position
.                       ;Machining
M05                     ;Spindle OFF
RET                     ;End of program
```

NC program 16 process 1

```
G00 G90 G54 G06 G08     ;Motion commands
X0 Y0 Z30               ;Start position
M03 S1500               ;Spindle ON
G01 X90 Y150 F1200      ;1st mach. position
.                       ;Machining
M05                     ;Spindle OFF
RET                     ;End of program
```

NC program 16 process 2

```
G18 G90 G54 G06 G08     ;Motion commands
G00 X0 Z0 Y55           ;Start position
M03 S1500               ;Spindle ON
G01 X10 Z110 F2000      ;1st mach. position
.                       ;Machining
M05                     ;Spindle OFF
RET                     ;End of program
```

Process Complete (Full Depth) ‘POK’

By programming the "POK" NC command (part O.K.), the NC programmer can determine from within the NC program when the process was completed. The "POK" command causes a signal to be sent to the SPS (process-specific).

Syntax **POK**

If the "POK" NC command is programmed in process "0," the SPS signals is not set to "1" until all processes defined by means of "DP" (including the external mechanisms) have already performed the "POK" command.

- The signals for the "POK" command are reset at the end of the program by "RET" or "BST" or by a Control-Reset.

9.2 Axis Transfer Between the Processes ‘FAX’, GAX’

Certain applications require that the fixed axis assignments to the processes be canceled and that the axes be divided into a number of interpolation groups (processes).

Each NC axis is assigned to a primary process; however, it can also be assigned to up to three different secondary processes. The axis name and meaning in the coordinate system is the same for all processes in which the axis is enabled. In addition, different axes having the same name can be called from different processes.

Syntax Free the axis <axis name> in the process in which the axis is located.

FAX (<axis name>) ⇨ **FAX (Y)**

Get the axis <axis name> from the process defined in the command parameter.

GAX (<process>:<axis name>) ⇨ **GAX (1:Y)**

- The primary process must always be stated when specifying the process for the "GAX" command. If the axis is called from the primary process via "GAX," it is not necessary to state the process number.

An axis transfer will not occur until the axis is freed by the process in which the axis is currently located and is called by a different process. The process which calls the axis (GAX) must wait until the other process frees the axis (FAX). Likewise, the process which frees the axis waits until a different process calls the axis. This prevents the axis from assuming a "*lost*" state.

Transferable axes are displayed in the position display of each process in which they can be present.

If a transferable axis is located in the indicated process, the complete axis data set is displayed for this axis. On the other hand, if the axis is assigned to a different process, two dashes are displayed instead of the position and speed data.

- All axes in the CNC—with the exception of the magazine and turret axes—can be transferred between the processes.
- The transfer from one process to another can only take place at a NC block transition. NC block processing is stopped and is not continued until it is certain that the override value for the new process is active for the axes.
- Rotary and linear axes can only be transferred between processes when they are stopped.
- Spindles can also be transferred between the processes at the specified spindle speed. However, spindle-dependent feed modes such as "feed per rpm" are deactivated when spindles are transferred.

- The axis continues to be assigned to the primary process, even after the axis is transferred to a secondary process. Thus, axis error and their diagnostic messages are displayed in the primary process.
- All axis belonging to a different primary process are freed (free) at the end of the program by "RET" or "BST" or by a control reset and by jogging axes in the setup mode; and all axes in a different process are requested (get).

Note: The machine builder specifies the processes between which an NC axis can be transferred in the axis parameters.

Example NC program—Axis transfer

A machining center having two tables is divided into 3 NC processes. Since the parts which are to be machined on the two tables can be identical, the machine operator wants to be able to use the same NC programs. The X axis offset is generated by overwriting the zero offset.

The process is divided as follows:

– Process 0 is the machining process, which has 3 main axes, "X," "Y" and "Z" as well as main spindle "S." Processes "0," "1" and "2" are started simultaneously by pressing the NC start key.

– Process 1 manages the rotary table (B axis) on the right side and either frees or gets the B axis as needed. Process synchronization is established by means of the programmed NC events.

– Process 2 manages the rotary table (B axis) on the left side and either frees or gets the B axis as needed. Process synchronization is established by means of the programmed NC events.

The necessary initializations and the corresponding reverse program are not shown in the NC program. If the NC program is interrupted, various mechanisms and initializations would be needed to obtain a defined state.

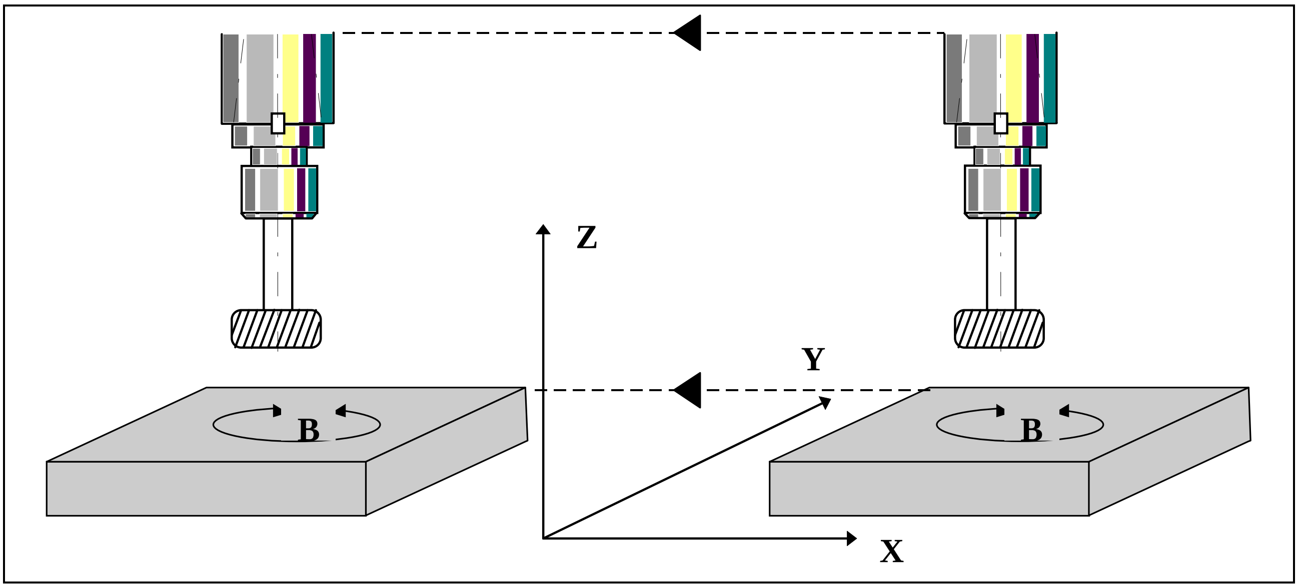


Fig. 9-2: Axis transfer on a machining center having 2 machining tables

Process 1 "B axis right"		**Process 2 "B axis left"**	
.BEARB	Label for the branch loop	.BEARB	Label for the branch loop
FAX (B)	Free B axis	FAX (B)	Free B axis
WES 9	Wait until B axis in P0	WES 9	Wait until B axis in P0
RE 9		RE 9	
GAX (B)	Get B axis if freed in machining process	GAX (B)	Get B axis if freed in machining process
BER .BEARB 10	Loop until machining is completed in P0	BER .BEARB 10	Loop until machining is completed in P0
RE 10		RE 10	
RET		RET	

Process 0 "Machining"	
RE 1:10 RE 2:10	Reset NC events for branch loops in process 1 + 2
T1 BSR .M6	Tool change of first tool
[right side]	
GAX (1:B)	Get B axis from process 1
SE 1:9	Process 1 is stopped up to this NC block
WER 1:9	Wait until process 1 is synchronized
BSR .BET1	Machine right side
[left side]	
GAX (2:B)	Get B axis from process 2
SE 2:9	Process 2 is stopped up to this NC block
WER 2:9	Wait until process 2 is synchronized
BSR .BET1	Machine left side
T2 BSR .M6	Tool change of second tool
[right side]	
GAX (1:B)	Get B axis from process 1
SE 1:9	Process 1 is stopped up to this NC block
WER 1:9	Wait until process 1 is synchronized
BSR .BET2	Machine right side
[left side]	
GAX (2:B)	Get B axis from process 2
SE 2:9	Process 2 is stopped up to this NC block
WER 2:9	Wait until process 2 is synchronized
BSR .BET2	Machine left side
• •	
SE 1:10 SE 2:10	End branch loops in processes 1 and 2.
T0 BSR .M6	
RET	End of program
.BET1	Machining program 1st tool
G00 G54 G90 X0 Y0 Z100 B0	Motion commands, interpolation conditions
M03 S1000	
•	
;machining	
•	
M05	
FAX (B)	Free B axis
RTS	End of machining subroutine 1
.BET2	Machining program 2nd tool
•	
RTS	End of machining subroutine 2

9.3 Program Control Commands

Return to NC program Begin ‘RET’

The "RET" command identifies the end of an NC program. The "RET" command acts like functions "M002"/"M030," however an auxiliary function is not passed on to the SPS. When the "RET" command is performed, processing branches to the first NC block in the active NC program, sets the preparatory functions for the power-on state, and waits for a start signal. After the "RET" command has been performed, the current reverse vector points to the branch label ".HOME".

Syntax **RET**

After the "RET" command is performed, all subroutine levels and their reverse vectors are cleared and the controller is in the initial state in the main program level.

- In terms of its function "RET" is comparable to the "M002"/"M030" functions defined in DIN 66025.

Branch with Stop ‘BST’

The "BST" command branches to the branch label which is set in the command parameter, sets the preparatory functions of the "power-on state" and waits for a start signal. After a "BST", the current reverse vector points to the branch label ".HOME".

Syntax **BST <branch label>** ⇨ **BST .HALT**

After a "BST" command, all subroutine levels and their reverse vectors are cleared and the controller is in the initial state.

- The "BST" command cannot be used within a subroutine . The branch from the subprogram will result in an error message.

Programmed Halt ‘HLT’

The "HLT" command interrupts program execution and waits for a new start signal. The "HLT" command acts like function "M000," however an auxiliary function is not passed on to the SPS:

Syntax **HLT**

If a message is to be output with the "HLT" command, it is important to note that the message must be programmed in a NC block prior to the "HLT" command. The reason for this is that the "HLT" command is executed ahead of a message in the standard order in which NC commands are carried out (see Chapter "Elements of an NC block").

Branch Absolute ‘BRA’

The "BRA" command branches to the label set in the command parameter and continues program execution there.

Syntax **BRA <branch label>** ⇨ **BRA .WEITER**

Jump to NC Program ‘JMP’

The "JMP" command jumps to the NC program number set in the command parameter and continues program execution in this new NC program in the first NC block.

Syntax **JMP <program number[1..99]>** ⇨ **JMP 50**

JMP <variable> ⇨ **JMP @100**

The jump can go to any desired NC program in the active NC program package of the NC memory. The reverse vectors an not changed by a jump to a different NC program.

9.4 Subroutines

Subroutine Technique

When workpieces are being machined it is sometimes necessary to repeat a given operation a number of times. This operation could be programmed as a subroutine so that the similar processing sequences could be called repeatedly. This subroutine could be called from any point in the NC machining program as a complete function module.

Subroutines are organized in the CNC based on the following structure.

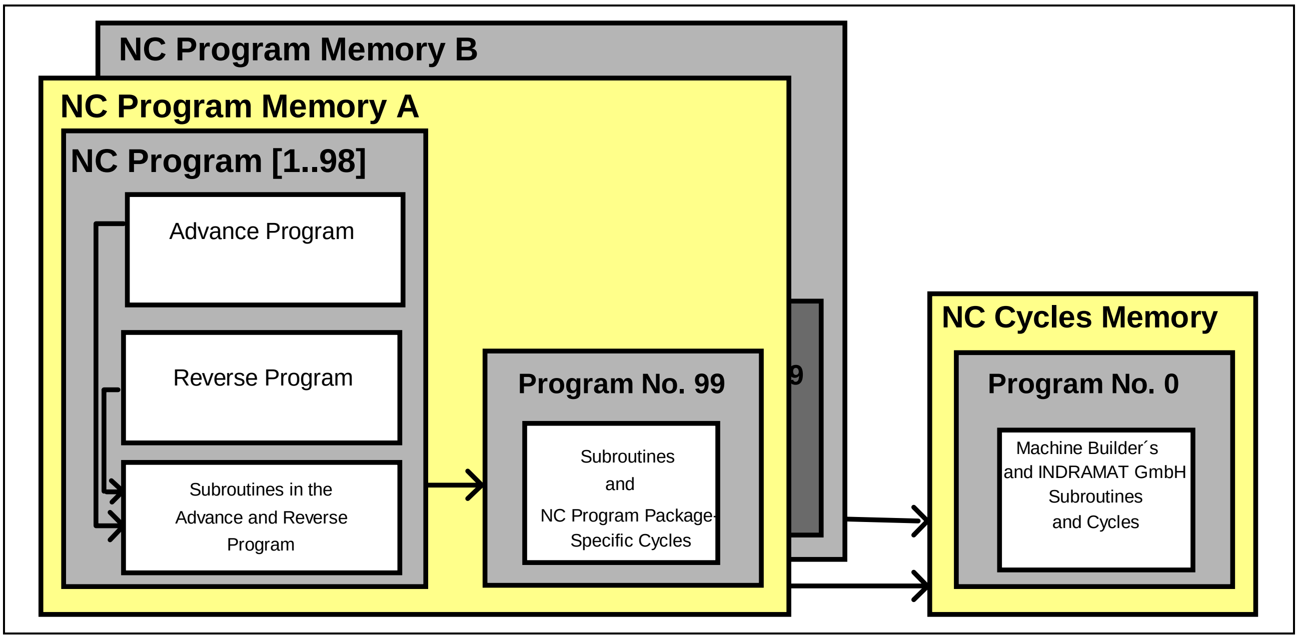


Fig. 9-3: Program organization in the CNC

Subroutines which are specific to the NC program are programmed in the current NC program. Subroutines which are specific to the NC package are programmed in the program using number "99". They can be called from any NC program in the package. Parameterizable subroutines and machining NC cycles are programmed/loaded in the NC cycles memory. These NC cycle programs can be called from any NC memory, process and NC program package.

Subroutine Organization

A subroutine consist of the:

- Beginning of the subroutine
- NC blocks in the subroutine
- Return from the subroutine (end)

.LABEL	Start of subroutine
NC blocks	NC blocks in subroutine
RTS	Return from subroutine

Fig. 9-4: Subroutine structure

In terms of syntax, the "jump label" begins with a decimal point followed by at least one and no more than six legal characters. The syntax is NOT case sensitive. The "*" sign following the decimal point is reserved for INDRAMAT canned NC cycles.

Subroutine Nesting

A subroutine can be called from an NC program as well as from a different subroutine. This is referred to as "subroutine nesting."

The CNC allows 10 subroutine nesting levels. This means that subroutines can be nested no more than 9 levels deep.

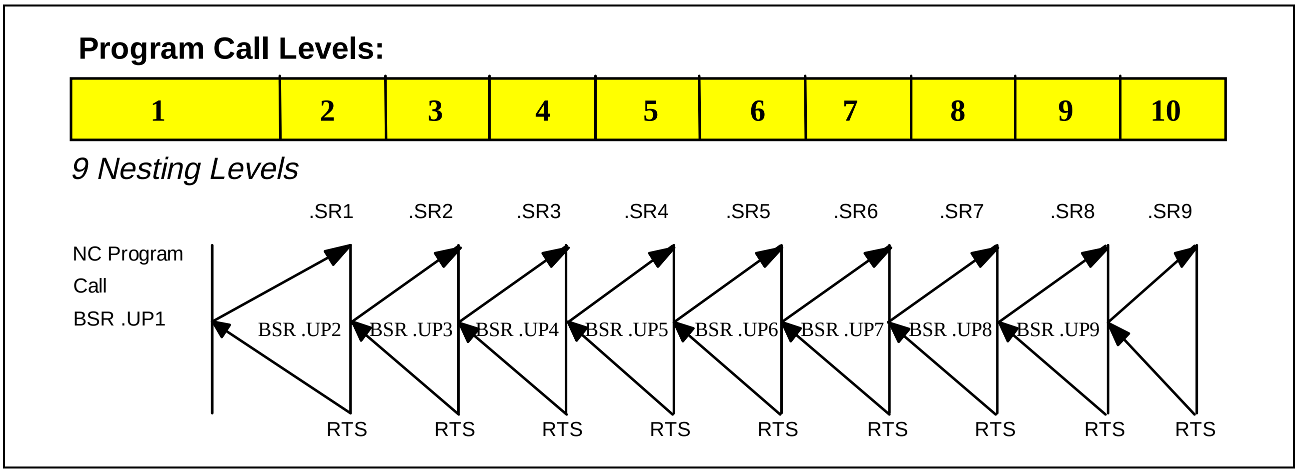


Fig. 9-5: Subroutine nesting

Jump to NC Subroutine 'JSR'

The "JSR" command jumps to the NC program number set in the command parameter and continues program execution in this new NC program in the first NC block. In contrast to the "JMP" command, the called NC program returns to the NC program from which is was called after the "RTS" command has executed. This allows entire NC programs to be used as subroutines.

Syntax **JSR <program number[1..99]>** ⇨ **JSR 15**

JSR <variable> ⇨ **JSR @25**

The jump can go to any desired NC program in the active NC program package. The reverse vectors are not changed by a jump to a different NC program.

Branch to NC Subroutine 'BSR'

The "BSR" command branches to the label set in the command parameter and continues program execution there.

Syntax **BSR <label>** ⇨ **BSR .UP1**

After the return from a subroutine called by using the "BSR" command via the "RTS" command, the calling program is continued at the next NC block.

Return from NC Subroutine 'RTS'

The "RTS" command marks the end of the subroutine. After the "RTS" command finished, processing returns to the NC program from which the call was made, and NC block processing is continued in the NC block following "BSR" or "JSR."

Syntax **RTS**

- If a subroutine call did not precede the return from a subroutine (BSR, JSR), the program will be stopped and an error message will be generated.

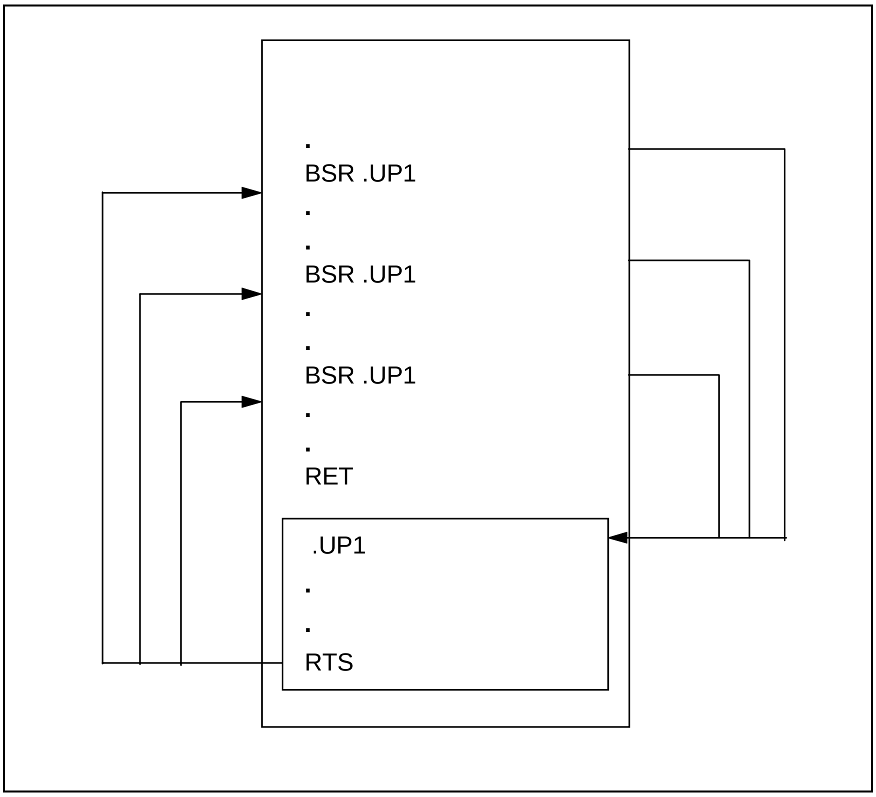


Fig. 9-6: Branch to NC subroutine

9.5 Reverse Vectors

The CNC permits flags to be defined for reverse programs based on various program states relating to certain machine positions. These withdrawal programs (reverse programs) are used to program how the NC axis must withdraw from the various positions and return to a defined state. The flags for the reverse programs, which are identified by labels, are referred to as "reverse vectors."

The label ".HOME" was defined as the basic reverse vector for the main program after control power-on. This basic reverse vector must be part of every NC program, or it must be present in program no. 99 or in the NC cycle memory, and it must mark the beginning of the basic reverse program.

After each end of program via "RET" or "BST" and after each time the controller is reset in the "power-on state," the reverse vector in the main program points to the label ".HOME", and all reverse vectors in the subprograms are cleared.

Set Reverse Vector ‘REV’

The NC block containing the label declared as the command parameter is defined as the first NC block in the reverse program—in other words, a reverse program would start processing at this label beginning at the NC block.

Syntax **REV <label>** ⇨ **REV .HOLE1**

Reverse vectors can also be defined within subroutines. Such reverse vectors in subroutines have the same nesting structure in the reverse program as in the advance program. Reverse programs from subroutines must also be terminated by the "RTS" command.

- When a subroutine is closed, the reverse vectors set up in it are automatically cleared.
- A reverse vector programmed in an NC block will not be activated until the end of the NC block execution.
- The label programmed in conjunction with "REV" must be located in the NC program in which the "REV" command was programmed. The "REV" command will not find the label in the global program identified by number 99 or in the NC cycles memory.

Example	NC program - Global Homing Program
.HOME	Basic reverse vector
MRF	Reference tool magazine
D0	Cancel D overrides
G40 G47 G53 G90	Home
G74 Z0 F1000	Go to Z axis reference point
G74 X0 Y0 F1500	Go to X and Y axis reference point
T0 BSR .M6	Tool from spindle to magazine
MRY	Wait until magazine is in position
RET	End of program

CAUTION

All reverse vectors are cleared upon a control-reset. The branch label of the reverse program points to the basis reverse vector .HOME. The NC blocks that are defined by the reverse vectors (REV) are no longer processed. Merely the NC blocks of the base reverse vector .HOME are included.

Example

```
;          Tool changing program.
N0000 .M6
;          install new tool?
N0001 .M6_TOL
           @0:00=TLD(,0,1,1,0,5,)                    Read tool no. spindle 1
N0002 @0:00=@0:00-T BEQ .M6_T0                       Must tool be changed?
;          Magazine positioning
N0003 BTE .M6_BAC                                    T0 programmed ?
N0004 MTP                                            Move to programmed
                                                     location
N0005 BRA .M6_TCH
N0006 .M6_BAC
         MFP                                         Move to free location
;          tool change
N0007 .M6_TCH
           G40 G47 G53 G90 M9                        Tool correction OFF,
                                                     Machine zero point,
                                                     absolute dimension
N0008 SE 0:15
N0009 G0 Z392 M19 S90 MRY  REV .RM6_2                Z axis and spindle in
                                                     change position
N0010 Q1                  REV .RM6_3                 Close gripper
N0011 Q2                  REV .RM6_4                 Loosen tool
N0012 TMS                 REV .RM6_5
N0013 Q7                  REV .RM6_6                 Extend gripper
N0014 Q3                  REV .RM6_7                 Rotate gripper
N0015 Q8                  REV .RM6_8                 Retract gripper
N0016 Q6                  REV .RM6_9                 Spindle clamp closed
N0017 Q5                  REV .RM6_10                Open gripper
N0018 RE 0:12                                        Transfer: G1 ->
                                                     Spindle, G0 -> Mag.
N0019 TSM                 REV .RM6_12
N0020 RE 0:15
N0021 BTE .M6_T0                                     was T0 programmed?
N0022 G48 [ ] RTS
;changing tools not necessary (tool already in spindle) or
;T0 has been programmed
N0023 .M6_T0
N0024 [ ] RTS
;
```

; Reverse vectors for the tool changing program	
N0025 .RM6_6 Q3	Turn arm back
N0026 .RM6_5 Q8	Retract gripper
N0027 .RM6_4 SE 0:12	Transfer. G1 -> Mag. G0 -> Spindle
N0028 TSM	
N0029 .RM6_3 Q6	Spindle clamp closed
N0030 .RM6_2 Q5	Open gripper
N0031 RTS	
N0032 .RM6_7 Q8	Retract gripper
N0033 .RM6_8 Q6	Clamp closed
N0034 .RM6_9 Q5	Open gripper
N0035 .RM6_10 RE 0:12	
N0036 TSM	
N0037 .RM6_12 BTE .M6_T0	
N0038 G48 [ ] RTS	
N0039 RTS	

Consistent reverse vector programming permits errors that occur during program execution to be taken into account.
If, for example, a malfunction occurs while a Q function is being executed, the reverse vectors are employed for moving the machine back to an uncritical state.
This is no longer possible if the reverse vectors are cleared by a control-reset.

- Remedial action

In these situations, clearing the reverse vectors by control-reset must be prevented.
This is possible by an event (here: event 0:15) and its nesting in the SPS program.

```
              E0:15                        CtrlReset
├......─────┤/├──────────────────────────(S)──────┤
```

Control-reset is not possible as long as the event is set (during the execution of the Q functions). Control-reset is only possible after the event has been reset.

Note: If, in exceptional situations, control-reset shall be possible even after an event has been set, the event can manually be reset via the user interface.
This enables the machine manufacturer to distinguish between authorized and non-authorized end users.
With tool changers, updating the tool management must be ensured.

9.6 Conditional Branches

Conditional branches are not performed unless the corresponding condition is met. If this condition is not met, the program continues to execute starting at the following NC block.

Branch if Spindle is Empty ‘BSE’

The BSE branch command can be used to determine whether or not the spindle is empty.

Syntax **BSE <label>** ⇨ **BSE .SPLE**

If the spindle is empty, program execution is continued from the branch label that is specified in the command parameter.

Branch If Tool T0 Selected ‘BTE’

The "BTE" command can be used to determine whether "T0" was last selected, in other words: whether the tool must be removed from the spindle without loading a new tool into the spindle.

Syntax **BTE <branch label>** ⇨ **BTE .PRT0**

If "T0" was programmed last, program execution continues at the branch label defined in the command parameter.

Branch If Reference ‘BRF’

The "BRF" branching command can be used to determine whether the NC axes in the CNC are located at their reference points.

Syntax **BRF <branch label>** ⇨ **BRF .NORE**

If the NC axes are properly referenced, program execution continues at the branch label defined in the command parameter.

Branch If NC Event Set ‘BES’

The "BES" command "branch if NC event set" is used to continued program processing at the declared branch label if the NC event defined in the command parameter is set.

Syntax

BES <branch label> <process number [0..6]>:<NC event number[0..31]> ⇨ **BES .LABEL 1:15**

BES <branch label> <NC event number[0..31]> ⇨ **BES .LABEL 9**

- If the symbol "∗" is declared instead of the "NC event number," processing to the addressed branch label if at least one NC event in the specified process is set.
- NC events can also be changed by the SPS program. Therefore please refer to the machine builder's information since the builder may have used various NC events for synchronization purposes.

Branch If NC Event Reset ‘BER’

The "BER" command "branch if NC event reset" is used to continued program processing at the declared branch label if the NC event defined in the command parameter is reset.

Syntax

BER <branch label> <process number[0..6]>:<NC event number[0..31]> ⇨ **BER .LABEL 1:15**

BER <branch label> <NC event number[0..31]> ⇨ **BER .LABEL 9**

- If the symbol "*" is declared instead of the "NC event number," processing to the addressed branch label if all the NC events in the specified process are reset.
- NC events can also be changed by the SPS program. Therefore please refer to the machine builder's information since the builder may have used various NC events for synchronization purposes.

9.7 Conditional Branches Upon the Results of Arithmetic Operations

"Branches which are conditional upon the results of arithmetic operations" relate to the results of the most recently performed arithmetic operation.

Branch If Equal to Zero ‘BEQ’

The command "BEQ" is used to continue program execution at the specified label if the result of the most recent mathematical operation was equal to zero.

Syntax **BEQ <label>** ⇨ **BEQ .ZERO**

Branch If Not Equal to Zero ‘BNE’

The command "BNE" is used to continue program execution at the specified label if the result of the most recent mathematical operation was not equal to zero.

Syntax **BNE <label>** ⇨ **BNE .NZERO**

Branch If Greater Than or Equal to Zero (If Minus) ‘BPL’

The command "BPL" is used to continue program execution at the specified label if the result of the most recent mathematical operation was greater than or equal to zero.

Syntax **BPL <label>** ⇨ **BPL .GZERO**

Branch If Less Than Zero (If Minus) ‘BMI’

The command "BMI" is used to continue program execution at the specified label if the result of the most recent mathematical operation was less than zero.

Syntax **BMI <label>** ⇨ **BMI .LZERO**

Overview:

	@10=A-B	@10=B-A
A = B	BEQ	BEQ
A <> B	BNE	BNE
A < B	BMI	---
A <= B	---	BPL
A > B	---	BMI
A >= B	BPL	---

Example NC program Loop construct

@51=0	Pre-assigning the loop variable
.NEXT	Start-of-loop label
@51=@51+1	Increment loop variable
@100=MTD(250,0,1,@51)	Read machine data variable Page=250, LV1=0, LV2=1, Element=@51
@100=@100-25 BEQ .BREAK	Exit loop if machine variable = 25
@100=@51-10 BMI .NEXT	Interrogate loop variable if loop condition is still true
[no element of the machine data has a value of 25]	Output message
M00	Acknowledge programmed halt from SPS
BRA .EXIT	Branch to end of program
.BREAK	Loop exit label
[one element of the machine data has a value of 25]	Output message
M00	Acknowledge programmed halt from SPS
.EXIT	End-of-program label
M30	Acknowledge end of program from SPS

10 Variable Assignments and Arithmetic Functions

10.1 Variables

NC variables are used in an NC program to represent a numerical value. A value can be assigned to a NC variable by the NC program, PLC program or from the user interface, and the value of the NC variable can likewise be read by these programs or by the user interface.

NC variables are identified

- by the address @,
- by optionally stating the process number followed by a colon, and
- by a 1–3-digit number.

256 *NC variables* (0 to 255) are available for each of the 7 processes in the CNC. In theory, a total of 1792 NC variables are available in the CNC, that can be used independent on how many processes are defined.

Syntax

@<process number[0..6]>:<variable number[0..255]> ⇨ **@1:100**

If the process number is not declared, the NC variable relates to the process in which the NC variable was programmed.

Syntax for assigning a value to an NC variable

@<process number[0..6]>:<variable number[0..255]>=<arithmetic expression>

@1:100=5*100

Internally, the data appears in a "double real" format. The value range for the entry is $-1.0E^{\pm300}$ to $+1.0E^{\pm300}$. No more than 15 places can be entered or displayed.

Syntax for presenting the data

.123456789123456

123456789123456

15E+20

90E-10

If the content of a NC variable is to be negated, the NC variable must be placed within parentheses.

Syntax for negating the contents of an NC variable

X=-(@100)

@120=-(@119)

-(@57)=@58

@130=X

CAUTION

Irrespective of the display mode (workpiece or machine coordinate system), machine coordinates are always output when axis values are read.

Reading/Writing NC Variable Data

The values of the following addresses can be assigned to the CNC NC variables, or the following values from the CNC addresses can be written to the NC variables.

Coordinate values of existing axes

{ XE „Variables:Variable assignments:Coordinate values of existing axes“ **}**The machine coordinates are read into the NC variable when the coordinate values are read.

Valid addresses:

X, Y, Z, A, B, C, U, V, W
X[1..3], Y[1..3], Z[1..3], A[1..3], B[1..3], C[1..3], U[1..3], V[1..3], W[1..3]

@100=X Write X axis position value to the NC variable.
X1=@101 X1 to position stored in the NC variable.

Interpolation parameters

Valid addresses: **I, J, K**

J=@102 Circle center point coordinates of the Y axis from the NC variables.

Radius

Valid addresses: **R**

R=@103 Radius statement via the contents of the NC variable.

Feed rate

Only the active feedrate (@xxx=F) can be read. However, all F values can be defined, such as G04 F=@99 for a dwell time.

Valid address: **F**

@104=F Write active feedrate to the NC variable.
F=@105 F value via the contents of the NC variable.

Spindle speed

Valid addresses: **S**
S[1..3]

@106=S Write active spindle speed to the NC variable.
S1=@107 Spindle speed via the contents of the NC variable.

Plane rotation angle

Only angle of rotation "P" of the coordinate rotation can be read. With threading, the starting angle "P" cannot be read.

Valid address: **P**

G33 Z30 K3 P=@109 Thread starting angle via the contents of the NC variable.

Acceleration factor

Valid address: **ACC**

ACC=@111 Acceleration factor via the contents of the NC variable.

Tool number

Valid address: **T**

@112=T Write active tool number to the NC variable.
T=@113 Tool call via the contents of the NC variable.

Tool edge number

Valid address: **E**

@114=E Write tool edge number to the NC variable.
E=@115 Tool edge selection via the contents of the NC variable.

Effective radius distances

The effective distances "RX," "RY" and "RZ" cannot be read.

Valid addresses: **RX, RY, RZ**

RX=@116	Effective radius distance to the X axis via the contents of the NC variable.

Zero offset table

Valid address: **O**

O=@116 Select zero offset table via the contents of the NC variable.

@117=O Read active zero offset table.

Auxiliary function

The active auxiliary function "Q" cannot be read.

Valid address: **Q**

Q=@117 Output the auxiliary Q function via the contents of the NC variable.

D correction

The active D correction "D" cannot be read.

Valid address: **D**

D=@122 Select the D correction via the contents of the NC variable.

Preparatory functions

Legal address for reads: **G(<G code group[1..19]>)**
Legal address for writes: **G = expression**

G-code	G-code Group	Active	Meaning
G00, G01, G02, G03	1	modal	Interpolation Functions
G17, G18, G19, G20	2	modal	Plane Selection
G40, G41, G42	3	modal	Tool path compensation
G52 through G59	4	modal	Zero Offsets
G15, G16	5	modal	Radius/diameter programming
G90, G91	6	modal	Dimension Statements
G65, G94, G95	7	modal	Feed programming
G96, G97	8	modal	Spindle speed programming
G70, G71	9	modal	Dimensional Units
G43, G44	10	modal	Transition element
G61, G62	11	modal	Block transition selection
G98, G99	12	modal	Speed at contour/center line
G47, G48, G49	13	modal	Tool length compensation
G08, G09	14	modal	Contouring mode
G06, G07	15	modal	Interpolation method
G04 G33 G50, G51 G63, G64 G74 G75, G76 G77 G92 G93	16 16 16 16 16 16 16 16 16	block block block block block block block block block	Dwell time Thread cutting Prog. zero offset Tapping Homing Feed to positive stop Reposition and NC block restart Spindle speed limit Time programming
G30, G31, G32	17	modal	Transformation
G72, G73	18	modal	Mirror Imaging
G78, G79	19	modal	Scaling
G36, G37, G38	21	modal	Rotary axis startup logic

The block active "G-code" can only be read in the NC block in which they are programmed. Otherwise a value of "1" is output when the "block-active G-codes" are read.

@118=G(4) Write active G code of group 4 to the NC variable.
G=@119 Set a G code via the contents of the NC variable.

M functions

The programmable M functions are subdivided into 16 M function groups.

Legal address for reads: **M(<M function group[1..16]>)**
Legal address for writes: **M = expression**

M-function	M-function Group	Active	Meaning
M000, M001, M002, M030	1	modal	Program control commands
M3, M4, M5, M13, M14	2	modal	Spindle commands S
M103, M104, M105, M113, M114	2	modal	Spindle commands spindle 1
M203, M204, M205, M213, M214	3	modal	Spindle commands spindle 2
M303, M304, M305, M313, M314	4	modal	Spindle commands spindle 3
M007, M008, M009	5	modal	Coolant S
M107, M108, M109	5	modal	Coolant S1
M207, M208, M209	6	modal	Coolant S2
M307, M308, M309	7	modal	Coolant S3
M010, M011	8	modal	Clamp & Unclamp S
M110, M111	8	modal	Clamp & Unclamp S1
M210, M211	9	modal	Clamp & Unclamp S2
M310, M311	10	modal	Clamp & Unclamp S3
M040, ..., M045	11	modal	Gear selection S
M140, ..., M145	11	modal	Gear selection S1
M240, ..., M245	12	modal	Gear selection S2
M340, ..., M345	13	modal	Gear selection S3
M046, M047	14	modal	Spindle override
M048, M049	15	modal	Feed override
M019, ..., M319, Mxxx	16	block	Spindle positioning, auxiliary M function

The M functions which are active only in the given NC block can only be read in the NC block in which they are programmed. Otherwise a value of "1" is output when the "block-active M functions" are read.

@120=M(13) Write actively programmed group (13) M function to the NC variable.

M=@121 Set an M function via the contents of the NC variable.

10.2 Angle Unit for Trigonometric Functions 'RAD', 'DEG'

The arguments of the trigonometric functions "SIN," "COS," "TAN" and the results of the inverse functions of the trigonometric functions "ASIN," "ACOS," "ATAN" can be stated or calculated in the unit "radians" as well as a fraction or multiple of the size of the unit circle (radius = 1) and as the unit "degrees."

Syntax

RAD

DEG

- The "RAD" unit is the power-on state and is modally active until it is overwritten by the unit "DEG." "RAD" is set automatically at the end of the program (RET) or by the "BST" command, depending on process parameter Bxx.042.

10.3 Mathematical Expressions

The assignment of an expression is initiated by an equal sign and is ended by a space or the end-of-line character.

- Within an expression, a space is interpreted as the end of the expression, which therefore leads to a premature termination. The following text characters then usually result in syntax errors.

Calculation of an expression halts NC block preparation, in other words, look-ahead interpretation of the subsequent NC blocks is not resumed until the expression is fully calculated. This means that traverse move stop at the programmed end point and that steps to achieve smooth block transitions (G06, G08) do not take effect.

Expressions are comprised of:

- Operands
- Operators
- Parenthetical signs
- Functions

Examples	of expressions

```
@100=X+SQRT(2)*SQRT(X*X+Z*Z)
F=0.1*PI*800
@101=TAN©
@102=SQRT(@100)+F
@103=@105+@106/@107-50
```

Operands

Operands can be:

- Constants
- System constants
- NC variables
- Address letters, and
- Functions

Constants

Floating decimal point constants can be comprised of the following elements:

- Sign of the mantissa
- Up to 6 decimal places
- Number of places to the left of the first through sixth decimal digit
- Exponent symbol "E"
- Sign of the exponent, and
- Up to 2 decimal places for the exponent

In order for the use of internal floating decimal point calculations, the decimal point or the exponent sign must be present.

Example	of legal floating-decimal-point constants
-0. +123456. 1E0 -123456E+1 0.1E-00 +100.000E12	

The decimal numerical value statements is interpreted as an integer constant, both without the decimal point and without the exponent. Integer constants can optionally consist of a sign and up to ten decimal places.

Example of	legal integer constants
-0 1 +1234567890	

System constants

The circle number "PI" (3.14159265...) and the conversion factor to go from the inch system to the metric "KI" system (25.4) are available for use as system constants which are programmed using their symbolic names. Because of their higher internal accuracy, these constants should always be used.

Operators

The standard symbols for basic mathematical operations can be used as operators.

+	Addition
–	Subtraction
*	Multiplication
/	Division
%	Remainder integer whole division (modulo)

- Division by "0" will cause an error.
- Higher-order operations are implemented by functions.

Parentheses

To nest expressions and circumvent the integrated point-before-line logic, partial expressions can be placed within parentheses. The number of nesting levels is unlimited.

Functions

The CNC provides the following mathematical functions:

ABS	Absolute value
INT	Integer component
SQRT	Square root
SIN	Sine
COS	Cosine
TAN	Tangent
ASIN	Arc sine
ACOS	Arc cosine
ATAN	Arc cotangent
E^	Power to the base "e"
10^	Power to the base 10
2^	Power to the base 2
LN	Logarithm to the base "e"
LG	Logarithm to the base 10
LD	Logarithm to the base 2
TIME	Time in seconds

The mathematical functions enclose their operands in parentheses The operands used in functions can also be expressions — in other words, the functions can be nested.

Absolute value - ABS

The absolute value function delivers the positive value of its operand.

x < 0:	ABS(x) =-x
x = 0:	ABS(x) = 0
x > 0:	ABS(x) = x

Example

ABS(-1.23)	⇨	1.23

Integer component - INT

The "INT" function delivers the next smallest whole number for the operand.

Example

INT(1.99)	⇨	1
INT(1.01)	⇨	1
INT(-2.99)	⇨	-2
INT(-2.01)	⇨	-2

Square root - SQRT

The SQRT function produces the square root of its operand.

Example

SQRT(2) ⇨ 1.4142.

The "SQRT functions" does not permit any negative operands.

Sine - SIN

The operand for the SIN function is interpreted depending on which angle unit is set (RAD, DEG).

Value range: -1 ⇦ SIN(x) ⇨ +1

Example

RAD
SIN(PI/6) ⇨ 0.5

DEG
SIN(30) ⇨ 0.5

Cosine - COS

The operand for the COS function is interpreted depending on which angle unit is set (RAD, DEG).

Value range: -1 ⇦ COS(x) ⇨ +1

Example

RAD
COS(PI/6) ⇨ 0.866..

DEG
COS(30) ⇨ 0.866..

Tangent - TAN

The operand for the TAN function is interpreted depending on which angle unit is set (RAD, DEG).

Example

RAD
TAN(PI/4) ⇨ 1

DEG
TAN(45) ⇨ 1

The TAN function is not defined for π/2 and for -π/2.

Inverse sine - ASIN

The operand for the ASIN function must be greater than or equal to -1 or less than or equal to +1.

When the angle unit “radians” is set:

Value range: -π/2 ⇦ ASIN(x) ⇦ +π/2

Example

ASIN(0.5) ⇨ 0.523.. (π/6)

When the angle unit "degrees" is set:
Value range: -180 ⇦ ASIN(x) ⇦ +180

Example

ASIN(0.5) ⇨ 30

Inverse cosine - ACOS

The operand for the ACOS function must be greater than or equal to -1 or less than or equal to +1.

When the angle unit “radians” is set:

Value range: -π/2 ⇦ ACOS(x) ⇦ +π/2

Example

ACOS(0.5) ⇨ 1.047.. (π/3)

When the angle unit "degrees" is set:
Value range: -180 ⇦ ACOS(x) ⇦ +180

Example

ACOS(0.5) ⇨ 60

Inverse tangent - ATAN

When the angle unit “radians” is set:

Value range: -π/2 ⇦ ATAN(x) ⇦ +π/2

Example

ATAN(-1) ⇨ -0.785.. (-π/4)

When the angle unit "degrees" is set:
Wertebereich: -180 ⇦ ATAN(x) ⇦ +180

Example

ATAN(-1) ⇨ -45

Power to base - E^

Example

E^(-2.5) ⇨ 0.082...

Power to base - 10 10^

Example

10^(3) ⇨ 1000

Power to base - 2 2

^Example

2^(8) ⇨ 256

Logarithm to base - e LN

The operand for the LN function must be greater than zero.

Example

LN(10) ⇨ 2.302...

Logarithm to base - 10 LG

The operand for the LG function must be greater than zero.

Example

LG(100) ⇨ 2

Logarithm to base - 2 LD

The operand for the LD function must be greater than zero.

Example

LD(8) ⇨ 3

Time in seconds - TIME

The TIME function supplies a reference-free time in seconds accurate to 2 milliseconds. This time can be used to determine time differences.

Example	
@50=TIME	Determine active time
•	
•	
•	
@60=TIME-@50	Determine time difference

The TIME function does not have an operand.

Time recording starts when the controller is powered on and continues for about 50 days.

Example NC program - subroutine programming

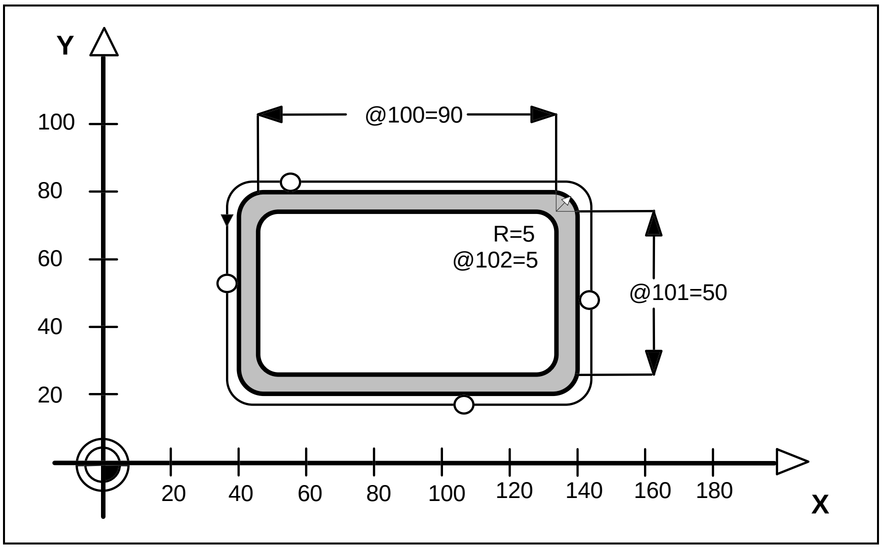


Fig. 10-1: Rectangle as subroutine

NC program

```
T4 BSR .M6                                Tool change
G00 G54 G06 G08 X160 Y80 Z10              Start position
G01 Z-10 F1000                            Infeed Z axis
G42 X135 Y80 F1500                        Establish tool path
                                          compensation
@100=90 @101=50 @102=5 @103=1200          Preload NC variable
                                          contents
BSR .RE1                                  Subroutine call
G90 G00 Z10                               Z axis to safety distance
G40 G01 X160 Y110                         Cancel tool path
                                          compensation
T0 BSR .M6                                Store tool
RET                                       End of program

.RE1                                      "Rectangle" subroutine
G01 G91 F=@103                            Incremental, set feed
X=-(@100)                                 1st straight line in X
G03 X=-(@102) Y=-(@102) J=-(@102)         1st ¼ circle
G01 Y=-(@101)                             1st straight line in Y
G03 X=@102 Y=-(@102) I=@102               2nd ¼ circle
G01 X=@100                                2nd straight line in X
G03 X=@102 Y=@102 J=@102                  3rd ¼ circle
G01 Y=@101                                2nd straight line in Y
G03 X=-(@102) Y=@102 I=-(@102)            4th ¼ circle
G01 X=-(@101/50)                          Traverse X axis until clear
Y=@101/10                                 Traverse Y axis until clear
RTS      Return from subroutine
```

11 Special NC Functions

11.1 Position Values with Analog Drives

The functions "PMP" and "NMP" supply the positive value of the axis which is declared to be the operand by means of the axis letters when there is a positive or negative edge at the measurement input AxxC.SRTBP.

Positive Memorized Position 'PMP'

The command "PMP" supplies the position value of the axis which is declared to be the operand by means of the axis letters when there is a positive edge at the measurement input AxxC.SRTBP.

Syntax **PMP(<axis name>)** ⇨ **@50=PMP(X)**

Note: The "PMP" command "positive memorized position" is only available with analog drives.

Negative Memorized Position 'NMP'

The command "NMP" supplies the position value of the axis which is declared to be the operand by means of the axis letters when there is a negative edge at the measurement input AxxC.SRTBP.

Syntax **NMP(<axis name>)** ⇨ **@51=NMP(Y)**

Note: The "NMP" command "negative memorized position" is only available with analog drives.

11.2 APR Sercos Parameters

Digital Drive Data Read/Write 'AXD'

The "AXD" command can be used to read or write the drive data from or to the NC program for a digital drive which is connected to the MT-CNC by means of a digital SERCOS interface . The drive datum which is to be read or written is addressed using the data address declared in the command parameter.

Data address **<axis name>:<SERCOS ident number>**

The letters X, Y, Z, U, V, W, A, B, C and S may be used as the axis name. The extension [1..3] can also be appended to the letters. It is essential that these axes also be parameterized and that they be digital drives which are connected via the SERCOS interface.

SERCOS ident number **<Group letter>-<parameter set number>-<data block number>**

The group letter differentiates between:

- standard data (S),
  defined by the SERCOS standards committee, and
- product data (P),
  defined by the drive manufacturer.

The minus sign (-) is used as a delimiter character between the individual parameters.

The parameter set number addresses the desired parameter set, and can have a value from 0 to 7.
The corresponding drive datum is addressed via the data block number. The data block number can have a value from 0 (as well as 0000) to 4095.

The meaning of the SERCOS parameters (group letter S) and their functions are described by the SERCOS committee in the publication "SERCOS Interface."

The meaning of the SERCOS parameters (group letter P) and their functions are described in the documentation for the SERCOS digital drive.

- The reading or writing of drive data using the "AXD command" should be programmed in a separate NC-block which does not contain any other NC-commands.
- The reading or writing of drive data using the "AXD command" always takes place at the end of the NC-block. In other words, the assignment of a value to a NC-variable into which the drive datum was read cannot be used in the same NC-block as the basis for deciding whether a conditional branch/jump is to be performed.
- When drive data is read or written using the "AXD" command, NC block preprocessing is interrupted. Thus if tool path compensation (G41, G42) is active, it is considered to be finished. Likewise, "contouring mode (acceleration)" (G08) is no longer possible.
- A drive data which has been read can only be assigned to a NC variable and not to an address letter. The expression which is to be assigned can only consist of the "AXD command." No other operands or operators are permitted.
- When the "AXD command" is used to write drive data, the assigned expression can be a formula or a constant.

NOTE

Please remember that any parameters which you modify using the "AXD command" will henceforth be active on the drive and will use the new value in all operating modes. For this reason, be certain to use the CNC user interface to a save default parameter set which is known to work properly as a backup on your hard drive.

Example NC program - AXD command

Activating friction torque compensation allows one to compensate for position deviations at circle quadrant transitions In the example shown here, the active gain factor is increased from 4 to 7.

NC program

T11 BSR .M6	Tool change SF D10
G00 G90 G54 G06 G08 X199 Y136 Z5	Start position
S5000 M03	Spindle ON
@50=AXD(X:S-0-0104)	Read active gain factor for X axis
@51=AXD(Y:S-0-0104)	Read active gain factor for Y axis
AXD(X:S-0-0104)=7*1000	New gain factor for the X axis
AXD(Y:S-0-0104)=7*1000	New gain factor for the Y axis
AXD(X:S-0-0155)=70	Friction torque compensation for X
AXD(Y:S-0-0155)=110	Friction torque compensation for Y
G01 Z-5 F1000	Lower cutter into material
G41 X199 Y141 F8000	Starting point for circ. machining
G03 X180 Y122 I199 J122	Insertion circle
G01 X180 Y100	Transition element
G02 X180 Y100 I100 J100	Full circle ∅ 160
G01 X180 Y77	Transition element
G03 X198 Y59 I198 J77	Withdrawal circle
G00 Z5	Cutter to safety distance
AXD(X:S-0-0104)=@50	Old gain factor for the X axis
AXD(Y:S-0-0104)=@51	Old gain factor for the Y axis
AXD(X:S-0-0155)=0	Friction torque comp. OFF for X
AXD(Y:S-0-0155)=0	Friction torque comp. OFF for Y
T0 BSR .M6	Tool change
RET	End of program

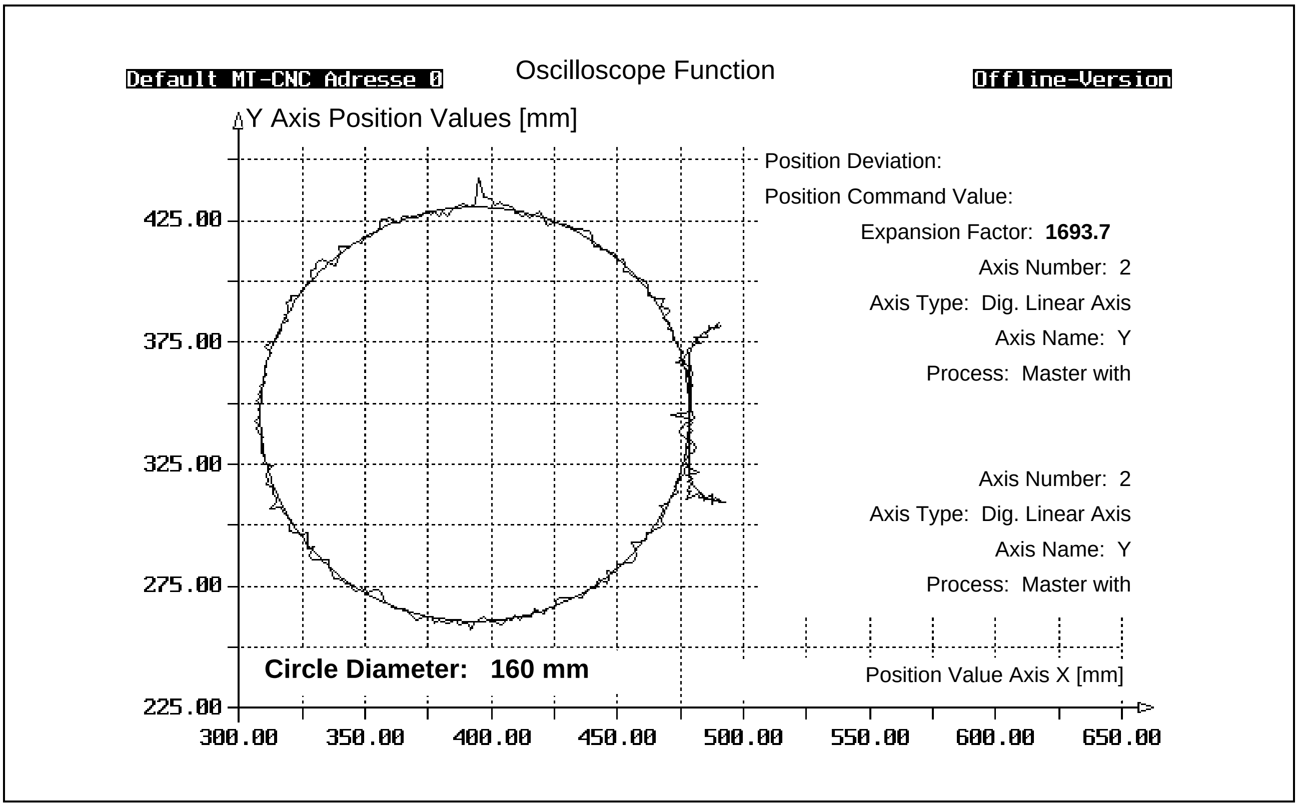


Fig. 11-1: Friction torque compensation at quadrant transitions

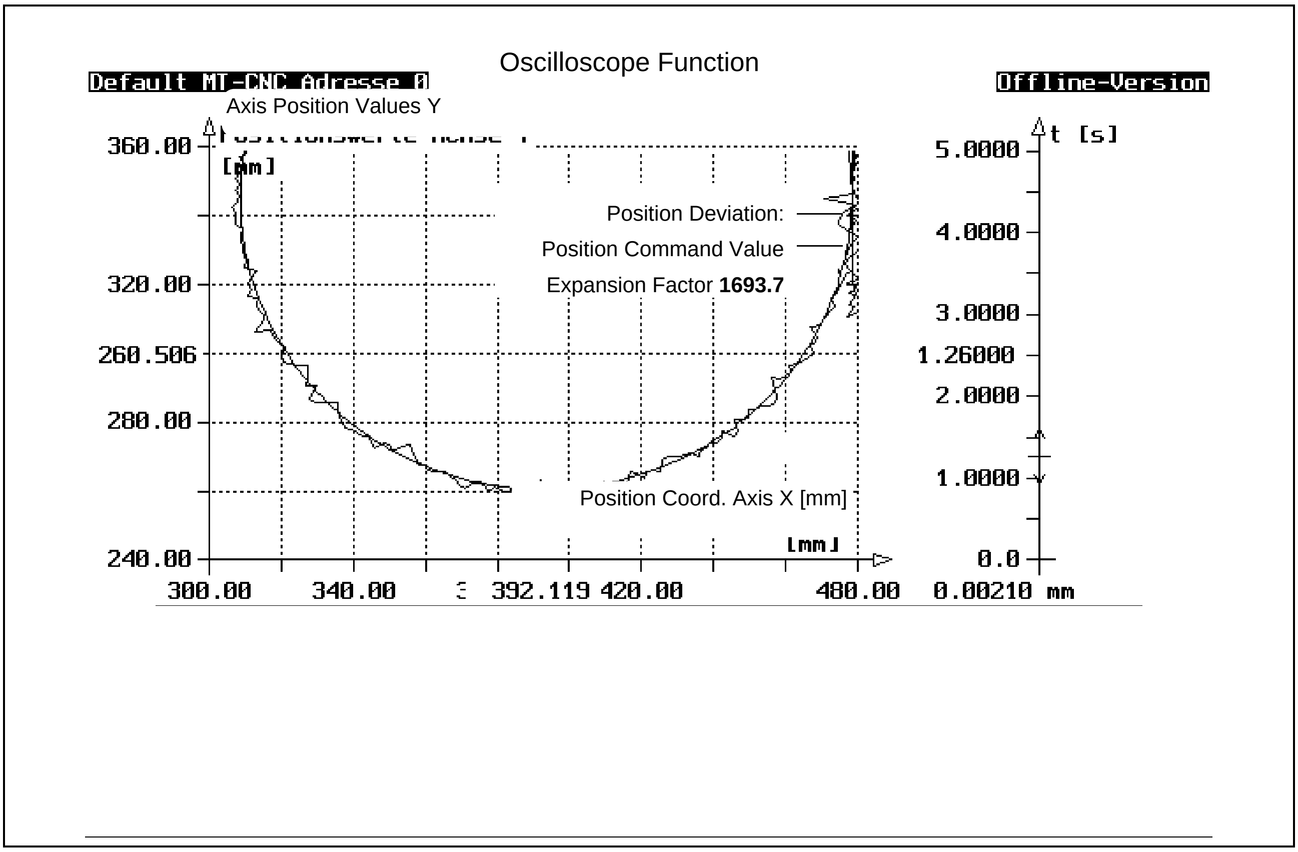


Fig. 11-2: Segment of circle for determining position deviation

Electronic Axis Coupling and Table Interpolators

Electronic axis coupling permits additional couplings to be established between axes. From a reference axis, the

- command position,
- actual position 1 or
- actual position 2 (status encoder)

can optionally be read and, according to the selected calculation mode, multiplied by a factor, or a position offset can be taken from a writable table and be added to the command value of the axis that is to be manipulated.

Example Oblique axis

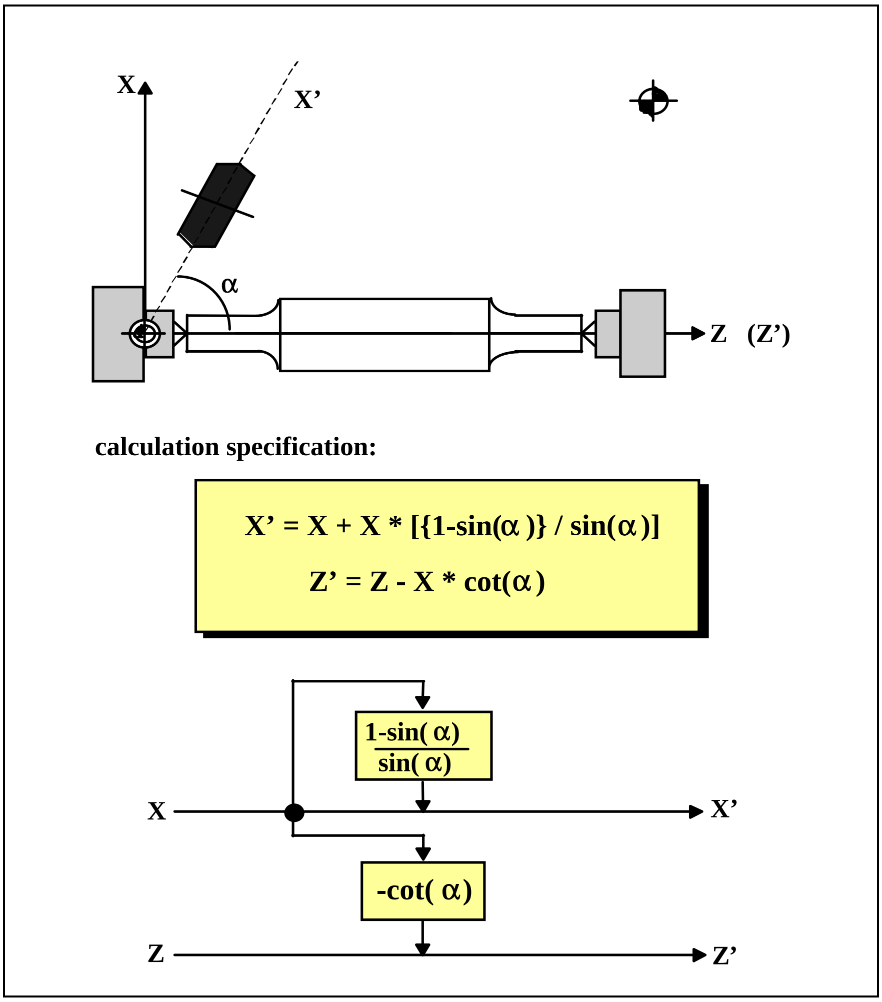


Fig. 11-3: Oblique axis

Activating transformation in the reference program

. HOME	
...	
BRF .HOME_1	
G74 Z0	to reference point
G74 X0	
G1 Z0 F5000	to machine zero point
G1 X0 F5000	
AXD(X:P-7-3608)=(travel limit X+)*10000	Travel limit
AXD(X:P-7-3609)=(travel limit X-)*10000	Set X axis
AXD(X:P-7-3613)=2	Position offset ON
AXD(X:P-7-3616)=(1-sin(α)/sin(α))*10000	Table factor in 0.0001
AXD(X:P-7-3619)=2	Multiplication ON
AXD(X:P-7-3620)=axis numberr of X axis	Axis number of oblique axis
AXD(X:P-7-3621)=1	Transformation X ON
AXD(Z:P-7-3608)=(travel limit Z+)*10000	Travel limit
AXD(Z:P-7-3609)=(travel limit Z-)*10000	Set Z axis
AXD(Z:P-7-3613)=2	Position offset ON
AXD(Z:P-7-3616)=(-cot(α))*10000	Table factor in 0.0001
AXD(Z:P-7-3619)=2	Multiplication ON
AXD(Z:P-7-3620)=axis numberr of X axis	Axis number of oblique axis
AXD(Z:P-7-3621)=1	Transformation Z ON
.HOME_1	
...	

De-activating transformation

- The command line
  AXD(<axis name>:P-7-3621)=0
  de-activates transformation for the selected axis.
- Transformation is de-selected when the controller is switched off and back on .

CAUTION

When transformation is de-activated via the AXD command, the axes move at maximum velocity to their programmed positions.

The position correction by the calculation formula is no longer taken into account.

⇒ De-activating the transformation via the AXD command is only permitted when the machine is in a secured state.

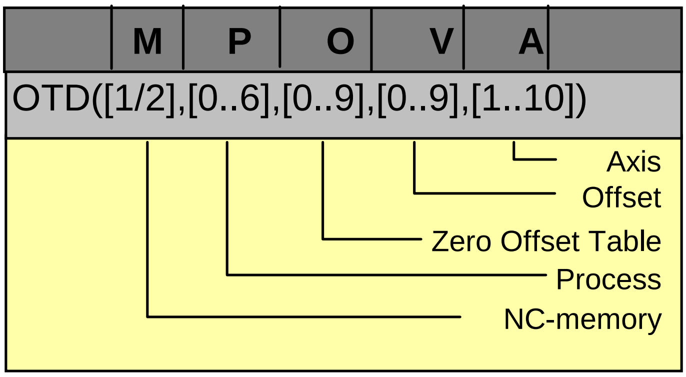
Virtual axis

The functionality of a virtual axis will be available from Version 5.17 onwards.

11.3 Reading and Writing ZO Data to/from the NC Program 'OTD'

The "OTD command" (Offset Table Data) can be used to read and write the data in the zero offset table and the zero offsets which have been activated in the NC program from the NC program.

Syntax



Name	Symbol	Range	Meaning
NC memory	M	1 / 2	1: NC memory A or 2: NC memory B If the parameter is not declared, the active NC memory is addressed.
Process	P	0..6	If a process number is undeclared, the current process where OTD is programmed is addressed.
Zero Offset Table	O	0..9	If the parameter is not declared, the active zero offset table is addressed.
Offset	V	0..9	0 = active offset (total) 1 = value of G50/G51 offset 2 = value of G52 offset 3 = general offset 4 = G55 value 5 = G55 value 6 = G56 value 7 = G57 value 8 = G58 value 9 = G59 value If the value is undeclared, the active offset (0) is addressed.
Axis	A	1..10	1 = value of the X axis 2 = value of the Y axis 3 = value of the Z axis 4 = value of the U axis 5 = value of the V axis 6 = value of the W axis 7 = value of the A axis 8 = value of the B axis 9 = value of the C axis 10 = value of angle of rotation The axis parameter must be declared. The axis letter refers to the axis designation.

General requirements for the OTD command

- An NC variable can be used as parameter instead of the constant.
- A mathematical calculation cannot be used instead of a constant or an NC variable.
- The optional parameters do not need to be set.
- The commas used to separate the parameters must always be used.

The zero offset values for "G50/G51," "G52" and the active zero offset value **cannot** be written using the OTD command.

Example	NC program - read zero offset table data
@100=OTD(,,,,1)	Read total active X axis zero offset
•	
X=OTD(1,0,2,4,1)	Traverse X axis to the position which is located in the ZO table in NC memory A for process 0 of the 2nd zero offset table for G54
•	
@80=G(4)	Read G-code of zero offset
@80=@80-50	Prepare value for the OTD command
•	
@100=OTD(,,,@080,1)	Read active X axis zero offset for the ZO entry corresponding to the active G-code (G50-G59)

Example	NC program - write zero offset table data
OTD(,,,4,1)=SQRT(X*X+Y*Y)	Assign the result of the declared calculation to the X axis entry for the offset per G54 in the current NC memory for the active process in the active zero point table.
•	
OTD(,,,4,1)=@100+OTD(,,,,1)	Calculate the new X axis zero offset value corresponding to G54 from the contents of the variable 100 and the active X axis zero offset.

CAUTION

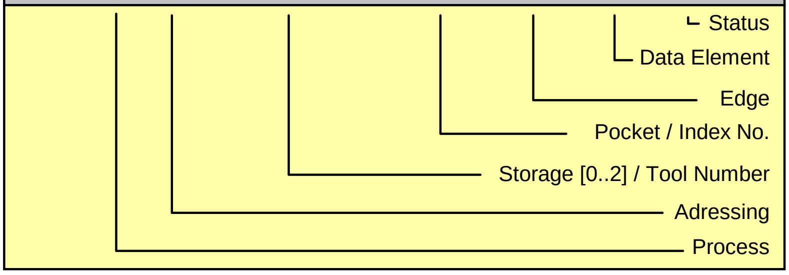
The read zero point data is in machine coordinates.

11.4 Read/Write Tool Data from the NC Program ‘TLD’

The "TLD command" (tool data) can be used to read the tool data into the NC program and to write them from the NC program, however some restrictions apply to writing.

Syntax

	P	A	S/T	L/D	E	D	S
TLD([0..6],[0],			[0..2]	,[1...999],[0..9],[1..35],[1..32])			
TLD([0..6],[1],[1..9999999],[1...999],[0..9],[1..35],[1..32])							



All data present in the tool list can be read. The individual data elements are addressed by means of elements. The identifiers for the individual data elements are shown in the table Tool list data for the TLD command.

Range and meaning of the parameters

Name	Sym-bol	Range		Meaning	
Process	P	0..6		Process no.	
Addressing	A	0	**1**	0: Addressing via storage and loca-tion	**1:** Addressing via tool and index number
Storage	S	0..3		S=0: Magazine/turret S=1: Spindle S=2: Gripper S=3: Position	
Location	L	S=0: 1..999 S=1: 1..4 S=2: 1..4 S=3: 1..4		S=0: Mag.-/turret loc. S=1: No. of tool spindle S=2: Gripper number S=3: Position number	
Tool no. (T no.)	**T**		**1..9999999**		**Tool number**
Tool index number	**D**		**1..999**		**Tool index number**
Edge	E	0..9		E=0: Basic tool data E=1..9: Edge data	
Data Element	D	E=0: 3..28 E=1..9: 1..35		E=0: Access basic tool data E=1..9: Access edge data	
Status	S	E=0: 1..32 E=1..9: 1..16		E=0: Access tool status bits E=1..9: Access edge status bits	

Tool List Data for the TLD Command:

NAME	RANGE	DATA TYPE	UNIT	DATA ELEMENT	OPTION	EL	WL
Basic tool data	(per tool)						
Tool Identification							
Index address	Hexadecimal long word using 32 bits (read only)		-	01			
Tool name (ID)	up to 28 characters of any type	STRING28	-	02		X	X
Storage	0 - 2 (0: Magazine/turret, 1: Spindle, 2: Gripper		-	03			X
Location	0 - 999		-	04			X
Tool number	1 - 9999999	DINT	-	05		X	X
Tool index number	1 - 999	INT		06			X
Correction type	1 - 4	USINT	-	07		X	X
Number of edges	1 - 9	USINT	-	08		X	X
Tool status	0/1 (32 status bits)		-	09			X
Location Data							
Unused locations	0 - 4	USINT	-	10			X
Old location	1 - 999	INT	-	11			X
Stor. of next spare tool	0 - 2 (0: Magazine/turret, 1: Spindle, 2: gripper)	INT	-	12			
Loc. of next spare tool	1 - 999	INT	-	13			
Stor. of prev. spare tool	0 - 2 (0: Magazine/turret, 1: Spindle, 2: gripper)	INT	-	14			
Loc. of prev. spare tool	1 -999	INT	-	15			
Units							
Time unit	0/1 (0: min, 1: cycles.)	USINT	-	16			X
Length unit	0/1 (0: mm, 1: inch)	USINT	-	17			X
Technology data							
Tool code	1 - 9	USINT	-	18		X	X
Representation type	0 - 999	INT	-	19		X	X
User data							
User data 1	+/- $1.2 * 10^{-38}$ - +/- $3.4 * 10^{+38}$ and 0 (current input via user interface: as with geometry data)	REAL	any	20	X		X
. . .	. . .	. . .	. . .	. . .	. . .		. . .
User data 9	+/- $1.2 * 10^{-38}$ - +/- $3.4 * 10^{+38}$ and 0 (current input via user interface: as with geometry data)	REAL	any	28	X		X
Comment	up to 5 x 76 characters of any type		-		X	X	
Edge data	(per edge)						
Edge ID							
Edge orientation	0 - 8	USINT	-	01		X	X
Edge status	0/1 (16 status bits)	WORD	-	02			X
Tool Life Data							
Remaining tool life	0.0 - 100.00	REAL	%	03	X		X
Warning limit	0.1 - 100.00	REAL	%	04	X		X
Max. tool life	0 - 9999999 (0: tool life data processing OFF)	REAL	min or cycles	05	X		X
Time in use	0 - 9999.999	REAL	min or cycles	06	X	X	
Geometry Data							
Length L1	-9999.9999 - +9999.9999 or -999.99999 - +999.99999	DINT	mm or inch	07			X
Length L2	-9999.9999 - +9999.9999 or -999.99999 - +999.99999	DINT	mm or inch	08			X
Length L3	-9999.9999 - +9999.9999 or -999.99999 - +999.99999	DINT	mm or inch	09			X
Radius R	-9999.9999 - +9999.9999 or -999.99999 - +999.99999	DINT	mm or inch	10			X
Wear L1	-9999.9999 - +9999.9999 or -999.99999 - +999.99999	DINT	mm or inch	11	X		X
Wear L2	-9999.9999 - +9999.9999 or -999.99999 - +999.99999	DINT	mm or inch	12	X		X
Wear L3	-9999.9999 - +9999.9999 or -999.99999 - +999.99999	DINT	mm or inch	13	X		X
Radius R	-9999.9999 - +9999.9999 or -999.99999 - +999.99999	DINT	mm or inch	14	X		X
Offset L1	-9999.9999 - +9999.9999 or -999.99999 - +999.99999	DINT	mm or inch	15	X		X
Offset L2	-9999.9999 - +9999.9999 or -999.99999 - +999.99999	DINT	mm or inch	16	X		X
Offset L3	-9999.9999 - +9999.9999 or -999.99999 - +999.99999	DINT	mm or inch	17	X		X
Offset R	-9999.9999 - +9999.9999 or -999.99999 - +999.99999	DINT	mm or inch	18	X		X
Geometry limits							
L1_min	-9999.9999 - +9999.9999 or -999.99999 - +999.99999	DINT	mm or inch	19	X	X	
L1_max	-9999.9999 - +9999.9999 or -999.99999 - +999.99999	DINT	mm or inch	20	X	X	
L2_min	-9999.9999 - +9999.9999 or -999.99999 - +999.99999	DINT	mm or inch	21	X	X	
L2_max	-9999.9999 - +9999.9999 or -999.99999 - +999.99999	DINT	mm or inch	22	X	X	
L3_min	-9999.9999 - +9999.9999 or -999.99999 - +999.99999	DINT	mm or inch	23	X	X	
L3_max	-9999.9999 - +9999.9999 or -999.99999 - +999.99999	DINT	mm or inch	24	X	X	
R_min	-9999.9999 - +9999.9999 or -999.99999 - +999.99999	DINT	mm or inch	25	X	X	
R_max	-9999.9999 - +9999.9999 or -999.99999 - +999.99999	DINT	mm or inch	26	X	X	
Wear factors							
Wear factor L1	-9999.9999 - +9999.9999 or -999.99999 - +999.99999	DINT	mm or inch/ min or cycles	27	X		X
Wear factor L2	-9999.9999 - +9999.9999 or -999.99999 - +999.99999	DINT	mm or inch/ min or cycles	28	X		X
Wear factor L3	-9999.9999 - +9999.9999 or -999.99999 - +999.99999	DINT	mm or inch/ min. or cycles	29	X		X
Wear factor R	-9999.9999 - +9999.9999 or -999.99999 - +999.99999	DINT	mm or inch/ min. or cycles	30	X		X
User data							
User data 1	+/- $1.2 * 10^{-38}$ - +/- $3.4 * 10^{+38}$ and 0 (current input via user interface: as with geometry data)	REAL	any	31	X		X
. . .	. . .	. . .	. . .	. . .	. . .		. . .
User data 5	+/- $1.2 * 10^{-38}$ - +/- $3.4 * 10^{+38}$ and 0 (current input via user interface: as with geometry data)	REAL	any	35	X		X
User data 6	-9999.9999 - +9999.9999 or -999.99999 - +999.99999	DINT	any	36	X		X
. . .	. . .	. . .	. . .	. . .	. . .		. . .
User data 10	-9999.9999 - +9999.9999 or -999.99999 - +999.99999	DINT	any	40	X		X

Legend **EL**: = setup-list-specific data item **WL**: = tool-list-specific data item

Tool Status Bits for the TLD Command:

Group name	Group information	Sym-bol	Written by	Type	Bit	Val.	Comment
Present	Tool not present/ tool present	!	WZM	EL	1	1 0	Tool not present
	Tool not required/ tool required	?	WZM	EL	2	1 0	Tool not required for process
Error correction type	Override type error/ no override type error	t	WZM	EL	3	1 0	Override type does not meet requirements
Error number of edges	Number of edges error/ Number of edges OK	e	WZM	EL	4	1 0	Edge number does not meet requirements
Edge error	Edge(s) error/ edge(s) OK	f	WZM	EL	5	1 0	Edge data does not meet requirements
Reserved for future enhancements (bits 6 - 8)							
Location locking	Location locked/ location not locked	B	ANP/BED WZM	PL	9	1 0	UP/OP: For example: location damaged WZM: Tool is entered
	Upper half pocket for flc tool locked/not locked		WZM	PL	10	1 0	Locked for flc tool located in gripper or spindle
	Lower half pocket for flc tool locked/not locked		WZM	PL	11	1 0	Locked for flc tool located in gripper or spindle
Location reservation	Upper half pocket reserved/not reserved		ANP	PL	12	1 0	For example: for a tool which is to be merged into the process
	Lower half pocket reserved/not reserved		ANP	PL	13	1 0	For example: for a tool which is to be merged into the process
Location in use	Upper half pocket is covered/not covered		WZM	PL	14	1 0	The upper half pocket is covered by a tool.
	Lower half pocket is covered/not covered		WZM	PL	15	1 0	The upper half pocket is covered by a tool.
	Pocket in use/not in use		WZM	PL	16	1 0	A tool is located in the pocket
Wear condition	Tool dull/tool not dull	d	WZM	WZ	17	1 0	Tool cannot be used any longer (replace)
	Warning limit reached/ warning limit not reached	w	WZM	WZ	18	1 0	Tool life almost over (replace)
Spare ID	Machining tool/ not machining tool	p	WZM	WZ	19	1 0	There is a primary (machining) tool for each spare tool group.
	Replacement tool/ no replacement tool	s	WZM	WZ	20	1 0	A spare tool is a tool which is still usable, not a primary tool
Fixed-location coding (flc)	Fixed-location tool non-fixed-location tool	C	ANP/BED	WZ	21	1 0	The tool always stays in the same pocket in the magazine.
Tool status	Tool locked/ tool not locked	L	ANP/BED	WZ	22	1 0	By user or user program, for example: edge broken
Reserved for future enhancements (bits 23–24)							
User Tool Status 1	User Tool Status Bit 1	any	ANP/BED	WZ	25	1 0	Any desired meaning
. . .							
User Tool Status 8	User Tool Status Bit 8	any	ANP/BED	WZ	32	1 0	Any desired meaning

Abbreviations:

WZM: = Tool management
ANP: = User-specific programs on PLC or CNC
BED: = Operator
EL: = Setup list-specific status bit
PL: = Location-specific status bit
WZ: = Tool-specific status bit

Edge status bits for the TLD command:

Group name	Group information	Sym-bol	Write access	Type	Bit	Value
Edge orientation incorrect	Edge orientation correct/incorrect	o	WZM	EL	1	1 0
L1 incorrect	L1 correct/incorrect	1	WZM	EL	2	1 0
L2 incorrect	L1 correct/incorrect	2	WZM	EL	3	1 0
L3 incorrect	L1 correct/incorrect	3	WZM	EL	4	1 0
R incorrect	R correct/incorrect	r	WZM	EL	5	1 0
Reserved for future enhancements (bits 6 - 8)						
Wear status	Edge done/not done	d	WZM	WZ	9	1 0
	Warning limit reached/not reached	w	WZM	WZ	10	1 0
Reserved for future enhancements (bits 11 - 12)						
User edge status 1	User edge status bit 1	any	ANP/BED	WZ	13	1 0
. . .						
User edge status 4	User edge status bit 4	any	ANP/BED	WZ	16	1 0

Abbreviations:

WZM:	= Tool management	EL:	= Setup list-specific status bit
BED:	= Operator	PL:	= Location-specific. status bit
WZ:	= Tool-specific status bit	ANP:	= User-specific programs on PLC or CNC

General requirements for the TLD command

- An NC variable can be used instead of the constant.
- A mathematical calculation cannot be used instead of a constant or a NC variable.
- The optional parameters do not need to be set.
- The commas used to separate the parameters must always be used.

Optional parameters for the TLD command

- If the process [0..6] is not declared, the CNC will used the current process where TLD is used.
- If the "addressing" parameter [0/1] is not declared, the CNC will use "0" as the value and will interpret the following two parameters as the storage unit and location.
- If the tool index number [1..999] is not declared, the CNC will use the index number of the corresponding primary tool.
- If the edge is not declared [0..9], the CNC will use "0" as the value, thereby accessing the basic tool data.
- The parameter status [1..32] does not need to be declared unless a tool or an edge status bit is being accessed.

General tests for the TLD command

The validity of the programmed parameter values cannot be tested until the command is executed, in other words: when the NC program is running. If one of the parameters is incorrect or illegal, the CNC performs an immediate stop and issues the following error message:

```
Incorrect Parameter [no. of incorrect parameter]
in data access command
```

Tests during write operations for the TLD command

- Setup list-specific data elements cannot be written.
- No tool or edge status bits assigned to the tool management may be written.
- The data elements "location", "storage" and "tool number" cannot be written.
- If one of these conditions is violated when an attempt is made to write a data element, the CNC performs an immediate stop and issues the following error message:

```
Illegal access to a data element !
```

Example NC program - read with TLD command

The tool number of the tool located in tool spindle 2 is to be assigned to a NC variable.

@55=TLD(,0,1,2,0,5,)

Data Element = 5 : Tool Number
Edge = 0 : Basic Tool Data
Loc. = 2 : Spindle 2
Storage = 1 : Spindle
Adressing = 0 : Adressing Via Storage and Location
Process : Current Process

Example NC program - write with TLD command

The most recently used tool is to be locked.

@55=T ; Save Number of Current Tool
; in a NC-variable

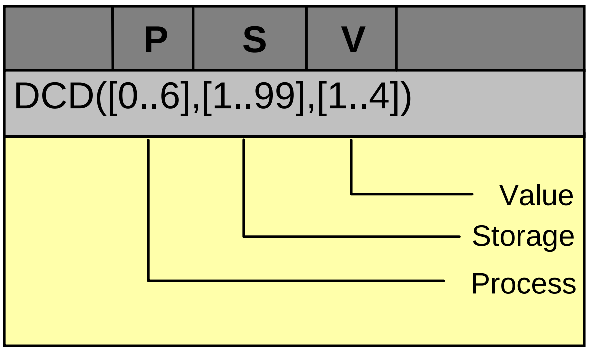
TLD(3,1,@55,,0,9,22)=1 ; Lock Tool

Tool Status Bit = 22 : Tool Locked
Data Element = 9 : Tool Status Bit
Edge = 0 : Basic Tool Data
Index No. : Index No. of Associated Primary Tool
Tool No. = @55 : Tool Number via NC-variable 55
Adressing=1 : Adressing via Tool and Index Number
Process = 3 : Process 3

11.5 Reading and Writing D Corrections from the NC Program 'DCD'

The DCD command enables the D corrections to be read and written from the NC program.

Syntax



Name	Sym-bol	Range	Meaning
Process	P	0..6	The active process is addressed if a process number is not specified.
Memory	S	1..99	The active memory is addressed if the parameter is not specified
Value	W	1..4	1 = value of the length correction L1 2 = value of the length correction L2 3 = value of the length correction L3 4 = value of the radius correction R

General requirements for the DCD command

- An NC variable can be used instead of the constant.
- A mathematical calculation cannot be used instead of a constant or a NC variable.
- The optional parameters do not need to be set.
- The commas that are used for separating the parameters must always be used.

Tests during the access

The parameter specifications must be inside the valid range. The NC does not check the validity before the program execution. If a parameter value is outside the valid range, the NC interrupts program execution and issues an error message.

Example	
@102=DCD(,3,4)	The variable 102 obtains the radius correction value R of the D memory 3.
DCD(1,2,1)=Z-10	The value 'Z10' is written to the length correction value L1 of the D memory 2 of process 1
DCD(,,3)=DCD(,,3)+1	The value L3 of the active D memory and of the active process is incremented by 1.

11.6 Reading and Writing Machine Data

Machine Data Utilization

Task

Modifiable machine data is employed

- as modifiable machine parameters (controller machine data) for certain control functions, such as setup registers, slave and gantry axes, or main spindle synchronization;
- as protected data (OEM machine data), such as machine option management or saving measured data;
- as working memory in which the machine manufacturer stores structured data (OEM machine data), e.g. for implementing a palette management or saving axis positions; or
- for processing large data quantities (user machine data), e.g. for saving geometry data and tolerances for parts manufacturing.

Required data structures

The majority of the data required by the machine manufacturer controller and the end user can be represented in the form of

- a structure,
- a one- or two-dimensional array, or
- a one- or two-dimensional array onto a structure.

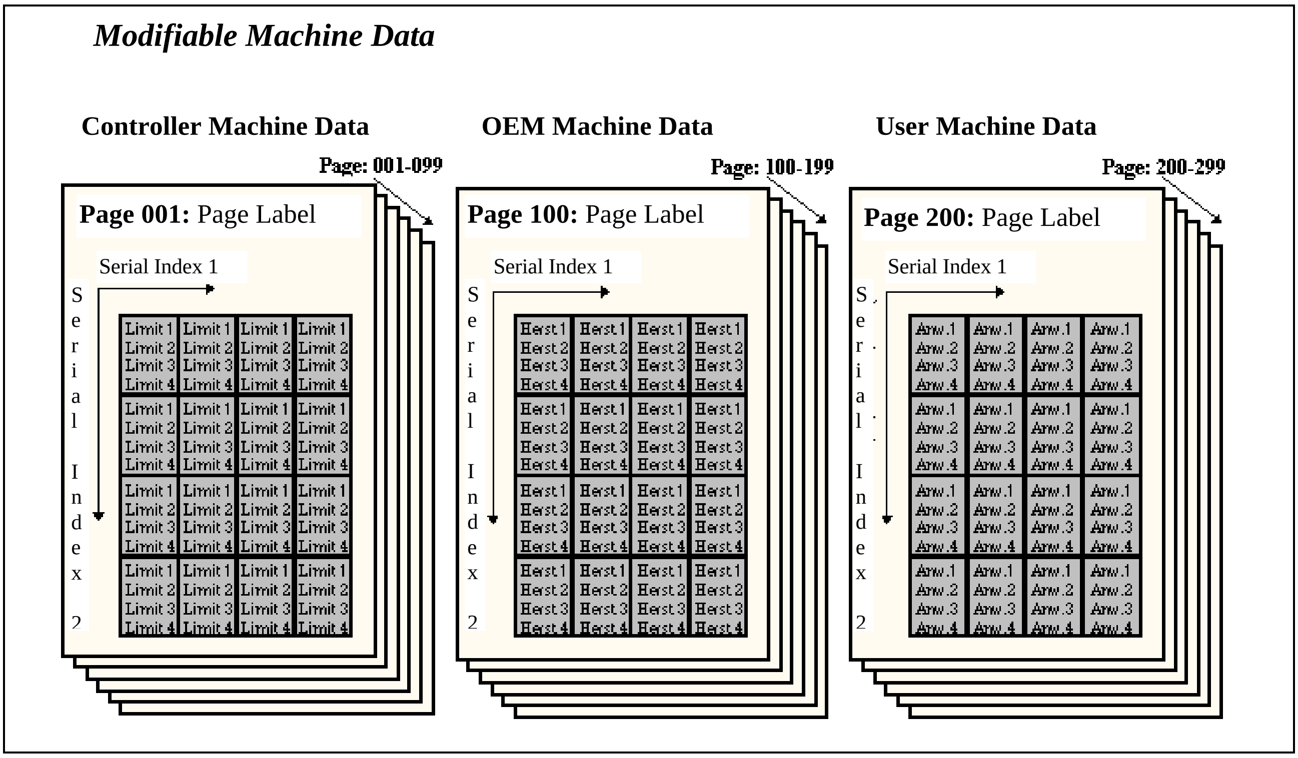


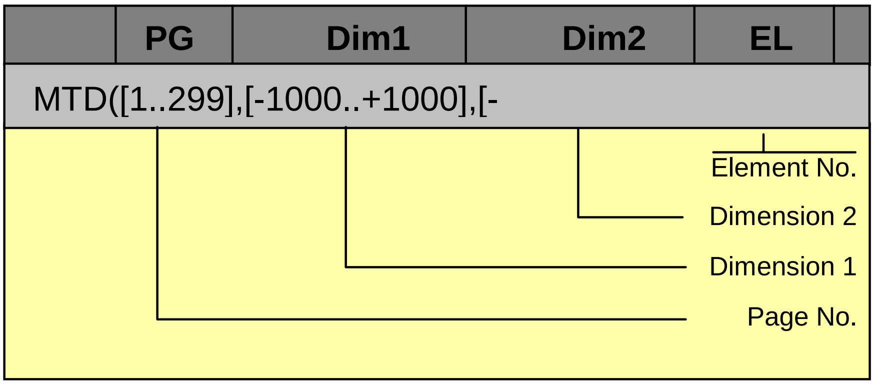
Fig. 11-4: Basic structure of the machine data

Read and Write the Machine Data Element ‘MTD’

MTD command

The MTD command (machine table data) can be used to read and write individual elements of the machine data from the NC program, provided that a write access is permitted for the given element.

Syntax



Name	Sym-bol	Range	Meaning
Page no.	PG	1..299	001 .. 099 pages of controller machine data 100 .. 199 pages of OEM machine data 200 .. 299 pages of user machine data
Run variable 1	L1	min. value ..max. value	Min. value: first value from structure definition (≥ - 1000) max. value: second value from structure definition (≤+1000) (max. value - min. value ≤ 1000)
Run variable 2	L2	min. value ..max. value	Min. value: first value from structure definition (≥ - 1000) max. value: second value from structure definition (≤+1000) (max. value - min. value ≤ 1000)
Element no.	EL	1..max. value	max. value ≤ 1000

General requirements for the MTD command

- The individual numbers must be separated by commas.
- An NC variable can be used instead of a constant.
- A mathematical calculation cannot be used instead of a constant or a NC variable.
- All of the above parameters must always be specified.

Tests during access

The parameter declarations must lie within the specified value range. The NC does not check for legality until the program is actually executed. If a parameter declaration is outside the legal value range, the NC will interrupt program execution and issue an error message. The NC will respond in a similar manner if the user attempts to write to a write-protected data element from the NC program. If a user assigns a value which is outside the legal range to a data element, the NC automatically limits the value to the smallest or largest legal data element without issuing an error message.

Detailed description

Please refer to the ‘Machine Data’ description, Folder 1, for further information about functions and handling of the machine data.

Example	
@100=MTD(250,1,2,4)	Read machine data element Page=250, L1=1, L2=2, EL=4
X=MTD(260,1,,5)	Move X axis to the position that is specified in the machine data element. L2 does not exist.
@50=MTD(270,,3,6)	L1 is of the PROCESS type. The elements of the active process are read. A specific process specification is possible.
@120=MTD(280,1,1,4)+4	Utilization in a calculation.
MTD(250,1,2,4)=@100	Write machine data element.
MTD(260,1,,5)=X	Write the current X value to the machine data element.
MTD(270,,3,6)=@110+@120	Allocate calculation.

NOTE

The MTD command can be used within an NC block for reading any number of data elements from the machine data. However, only one data element can be written to at any one time (see Chapter 'Possible Allocations Between AXD, TLD, OTD, DCD, MTD' below).

11.7 Possible Allocations Between AXD, OTD, TLD, DCD, MTD

Some restrictions must be observed when AXD, OTD, TLD, DCD, or MTD commands are handled.

Handling AXD Commands

Possible allocations - Examples

AXD(X:P-7-3616)=@100
AXD(X:P-7-3616)=@100+@110+@120
@100=AXD(X:P-7-3616)

Illegal allocations - Examples

@100=AXD(X:P-7-3616) @110=AXD(X:P-7-3616)
@100=(AXD(X:P-7-3616)+@110)+@120
AXD(X:P-7-3616)=1000 AXD(X:P-7-3616)=1
AXD(X:P-7-3616)=AXD(X:P-7-3616)

CAUTION

Only one AXD command is permitted in an NC block.

Several AXD allocations in a line are not permitted. AXD commands in parentheses are not permitted.

Handling OTD Commands

Possible allocations - Examples

@100=OTD(,,,4,1)
OTD(,,,4,1)=@110
OTD(,,,4,1)=@100+@110+@120
@100=OTD(,,,4,1)+OTD(,,,4,1)
@100=OTD(,,,4,1)+OTD(,,,4,1)+OTD(,,,4,1)
@100=OTD(,,,4,1) @110=OTD(,,,4,1) @120=OTD(,,,4,1)
OTD(,,,4,1)=OTD(,,,5,1)
OTD(,,,4,1)=OTD(,,,5,1)+OTD(,,,5,1)

Illegal allocations - Examples

OTD(,,,4,1)=@100 OTD(,,,5,1)=@110 OTD(,,,6,1)=@120
@100=(OTD(,,,4,1)+@110)+@120

CAUTION

The OTD command can be used within an NC block for reading any number of data elements from the zero point table. However, only one data element can be written to at any one time. OTD commands in parentheses are not permitted.

Handling TLD Commands

Possible allocations - Examples

@100=TLD(,1,1,,0,6,)
TLD(,1,1,,0,6,)=5
TLD(,1,1,,0,6,)=3+1+2
@100=TLD(,1,1,,0,6,)+TLD(,1,1,,0,5,)
@100=TLD(,1,1,,0,6,)+TLD(,1,1,,0,5,)+TLD(,1,1,,0,6,)
TLD(,1,1,,0,6,)=TLD(,1,1,,0,5,)
TLD(,1,1,,0,6,)=TLD(,1,1,,0,6,)+TLD(,1,1,,0,5,)

Illegal allocations - Examples

@100=TLD(,1,1,,0,5,) @110=TLD(,1,1,,0,6,) @120=TLD(,1,1,,0,6,)
TLD(,1,1,,0,5,)=1 TLD(,1,1,,0,6,)=1 TLD(,1,1,,0,6,)=1
@100=(TLD(,1,1,,0,5,)+@110)+@120

CAUTION

The TLD command can be used within an NC block for reading any number of data elements from the tool data. However, only one data element can be written to at any one time.
In contrast to OTD and MTD commands, only one allocation is permitted in an NC block (also for reading).
TLD commands in parentheses are not permitted.

Handling DCD Commands

Possible allocations - Examples

@100=DCD(,,1)
DCD(,,1)=@110
DCD(,,1)=@100+@110+@120
@100=DCD(,,1)+DCD(,,1)
@100=DCD(,,1)+DCD(,,1)+DCD(,,1)
@100=DCD(,,1) @110=DCD(,,1) @120=DCD(,,1)
DCD(,,1)=DCD(,,1)
DCD(,,1)=DCD(,,1)+DCD(,,1)

Illegal allocations - Examples

DCD(,,1)=@100 DCD(,,2)=@110 DCD(,,3)=@120
@100=(DCD(,,1)+@110)+@120

CAUTION

The DCD command can be used within an NC block for reading any number of D corrections. However, only one D correction can be written to at any one time.

DCD commands in parentheses are not permitted.

Handling MTD Commands

Possible allocations - Examples

@100=MTD(110,1,1,1)
MTD(110,1,1,1)=@110
MTD(110,1,1,1)=@100+@110+@120
@100=MTD(110,1,1,1)+MTD(110,1,1,1)
@100=MTD(110,1,1,1)+MTD(110,1,1,1)+MTD(110,1,1,1)
@100=MTD(110,1,1,1) @110=MTD(110,1,1,1) @120=MTD(110,1,1,1)
MTD(110,1,1,1)=MTD(110,1,1,2)
MTD(110,1,1,1)=MTD(110,1,1,2)+MTD(110,1,1,3)

Illegal allocations - Examples

MTD(110,1,1,1)=@100 MTD(110,1,1,2)=@110 MTD(110,1,1,3)=@120
@100=(MTD(110,1,1,1)+@110)+@120

CAUTION

The MTD command can be used within an NC block for reading any number of data elements from the machine data. However, only one data element can be written to at any one time.

MTD commands in parentheses are not permitted.

Allocations Between AXD, OTD, TLD, DCD and MTD Commands

Possible allocations - Examples

AXD(X:P-7-3616)=MTD(110,1,1,1)+MTD(110,1,1,1)
AXD(X:P-7-3616)=OTD(,,,4,1)+OTD(,,,4,1)
AXD(X:P-7-3616)=TLD(,1,1,,0,6,)+TLD(,1,1,,0,6,)
AXD (X:P-7-3616)=DCD(,,1)+DCD(,,1)

Illegal allocations - Examples

MTD(110,1,1,1)=AXD(X:P-7-3616)
TLD(,1,1,,0,6,)=AXD(X:P-7-3616)
OTD(,,,4,1)=AXD(X:P-7-3616)
DCD(,,1)=AXD(X:P-7-3616)

NOTE

The restrictions for the individual commands must be observed when allocations are made between the AXD, OTD, TLD, DCD, and MTD commands.

12 NC Compiler Functions

12.1 Basics

NC compiler

From software version 5.17 onwards, the NC compiler has been integrated into the user interface. It permits NC programs to be pre-compiled.

Using these features, the following functions have been implemented:

- Chamfers and roundings,
- enhanced look-ahead function,
- graphical NC editor (for contour and machining programming),
- macro technique, and
- modal function.

12.2 Chamfers and Roundings

Chamfers and roundings

The commands

- CF (insert chamfer) and
- RD (insert rounding)

enable chamfers and roundings to be inserted.

Syntax

CF.. or CF=... ;insert chamfer (chamfer)
RD.. or RD=... ;insert rounding (round)

Explanation

- A further linear contour (chamfer) or an arc (rounding) can be inserted between linear or circular contours.

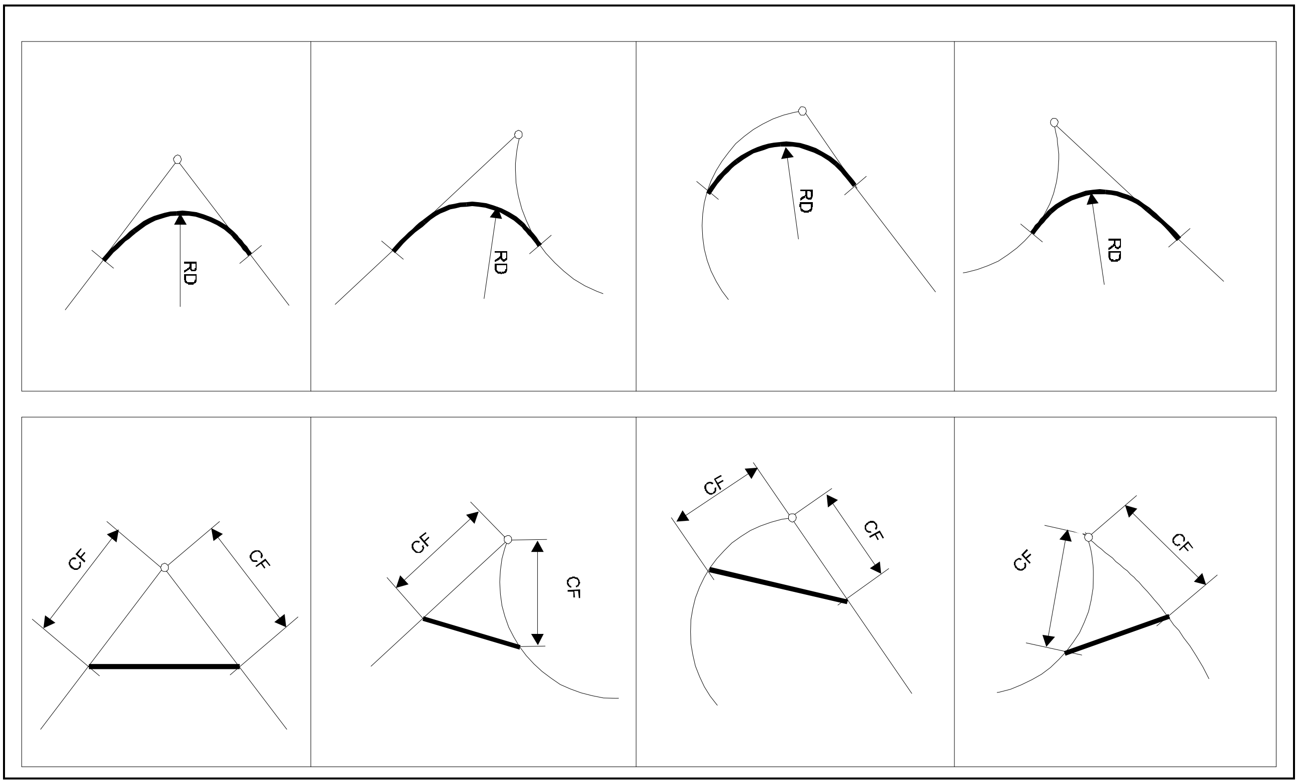
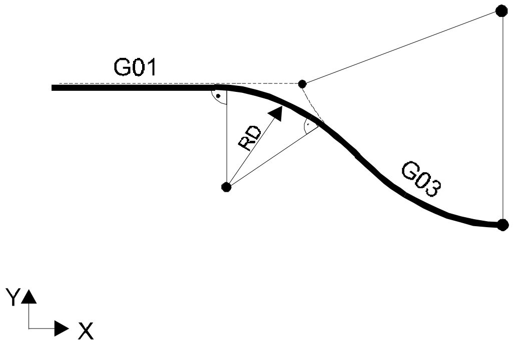


Fig. 12-1: Inserting chamfers and roundings between linear and circular contours

- Specifying the RD command tangentially inserts an arc of the radius RD between the preceding and the subsequent motion command.
- The CF command has the following effect: Starting from the intersection point of the motion commands involved, the chamfer width CF is removed from both motion blocks; and the resulting co-ordinate values are interconnected by a linear path (G1).
- The value that follows CF specifies the chamfer width; the value after RD specifies the rounding radius.
- The instructions CF and RD may be inserted between two motion blocks, at the end of the first block. The required chamfer or rounding will then be inserted after the block in which it has been programmed. Alternatively, the CF or RD command may be inserted in a separate block between two motion blocks.
- Chamfers and roundings are always produced on the active plane.

Example




```
.
.
.
N0057   G1  X...  Y...  RD = 3
N0058   G3  X...  Z...  I... J...
.
.
.
```

Fig. 12-2: Inserting a rounding

Contiguous motion blocks

- Chamfers and roundings should only be inserted between contiguous motion blocks. There may be a maximum of <u>twenty</u> blocks without motion between two motion blocks that shall be interconnected by a chamfer or rounding.
- The preceding and the subsequent motion block must contain either a linear or a circular movement.
- The command for inserting a chamfer or rounding must be written either in the first motion block, or after it, but always before the second motion block. If the compiler encounters the insertion command for a chamfer or rounding in the second motion block, it inserts the chamfer or rounding between the second and the subsequent movement.
- If the instruction for inserting a chamfer or rounding is written in a separate NC block, the immediately preceding NC block must contain the related linear or circular movement.
- Movements that are outside the active working plane cannot be interconnected by chamfers or roundings.

Illegal commands

Chamfers or roundings cannot be inserted between two motion blocks if one of the following functions is selected or de-selected:

- Radius/diameter programming (G15, G16),
- Changing planes (G17, G18, G19 and G20),
- Transformation functions (G30, G31, G32),
- Zero offsets and rotations (G50 through G59),
- Dimension inch/mm (G70, G71),
- Mirror function (G72, G73),
- Homing axes (G74),
- Travel to dead stop / canceling any axis pre-loading (G75, G76),
- Repositioning and restarting (G77),
- Scaling function (G78, G79),
- Absolute/incremental dimension (G90, G91),
- Jump instructions and program branches (BEQ, BER, BES, BEV, BMI, BNE, BPL, BRA, BRF, BSR, BST, BTE, JVE JMP, JSR)
- Jump labels.

No variables

For the NC blocks, between which a chamfer or rounding shall be inserted, the end points that lie in the current working plane must not be specified by variables.

Note: Inserting a specified chamfer or rounding between the preceding and the subsequent motion block must geometrically be possible. If this is not possible, the compiler automatically reduced the chamfer or rounding concerned to a corresponding value (if necessary even to '0', without error message).

12.3 Macro Technique

Macro

A macro is the combination of individual instructions, that usually must be programmed repeatedly, into a comprehensive instruction with its own name.

Syntax

DEFINE ... AS ...

Explanation

A macro permits instructions to be combined, that must always be written in the same sequence (for safety reasons, for example). It enables DIN G codes (such as the drilling cycles G80 through G89) or DIN auxiliary functions (such as M6) to be simulated. Furthermore, it enables functional sequences that cannot be accessed from the PLC (such as spindle control during program mode) to be controlled by a single command from the NC.

Global / local macros

Besides the local macros, which the user may define within an NC program and employ subsequently, the machine manufacturer can store global macro definitions in the *NC Options* menu (in the *NC Programming* menu item). In contrast to the local macro definitions, they are valid in all NC programs and in MDI operation of the graphical user interface.

Examples

1. Changing tools

```
      :
N0035  DEFINE  M860 AS  M86 M3 S10  Declutching while the spindle
                                     rotates slowly
N0036  DEFINE  M6 AS  BSR .WZW      Simulating the M6 DIN tool
                                     changing function
N0037  DEFINE  QUICK  AS  G01 F15000
                                    swift motion at 35 m/min
N0038  DEFINE  ANPOS_X  AS  MTD (112, 1, 8, 1)
                                    X load position for tool change
N0039  DEFINE  ANPOS_Y  AS  MTD (112, 1, 8, 2)
                                    Y load position for tool change
N0040  DEFINE  ANPOS_Z  AS  MTD (112, 1, 8, 3)
                                    Z load position for tool change
;
N0041  QUICK  X = ANPOS_X  Y = ANPOS_Y  M860
                                    swift loading in X, Y and
                                     declutching
N0042  Z = ANPOS_Z  M6              swift loading in Z and
                                     changing tools
          :
```

2. Tool correction compensation

```
          :
N0086  DEFINE  L3_KORR  AS  TLD ( , 1, @101, , 1, 13, )
                                    tool wear
N0087  DEFINE  D_SOLL  AS  MTD (114, 2, 0, 1)
                                    actual tool diameter
N0088  DEFINE  D_IST  AS  MTD (114, 2, 0, 2)
                                    tool command diameter
;
N0089  L3_KORR = (D_SOLL - D_IST) /2  computation of the tool wear
          :
```

Notes:

- A macro name may have up to 20 characters.
- The instruction related to a global macro may contain up to 156 characters (consisting of 2 lines with up to 78 characters each).
- With a local macro, the compiler interprets all NC instructions that follow the AS key word as the instruction sequence that must be inserted instead of the macro name.
- Nesting macros is not permitted. This means that there may be no further macro calls within an instruction sequence that is to be inserted.

  Example: DEFINE M860 AS M86 M3 S10
- In contrast to the textual user interface and to the SOT, within the graphical user interface, the user may program global macros in MDI mode.
- Key words may not be super-defined by macros.

CAUTION

Macro technique permits the programming language to be heavily simplified. Thus, it must be used with extreme care.

Enhancing NC Functions by Macro Technique

Using the macro technique enables the machine manufacturer to define customized NC functions that may be employed by the user in the NC program.
Global macros can be created in the „NC programming“ („NC options“ submenu) menu item. They are valid in all NC programs and in MDI mode. Please refer to the „NC Compiler“ description for details.

Invariably defined positions

The machine manufacturer can enter several fixed positions in the macro table (such as reference positions, tool changing positions,loading and unloading positions, etc.). These positions can have mnemonics assigned which the user may employ later in the NC program.

Example

Macro table: DEFINE P_WSW AS X... Y...
:

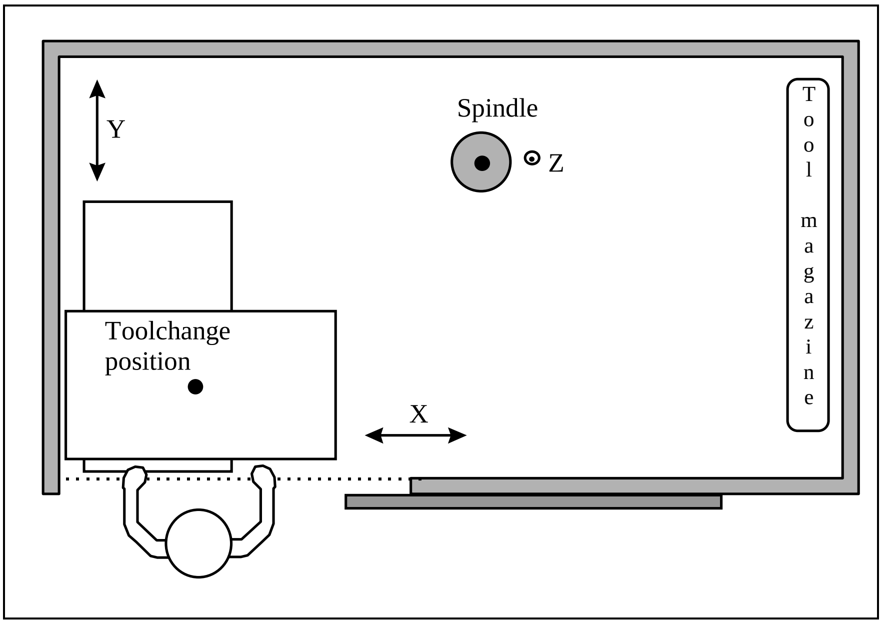


Fig. 12-3: Moving to invariably defined points

:
G00 P_WSW
:

Note: Entire NC blocks or subroutine calls may be programmed in the macro table, and be called by a key word. This enables the machine manufacturer to define specific plant-related motion blocks which can be activated by the user via key words.

Retract motion with intermediate position

In the process of moving to the reference position or to the tool changing position, the tool must frequently first be moved away from the machining area before it can safely be retracted. Using the macro technique, both movements can be combined in a single command.

Example

Macro table: DEFINE RETURN AS G0 BSR .P_RT

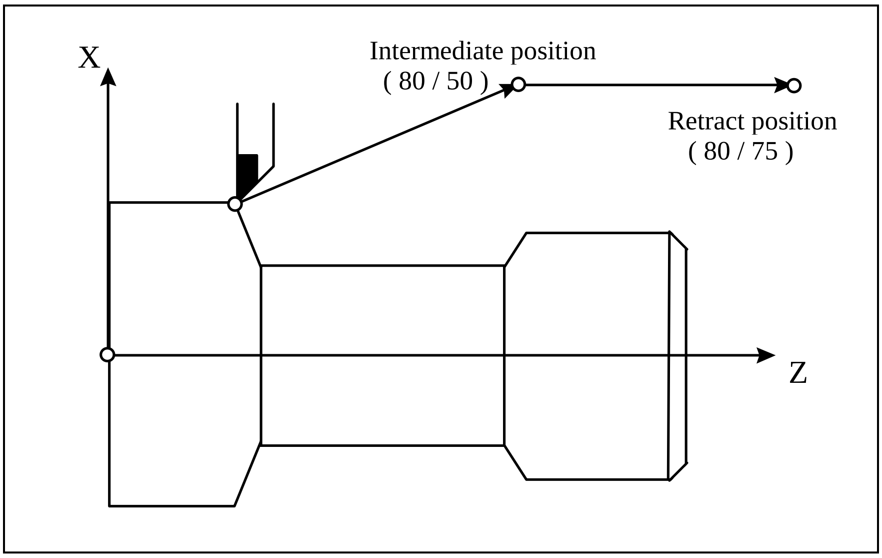


Fig. 12-4: Retract motion with intermediate position

```
:
RETURN X80 Z50                ;Programming the intermediate position
:
M30
```

The following subroutine is entered in the cycle memory:

```
.P_RT G0 X80 Z75 RTS          ;Move to retract position cycle
```

Note: Further DEFINE instructions and further subroutines may be defined. This enables fixed positions to be approached via an intermediate point. The names of the macros and subroutines may be defined by the user.
Entire sequences can be programmed in the subroutines.
The machine manufacturer creates the subroutines and the macros. The user merely enters the NC program line RETURN.

12.4 Modal Function

Modal function

The MODF_ON(STRI) modal function(STRI) permits repeatedly used expressions to be written once only.

Syntax

MODF_ON(STRI) ;Activate modal function (modal function on)

MODF_OFF ;De-activate modal function (modal function off)

Explanation

- The string *STRI* that is, in parentheses, transferred with the modal function may contain up to 80 characters.
- It is inserted in all subsequent blocks with axis movements.
- The modal function is de-selected using the MODF_OFF key word.

Notes:

- The instruction concerned is executed immediately in the NC blocks in which the user writes a modal instruction using MODF_ON.
- The MODF_OFF instruction de-activates the modal instruction in the block in which it is programmed.
- It must be noted that the modal function (such as MODF_ON(RD 2)) does not have an effect on blocks without axis movements (i.e. without feed axes). This is also true for contours that were created in the graphical editor and were saved as function block in the NC program.

Examples 1) Drilling holes

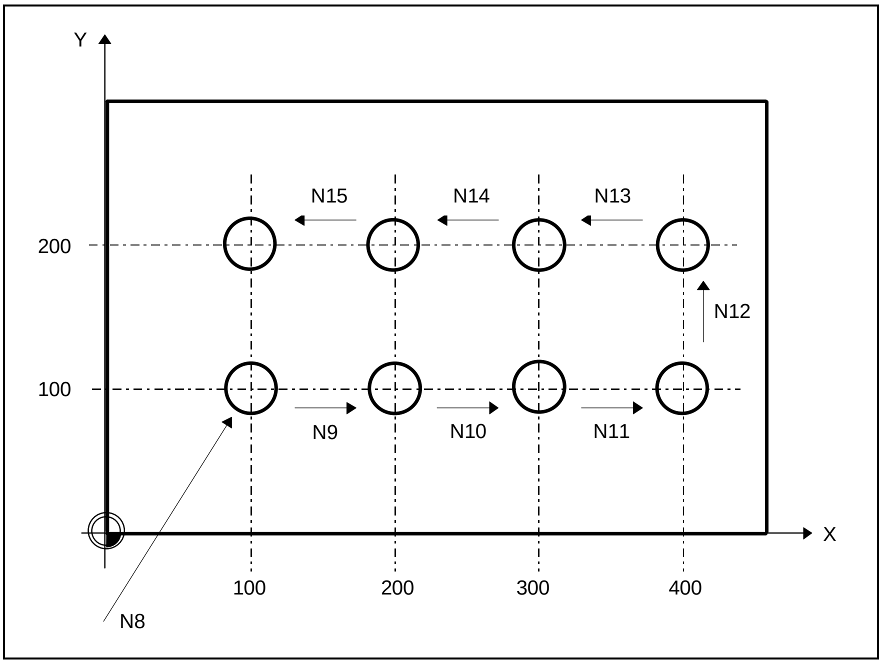


Fig. 12-5: Example: Drilling holes

```
;
N0000 T6 M6
N0001 G54 G0 X-10 Y-10 Z50 S3500 M3
;
;**************** G83 - deep hole drilling chip removing **********************
;
N0002 @171=-20.0                    depth (abs)
N0003 @172=6.0                      chip depth (inc)
N0004 @173=2.0                      safety distance (abs)
N0005 @174=0.5                      cutter distance (inc)
N0006 @175=0.0                      dwell
N0007 @176=250.0                    feed rate
;******************************************************************************
;
N0008 X100 Y100 Z10 MODF_ON (BSR .*G83)
N0009 X200
N0010 X300
N0011 X400
N0012 Y200
N0013 X300
N0014 X200
N0015 X100
N0016 MODF_OFF
N0017 T0 M6
N0018 G0 G53 X570 Y490
N0019 M30
```

2) Modal rounding and chamfering

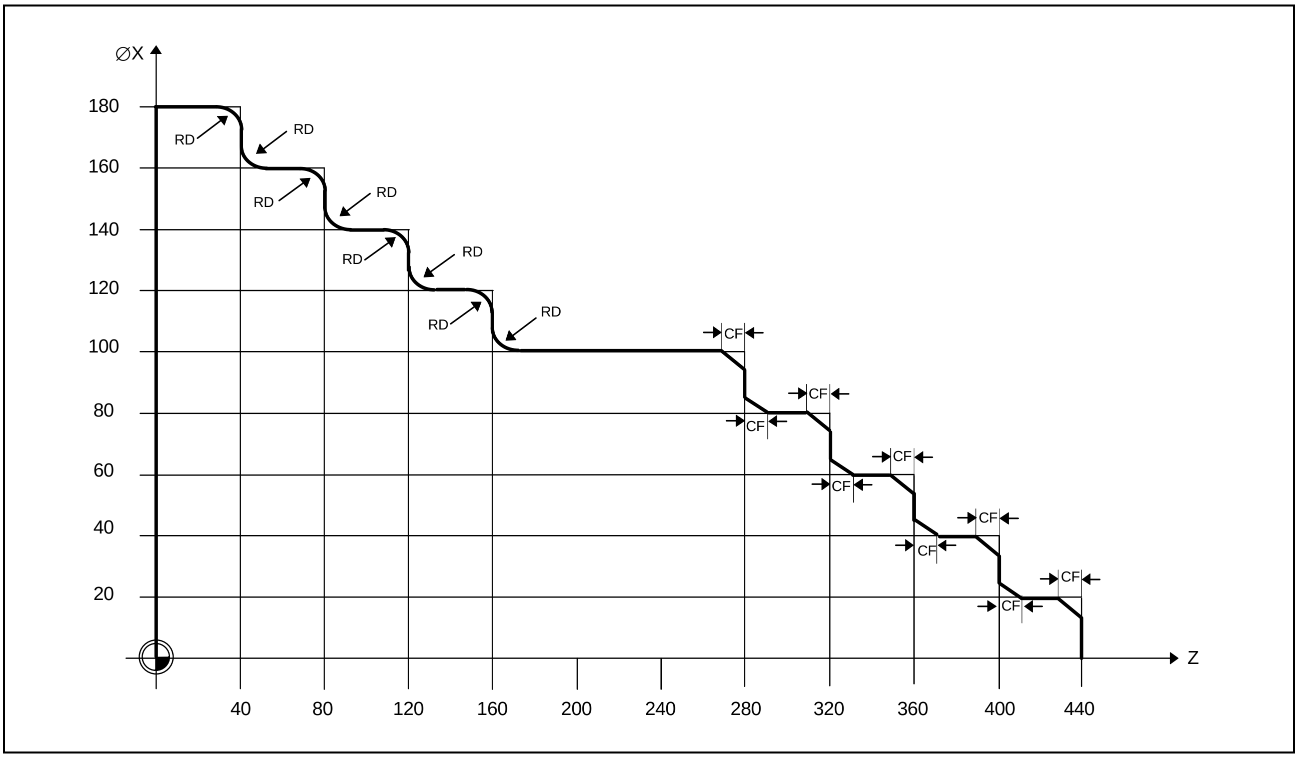


Fig. 12-6: Example: Modal rounding and chamfering

N0000 (parts name : stairs)
N0001 T3 BSR .M6 (PRE-TURNING TOOL)
N0002 G18 G54 G16 G90 G71
N0003 M69
N0004 G92 S2000
N0005 [turning contour C1 without cut segmentation]
N0006 G0 G18 G54 G16 G95 G97 G9 G7 Z444 S2000 M3 M9
N0007 X0
N0008 G1 G42 Z440 F.3
N0009 X20 MODF_ON (CF2.0)
N0010 Z400
N0011 X40
N0012 Z360
N0013 X60
N0014 Z320
N0015 X80
N0016 Z280
N0017 X100
N0018 Z160 MODF_ON (RD2.5)
N0019 X120
N0020 Z120
N0021 X140
N0022 Z80
N0023 X160
N0024 Z40
N0025 X180
N0026 Z0 MODF_OFF
N0027 G0 G40 X182 Z1
N0028 X184
N0029 Z450
N0030 M5
N0031 M70
N0032 M62
N0033 G53 G90 G47 M5
N0034 M30 [ ]

12.5 Enhanced Look-Ahead Function

Enhanced look-ahead function

The enhanced look-ahead function optimizes the velocity curve of the programmed path movement during compilation and/or the program download. If required and without modifying the programmed contour, the look-ahead function inserts intermediate blocks in order to achieve a steadier path velocity curve.

Using the enhanced look-ahead function

Using the enhanced look-ahead function is always expedient if an NC program is to be executed that consists of very short NC blocks, and if the internal block look-ahead function proves insufficient.

With non-tangential block transitions, the NC always reduces the velocity to zero at transitions that are crossed with G6 or G8. In order to be able to stop in the last block, this process frequently requires continuous deceleration across several blocks. With very short NC blocks, the internal CNC look-ahead function, however, usually does not recognize the end of the polygon blocks, or too short an NC block, or a non-tangential block transition in time. Consequently, the NC does not induce the deceleration process in time, aborts NC program execution during the deceleration process, and issues the error message

```
'deceleration distance too short'.
```

Using the enhanced look-ahead function enables the compiler to adjust the velocity profile of certain program sequences within the NC program to the maximum velocities and the acceleration capability of the individual axes. During acceleration and deceleration processes, the compiler therefore splits the NC blocks into sub-blocks of different F values wherever that is necessary.

Syntax

LA_ON	**;activates the enhanced look-ahead function (<u>L</u>ook-<u>a</u>head function, <u>on</u>)**
LA_OFF	**;de-activates the enhanced look-ahead function (<u>L</u>ook-ahead function, <u>off</u>)**

Global variables

Global variables have been introduced that are used as transfer parameters for the enhanced look-ahead function. Usually, the user can employ these variables without modification. Some variables may be pre-assigned in the *NC Options* menu (in the *NC programming* menu item).

METB	;*Minimum execution time of an NC block*
Explanation:	The global variable *minimum execution time of an NC block* (METB) specifies the shortest execution time of an NC block within the polygon sequence that is to be optimized. It must be greater than the related block cycle time.
VFBT	;*Velocity factor for block transition*
Explanation:	This variable permits the velocity changes at non-tangential block transitions to be influenced.
BBTRC	;*Block buffer for tool radius compensation*
Explanation:	This variable specifies how many NC blocks the enhanced look-ahead function shall take into account in advance when it computes and checks the tool radius compensation.

TL_RADIUS ;*Specify tool radius*

Explanation: Using the TL_RADIUS[T no., E no.] command, the tool radii that are required for the enhanced look-ahead function may centrally be defined at the beginning of the program. The compiler employs the current T or E no. if a T no. or an E no. has not been specified.

Example:

```
:
N0005  TL_RADIUS[1234567,1]=24.995
N0006  TL_RADIUS[923,3]=20.31
N0007  TL_RADIUS[9,9]=29.89
:
```

CAUTION

If the tool radius path correction of the enhanced look-ahead function is employed (TRC <> 0), the tool radius that, using the pre-defined TL_RADIUS[T no., E no.], has been specified in the NC program during compilation must exist during machining.

TRC ;*Tool radius correction*

Explanation:

TRC=0: The enhanced look-ahead function does not perform radius correction.

TRC=1: The enhanced look-ahead function performs radius correction to the left of the contour, using the tool radius specified under TL_RADIUS.

TRC=2: The enhanced look-ahead function performs radius correction to the right of the contour, using the tool radius specified under TL_RADIUS.

ADTRC ;*Approach distance for tool radius compensation*

Explanation:

ADTRC = 0 To set up the tool radius compensation, the enhanced look-ahead function does not take any approach or retract distance into account.

ADTRC $\neq$ 0 If tool radius compensation is activated with TRC=1 or TRC=2, the enhanced look-ahead function inserts a straight line with tangential transition and of the length that must be specified here before the first polygon element (first motion block after LA_ON), and after the last polygon element (last motion block before LA_OFF).

Contiguous motion blocks

Only NC blocks that contain G1, G2, G3 movements, event commands (SE,RE) velocity specifications (F), acceleration limits (ACC_EFF) and swift auxiliary function outputs (MQxxx, QQxxxx and Sxxxxx.xx, if S has been selected as a swift auxiliary function) may occur within the program sequence that shall be optimized.

No variables

The end points of NC blocks whose velocity profile shall be processed by the enhanced look-ahead function may not be specified by variables.

Tool management

Changing tools, including the related T call and the edge selection, must be performed prior to activating the enhanced look-ahead function or after it has been de-activated.

Per cent acceleration correction

In certain program sequences and, if applicable, depending on the tool or workpiece weight, the resulting path acceleration must be reduced.

ACC_EFF ;changing the efficient resulting path acceleration

permits the actual resulting path acceleration to be modified. This acceleration factor ranges from 1% through 200%.

Note: In contrast to the ACC command, the ACC_EFF command does not delimit the maximum path acceleration that is specified in the process parameters. It modifies the actual path acceleration according to the specification.

Axis-related velocities

Besides programming the path velocity via the F value, axis velocities may also be programmed during the look-ahead function.

To specify an axis velocity, the 'F' must immediately (without blank) be followed by the axis name.

Syntax:

F<axis name>=<axis velocity in mm/min>

Example: :

N0045 G01 X 2034 Z1 421 FZ1=4500 ;axis-related velocity for Z1

:

Note: If the user programs several velocities within an NC block, that NC block and the subsequent NC blocks are executed with the last velocity to have been specified until the next velocity instruction is encountered.

Access to current data in the controller

The command „access to current data" ACD_COMP[...] permits the access to current controller data (currently only NC variables) during compilation.

Example: Reading the tool radius during compilation

After each dressing of a grinding wheel, a dressing program updates half the diameter of the grinding wheel in the NC variable '@1:120'. During compilation, that value must be taken into account as the tool radius.

TL_RADIUS[1,1] = ACD_COMP[@1:120]-0,2; Read tool radius from NC variable @1:120 and subtract 0.2 mm.

Example: Needle grinding

A given polygon curve must be traversed in reciprocated movement at highest velocity possible. This requires the velocity curve of the programmed path motion to be optimized, using the enhanced look-ahead function.

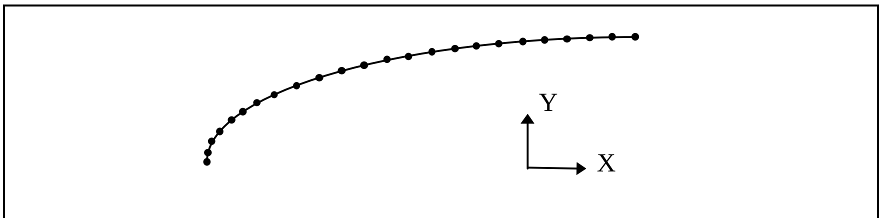


Fig. 12-7: Velocity curve of a polygon that is to be optimized for grinding needles

```
;Grinding needles on the XY plane
;Grinding wheel radius:          2.50000
;File name:                      TP1
;
N0000  (parts name: TP1)
N0001  T2 BSR .M6  [SCHLEIFSCHEIBE D5]    activate tool
N0002  TL_RADIUS [ ] = ACD_COMP[@200]     read current tool radius
                                          for compiler
N0003  G0 G17 G40 G54 G71 G48 G8 G6 G98 X-0.19306
        Y3.49431 S1 3000 M3               establish initial  state
N0004  @101=200                           loop counter for number
                                          of oscillating strokes =
                                          200
N0005  .PEN @100=@101-0 BEQ .ENDPEN       terminate oscillation ?
N0006  F4000                              set path velocity
;
N0007  TRC=1                              tool radius correction
                                          left of the contour

N0008  ADTRC=1                            approach dist. to set up
                                          tool radius compens.
N0009  ACC_EFF=90                         modify effective path
                                          acceleration
N0010  LA_ON                              enhanced look-ahead
                                          function ON
;
N0011  G1 X0.8 Y1.2                       polygon curve
        :
        :
N0030  LA_OFF                             enhanced look-ahead
                                          function OFF
        :
;
N0051  @101=@101-1 BRA .PEN               decrement loop
                                          counter
N0052 .ENDPEN BSR .ABRICH                 call dressing cycle
N0053  RTS
;
N0054  PROGRAMMENDE
```

Notes:

- In reverse programs, the LA_OFF command must be programmed when the LA_ON command is used.
- The compiler does not take into account any velocity changes of the axes that are caused by a rotation of the contour.

Detailed description

Please refer to the NC Compiler description in Folder 5 for detailed information about these NC compiler functions.

12.6 Graphical NC Editor

Function

The graphical NC editor represents an efficient and highly precise tool that supports parts programming. It enables the user to easily define geometric elements (e.g. parts contours) graphically, and to specify their machining.

At the end of the dialog, the user may chose whether the data that is required for machining shall be saved in the form of NC blocks or in the form of a function call, together with the related parameters, in the NC program.

Syntax

The graphical NC editor produces the following instructions:

• WINDOW_01 (..., ..., . . .)	;Define window size for turning
• WINDOW_02 (..., ..., . . .)	;Define window size for milling
• CONT (..., ..., . . .)	;Definition of the initial part contour or of the final part contour
:	
:	
END_CONT	
• FORM_20 (..., ..., . . .)	;recess - turning
• FORM_50 (..., ..., . . .)	;straight elongated hole - milling
• FORM_51 (..., ..., . . .)	;round elongated hole - milling
• FORM_52 (..., ..., . . .)	;circle - milling
• FORM_53 (..., ..., . . .)	;polygon - milling
• FORM_54 (..., ..., . . .)	;straight text - milling
• FORM_55 (..., ..., . . .)	;round text - milling
• FORM_56 (..., ..., . . .)	;rectangle - milling
• FORM_57 (..., ..., . . .)	;rectangle centered - milling
• CYCLE_10 (..., ..., . . .)	;contour cut - turning
• CYCLE_11 (..., ..., . . .)	;roughing - turning
• CYCLE_12 (..., ..., . . .)	;residual cut - turning
• CYCLE_40 (..., ..., . . .)	;contour cut - milling

CAUTION

The data items
- tool edge orientation,
- tool radius,
- corner angle, and
- setting angle

that had been assumed when the machining program was created must exist when machining is performed.

Detailed description

Please refer to the NC Compiler description in Folder 5 for detailed information about these NC compiler functions.

13 NC Programming Practices

13.1 Efficient NC Programming

The following rules will help to ensure that the CNC operates at its maximum performance level.

Note: Whatever can be programmed in a single NC block in terms of syntax should be in fact be programmed in a single NC block, provided it does not violate program flow logic.

What can be programmed in a NC block?

- Labels (e.g. .HOME)
- Preparatory functions (1 function from each of 16 groups)
- Trigonometric angle unit ∈ {RAD, DEG}
- Assigning a value to an NC variable (repeatedly) (e.g. @12=3)
- Assignment of value to a drive datum (e.g. AXD(X:S-0-0405)=3)
- Position statement (one position statement for each axis) {X,Y,Z,U,V,W,A,B,C}
- Interpolation parameter I
- Interpolation parameter J
- Interpolation parameter K
- F-word
- S-word ∈ {S,S1,S2,S3}
- P-word
- Zero point offset table (O word)
- Path acceleration as percent (ACC)
- Auxiliary M functions (one aux. M function from each of 16 groups)
- Auxiliary Q-function (Q word)
- Tool number (T word)
- Edge number (E word)
- Tool command
- Setting of a NC event (SE)
- Reset of a NC event (RE)
- Wait until NC event is set (WES)
- Wait until NC event is reset (WER)
- Define process (DP) (repeatedly)
- Select NC program for process (SP)
- Reverse process (RP) (repeatedly)
- Advance program (AP) (repeatedly)
- Wait for process (WP) (repeatedly)
- Lock process (LP) (repeatedly)
- Set process complete status (POK)
- Program control command
- Message
- Comment

Example	NC program

N0000 G00
N0001 S5000
N0002 M03
N0003 F10000
N0004 X100 Y50

Optimized for time, spindle starts after the move:
N0000 G00 X100 Y50 F10000 S5000 M03

Optimized for time, spindle starts before the move:
N0000 M03 S5000
N0001 G00 X100 Y50 F10000

The priority for processing an NC block in the NC memory is as follows:

Block number	Label	aux. fct. before move	G codes	Variables	Axis values	IPO parameter	F value	S value	aux. fct. after move	Pallet com-mands	Tool com-mands	Events	Proc. com-mands	Program control commands
N1234	**.ENDE**	**M03**	**G01**	**@100=x**	**X100 Y100**	**I0 J50**	**F1000**	**S800**	**M03**	**SEL 1**	**MTP T6**	**SE 5**	**DP 1**	**HLT**

- While all of the above NC commands can, in theory, be programmed in a single NC block, the maximum block length is limited to 240 characters.
- While "auxiliary M-functions" can be used from all 16 groups, no more than four auxiliary functions (S, M, Q words) can be programmed in a single NC block.

Note: Avoid repeating functions (G-codes) which are already active. Remember which functions are modally active as a consequence of the "power-on status."

Example	NC program

N0000 G07 G09 G40 G43 G47 G53 G62 G90 G94 RAD
power-on states

N0001 G00 G90 S5000 M03 F10000 X100 Y50
N0002 G00 G90 F10000 X200 Y50
N0003 G01 G90 F10000 Y100

Time-optimized:
N0000 G00 X100 Y50 F10000 S5000 M03
N0001 X200
N0002 G01 Y100

Note: Calculate all constants when you create the program, and assign these constants without using equal signs.

Example	NC program

N0000 DEG X=100 Y=20+100*SIN(30)

Time-optimized:
N0000 X100 Y70

Note: Avoid using NC commands that stop NC block processing.

NC commands that stop NC block processing

- Preparatory functions

  ∈ {G33, G50 ... G59, G63, G64, G65, G74, G75, G95, G96} and
- cancellation of preparatory functions via G93, G94 and G97
- Assigning values to NC variables, working pallets or drive datum
- Auxiliary functions (S, M, Q words)
- Tool number (T-word)
- Tool commands
- Wait until NC event set/reset (WES, WER)
- Process control commands
- Program control commands

  ∈ {BST, BES, BER , JMP, RET, BTE, BSE, BRF, HLT, JEV, BEV, CEV, JSR}

The program control commands:

RTS, BRA, BSR, REV, BEQ, BNE, BPL, BMI, EEV and DEV

do **NOT** stop look-ahead block processing.

Note: Use tool management as a parallel process through optimal programming.

Example NC program for tool changer with double gripper

N0000 T1 MTP	Position magazine: tool 1
N0001 TCH	Switch tools between spindle and magazine location
N0002 BSR .BEARB1	Machining process 1
N0003 T2 MTP	Position magazine: tool 2
N0004 TCH	Switch tools between spindle and magazine location
N0005 BSR .BEARB2	Machining process 2

Time-optimized:

N0000 T1 MTP	Position magazine: tool 1
N0001 TCH	Switch tools between spindle and magazine location
N0002 T2 MTP	Position magazine: tool 2 (parallel)
N0003 BSR .BEARB1	Machining process 1
N0004 TCH	Switch tools between spindle and magazine location
N0005 BSR .BEARB2	Machining process 2

Positioning of the magazine in block N0000 takes place asynchronously to the execution of the NC program—in other words, execution of the NC program can continue unhindered.

The TCH command will automatically wait unit spindle positioning is completed.

CNC Time Data	Time Data with Digital Drives
• Block cycle time 6 ms • Block transition time 2 ms • Interpolation cycle time 2 ms • Position control cycle time 2 ms	• Precision interpolation 0.25 ms • Position control cycle time 0.25 ms

14 Appendix

14.1 Table of G Code Groups

G Function	G Code Group	Active	Meaning
G00, G01, G02, G03	1	modal	Interpolation Functions
G17, G18, G19	2	modal	Plane Selection
G40, G41, G42	3	modal	Tool Path Compensation
G52 to G59	4	modal	Zero Offsets
G15, G16	5	modal	Radius/Diameter Programming
G90, G91	6	modal	Dimension Statements
G65, G94, G95	7	modal	Feed Programming
G96, G97	8	modal	Spindle Speed Programming
G70, G71	9	modal	Dimensional Units
G43, G44	10	modal	Transition Element
G61, G62	11	modal	Block Transition Selection
G98, G99	12	modal	Speed at Contour/Center Line
G47, G48, G49	13	modal	Tool Length Compensation
G08, G09	14	modal	Contouring Mode
G06, G07	15	modal	Interpolation Method
G04 G33 G50, G51 G63, G64 G74 G75 G76 G77 G92 G93	16 16 16 16 16 16 16 16 16	block block block block block block block block block	Dwell Time Thread Cutting Prog. Zero Offset Tapping Homing Feed to Positive Stop Reposition and NC block restart Spindle Speed Limit Time Programming
G30, G31	17	modal	Transformation
G72, G73	18	modal	Mirror Imaging
G78, G79	19	modal	Scaling
G36, G37, G38	21	modal	Rotary axis start-up logic

The G functions which are active only in the given block can only be read in the block in which they are programmed. Otherwise a value of -1 is output when the block-active G functions are read.

14.2 Table of M Function Groups

M Function	M Function Group	Active	Meaning
M000, M001, M002, M030	1	modal	Program Control Commands
M3, M4, M5, M13, M14	2	modal	Spindle Commands S
M103, M104, M105, M113, M114	2	modal	Spindle Commands Spindle 1
M203, M204, M205, M213, M214	3	modal	Spindle Commands Spindle 2
M303, M304, M305, M313, M314	4	modal	Spindle Commands Spindle 3
M007, M008, M009	5	modal	Coolant S
M107, M108, M109	5	modal	Coolant S1
M207, M208, M209	6	modal	Coolant S2
M307, M308, M309	7	modal	Coolant S3
M010, M011	8	modal	Clamp & Unclamp S
M110, M111	8	modal	Clamp & Unclamp S1
M210, M211	9	modal	Clamp & Unclamp S2
M310, M311	10	modal	Clamp & Unclamp S3
M040, ..., M045	11	modal	Gear Selection S
M140, ..., M145	11	modal	Gear Selection S1
M240, ..., M245	12	modal	Gear Selection S2
M340, ..., M345	13	modal	Gear Selection S3
M046, M047	14	modal	Spindle Override
M048, M049	15	modal	Feed Override
M019, ..., M319, Mxxx	16	per block	S Positioning & M-auxiliary machine sp. Functions

The M functions which are active only in the given block can only be read in the block in which they are programmed. Otherwise a value of -1 is output when the block-active M functions are read.

14.3 Table of Functions

I. G00 through G20

Func-tion	G Group	Meaning	Description	Page
G00	1	Lin. interpolation, rapid traverse * modal	**Syntax: G00** ; The programmed coordinates are traversed at maximum path velocity.	4-14
G01	1	Lin. interpolation, rapid traverse * modal	**Syntax: G01 F value** ; The programmed axes start and reach their end point together.	4-15
G02	1	Circular interpol., clockwise, * modal	**Syntax: G02 <end point> <interpolation parameters [I,J,K]> or. <radius [R]>** ; A circular motion is performed in the selected plane (G17, G18 G19).	4-16
G03	1	Circular interpol., couterclockwise, * modal	**Syntax: G03 <end point> <interpolation parameters [I,J,K]> or. <radius [R]>** ; A circular motion is performed in the selected plane (G17, G18 G19).	4-16
G04	16	Dwell time * block	**Syntax: G04 F<time in seconds>** ; The maximum dwell time is 600 seconds.	4-39
G06	15	Position with minimized lag * modal	**Syntax: G06** ; Algorithm for positioning with minimized lag for all axis moves. Block transitions are not rounded.	4-2
G07	15	Positioning w. lag * default, * modal	**Syntax: G07** ; Algorithm for positioning with lag for all axis moves. Block transitions which are not tangential will be rounded.	4-5
G08	14	Contouring Mode (Acceleration) * modal	**Syntax: G08** ; The final speed at the end of the block is adjusted to ensure that the transition to the next NC block occurs at the highest possible speed.	4-7
G09	14	Contouring mode (deceleration) * default, * modal	**Syntax: G09** ; G09 reduces position differences at block transitions.	4-9
G15	5	Radius programming * modal	**Syntax: G15** ; The machine builder sets the "power-on state" for radius/diameter programming in the process parameters.	3-19
G16	5	Diameter programming * modal	**Syntax: G16** ; The machine builder sets the "power-on state" for radius/diameter programming in the process parameters.	3-19
G17	2	Plane selection XY * modal	**Syntax: G17** ; The machine builder sets the default plane in the process parameters.	3-15
G18	2	Plane selection ZX * modal	**Syntax: G18** ; The machine builder sets the default plane in the process parameters.	3-15
G19	2	Plane selection YZ * modal	**Syntax: G19** ; The machine builder sets the default plane in the process parameters.	3-15
G20	2	Free plane selection * modal	**Syntax: G20 [1st axis of plane] [2nd axis of plane] {vertical axis}** ; When free plane selection is activated via G20, the controller deselects the constant cutting speed (G96) and activates the spindle speed in rpm (G97) function. The controller activates linear interpolation.	3-15

II. G30 through G49

Func-tion	G Group	Meaning	Description	Page
G30	17	Coordinate transformation canceled * default, * modal	**Syntax: G30** ; G30 cancels an existing coordinate transformation. The fictive axes must not be programmed any more.	4-56
G31	17	Coordinate transformation ON * modal	**Syntax: G31** ; The NC activates the G17 plane and the corresponding real axes become fictive axes.	4-51
G32		Selection of lateral cylinder surface machining * modal	**Syntax: G32 RI w** or **G32 RI=w** ; The NC produces straight lines and circles on a lateral cylinder surface. Prior to activating lateral cylinder surface machining, at least one rotary axis must span the activated working plane.	4-54
G33	16	Thread cutting * block	**Syntax: G33 <end point> <lead> <starting angle>** ; G33 cuts single- or multiple-thread longitudinal, face and tapered threads using a constant lead.	4-24
G36	21	Start-up logic for endlessly rotating rotary axes * modal	**Syntax: G36** ; Positioning with modulo calculation „shortest distance“. Modulo calculation can only be used with absolute programming (G90).	4-49
G37	21	Start-up logic for endlessly rotating rotary axes * modal	**Syntax: G37** ; Positioning with modulo calculation „positive direction“. Modulo calculation can only be used with absolute programming (G90).	4-51
G38	21	Start-up logic for endlessly rotating rotary axes * modal	**Syntax: G38** ; Positioning with modulo calculation „negative direction“. Modulo calculation can only be used with absolute programming (G90).	4-51
G40	3	Cancel tool path compensation * default, * modal	**Syntax: G40** ; If an active tool path compensation is canceled, the next move which is expected is a linear move lying in the plane.	5-34
G41	3	Tool path compensation left of workpiece contour * modal	**Syntax: G41** ; If G41 is programmed after an active G40 or G42, the next anticipated move is a linear move in the process plane.	5-35
G42	3	Tool path comp. right of workpce. contour * modal	**Syntax: G42** ; If G41 is programmed after an active G40 or G42, the next anticipated move is a linear move in the process plane.	5-35
G43	10	Insert contour transition "arc" * default, * modal	**Syntax: G43** ; When tool path compensation is active (G41 or G42) G43 inserts an arc as the contour transition element for outside corners.	5-37
G44	10	Inserting contour transition "chamfer" * modal	**Syntax: G44** When G41 or G42 is active, a chamfer is inserted as the contour transition with outside corners whose transition angle exceeds 90°.	5-37
G47	13	No tool length correction * default, * modal	**Syntax:** G47 ; When movements are being performed in the direction of the tool, all position data relates to the position of spindle nose.	5-40
G48	13	Tool length correction positive * modal	**Syntax: G48** ; The entered tool length is corrected in the direction of the main axes when the axis direction is positive.	5-40
G49	13	Tool length correction negative * modal	**Syntax: G49** ; The entered tool length is corrected in the direction of the main axes in the negative axis direction.	5-40

III. G50 through G73

Fun-ction	G Group	Meaning	Description	Page
G50	16	Programmable absolute zero offset * block	**Syntax: G50 <axis>** ; absolute offset of the machining zero point by the value programmed using G50 under the address letter for the axis.	3-12
G51	16	Programmable incremental zero offset * block	**Syntax: G51 <axis>** ; incremental offset of the machining zero point by the value programmed using G50 under the address letter for the axis.	3-12
G52	4	Programmable workpiece zero point * modal	**Syntax: G52 <axis>** ; A workpiece zero point is programmed using the value specified at the axis address. All zero offsets which are already active are canceled	3-13
G53	4	Cancel zero off-sets * default, * modal	**Syntax: G53** ; switch from workpiece coordinate system to mach. coordinate system.	3-14
G54 - G59	4	Adjustable zero offsets * modal	**Syntax: G54-G59** ; offsets are entered the user interface. G52 or G53 cancels G54...G59.	3-8
G61	11	Exact stop * modal	**Syntax: G61** ; the programmed target position is traversed to within a specified exact stop limit.	4-10
G62	11	Block transition with lag * modal	**Syntax:** G62 ; sudden contour changes and non-tangential transitions are rounded off by programming G62.	4-12
G63	16	Rigid tapping * block	**Syntax: G63 <end point> <feed per spindle revolution [F]>** ; with G63 the spindle will stop at the end of movement.	4-30
G64	16	Rigid tapping * block	**Syntax: G64 <end point> <feed per spindle revolution[F]>** ; with G64 the spindle continues to rotate at the end of the move.	4-30
G65	7	Floating tapping spindle as lead axis * modal	**Syntax: G65 <feed per spindle revolution[F]>** ; G65 is used to tap threads using non-interpolating main spindles.	4-34
G66	8	Constant grinding wheel peripheral speed * modal	**Syntax: G66 S <Constant grinding wheel peripheral speed>** ; Programming G66 causes the programmed S value to be in-terpreted in m/s or feet/s.	4-44
G70	9	Unit: Inch * modal	**Syntax: G70** ; The machine manufacturer defines the base programming unit in the process parameters.	3-20
G71	9	Unit: Millimeters * modal	**Syntax: G71** ; The machine manufacturer defines the base programming unit in the process parameters.	3-21
G72	18	Mirror function OFF * default, * modal	**Syntax: G72** ; the mirror function is canceled in all axes.	3-22
G73	18	Mirror function ON * modal	**Syntax: G73 <axis name>-1** ; the coordinates of the axes entered in the axis name are mirror imaged.	3-22

IV. G74 through G99

Func- tion	G Group	Meaning	Description	Page
G74	16	Axis homing cycle * block	**Syntax: G74 <axis name> <coordinate value> <feed** ; G74 activates G40, G47, G53, G90, G94	3-26
G75	16	Feed to positive stop * block	**Syntax: G75 <axis name> <coordinate value> <feed>** ; G75 is possible with G90 or G91.	3-26
G76	16	Cancel all feeds to positive stop * block	**Syntax: G76** ; G76 cancels the axis pre-loads on all axes which are pre-loaded using G75 traverse to fixed stop.	3-28
G77	16	NC block restart and repositioning * block	**Syntax: G77 <axis name> <coordinate value[0]>** ; The originally programmed coordinate value (spindle speed) is restored.	3-29
G78	19	Scaling OFF * default, * modal	**Syntax: G78** ; the scaling function is canceled in all axes.	3-24
G79	19	Scaling function ON * modal	**Syntax: G79 <axis name><scaling factor>** ; the scale for the distance to be traversed on the specified axis is increased or decreased.	3-24
G90	6	Input data as ab-solute dimensions * default, * modal	**Syntax: G90** ; all dimensions are input relative to a specified zero point.	3-3
G91	6	Input data as in-cremental values * modal	**Syntax: G91** ; all subsequent dimension inputs are stated as the difference relative to the start/start position.	3-4
G92	16	Spindle limit speed active * block	**Syntax: G92 S<upper spindle speed limit>** ; The set speed limit remains modal active.	4-47
G93	16	Time program-ming * block	**Syntax: G93 F<time in seconds>** ; G93 is superimposed on G94 or G95 in the NC block.	4-37
G94	7	Input feedrate in inches or mm per minute * default, * modal	**Syntax: G94** ; The programmed F word is interpreted as the feed in mm/min. G94 is removed by G95 or G65.	4-38
G95	7	Input feedrate in inches or mm per spindle revolution * modal	**Syntax: G95 F<feed per revolution>** ; The programmed F word is interpreted as mm or inches per spindle revolution.	4-38
G96	8	Constant surface speed (CSS) * modal	**Syntax: G96 S<constant surface speed in m/min>** ; The CNC determines the correct spindle speed for the current diameter.	4-44
G97	8	Spindle speed in rpm * default, * modal	**Syntax: G97** ; The programmed S word is interpreted as RPM.	4-47
G98	12	Constant feed on tool center line * default, * modal	**Syntax: G98** ; The path velocity is NOT corrected in arcs if G41 or G42 is active.	5-38
G99	12	Constant feed at the contour * modal	**Syntax: G99** ; The path velocity is corrected in arcs if G41 or G42 is active.	5-38

V. ACC through BTE

Function	G Group	Meaning	Description	Page
ACC		Programmable acceleration * modal	**Syntax: ACC <constant>** ; The programmed constant (0 .. 100) limits the acceleration of all axes programmed in NC block ACC.	4-13
AP		Advance program	**Syntax: AP <process>** ; The advance program which was selected using SP is started for the specified process.	9-3
AXD		Data exchange with digital drives	**Syntax: AXD(<axis name>: <SERCOS ID number>)** ; Read and write drive data using the SERCOS.	11-1
BEQ		Branch if equal to zero	**Syntax: BEQ <label>** ; The program continues executing if the last result is equal to zero.	9-16
BER		Branch if event reset	**Syntax: BER <label> <process number>: <event number>** ; Program execution continues at the defined label if the event is reset.	9-15
BES		Branch if NC event is set	**Syntax: BES <label> <process number>: <event number>** ; The program execution is continued at the specified label if the defined NC event is set.	9-15
BEV		Branch on NC event to NC subroutine (interrupting)	**Syntax: BEV <label>: <NC event number>** ; The defined process NC event (0 .. 7) is monitored by the NC after executing the NC command BEV. NC block execution at the NC block with the defined label if the NC event has a status of '1'.	7-6
BMI		Branch if less than zero (minus)	**Syntax: BMI <label>** ; Program execution continues at the specified label if the result of the last mathematical expression was less than zero (minus).	9-16
BNE		Branch if not equal to zero	**Syntax: BNE <label>** ; Program execution cont. at the NC block starting with the specified label if the result of last math operation was not equal to zero.	9-16
BPL		Branch if equal to or greater than zero (if plus)	**Syntax: BPL <label>** ; Program execution cont. at the NC block starting with specified label if result of last math operation was equal or greater than zero.	9-16
BRA		Branch absolute	**Syntax: BRA <label>** ; Program execution continues at the NC block with the specified label.	9-9
BRF		Branch if reference	**Syntax: BRF <label>** ; Program execution continues at the NC block with the specified label if all process axes are referenced (homed).	9-15
BSE		Branch if spindle is empty	**Syntax: BSE <label> ⇨ BSE .SPLE** ; The BSE branch command is used for determining whether or not the spindle is empty.	8-9
BSR		Branch to NC subroutine	**Syntax: BSR <label>** ; Program execution continues at the NC block starting with the specified label (identifies the NC subroutine begin).	9-11
BST		Branch with Stop	**Syntax: BST <label>** ; The NC program branches to the defined label, sets the default preparatory functions (G codes) and waits for a new start.	9-8
BTE		Branch if tool T0 selected	**Syntax: BTE <label>** ; Program execution continues at the NC block starting with the defined label if the tool T0 (no tool) has been programmed.	9-15

VI. CEV through MOP

Function	G Group	Meaning	Description	Page
CEV		Cancel NC event supervision (Interrupt)	**Syntax: CEV: <NC event number>** ; CEV must be used to cancel the supervision (BEV, JEV) of a single interrupting NC event (0 .. 7).	7-7
D		D-correction selection * modal	**Syntax: D<D-correction no. 0..99]>** ; D1 .. D99 selects offsets defined in the D-correction table. They are activated as additive tool geometry shifts when activating tool management and G48/G49 or G41/G42. D0 cancels active D-correction offsets.	5-41
DEG		Angle unit degrees	**Syntax: DEG** ; Arguments and reciprocal functions of the trigonometric functions SIN, COS, TAN, and ASIN, ACOS, ATAN in the angle unit Degrees.	10-5
DEV		Disable NC event supervision (Interrupt)	**Syntax: DEV** ; Temporarily disables supervision (BEV, JEV) of all interrupt. NC events (0 .. 7) until enabled again with EEV or at the NC program end.	7-7
DP		Define process	**Syntax: DP <process>** ; DP informs the SPS via the corresponding Gateway signal that the process will be required for NC program execution.	9-2
E		Edge selection * modal	**Syntax: E<edge number>** ; Selects the data of the defined tool edge (0 .. 9).	8-2
EEV		Enable NC event supervision	**Syntax: EEV** ; Enables the supervision (BEV, JEV) of all disabled (DEV) NC events.	7-7
FAX, GAX		Get axis from other process	**Syntax: FAX (<axis designation>) ,GAX (<process>: <axis designation>)** ; Free AXis for another process; Get AXis of another process.	9-5
HLT		Programmed Halt	**Syntax: HLT** ; Interrupts NC program execution and the process waits for a new start signal.	9-8
JEV		Jump on NC event (Interrupt)	**Syntax: JEV <label> <NC event number>** ; Def. NC event (0..7) is monitored by the CNC. NC event status of '1' continues NC program execution at the NC block with the defined label (not a subroutine).	7-6
JMP		Jump to NC program	**Syntax: JMP <NC program number>** ; NC program execution continues with the first NC block of the defined NC program.	9-9
JSR		Jump to NC subroutine	**Syntax: JSR <NC program number>** ; NC program execution continues with the first NC block of the def. NC program (must end with a RTS, NC subroutine).	9-10
LP		Lock process	**Syntax: LP <process>** ; Command informs the SPS via the corresponding Gateway signal that the process will be locked in a user defined state.	9-4
MEN		Tool Magazine (storage) Enable for manual mode	**Syntax: MEN** ; Enables the manual tool storage mode while continuing NC program execution.	8-7
MFP		Move Free Pocket into change Position	**Syntax: MFP(<position>,<direction>) { (.,.) optional }** ; Causes tool storage (magazine) movement to bring next empty location into spec. change pos.	8-6
MHP		Tool Storage to Home Position	**Syntax: MHP(<direction>) { (.) optional }** ; Causes the tool storage (turret/magazine) to move to its home (base) position (pocket 1).	8-3
MMP		Move programmed Location into Position	**Syntax: MMP(<position>,<direction>) { (.,.) optional }** ; Causes the tool storage (turret/location) to move the location specified via the T-number in the defined direction to the defined change position.	8-5
MOP		Move Old Pocket into Position	**Syntax: MOP(<position>,<direction>, <spindle>) { (.,.,) optional }** ; Causes tool storage (magazine) to move the pocket of the tool in the active tool spindle into the defined change position.	8-6

VII. MRF through SE

Function	G Group	Meaning	Description	Page
MRF		Tool storage to Reference	**Syntax: MRF** ; Initiates the referencing sequence of the tool storage.	8-3
MRY		Tool Storage Ready ?	**Syntax: MRY** ; Stops the NC program execution until the active tool storage movement is completed.	8-7
MTD		Reading and writing the machine data elements	**Syntax: MTD([Page no.],[control variable 1], [control variable 2], [element no.])** ; Within an NC block, any number of data elements may be read from the machine data. However, only one data element can be written to at any one time.	11-14
MTP		Move programmed Tool into Position	**Syntax: MTP(<position>,<direction>) { (.,.) optional }** ; Causes tool storage to move location of last programmed tool (T-number) in defined direction to defined change position.	8-4
NMP		Negative Memorized Position	**Syntax: NMP(<axis designation>)** ; Reads the position of an axis that was strobed with ‘0’→‘1’ of the AxxC.STRBP Gateway signal.	11-1
O		Offset Table Data selection for G54 .. G59	**Syntax: O <offset table number>** ; Depending on the process parameters def., the Offset Table 0 .. 9 can be selected. Offset Table 0 is active by default.	3-10
OTD		Read / write Offset Table Data	**Syntax: OTD([NC memory],[process],[offset table],[offset],[axis])**	11-6
P		Active plane rotation together with G50, G51, G54 .. G59	**Syntax: G50-G51 P<angle>** ; Interpolation plane rotation. Becomes active in the next NC block.	3-6
PMP		Positive Memorized Position	**Syntax PMP(<axis designation>)** ; Reads the position of an axis that was strobed with ‘1’→‘0’ of the AxxC.STRBP Gateway signal.	11-1
POK		Process complete (full depth)	**Syntax: POK** ; POK can be used to define when the machining is complete (if supported by SPS).	9-5
RAD		Angle unit radians	**Syntax: RAD** ; Arguments and reciprocal functions of the trigonometric functions SIN, COS, TAN, and ASIN, ACOS, ATAN in the angle unit Radians.	10-5
RE		Reset NC event	**Syntax: RE <process no.>: <NC event number>**	7-2
RET		Return to NC program begin	**Syntax: RET** ; NC program jumps to the first (top) NC block, stops execution and activates defaults.	9-8
REV		Set Reverse Vector	**Syntax: REV <label>** ; The defined label identifies the NC block where the NC program execution continues when the reverse NC program is started.	9-12
RP		Reverse Process	**Syntax: RP <process>** ; The advance NC program is stopped and the reverse NC program is started for the defined process (if supported by the SPS).	9-3
RTS		Return from NC subroutine	**Syntax: RTS** ; NC program execution cont. with NC block that follows NC block containing the last executed ‘branch to subroutine’ (BSR, JSR, etc.)	9-11
SE		Set NC event	**Syntax: SE <process no.>: <NC event no.>**	7-1

VIII. SP through WP

Function	G Group	Meaning	Description	Page
SP		Select NC program for process	**Syntax: DP <process> <program number>** ; The defined NC program is selected (if no continuous selection in SPS) for the specified process.	9-2
SPC		Select main spindle for transformation * modal	**Syntax: SPC <spindle number>** ; SPC selects main spindle for Transformation (G30, G31, G32).	4-56
SPF		Select main spindle for feed programming * modal	**Syntax: SPF <spindle number>** ; SPF selects the main spindle for spindle - feed coupled G codes (G33, G63/G64, G65, G95 and G96).	4-43
SPT		Selects Tool Spindle * modal	**Syntax: SPT <spindle number>** ; SPT selects the tool spindle for the tool edge selection via the NC command E.	8-2
T		Tool selection and call	**Syntax: T<number>** ; Selects the specified Tool Number and its data (MTP) or location (MMP).	8-1
TCH		Complete Tool Change	**Syntax: TCH(<position>,<spindle>) { (.,.) optional }** ; Initiate complete tool change between tool spindle and magazine location.	8-8
TLD		Read/write Tool Data	**Syntax: TLD([process],[address],[Storage/T-number], [location/index number], [edge],[data element],[Status])**	11-8
TMS		Tool from Magazine to Spindle	**Syntax: TMS(<position>,<spindle>) { (.,.) optional }** ; Initiate tool transfer (physical / logical) from the magazine pocket in change position to the selected tool spindle.	8-8
TSM		Tool from Spindle to Magazine	**Syntax: TSM(<position>,<spindle>) { (.,.) optional }** ; Initiate tool transfer (physical / logical) from the selected tool spindle to the magazine pocket in the change position.	8-9
WER		Wait until NC event is Reset	**Syntax: WER <process number>: <NC event number>** ; NC program execution stops until the defined process NC event is reset (has status ‘0’).	7-3
WES		Wait until NC event is Set	**Syntax: WES <process number>: <NC event number>** ; NC program execution stops until the defined process NC event is set (has status ‘1’).	7-2
WP		Wait for Process	**Syntax: WP <process>** ; NC program execution stops until the defined process is done (acknowledged via SPS).	9-3

14.4 Table of Preparatory G code Functions

Legend * *default*
P *default can be defined in process parameters*
S *NC block active*

I. G00 through G50

G code function	Meaning	Syntax	Page
G00 *P*	Linear interpolation at rapid traverse	**G00**	4-14
G01 *P*	Linear interpolation	**G01**	4-15
G02	Circular / Helix interpolation, clockwise	**G02 <end point> <interpolation parameter [I,J,K]> or <radius[R]>**	4-16
G03	Circular / Helix interpolation, counter clockwise	**G03 <end point> <interpolation parameter [I,J,K]> or <radius[R]>**	4-16
G04 *S*	Dwell time	**G04 F<time in seconds.>**	4-39
G06	Positioning with minimized lag (following error)	**G06**	4-2
G07 *	Positioning with lag (following error)	**G07**	4-5
G08	Contouring mode (acceleration)	**G08**	4-7
G09 *	Contouring mode (deceleration)	**G09**	4-9
G15 *P*	Radius programming	**G15**	3-19
G16 *P*	Diameter programming	**G16**	3-19
G17 *P*	XY-plane selection	**G17**	3-15
G18 *P*	ZX-plane selection	**G18**	3-15
G19 *P*	YZ-plane selection	**G19**	3-15
G20	Free plane selection	**G20 [1st axis of plane] [2nd axis of plane] {vertical axis}**	3-15
G30 *	Coordinate transformation, cancel	**G30**	4-56
G31	Facing ON	**G31**	4-51
G32	Lateral cylinder surface machining ON	**G32 RI w or G32 RI=w**	4-54
G33 *S*	Thread cutting	**G33 <endpoint> <pitch> <start angle>**	4-24
G36 *P*	Rotary axis start-up logic	**G36 (shortest distance)**	4-49
G37 *P*	Rotary axis start-up logic	**G37 (positive direction)**	4-51
G38 *P*	Rotary axis start-up logic	**G38 (negative direction)**	4-51
G40 *	Tool path compensation, cancel	**G40**	5-34
G41	Tool path compensation, left of workpiece contour	**G41**	5-35
G42	Tool path comp., right of workpiece contour	**G42**	5-35
G43	Contour transition ‘arc’	**G43**	5-37
G44	Contour transition ‘chamfer’	**G44**	5-37
G47 *P*	Tool length correction, cancel	**G47**	5-40
G48 *P*	Tool length correction. positive	**G48**	5-40
G49	Tool length correction, negative	**G49**	5-40
G50 *S*	Programmed absolute zero offset	**G50 <axis name(s)> <coordinate value(s)>**	3-12

II. G51 through G99

G function	Meaning	Syntax	Page
G51 *S*	Programmed incremental zero offset	**G51 <axis name(s)> <coordinate value(s)>**	3-12
G52	Programmed workpiece zero point	**G52 <axis name(s)> <coordinate value(s)>**	3-13
G53 *P*	Machine Zero Point, cancel	**G53**	3-14
G54 *P*	Workpiece Zero Point 1	**G54**	3-8
G55 *P*	Workpiece Zero Point 2	**G55**	3-8
G56 *P*	Workpiece Zero Point 3	**G56**	3-8
G57 *P*	Workpiece Zero Point 4	**G57**	3-8
G58 *P*	Workpiece Zero Point 5	**G58**	3-8
G59 *P*	Workpiece Zero Point 6	**G59**	3-8
G61	Exact stop before block transition (lag finishing)	**G61**	4-10
G62 *	Block transition with lag	**G62**	4-12
G63 *S*	Rigid tapping with spindle off at the NC block end	**G63 <end point> <feed per spindle revolu-tion[F]>**	4-30
G64 *S*	Rigid tapping with spindle on at the NC block end	**G64 <end point> <feed per spindle revolu-tion[F]>**	4-30
G65	Floating tapping (spindle = lead axis), tension/compression	**G65 <feed per spindle revolution[F]>**	4-34
G66	Constant grinding wheel peripheral speed	**G66 S <constant grinding wheel peripheral speed>**	4-44
G70 *P*	Unit: Inch	**G70**	3-20
G71 *P*	Unit: Millimeter	**G71**	3-21
G72 *	Mirror function, OFF (all axes)	**G72**	3-22
G73	Mirror function, ON	**G73 <axis designation>-1**	3-22
G74 *S*	Axis reference (homing) cycle	**G74 <axis designation> <coordinate value [0]> <F-word>**	3-26
G75 *S*	Feed to positive stop	**G75 <axis designation> <coordinate value> <F-word>**	3-26
G76 *S*	Feed to positive stop, cancel	**G76**	3-28
G77 *S*	NC block restart / re-positioning	**G77<axis designation> <coordinate value [0]>**	3-29
G78 *	Scaling, OFF (all axes)	**G78**	3-24
G79	Scaling, ON	**G79 <axis designation> <Scaling factor>**	3-24
G90 *	Input data as absolute dimensions	**G90**	3-3
G91	Input data as incremental dimen-sions	**G91**	3-4
G92 *S*	Upper spindle speed limit	**G92 S<upper spindle speed limit>**	4-47
G93 *S*	Input feedrate as inverse time value	**G93 F<time in seconds>**	4-37
G94 *P*	Input feedrate in INCH or MM per minute	**G94**	4-38
G95 *P*	Input feedrate in INCH or MM per spindle revolution	**G95 F<feed per spindle revolution>**	4-38
G96 *P*	Constant Surface Speed (CSS)	**G96 S<constant surface speed in m/min>**	4-44
G97 *P*	Spindle speed in RPM	**G97**	4-47
G98 *	Constant feed on tool center line	**G98**	5-38
G99	Constant feed at the contour	**G99**	5-38

14.5 File Header

The editors that are available in the user interface are not the only means that may be used for creating an NC program. Any other external text editor may as well be used for that purpose.

Data import

The NC programs that are created with an external text editor must be provided with a file header. This enables them to be read in the corresponding file directories, using the „Data import“ function. The data header consists of the following elements:

Example

%NPG:0:01:1:001

!01.00

#Parameter set 1 1670127.04.9719:05:04

$Comment ...

$Comment ...

$Comment ...

$Comment ...

*Progr. No. 1

%NPG

The lines of the file header have the following meaning:

Code	Meaning	Range
%NPG	Identifies the file as an NC program	-
:0	Device number	0 - 15
:01	NC package number	01 - 99
:1	Process number	0 - 6
:001	Directory number	001 - 099
!01.00	Version	-
#Parameter set 1	Parameter set under which the NC program was created	-
$Comment ...	4 lines of text	max. 78 characters per line
*Progr. No. 1	Program designator	max. 32 characters
%NPG	Marks the end of the file header	-

Fig. 14-1: File header of an NC program

Minimum file header

A complete file header is included in the output when an NC program is exported to an internal or external data carrier. Merely a „minimum file header“ is necessary for import. Such a file header consists of the following character strings:

%NPG:0:00:0:0
!01.00
#
$
*
%NPG

If a program designator is expected to appear in the NC program directory after import, that designator must be entered at '*'. When an NC program is imported, the file header, with the exception of the program designator and the comment lines, is overwritten with the current values of device number, NC package number, process number, directory number, and active parameter set.

NC block numbers

Several options may be selected in the main menu item 2 „Edit NC program“ of the user interface. With respect to the data import/data export function, you may define here whether or not NC block numbers will be output. Taking into consideration that externally created programs may or may not contain block numbers, the four possible combinations result as:

No	File to be imported	NC block number output
1	with block numbers	yes
2	without block numbers	yes
3	with block numbers	no
4	without block numbers	no

Fig. 14-2: Output of NC block numbers Yes/No

Only the combinations 1 and 4 will provide a correctly imported NC program. Thus, if the file that is to be imported contains block numbers, the selection of „NC number output“ must be set to „Yes“. If block numbers are not contained, that option must be set to „No“.

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