SOFTWARE GSVISW - Version B

for WINDOWS NT, 95 or better

USER MANUAL

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QUICK INSTALLATION AND SURVEY

Installation

Insert the CD in its drive. If its contents do not self display, open it with **Windows Explorer**.

To install **GSVISW** on your hard disc, double-click on the installation programme **InstalVis**. It will create a folder named **GSREPER** (if not yet existing) and will copy in it the software. In addition, it will create a short cut and its icon on your computer desktop ; you will just have to double-click on the icon to run **GSVISW**.

If convenient, the file **GSVISW.exe** can be moved manually anywhere on your hard disc.

Survey

The organigram of **GSVISW** is visible from all pages (except Help pages) by clicking on the red button **O** located in the upper left corner. From it you can see where you are in the programme and where to go.

Help is available when necessary by clicking on menu **Help**. In addition, some datum fields provide a specific help ; when passing over them with the cursor, a bubble « F1 = Help » appears. Click now on the field to focus it and press the key **F1**.

IMPORTANT

The use of this software is subject to your acceptance of the conditions stipulated in the User License. It should not be transferred to any other people without the author's permission.

FOREWORD

Less than any other type of gearing the worm wheel sets allow poor quality. However when well designed and machined by skilled workmen they are capable of excellent performances, quiet running, high capacity to sustain shocks and reliability. If their efficiency is never equivalent to that of parallel gearing, it is however much higher than usually expected when a correct quality level has been achieved.

GSVISW allows quick and accurate determination of the main parameters and dimensions of the worm wheel sets and, when possible, of the gauging dimensions and tolerances.

In addition it provides the following possibilities and options :

- detection of undercutting and interference which can then be cured.

- drawing of the surface of contact.

- determination of the bearing loads, stress in the worm core and deflection of the worm under load.

- possibility to record all dimensions and parameters of the worm and wheel set for a later recall.

- determination of the cutting times.

The extension LOAD CAPACITY allows quick determination of the torque and power ratings based on three of the best available methods :

- british standard BS 721-1983.

- american standard 6034-A87 of March 1988.

- a third method of the author optimising the BS 721.

For a new project the rating will be determined with an approached centre distance and the centre distance will be modified according to the torque and power obtained. GSVISW gives an estimated value of the output torque which can be expected, thus allowing the determination of an approached centre distance.

The extension TOOLS provides a unique process to make high precision fly cutter with a simple equipment normally available in every workshop.

LIMITS

GSVISW is suitable only for sets at right angle.

It allows the use of :

- british standard BS 721-1983.

- german standard DIN 3975.

- normal system given by G. HENRIOT in his well known book.

- american standard AGMA 341-02

- out of standard user specified dimensions.

When BS 721 is used the worm profile is ZI (involute helicoïd). For any other standard either ZA or ZK or ZI can be selected.

Informations and comments are given later about these options.

RUNNING GSVISW

The software is protected by 3 key codes, the first one for the dimensional section, the second one for the extension LOAD CAPACITY and the third one for the extension TOOLS. If you are in a trial period and therefore do not know the codes, you will however have full access to all functions and options of GSVISW, but only even number of starts and teeth will be accepted.

When numbers in parenthesis are displayed they refer to the corresponding paragraphs of this leaflet.

GSVISW will display a first menu as follows :

- **a new case** : to be selected for a new application. After treatment it will be possible to record on disk for a later recall.
- **read a set on disk with modification** : recalls a recorded set and allows modification of data.
- **read a set on disk without modification** : recalls a recorded set without modification of data.
- **create a set from an existing one to be replaced.**
- **delete a set on disk** : to delete a previously recorded set.
- **save the file WORSETW.DAT** : it is wise to save periodically this file containing the records.
- **exit GSVIS** : if an application has been dealt with, you will be asked whether you wish to save it before living.

In the case of option 1 GSVISW will ask you to select the standard to be applied. Following standards are available :

- British standard BS 721 - 1983.

- Normal system as given by G. HENRIOT in his “Traité Théorique et Pratique des Engrenages”.

- German standard DIN 3975.

- American standard AGMA 341-02

- or out of standard as per your own dimensions.

Enter or modify the necessary data. Only those required by the selected standard are accessible.

When necessary, help on line is available by clicking on **Help** or selecting the proper field and pressing **F1**.

GSVISW will advise :

- any undercutting or interference on worm or wheel.

- when the worm or wheel tip thickness is abnormally small or sharp.

RECORDING

Each time a set has been created or modified, GSVISW will ask whether you wish to record it for a later recall.
The set is identified by a reference (30 characters maximum), a number (8 characters maximum) and if required an index.

If the reference or number has been omitted, they will be asked for before recording.

If a set has been only modified, it will be re-recorded with the same reference and number.

READING A RECORDED SET

A selection grid is displayed.

Sorting can be made according to alphabetic references, or increasing numbers or increasing centre distances.

On each line is shown the set reference, number, index if any, centre distance, number of starts and number of teeth.

When the option “read without modification” has been selected the general dimensions are directly displayed. When the option “read with modification” has been selected the editing form is displayed.

DIMENSIONAL SECTION

GENERAL FEATURES ABOUT WORM GEARING

It is important, to deal satisfactorily with this type of gearing, to have in mind some clear ideas regarding the problems involved in its use and machining. Some basic informations given below will certainly prove helpful.

The tooling to cut and grind the worm is usually simple and of low cost. However the necessary tooling to cut the wormwheel is always expensive. When the quantity required is not important the wheel can be cut with a fly cutter. This tool is of moderate cost and when correctly machined can provide an excellent quality level but the time required for cutting the wheel is considerably longer than with a hob. In order to prevent very difficult problems of indexing, it is important that there is no common divisor between z_2 and z_1 : for example 4 starts and 29 or 31 teeth are to be strongly preferred to 30 teeth. When the quantity required is worth of, it will be economically preferable to use a hob. The cost is much higher but it will save a considerable time in the hobbing process. Although not as absolutely necessary as with a fly cutter, again it is not recommended that a common divisor exists between z_2 and z_1.

Whatever the type of tool, fly cutter or hob, it must be exactly conjugate to the worm. Wheels having different numbers of teeth can therefore be cut with the same hob provide they are meshed with the corresponding worm, i.e. they have same normal module, normal pressure angle, lead angle etc. The centre distance should be equal to half the sum of the worm and wheel pitch diameters, with some allowance by giving positive or negative addendum modification to the wheel.

It results from the considerations above that, at the opposite of the parallel axis gearing, there is and there can be no standardisation of the toolings. An engineer facing a new design should only ask himself whether there is any possibility to use an existing tool in a satisfactory way i.e. with an acceptable amount of addendum modification and therefore of centre distance. If no tool is available then he can consider himself as absolutely free to select any module, lead angle etc. and there is no necessity to choose modules being integer or round, and as many digits as necessary can be used after the decimal point.

(2) GSVISW provides the choice of "with or without addendum modification" and clearly the first option should be selected only in an attempt to use an existing tool. In this case it is important to make sure that the amount of addendum modification is acceptable. The author strongly recommends to avoid whenever possible any amount of negative addendum modification of some importance. They indeed have a tendency to cause undercutting and reduce the load carrying capacity. Positive addendum modification does not involve this problem but when exagerate can lead to a too narrow crest width with subsequent life reduction. See paragraph **(6)** below.

When a new tool must be made, i.e. in the case "without addendum modification", the software asks the diameter factor **q** of the worm. The diameter factor is a fictitious number determining, for a given number of starts and axial module, all other dimensions of the worm. The diameter factor is equal to the reference pitch circle diameter divided by the axial module. The larger the diameter factor, the smaller the lead angle and the larger the root diameter. Theoretically it would be advantageous to choose as small a diameter factor as possible in order to have a high lead angle and thus the highest possible efficiency. Practically it is wise to be moderate because too small a diameter factor leads to too small a root diameter and to an important deflection under load which impairs the actual meshing and the efficiency ; it can also lead to an excessive stress in the worm core and to failure by fatigue. In the most usual cases where the meshing point is not overhanging but is located inside the bearing span the software gives the amount of deflection and stress at this point for a unity output torque thus providing a simple way to make sure that they are acceptable with the actual torque. Use the option “Bearing load” to obtain these values.

The table below gives suggested average values for the diameter factor **q** vs the number of starts $\mathbf{z_1}$.

z1	1	2	3	4
q	10 to 16	9.5 to 15	9.5 to 14	9.5 to 13

z1	5	6	7	8
q	9 to 12	9 to 11	8.5 to 11	8.5 to 11

These values are suggested but should not be considered as absolutely necessary. In any cases they should be checked regarding deflection and stress when smaller values have been used to improve efficiency.

Theoretically the cutting tool, hob or fly cutter, should be the exact replica of the worm regarding the profile, pitch and number of starts. It should depart from the worm only by slightly larger outside diameter and thread thickness to provide some clearance between worm tip and wheel root and some operating backlash.

Practically this is not recommended and is not possible with hobs. If the tool is made in accordance with the theory the contact pattern between thread and wheel tooth will spread over the whole face width and the smallest misalignment resulting from some inaccuracy in assembly or deflection under load would shift the contact to the tooth sharp edge with the drastic consequences which can be imagined. It is therefore strongly recommended to design the tool with a pitch diameter slightly larger than the worm, thus limiting the contact pattern in the central area and making centering and deflection less critical. This is very similar to what is obtained by crowning in parallel axis gearing. With profile ZI it is possible to examine the light load contact pattern vs the cutting centre distance (see later).

The diameter increment to be given to the tool depends on too many parameters to be obtained from some simple formula but never exceeds a few percent.

Another extremely difficult problem lies in the fact that the cutting edges of the tool must be relieved and this makes its geometry very difficult. Since the performances of the set depend widely on the meshing accuracy, it is recommended to contact true specialists for the manufacture of the set and still more for the tool.

The BS 721 system involves the use of profile ZI. All other systems provide the possibility to select in addition either the profile ZA or ZK. As far as performances are considered it is hard to claim that such profile is better than the others. But what is most important is that the worm and wheel profiles are perfectly conjugate and at this point the profile ZA and still more the profile ZI are much better than the profile ZK because they lend themselves to simple inspection as will be shown later.

It is also important to realise that all profiles do not differ significantly when the lead angle is low, i.e. in most cases of single start worm : differences are only a matter of microns and can purely be neglected. This is why the profile ZK should be used only for single start worms.

(3) BS 721 does not allow wormwheels with number of teeth $\mathbf{z_2}$ smaller than 17. Even though there is no strict theoretical impossibility to go beyond this limit, it is certainly not recommended. This indeed leads to too large modules in relation with the general dimensions of the set. It is quite preferable to increase the number of starts in the worm and the number of teeth in the wheel and the author even suggests not to use number of teeth smaller than 20. GSVISW asks confirmation when a number of teeth smaller than 17 is entered.

Hobbing of the wormwheel is subject to two kinds of interferences :

(4) undercutting of the tooth : it is exactly similar to that of parallel gearing when the number of teeth is too small. GSVISW advises this interference but however does accept it. It is obviously strongly recommended to avoid it but if it is decided to pass over it will be wise to evaluate how important it is by examining carefully the surface of contact ; interference is visible by an interrupted curve on the left of the screen representing the boundary of the surface by the worm outside diameter. To cure this interference just give some positive addendum modification or still simpler increase the pressure angle.

(5) Positive addendum modification, when excessive, leads to a narrow crest width with corresponding reduced life. GSVISW advises any addendum modification amount leading to a crest width $\mathbf{s_{na}}$ smaller than 0.6 normal module, corresponding approximately to 20 % less than the normal width and life. Confirm when the life is not critical as in intermittent running or modify the basic data, for example by adding 1 tooth to $\mathbf{z_2}$.

(6) Too high a pressure angle can lead to too narrow a crest width or even to a sharp crest. GSVISW asks for confirmation when the tip thickness is smaller than 0.3 normal module and does not accept sharp crest.

(7) Plotting of the surface of contact, accessible from the DIMENSIONS page, shows its boundaries, corresponding to the worm outside diameter on the left side of the screen, and to the wheel throat and outside diameters on the right side of the screen. The lines of contact between worm and wheel are shown in the critical position of the meshing cycle, i.e. in the position where the sum of their lengths is shortest. On the right of the screen can be seen line N° 0 plotted in green, which is a fictitious line drawn exactly when entering the surface. Line N° 1 and when existing line N° 2 are plotted in blue. Observation of this screen shows any possible interference by undercutting and gives an idea of the contact ratio.

In some extreme cases, particularly with too important an amount of positive or negative addendum modification, the surface of contact cannot be entirely plotted.

BRITISH STANDARD BS 721

It is the author's opinion that this system is the most advanced and complete.

The worm profile is the ZI, i.e. involute helicoïd.

(8) The normal reference pressure angle is 20°, but it is the author's opinion that there is no reason not to increase slightly this value when necessary to prevent undercutting rather than to make depth reduction as suggested by the standard.

(9) The base diameter $\mathbf{d_{b1}}$ of the worm must be smaller than or equal to the minimum working diameter (equal to the outside diameter less 4 normal modules).

(10) Some allowance is given in the value of the wheel face width $\mathbf{b_2}$ which in no case should exceed 2.3 mx $(q+1)^{0.5}$. It is not necessarily an advantage to choose the largest values : with lead angles of some importance it can be seen from the surface of contact that increasing $\mathbf{b_2}$ to a maximum does not increase proportionately the length of line N° 1.

(11) Some allowance is also left in the choice of the wheel outside diameter $\mathbf{d_{e2}}$. Whenever possible it is recommended to enter the larger value as it significantly increases the load capacity.

Profile ZI provides many advantages :

- it prevents the interference at the tip of the wheel tooth and reduces undercutting at the root.

- calculations involved in the design of a hob or a fly cutter are much easier. In the case of a hob, the wheel tooth profile is conjugate to the worm profile during the whole tool life (cf the author's book GEOMETRY OF WORM GEARS).

- inspection of the worm profile is particularly easy by travelling a dial indicator along the straight generator line tangential to the base helix. Since the incident angle along this line is zero, the dimension and shape of the indicator stem does not affect the measurement.

Grinding of this profile requires a special wheel dresser, but this is true for any other profile except ZK, but profile ZK has many considerable disadvantages as will be seen later.

(12) In addition BS 721 provides a comprehensive tolerance system well suited to the worm wheel sets, with 5 grades of backlash from 1 to 5, number 1 being the minimum and number 5 the maximum. Grades 1 and 2 must be used cautiously when the gear set is subject to appreciable heating to prevent possible seizure. Grades 3 and 4 are suitable for commercial applications and grade 5 allows working temperature up to 120° C. Four precision classes are also provided, class A being the most accurate and class D the less. Incidentally class C is suitable for commercial applications. This system covers pitch tolerances of the worm (including angular and linear spacing of the threads), profile tolerances of the worm, thickness tolerances of the threads and pitch tolerances of the wheel.

(13) worm pitch tolerance : from any point of a thread flank and at a distance **Lx** the tolerance is given for each thread at the same radius.

(14) worm profile tolerance (fig. 1) : measured as a departure from the straight generator line tangential to the base helix, the origin being at mid working height. The dial indicator travel is offset from the worm axis by the base radius $\mathbf{d_{b1}}$ / 2 and inclined to the base lead angle **gamma.**$_{\mathbf{b1}}$.

(15) worm thickness tolerance : measured on the constant chord $\mathbf{s_{cn}}$ at a height $\mathbf{h_{cn}}$ from the thread tip. Alternatively it can be measured on two (even number of starts) or three (odd number of starts) gauging rollers.

(16) wheel pitch tolerance : one tooth being chosen as origin the tolerance is measured on each tooth numbered 1 to $\mathbf{z_2}$ / 2 corresponding to half the circle. Clearly the measurement is to be carried out in both directions and flanks.

GSVISW gives all these tolerances .

GERMAN STANDARD DIN 3975

The worm addendum is 1 axial module and the worm or wheel operating height is 2 axial module. The worm or wheel clearance is from 0.167 to 0.3 axial module ; 0.2 is to be preferred. The profile is ZA, ZK or ZI. The wheel section is shown on fig. 2.

NORMAL SYSTEM (of G. HENRIOT)

gamma < 15°

The worm addendum is 1 axial module, the operating worm height is 2 axial module and the worm clearance is 0.2 axial module.

gamma >15°

The worm addendum is 1 normal module, the operating worm height is 2 normal module and the worm clearance is 0.2 normal module. The profile is ZA, ZK or ZI.

PROFILES

(17) Profile ZA This profile is straight sided in the axial plane, i.e. in a plane containing the worm axis.

(18) The reference pressure angle is the worm axial pressure angle equal to the wheel transverse pressure angle and it is suggested to enter 15° for the wheels having 60 teeth and above and up to 30° for the wheels having 20 teeth and less (incidentally so small number of teeth are not recommended). As a consequence calculations are easy and similarly checking the profile is easy since it just requires to travel a dial indicator along the straight generator. However, because the lead angle varies along the generator, it is **absolutely necessary to use an indicator with a sharp stem**, otherwise the readings are affected by important errors.

Because of its shape this kind of profile is more subject than any other to all kinds of interference, either at the wheel tooth tip or by undercutting the wheel tooth base.

Calculations involved in the tool design are much more difficult and, in the case of a hob, it is theoretically impossible to ensure perfectly conjugate profiles during the whole hob life.

As with the involute the grinding wheel dressing requires a special equipment.

Since no tolerance system is available, the software asks the actual tolerance of the axial thickness $\mathbf{s_x}$ and gives the corresponding maximum and minimum dimensions over rollers. If convenient, tolerances according to the BS 721 system can be specified, being clear that the worm profile is to be checked along the axial straight generator.

(19) Profile ZK This profile is that generated by a tool (either grinding wheel or mill) the section of which is straight sided and inclined at a pressure angle equal to the worm normal pressure angle.

(20) The reference pressure angle is therefore the normal pressure angle and as a first approach can be taken equal to 20°. It should be noted that, on the opposite of what is often thought, the worm profile is more or less convex but never straight. Incidentally it is interesting to note that the profile ZI i.e. involute helicoïd is nothing but a profile ZK obtained with a tool of infinite diameter, since generated by a rack. The worm cutting tool can be external, and this is the most frequent case, for example as a grinding wheel or a mill. In this case the worm profile is slightly convex, mid-way between the profiles ZA and ZI. But it can also be an internal tool, for example with a BURGSMULLER equipment, and in this case the worm profile is still more convex than the ZI.

(21) The tool diameter is measured at its overall diameter for an external tool and at the tool tips for an internal one as a BURGSMULLER.

Except the fact that this profile can be obtained with a straight sided grinding wheel, thus easy to dress, this profile involves a lot of disadvantages.

- the profile is not constant and the amount of convexity depends on the tool diameter. The smaller the tool, the less convex the profile. With a tool of infinite diameter the profile is an involute. With a tool having a diameter "larger" than infinite, i.e. in the case of internal cutting, the profile is more and more convex.

- the profile has no straight generator, and this makes the inspection particularly difficult. As for the ZA **it is absolutely necessary to use an indicator with a sharp stem**.

- all calculations concerning the interferences and regarding a hob detail dimensions are extremely arduous.

(22) As for the ZI the profile does not exist below a particular diameter where the pressure angle becomes zero. This diameter is analogous to the base diameter of the ZI, but it depends on the tool or wheel diameter used to cut or grind the worm : the larger the tool, the larger this "base" diameter. It is still larger with an internal tool and this is why this cutting process should be used only for low lead angles. Any attempt to cut below it causes undercutting but is advised by GSVISW. When using an internal tool it must have a sufficient diameter : GSVISW advises when it is too small.

For all these reasons the software does not allow plotting of the surface of contact

(23) The software gives the axial coordinates of the profile vs the tool diameter in order to allow the profile inspection (fig. 3).

(24) For high lead angles with profile ZK, it may be necessary to increase the tool diameter without altering the worm-tool centre distance in order to achieve generation over the total working height. The worm root diameter $\mathbf{d_{f1}}$ is then reduced accordingly. This modification is advised when necessary.

(25) BEARING LOADS

The software provides a simple way to calculate the polar coordinates of the bearing loads for a unity output torque i.e. **M2** = 1. Values displayed for **F** must therefore be multiplied by the actual torque in N.m to obtain the actual loads in Newton. The software also gives the angle ***delta*** of their direction.

(26) Distances **L** defining the bearings location must be entered **in full respect of the signs** as shown on fig the figures obtained with the Help in line..

(27) The software also gives the amount of deflection and the maximum stress in the worm core at the meshing point for a unity output torque. Again it is therefore necessary to multiply these figures by the actual torque in N.m to obtain the actual values of stress in N/mm^2 or of deflection in microns.

(28) EFFICIENCY CURVES

They can be plotted for direct and reverse efficiency and for input speeds ranging from 0 to 3000 rpm.

They are based on sets incorporating a hardened and ground worm and a phosphor bronze wheel perfectly conjugate to the worm, after running in has been achieved. Lubrication should be satisfactory.

However many parameters can affect the actual value of efficiency. It is therefore not realistic to rely on irreversibility even when the reverse efficiency curve shows a negative value.

(29) LIGHT LOAD WORM TO WHEEL CONTACT PATTERN

For more details regarding this option, refer to the author's book GEOMETRY OF WORM GEARS - THEORY AND PRACTICE.

GSVISW provides an option to picture on the screen the light load blue print contact pattern obtained vs the cutting centre distance. This powerful option involves heavy calculations and this is why it is practically possible only for profile ZI. For other profiles it can however give a satisfactory approximation using the same basic data.

Below are given the principles ruling this representation and allowing its correct interpretation.

Theoretically, as soon as the cutting centre distance is increased, the worm and wheel make point contact along the normal path of contact which is normal to the conjugate profiles. This can be understood as follows.

Since the worm has an involute profile, it is actually nothing but a pinion with a very small number of teeth (starts) and very high helix angle ***beta* = 90° - *gamma***. If the centre distance is increased to infinite, the hob becomes a rack, the wheel is a conventional helical wheel and the set is skew or crossed axis gears : it is well known that this type of gears makes point contact along the normal path of contact. It can then be understood that, even with a limited centre distance increment, the contact can no more spread over the full face width but is theoretically limited to only the normal path of contact.

Practically, because the increment is small, the profiles depart very progressively from the theoretical path of contact. The smaller the increment, the wider the practical contact pattern.

Clearly the blue print contact pattern depends widely on the blue coating thickness and it is recommended to make it as thin as possible. The screen picture is by default based on a thickness of 5 microns corresponding to a very thin layer spread very evenly. If wished, the blue thickness can be modified.

When the lead angle is high, in fact for multi-starts worm, and when the centre distance increment is appreciable, an interference appears in the leaving side upper corner of the wheel tooth. This interference consists actually in an excess of material left by the cutting tool, hob or fly cutter. As long as this excess of material does not exceed 10 or 20 microns, it does not affect significantly the gear performance as being quickly deleted by running-in. But with larger values it can affect substantially or even drastically the gear set behaviour. This interference is shown on the screen picture as small red circles of different size : smaller circles represent an interference < 10 microns, medium circles an interference between 10 and 50 microns and larger circles an interference > 50 microns. It should be noted that when an interference exists the actual contact obtained will be restricted to the interference zone, the normal contact zone being superseded by the interference.

When the wheel section is machined in accordance with DIN 3975, the chamfers usually cover most of the interference zone.

Above the picture are displayed for 11 sections the distance from the centre plane, the wheel radius where the gap is minimum, and the gap value. Negative gaps means excess of material and interference.

NOTATIONS, SYMBOLS AND UNITS

Unless otherwise specified all dimensions are in mm, loads in Newton, torques in N.m and angles in degrees.

Index 1 refers to the worm, 2 to the wheel.

a centre distance

$\mathbf{b_1}$ worm face width i.e. length of thread . IMPORTANT : the value displayed is strictly theoretical and it is therefore absolutely necessary to provide some allowance at each end.

$\mathbf{b_2}$ wormwheel face width.

d reference pitch diameter.

$\mathbf{d_a}$ tip diameter for the worm. Throat diameter for the wheel.

d_{b1} worm base diameter (profile ZI).

d_f root diameter.

d_{e2} wormwheel overall diameter.

E1 modulus of elasticity of worm (N/mm¨).

F 1,2,3,4. Load on bearing 1,2,3,4 for unity output torque.

h_{cn} constant chord height.

j_t backlash.

L 1,2,3,4. Negative or positive locating distance of bearing 1,2,3,4.

Lx axial distance from any two points at the same radial distance from the worm axis.

m_n normal module.

m_x axial module of worm = transverse module of wheel.

q diameter factor.

s_{cn} constant chord.

s_{na} normal crest width at wheel throat diameter **d_{a2}**.

s_x axial thickness of thread.
Tf maximum bending stress in worm core for unity output torque.

Tt maximum torsional stress in worm core for unity output torque.

x wheel addendum modification coefficient.

z number of starts in worm or teeth in wheel.

***alpha*.n** normal pressure angle.

***alpha*.x** axial pressure angle.

delta 1,2,3,4. Angle of load direction on bearing 1,2,3,4.

gamma lead angle.

OPTION LOAD CAPACITY

Several methods are available to evaluate the load capacity of worm gears. None of them is easy to use.

This option provides a simple way to use two of them amongst the best known :

- the method given by the American Gears Manufacturers Association (AGMA) in its standard 6034-A87 of March 1988.

- the method given by the British Standard BS 721 (metric units).

- and a third one proposed by the author and optimising the BS 721.

GSVISW makes them available even to those who are not specialists of worm gears and will certainly prove helpful to specialists.

Parallel gears normally require a double calculation for wear and for strength. In most cases strength calculation is not necessary with worm gears, and is never necessary when the set has been correctly designed.

AGMA 6034 gives indeed no method of calculation for strength. BS 721 gives one which should normally be applied to both worm and wheel. GSVISW allows its application to the wheel only, since the worm is **never** critical regarding strength.

AGMA requires that the worm be hardened for HRc 58 minimum. BS 721 does not impose a minimum hardness and therefore requires the double calculation for wear.

In accordance with AGMA the author thinks that reliable results cannot be expected with not hardened worms : such worms should be restricted to low speed and low load applications. Each time the worm is hardened for HRc 58 and over the calculation of the worm for wear is no more required.

BS 721 specifies the profile as ZI (involute helicoïd), while AGMA does not impose a particular profile but specifies that it must be conjugate with the wheel.

Clearly the gears should be interference free.

The material used for the wheel is of great importance and it is recommended to be cautious with commercial bronzes normally available which in most cases are not satisfactory regarding analysis and/or elaboration.

Whatever the method used, the values obtained are for continuous running steady load (Class I). Some appropriate coefficient should therefore be applied for other conditions.

Values obtained are "mechanically" rated. For high speed and load the continuous rating may be limited by the oil sump temperature which, with mineral oil, should not exceed 90°C (synthetic oil allows higher temperature).

GSVISW gives, for the entered speed, the direct efficiency which can be reasonably expected after running in with sets of excellent quality.

AGMA 6034-A87 (March 1988)

As said above this method deals only with wear and for the wheel only. The worm should be hardened for HRc 58 minimum and should have a smooth finished surface.

Values obtained are based on an expected life of 25000 hours. For other values of life AGMA specifies that a convenient factor should be applied but gives no information regarding this factor.

The worm speed is limited at 3600 rpm and the rubbing speed at 30 m/s. GSVISW clearly takes these limits into account.

(30) The AGMA maximum wear factors **Cs** are given at the end of this manual and with the Help in line. It is the author's opinion that nothing justify the second table given for centre distance smaller than 76 mm and that therefore values of the first table can safely be applied even to small wheels.

BS 721 : 1983 : PART 2 METRIC UNITS

As said above this method deals with both wear and strength. GSVISW allows both calculations except for strength for the worm.

This method takes into account the expected life (normal base 26000 hours).

(31) Equations of BS 721 limit the rubbing speed at 50 m/s and, for wear, the worm rotational speed at 3000 rpm. When the worm is hardened and ground there is certainly no objection in overcoming this limit ; the calculation is then to be done for the wheel only since clearly GSVISW takes these limits into account.

(32) BS 721 accept the capacity calculations only within certain limits of the diameter factor **q**.

(33) When the calculation has been done for strength GSVISW gives the safety factor from the ultimate tensile strength of the wheel material.

AUTHOR's METHOD

Both AGMA and BS 721 methods evaluate the allowable torque for wear from an empirical formula given below :

$$\mathbf{M2 = k \cdot X_c \cdot \textit{sigma} \cdot Z \cdot d2^{1.8} \cdot mx}$$

where :

k coefficient depending on units.

$\mathbf{X_c}$ speed factor.

sigma material factor for wear.

Z geometry factor taking the particular meshing conditions in account.

d2 pitch diameter of wheel.

mx axial module.

NOTE : the empirical index 1.8 (instead of 2) takes into account the decreasing load capacity of the wheel material (***sigma***) when the wheel diameter is increased.

The factor **Z** in AGMA is very simplified since it only depends upon the gear ratio : it is for example the same for 1 and 30 or 2 and 60. The BS 721 factor is more sophisticated since it takes the worm geometry in account, but not the number of teeth in the wheel.

The author method, while using the same basic equation, calculates the factor **Z** from a complete analysis of the surface of contact. It takes into account not only the actual face width **b2**, which does not AGMA, but also the actual overall diameter **de2**, which does none of both methods. It is therefore much more sophisticated.

Practically the factor **Z** is higher when the number of teeth is large and smaller when it is small, the equivalence being reached for approximately 30 teeth.

As AGMA it deals only with wear and assumes that the worm is sufficiently hardened, HRc 55 being a minimum and HRc 58 being wishable.

It also takes into account the expected life.

The same values as BS 721 are to be used for the wheel wear factor ***sigma***.

NOTATION, SYMBOLS AND UNITS

Unless otherwise specified all dimensions are in mm, loads in Newton, torques in N.m and powers in kW.

Index 1 applies to the worm and 2 to the wheel.

Cs material factor for wear AGMA.

H duration of a period in a cycle of variable load and speed.

M2 output torque.

Mi initial torque in a period (cycle of variable speed and load).

Mf final torque in a period (cycle of variable speed and load).

N2 output speed (rpm).

Ni initial speed in a period (cycle of variable speed and load).

Nf final speed in a period (cycle of variable speed and load).

sigma.bm material factor for strength BS 721 (see Help in line).

sigma.cm material factor for wear BS 721 (see Help in line).

P1 input power.

VARIABLE LOADING

With BS 721 and the Author method, it is possible to make application of the clause 9.3 of BS 721 allowing to deal with cases where the worm and wheel set is loaded by repeated cycles composed of several periods of different durations each of them having its own uniformly variable or steady torque and/or speed. This option determines equivalent parameters, i.e. life, torque and speed from which the set can be dimensionned.

OPTION TOOLS > FLY CUTTER

Fly cutters are indeed too frequently ground with a trapezoïdal section or to the worm profile : in the latter case, this is correct only when the hobbing centre distance is equal to the operating one, but as seen above this is not recommended. This option provides 3 different ways to grind a high precision fly cutter. When the hobbing centre distance is larger than the operating one, which should be the general case to prevent contact on the wheel side edges, the fly cutter profile is no more identical to the worm one but is conjugate to it.. This provides a contact pattern localised in the centre of the wheel face in a way very similar to what is obtained by crowning in parallel axis gearing.

With the 4 methods the cutting face is a plane normal to the pitch lead helix. The profile can then be checked without theoretical error on a profile projector by comparison with the theoretical profile. This theoretical profile can easily be drawn and printed at the required enlargement.

The method to be chosen depends on the machining facilities available :

Relief grinding with a flat wheel. It just requires a universal sharpening machine fitted with a lead generator. The grinding wheel is flat and requires no form dressing. It is possible to use an easily available diamond compound wheel allowing the grinding of high resistance carbide cutters.

Relief grinding on a NC worm grinder by coordinates of the wheel. To be used when the machine provides facilities to dress the wheel from its coordinates.

Relief grinding on a NC worm grinder by modification of the worm profile. To be used when the machine provides facilities to modify the worm profile.

Relief grinding on a worm grinder by involute. To be used when the machine provides facilities to grind the ZI (involute) profile. This is the case of all NC grinders. Setting up the grinder is particularly simple.

(33) > FLY CUTTER > RELIEF GRINDING WITH FLAT WHEEL

This method just requires a universal sharpening machine fitted with a lead generator. High precision fly cutters perfectly conjugate to the worm are obtained.

DESCRIPTION AND THEORETICAL BASIS

The cutting face is a plane (flat). Its profile is therefore symmetrical and corresponds exactly to the profile of the ghost worm equivalent to the tool. This ghost worm is conjugate to the worm and therefore is generated by the same basic rack. It is identical whatever the lead hand.

Since the tool is not integer with its spindle, it is possible to modify its angle during the grinding process of the relieved flanks.

The process takes advantage of these properties to achieve correct profiles of the tool.

It is well known that an involute helicoïd can be obtained with a flat grinding wheel inclined at the base lead angle and with its axis offset to allow grinding down to the thread bottom.

The software then makes the following calculations in the stated order :

1°/ From the hobbing centre distance, determination of the axial coordinates of the equivalent worm conjugate to the worm.

2°/ Determination of the coordinates of the same profile in a plane normal to the lead pitch helix.

3°/ By modification of the angle of the tool cutting face, determination of parameters generating an involute helicoïd in exact coïncidence with the required profile at the pitch, top and bottom radii. The relieved flanks are ground to this involute helicoïd.

It is clear that, since the generated profile is not strictly exact, some errors are remaining at mid-distance between top and pitch, and pitch and bottom. But these remaining errors are fully negligible : for example, they do not exceed 4 microns with a worm of module 10, lead angle 33° and relief angle 3°. The software displays the value of the maximum error.

LIMITS

An involute profile is always convex. But in some cases with low lead angles, particularly with profile ZA, the required profile may be practically a straight line. In this case it is no more possible to ensure the coïncidence but clearly the fly cutter can now be ground trapezoïdal.

With profiles ZI and ZK the process is applicable only when the worm thread is undercutting free.

Theoretically resharpening is not possible. It is however clear that a few slight refreshments of the cutting edges will be acceptable. In addition, carbide tools can be easily machined since flat diamond wheels are available at low cost.

NOTATION AND SYMBOLS

De external diameter of grinding wheel

Di maximum internal diameter of grinding wheel

mxd axial module to be used during the grinding process

gamma.bd base lead angle during the grinding process

Hm offset amount of the wheel axis.

Xm distance between the tool axis and the flat wheel face

PROCESSING

Since the cutting face is flat, the right and left profiles are perfectly symmetrical. It results that the parameters used to grind the right flank can be equally used to grind the left flank if they are inversed as seen in a mirror. For example, if the right flank has been ground with a RH lead, the left flank will be ground with a LH lead.

In most cases, the software provides two possible set of data corresponding to two settings of the grinding wheel. Both can be used indifferently. All this is clearly shown on figures available from the Help in line which must be strictly respected. It can be noticed that dispositions 1 RH and LH, and dispositions 2 RH and LH are mirror images to each other.

It is important that the symmetry axis of the profile passes through the tool core axis. It is indeed necessary that, when the angle is modified to restore the cutting conditions, the rotation axis coïncidates with the profile symmetry axis.

The angle **teta.d** should be adjusted carefully but however does not require an extreme precision. The pitch **z . PI . mx.d** must be adjusted with greater care for larger pitches. The angle **gamma.d** should be adjusted with greatest care since it controls the pressure angle ; practically it is wise to check the pressure angle after a light rough grinding and to bring the necessary correction before finish grinding.

It is most **important** to make sure that the cutting edges are ground during the process by the **flat surface** of the wheel and not by its tip radius. Dimensions **Xm** and **Hm** locate the wheel for this being achieved when the spindle diameter is equal to the root diameter of the equivalent worm. But when it is smaller, as frequently, it is only necessary to make sure that the condition above is fulfilled. The flat face of the wheel represents indeed the basic rack flank.

During the grinding process the shaft is turned sufficiently to generate the full profile.

Clearly the fly cutter should be reset at its normal lead angle before hobbing.

RELIEF

The amount of error is affected by the relief : it is therefore recommended to use as small a relief angle as rea sonable. Since a fly cutter is normally fed tangentially, the relief angle required is just the static relief. For tin bronze, a satisfactory value is 2.5°.

INSPECTION

Since the cutting face is flat, it is possible and easier to check the profile using a profile projector. The option “Profile” accessible from the page “Fly cutter” allows printing of the profile at the required scale.

(34) > FLY CUTTER > RELIEF GRINDING WITH NC WORM GRINDER > WHEEL COORDINATES

This method can be used when a NC worm grinder is available providing facilities to dress the wheel profile from its coordinates.

DESCRIPTION AND THEORETICAL BASE

The cutting face of the fly cutter is a plane (flat). Its profile is therefore symmetrical and the cutting edges lie exactly on the flank surfaces of the ghost worm equivalent to the tool. This ghost worm is conjugate to the worm and therefore generated by the same normal basic rack. It is identical whatever the lead hand.

The software then makes the following calculations in the stated order :

1°/ From the hobbing centre distance, determination of the axial coordinates of the equivalent worm conjugate to to the worm.

2°/ Determination of the coordinates of the same profile in a plane normal to the lead pitch helix.

3°/ Determination of the coordinates of the section to be given to the grinding wheel to obtain this profile when grinding the flanks as a worm the lead angle of which is equal to that of the worm + or - the relief angle.

LIMITS

With profiles ZI and ZK the method is applicable only when the equivalent worm is undercutting free. But the software accepts only such worms.

Resharpening is theoretically not allowed. It is nevertheless clear that some refreshments are possible without appreciable errors.

NOTATION AND SYMBOLS

De grinding wheel diameter.

mxd axial module to be used to grind the relieved flanks.

gamma.d lead angle to be used to gind the relieved flanks.

Left/Right flank for an observer facing the cutting plane.

PROCESSING (figure 4)

The grinding wheel being formed to the coordinates obtained, the tool is secured normally on its spindle. The flanks are then relieved using the parameters obtained. The profile to be used (ZA, ZI or ZK) is the same as the worm.

Since the cutting face is flat, the right and left profiles are exactly symmetrical. It results that the parameters used to grind the right flank can be equally used to grind the left flank if they are inversed as seen in a mirror. For example, if the right flank has been ground with a RH lead, the left flank will be ground with a LH lead.

RELIEF

Since a fly cutter is normally fed tangentially, the actual relief angle should be just the static relief. With tin bronzes a satisfactory value is in the vicinity of 2.5°.

INSPECTION

Since the cutting face is flat, it is possible and easier to check the profile using a profile projector. The option "Profile section" accessible from the page "Fly cutter" allows printing of the profile at the required scale.

(35) > FLY CUTTER > RELIEF GRINDING WITH NC WORM GRINDER > PROFILE MODIFICATIONS

This method can be used when a NC worm grinder is available providing facilities to modify the worm profile.

DESCRIPTION AND THEORETICAL BASE

The cutting face of the fly cutter is a plane (flat). Its profile is therefore symmetrical and the cutting edges lie exactly on the flank surfaces of the ghost worm equivalent to the tool. This ghost worm is conjugate to the worm and therefore generated by the same normal basic rack. It is identical whatever the lead hand.

The software then makes the following calculations in the stated order :

1°/ From the hobbing centre distance, determination of the axial coordinates of the equivalent worm conjugate to to the worm.

2°/ Determination of the coordinates of the same profile in a plane normal to the lead pitch helix.

3°/ Determination of the modifications to be given to the the worm profile to obtain this profile when grinding the flanks as a worm the lead angle of which is equal to that of the worm + or - the relief angle.

LIMITS

With profiles ZI and ZK the method is applicable only when the equivalent worm is undercutting free. But the software accepts only such worms.

Resharpening is theoretically not allowed. It is nevertheless clear that some refreshments are possible without appreciable errors.

NOTATION AND SYMBOLS

mxd axial module to be used to grind the relieved flanks.

alpha.n/x pressure angle to be used to grind the relieved flanks.

gamma.d lead angle to be used to grind the relieved flanks.

d pitch diameter to be used to grind the relieved flanks.

sx axial thickness to be used to grind the relieved flanks.

M modifcation to the profile in the axial plane at radius **R**.

R radius for the modification **M**.

Left/Right flank for an observer facing the cutting plane.

PROCESSING (figure 5)

The tool is secured normally on its spindle. The flanks are then relieved using the parameters obtained. The profile to be used (ZA, ZI or ZK) is the same as the worm.

Since the cutting face is flat, the right and left profiles are exactly symmetrical. It results that the parameters used to grind the right flank can be equally used to grind the left flank if they are inversed as seen in a mirror. For example, if the right flank has been ground with a RH lead, the left flank will be ground with a LH lead.

RELIEF

Since a fly cutter is normally fed tangentially, the actual relief angle should be just the static relief. With tin bronzes a satisfactory value is in the vicinity of 2.5°.

INSPECTION

Since the cutting face is flat, it is possible and easier to check the profile using a profile projector. The option “Profile section” accessible from the page “Fly cutter” allows printing of the profile at the required scale.

(36) FLY CUTTER > RELIEF GRINDING WITH NC WORM GRINDER > BY INVOLUTE

This option is a variant of the option WITH FLAT WHEEL described above. It should be chosen when a worm grinder is available providing facilities to grind the flanks according to profile ZI (involute), which is the case of all NC grinders. Setting up of the grinder is particularly easy.

It uses exactly the same description, theoretical basis and limits as the flat wheel option but instead of generating the involute profile with a flat wheel it uses the facilities provided by the NC grinder.

Refer to the FLAT WHEEL OPTION for theoretical basis, limits ans inspection.

Setting up is clearly described and illustrated in the Help pages available from the programme **GSVISW**.

(37) OPTION > ROUGHING TOOL

This option allows the determination of the profile of a roughing pre-grind mill leaving a constant grinding allowance and thus limiting the grinding time to a minimum.

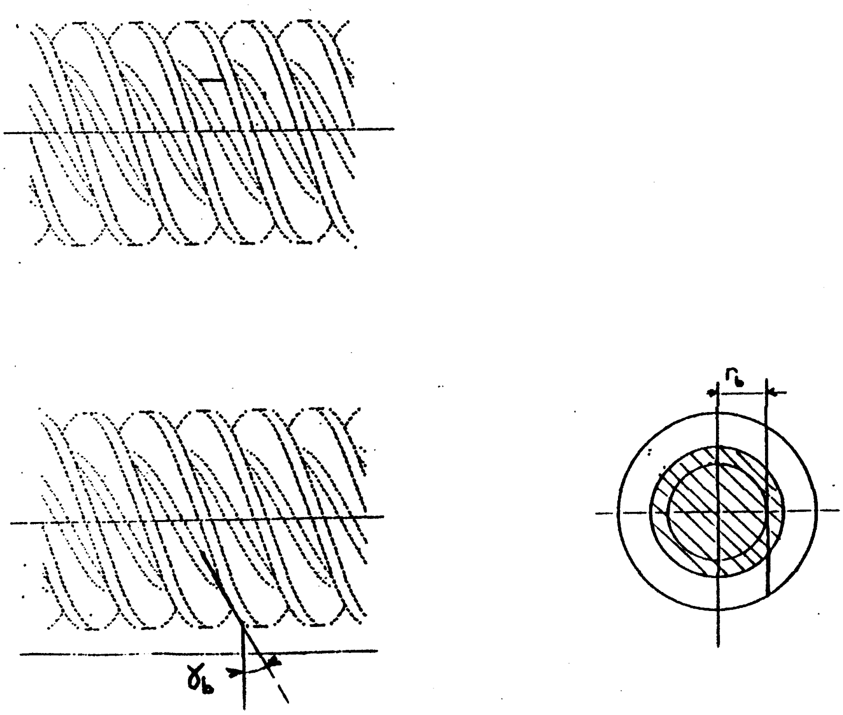


Fig. 1

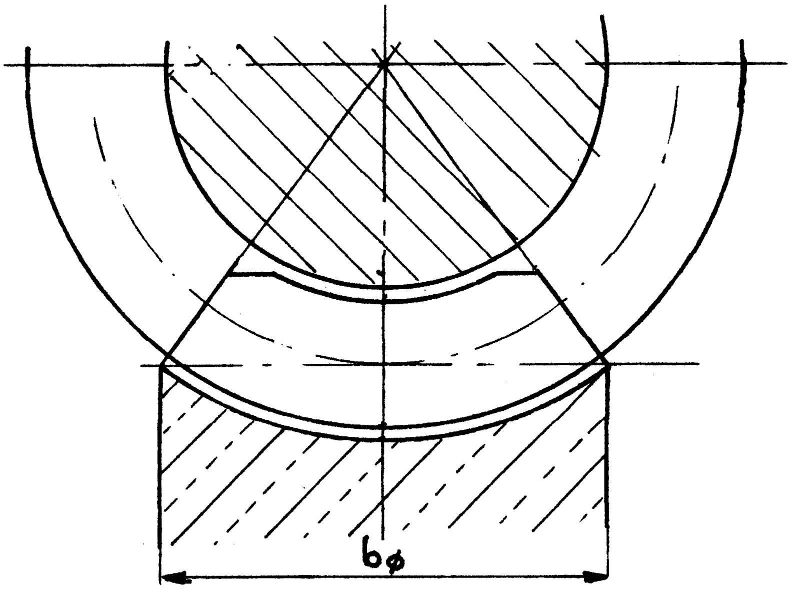


Fig. 2

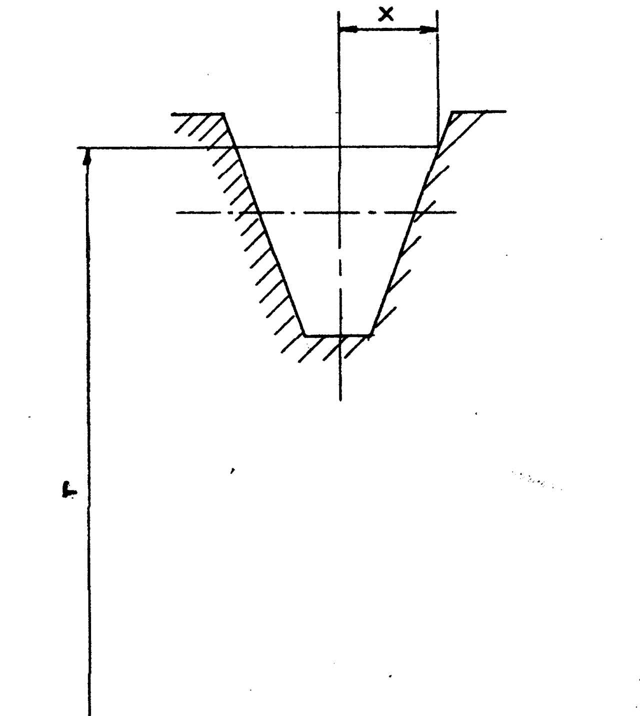


Fig. 3

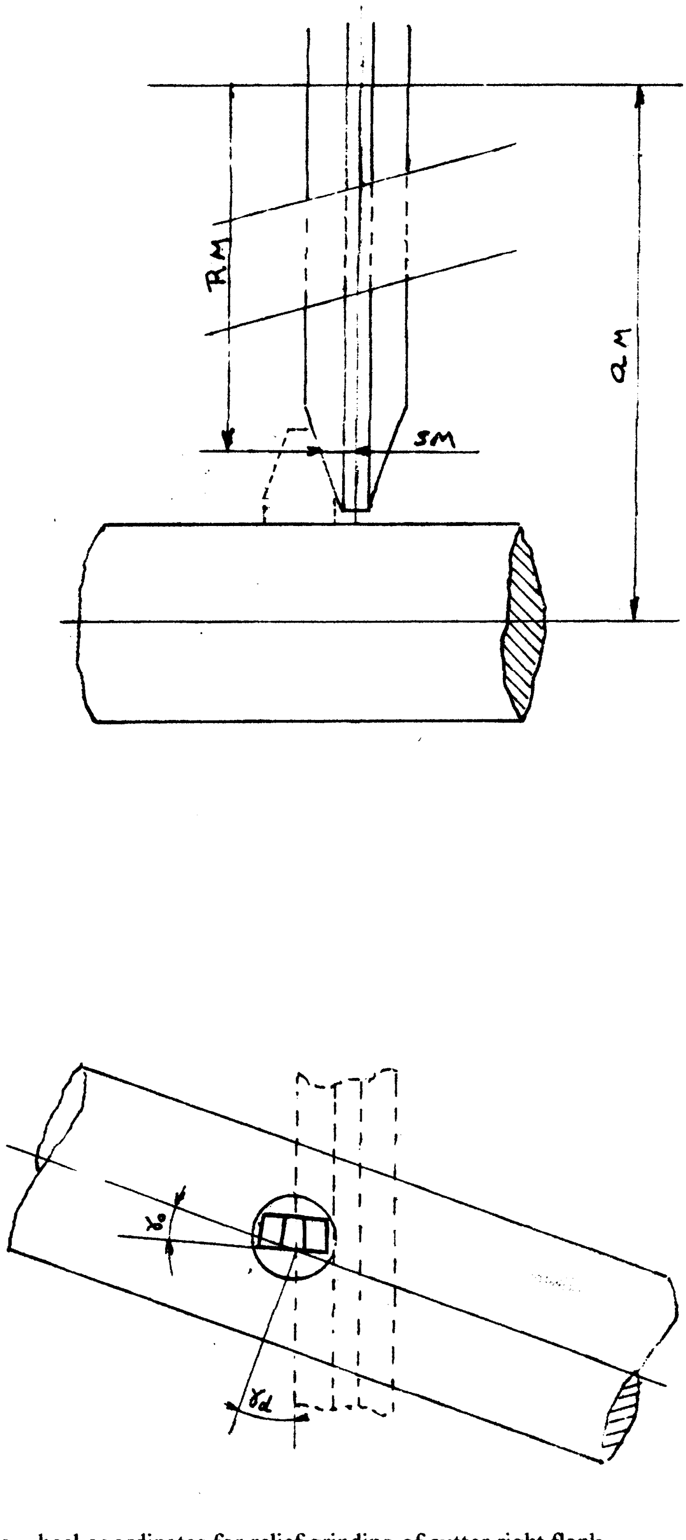
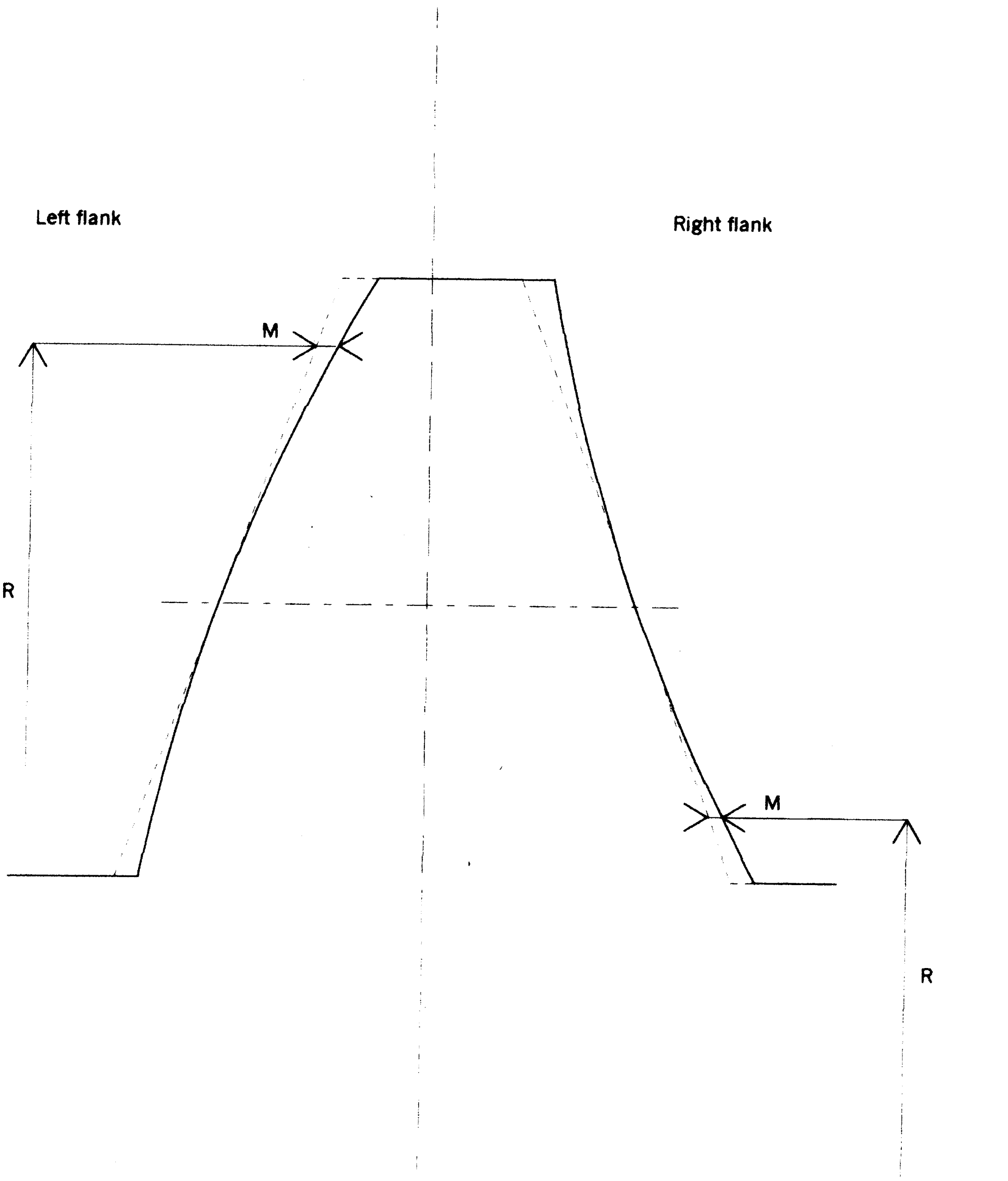


Figure 4 Grinding wheel coordinates for relief grinding of cutter right flank.



- - - - - - - Unmodified profile
——— Modified profile

Negative modifications on right flank

Positive modifications on left flank

Figure 5 Modifications of profile for releif grinding

Disposition N° 1 - LH Lead

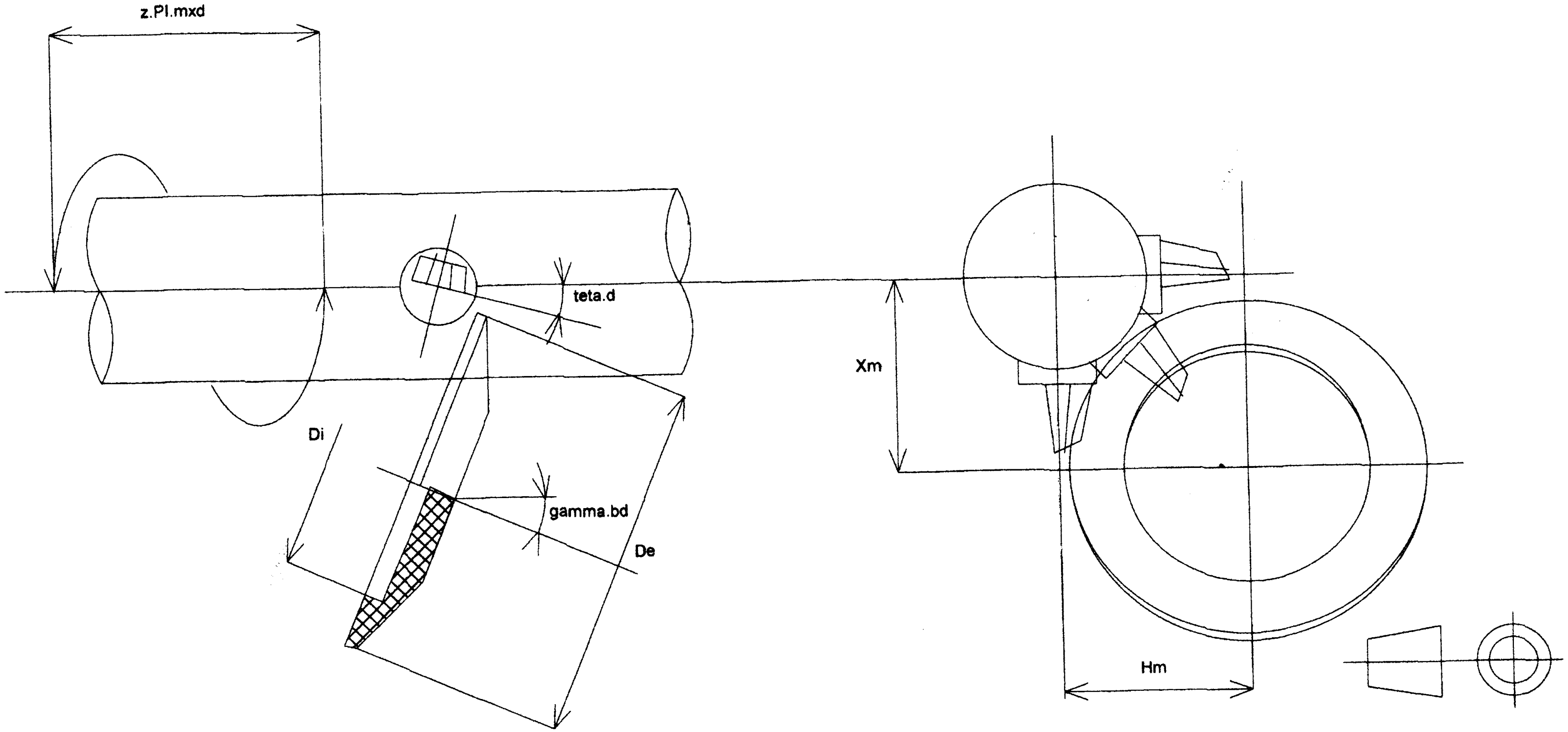


Fig. 7

Disposition N° 1 - RH Lead

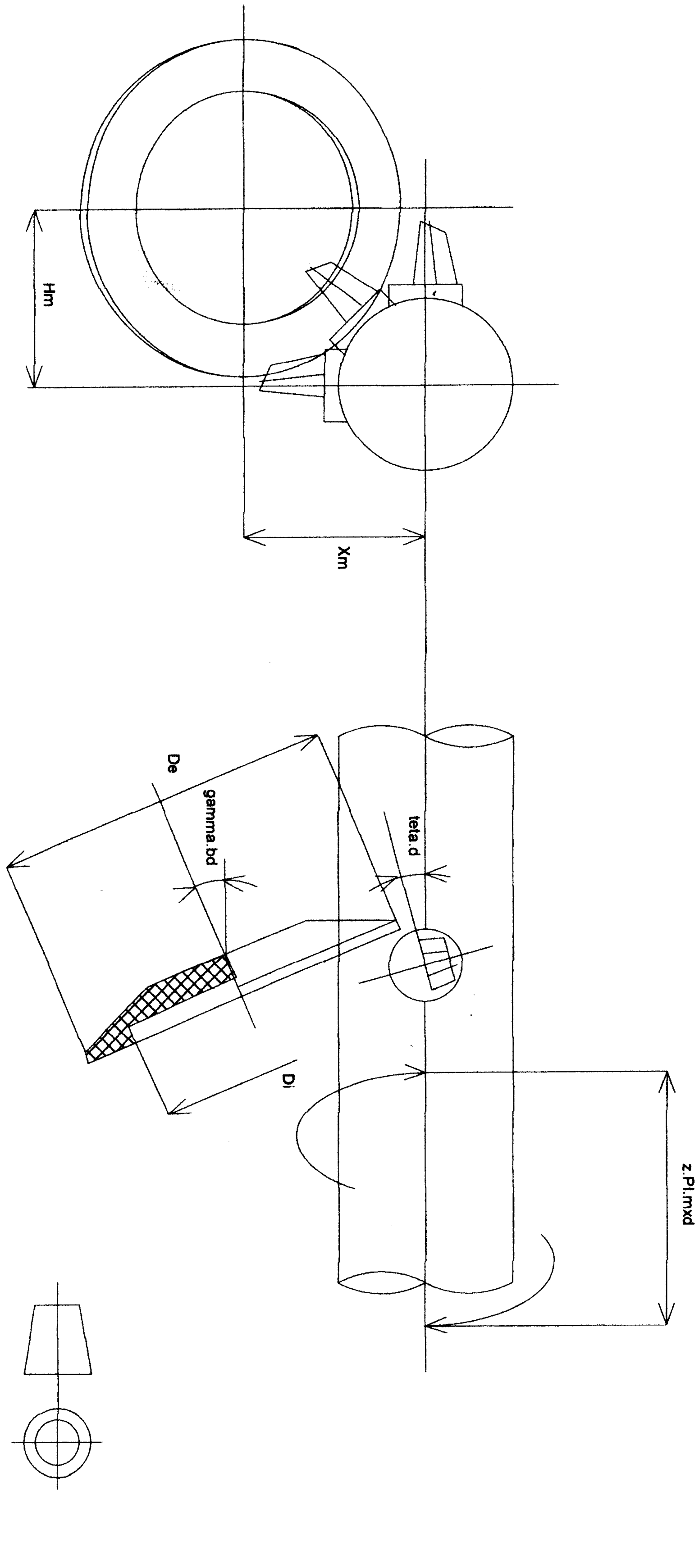


Fig. 8

Disposition N° 2 - LH Lead

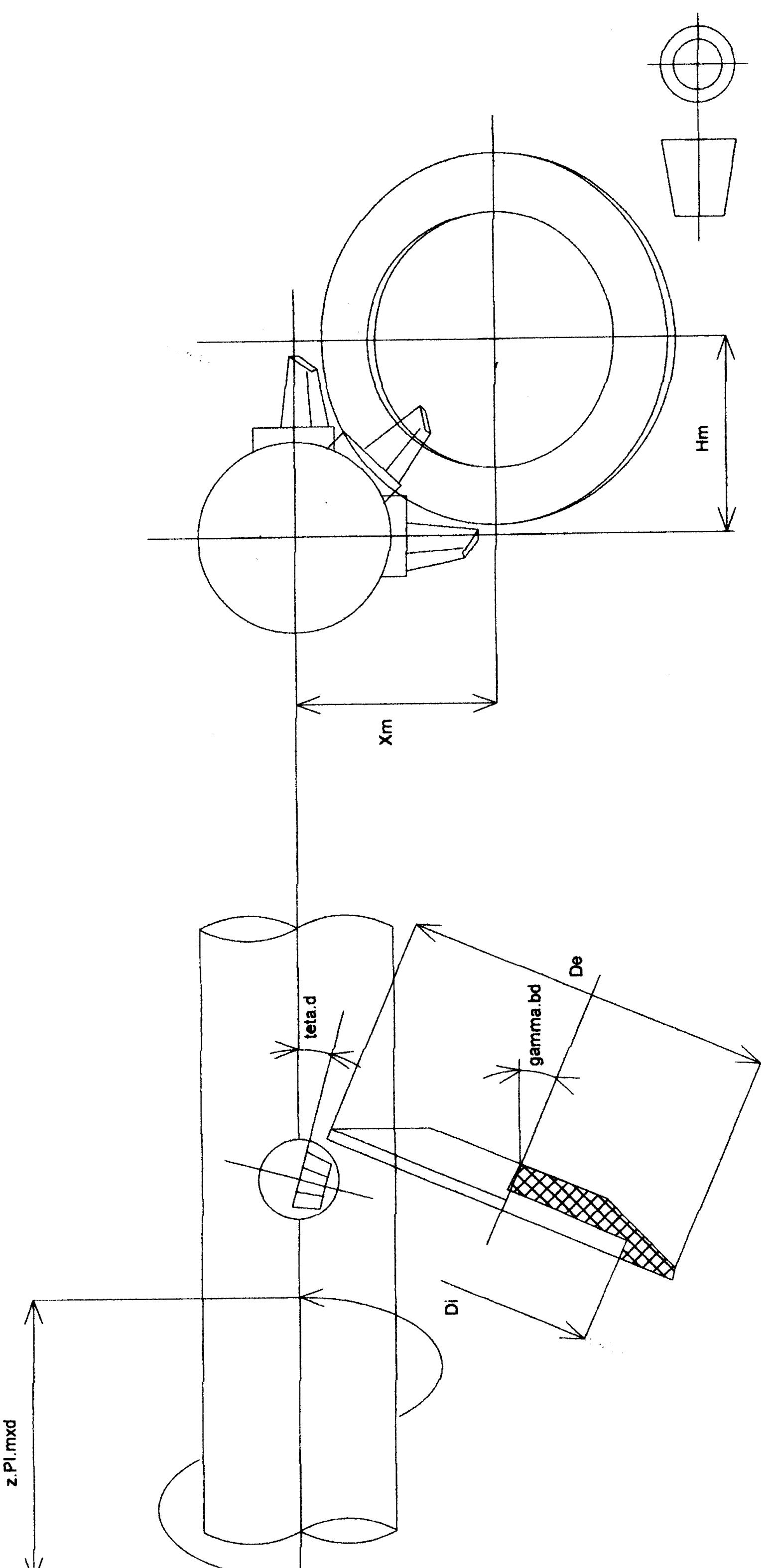


Fig. 9

Disposition N° 2 - RH Lead

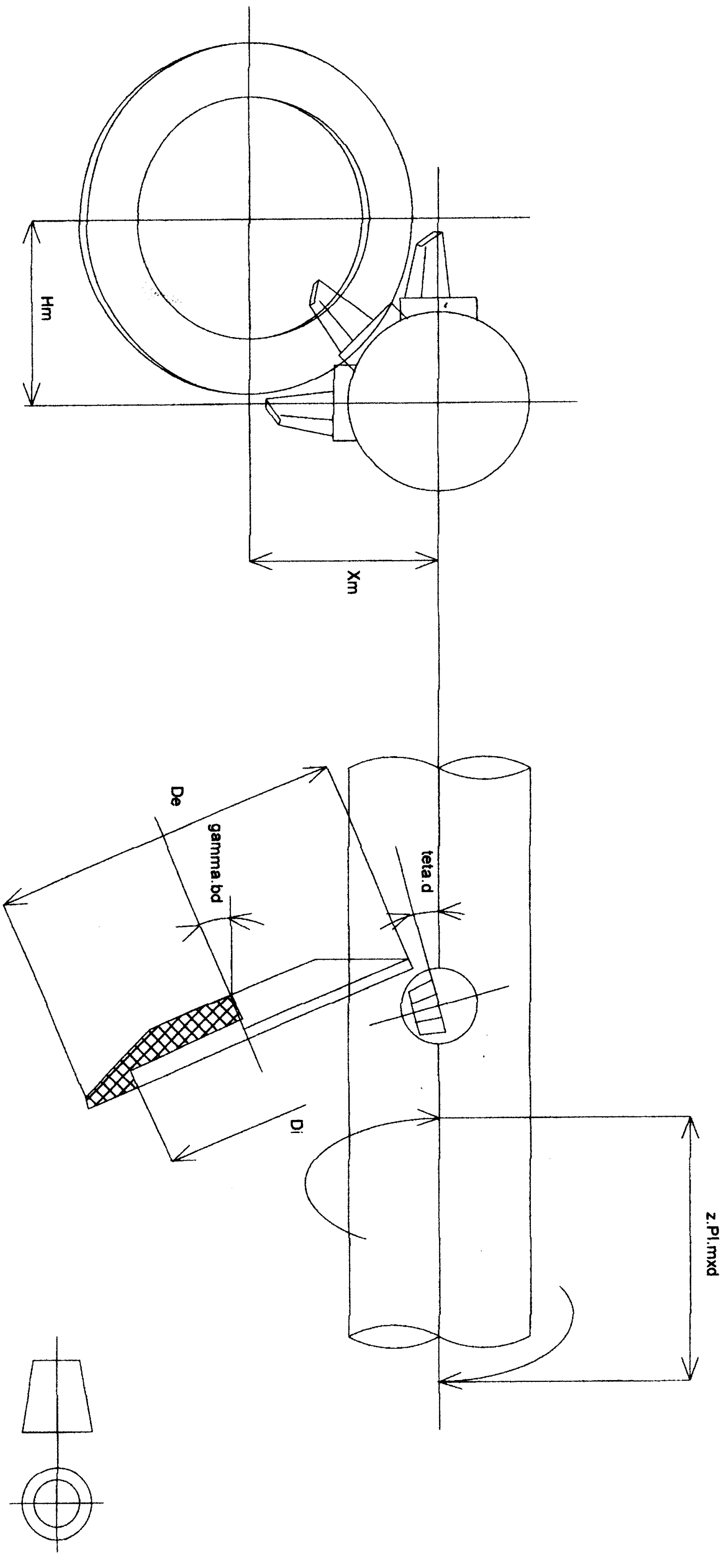


Fig. 10

Table 3-1
Chemical Analysis of Wormgear Materials

Material Type	Copper	Tin	Nickel	Iron	Mang.	Silicon	Phos.	Lead	Zinc	Impurities
	Percent of Material									
Manganese Bronze	(By Agreement between Gear Manufacturer and Producer)									
MNBR 1	59.0–62.0	--	--	0.35 max	2.0–3.5	0.5–1.5	--	0.5–1.75	Remainder (31.25–38.0)	--
Phosphor Bronze	(By Agreement between Gear Manufacturer and Producer)									
Bronze 1	88.0–90.0	9.75–10.75	1.25–1.75	--	--	--	0.05 max	--	--	0.25 max
Bronze 2	86.0–90.0	10.0–12.0	--	--	--	--	0.05 max	--	2.0 max	0.25 max
Bronze 3	86.0–89.0	9.0–11.0	--	--	--	--	0.05 max	1.0–2.0	--	0.25 max
Bronze 4	86.0–89.0	11.0–13.0	0.5 max	--	--	--	0.1–0.3	--	--	0.25 max
Bronze 5	86.0–88.0	11.2–12.5	1.25–1.75	--	--	--	0.1–0.3	--	--	0.25 max

Table 3-2
Mechanical Properties of Wormgear Materials

Type	Condition	Minimum Tensile Strength lb/in² (MPa)	Minimum Yield Strength lb/in² (MPa)	Elongation in 2 inch percent, min	BHN min 500 kgf
Manganese Bronze		(By Agreement between Gear Manufacturer and Producer)			
MNBR 1	As Forged	75 000 (520)	42 000 (290)	20.0	135
Phosphor Bronze		(By Agreement between Gear Manufacturer and Producer)			
Bronze 1 Thru 5	Sand Cast	40 000 (275)	20 000 (140)	25.0	70
Bronze 1 Thru 5	Chill Cast	45 000 (310)	24 000 (165)	20.0	80
Bronze 1 Thru 5	Centrifugal Cast	50 000 (345)	26 000 (180)	15.0	90

NOTE: For Tables 3-1 and 3-2. The resistance to pitting of wormgears is greatly dependent on the method of forming or casting the gear blank (see Figs 3-1 and 3-2). Forged bronze has been utilized only for smaller size gear blanks, and sliding velocity should be limited to approximately 500 fpm (2.5 m/s) unless proper operation can be supported by test results.

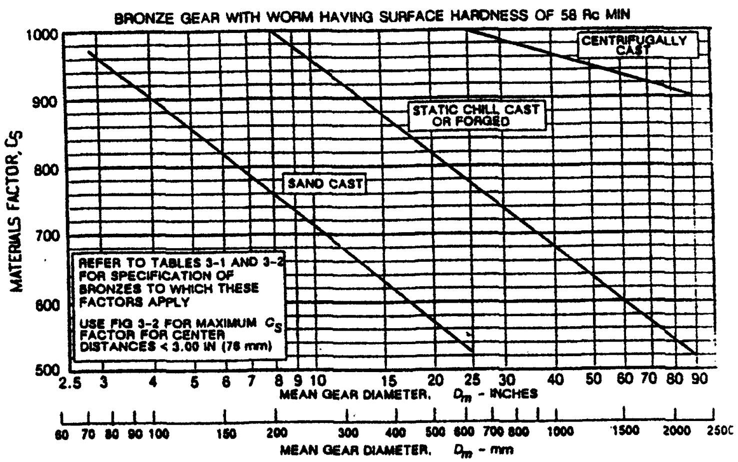


Fig 3-1 Materials Factor, C_S, for Center Distances > 3.0 in (76mm)

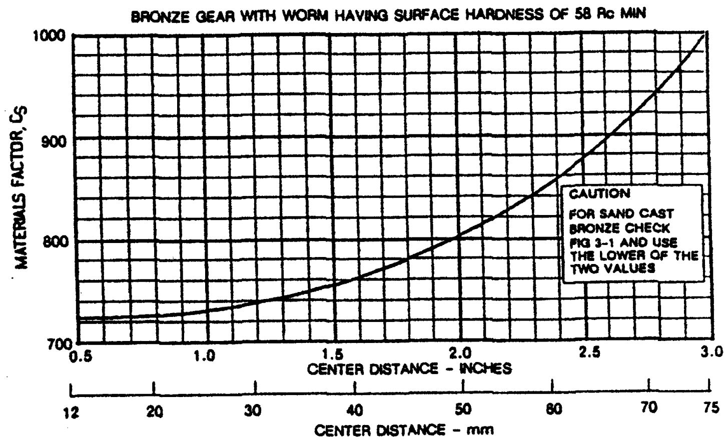


Fig 3-2 Maximum Materials Factor, C_S, for Center Distances < 3.00 in (76 mm)

Extrait du standard AGMA 6Ø34-A87, Practice for Enclosed Cylindrical Wormgear Speed Reducers and Gearmotors avec l'autorisation de l'éditeur, the American Gear Manufacturers Association, 15ØØ King Street, Suite 2Ø1, Alexandria, Virginia, USA.