3. Data input program

Program for description of objects is intended for creation, correction multibody systems, as well as for automatic generation of equations of motion and their compilation. List of files in the program:

bin\UMInput.exe
bin\um.rsc (file of string resources)
bin\GraphRes.rsc (file of string resources)

Basic elements of program (UMInput.exe) are the following (Fig. 3.1):

- The main menu;
- The tool panel with buttons, which duplicate some most often used command of the main menu;
- The set of sheets with typical elements for visual construction of simple objects;
- The object constructor – the main tool for object description and correction.

The Data input program is a multitasking tool, which allows opening several constructors with description of various objects. An object, whose constructor is placed over all others, is the *active* one.

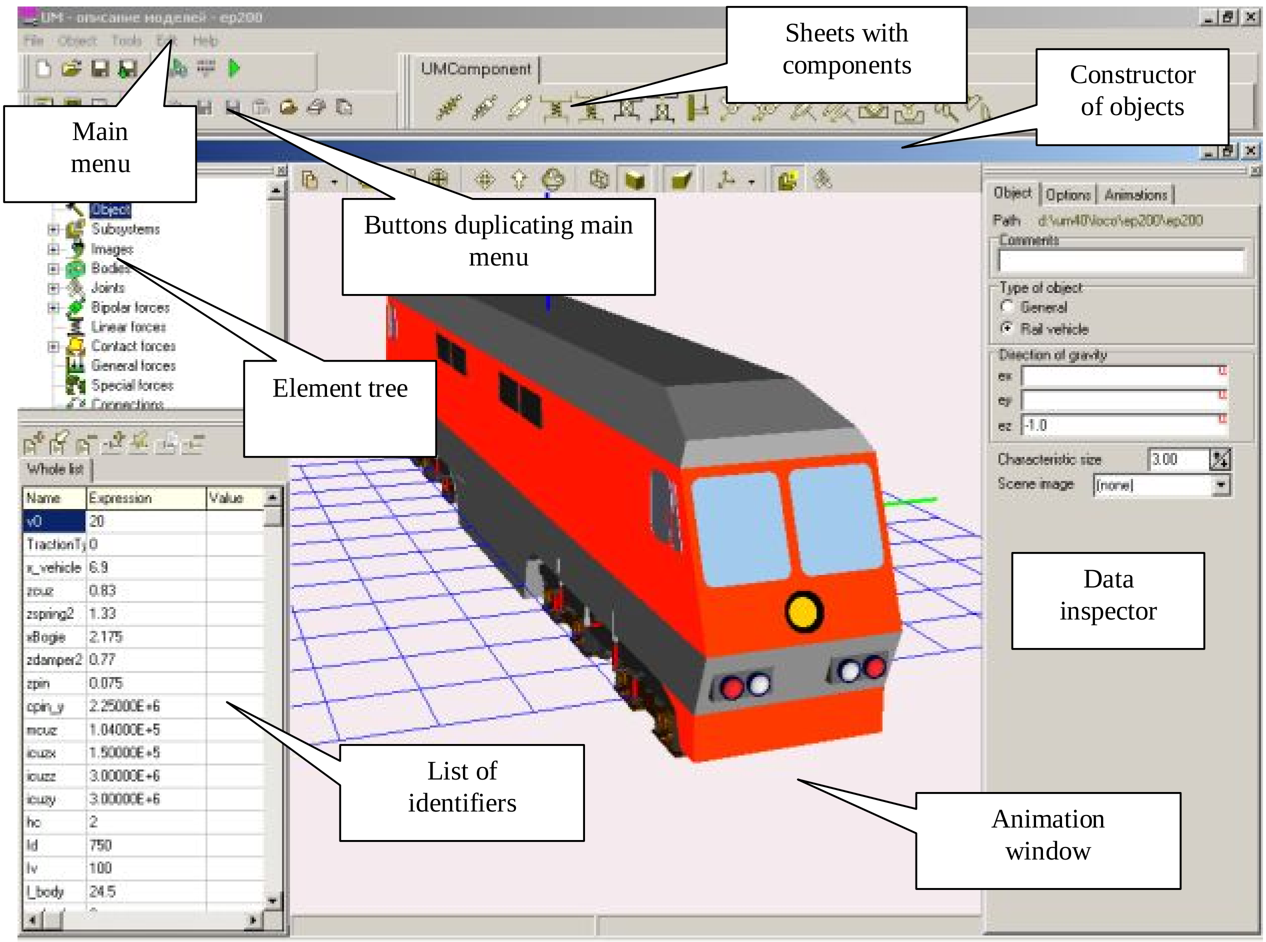


Fig. 3.1

Options of Input program

To set or modify options of the Input program

- Run **UMInput.exe**;
- Call the option window with the **Tools | Options** main menu command;
- Use the **OK** button of the window to store changes in the computer registry.

3.1.1. Setup of symbolic generation of equations of motion

UM generates equations of motion of objects with the help of a built-in specialized computer algebra system. To simulate the object dynamics, the equations should be compiled with the help of an external compiler (Delphi 4.0-7.0, Visual C++ 5.0-6.0, Borland C++ Builder 3.0-5.0, BDS 2005-2006), which is not delivered with UM. First of all, make sure that a proper compiler is installed on your computer or on a server. Then use the **General** tab to set the default external compiler. In fact, *UM can use numeric-iterative method of the generation of equations of motion without an external compiler.*

3.1.1.1. Delphi

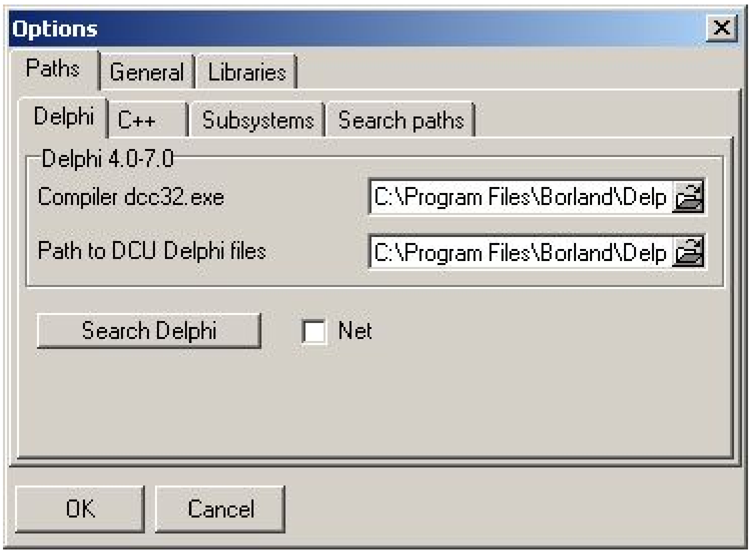


Fig. 3.2. Paths to Delphi

Use the **Paths | Delphi** tab (**Fig. 3.2**) to specify paths to a Delphi compiler and the Delphi VCL files. If the current computer has Delphi 4.0-7.0 (or higher) installed, it is enough to click the **Search Delphi** button to set the paths. If Delphi can be found in the local net try to find it automatically using the same button and the option Net turned on. In this case the paths will be found if the registry of the corresponding net computer is available for reading. If reading of the registry is not allowed, the paths should be set manually. To do this, use the  buttons in the right hand side of two boxes and find

- Delphi compiler dcc32.exe (usually [path to Delphi]\bin),
- Directory containing Delphi VCL *.dcu files (usually [path to Delphi]\lib).

Example:

- D:\Delphi5\bin\dcc32.exe,
- D:\Delphi5\lib.

3.1.1.2. C++

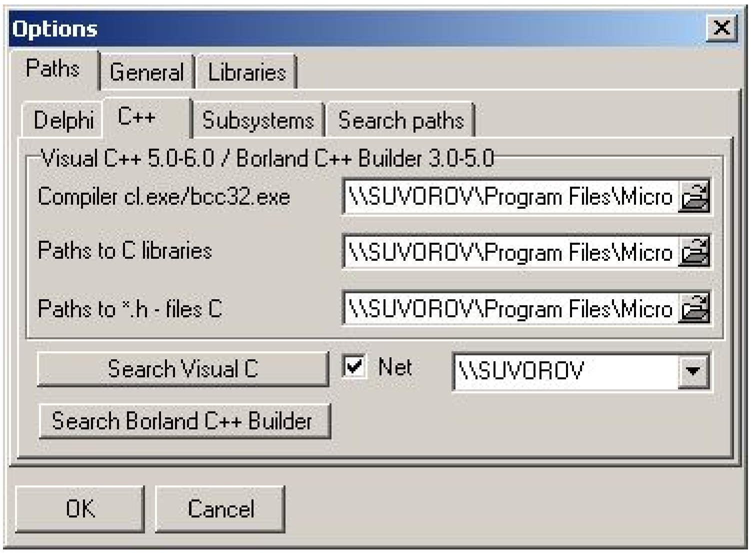


Fig. 3.3. Paths to C++

Use the **Paths | C++** tab (**Fig. 3.3**) to specify paths to a C++ compiler. If the current computer has Visual C++ 5.0-6.0 or Borland C++ Builder 3.0-5.0, installed, it is enough to click the corresponding button to set the paths. If C++ can be found in the local net, try to find it automatically using the same button and the option Net turned on. In this case the paths will be found if the registry of the corresponding net computer is available for reading. If reading of the registry is not allowed, the paths should be set manually. To do this, use the buttons in the right hand side of two boxes and find

- C compiler cl.exe/bcc32.exe;
- Paths to C libraries (lib-files);
- Paths to the standard *.h files.

Example for Visual C++ installed on computer *Suvorov*:

- \\SUVOROV\Program Files\Microsoft Visual Studio\VC98\bin\cl.exe
- \\SUVOROV\Program Files\Microsoft Visual Studio\VC98\lib
- \\SUVOROV\Program Files\Microsoft Visual Studio\VC98\Include

3.1.2. Paths to external subsystems

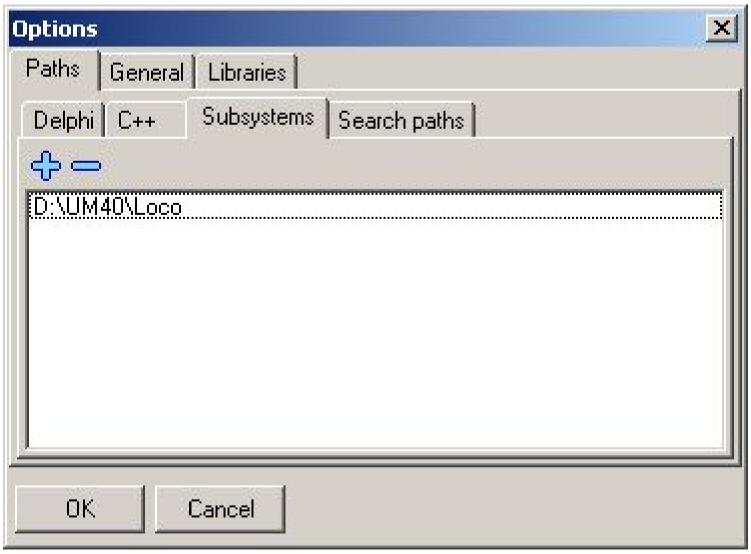


Fig. 3.4. Paths to external subsystem

Use the **Paths | Subsystems** tab (**Fig. 3.4**) to add/delete paths to directories with *external subsystems*. UM uses these paths to search DLL with equations of external subsystems as well as other files necessary for simulation.

Remark. Option is important if your version of UM has the Subsystem Module.

3.1.3. Paths to user's units

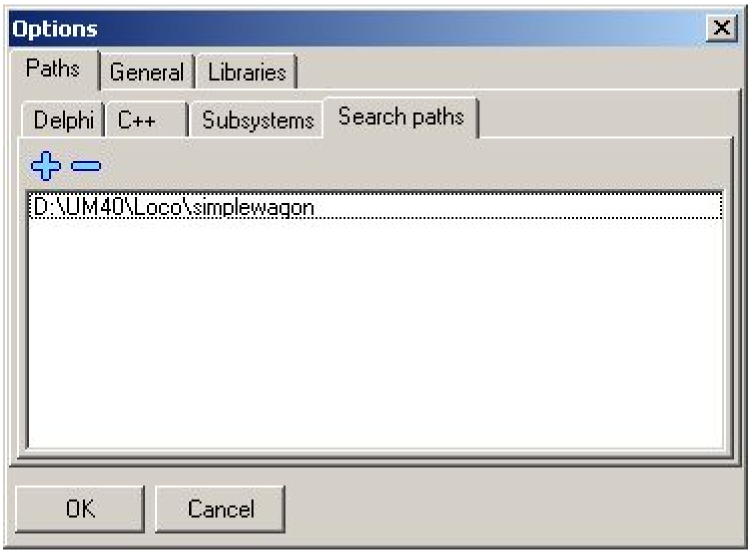


Fig. 3.5. Paths to user's units and files

Use the *Paths* | *Search paths* (**Fig. 3.5**) tab to add/delete paths to directories with user's units and file, which are used as parts of user's code (programming in UM environment). The paths are used by the external compiler.

3.1.4. General options of the Input program

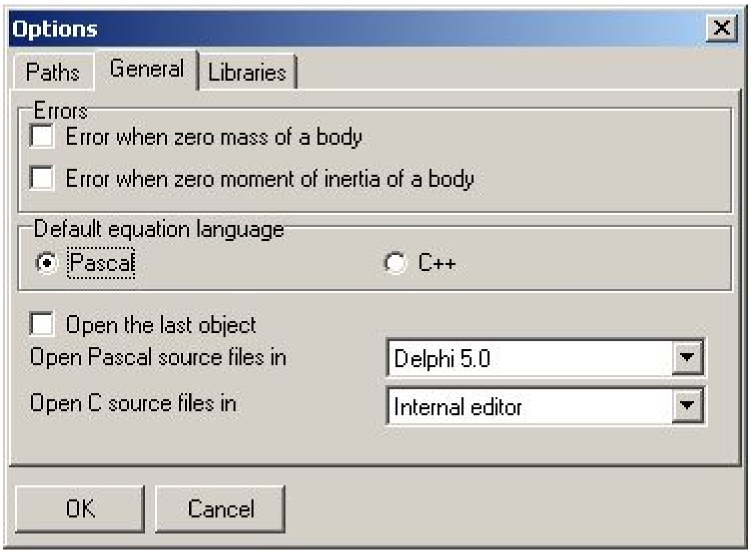


Fig. 3.6. General options

Use the **General** tab parameters (Fig. 3.6) to specify the following parameters:

- **Error when zero mass of a body** – if turned on, zero mass is considered as a input error, else as a warning;
- **Error when zero moment of inertia of a body** – if turned on, zero inertia moment is considered as a input error, else as a warning;

- The **default language** for automatically generated equations of motion and programming in the UM environment; choice depends on the presented compiler (Sect. 3.1.1);
- **Open the last object** – if checked, the latest active object will be opened automatically when the Input program starts.
- **Open Pascal source files in** – allows selecting an editor for programming on Pascal language.
- **Open C source files in** – allows selecting an editor for programming on C language.

Remark. Handling zero inertia parameters as an error is recommended for beginners only to avoid the degeneration of the mass matrix at the simulation of objects. These options are ignored for railway vehicle models.

3.1.5. Component libraries

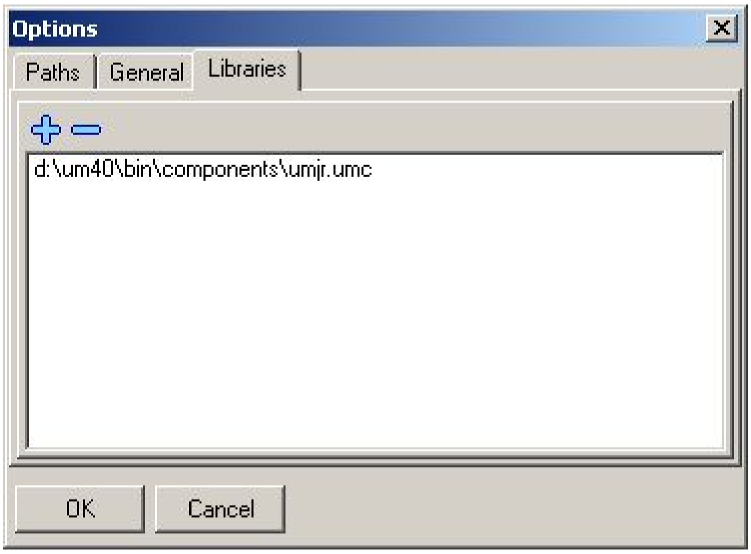


Fig. 3.7. Component libraries

Use the **Libraries** tab to add or remove component library files. To add new component library click the button  and select necessary file using standard dialog window **Open**. To remove selected library use the button .

3.2. Main menu commands and tool panel

3.2.1. File

- **New object** (*Ctrl+N*) – opens constructor of a new object with the default name **UmObj[Index]**.
- **Open object** (*Ctrl+O*) – calls a special dialog box for choice an existing object (Fig. 3.8). The dialog box contains a tree of objects found in the *directory for reviewing objects*. To set the default path to the *directory for reviewing objects* use the menu command **Tools | Options** and the page **Paths | Objects** in the window *Options* or use the  button in the top edit box to choose the root directory and the *Accept as default* button right after that.

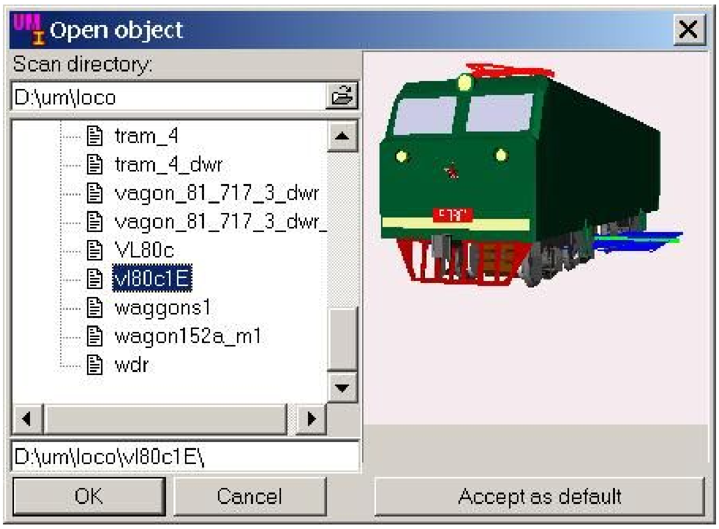


Fig. 3.8. Open object dialog box

Use the **F5** button or the pop-up menu to refresh the tree of objects in the *Open object* dialog box. Use the upper edit box for changing the current directory.

- **Reopen** – allows the user to open recently used objects.
- **Save** (*Ctrl+S*) – **saves** the active object in the object directory. The command is executed if the active object has been modified and the object directory has already been created. If the directory does not exist, the *Save as…* command is executed.
- **Save as…** – **saves** the active object in a directory pointed out by the user. Use the ***Save as...*** dialog box to select or enter a path to the object including its name. If necessary, new directories are created. *The object takes the last directory in the path as its own name.*

Fig. 3.9

Remark. Object name (i.e. the last directory in the path) must be an identifier, that is then name contains the letters a…z, A…Z, digits 0…9, and the '_'. The first symbol must be a letter.

- **Exit** (*Alt+X*) – closes **the** program.

3.2.2. Object

- **Verify** data (*F7*) – verifies correctness and fullness of the object description.
- **Generate equations…** (*F8*) – saves modified active objects, deletes old UMTask.dll file of equations, and verifies the object description. If no errors are found, the window for generating and compiling equations starts.

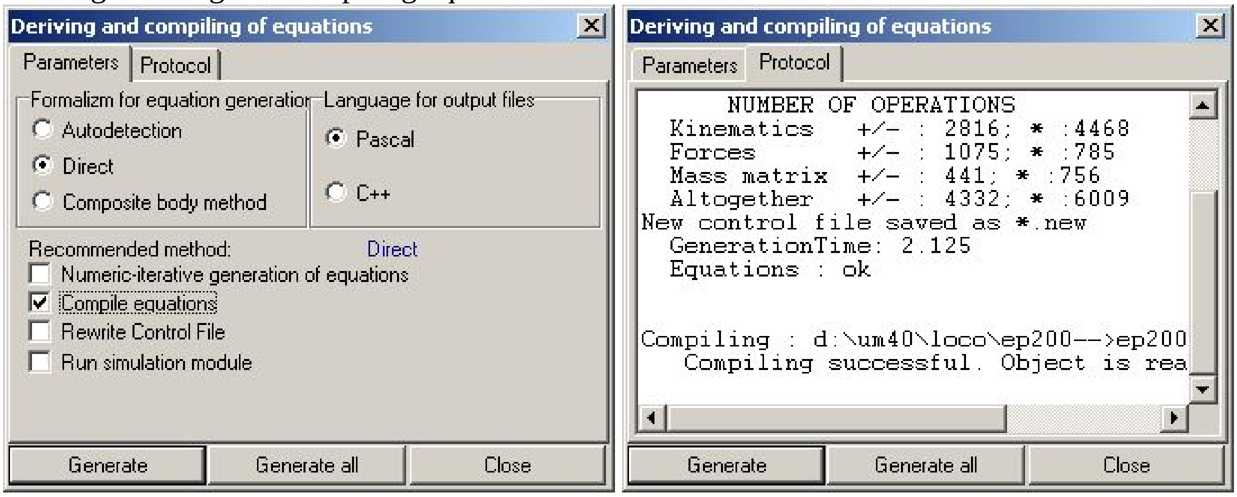


Fig. 3.10.

- **Compile equations** (*Ctrl+F9*) – runs compiling of equations if they are generated.
- **Simulation…** (*F9*) – verifies whether the UMTask.dll file exists for the active object and runs the simulation.

3.2.3. Tools

- **Editor…** – runs the built-in text editor.
- **Calculator of expressions…** – runs the calculator of chains of symbolic expressions (Sect. 3.3.2.4.2).
- **Inspector** (*F12*) – brings to front the *Data Inspector* for the active object if it is located on a separate window (Sect. 3.3.2).
- **List of elements** (*F11*) – brings to front the *List of elements* for the active object if it is located on a separate window (Sect.3.3.2.1).
- **Identifiers** (*Alt+I*) brings to front the *List of Identifiers* of the active object if it is located on a separate window.
- **List of windows** (*Alt+0*) – calls the window containing the list of open windows.
- **Control File…** (*Alt+C*) – opens the Control file for the active object in the text editor.
- **File of elements…** – creates a file n[NameOfObject].txt in the object directory and opens it in the text editor. The file contains lists of all the object elements (bodies, joints, identifiers, force elements etc.) and their names.
- **Graphical converter…** – opens a graphical converter of *3ds* and *ASC* formats in the *UMI* (UM) graphical format. Utility is used for import of external graphical objects.
- **Transformation of coordinates…** (*Alt+T*) – opens the forms for transformation of coordinates of points into different system of coordinates (Sect. 3.4.8.5).
- **Wizard of components…** – tool for edition of component libraries.
- **List of components…** – open window with the list of loaded components.

- **Options** – opens a dialog box with UM options: paths to external compiler, standard and user's libraries etc. (Sect. 0).

3.2.4. Edit

- **Copy in clipboard** – copy parameters of selected elements to clipboard.
- **In clipboard as component** – write parameters of the selected element and the graphic object connected with it to clipboard. If the element has no graphical object the option is disabled.
- **Copy into file… –** write parameters of the selected element into file.
- **Save as component…** – save parameters of the selected element and the graphic object connected with it in file.
- **Insert** – insert element/component from clipboard.
- **Read from file…** – add all elements from file to the object.

3.2.5. Help

- **Lessons** – access to several lessons, teaching UM environment

It is recommended to study the lessons before working with UM.

- **About** – short information about UM version and the list of developers.

3.2.6. Tool panel

Buttons located on the tool panel have the following functions:

 – creates a new object;

 – opens an existing object;

 – saves the active object;

 – saves the active object with a new name;

 – opens the text editor;

– opens symbolic calculator;

 – verifies correctness of the active object description;

 – generates and compile equations for the active object;

 – compiles equations for the active object;

 – runs simulation of the active object.

3.3. Object constructor

3.3.1. Basic elements of constructor

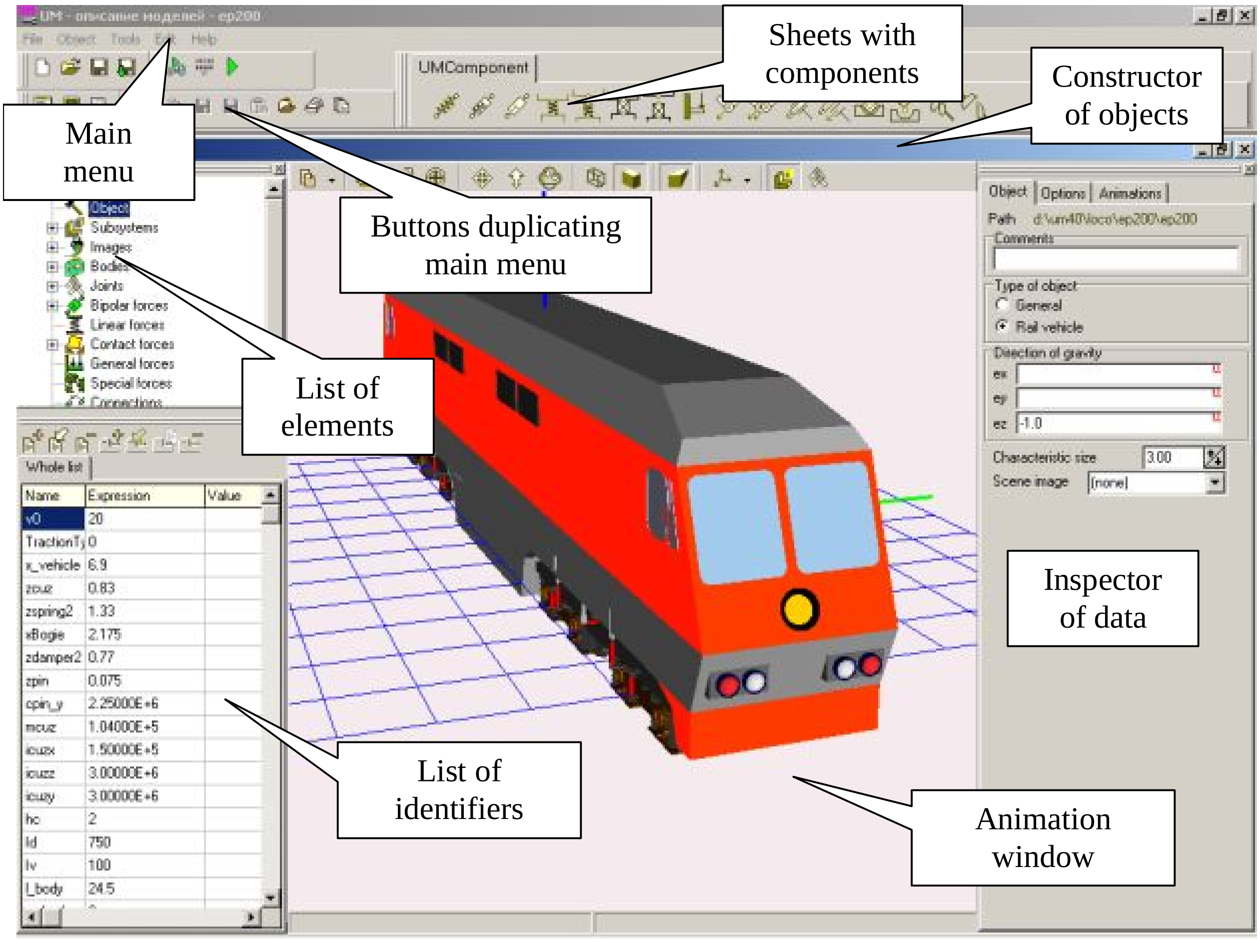


Fig. 3.11. Object constructor

Constructor allows describing an object (multibody system) as a set of standard elements: bodies, joints, force elements. Basic parts of the constructor are

- **Inspector of Data** is used for input, modification and representation of object elements as well as some other information about the object.
- **Animation window** gives the object image or its parts according to active elements presented in the inspector. It can be use also for visual construction of models.
- **List of elements** presents the list of all object's elements and organizes access to parameters of separate elements
- **List of identifiers** is used for modification of identifiers of the model. It is a base of the full parameterization of UM models (Sect.3.3.2.4.2).
- **Sheets with components** can be also considered as a basic element of the constructor. This tool allows adding to the model some simple standard elements: bodies, joints, force elements or graphic objects. This tool is used at a study level.

The *drag-and-dock* technology is used for the element list and the inspector. They can be removed from the constructor window and placed on a separate window with the help of the mouse. If the list and the inspector are located as separate windows, the hot keys *F11*, *F12*, *Alt+I* are used to bring them in front.

Separate location of the list and the inspector are used to increase the animation window size when creating complex objects if necessary.

3.3.1.1. List of object elements

An object is a multibody system, which consists of separate typical elements. Access to the elements is realized by means of the list of elements (Fig. 3.11), visually (3.3.1.2) or with the help of hot keys (3.3.3).

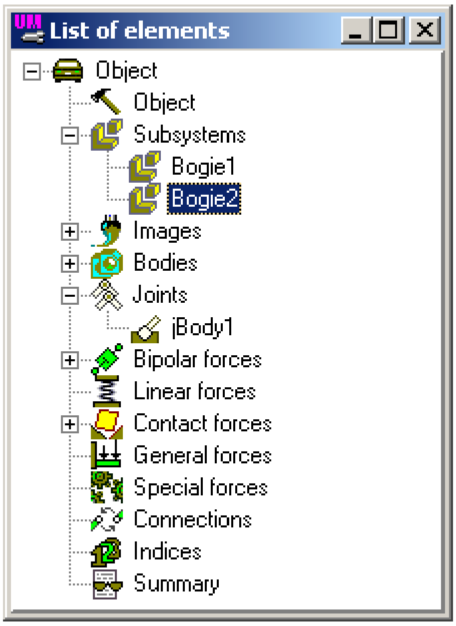


Fig. 3.12. List of object elements

Click on a list item (Fig. 3.12) causes appearance of the corresponding information in the object data inspector (3.3.2). The list contains the following items:

- **Object** – general object options, object type, gravity, background color etc. (3.3.2.2).
- **Subsystems –** list of subsystems (wheelsets, vehicle suspensions, caterpillar, including user's subsystems in the object). For UM version with subsystem technique only.
- **Images** – list of images, which are used for visualization of the scene, bodies and force elements (3.4.6).
- **Bodies –** list of **bodies** and their parameters (mass, moments on inertia, coordinates of centers of mass etc., Sect.3.4.7).
- **Joints** – **input** of joints (rotational, translational etc.) as well as coordinates of bodies (Sect.3.4.9).
- **Wizard of forces –** is **not** used in this UM version, a perspective future development for construction of complex force models.
- **Bipolar forces –** list **of** bipolar forces, i.e. forces acting along the axis of element, which connects two points of bodies (Sect.3.4.10.1). The force element is used for modeling dampers, dogs etc.
- **Linear forces –** list of generalized linear force elements described by 6×6 stiffness or damping matrices (Sect.3.4.10.2). The element is used for modeling springs, resistance of the environment etc.
- **Contact forces –** list of force elements, which models contact interaction between bodies (Sect.3.4.10.4).

- **General forces –** list of forces used mainly for their programming in the UM environment (Sect. 3.4.10.5).
- **Special forces –** models of special force interactions (gearing, cams, combined friction etc. Sect.3.4.10.6).
- **3D Contact** – setting for 3D contact model. Reserved for future use. For more detailed description of using 3D Contact see Sect. 3.4.7.5.
- **Connections –** a tool for assignment of attachment points for external joints and force elements. For UM version with subsystem technique only.
- **Indices –** internal UM indices of object elements and coordinates useful for programming in the UM environment.
- **Summary –** contains information about correctness of the object description as well as lists of errors and warnings.

3.3.1.2. Animation window

3.3.1.2.1. Visualization of object elements

The whole object or their active elements are visualized in the animation window depending on the window mode (Sect.3.3.1.2.2). The following types of visual elements are used for visualization of different elements:

- **Graphic objects (GO)** created by the user – for bodies, bipolar and generalized linear force elements, special force elements spring, rod constraint images (Sect.3.4.6);

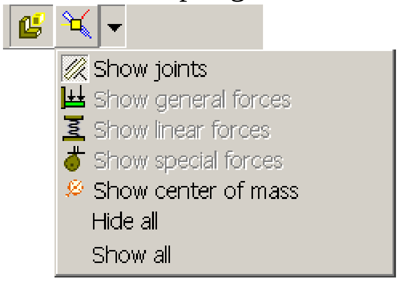


Fig. 3.13. Visualization commands

- **Icons** – for force element of general type, linear and special force elements, connection points, external elements (Fig. 3.13), the full object mode should be on (the  button);
- **Points**.

Every type of listed visual elements has active regions, which are used for visual selection of the corresponding object elements with the mouse.

- **GO** – the active region is the whole image;
- **Icon** – the active region is a small neighborhood of the left bottom part pointed out by the arrow, e.g. for the joint icon:

- **Point** – active region is a small neighborhood of the point.
- **Image** – the set of bitmaps for representation of enabled degrees of freedom. Used for joints only.

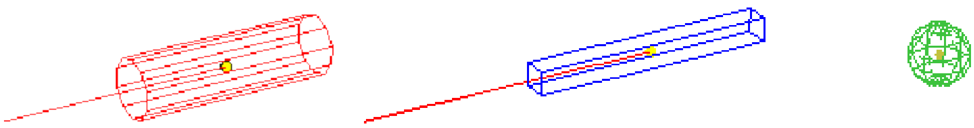


Fig. 3.14. Images for enabled degrees of freedom:

a) rotational; b) translational; c) three rotational (spherical joint).

3.3.1.2.2. Modes of animation window

Animation window has two modes of visualization of an object. The button  or a pop-up menu are used to switch them.

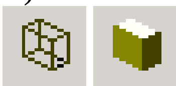
- **Whole object mode**

The whole object is visualized. In this mode, a mouse click on the active region of an image makes the corresponding element active (body, joint and force element, Sect. 3.3.1.2.1).

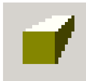
- **Single element mode**

A separate element is visible in this mode: GO, body, joint or force element (together with connected bodies).

Graphic mode (wire of surface graphics) can be changed with the help of two buttons



Orthogonal projection is turned on/off by means of the command **Perspective** of the pop-up menu or the button:



Parameters of the o*rthogonal projection* are modified with the help of the **Window parameters** command of the pop-up menu.

3.3.1.2.3. Basic system of coordinates, pop-up menu

The basic system of coordinates (SC0) is optionally presented in the animation window. Use the **Coordinate system** command of the pop-up menu to visualize of hide the axes. Coordinates of all elements attached the base must be given in this SC. A color principle is used to identify the SC0 axes (RGB):

- axis X – Red;
- axis Y – Green;
- axis Z – Blue.

A coordinate grid coincides with one of the coordinate planes. Use the **Window parameters** command of the pop-up menu to change the grid size and step.

Use the right mouse button to call a pop-up menu (Fig. 3.15).

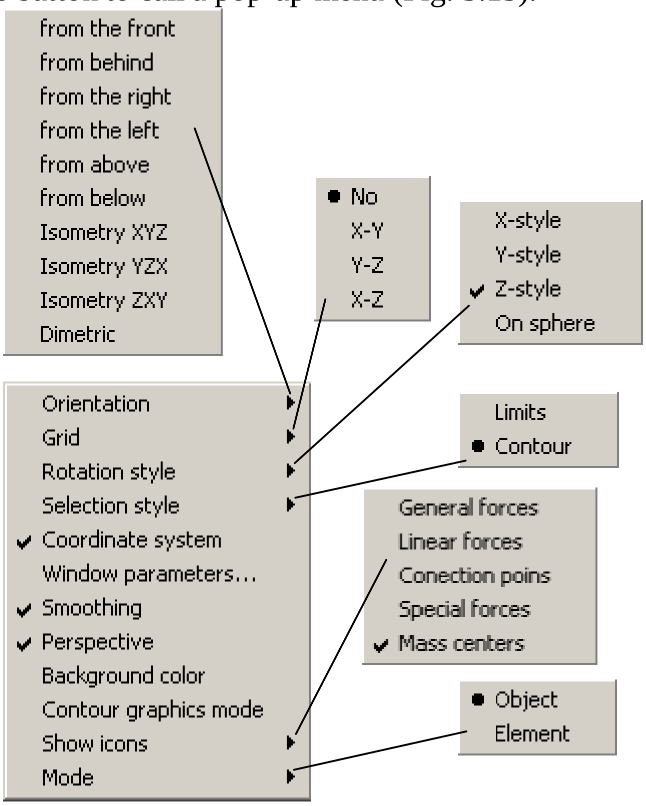


Fig. 3.15

Menu commands:

- **Orientation** – choice of one of the standard object orientations;
- **Grid** – choice of one of the standard grid locations;

  Click an image of the SC0 axis to set the grid perpendicular to the corresponding axis
- **Rotational style** – choice of style of rotation for objects in the animation window: **Z-style** used by default (from UM 3.0), **On sphere** – the style usually used in CAD systems.
- **Selection style** – the style of graphical visualization of an active element of the object (image contours or box rounding the element image);
- **Coordinate system** – turn on/off visualization of SC0;
- **Window parameters** – call of a window with perspective and grid parameters;
- **Smoothing** – turn on/off of smoothing mode;
- **Perspective** – turn on/off of orthogonal projection;
- **Background colo***r* – setting the background color of the animation window;
- **Contour graphic mode** – is used to obtain contrast black-and-white image which is suitable for printing.
- **Show icons** – is used for visualization of icons for joints, force element of general type, generalized linear force element etc. (for the whole object mode in the animation window only, Sect.3.3.1.2.2);
- **Mode** – switching the animation window modes (whole object / active element, Sect.3.3.1.2.2).

3.3.1.2.4. Tool bar

– Copy the window to clipboard or to a file (bmp);

 – Zoom in the selected area of animation window;

 – Show all (*F9*).

 – Zoom in/out of a selected point on the object: click the button and immediately click the left/right mouse button on an image point to zoom in/out the object and to shift the point in the window center. Use also *Alt+Shift + mouse click* on an object point;

 – Shift mode *(Ctrl + left mouse button*);

 – Zoom mode (*Shift + left mouse button*);

 – Rotation mode (left mouse button);

  – Choice of wire or surface graphics mode;

 – Turn on/off perspective;

 – Choice of one of standard views;

 – Switch full object / single element mode (Sect.3.3.1.2.2);

 – Show joint images.

See also Sect.3.3.4.3 for a list of hot keys.

3.3.2. Data inspector and some features of object element description

3.3.2.1. List of object elements and access to element description

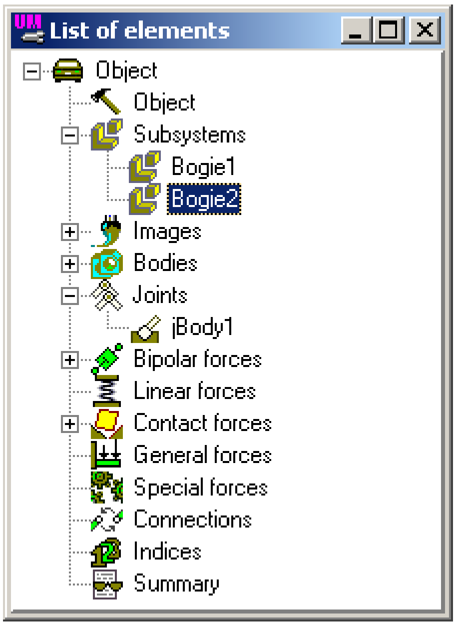


Fig. 3.16. List of object elements

List of elements allows creating and modification of all the object elements (bodies, force elements etc.). All the parameters and data describing the corresponding element are presented in the **Inspector** window. The list included the following items:

- *Object*: some general data (direction of gravity) and options, Sect.3.3.2.2
- *Subsystems*: input of standard or included/external subsystems (for UM version with subsystem technique abilities only)
- *Images*: creation of graphic objects of bodies, force elements and environment (Sect.3.4.6)
- *Bodies*: creation of bodies, input inertia parameters (Sect.3.4.7)
- *Joints*: joints, degrees of freedom, joint forces (Sect.3.4.9)
- *Bipolar forces* (bipolar springs, dampers, etc., Sect.3.4.10.1)
- *Linear forces* (general springs and dampers, Sect. 3.4.10.2)
- *Contact forces* (point-plane, sphere-plane, etc., Sect. 3.4.10.4)
- *General* forces (usually for external programming of forces, Sect. 3.4.10.5)
- *Special forces* (gearing, cams etc., Sect. 3.4.10.6)
- *Connections*: connection of external elements (for UM version with subsystem technique abilities only)
- *Indices*: useful information on indices of all the elements of the object
- *Summary*: information about correctness of the object description as well as list of errors and warnings

Remark. Access to parameters of visualized elements can be achieved by clicking the element image in the animation window if the window is in the *whole object mode* (Sect.3.3.1.2.2).

3.3.2.2. General object parameters and options

Use the **Object** tab of the inspector to set some general parameters and options for the current object (Fig. 3.17).

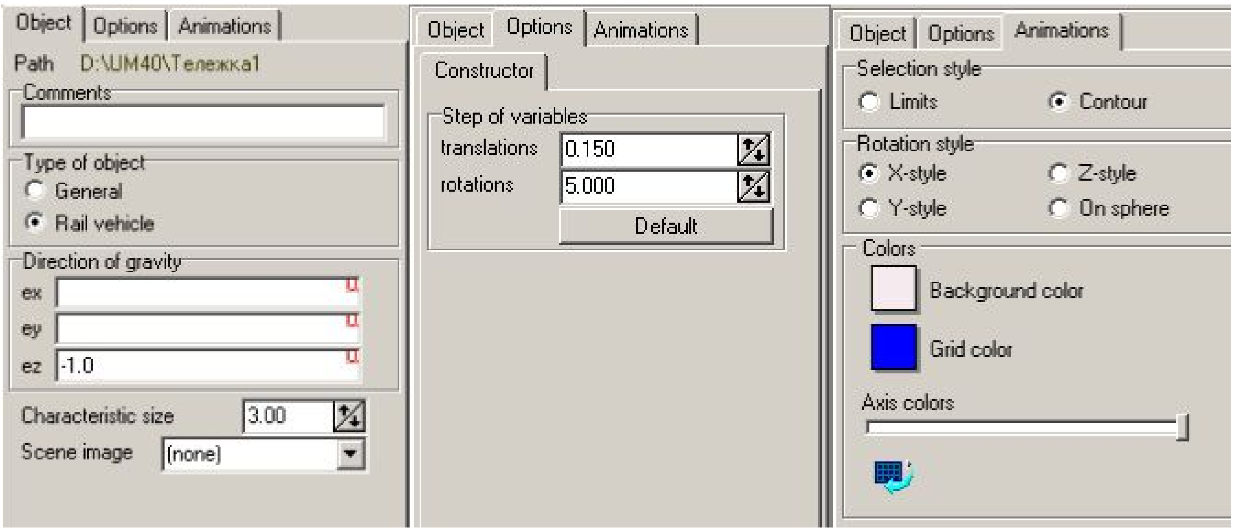


Fig. 3.17. Object general parameters and options

- **Type of object – General** or **Railway Vehicle** (for program version with support of dynamics of railway vehicles only).
- **Direction of gravity** is set by a vector, which specifies the direction of gravity relative to SC0. Vector components can be set as constant expressions or identifiers (Sect. 0). To turn off the gravity set zero value for the vector components. If the vector has not the unit length, the acceleration of the free falling decreases or increases its value proportionally. Direction of gravity for all subsystems of the objects is set by the main object. This means, that the directions entered in the subsystems (both included and external) are ignored.
- **Characteristic size** allows decreasing/increasing the default size of images in the animation window. This parameter is used for obtaining proper vector sizes for small or large objects.
- **Scene image** – assignment of a graphic object, which corresponds to fixed elements of the object as well as to environment. Press the **Delete** key to cancel the assignment of the scene image.

The **Options** tab contains values of stepwise changing angular and linear variables when special buttons in edit boxes are used

Angular variables are measured in degrees within the Input program and in radians in the Simulation program.

Use the **Animation window** tab to set the background, grid colors, rotational style as well as the axis color saturation in the animation window. Click the color box by the mouse to choose the color.

Check on/off the **Drag body** option to turn on/off visual dragging bodies by the mouse in the animation window. Dragging is used for simple object only as well as at a study level.

3.3.2.3. Lists of elements of a definite type

Each object (multibody system) is presented by sets of elements, most of which are grouped as *lists*. Every list contains elements of a single type, e.g., lists of bodies, joints, bipolar force elements and so on. Each element of a list has its own *name*, which is an arbitrary set of symbols. The name of element is the base of its identification, and it must be *unique within the corresponding list*, that is, it is not allowed setting one name for two elements of the same type (e.g., for two bodies). Elements of different lists as well as elements, which belong to different subsystems, may have the same names. So, the body and its image (or some joint) can have equal names.

Standard interface possibilities are used to manage the lists within the data inspector.

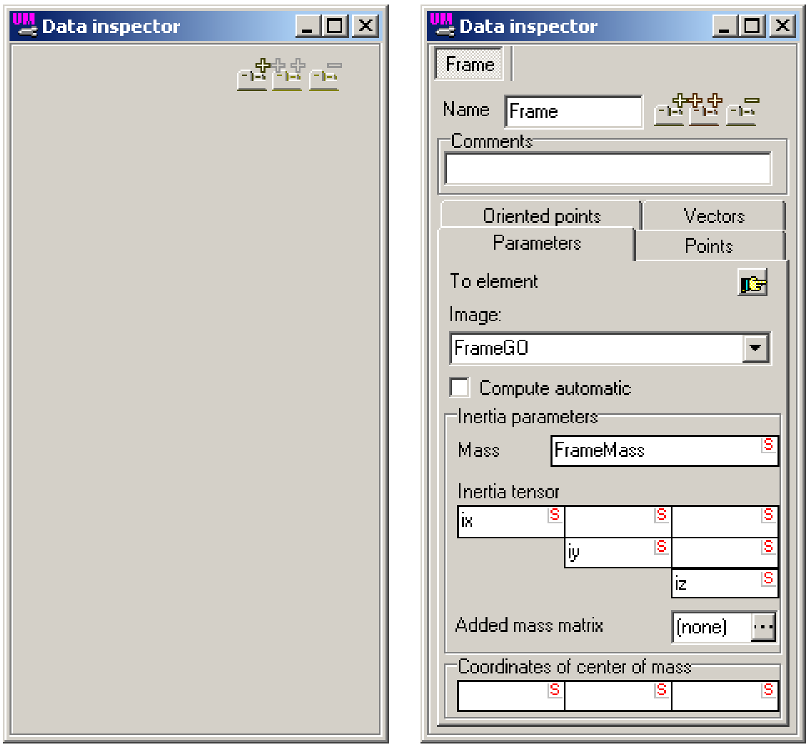


Fig. 3.18. Lists

Fig. 3.18a shows an empty list in the inspector, Fig. 3.18b shows the list, which contains several elements (bodies). Every element of the list has its own tab (or page). The name of a page coincides with the name of the corresponding element.

Edit box for the name and three buttons are located in the top of the tab:

 – adds a new element to the list;

 – creates an exact copy of the current element and adds it to the list;

 – deletes the current element.

See also Sect. 3.3.4.4.

Remark

Press the *Enter* key after modification of the name else the changes can be lost.

3.3.2.4. Data types

Information about each element of an object (element parameters) is entered in boxes of the data inspector. UM uses several standard data types. The user must know features of each data type to work with UM correctly.

A very important feature of object description using UM is the data parameterization. This means that many element parameters could be set not only by its numeric values but by expressions including numbers, identifiers, operations and functions. Consider the basic types of data presented in UM.

3.3.2.4.1. Numeric constants

UM uses standard syntax for numbers.

Examples: 1.23, 0.256e-3

3.3.2.4.2. Identifiers

Identifier is a set of symbols, which includes Latin letters, digits and character "_".

The first symbol in the identifier cannot be a digit or character "_".

Identifiers with the character "_" as the first symbol are reserved for internal presentation of identifiers in equations of motion generated by the program.

Reserved words of Pascal and C languages cannot be used as identifiers.

The program verifies syntax of entered expressions. If a new identifier is found, it is added to the *list of identifiers* of the object (Sect.3.3.1).

Example of correct identifiers:

mass_1 length_of_rod cdiss cstiff

Examples of wrong identifiers:

2mass – the first symbol is the digit 2;

length – the first symbol is the character "";

mass% - prohibited character "%";

do, as, while – reserved words of the Pascal language.

There exist two types of identifiers:

- Identifier – number;
- Identifier – expression.

Values of identifiers of the first type can be changed both in the Input and in the Simulation programs. Identifiers of the second type are presented by arbitrary expressions, which include

- numbers;
- identifiers of the first and the second types;
- standard functions (Sect. 3.3.2.4.3).

Expressions for identifiers of the second type are entered in the *List of Identifiers*. Chains of calculations may be programmed with the help of identifiers of the second type.

An example of a chain including identifiers of the both types is shown below.

Name	Expression	Value	Comments
Mass	1.12		Mass of rod
length	0.55		Length of rod
ix	mass*length^2/12	0.0282333333	Moment of inertia of the rod relative to X axis
iy	ix	0.0282333333	Moment of inertia of the rod relative to Y axis

Remark. Expression can only include identifiers located above the current identifier.

The same principle is used in the built-in calculator (the menu **Tools | Symbolic calculator** command).

3.3.2.4.3. Standard functions and constants

The following **standard functions** are used for description of data of several types (explicit function, identifiers-expressions):

- *sin, cos* – trigonometric functions, arguments are set in radians;
- *arcsin, arccos, arctan* – inverse trigonometric functions (rad);
- *arctan2(x, y)* computes an angle α, $\tan\alpha = x/y$ in radians in the interval from -π to π; quadrant for the angle is defined by signs of arguments *x,y* as if $x = \sin\alpha$, $y = \cos\alpha$;
- *exp* – natural exponent;
- *ln* – natural logarithm;
- *abs* – absolute value;
- *sign* – $sign(x) = \begin{cases} 1, x > 0 \\ 0, x = 0 \\ -1, x < 0 \end{cases}$
- ^ – power function, the expression *a^b* corresponds to a^b, the exponent must be an integer if the base is negative;
- *sqr* – square;
- *sqrt* – root square;
- *Heavi* – *Heavi(x)* = $\begin{cases} 1, x > 0 \\ 0, x \le 0 \end{cases}$
- if(c , v1, v2 , v3) = $\begin{cases} v1, c < 0 \\ v2, c = 0 \\ v3, c > 0 \end{cases}$

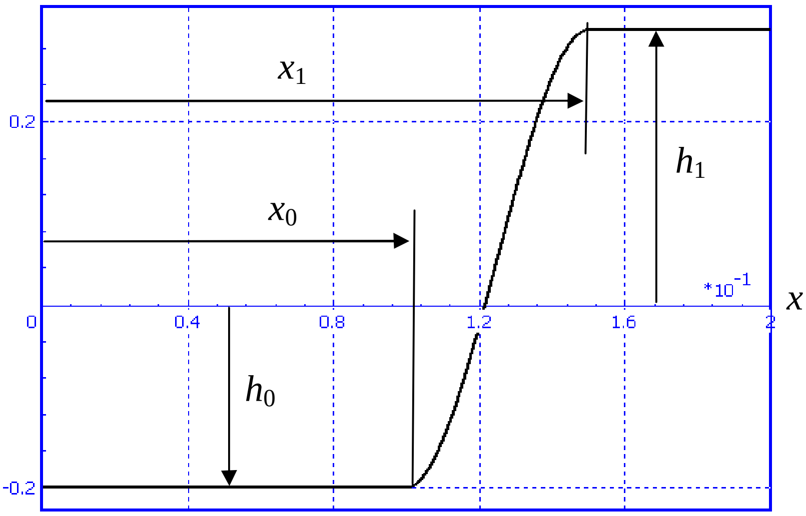


Fig. 3.19 Step function

- step(x , x0 , h0 , x1 , h1)= $\begin{cases} h_0, \; x < x_0 \\ h_0 + (h_1 - h_0)d^2(3-2d), \; d = \dfrac{x - x_0}{x_1 - x_0} \\ h_1, \; x > x_1 \end{cases}$

As a rule, the Step function is used for a smooth but fast transition of expression from one value to another. Example of the function step(t , 0.1 , -0.2 , 0.15 , 0.3) is shown in Fig. 3.19.

Standard constants

pi : number $\pi = 3.1415926536...$
e : number e=2.7182818285
rtod: factor converting radians to degrees, e.g. arctan(1)*rtod=45;
dtor: factor converting degrees to radians, e.g. 90*dtor=pi/2.

3.3.2.4.4. Constant symbolic expression

An constant symbolic expression is an expression, which contains

- identifiers;
- numbers;
- additions, subtractions, divisions and multiplication;
- standard functions (Sect.3.3.2.4.3).

It is not allowed usage of identifier *t* (time)

Example of correct constant symbolic expressions:

```
sqrt(2)*b1+sqrt(a1+a2)/2
```

The constant symbolic expression can be used for most of the element parameters (inertia and geometric parameters, coordinates of attachment points of the most type of force elements, sizes of graphic elements, coefficients of stiffness and damping and so on). The corresponding edit boxes in the data inspector have the standard interface

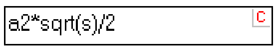


Fig. 3.20. Exit box for constant expressions

The letter ‘c’ in the right top part of the box points out that the parameter can be a *constant* expression. Double click the box or use the pop-up menu to call a tool for visual construction of the expressions.

3.3.2.4.5. Expression – explicit function

The expression of this type includes

- numbers;
- identifiers;
- standard functions;
- standard variables (*t, x, v, p1, p2, p* – depending on type of function).

Double click the edit box or use the pop-up menu to call a tool for writing the expressions. The corresponding window contains the list of identifiers and buttons with allowed functions.

Types of explicit functions:

- **Function of time - *t***

The standard variable is t – time. The function is used for description of joints.

- Joint of generalized type, elementary transformation of types *tt, rt* (Sect. 3.4.9.6.4);
- Rotational and translational joints in the cases when the joint coordinate is an explicit function of time (Sect. 3.4.9.4).

The corresponding edit boxes in the data inspector have the following standard interface

The letter ‘t’ in the right top part of the box points out that the expression is a time function.

- **Force description force functions – *x, v, t***

Standard variables are t – time as well as two additional variables *x* (coordinate), *v* (velocity).

The function is used for description of mathematical models of forces in the following cases:

- Description of *a bipolar force element* (the force type should be *expression*); *x* – length of the element, *v* – time derivative of the length (Sect. 3.4.10.1);
- Description of joint forces in the case of *joint of general type* (elementary transformations *rv*, *tv*, type of force – expression, Sect. 3.4.9.6.3) as well as for translational and rotational joints (Sect. 3.4.9.4); *x* – value of coordinate, *v* – its time derivative;
- Description of an axle force in the case of a special force of the *Combined friction* type. The corresponding edit boxes in the data inspector have the following standard interface (Fig. 3.21).

Fig. 3.21. Exit box for Pascal/C expressions

The letter ‘p’ – Pascal – in the right top part of the box points out that the data is a time function.

- **Functions of description of parametrical graphic elements** (Sect. 3.4.6.2.7).

Standard variables are *p1, p2* parameterize a surface or a curve. The corresponding edit boxes in the data inspector have the standard interface shown in Fig. 3.21.

- **Description of Z –surfaces**

Surfaces $z = f(x, y)$ in 3D space are used in description of a *Z – surface* graphic element (Sect. 3.4.6.2.9) as well as in *Point -- Z –surface and Sphere - Z – surface* contact force elements.

Standard variables are *p1, p2* parameterize a Z-surface. The corresponding edit boxes in the data inspector have the standard interface shown in Fig. 3.21.

- **Functions of description of profiled graphic elements (**Sect. 3.4.6.2.8).

A standard variable is *p* parameterizes the corresponding profile of section or an axis curve. The corresponding edit boxes in the data inspector have the standard interface shown in Fig. 3.21.

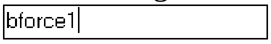
3.3.2.4.6. External functions

Usage of *external function* is directly connected with programming in the UM environment based on a *Control file.* As a rule, these functions are used when the corresponding mathematical model is too complicated for description as an implicit function (Sect. 3.3.2.4.5).

There exist three types of external functions, which are different with respect to arguments.

- Time functions (*t*) are used for joint of generalized type, elementary transformation of types *tt,rt* (Sect. 3.4.9.6.4) as well as for rotational and translational joints in the cases when the joint coordinate is an explicit function of time (Sect. 3.4.9.4).
- Function of three arguments (*x*, *v*, *t*) are used for description of
  - a bipolar force element (type of element – *external*, Sect. 3.4.10.1);
  - a joint force and torque in the cases of *joint of general type* (elementary transformations *rv*, *tv*, type of force – expression, Sect. 3.4.9.6.3) as well as for translational and rotational joints (Sect. 3.4.9.4); *x* – value of coordinate, *v* – its time derivative;
  - an axle force in the case of a special force of the *Combined friction* type. The corresponding edit boxes in the data inspector have the following standard interface (Fig. 3.21).
- Function of two arguments (*p1, p2*) are used for description of Z-surfaces (surfaces given by the function $z = f(x, y)$) in the cases of graphic element (type - Z-surfaces) (Sect. 3.4.6.2.9) and contact forces (Z-sphere).

To describe an external function, the user should enter its name (identifier) in the corresponding edit box of the inspector without arguments, for instance,



Syntax rules for name of function as the same as for identifier (Sect. 3.3.2.4.2).

UM generates a *template* for each external function in the control file. This means, that special functions will be added to the control file, where the external function will be initialized by zero values. The user should rewrite the corresponding procedures.

Consider a template of a time function. Let the identifier *alpha* were used as the name of external function. UM inserts the following procedure in the control file Cl[NameOfObject]:

```
procedure alpha( _isubs : integer; _t : real; var _Value, _dValue, _ddValue
: real_ );
var
   _ : _platfVarPtr;
begin
  _ := _PzAll[SubIndx[_isubs]];
  _Value := 0;
  _dValue := 0;
  _ddValue := 0;
end;
```

The input parameters are *_isubs* (the global index of subsystem), *_t* – the current time value. The output values: value of function (identifier *_Value*) as well as its first and second derivatives (*_dValue*, *_ddValue*).

Wrong programming of derivatives leads to wrong simulation results.

Consider a template for a function of (*t*, *x*, *v*). Let the identifier *bforce1* was used for external function corresponding to a bipolar or joint force. UM inserts the following function in the control file Cl[NameOfObject]:

```
function bforce1( _isubs : integer; _t, _x, v : real ) : real_;
var
  _ : _vehicleVarPtr;
begin
  _ := _PzAll[SubIndx[_isubs]];
  Result := 0;
end;
```

The input parameters are *_isubs* (the global index of subsystem), *_t* – the current time value, the current *x* and *v* values: *_x*, *_v*. The user should change the function code to calculate the output value *Result.*

Remarks

1. Functions of the one and same type, which have coinciding identifiers, are identified. That is, only one template of function or procedure will be generated for them in the control file. Different identifiers must be used for external functions of different types.
2. Detailed information about the control file and programming in the UM environment can be found in the corresponding chapter of the user's manual.
3. The Simulation program calls external functions automatically.
4. After adding or deleting external functions, the user should verify the correctness of the *old* control file.

3.3.2.4.7. External identifiers

External identifiers give one of the possible forms for programming forces with complex mathematical model. This method is used exclusively for force elements of general type (Sect. 3.4.10.5). Projections of a force and a moment are identifiers, which values should be calculated in a standard procedure of the control file.

See the chapter devoted to programming in the UM environment for more information.

3.3.2.4.8. Time function from text file

Here we consider how to set dependences on time of angular and translational coordinates with the help of text files. The file can contain both full-scale test and simulation results.

Coordinates as time functions are realized in the following joints

- generalized joint, elementary transformations *tt, rt* (3.4.9.6.4);
- translational and rotational joints when the coordinate is a time function (3.4.9.4).

Format of a text file

A text file with a time function should contain two columns separated by space symbols. The first column contains time in seconds starting with zero or small value. The second column contains the corresponding values of the function in meters for a translational coordinate and in radians for an angular coordinate.

First symbol in comment lines should be %.

The file should be created beforehand and located in the directory of the model, which uses it.

If UM does not find the file, zero value is set for the corresponding function.

Creation of files with a time function as a simulation result

Each plot in graphic windows can be saved in a text file after simulation of a UM model (Chapt. 4, Sect. *Graphical window* | *Copying graphs to clipboard, text file and file of calculated variables*). The file format matches the above requirements if

- % symbol is set as a prefix for comments (Chapt.4. Sect. *Options of simulation program* | *General*), otherwise comments should be deleted from file manually;
- one variable is saved;
- time is laid off as abscissa.

Fragment of an automatically generated compatible text file with a time function:

```
%
% 1 - time
% 2 - dyWheelset4 [Lateral position of Wheelset4]
%
2.00000002337219E-7 2.82372854E-15
1.03125004097819E-2 2.03257468E-6
2.09375005215406E-2 7.46718570E-6
3.21874991059303E-2 1.76279409E-5
4.21875007450581E-2 3.07774899E-5
```

Standard interface for setting the file

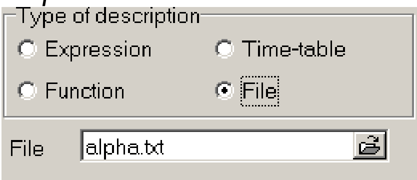


Fig. 3.22. Time function from file

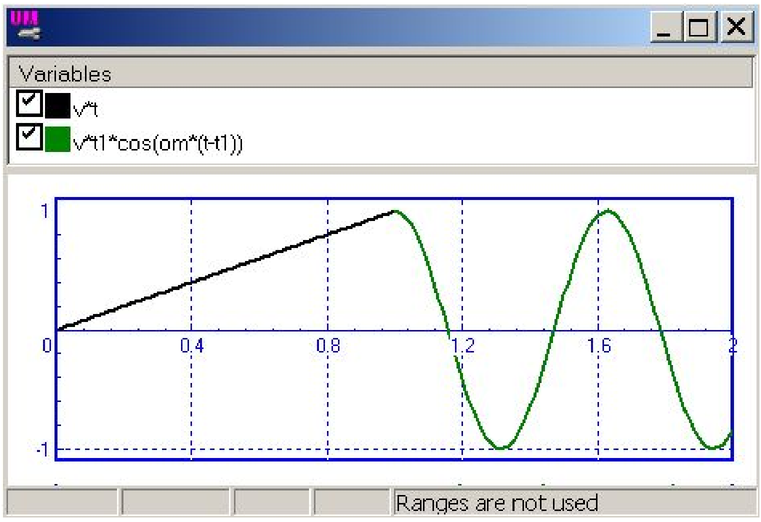
To set a name of the file, use the button or write the name directly.

Note 1. UM uses a spline interpolation of discrete file data to get function value in intermediate time moments as well to compute the first and the second derivative, which are necessary for simulation.

Note 2. The user should take care of a sufficient smoothness of data in file.

Note 3. When the current simulation time exceeds the latest time point in the file, the function value is constant equal the latest one in the file.

3.3.2.4.9. Timetable as a method of description of time functions

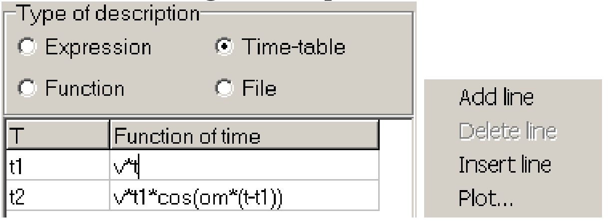


Timetable is a generalization of time function description by an expression. This method is used if the function can be described by different symbolic expressions on several time intervals.

For instance, the function in figure satisfy the following relations:

$$f(t)=\begin{cases} vt, \; t\in[0,t_1] \\ vt_1\cos(\omega(t-t_1)), \; t\in[t_1,t_2] \end{cases}$$

A standard interface is used for setting such dependencies:



Use a pop up menu to add, delete insert a line into the timetable. The *Plot* item is used for plotting the functions.

The table can contain any number of lines.

Time in the left column can be set by expressions (identifiers *t*1, *t*2 in our example).

Note 1. The user should take care of a continuity of the function.

Note 2. When the current simulation time exceeds the latest time point in the timetable, the function value is constant equal the latest one in the table.

3.3.3. Curve editor

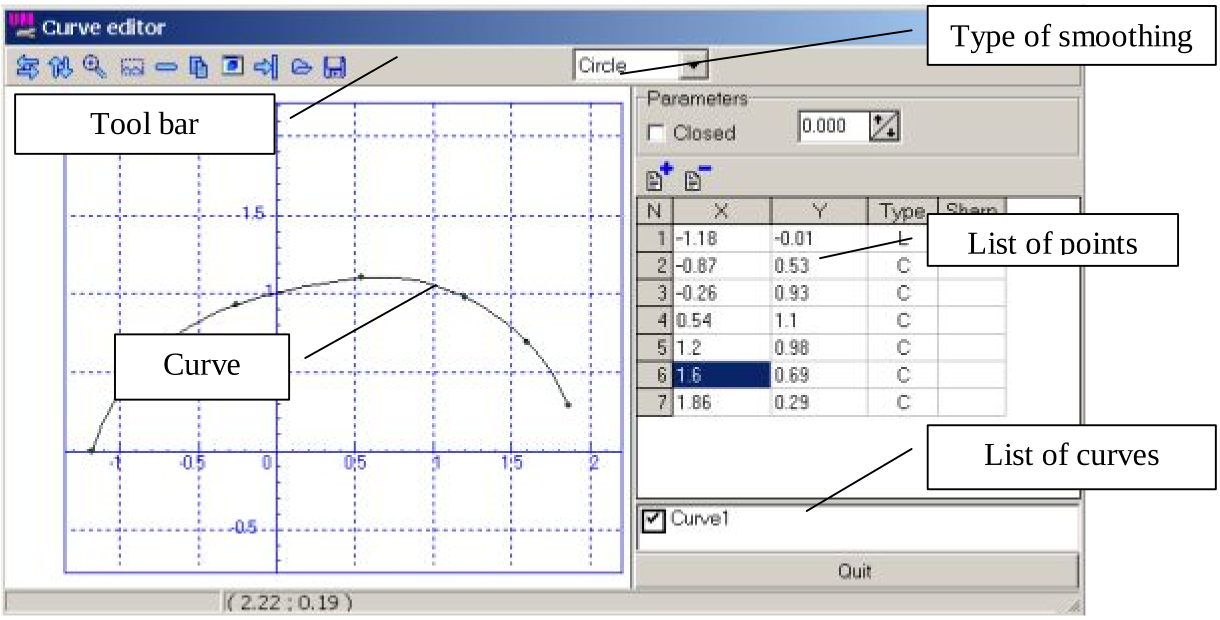


Fig. 3.23. Curve editor and its elements

Curve editor is a tool for input of data in a graphic form. The editor allows the user to create a curve, a function or a set of curves by a set of points. Here we consider some features of working with the editor. Additional information about usage this tool for creation of 2D graphic images can be found in Sect.3.4.6.6.

3.3.3.1. Modes of curve editor

There exist two modes of the editor depending on the problem to be solved.

- Mode of creation of a set of curves
- Mode of creation of a function

The second mode imposes a number of restrictions and additional features:

- one curve only;
- ordering points according to abscissa value;
- plots the first and second derivative as well as a curvature in a separate window is available.

3.3.3.2. Tool bar

Consider functions of buttons on the tool bar. Note that sets of buttons differ for different modes of the editor.

- left or right shift depending on the mouse button;
- up or down shift depending on the mouse button;
- zoom in/out depending on the mouse button;
- horizontal zoom in/out depending on the mouse button;
- vertical zoom in/out depending on the mouse button;
- zoom in of a rectangle area selected by the mouse;
- optimal view of inputted data;
- delete a selected fragment;
- copy to clipboard as a picture or as a text data;

- preview of data in a 3D animation window (for 3D graphic elements only, Sect. 3.4.6.2.8).

- shift of the left border of the plot area;

- read data from file;

- save data to file;

- buttons for plotting the first and second derivative as well as a curvature in a separate window is available for an inputted function;

- switch on/off a mode of equal scales along abscissa and ordinate axes;

- parameters of the plot area (Fig. 3.24).

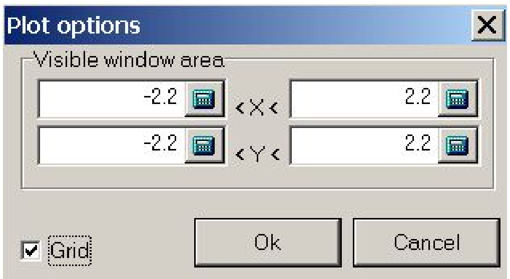


Fig. 3.24. Parameters of the plot area

3.3.3.3. Adding, positioning, and deleting separate point on a curve

There exist too methods for **adding** a point to a curve.

1. Double click by the left mouse button in the position off the adding point.

With this method a point can be added both to begin and the end of a non-closed curve, as well as inside the closed or non-closed curve. When a point is added to the begin or to the end of e curve, it is recommended to put it near the corresponding first or last point of the curve and then to drag it to the desirable position.

2. Button over the list of points (Fig. 3.23).

With this method you can add point to the end of the curve only.

Positioning the point means setting its desirable position. Two methods are realized for this purpose.

1. Positioning by the list of points.

Find the point in the list, e.g. by clicking on its image in the plot area, and set its new coordinates.

2. Positioning by dragging.

This is the most often used method for approximate positioning points. Move the mouse cursor near the point image. The cursor must change to . Press the left mouse button and drag the point to the desirable position.

To **delete** a point either select it in the list of point and click the button, or move the mouse cursor near the point image until it changes to , call the pop up menu (click the right mouse button) and select the *Delete* menu item.

3.3.3.4. Selecting, copying, deleting and moving fragments and curves

To select a fragment (a set or points) draw a rectangle region in the lot area by dragging the mouse cursor (Fig. 3.25).

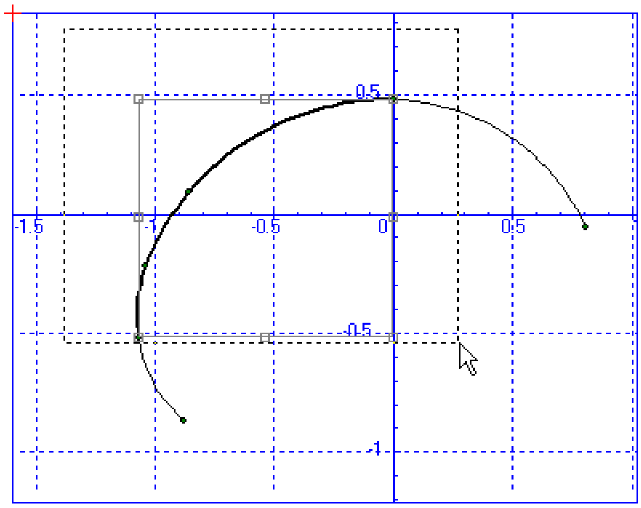


Fig. 3.25. Fragment selection by mouse

There exist to methods for the **selection of a curve**.

1. Select the name of a curve in the list of curves (Figure 3.26).

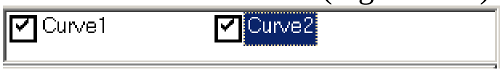


Figure 3.26. Selection of a curve in the lst of curves

2. Move the mouse cursor near the curve until it changes to , call the pop up menu (click the right mouse button) and select the *Select whole curve* menu item.

To **select all points** call the pop up menu (click the right mouse button) and select the *Select all* menu item.

To **remove a selection**, click by the left mouse button anywhere outside the selection rectangle.

To **move a fragment or a curve**, select it, move the mouse cursor until it changes to , press the left mouse button and drag the fragment. *Moving a fragment is forbidden in the mode of creation of a function.*

To **delete a fragment or a curve** select it and press the *Delete* key.

To **copy a fragment or a curve** select it, press the *Ctrl+C* and *Ctrl+V* hot keys, and move the copied fragment into a desirable position.

3.3.3.5. Closing curve

Two methods of closing a curve:

1) move one of the curve end point by the mouse to a small neighborhood of another one;
2) use the  key over the list of points.

3.3.3.6. Smoothing

To smooth a curve of a fragment, select it and choose one of the smoothing type from the list (Fig. 3.23)

3.3.3.7. Usage of clipboard for creating curves and functions

For input from the clipboard, points should be written as a text in two columns. The first column contains abscissa values, the second one - the ordinate values:

-68.9	11.7
-66.4	8.88
-63.9	6.98
-61.4	6.48
-58.9	5.99

…….

To get points from the clipboard

- Copy the new data to the clipboard from any text editor in a standard manner
- Activate the curve editor by the mouse and paste data from the clipboard (*Ctrl+V* or *Shift+Insert*).

3.3.4. Hot keys

3.3.4.1. Constructor

Ctrl+Alt+W – make animation window active;
Ctrl+Alt+X – make list of elements active;
F11 – bring to front the list of elements (if it is located as a separate window);
F12 – bring to front the data inspector (if it is located as a separate window).

3.3.4.2. Inspector

Open element data (a tab of the constructor):
Ctrl+Alt+O – object;
Ctrl+Alt+S – subsystems;
Ctrl+Alt+B – bodies;
Ctrl+Alt+G – graphic objects;
Ctrl+Alt+J – joints;
Ctrl+Alt+F – bipolar forces;
Ctrl+Alt+L – linear forces;
Ctrl+Alt+C – contact forces;
Ctrl+Alt+A – forces of general type;
Ctrl+Alt+E – special forces;
Ctrl+Alt+Z – external connections;
Ctrl+Alt+I – indices;
Ctrl+Alt+P – protocol.

3.3.4.3. Animation window

Ctrl+Alt+W – make the animation window active.
If the animation window is active:
←↑→↓ – move the object;
X, Shift+X, Y, Shift+Y, Z, Shift+Z – rotate the object around the corresponding screen axis (positive and negative directions);
GrayPlus, GrayMinus – zoom in/out;
R – reset position and orientation.

Combination of keys and mouse operations (Sect.3.3.1.2.4).
Shift+ mouse click on a button for shift, zoom, rotation – the corresponding action but with a small step size;
Ctrl+ mouse click on a button for rotation – rotation around axis of SC0 (instead of screen axis);
Ctrl+Shift+ mouse click on a button for rotation – rotation around axis of SC0 with a small step size.
Ctrl+Shift+ mouse click on an object point – zoom in (left button) / zoom out (right button) from the selected point.

Mouse move over a body image allows the user to get coordinates of the corresponding points of the body relative to SC0. If the *Shift* key is pressed, the coordinates will be given in the body-fixed SC. If the *Ctrl* key is pressed, the coordinates of body-fixed SC origin in SC0 are shown.

3.3.4.4. Inspector tab with a list

Ctrl+Alt+↑, *Ctrl+Alt+Home* – to the first element of the list;
Ctrl+Alt+↓, *Ctrl+Alt+End* – to the last element of the list;
Ctrl+Alt+→ – to the next element of the list;
Ctrl+Alt+← – to the previous element of the list;
Ctrl+Alt+GrayPlus – add element;
Ctrl+Alt+GrayMinus – delete the current element;
*Ctrl+Alt+Gray** – copy the current element;
Ctrl+Alt+N – edit name.

For elements connecting a pair of bodies (joints, force elements):
Ctrl+Alt+1 – choose the first body from the list of bodies;
Ctrl+Alt+2 – choose the second body from the list of bodies;
Ctrl+Alt+T – choose element type.

3.4. Data Input

3.4.1. Data Input Sequence

The following sequence of object data input is recommended.

1. Bodies, their graphical images and the corresponding joints.

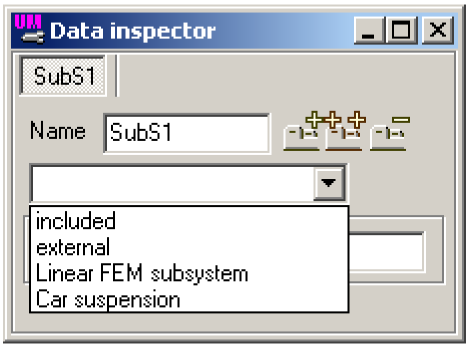
The sequence of description of bodies is usually defined by the kinematical scheme of the object. At first, the bodies connected with the base body (SC0) are described, and then the bodies connected with already described bodies and so on. By such a description sequence of kinematical scheme of object all its bodies are drawn not only in the current element animation window but also in the whole object mode of the animation window (Sect. 3.3.1.2.2). It is important to remember, that in the mode of whole object animation, the described body is drawn in the animation window only if there exists a path from the current body to the base body through the described joints.

2. Force elements and their graphical images

After describing the object kinematical scheme, force element images are drawn in the animation window both in the current element and the full object animation mode, which allows the user to control geometrical parameters of force elements visually.

3.4.2. Input of subsystems

Subsystems are widely used for modeling of complex and specific mechanical systems. (see Chapter 2, Sect. *Subsystems*).



There exist the following buttons:

 – create a subsystem;

 – copy an existing subsystem;

 – delete a current subsystem.

There are three types of subsystems: included, external, and standard ones. Standard subsystems are prepared subsystems, which are delivered together with additional modules of UM and described in the corresponding part of user's manual (for example subsystem "wheelset" delivered and described in the railway module UM Loco). After choice of subsystem type (included or external) user needs to open UM object which will be a subsystem in the current object.

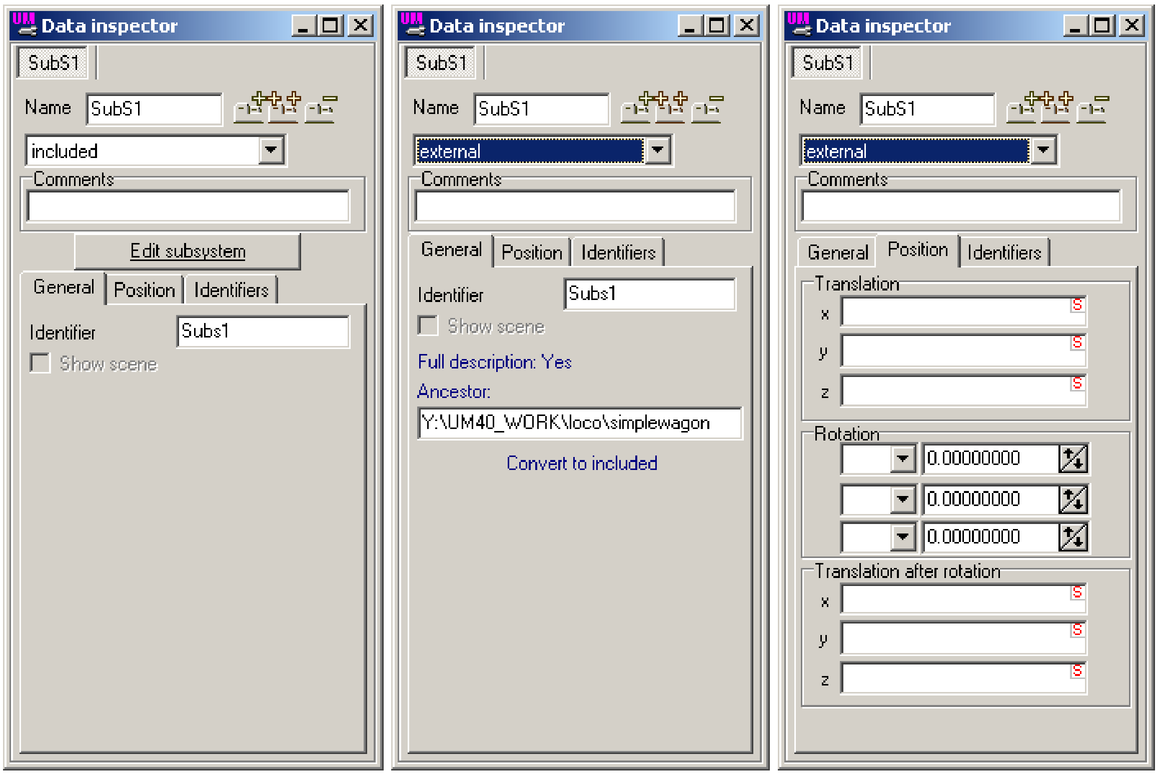


Fig. 3.27. Data inspector for subsystems.

Main parameters of external and included subsystems are almost the same. They are name, comment, position of the subsystem, identifiers used in the subsystem, and the identifier of the subsystem used for programming. Also an external subsystem has one more parameter **Ancestor**, which is the path to the folder with ancestor of the subsystem. To convert an external subsystem to an included one click the button **Convert to included** on the tab **General**.

3.4.2.1. Setting connection with external subsystems

Two methods can be used to connect bodies of different subsystems with joints or force elements: 1) create necessary element (joint or force element) in the main object; 2) use external bodies in subsystems (3.4.8.1). In the second method, it is necessary to point bodies and characteristic points of these bodies for joints and force elements which use external bodies. For that user should select the element **Connections** from the **List of elements**. The element **Connections** is the list which contains all joints and force elements with the second body that is external. Setting a connection means to point which body is external for considered element and which point of this body is characteristic for the element. Double click checks the box on the left of the element in the **List of elements** and opens the object tree where the lower level is the level of connection points. Select the necessary connection point of the body. The connection is ready. If it is needed to reset the connection uncheck the box of the element and use double click to set it again.

3.4.3. Standard interface for setting local system of coordinates

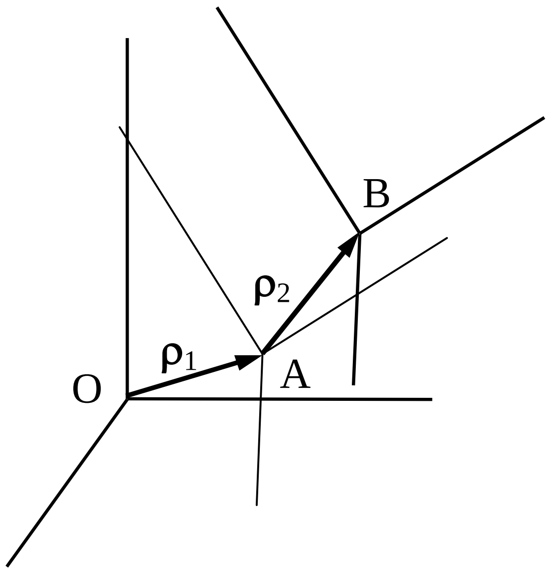


Fig. 3.28 Setting position of local SC

The interface allows the user to define a fully parameterized position of a local system of coordinates (LSC) relative to SC of a body, a graphic object or a graphic element. Consider a SC with an origin in point O (SCO). It is necessary to define the position of SCB relative to SCO.

First, an auxiliary SC with the origin in point A (SCA) is introduced, which position relative to SCO is set by the shift vector ρ_1 and by a set of up to three sequential rotations. After that the position of point B relative to SCA is specified by the vector ρ_2. Thus, axis of SCA and SCB are parallel. In particular case $\rho_2 = 0$ and SCB coincides with SCA.

The auxiliary SCA is sometimes useful when shifts could be specified simpler relative to already rotated exes, i.e. relative to SCA.

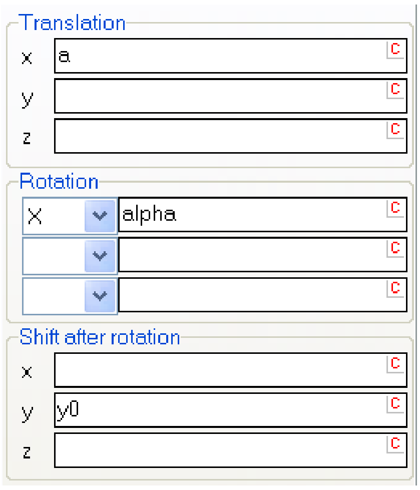


Fig. 3.29 Window for specifying an LSC

The standard interface for setting LSC is shown in Fig. 3.29. Data are entered in three groups.

- **Translation**. Projections of vector ρ_1 in SCO are entered.

- **Rotation**. Sequence of rotations specifies orientation of SCA and SCB relative to SCO. It is allowed up to three rotations. Angles of rotation are set here in degrees.

- **Shift after rotation**. Projections of vector ρ_2 in SCA are entered, i.e. shifts along axes of SCA.

Both projections of vectors and angles of rotation can be parameterized.

The interface is used for input of the following data types.

- Position of a graphic object (Sect. 3.4.6)
- Position of a graphic element relative to SC of graphic object (Sect. 3.4.6.4).
- Setting local SC for special force element of the “Bushing” type (Sect. 3.4.10.6.5).
- Setting local SC for scalar torques (Sect. 3.4.10.2).
- Setting local SC for 6 d.o.f. joint (Sect. 3.4.9.5).

3.4.4. Assigning Graphical Image to Object Element

Graphical images (graphical objects, GOs) can be assigned to the most of UM elements, for example, to the scene, bodies, some kinds of joints (e.g. a rod), some kinds of force elements (bipolar, linear) and so on. Clicking a graphical image of element by mouse, the user can open the element description in the object inspector. For this purpose the *whole object animation mode* must be set in the animation window (Sect.3.3.1.2.2).

Graphical image *is assigned* to an object element from the list of the previously described GOs using a drop-down list in the inspector of the current element (body, for example).

Fig. 3.30. Assignment of a GO

The drop-down list contains *names* of GOs, which have been set by the user while describing graphical objects or by default. To make choosing GO easier, it is recommended to give sensible names to GOs (Fig. 3.30).

Activate the corresponding drop-down list and press the *Delete* key to *cancel* the assignment of a GO to the element.

There are some features by assigning GO to the object element.

GO can be assigned to each body; the same GO may correspond to several bodies (this is the main principle). The GO system of coordinate is automatically superposed with the SC of the corresponding body. All elements of mechanical system, which are fixed relative to the base SC0 (e.g. plane supporting a rolling ball, obstacles etc.), should be presented by a single GO, which is assigned to the scene image (**Common | Scene image** inspector tab).

While drawing GO in the animation window, UM superposes the point (0,0,0) with the first connection point (of the first interconnected body), and the point (0,0,1) with the second connection point, at that UM properly changes the length and the orientation of the GO.

All elements (bodies, joints, force elements) having graphical image can be selected by the mouse pointer in the animation window and then be accessed in the element inspector form. This feature is very useful in cases if the object description contains many elements.

3.4.5. Assignment of graphic images to rods, linear and bipolar force elements

A GO can also be assigned to a linear or bipolar force element (Sect. 3.4.10.2, 3.4.10.1) or to a weightless rod constraint (Sect. 3.4.9.8). These elements link two points of different bodies. UM automatically puts the assigned GO between the points. There is an obligatory condition while creating such a GO:

A GO corresponding to a linear or bipolar force element or to a rod constraint must be located along the Z axis of the SC GO between the points (0,0,0) and (0,0,1), that is the GO must have the unit length.

3.4.6. Input of Graphical Objects

For description of graphical objects (GO), a built-in graphical editor is used. It is accessible with the inspector tab **Images**. Notice that it is recommended to describe the rest of object elements *after* the complete description of graphical images. In this case the visual verification of input data is possible, and it allows avoiding a lot of input errors.

3.4.6.1. Lists of Graphical Objects and Graphical Elements

To visualize any system element (body, joint, force element and others; bodies will only be mentioned below), it is necessary to assign a *graphical object* to it. GO is a set of *graphical elements (GEs)*, which should be created using the built-in graphical editor. The same GO may belong to different (geometrically identical) bodies. For example, for description of GO of a bogie having four similar wheels (even if their have different masses), it is enough to create two GOs: a body and a wheel. The same wheel GO is assigned to each of the wheels.

It is desirable to create a full set of GOs before input of data for bodies, joints etc. In this case the visual verification of input data is possible.

After assigning a GO to an object element, UM superposes the SC of GO with the element SC in a certain rule, but it should be remembered, that the shape and sizes of GO *are not connected at all* with inertia parameters of body, stiffness of spring and other parameters of the object elements, which should be described separately. Exclusion presents the case when the option for automatic calculation of body inertia parameters is turned on.

To go to describing (or changing) *graphical objects or elements (GOs or GEs)* use the **Graphical images** tab, Fig. 3.11. The object inspector is shown in Fig. 3.31.

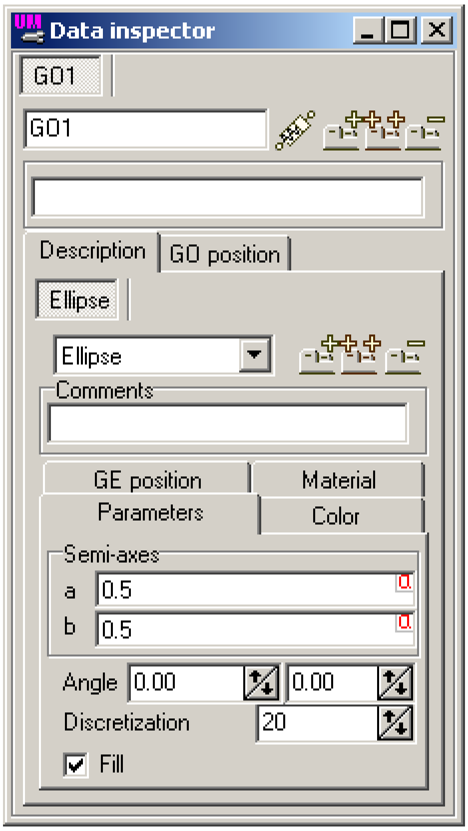


Fig. 3.31. Graphical object in the data inspector

On top of the inspector, tabs for graphical elements marked with their names are located. The user can rename GOs using the corresponding edit box.

The current GO can be replaced from or stored in a text file using buttons .

Each GO is a set (list) of *graphical elements (GE)*, which is shown a bit below. Lower buttons are intended for:

- adding a new GE;
- copying (duplicating) the current GE;
- deleting the current GE.

To set (change) the type of the current GE a drop-down box is used, which contains names of the standard GEs:

- polyhedron;
- ellipse;
- box;
- spiral;
- ellipsoid;
- cone;
- parametrical GE;
- profile GE;
- Z-surface.

While describing almost all parameters of GEs, identifiers and symbolic expressions may be used.

Remark. Changing a type deletes previously entered data for the current GE.

3.4.6.2. Input of graphical elements (GE)

Each GE has four groups of parameters located in the different *tabs* (Fig. 3.31):

- **Parameters –** a tab with GE parameters depending on its type;
- **Colors –** a tab with GE color information;
- **Position –** a tab with parameters describing position and orientation of the current GE in the SC of the current GO;
- **Material** – parameters defining inertia properties of the GE material (such as density). They are used for automatic calculation of inertia parameters of bodies.

3.4.6.2.1. Polyhedron

A polyhedron is used when a GE of irregular shape is needed. An UM polyhedron is a set of 3D vertices forming one or more polygons. The polygons may be drawn both in line and filled modes.

To describe a polyhedron the following parameters should be set (Fig. 3.32):

- Coordinates of vertices. If only vertices are given then the result is a single broken line formed with these vertices. But if several polygons are needed then the lower part of the form shown in (Fig. 3.32) is to be filled:
- For each polygon, vertex indices delimited with commas should be pointed; filled polygons should be marked with ☑.

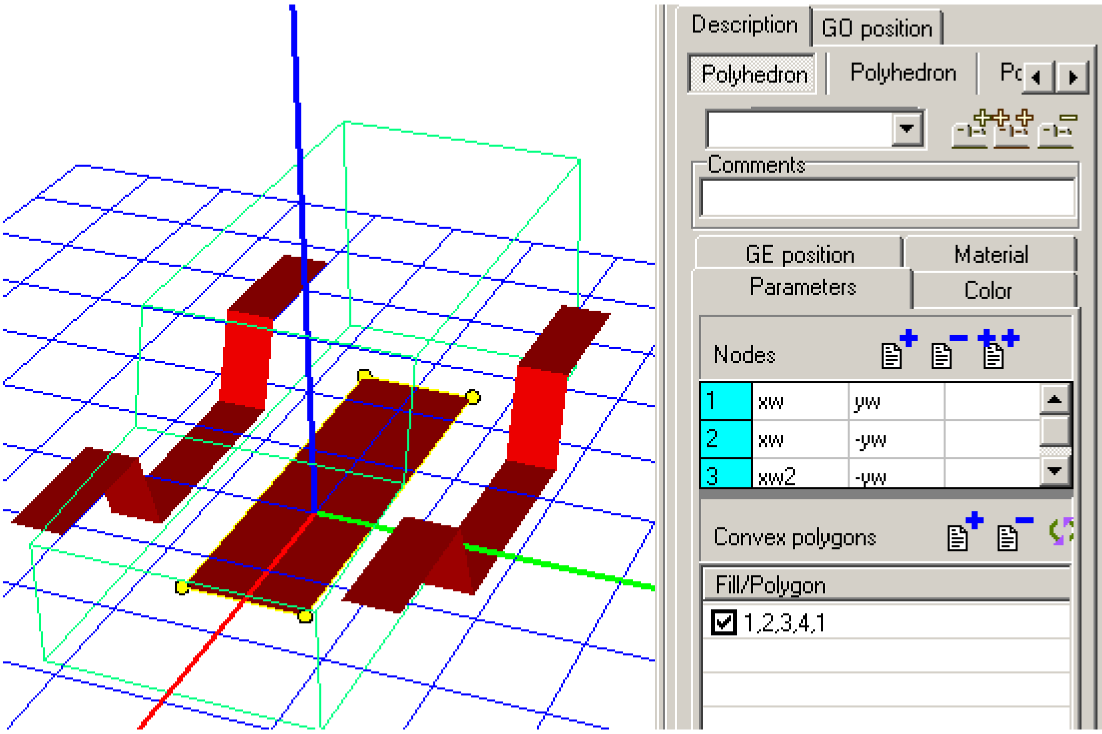


Fig. 3.32. Polyhedron

Example. Four vertices might set a tetrahedron

(0 0,0), (1,0,0), (0,1,0), (0,0,1)

and four polygons

(1,2,4), (4,2,3), (1,4,3), (1,3,2).

3.4.6.2.2. Ellipse

Parameters of an ellipse (Fig. 3.31):

- **a, b** – semi-axes;
- starting and ending **angles** (for a elliptic sector). Default values *(0,0)* correspond to a full ellipse;
- **discretization** is the number of points approximating the ellipse;
- **filled** option determines the element either as plane or a line.

3.4.6.2.3. Box

All ribs of a *box* are parallel to the axes of the GE-fixed SC. The box parameters are

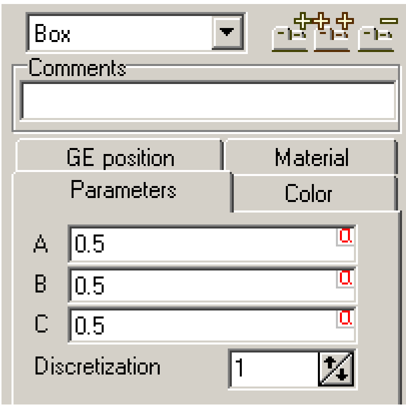


Fig. 3.33. Box parameters

- Length, width, height **A, B, C** (constant symbolic expressions);
- **Discretization** (0..4) specifies the number of finite elements on a box side (about 2^n elements on each side) in the line mode.

3.4.6.2.4. Spiral

This GE is used customarily as to draw elastic linear of bipolar force elements. The spiral parameters are (Fig. 3.34):

- coil radius *r* (a constant symbolic expression);
- spring height *H* (a constant symbolic expression);
- the number of coils;
- coil discretization.

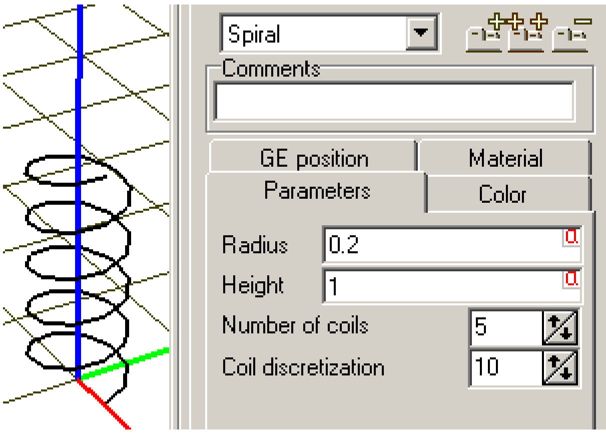


Fig. 3.34. Parameters of a spiral

The axis of the spiral coincides with the z-axis of the GE-fixed SC.

3.4.6.2.5. Ellipsoid

This GE allows showing an ellipsoid or, particularly, a sphere (Fig. 3.35).

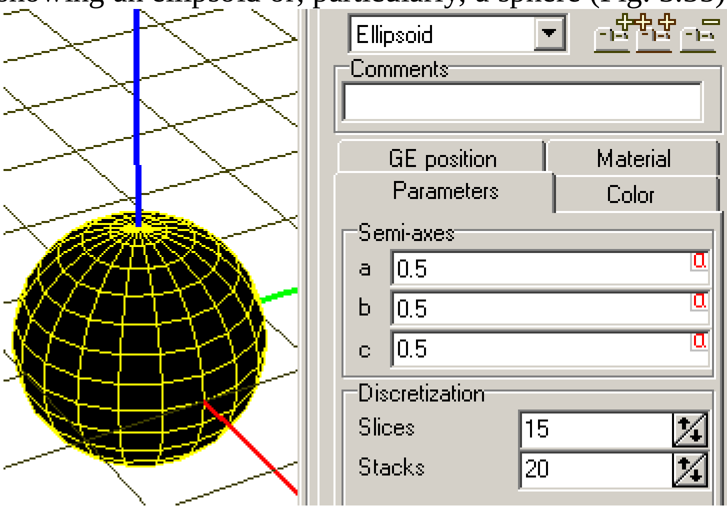


Fig. 3.35. Parameters of an ellipsoid

The parameters of an ellipsoid are:

- **a, b**, **c** – its semi-axes;
- **Slices, Stacks** – number of points to approximate the ellipsoidal surface.

The center of the ellipsoid is placed into the begin of the GE SC.

3.4.6.2.6. Cone

The dialog form for input of a cone is shown in Fig. 3.36.

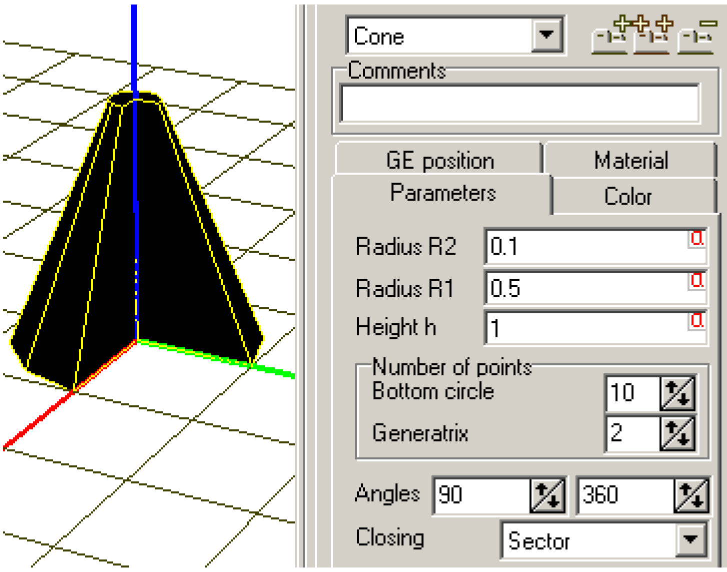


Fig. 3.36. Cone

The GE allows getting such images as cylinder, cone and truncated cone, also only a part of these surfaces.

For description of conic surface the user should input the parameters:

- **R1, R2** – radii of the upper and bottom circle-bases;
- **h** – height of cone;
- **Angles** – starting and finishing angles (in degrees) that form a plate angle at the Z-axis, which delimits the conic surface. The angles are counted from the X-axis counterclockwise. In case if both angles are zeros then the full cone (cylinder) is generated;
- **Number of points** on the circle bases and the generating line, which define a discretization of the conic surface;
- **Closing** – this switch has three positions *(None)*, *Sector*, *Segment* and defines how the conical surface should be closed.

3.4.6.2.7. Parametrical GE

The GE provides the wide possibilities to describe the complex surface as analytical surface in a parametric form (Fig. 3.37). Description of 3D curves and surfaces is allowed. The user should describe them as arbitrary functions of a single (*p1* or *p2*) or the two parameters (*p1* and *p2*).

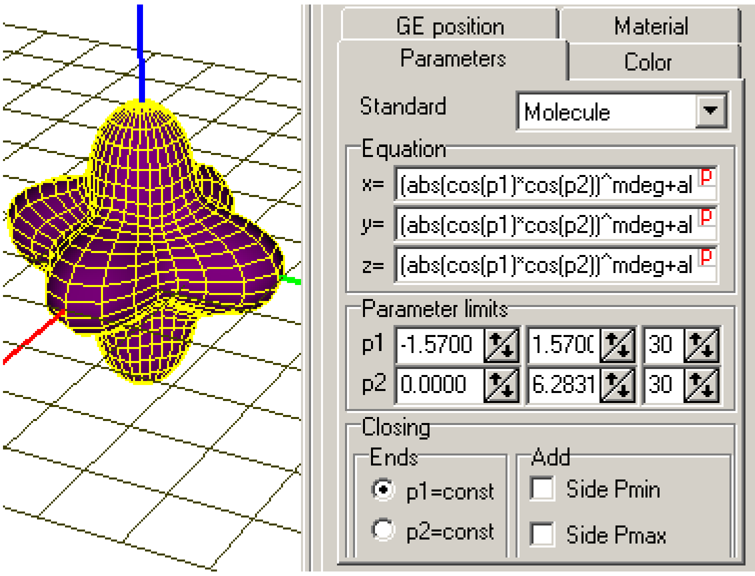


Fig. 3.37. Parametrical GE

The parameters of the parametrical GE are

- **Standard –** there are a set of standard parametrical elements:

Plane	Ellipsoid	Ring
Torus	Cone	Paraboloid
Spring	Horn	Molecule (Fig. 3.37)
Smooth cube	Gear	Elliptic gear

- **Equation** – analytical expressions describing the dependence of the Cartesian coordinates X, Y and Z on a parameter *p1* or *p2* (for a 3D curve), or *p1* and *p2* (for a 3D surface);
- **Parameter limits** – for each parameter, the minimal and the maximal values should be given, and the number of points inside the interval to approximate the surface, too; for example, the values *p1* from –1.4 to +1.2, *p2* from –0.2 to 4.8 modify the surface above as shown in Fig. 3.38.

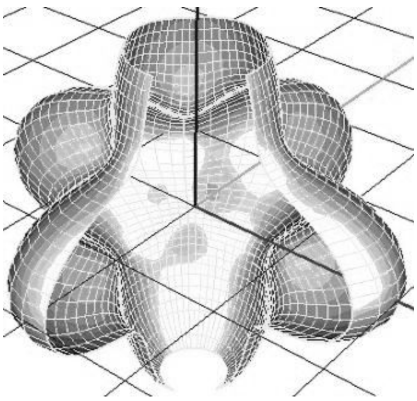


Fig. 3.38. Influence of the parameters p1, p2 on the GE shape

- **Closing –** there is a possibility to complete the surface to the closed one by adding lids; since the parameters *p1* and *p2* are equivalent, so a lid can be treated either as the *p1=const* or as the *p2=const* surfaces (Fig. 3.39); for this purpose the corresponding switch is intended (Fig. 3.37).

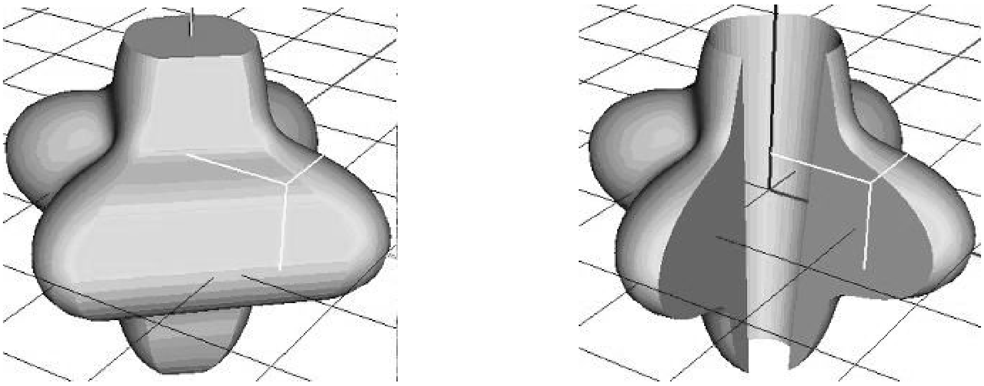


Fig. 3.39. Different ways of making the parametric GE closed

3.4.6.2.8. Profiled GE

This GE has many possibilities. It defines a surface formed by moving a certain *profile* curve along another *axis curve*, a number of ways to build the curves being possible.

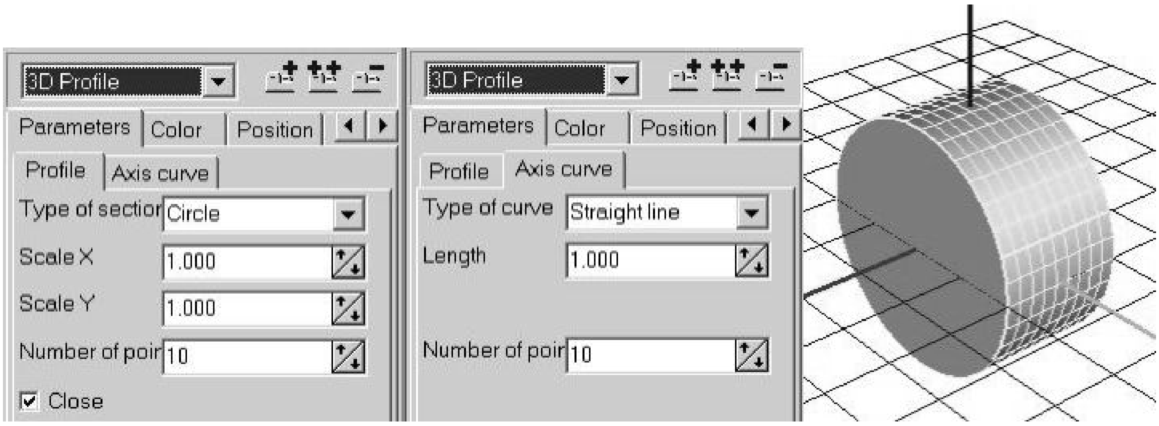


Fig. 3.40. Profiled GE: a cylinder

An example of the profiled GE is shown in Fig. 3.40.

Parameters of the *profile* are:

- **Type of section** – possible values are:
  - *Circle*: semi-axes are **Scale X, Scale Y;**
  - *Curve 2D*: a section given by a number of points, holes are allowed, too;
  - *Spline 3D*: a set of consecutive sections given by points;
  - *Expression*: a section given by analytical formulas.
- **Scale X, Scale Y** – scales in X and Y axes;
- **Number of points** to approximate the section;
- **Close** – a switch for automatic adding lids to make the surface closed.

Parameters of the *axis curve* are:

- **Type of curve** – possible values are:
  - Straight line;
  - Circle;
  - *Curve*: given by points;
  - *Expression*: given by analytical formulas.
- **Length** – the length of the axial line (in case of straight axis curve);
- **Number of points** to approximate the axial curve.

Using various combinations «type of profile curve – type of axis curve», it is possible to get different shapes of GE.

Examples of profiled elements

After choosing the profile type **Curve 2D** or **Curve 3D**, a new input parameter **Description** appears (Fig. 3.41).

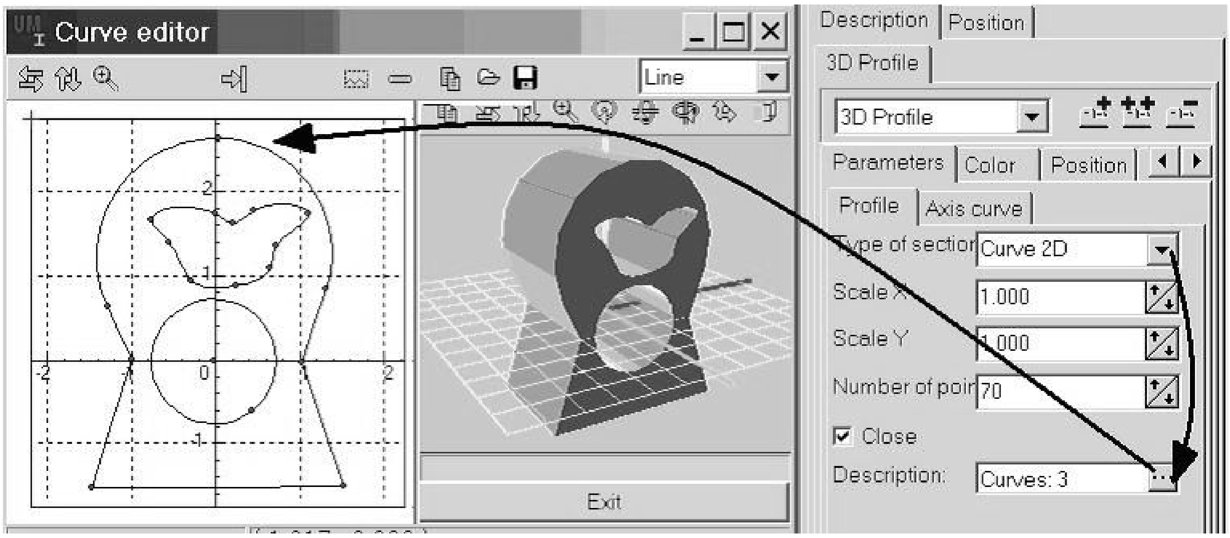


Fig. 3.41. Profiled GE: a Curve 2D section

Clicking mouse button on [...], the user can open a window of the curve editor (see Sect. 3.4.6.6) and input the section.

If several curves are presented with the **Curve 2D** type then the profile section will be multiple connected (Fig. 3.41).

In case of the **Curve 3D** section type, several curves are treated as a set of consecutive sections along the axis curve (Fig. 3.42).

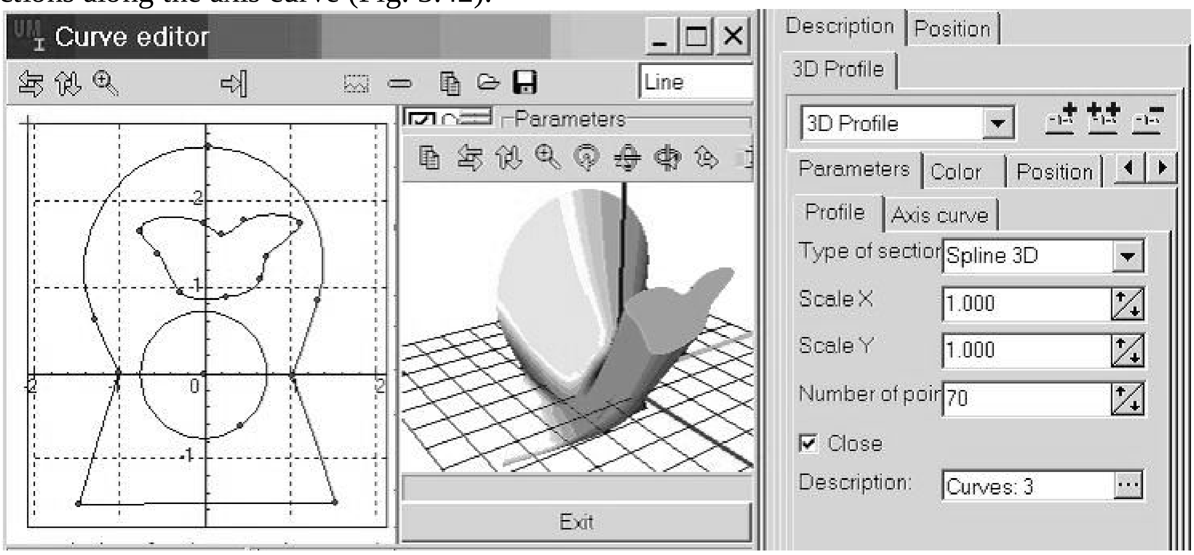


Fig. 3.42. Profiled GE: a Curve 3D section

After choosing the **Expression** type of profile section, a new parameter group appears (Fig. 3.43):

- **x(p), y(p)** – parametric equations of the profile contour depending on **p**;
- **Pmin, Pmax** – limits of changing **p**.

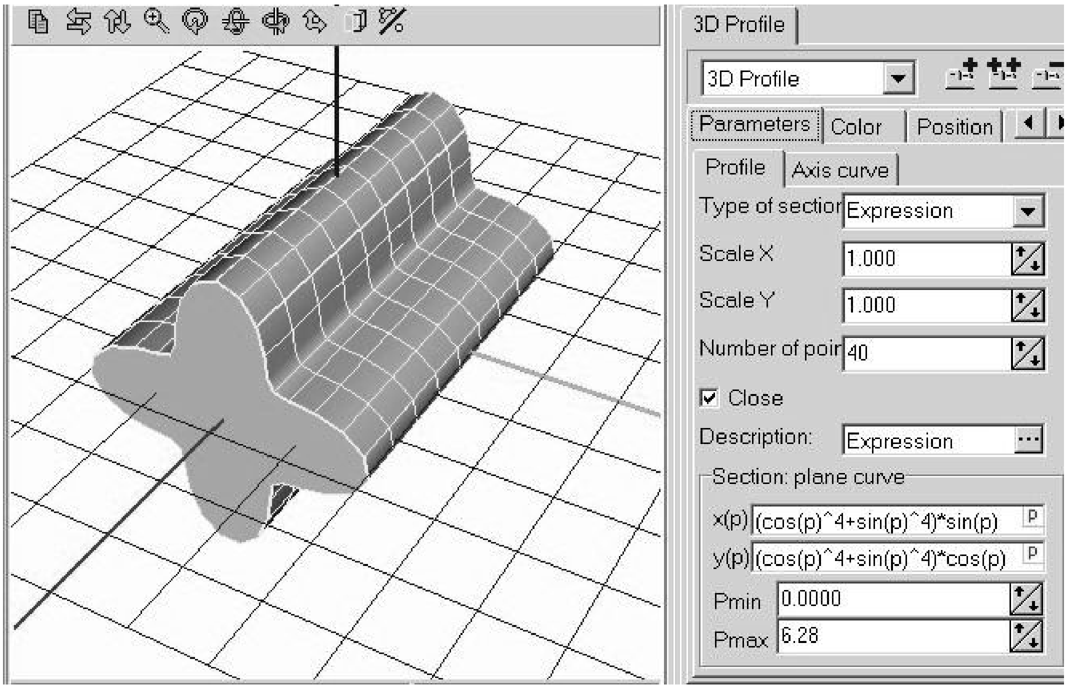


Fig. 3.43. Profiled GE: section given by formulas

Analogously, the axis curve can be described by points (Fig. 3.44).

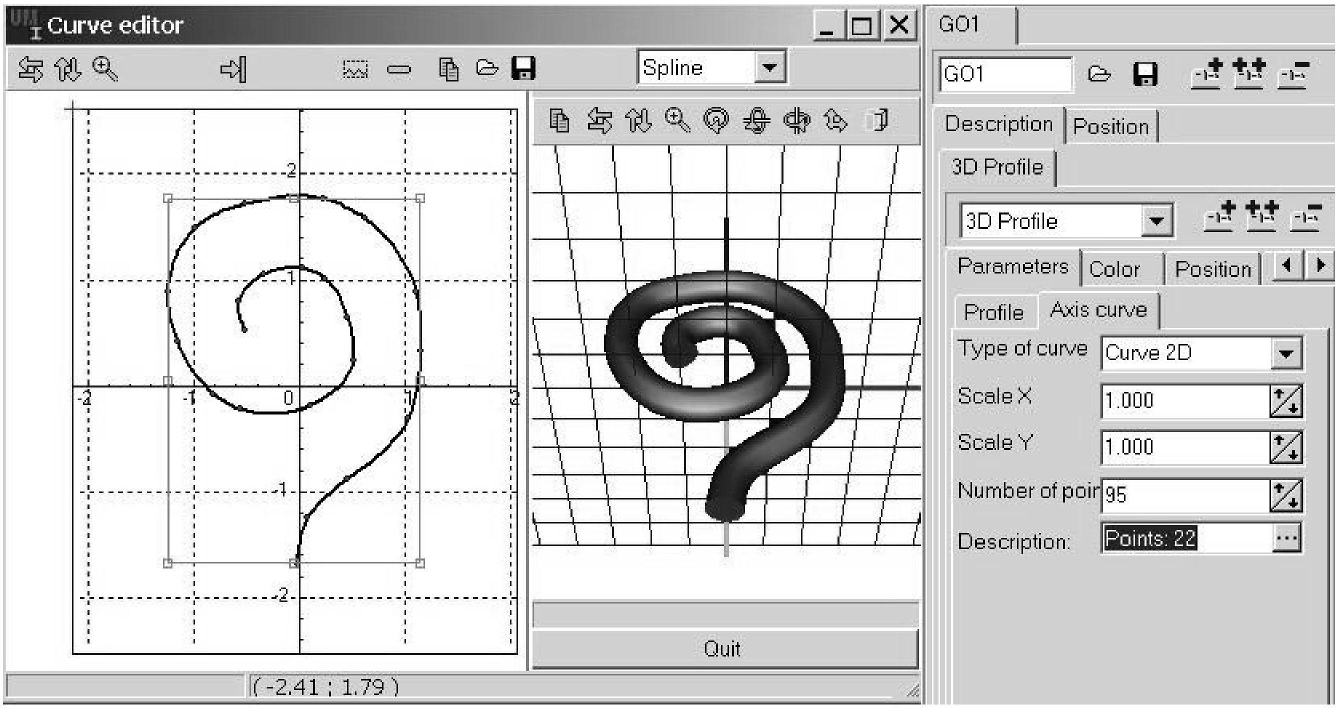


Fig. 3.44. Profiled GE: a 2D axis curve given by points

3.4.6.2.9. Z-surface

A GE of this kind is intended for programming graphical image of an arbitrary surface in the control file. The surface should be described as

$$z = f(x, y),$$

where x and y coordinates correspond to parameters *p1*, *p2*.

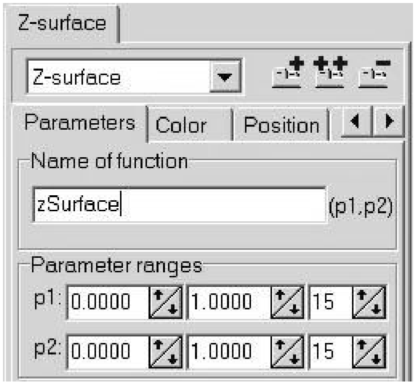


Fig. 3.45. Z-surface parameters

The GE description includes

- **name of function**;
- **parameter ranges** – limits of changing both *p1* and *p2* parameters and numbers of pointes to approximate the surface.

When generating equations of motion, a template for *zSurface* function is included in the control file (for example, as Pascal code):

```
function ZGraphicElementFunctions(
  _index, _isubs : integer;
  _p1, _p2 : real_ ) : real_;
begin
  _ := _PzAll[SubIndx[_isubs]];
  case _index of
    0 : begin
      { Function zSurface }
      Result := 0;
    end;
  end;
end;
```

For each function of type Z-surface introduced for representation of graphical images, an operator *Result := 0* is inserted, and the user should replace it with a proper calculation.

GE of type Z-surface is used to represent images with the help of complex implicit functional expressions, including time-dependent ones. For example, the Z-surface was used to get a traveling wave (Fig. 3.46).

Fig. 3.46. Z-surface

More detailed information concerning this GE is discussed in the manual for programming in UM environment.

Remark. Since the real description of the GE is located in the control file and is accessible in the UM Simulation program only, so in the input program the element is showed as a rectangle of sizes defined by change limits of parameters *p1*, *p2*.

3.4.6.2.10. GO as a graphic element

A previously created GO can be included in the current GO as a graphic element (type GO of the graphic element). This feature allows the user to create a many time repeating group of graphic elements as a separate GO and insert it several times in another GO. After that the correction of included GO leads to modification of all the GE-GO.

For example, consider an image of a fright couch body. It includes a lot of repeating parts (stiffening ribs) one of which is selected in the picture (Fig. 3.47). It should be created a GO corresponding to a separate rib and then this image is dozens of times included in the image of the body as GE-GO and positioned by a proper way. If the image of the rib must be modified (e.g. its height must be reduced), the only GO of the rib should be corrected, and all the ribs included in the image of the coach body are changed automatically.

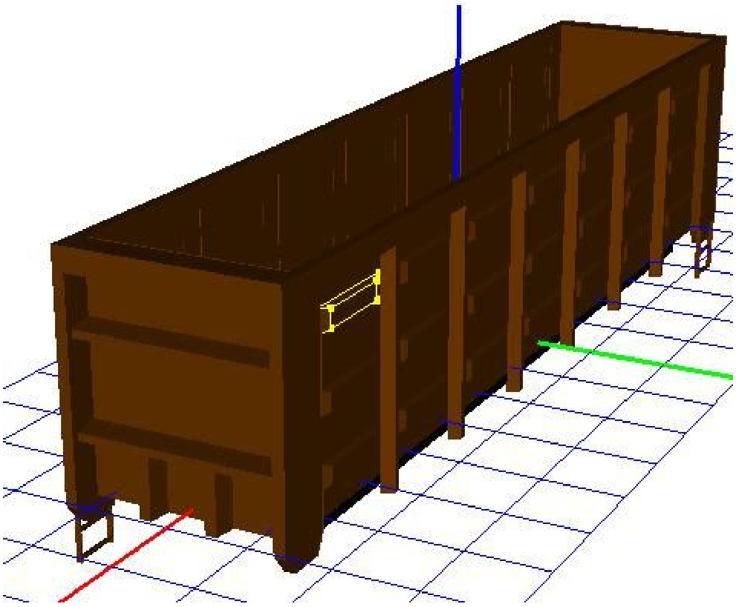


Fig. 3.47. Graphic image of a fright couch body

3.4.6.3. GE colors

Colors of a GE are set by parameters on the tab **Color** (Fig. 3.48).

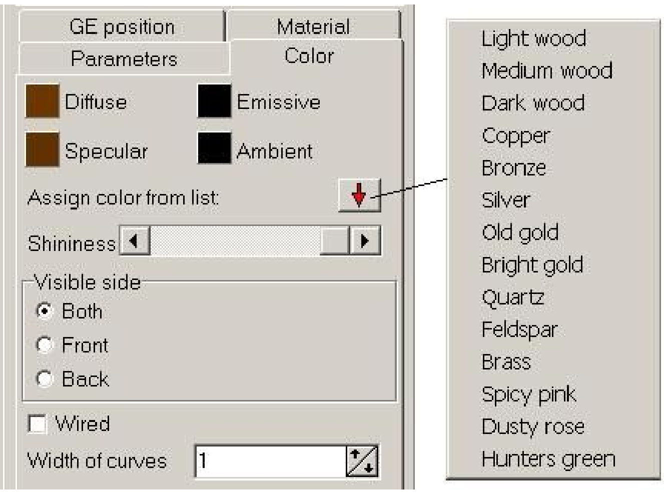


Fig. 3.48. Colors of GE

There are several kinds of colors:

- **Diffuse** (color of material);
- **Specular** (color of the reflected light); black color means no reflection;
- **Emissive** (the object shines with this color); it is off if the color is black;
- **Ambient** (usually not used).

To choose each of the colors click mouse button on the corresponding color rectangle.

Use the  button to select one of the standard color sets.

The parameter *Shininess* defines size of the reflected light's spot.

Check the **Wired** option to convert the element into the wire mode; simultaneously the **Width of curves** parameter set the line width.

3.4.6.4. Position and Orientation of GE

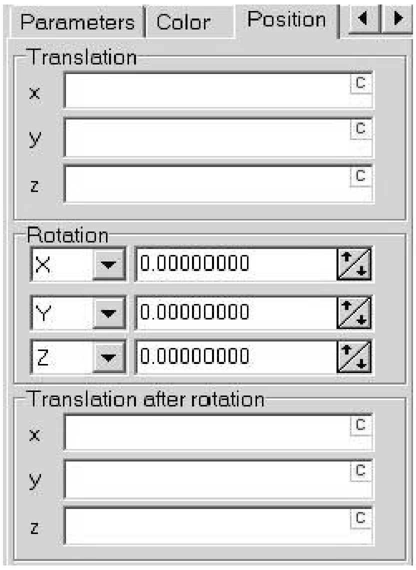


Fig. 3.49. Position and orientation of GE

Each GE contained in GO is described in its own system of coordinates – SC GE, which can be positioned in SC GO in an arbitrary way – it can be turned through some angles about the three axes in an arbitrary order and can be translated. Rotation angles are given in degrees, rotation axes being chosen previously.

3.4.6.5. Inertia parameters of GE

Fig. 3.50. Inertia parameters of GE material

Inertia parameters of bodies (mass, tensor of inertia, coordinates of center of mass) can be computed automatically according to the body image. A necessary condition for that is filling the material properties for graphic elements (at least for one of them). On the **Material** tab (Fig. 3.50) set

- **Density**
- **Type of graphic element** (solid, hollow) or frame (for wire element, Sect.3.4.6.3)
- A thickness and a section square should be set for a hollow and a wire GE

Warning. Automatic computing of inertia parameters may lead to wrong results if separate graphic elements intersect. The intersected volumes are taken into account several times. For example, the mass of the body is computed according to the formula

$$m = \sum m_i$$

where m_i is the mass of a separate GE calculated independently on possible intersections.

3.4.6.6. Curve editor

The window of the curve editor is shown in Fig. 3.51. See Sect.3.3.3 for basic information about this tool.

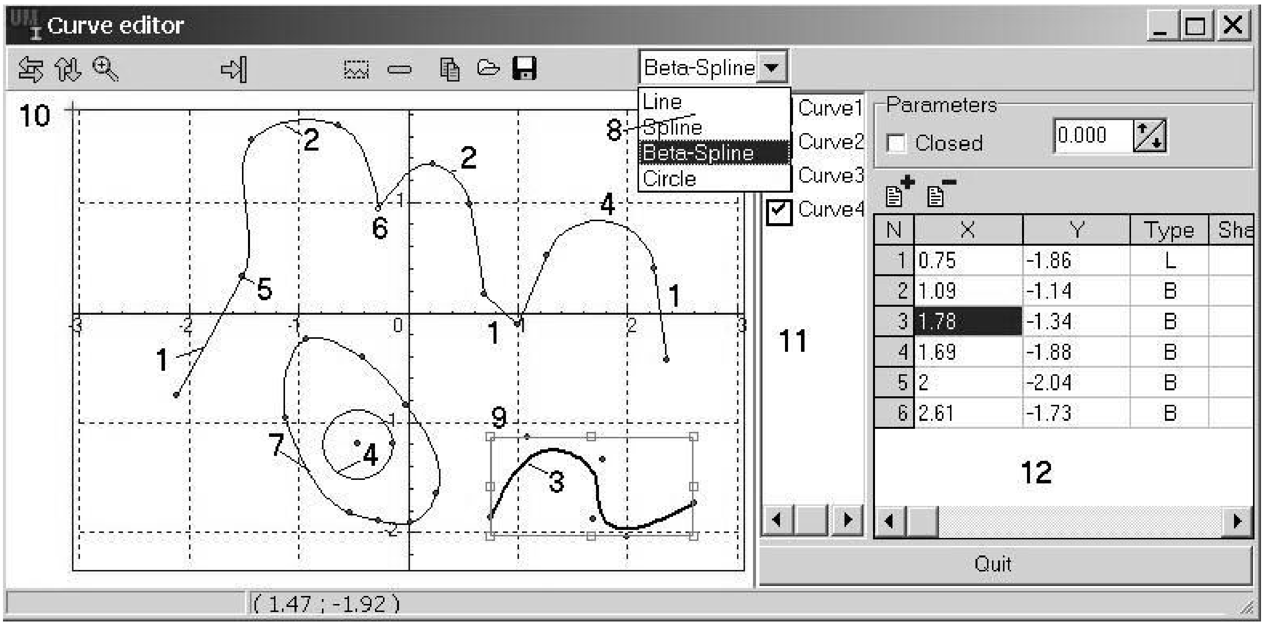


Fig. 3.51. Curve editor

Main elements of the editor are marked by indices:

- graphical primitives:
  - 1 – straight lines;
  - 2 – cubic splines;
  - 3 – beta-splines (special kind of splines);
  - 4 – circle (arc);
- points (vertices):
  - 5 – a point of smooth conjugation of primitives;
  - 6 – a point of non-smooth (sharp) conjugation of primitives;
- continuous curves (continuums):
  - 1-5-2-6-2-1-4-1, and also 3 – non-closed curves;
  - 4, 7 – closed curves;
- other controls and possibilities of the editor:
  - 8 – drop-down list of types of primitives;
  - 9 – selection of a group of primitives by means of the mouse;
  - 10 – panel of control buttons;
  - 11 – list of curves;
  - 12 – grid with coordinates and parameters of the current (selected) curve.

For adding points (vertices), double clicking the left mouse button is using.
To copy (duplicate) a curve:

- select it using mouse pointer;
- put it to the Windows clipboard;
- insert from the clipboard.

Exchange with the clipboard is performed using a text format. So, the user can type coordinates of vertices as two columns of numbers in any text editor, and insert them into the curve editor.

Pop-up menus are used for various actions with primitives and points of curves. It appears after clicking the right mouse button over the corresponding element.

For example, clicking over the free field of the curve editor results in appearing a pop-up menu shown in Fig. 3.52.

Fig. 3.52. Curve editor main pop-up menu

The menu has two items:

- **Start new curve** – the next point being input will be the start point of the new curve (continuum);
- **Select all** – is used to select all curves in the editor.

Clicking right mouse button over any vertex results in appearing a pop-up menu for a point (Fig. 3.53).

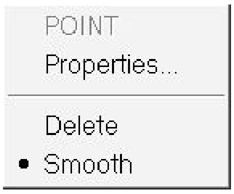


Fig. 3.53. Pop-up menu for a point

Actions allowed for a selected point are:

- **Properties...** – opens a point property dialog box intended for changing the point coordinates;
- **Delete** – removes the selected point;
- **Smooth –** turns on/off the smooth conjugation of primitives.

A pop-up menu for a primitive appears after clicking any primitive (line, spline or circle); see Fig. 3.54.

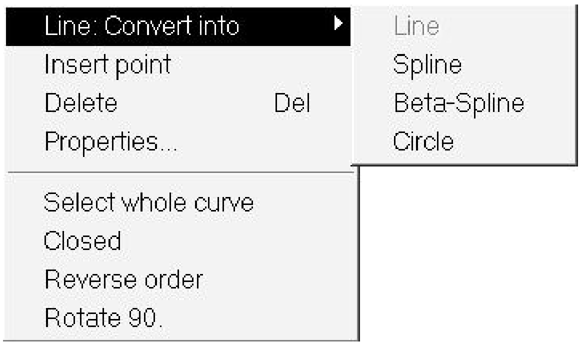


Fig. 3.54. Pop-up menu for primitive

Actions allowed for a primitive are:

- **Convert into** – changes the type of the selected primitive;
- **Insert point** – a new point will have the coordinates defined by the current position of the mouse pointer (double clicking the left mouse button has the same effect);
- **Delete** – removes the selected primitive;
- **Properties...** – calls a primitive property dialog box;

- **Select whole curve –** selects the curve (continuum) containing the selected primitive;
- **Closed –** a tag for closing the curve containing the selected primitive;
- **Reverse order –** for inverting the ordering of points**;**
- **Rotate 90 –** turns the current continuum through 90 degrees counterclockwise.

3.4.7. Input of bodies

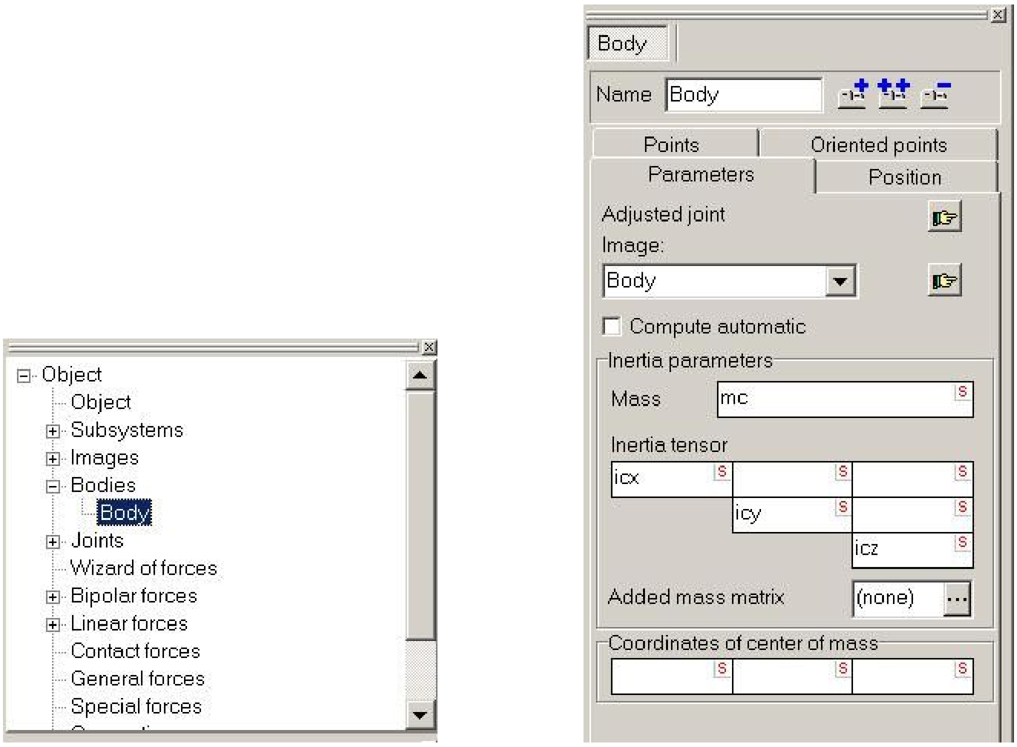


Fig. 3.55. *Bodies* item of the object element list and Body parameters

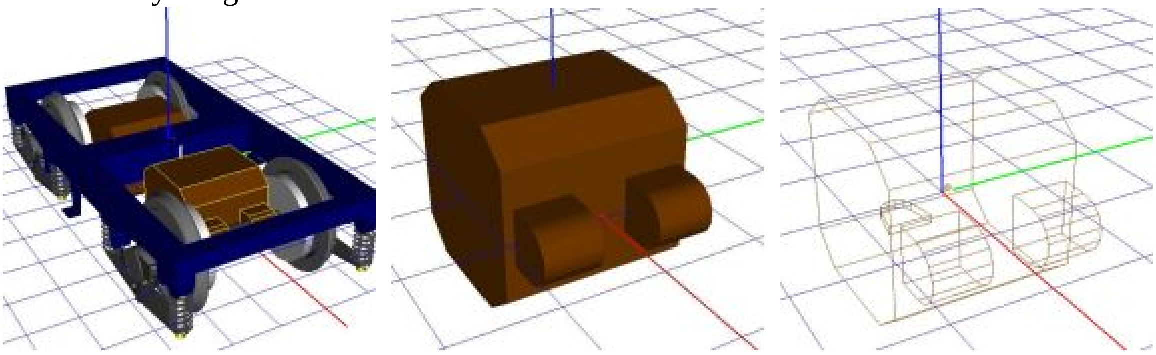
The *Bodies* item of the object element list (Fig. 3.55 left, Sect.3.3.2.1) is used for access to procedures of creation and modification of the list of bodies and their parameters. Alternative ways are the Ctrl+Alt+B hot key or clicking by the mouse on the corresponding body image in the whole object mode of the animation window (Sect.3.3.1.2.2). The right picture in Fig. 3.55 shows the inspector with parameters of a body.

3.4.7.1. Image and visualization of a body. Body-fixed SC

The *Graphic image* pull-down list contains all entered graphical objects (see Sect. 3.4.2). Click the ☞ button to access the assigned GO parameters or to create a new GO, which will be assigned to the body.

The SC of the assigned GO coincides with the body-fixed SC. That is why the image moves when the body changes its position and orientation.

Use the single element mode of the animation window (Sect.3.3.1.2.2) to see the body-fixed SC and the body image.



a) b) c)

Fig. 3.56. Visualization of an active body in different modes of the animation window

Fig. 3.56 shows visualization of a *motor* body in different modes of the animation window:

a) *Full object mode*, the active body is drawn as selected, axes of the SC0 are drown
b) *Single element mode*, the window contains the body image in the body-fixed SC which axes are drawn
c) *Single element mode*, *wire graphics*

Important remark. A body is drawn in the full object mode of the animation window if there exists a path from the body to the Base0 through the joints (Chapt. 2, Sect. *Compendency of systems and the definition of a joint*). For example, if body2 is connected to body1 and body1 is connected to Base0 by means of two rotational joints, both body1 and body2 are visible in the full object mode. If the joint between body1 and Base0 is removed, both bodies disappear. If the joint between body2 and body1 is removed, body1 disappears.

3.4.7.2. Inertia parameters

Inertia parameters of a body are:

- mass;
- symmetric inertia tensor;
- coordinates of center of mass in the body-fixed SC;
- symmetric added mass matrix.

The icon marks the position of the center of mass in the animation window.

Important **remark and warning**. Moments of inertia and elements of the added mass matrix should be calculated in SC, which origin coincides with the center of mass and axes are parallel to those of the body-fixed SC.

There exist two modes for entering the inertia parameters (except the added masses). Use the **Automatic calculation** button to switch them. (Fig. 3.55).

User's defined inertia parameters

All parameter boxes are enabled in this mode. All parameters might be *constant symbolic expressions* (Sect.0).

Automatic calculation of inertia parameters

The parameters are calculated automatically according to the body image (Sect.3.4.6.5). Parameter boxes are not available for the user.

Remarks.

- Automatic calculation is enabled after assigning a GO to the body. The corresponding GO must include at least one GE with the assigned material which density is not zero.
- Inertia parameters are recalculated every time when the GO is modified in particular when identifiers parameterizing the GO are changed.

3.4.7.3. Adjust/adjusted joint

Use the ☞ button to create or modify an adjusted joint for the current body (Sect.3.4.9).

The adjusted joint is the nearest joint, which lies on the path from the body to the base. Use this joint to change the position of the body.

3.4.7.4. Connection points

Connection points are assigned to the body. They are used by

- operations with visual components;
- describing joints and force elements (visual assignment of bodies, joint and attachments points);
- assignment of bodies as will as the corresponding joint and attachment points to *external* joint and force elements (for subsystem technique only).

There exist three types of connection points:

- general
- oriented (local body-fixed SC)
- vectors

The following parameters should be set for each point

- coordinates in the body-fixed SC (coordinates are parameterized);
- comments simplifying operations with points (auxiliary parameter);
- orientation of point-fixed SC relative to the body-fixed SC (for oriented point); the orientation is set by three rotations.

An icon ▫ marks a connection point in the animation window (Fig. 3.57). A point-fixed SC are additionally drawn for oriented points, and a line section is drawn for a vector along its direction.

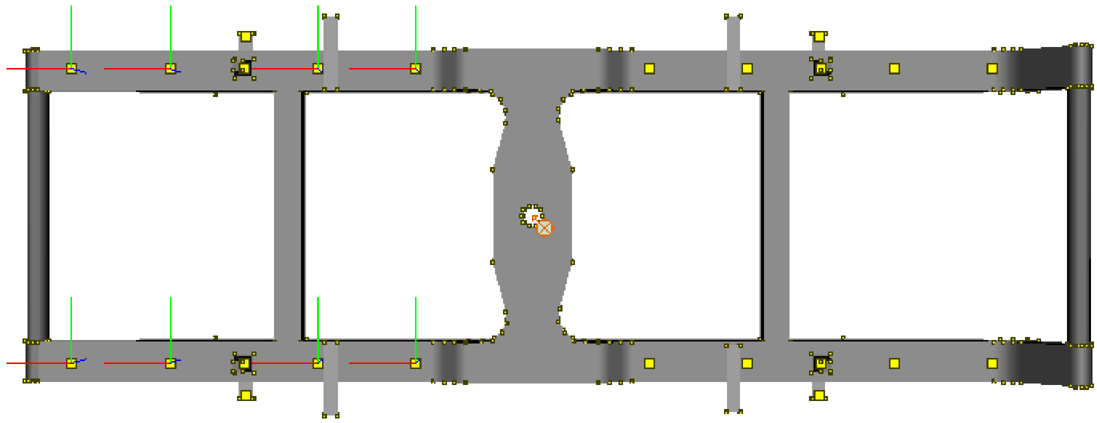
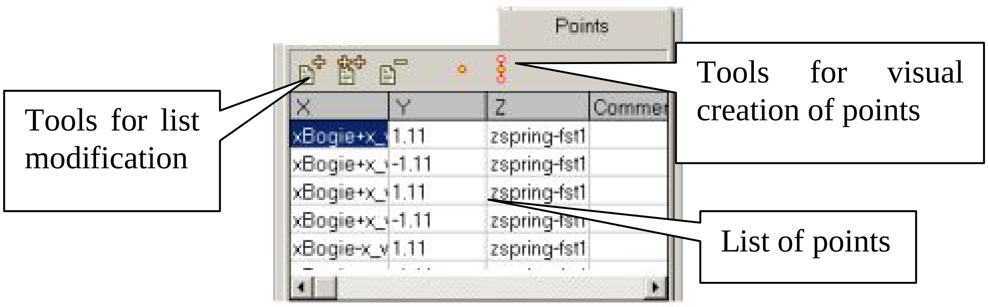


Fig. 3.57. Frame with general and oriented connection points

Note.

Connection points are used to assign their positions and/or orientation to object elements (joints and forces). At the same time the connection between the element and the points is not kept. This means that if the user changes the point parameters after its usage for description of an element, the corresponding changes are not transferred to the element automatically.

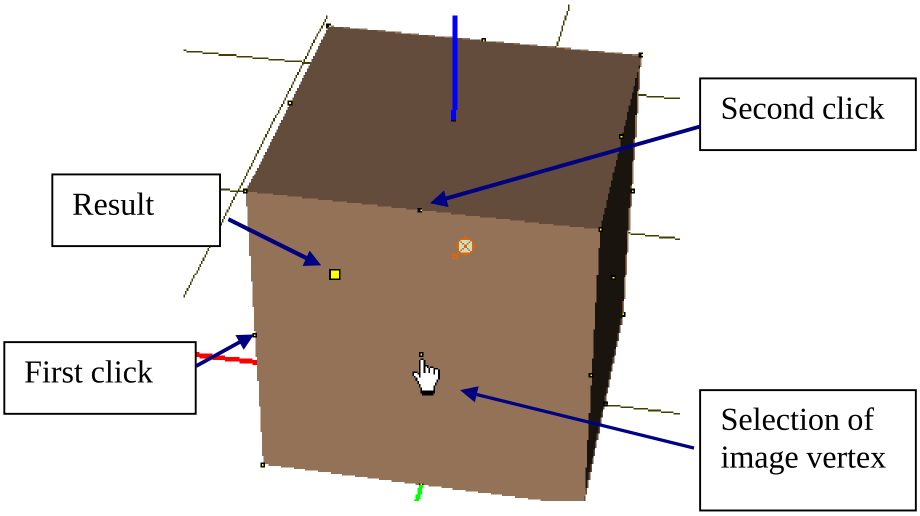
3.4.7.4.1. Adding general connection points



The **Points** tab is used to create or modify the list of points.

To add a point, the user should set its coordinates in the body-fixed SC. Here are instructions how to do this.

1. Use the (add) or the (copy) button. Set point coordinates as constant symbolic expressions, Sect. 0.
2. Click the button, select by the mouse a point on the body image, and click the mouse button again. The selected point is added automatically.



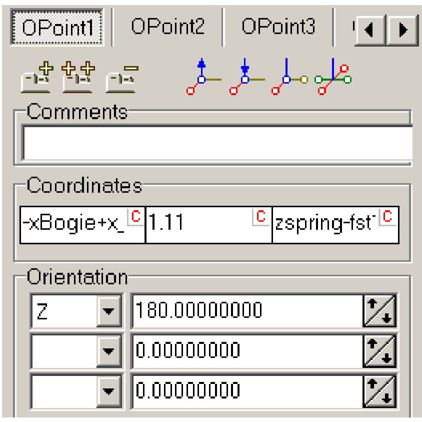
Adding a point as a middle point of a section

3. The ( ) button allows the user to get a point as a middle point of a section selected by the mouse.

Use vertices on the body image for exact positioning of points. Near the vertex the mouse cursor is changed to . After visual adding, the point can be corrected or removed by the button.

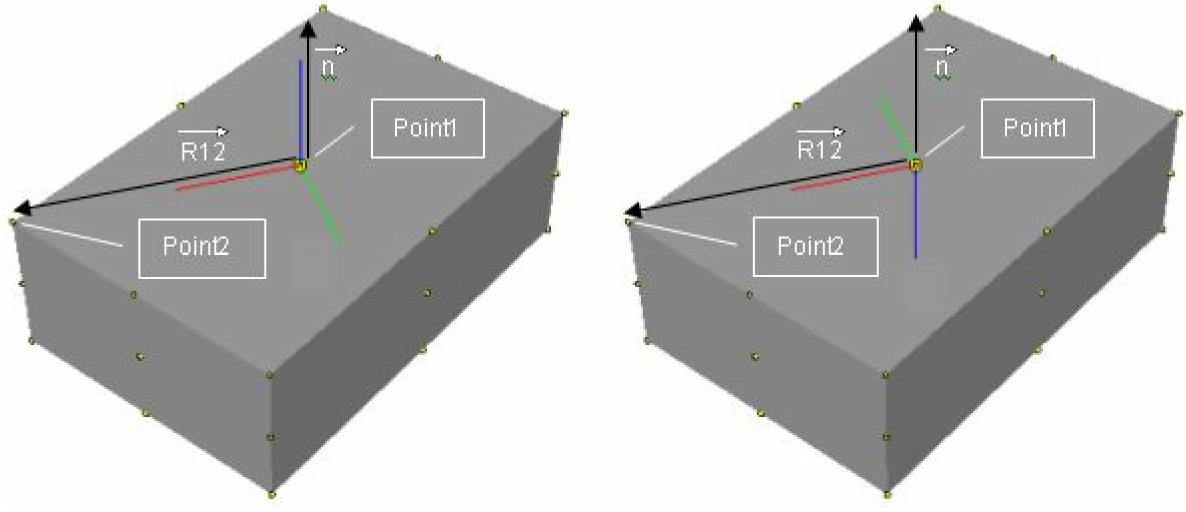
3.4.7.4.2. Adding oriented connection points

Use the **Oriented points** tab to add an oriented connection points (a local system of coordinates, LSC). Its description includes coordinates of the points and the orientation of axes of the LSC in the body-fixed SC. The orientation is set as a sequence of tree successive elementary rotations.



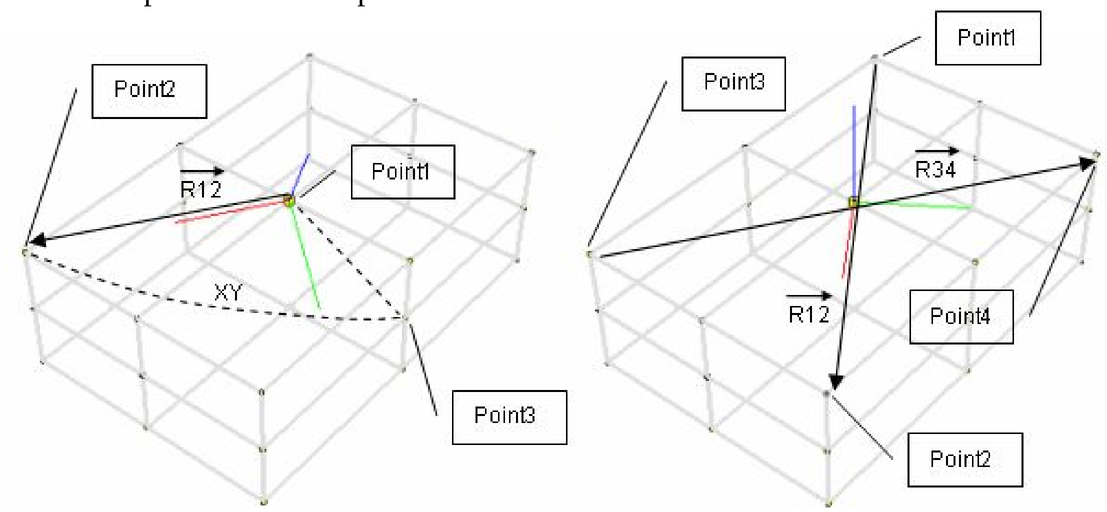
Here five methods for adding oriented points (LSC) are described.

1. Use the (add) or the (copy) button. Set point coordinates as constant symbolic expressions, Sect. 0. Set rotation axes and angles in *degrees* to define the orientation.



Adding a LSC by a normal and a point

2. Visual adding by a normal and a point.
   - Click the button.
   - Select a vector or a point on a plane for the origin and the Z-axis of the LSC.
   - Select a point in the XZ-plane.
3. Visual adding by an opposite normal and a point.
   - Click the button.
   - Select a vector or a point on a plane for the origin and the Z-axis of the LSC. The Z-axis is directed opposite to the vector or inside the plane surface.
   - Select a point on the XZ-plane.



Visual adding a LSC by tree and by four points

4. Visual adding by three points.
   - Click the button.
   - Select a point for the origin of the LSC.
   - Select a point on the X-axis.
   - Select a point in the XY-plane.
5. Visual adding by four points.
   - Click the button.

- Select two points. The middle point of the section is the origin of the LSC, and the vector $\mathbf{r}_{12}$ connecting the points set the X-axis.
- Select the 3rd and the 4th points. The cross product $\mathbf{r}_{12} \times \mathbf{r}_{34}$ sets the Z-axis.

3.4.7.4.3. Adding vectors

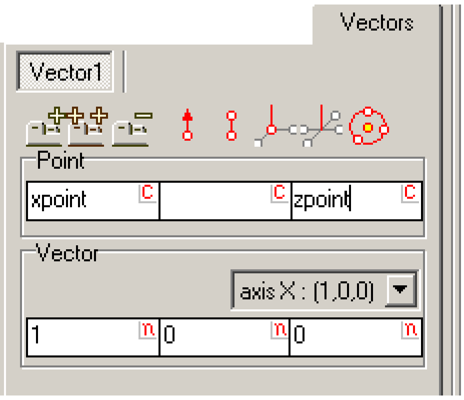


Fig. 3.58.

Use the **Vectors** tab to add a vector. Its description includes coordinates of the points and components defining the direction of the unit vector in the body-fixed SC. The vectors are used for visual correction and adding joints and some special force elements.

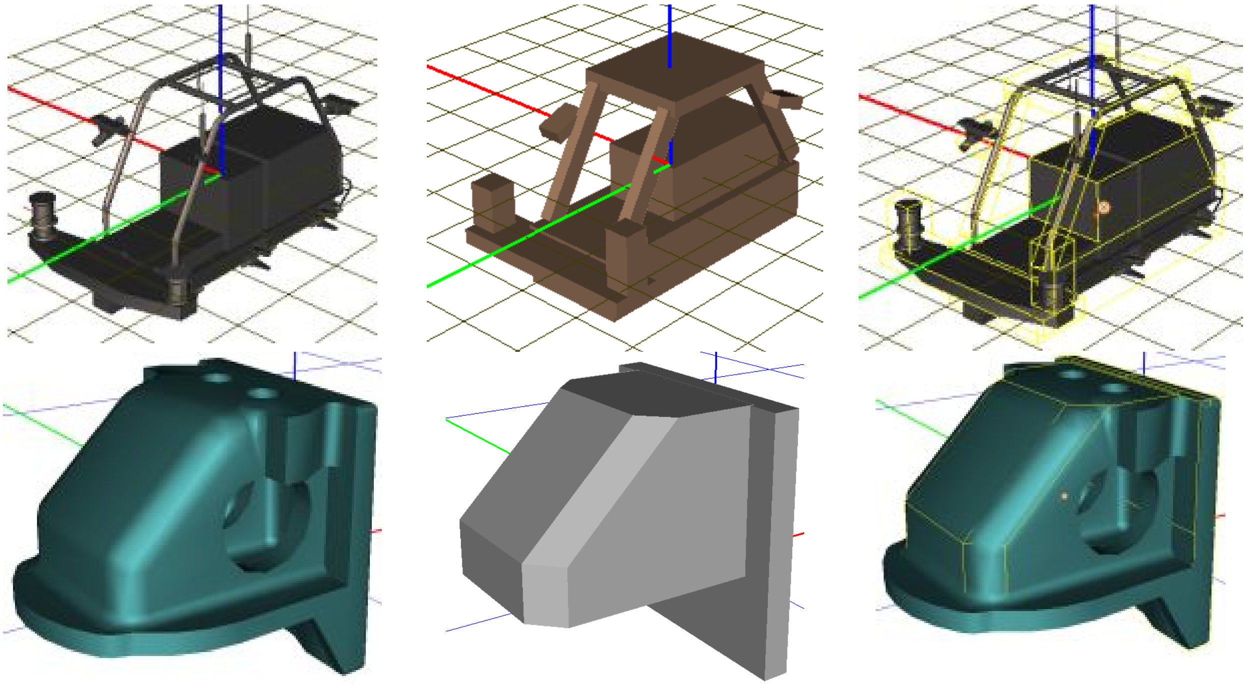
Here five methods for adding vectors are described.

1. Use the (add) or the (copy) button. Set point coordinates as constant symbolic expressions, Sect. 0. Set numeric values for the vector components.
2. Visual adding by a normal and a point.
   - Click the button.
   - Select a point on a plane for the vector, which is the external normal to the plane.
3. Visual adding by two points.
   - Click the button.
   - Select a point for the vector point.
   - Select the second point for the vector direction.
4. Visual adding by three points.
   - o Click the button.
   - Repeat actions for setting the LSC by three points from the previous section. The vector corresponds to the Z-axis.
5. Visual adding by four points.
   - Click the button.
   - Repeat actions for setting the LSC by four points from the previous section. The vector corresponds to the Z-axis.
6. Visual adding as a normal to the center of a circle passing through 3 points.
   - Click the button.
   - Select three points lying on a circle. The resulting vector begins at the circle center. The direction of the vector is perpendicular to the circle plane according to the right-hand screw rule according to sequence of selected points.

3.4.7.5. 3D Contact

There is a possibility to assign a contact manifold described as a graphical object (see. Sect. 3.4.6. Input of Graphical Objects, page 3-40) to a rigid body. All bodies that have such a contact manifold will interact between each other during simulation dynamics of a mechanical system in **UM Simulation**. Parameters of a contact interaction as well as turning on/off contact between pairs of bodies are available in **UM Simulation**.

3D Contact supports parameterization of graphical objects that are used as contact manifolds. Firstly parameterized graphical objects for contact manifolds you can consider various configuration of contacting bodies in quite wide range simply changing corresponding parameters without remaking the graphical object itself. Parameterization of graphical object may be effectively used, for example, for searching the optimal shape of the friction wedge for so-called three-piece bogie for freight cars, Fig. 3.59 below.



a) Graphical object (GO) b) Contact manifold (CM) c) GO and CM

Fig. 3.59. Graphical object and contact manifold for a body of wheeled robot

A graphical object that is assigned as a contact manifold for a body may differ from a graphical for the body. It is absolutely not necessary that it should be the same graphical objects. It is recommended to use simplified contact manifolds for decreasing the CPU efforts for simulation.

The contact manifold for the rigid body is selected from prepared in advance graphical objects that are available in the drop down list. Coordinate system of the contact manifold coincides with the coordinate system of the body. In the **Single element mode** (see Sect. 3.3.1.2.2. Modes of animation window, page 3-15) the contact manifold is drawn in yellow lines, see Fig. 3.60.

There is no possibility to assign a contact manifold for *Base0* body. If it is necessary you should create an extra rigid body with 0 d.o.f. and assign the contact manifold of *Base0* with this extra body.

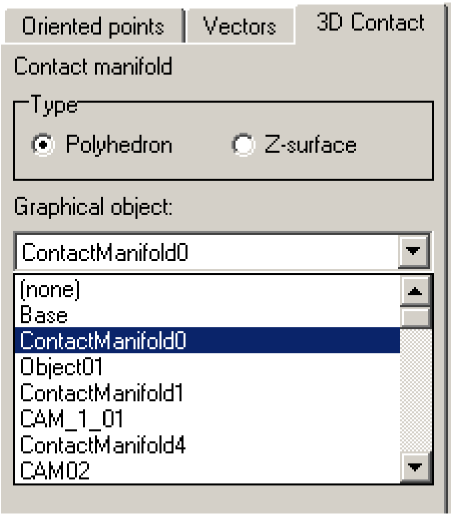


Fig. 3.60. 3D Contact parameters between pair of bodies

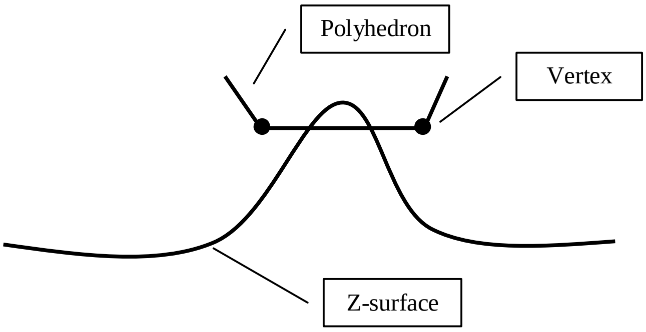
Types of contact manifold

Polyhedron. In general case use **Polyhedron** type for describing the contact interaction between bodies. Graphical objects that are chosen as contact manifolds should consist of graphical elements of the following types: **Box**, **Polyhedron** and **ASC**. Graphical elements of **Polyhedron** and **ASC** types should be convex and closed.

Z-surface. This type of contact manifold is used to describe contact between all bodies and the ground. Restrictions of convexity and closure are not applied for graphical objects for contact manifold of **Z-surface** type. Some comments concerning preparing a graphical object for using as a contact manifold of **Z-surface** type are given in Sect. 3.4.10.4.5. Points / Sphere / Circle - Z surface contact, page 3-100.

3D Contact simulation between **Polyhedrons** and **Z-surface** is based on using *Points – Z-surface* contact force that is described in Sect. 3.4.10.4.5. That is why it is also possible to describe contact interaction between polyhedrons and Z-surface with the help of *Points – Z-surface* contact force. The only difference between both variants is that **3D Contact** generates all contact forces of *Points – Z-surface* type automatically without necessity to create the forces for each body and the Z-surface manually. At the same time both variants are identical from point of view of results of simulation of dynamics of the system.

Treating the *Points – Z-surface* contact forces in **3D Contact** does not consider the interaction of edges and Z-surfaces, so contact forces will not appear in the case which is depicted in the Figure below.



Note 1. CPU efforts for simulation of *near contact* are proportional to square of count of faces and edges. To accelerate simulation process it is recommended to simplify contact manifolds 1 as far as possible for solving the particular problem.

Note 2. 3D Contact model as any mathematical model is just an approximation of real physical processes that take place between two bodies contacting bodies. Certainly the model has confined area of effective applications as well as there are cases where the model describes real processes incorrectly. 3D Contact model is rather a fast algorithm that is suitable for simulation of some models based on multibody system dynamics approach but surely is not suitable for detailed analysis of contact problem (contact stresses, deformations, wear, plastic effects and so on).

Comparison of the contact models.

Universal Mechanism software has to approaches to simulate contact interaction between rigid bodies. The first approach suppose using contact forces of “point-plane” and other types and the second approach is based on 3D Contact described above.

3D Contact based on using “point-plane” contact forces and in this sense can be considered as an algorithm that detecting interpenetration of rigid bodies arranges contact points and identifies nearest faces as contact planes. At the same time calculation of interpenetration of contact manifolds is rather time-consuming operation that takes quite many CPU efforts. That is why simulating models with contacts it necessary to understand clearly advantages and disadvantages of both approaches. Detailed overview of contact forces see in Sect. 3.4.10.4. *Input of contact force elements*, page 3-97.

3D Contact often makes simulation of contact interaction more easy-to-use, intuitive and more suitable for parameterization, as well as widens contact interaction for “edge-edge” penetration case, see Chapter 2, Sect. *3D contact*. To simulate “edge-edge” penetration with the help of contact forces of “point-plane” type it needs to create contact points on each edge with quite small distance between them that significantly increases CPU efforts that neglect the only benefit in comparison with 3D Contact.

Please note that 3D Contact widens possibilities of simulation of contact interactions but needs extra computational efforts. At the same time approach based on using contact forces generally faster but not so universal as 3D Contact one.

Examples.

Please find some examples of using 3D Contact in the following models:

- ..\Samples\Misc\Clockwork;
- ..\Samples\Misc\DominoDay;
- ..\Samples\Misc\Earthquake;
- ..\Samples\Misc\FallingFigures;
- ..\Samples\Rail vehicles\WedgeTest3DContact;
- ..\Samples\Robots\Manipulator;
- ..\Samples\Robots\krt_200.

3.4.8. Joints and force elements: some features of description

Joint and force elements have some parameters, which entering is quite analogous, e.g. a pair of bodies, attachment points or images should be assigned for the most of elements of these types. The standard interface is used for entering these parameters, for instance the corresponding interface for a 6 d.o.f. joint looks like this (Fig. 3.61):

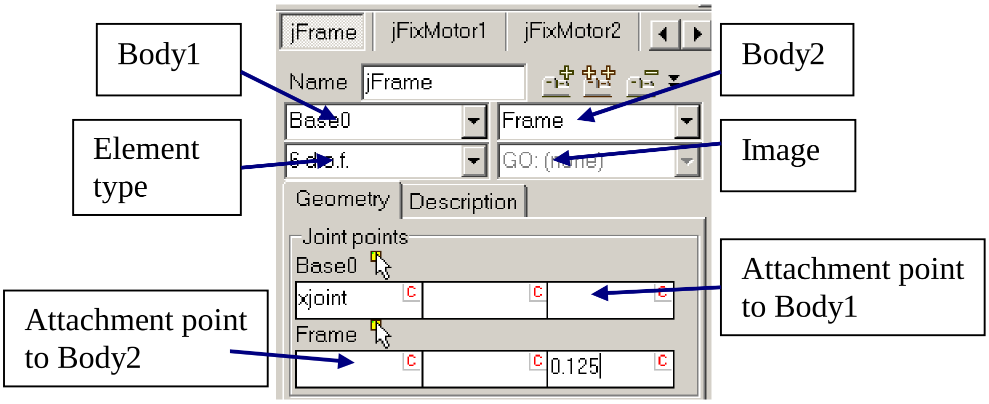


Fig. 3.61.

3.4.8.1. Assignment of bodies

A pair of bodies should be assigned for each joint or force element else the object description is considered as incomplete. One of the bodies is the *first* one (Body 1 in Fig. 3.61), another – the second one (Body 2). Use two upper drop-down lists to set the bodies (Fig. 3.62).

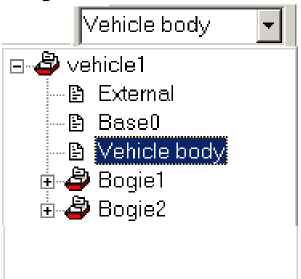


Fig. 3.62

The lists contain all bodies included in the object as well as the base body (Base0) and an *external* body (the second list only). The *Base0* is used for attachment of a body to a fixed point (to the base). The *External* body is used to make the element *external* (the subsystem technique).

The first and the second bodies must be different.

3.4.8.2. Type of element

A type must be chosen for the most of elements with the help of a drop-down list (Fig. 3.61, Fig. 3.63). Changing the type leads to deleting of previous element description.

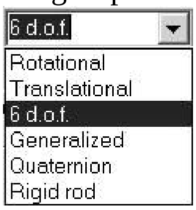
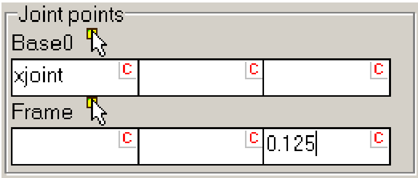


Fig. 3.63

3.4.8.3. Attachment points

Attachment points have different notations for elements of different types (‘joint points’, ‘attachment point’ etc.). Anyway two points should be assigned for each element. One of the points belongs to the first body, another point – to the second one. The coordinates of the point should be entered in SC of the corresponding body as constant symbolic expressions (Sect. 0).

3.4.8.4. Visual assignment of bodies and attachment points



To assign visually a body and the corresponding attachment point click one of the buttons and select a point, an oriented point or a vector, which should be preliminarily described (see Sect. 3.4.7.4. Connection points).

Note 1. The type of the point should be chosen depending on the element. For example, description of a generalized linear force element requires both oriented points and general point. The description of a bipolar force element requires two general points.

Note 2. If the element requires coordinates of a point only, all types of connection points can be used. If the element requires a vector, an oriented point can be used (Z-axis of the LSC is used as the vector).

3.4.8.5. Transformation of coordinates

Attachment points of force elements are set in body-fixed SC, that is why, a tool for transformation of coordinates of points into different SC could be useful. To call the corresponding tool use the **Tools** | **Transformation of coordinates** ore use the hot key *Alt+T* (Fig. 3.64).

Choose two bodies with the help of drop-down lists and set coordinates of a point in SC of one of the bodies (where the coordinates are known). After that click either the button (if the coordinates are known for the first body) or the button if the coordinates are known for the second body), and the coordinates are computed for SC of another body. Analogously can be computed projections of a vector onto axes of different SC.

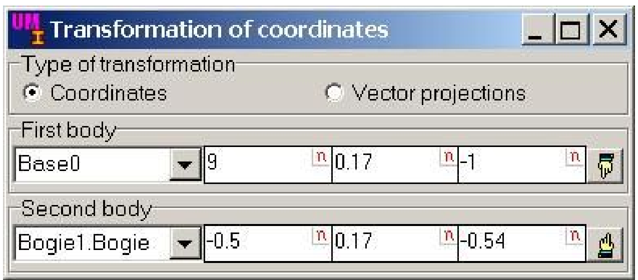


Fig. 3.64. Example of transformation of coordinates

3.4.9. Input of joints

3.4.9.1. Visualization of joints

In the single element mode of the animation window: a pair of bodies (kinematical pair) connected by the joint is drawn. A GO may be assigned for a *rod constraint* only.

In the full object mode of the animation window: the bodies of the kinematical pair are drawn as *active*. Optionally an icon marks a position of the joint point and visualizes its degrees of freedom (Sect. 3.3.1.2.1. Visualization of object elements). Click near the active region of the icon to call the description of the joint in the inspector (Sect. 3.3.1.2.1).

If the joint is *cut* (except rod, mate and CV joints), the second body is drawn twice in the full object mode: in the positions determined by adjusted and the cut joints (Sect. 3.4.9.1). It is recommended to change coordinate values in such a way that the both images of the body were close. The exact values of the coordinates are calculated in the Simulation program.

Note. By default some information about the joint is hidden. Use the button to make it visible.

3.4.9.2. Weight of joint

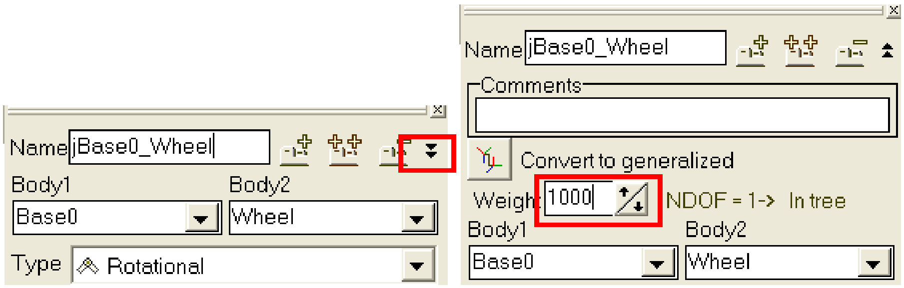


Fig. 3.65. Setting joint weight

A weight coefficient can be assigned to each of the joints. This parameter is used when the object has closed kinematical loops (Chapt.2, Sect. *System graph. Closed kinematical loops*). If a large weight (e.g. 1000) is assigned to a joint in a closed loop, it will be cut.

Note. By default the weight information is hidden. Use the button to make it visible, Fig. 3.65.

3.4.9.3. Convertion of joint type

Joints of types

- rotational
- translational
- six degrees of freedom (6 d.o.f.)

can be converted to the "generalized" joint type.

For example, a 6 d.o.f. joint can be converted to the generalized type to introduce joint forces for some degrees of freedom. A rotational or a translational joints is recommended to be transformed to the generalized joint type, e.g. to add degrees of freedom or to parameterize inclination of the joint axis.

To convert the joint type

- use the button to open additional joint information, Fig. 3.65.
- click the button to make the conversion.

Example. User’s manual, Chapt. 7, Sect. *Joint type conversion. Parameterization of axis inclination.*

3.4.9.4. Input of rotational and translational joints

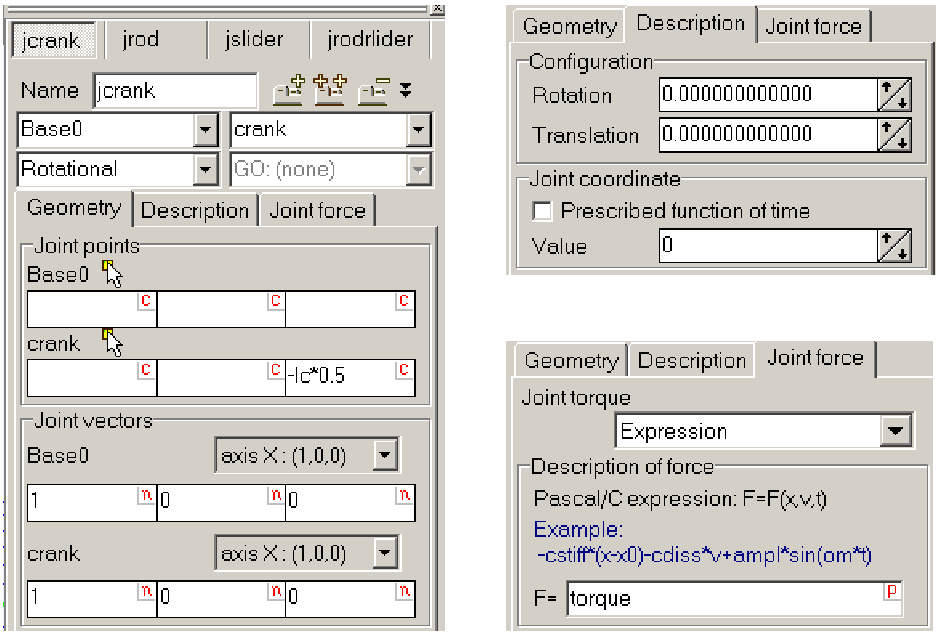


Fig. 3.66. Parameters of a rotational joint

Notions of translational and rotational joints are discussed in Chapter 2, Sect. *Translational and rotational joints.*

The following parameters should be entered in addition to bodies and joint points (Sect. 3.4.8.1, 3.4.8.3):

- projections of the joint vector on axes of two body-fixed SC (the **Geometry** tab, Fig. 3.66); the vector cannot be zero;
- additional shift and rotation (the **Description** tab, the **Configuration** group); the parameters are optional.

If the bodies connected by the joint are is in the tree (visible in the full object mode of the animation window, set the button in the 'down' state to verify this), the buttons can be used for visual entering both the joint points and the joint vectors. A joint vectors can be obtained from connection points of *vector* and *oriented point* types (see Sect. 3.4.8.4. Visual assignment of bodies and attachment points). Thus, selection of a vector or an oriented point allows the user to assign simultaneously: a body, a joint point and a joint vector.

Further description of joint depends on type of the joint coordinate. The coordinate can be a degree of freedom or a time function.

Coordinate is a degree of freedom

All parameters are optional:

- *value* of the coordinate – the box is usually used to verify the correctness of the joint description: stepwise changing of the value leads to motion of bodies;
- type of the joint force/torque (Chapter 2, Sect. *Joint forces and torques*) can be chosen from the drop-down list (Fig. 3.67) on the *Joint force* tab.

Fig. 3.67. Types of joint force

After the type has been chosen, the boxes for force parameters appear.

Some features of description of the force/torque see in
Linear, Sect. Linear force element
Frictional, Sect. Friction and elastic-frictional elements
Elastic-friction, Sect. Friction and elastic-frictional elements
Elastic-friction 2, Sect. Elastic-frictional element 2
Viscous-elastic, Sect. Viscous-elastic element
Points (numeric), Sect. Points (numbers)
Points (express.), Sect. Points (expressions)
Expression, Sect. Expression – explicit function
External function, Sect. External functions
List of forces, Sect. Fancher leaf spring

Coordinate is a time function

Use the *Prescribed time function* check box to set this type of the coordinate.

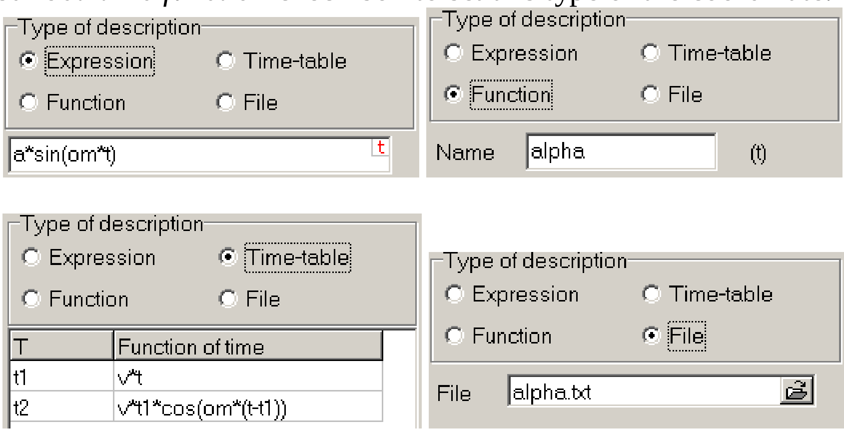


Fig. 3.68. Time function

The time function can be set as

- an explicit expression (Sect. 3.3.2.4.5)
- an external function (Sect. 3.3.2.4.6)
- a time table (Sect. 3.3.2.4.9)
- a function from a text file (Sect. 3.3.2.4.8)

Remark. Both rotational and translational joints is recommended to be transformed to the generalized joint type, e.g. to add degrees of freedom or to parameterize inclination of the joint axis, Sect. 3.4.9.3.

Example. User's manual, Chapt. 7, Sect. *Joint type conversion. Parameterization of axis inclination.*

3.4.9.5. Input of 6 d.o.f. joint

Detailed description of the joint can be found in Sect. Chapt.2, Sect. *Six d.o.f. joint*.

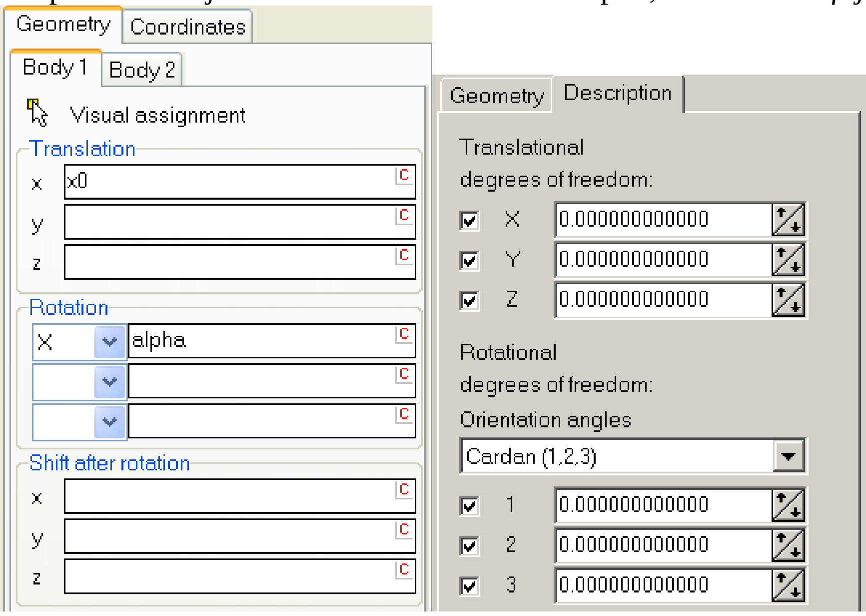


Fig. 3.69. Description of 6 d.o.f. joint

In addition to connected bodies (Sect. Sect. 3.4.8.1), the user should set positions of local joint system of coordinates SC1A and SC2B relative to SC1 and SC2 in the **Geometry** tab. For this purpose the sheets Body1 and Body2 are used, Fig. 3.69 left. The standard interface is used for parametric setting the SC positions, see Sect. 3.4.3.

The following parameters should be entered to specify the joint coordinates (Fig. 3.69, right):

- type of orientation angles;
- “turned on” degrees of freedom (check the presented degrees of freedom and turn off the others); the three upper rows correspond to translational d.o.f. (Fig. 3.69).

Use the buttons ↑↓ in the edit boxes to set initial values as well as to verify the correctness of the joint description.

Remark 1. Cut joints with **six** d.o.f. are ignored in the Simulation program.

Remark 2. 6 d.o.f. joint can be converted to the generalized type to introduce joint forces for some degrees of freedom, Sect. 3.4.9.3.

Example. An example of a joint used for setting six degrees of freedom of a box relative to SC0 according to data in Fig. 3.69 left for *x0*=1m, *alpha*=30 degrees is shown in Fig. 3.70. The box is shown in the position corresponding to zero values of joint coordinates. Features of the joint are the parametric description of both the SC1A origin (shift along the X-axis *x0*) and angle of rotation about the X axis (*alpha*). As a result two translational and two rotational degrees are specified along inclines axes Y and Z.

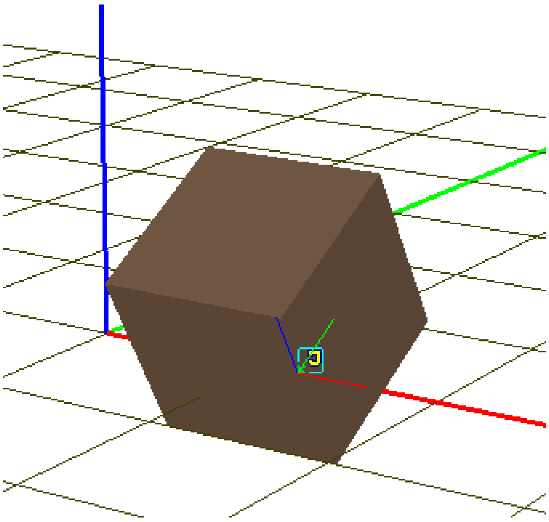


Fig. 3.70 Example of a joint with six degrees of freedom

3.4.9.6. Input of joint of generalized type

The joint description consists of a sequence of elementary transformations (ET), Chapt.2, Sect. *Generalized joint*.

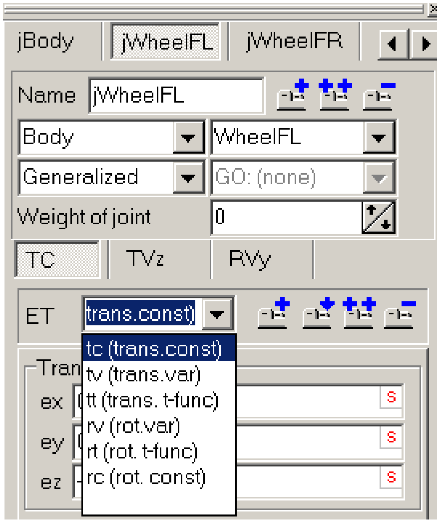
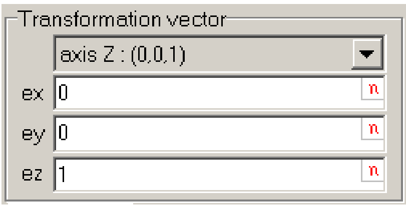


Fig. 3.71. Generalized joint

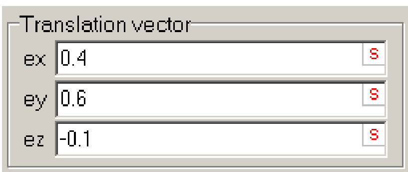
The list of ET is created with the help of the standard interface. To specify a type of ET use the pull-down menu (Fig. 3.71). Boxes for ET parameters appear after the choice of the type.

A unit transformation vector should be entered for all ET types except *tc* (the vector cannot be zero).



Use the pull-down list to set a standard value of the vector.

3.4.9.6.1. Elementary transformation tc



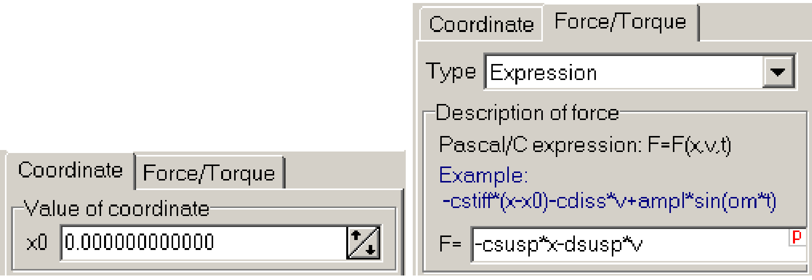
Enter a shift vector, which components are constant symbolic expressions (Sect.0).

3.4.9.6.2. Elementary transformation rc

Angle of rotation (in degrees) must be entered in addition to the transformation vector.

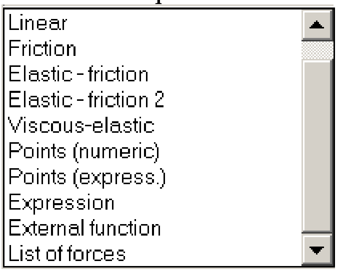
Remark. Use the *rt* type to set the constant rotation angle as an identifier or constant expression.

3.4.9.6.3. Elementary transformations tv, rv



The following parameters can be optionally set in addition to the transformation vector

- Numeric (initial) *value* of the joint *coordinate* (an angle coordinate is entered in degrees); use the buttons in the edit box to get the animation of motion corresponding to changing the coordinate.
- Mathematical model of a joint force/torque. Choose the force type from the list



After the type has been chosen, the boxes for force parameters appear.

Some features of description of the force/torque see in

Linear, Sect. Linear force element
Frictional, Sect. Friction and elastic-frictional elements
Elastic-friction, Sect. Friction and elastic-frictional elements
Elastic-friction 2, Sect. Elastic-frictional element 2
Viscous-elastic, Sect. Viscous-elastic element
Points (numeric), Sect. Points (numbers)
Points (express.), Sect. Points (expressions)
Expression, Sect. Expression – explicit function
External function, Sect. External functions
List of forces, Sect. Fancher leaf spring

3.4.9.6.4. Elementary transformations tt, rt

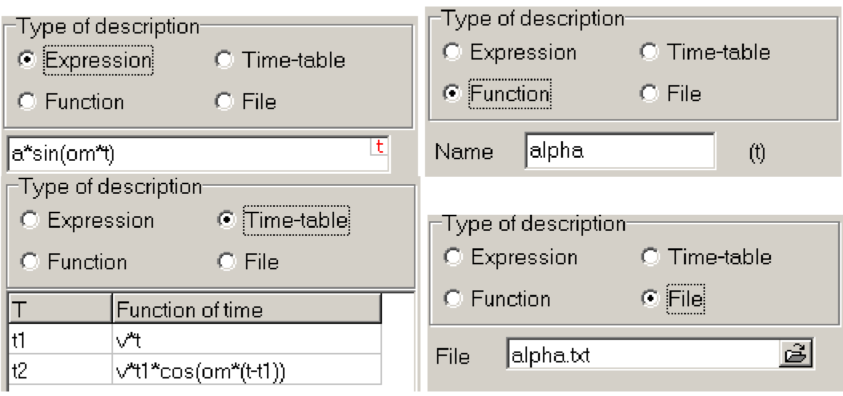


Fig. 3.72. Time function

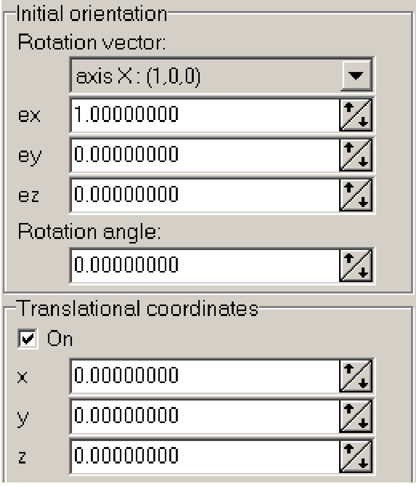
In addition to transformation vector enter a time function for the coordinate as

- an explicit expression (Sect. 3.3.2.4.5)
- an external function (Sect. 3.3.2.4.6)
- a time table (Sect. 3.3.2.4.9)
- a function from a text file (Sect. 3.3.2.4.8)

Remark. Use the type *rt* for entering a rotation with a constant angle, which can be set as an identifier or an explicit expression. In this case chose the *Expression* type of description and enter an expression, which does not depend on time *t* (Fig. 3.72, left).

Cut joints with 6 d.o.f. are ignored in the Simulation program.

3.4.9.7. Input of quaternion joint

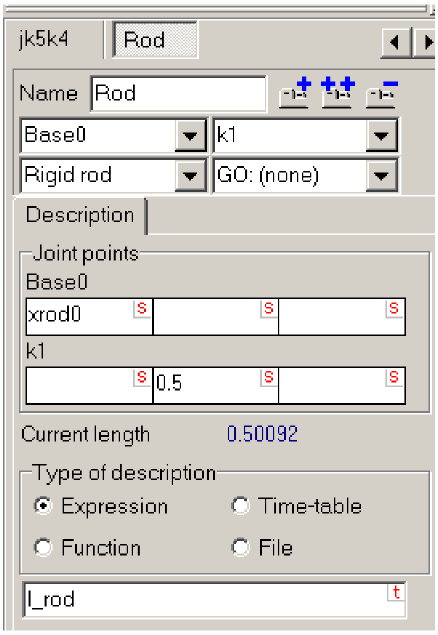


A detailed description of a quaternion joint can be found in Chapt.2, Sect. *Quaternion joint*. The following data can be set in addition to bodies and joint points (Sect.3.4.7.5):

- Initial orientation of the second body relative to the first one (angle is entered in degrees);
- Translational coordinates can be turned off to obtain a spherical joint;

Remark. Cut quaternion joints with 6 d.o.f. are ignored in the Simulation program.

3.4.9.8. Input of rod constraint



A detailed description of a rod joint can be found in Chapt.2, Sect. *Weightless rod constraint*. In addition to the bodies and attachment point (Sect. 3.4.7.5), the length of the rod should be entered. The length can be either constant of a time function.

Set a length as

- an explicit expression (Sect. 3.3.2.4.5)
- an external function (Sect. 3.3.2.4.6)
- a time table (Sect. 3.3.2.4.9)
- a function from a text file (Sect. 3.3.2.4.8)

As a rule, a graphic object is assigned to the rod (Sect. 3.4.5).

The current distance between the rod attachment points is presented in the *Current length* box. Use this parameter to verify the correctness of the length description.

Remark. The rod is a constraint. It does not introduce coordinates but restricts relative position of connected bodies. Exact calculation of positions in this case can be done in the Simulation program. That is why the current length of the rod in the Input program can differ from the real length entered by the user.

3.4.10. Input of force elements

The following constructor tabs are used for description of different force elements (Chapt. 2, Sect. *Force elements*): **Bipolar forces**, **Linear forces** (generalized linear force elements), **Contact forces**, **T-Forces**, **Special forces** (gearing and combined friction).

3.4.10.1. Input of bipolar force elements

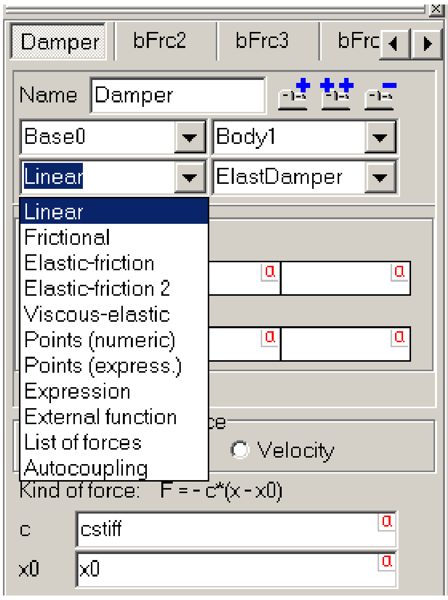


Fig. 3.73. Bipolar force element

General parameters of a bipolar element are:

- Adjusted bodies;
- Attachment points (constant symbolic expression);
- Type (use the drop-down list).

Other parameters of the element depend on its type and should be entered in boxes, which appear after choice of the type. Some features of description of the force as an explicit expression can be found in Sect. 3.3.2.4.5, as an external function – in Sect. 3.3.2.4.6.

Mathematical model of a bipolar force includes often the element length (the distance between the attachment points). Use the current *Length* parameter to verify the correctness of description of the element.

A GO is usually assigned to the bipolar force (Sect. 3.4.5).

Type of forces

Linear, Sect. Linear force element

Frictional, Sect. Friction and elastic-frictional elements

Elastic-friction, Sect. Friction and elastic-frictional elements

Elastic-friction 2, Sect. Elastic-frictional element 2

Viscous-elastic, Sect. Viscous-elastic element

Points (numeric), Sect. Points (numbers)

Points (express.), Sect. Points (expressions)

Expression, Sect. Expression – explicit function

Fancher leaf spring Sect. Fancher leaf spring

External function, Sect. External functions

List of forces, Sect. List of forces

3.4.10.1.1. Linear force element

General information about force element of this type can be found in Chapt. 2, Sect. *Types of scalar forces | Linear force*.

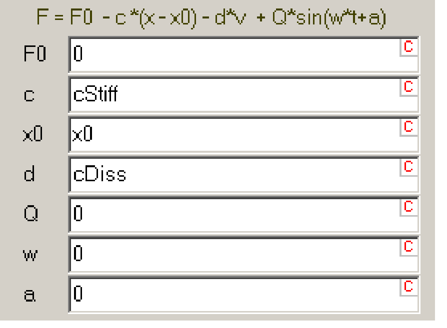


Fig. 3.74. Parameters of linear force element describing a linear viscous-elastic interaction

The boxes in the window (Fig. 3.74) correspond to the following parameters of the element:

- **F0** – constant component of the force;
- **cStiff** – stiffness constant;
- **cDiss –** damping constant;
- **x0 –** the coordinate for zero value of the elastic component;
- **Q, w, a** – amplitude, frequency (rad/s) and initial phase (rad) of the harmonic excitation.

All the parameters are constant symbolic expressions, Sect.0.

3.4.10.1.2. Friction and elastic-frictional elements

General information about force element of this type can be found in Chapt. 2, Sect. *Types of scalar forces | Friction force* and *Types of scalar forces | Elastic-friction force*.

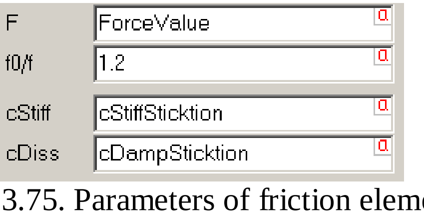


Fig. 3.75. Parameters of friction element

The following parameters should be specified:

- Friction force value *F;*
- Static/dynamic coefficient of friction ratio *f0/f;*
- Stiffness at sticking *cStiff*.
- Damping constant at sticking *cDiss*.

All parameters are constant symbolic expressions, Sect.0.

3.4.10.1.3. Elastic-frictional element 2

General information about force element of this type can be found in Chapt. 2, Sect. *Types of scalar forces | Elastic-friction force 2*.

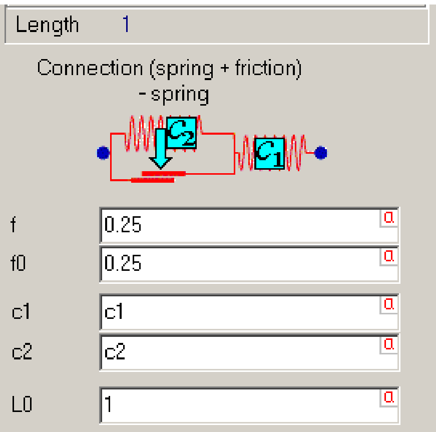


Fig. 3.76. Parameters of elastic-friction element 2

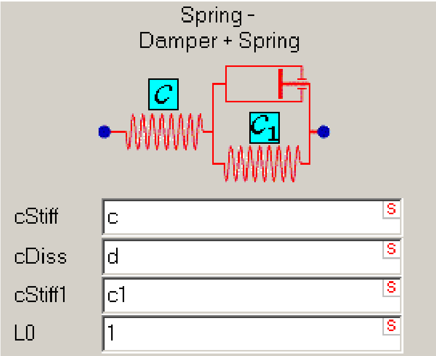
The following parameters should be specified:

- Dynamic coefficient of friction *f;*
- Static coefficient of friction *f*0 (usually equal to the dynamic one)*;*
- Stiffness of the first spring *c*1;
- Stiffness of the second spring *c*2;
- Element length in the unloaded state.

All parameters are constant symbolic expressions, Sect.0.

3.4.10.1.4. Viscous-elastic element

General information about force element of this type can be found in Chapt. 2, Sect. *Types of scalar forces* | *Stiffness and damping in series and in parallel*.



The following parameters should be specified:

- Stiffness *cStiff* in series (N/m), *c* in figure;
- Damping constant *cDiss* (Ns/m);
- Stiffness *cStiff* 1 in parallel (N/m), c_1 in figure (can be zero);
- Length of unloaded element L0 (ignored if c_1=0)

Parameters are constant symbolic expressions, Sect.0.

3.4.10.1.5. Points (numbers)

General information about force element of this type can be found in Chapt. 2, Sect. *Types of scalar forces* | *Points model*.

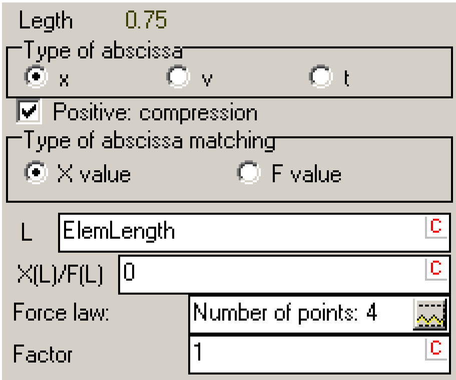
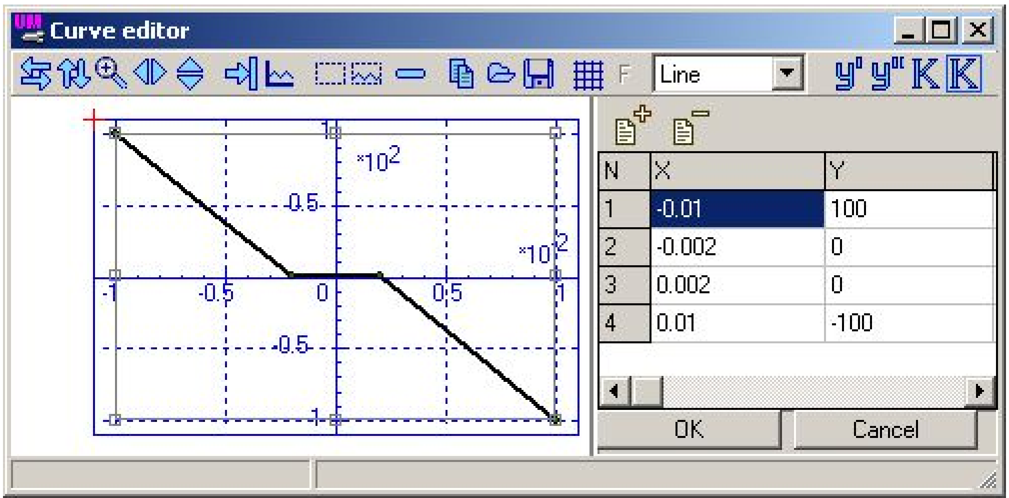


Fig. 3.77. Parameters of **Points (numbers)** element

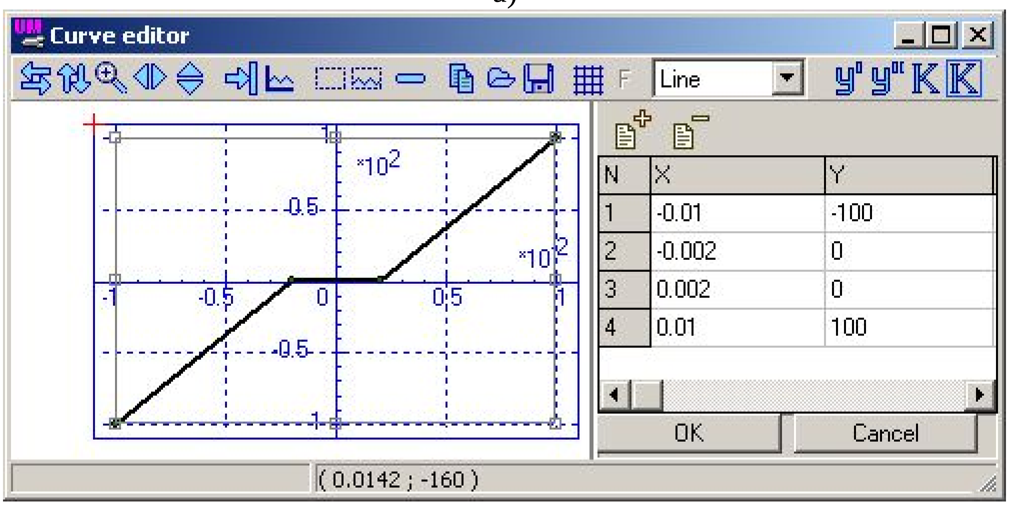
Curve editor is used to set a de of the force by a set of points (Sect.3.3.3, Fig. 3.78), use the button to call the editor.

The force can depend on the coordinate *x*, its velocity *v* or time *t*. Use the *Type of variable* group to select a necessary dependence.

The *Factor* parameter changes scale of ordinate values. Zero value of the factor, in fact, removes the element. Usually the multiplier is set by an identifier.



a)



b)

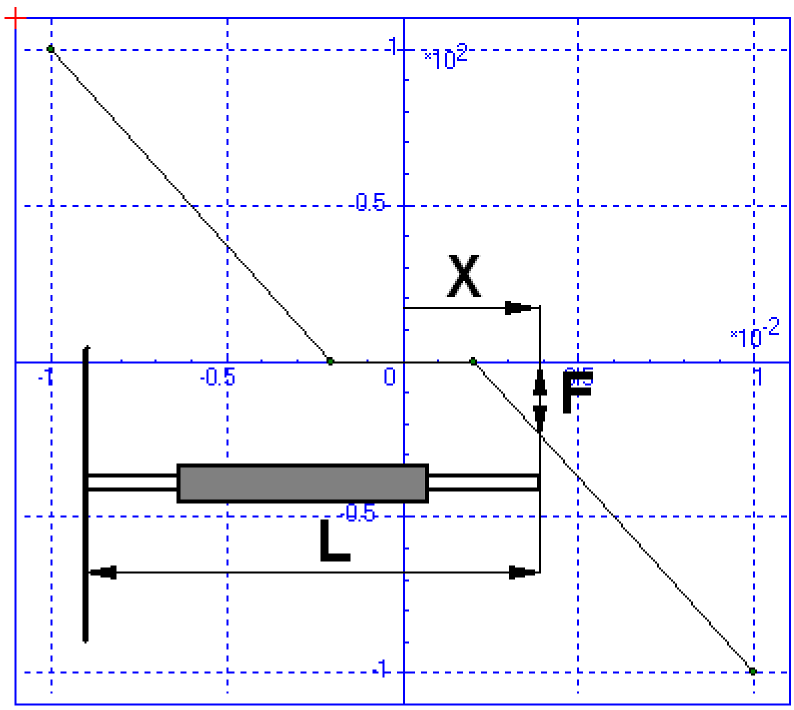
Fig. 3.78. Elastic bipolar force element with 4 mm gap; option "**Positive compression**" is off (a) and on (b)

The **Compression positive** option is used for choice of the positive abscissa value on the force law plot. If the option is *not checked* (the default value), abscissa **increases** with the growth of the length (coordinate); in this case the force usually decreases with the growth of abscissa. If the option is checked, on the contrary, abscissa **decreases** with the growth of the length (coordinate), and the force usually **increases** with the growth of abscissa.

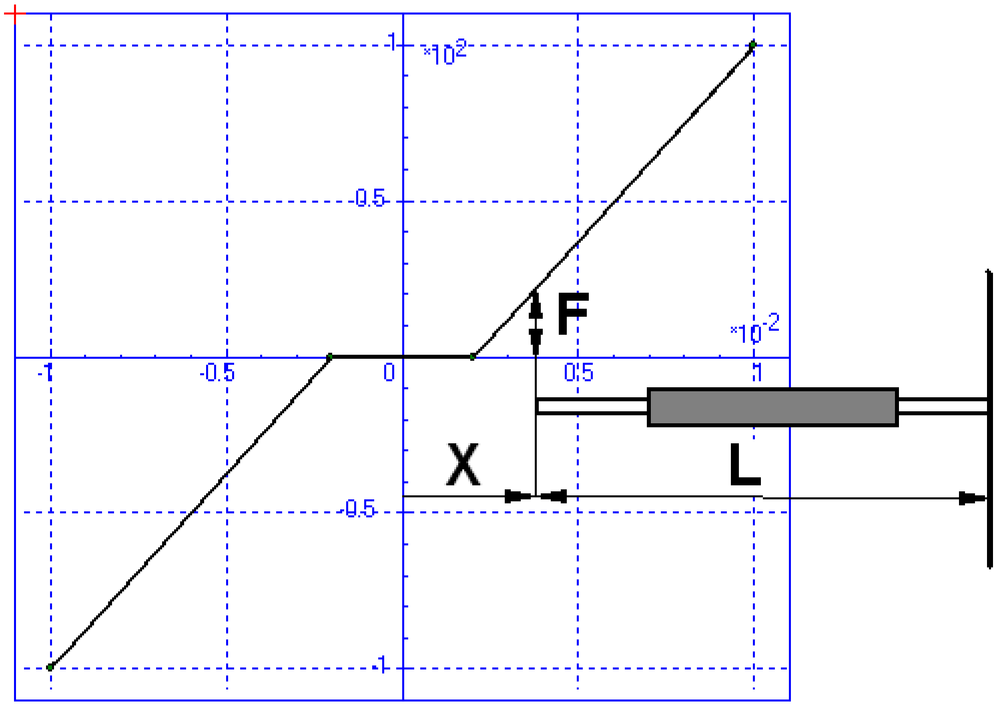
To insert data from a text file use the clipboard (Sect. 3.3.3.7).

Abscissa matching

Abscissa matching is often used in the case of a bipolar force element when the force depend on the element length. Matching means that abscissa value on the plot must correspond to a definite length *L* of the element, which value should be set in the **L** edit box**,** Fig. 3.77. Often L value is the element length for zero values of coordinates. Two methods can be used for assignment of abscissa value to the element length according to the **Type of abscissa matching** group**,** Fig. 3.77. If the **X-value** option is selected, the abscissa value corresponding to L is directly set in the **X(L)/F(L)** edit box. Often this value is zero, X(L)=0. If the **F-value** option is selected, the force value corresponding to the length L is set, and program compute the corresponding abscissa value automatically. It is clear that in the last case the user must ensure the existence and uniqueness of solution X(F).



To the notion of abscissa matching. The **Compression positive** option is not checked.



To the notion of abscissa matching. The **Compression positive** option is checked.

3.4.10.1.6. Points (expressions)

General information about force element of this type can be found in Chapt. 2, Sect. *Types of scalar forces* | *Points model*.

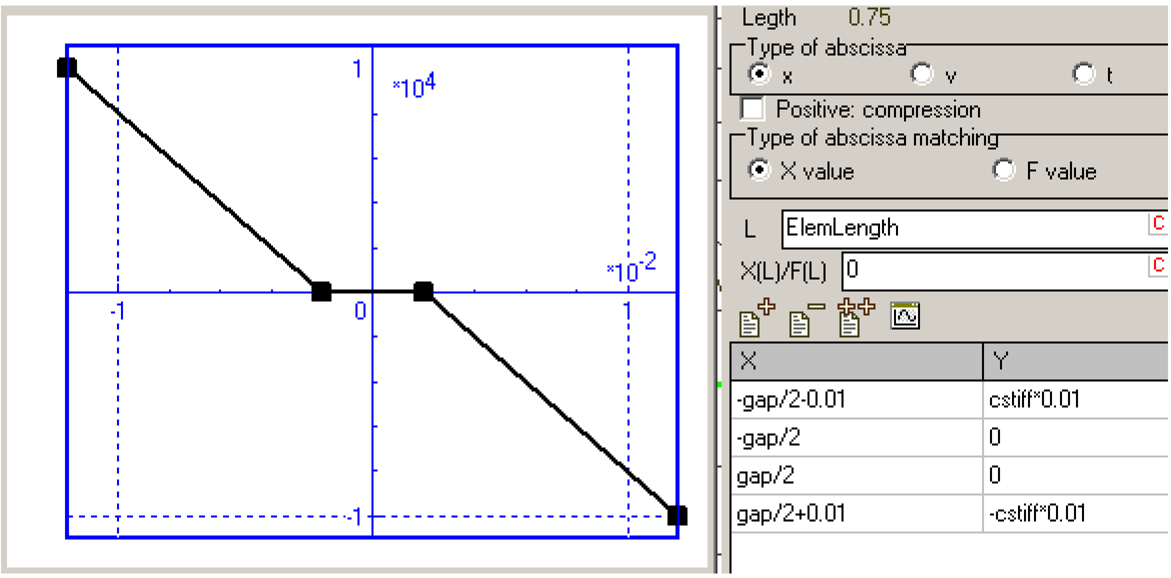
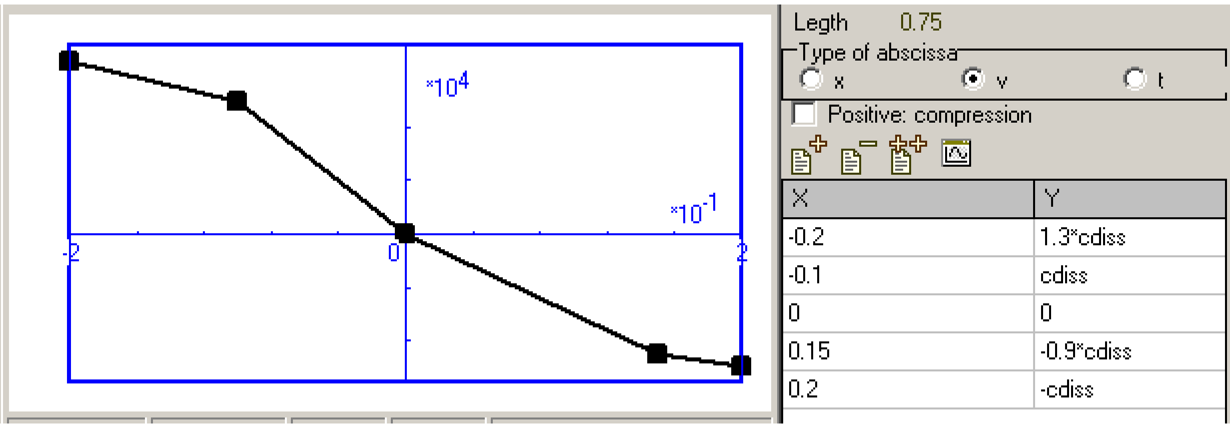


Fig. 3.79. Elastic bipolar force element with a gap, which value is set by the **gap** identifier

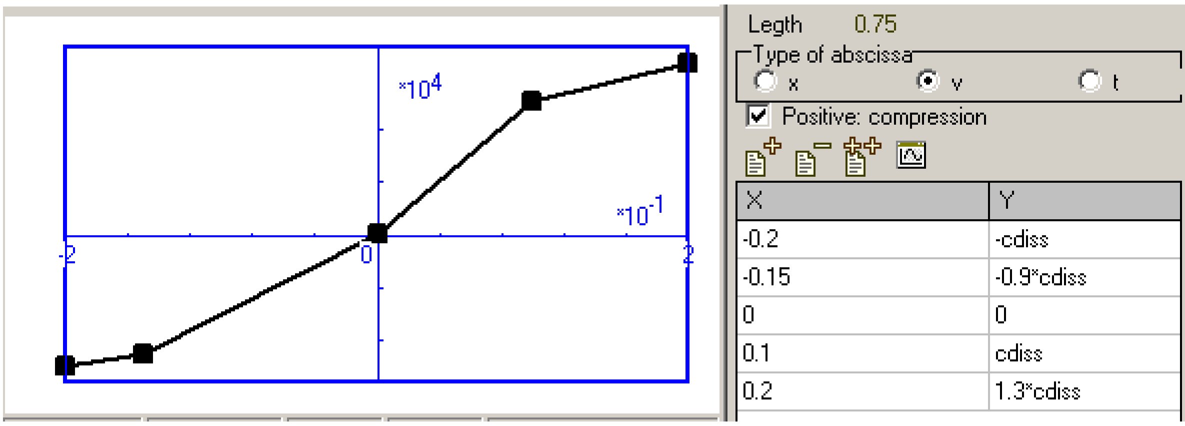
The force element is similar to the previous one, but both abscissa and ordinate coordinates of points can be set by expressions.

Use the buttons to add, copy or delete a selected point. The button is used for preview the function in a graphical window.

In the figures of this section we consider a description of the same function as in the previous one but the length of element, clearance, and stiffness are parameterized. Parameterization allows changing these parameters in the simulation.



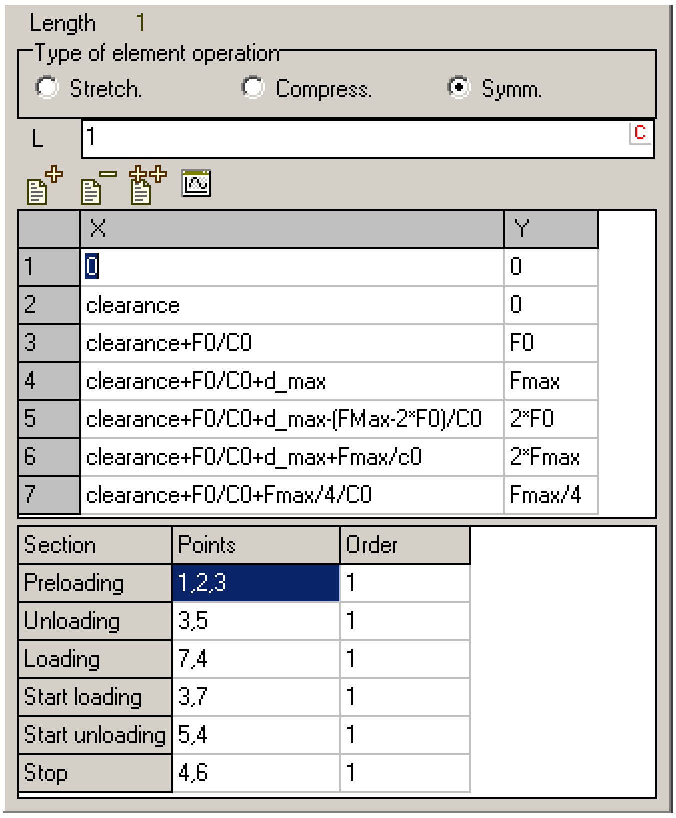
Nonlinear damper. The **Compression positive** option is not checked.



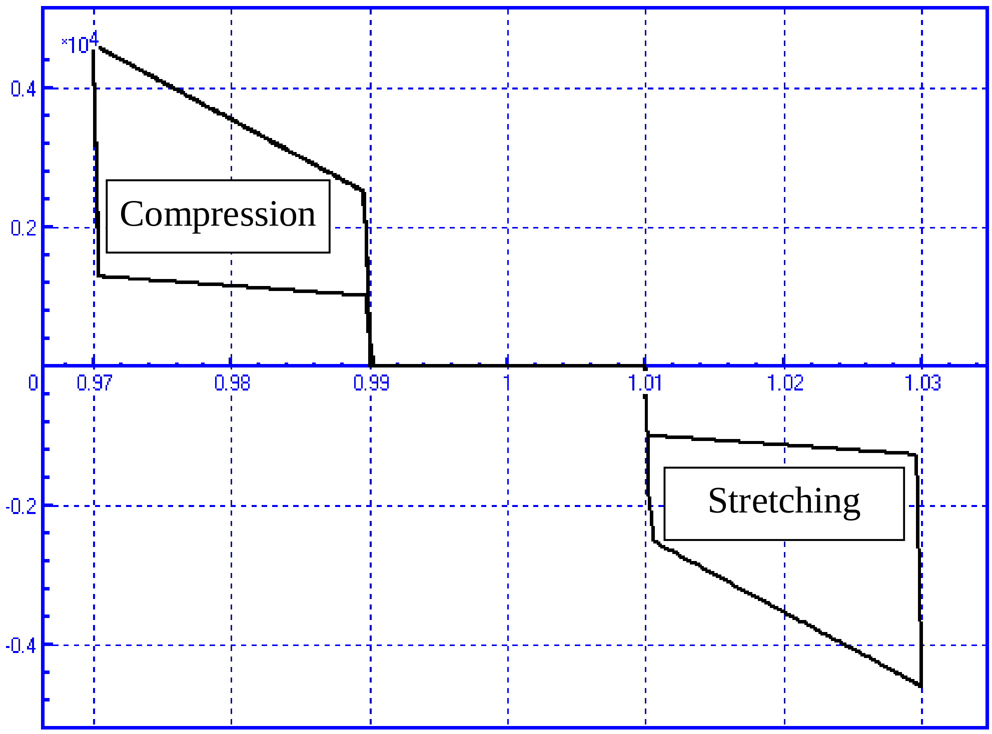
Nonlinear damper. The **Compression positive** option is checked.

3.4.10.1.7. Hysteresis

Mathematical model of the force is described in Chapt. 2, Sect. *Types of scalar forces / Hysteresis*.



Example of hysteresis data input window



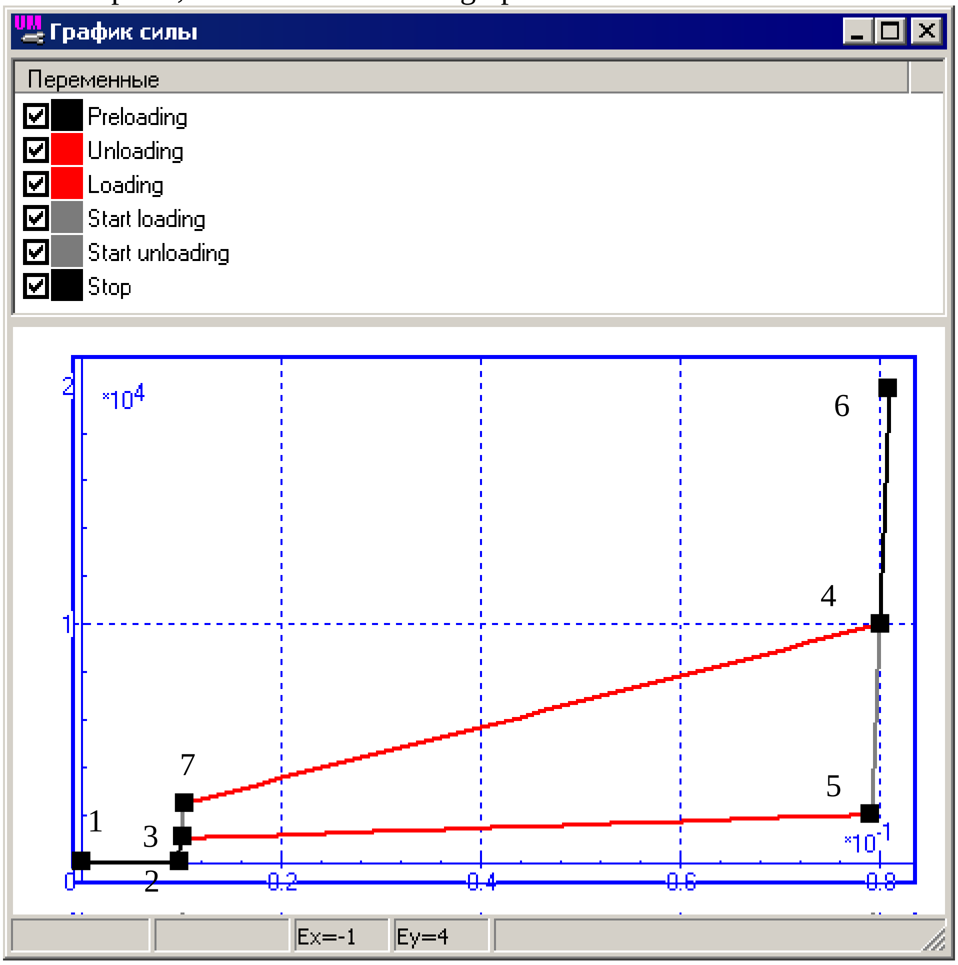
Example of hysteretic element with symmetric operation relative to length 1 m

The **Type of element operation** group:

- **stretch(ing)** – the element works only if coordinate value is greater than the value in the **L** box;
- **compress(ion)** – the element works only if coordinate value is less than the value in the **L** box;
- **symm(etric)** – the element works symmetrically both by stretching and by compression.

The **L** box – the element length/coordinate value corresponding to the zero value of abscissa of points.

The buttons of operations with the list of points – add a point, delete selected point, copy selected point, and draw data in the graphic window.



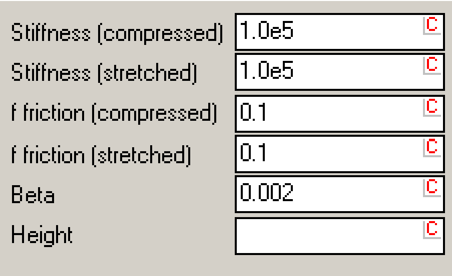
Graphic window with hysteresis data

Coordinates of points can be parameterized.

Numbers of points separated by commas for hysteretic curves are entered in the lowest table of the data window. Orders of interpolation polynomials are set in the last column of the table (order 1 corresponds to a polyline).

More details about hysteretic element can be found in Chapt. 2, Sect. *Types of scalar forces / Hysteresis*.

3.4.10.1.8. Fancher leaf spring



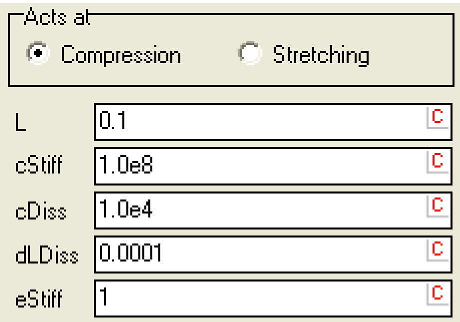
The mathematical model of the element can be found in Chapt.2, Sect. *Fancher leaf spring*.

Force model parameters:
Stiffness (compressed) – the spring vertical stiffness in the compressed state, c;
Stiffness (stretched) – the spring vertical stiffness in the stretched state, c;
f friction (compressed) – the value of friction coefficient in the compressed state, f;
f friction (stretched) – the value of friction coefficient in the stretched state, f;
Beta - the exponential suspension parameter, β;
Height – the height of the spring in the unloaded state x_0.

All the parameters are constant symbolic expressions, see Sect.0.

Remark. The user should remember that bipolar force elements degenerate at zero length. The lengths of the Fancher elements in the model of the leaf spring must be at least two times greater than the maximal dynamic shortening the element even if the real prototype has a less height.

3.4.10.1.9. Impact (bump stop)



Mathematical model of the force element of this kind is described in Chapt.2, Sect. *Impact*.

The model has the following parameters:
L is the length of the element at zero clearance when force element starts to work, l;
cStiff is a stiffness coefficient in a contact, c;
cDiss is a damping coefficient in a contact, d;
dLDiss is the contact deflection where damping coefficient reaches its maximal value **cDiss**, Δ_d;
eStiff is the force curve exponent, is not used in the current version of UM software, assumed to be 1.

All the parameters are constant symbolic expressions, see Sect.0.

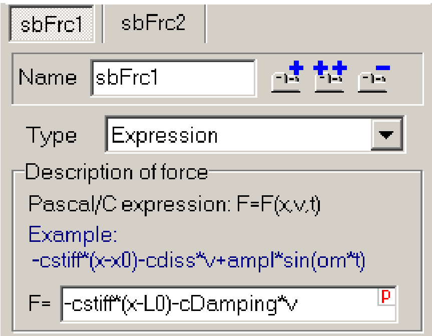
This force element can works as a border for compression and stretching modes. Let us consider the compression case. While the length of the force element more or equal to **L** than force is zero. As soon as the length of the element becomes less than **L**, the viscoelastic force starts to act. In the case of the stretching mode the force starts to act if the length of the element exceeds **L**.

If force element of *Impact* type acts as joint force than the **L** parameter should be considered as a joint coordinate. So introduced two force of this type (one for stretching, another one for compression) as joint forces in a joint we can define limits for the joint coordinate.

Dimensions of parameters for bipolar and joint forces are given in the table below.

Parameters	Dimension	
	Bipolar of joint force along translational degree of freedom	Joint force along rotational degree of freedom
L	m	rad
cStiff	N/m	Nm/rad
cDiss	Ns/m	Nms/rad
dLDiss	m	rad

3.4.10.1.10. List of forces



This type of force creates an arbitrary set of forces of the above types, which work in parallel. Use the  buttons to add, copy or delete a separate force.

3.4.10.2. Input of scalar torque force element

Mathematic model of the element is described in Chapt.2, Sect. *Scalar torque*.

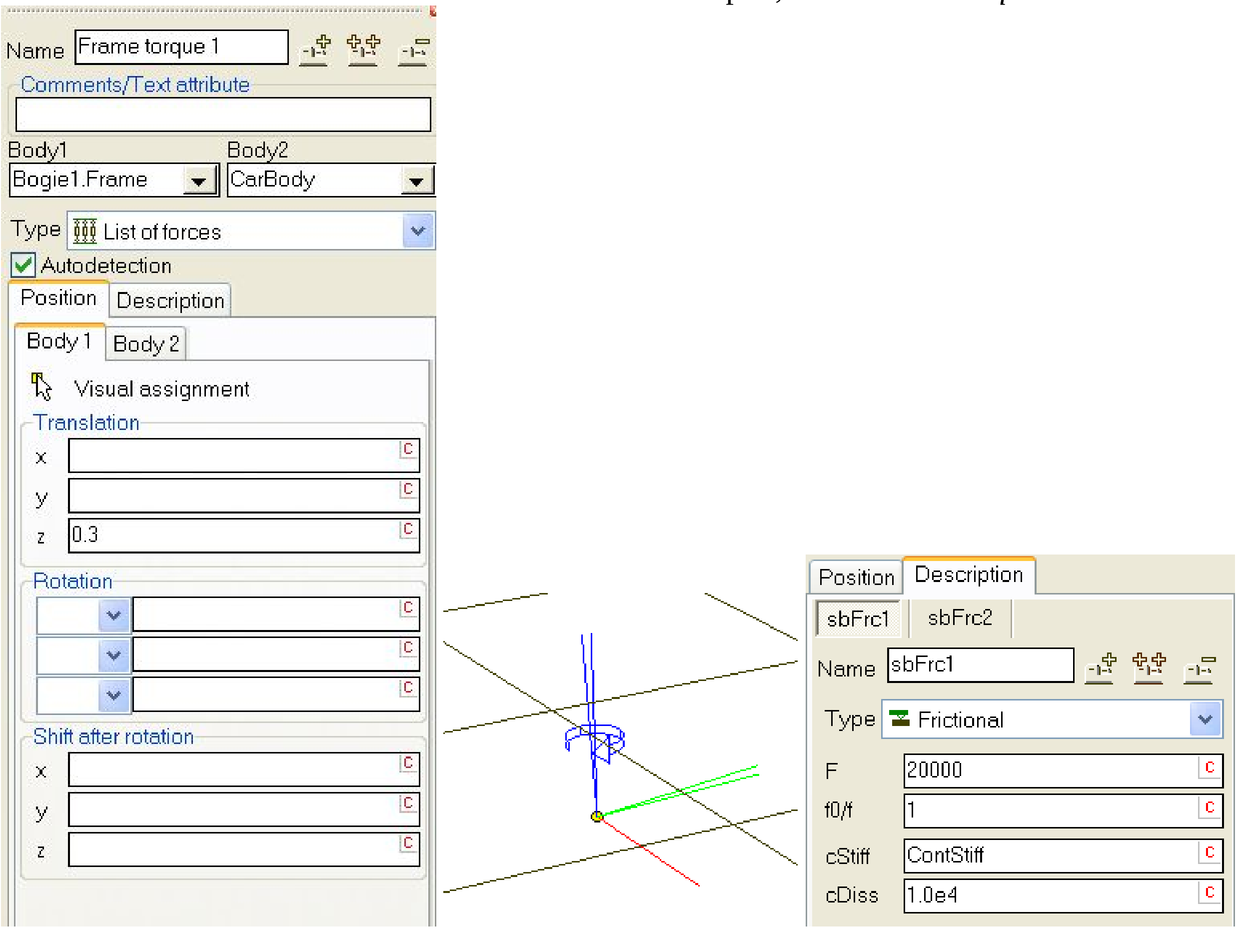


Fig. 3.80. Scalar torque description

Description of a scalar torques includes the following steps.

- Choice of interaction bodies.
- Setting additional local coordinate systems SCA1 and SCB2, Fig. 3.80, left. These systems of coordinates can be assigned visually by mouse using preliminary created oriented connection points for the necessary bodies. Systems of coordinates are drawn in animation window like in Fig. 3.80, middle. If the **Autodetection** mode is selected, position of SCB2 is computed by the program automatically: SCB2 coincides with SCA1 for *zero values* of all coordinates.
- Selection of the torque mathematical model type from the standard list of scalar forces. see Sect. Input of bipolar force elements for more details.

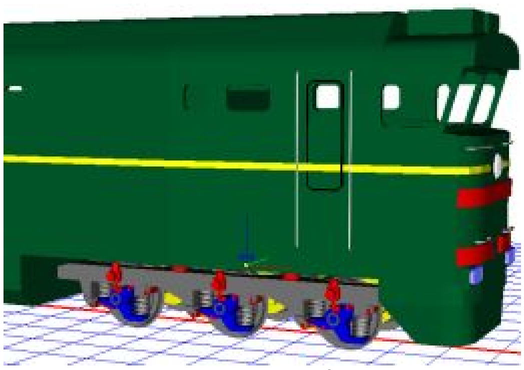


Fig. 3.81. Example of scalar torque

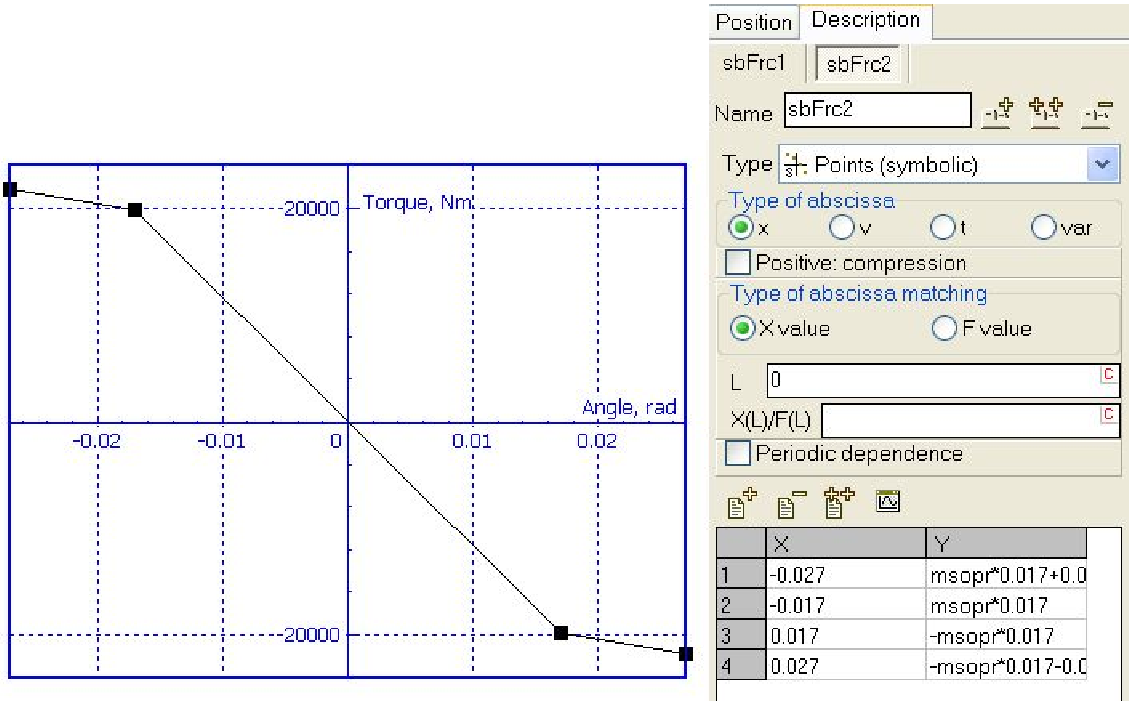


Fig. 3.82. Nonlinear elastic torque component

Example. Consider an example of usage of the scalar torque. In a model of a locomotive, a scalar torque appears when a car body turns relative to the bogie frame about the vertical axis, Fig. 3.81. The torque includes two components. The first one is a friction torque with the magnitude 2000Nm. The second one is a nonlinear elastic torque, which plot is shown in Fig. 3.82, left. In this case the torque type is ‘List of forces’. The list of forces includes two elements: a frictional (Fig. 3.80, right) and ‘Points symbolic’, Fig. 3.82, right.

3.4.10.3. Input of generalized linear force elements

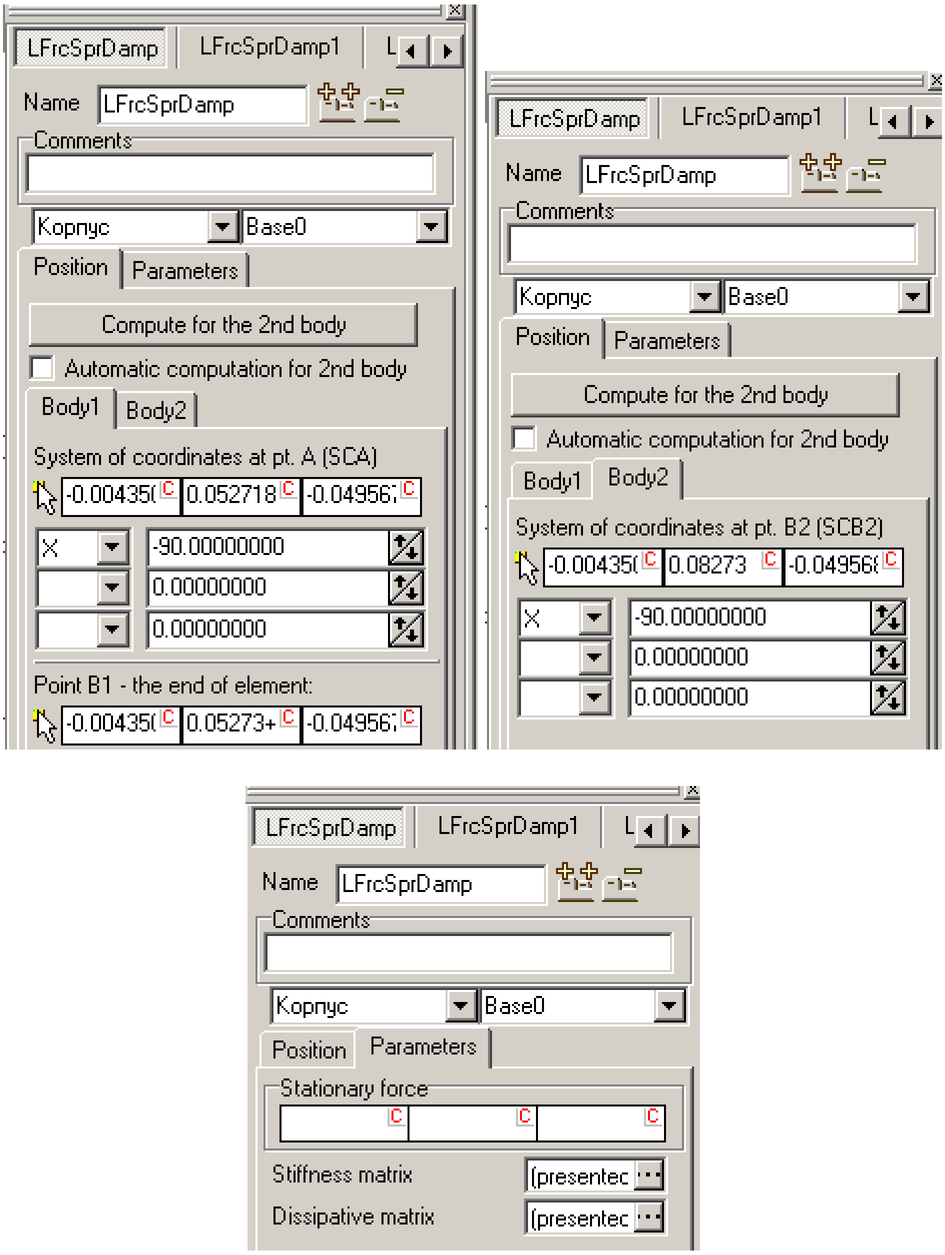


Fig. 3.83. Linear force element parameters

Mathematic model of the element is described in Chapt.2, Sect. *Generalized linear force element*.

Examples of description and/or usage:

- Chapt.7. Sect. *Models of Springs*
- model \demo\Manchester benchmarks\Vehicle1 (versions UM Loco, UM Demo)
- model \demo\wedgetest

General parameters of a linear element are:

- Adjusted bodies;
- Attachment points (constant symbolic expression) and element system of coordinates;
- Elements of stiffness and damping matrix (use the button in the corresponding box).

A GO is usually assigned to the linear elastic force (Sect. 3.4.2).

Coordinates of attachment points as well as elements of the stiffness/damping matrix are parameterized (Sect.0).

3.4.10.3.1. Some features of description of elastic element

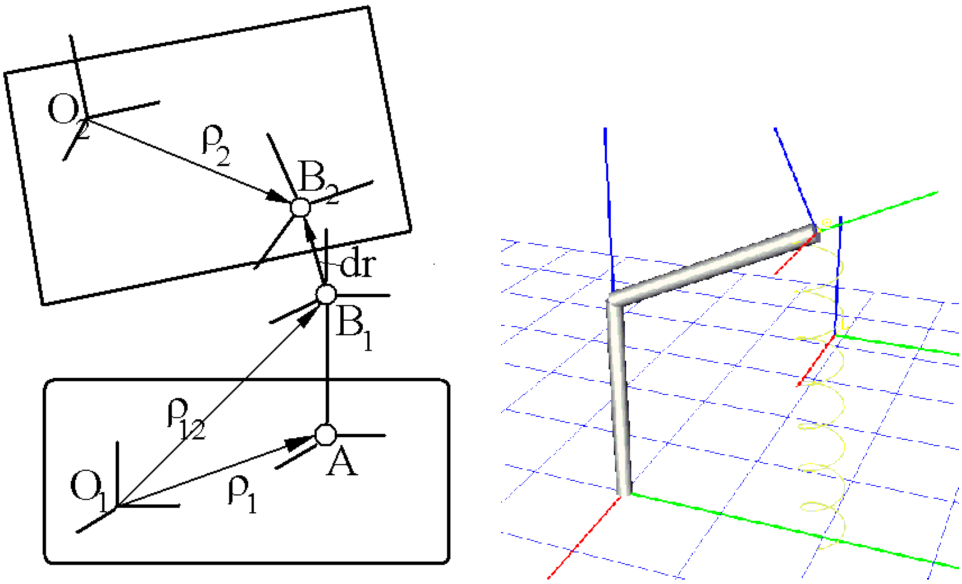


Fig. 3.84

Some details relevant to the elastic force element can be found in Chapt.2, Sect. *Generalized linear force element*. There can be found notations used in figures as well.

The following parameters should be entered for the first body attached to the element:

- Coordinates of points A, B_1 in SC of the first body;

For the second body (if the option *Automatic computation for 2^nd^ body* is off):

- Coordinates of point B_2 in SC of the second body;
- Orientation of SC connected with point B_2 relative to the SC of the second body (use up to three rotations). If the orientation does not set, the SCB_2 coincides with SC of the second body.

These data is not necessary for the second body if the *Automatic computation for 2^nd^ body* option in on. This option is used exclusively if the object is described in such a way that points B_1 and B_2 coincide at *zero values of model coordinates*. This case is quite usual for models of railway vehicles.

If you click the *Compute for the second body button*, UM computes coordinates of point B_1 in SC of the 2^{nd} body and inserts these values as coordinates of point B_2 (even if the *Automatic computation for 2^nd^ body* is off).

The stationary value of the force acting on the *second* body can be entered, too. The force is resolved in SC of the *first* body.

Coordinates of attachment points, components of stationary force, elements of the element matrix are parameterized (Sect.0).

Remarks:

1. Points A, B_1, B_2 as well as systems of coordinates attached to them are visualized in the single element mode (Sect.3.3.1.2.2). The icon marks point B_1.
2. These points are visualized in the whole object mode if the corresponding option is chosen (Sect. 3.3.1.2.2). Click the icon to call the window with element parameters.

3. Use general and oriented *connection points* (Sect. 3.4.7.4) to set points A, B_1, B_2 together with the attached SC. The connection points must be preliminary described for the corresponding body. The  buttons start the mode of visual selection of connection points.

3.4.10.4. Input of contact force elements

Use the **Contact forces** tab for description of the list of contact forces (Chapt.2, Sect. *Contact forces*).

Types of a contact force element:

- **Points-Plane;**
- **Sphere-Plane;**
- **Circle-Plane;**
- **Sphere-Sphere;**
- **Sphere-Z surface.**

Remark. Changing the type deletes all previous description of the element.

The first interacting body always contains the first type of contact manifold in the name of the contact. For instance, the first body contains *points* and the second one – a *plane* in the case of the **Points-Plane** contact.

There exist two tabs for description of an element:

- The **Parameters** tab contains **some** general contact parameters such as static and dynamic friction coefficient, contact stiffness and damping coefficient etc.;
- The **Geometry** tab contains **parameters** depending of the element type.

3.4.10.4.1. Points-Plane contact

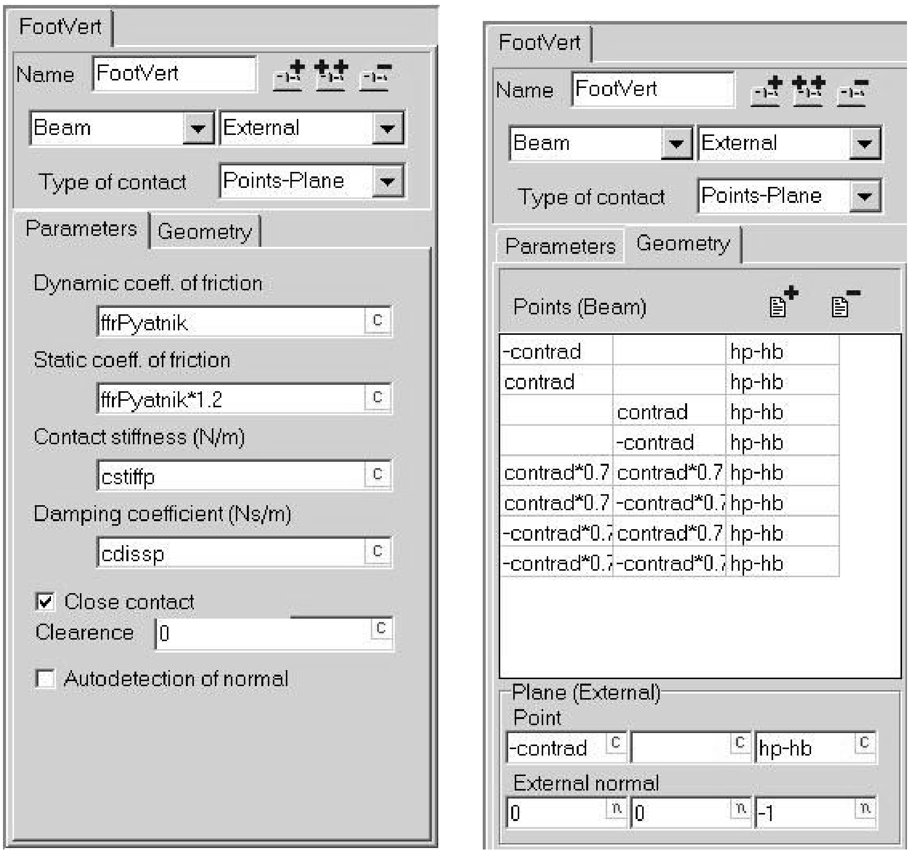


Fig. 3.85. Point-Plane contact

Check the *Close contact* box to set the mode of automatic detection of the normal to the plane and the point on the plane (Fig. 3.85). Some deviation of the normal as well as a clearance could be set in this mode.

Geometrical parameters of the contact are entered in the **Geometry** tab (Fig. 3.85).
Contact points belong to the first body. Use either keyboard or mouse to enter any set of the point.

Visual input of points

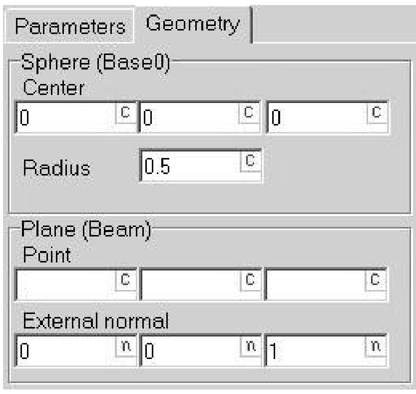
- Select the single element mode of the animation window (Sect. 3.3.1.2.2).
- It is often more simple to add a contact point by the mouse if the perspective is off and in the line graphics.
- Use the image of the first body and the *left* mouse button to add a new contact point to the list.
- Use the *right* mouse button to select visually a point already presented in the list. The left lower point of the corresponding icon is *active*.

To set the contact *plane* for the second body, enter the following parameters (if the *close contact* option is not set):

- A point on the plane in SC of the second body;
- **Outer normal** – a unit vector perpendicular to the plane directed to the first contacting body.

All the data except the normal are parameterized (Sect.0).

3.4.10.4.2. Sphere-Plane contact

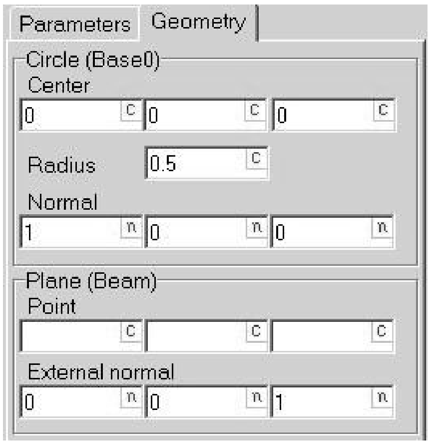


The contact sphere corresponds to the first body. The sphere is described by

- **Center** (a point in SC of the first body);
- **Radius**.

These data are parameterized.
The plane parameters are described in Sect. 3.4.10.4.1.

3.4.10.4.3. Circle-Plane contact

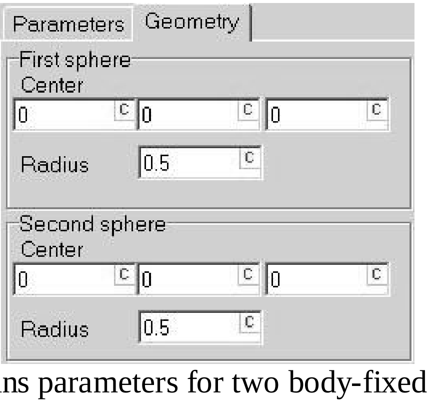


The contact circle belongs to the first body. The circle is described by

- **Center** (a point in SC of the first body);
- **Radius**;
- **Normal** to the circle plane (in SC of the first body).

The plane parameters are described in Sect. 3.4.10.4.1.
All the data except the normals are parameterized.

3.4.10.4.4. Sphere-Sphere contact

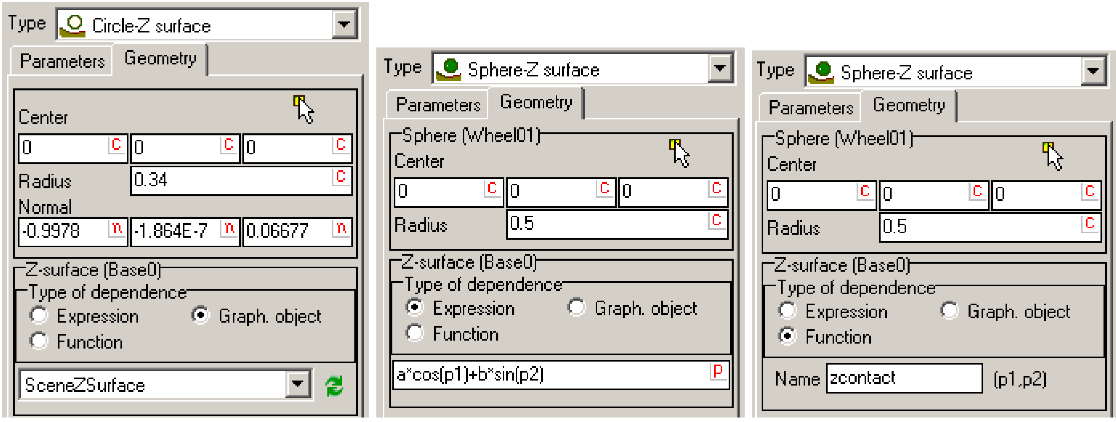


The element description contains parameters for two body-fixed spheres

- **Center** (a point in SC of the corresponding body);
- **Radius**.

These data are parameterized.

3.4.10.4.5. Points / Sphere / Circle - Z surface contact



The contact points / sphere / circle belong to the first body.

Sphere is described with the help of its center and radius. Circle is described with the help of its center, radius and normal to its plane.

A Z-surface belongs to the second body. The surface function corresponds to the second body and can be described by

- An explicit **expression** $z = z(p1, p2),\; p_1, p_2 \in (-\infty,+\infty)$;
- An external **function** *z = z(p1, p2)*, which should be programmed in the *Control file* (Sect. 3.3.2.4.6).
- A **Graph**[ical] **object** which is selected in the drop down list of graphical objects in the model.

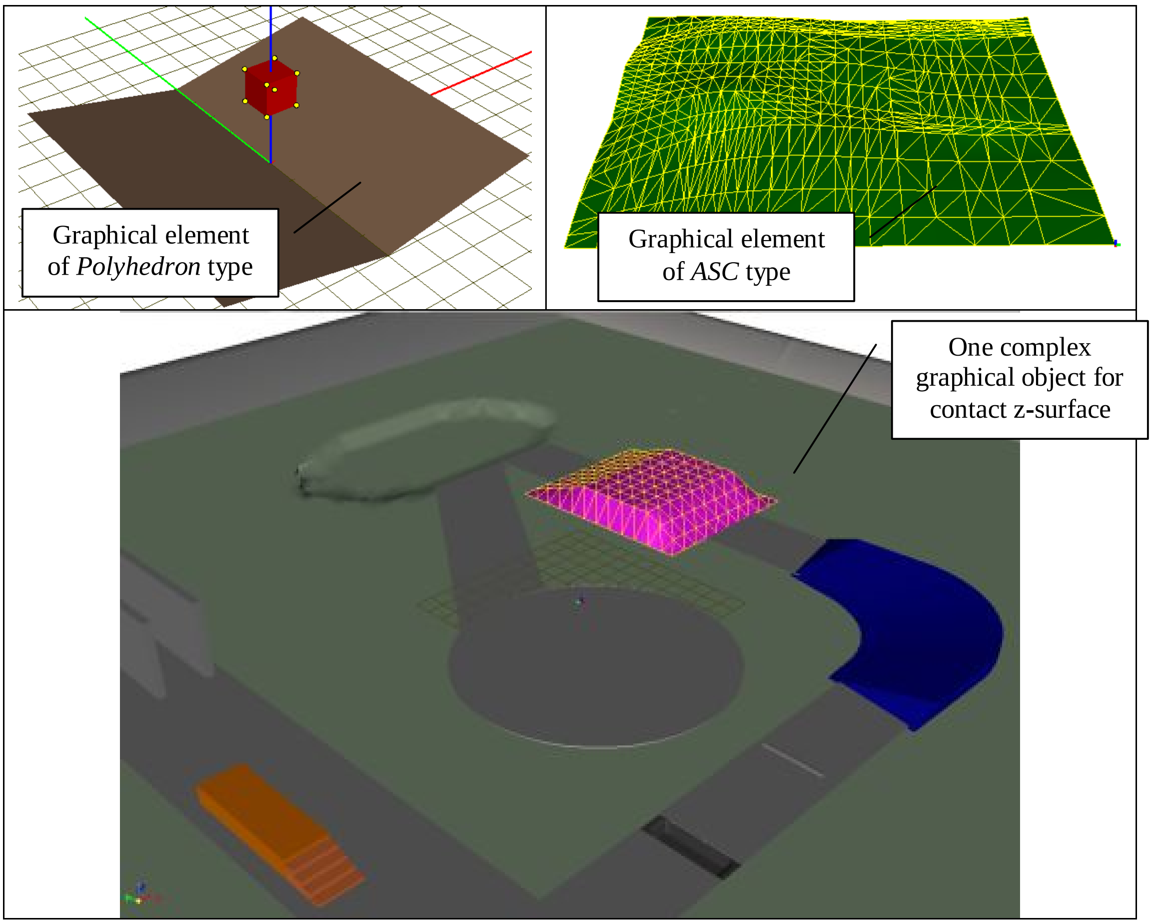


Fig. 3.86. Examples of graphical objects for z-surface

Please note the following things using z-surface as a **Graph**[ical] **object**.

- Selected graphical object can include one or several graphical elements of **Polyhedron**, **ASC**[1], **Box**, **Ellipsoid**, **Cone**, **Z-surface**.
- In the case if there are several possible *z*-coordinates for any (*x*, *y*) point the biggest *z*-coordinate will be considered.
- It is desirable that graphical object be smooth enough. Using essentially non-smooth surfaces might lead to incorrect results of simulation.

3.4.10.5. Input T-forces

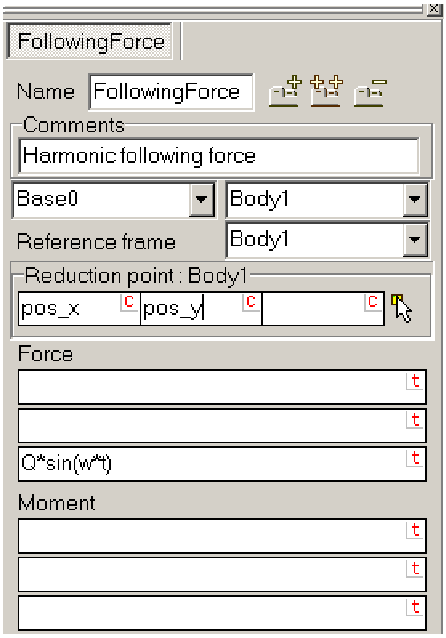


Fig. 3.87. Example of a harmonic following force

Use the **T-Force** tab to enter a set of force elements of T-type. An element is described by

- A pair of interacting bodies;
- A reference body for the force/moment components;
- A point the force is applied to (a point of the second body in the SC of this body); the button allows the visual setting the second body as well as the point of application using connection points (Sect. 3.4.7.4. Connection points).
- Force and moment components.

Remark 1. To describe a *following force*, set **Base0** as the first body, and the reference body coinciding with the second one.

Remark 2. Forces of this type are either explicit functions of time or are programmed by the user in the Control file.

Example. Description of a following harmonic force directed along Z-axis of the body1-fixed SC and applied to the point (*pos_x*, *pos_y*, 0) is shown in Fig. 3.87.

[1] Graphical objects of *ASC* type are created automatically during model import from external CAD-programms

3.4.10.6. Special forces

3.4.10.6.1. Gearing

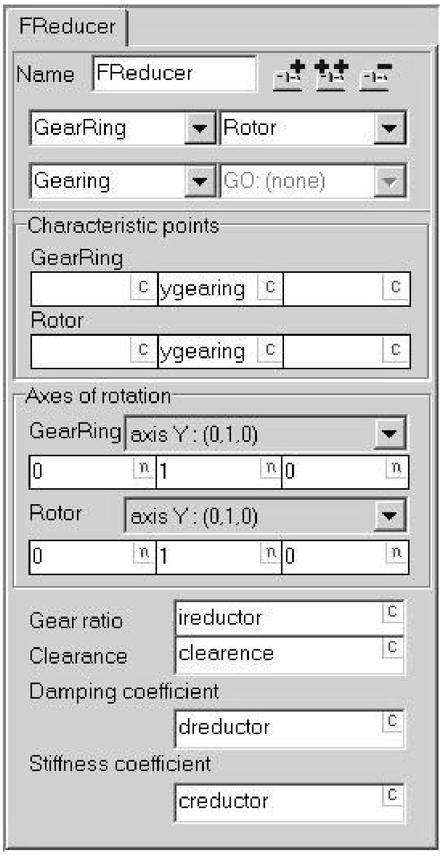


Fig. 3.88. Gearing parameters

A gearing is described by (Fig. 3.88)

- **Interaction points** (centers of gears in SC of the corresponding bodies);
- **Gear axes** (unit vectors in SC on the bodies);
- Gearing parameters: **gear ratio**, **clearance** (optionally), **stiffness** and **damping** coefficients of tangential contact of teeth.

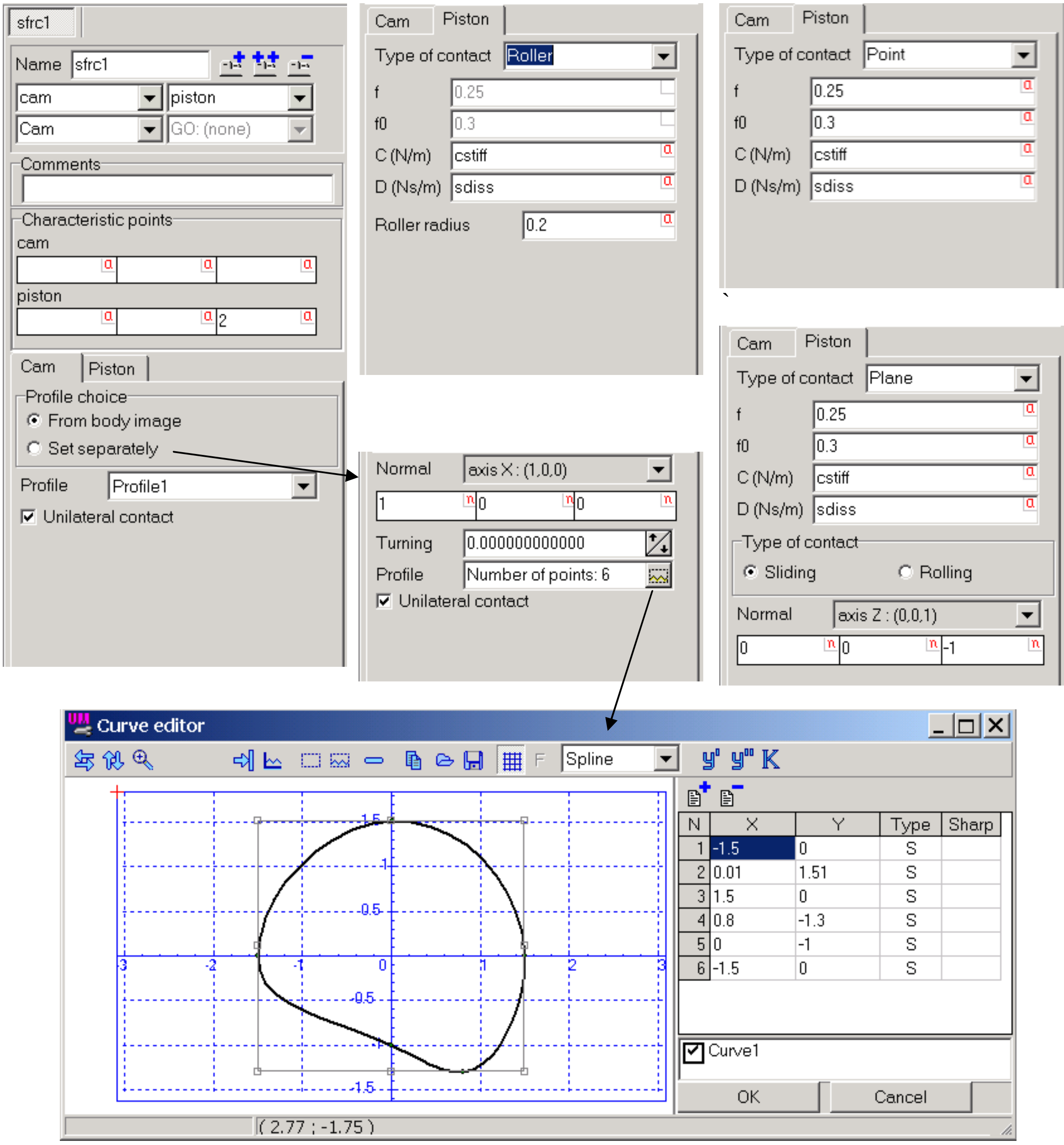
Check the **external/internal** option for plane gearing.
All the data except the gear axes are parameterized (Sect.0).
Gear axes and gear contours are visualized in the single element mode (Sect.3.3.1.2.2).

3.4.10.6.2. Cam

A plane cam connection is realized as a variant of a contact interaction of two bodies, see Chapt.2., *Special forces/Cam*

Example use usage:

- model \demo\cams



The *cam-piston* parameters are presented in the figure. The mathematical model of such the interaction is similar to the contact interaction described in Chapt. 2, Sect. *Contact forces*. To create a cam element, select the **Special forces** item in the element list add a new element. Set the type of the special force as **Cam**. As a result the inspector shows some boxes for the parameters of the cam (Body 1) and for the piston or the link (Body 2). The user should enter the following parameters:

- **Characteristic points** in SC of each body. The first point is a point of a cam profile plane (in the profile is not imported from the body image). The second one is a point of contact (contact type **Point**), the center point of a roller (contact type **Roller**) or a point on a contact plane (contact type **Plane**);

- **Profile of the cam** can be chosen as one of the graphic elements in the body 1 image (**From body image**) or as a planar closed curve created with the **Curve editor** (**Set separately**). Use **Unilateral contact** flag to choose either uni- or bilateral type of the contact;
- Set the **point**, **normal** to the profile plane and **angle** of rotation about the normal to define the location of the **separately** defined profile in the body1 SC;
- Cam profile can be chosen as one of the graphic elements in the body 1 if the image contain one of the following GE:
  - cone, if top and bottom radii are equal;
  - ellipse with equal semi-axes (circle);
  - element of the profiled type (*Curve* 2D profile type, axis should be a straight line), see. Sect. 3.4.6.2.8.
- **Piston parameters**. Here the user can set dynamic and static coefficients of friction (except the **Roller** contact type), coefficients of contact stiffness and damping and also radius of the roller (contact type **Roller**).
- Additional parameters for the Plane contact type
  - external **normal** to the piston plane;
  - type of contact **Sliding/Rollong**; the **Rollong** contact type, in particular, allow modeling the rolling of non-circular wheels on a plane.

All of the data except the normals and points on the cam profile points can be parameterized.

3.4.10.6.3. Spring

The mathematical model of the element is described in Chapt.2, Sect. *Special forces/Spring, Generalized linear force element*.

Examples of description and/or usage:

- Chapt.7. Sect. *Models of Springs*
- \demo\ac4 (versions UM Loco, UM Demo)

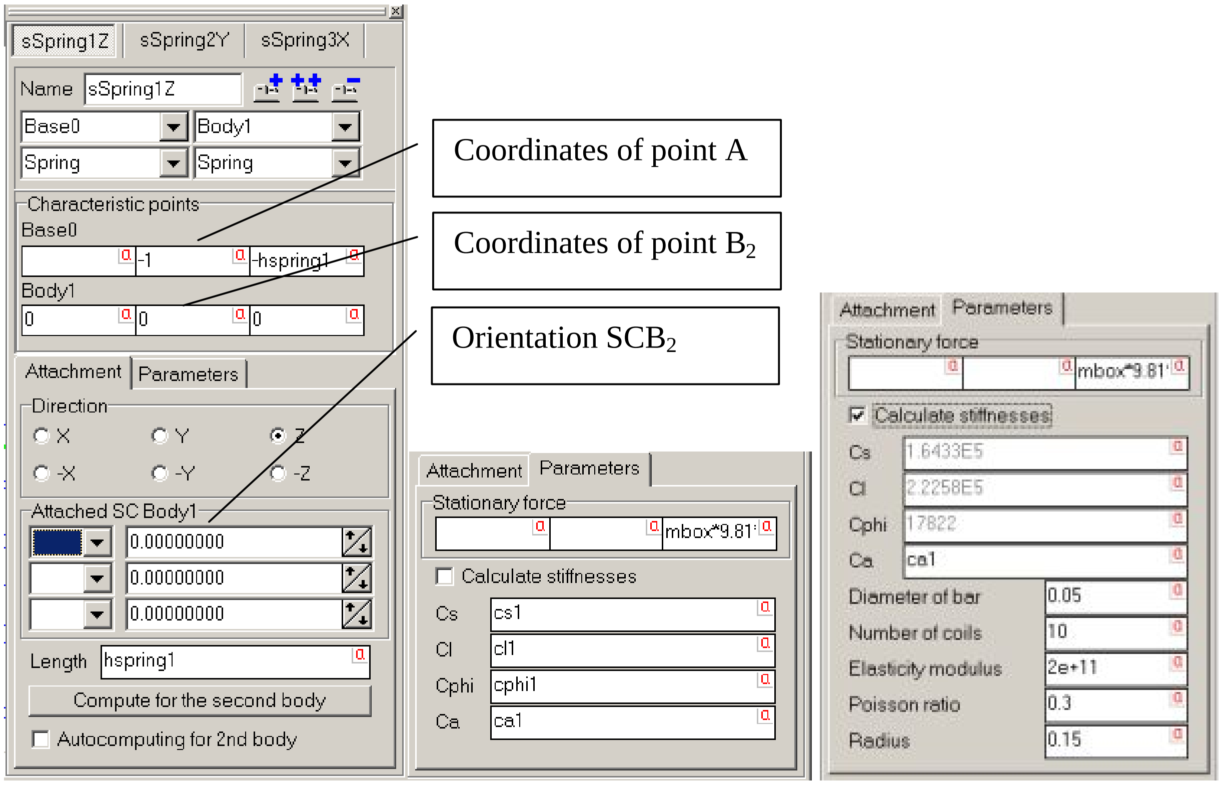


Fig. 3.89. Spring parameters

Description of spring parameters similar to that for a generalized linear force element to a considerable extent, namely:

- coordinates of points A, B_2,
- orientation of SCB_2,
- usage of the *Compute for the second body* button and the *Autocomputing for 2nd body* option,
- stationary force.

It is supposed therefore that the user have already studied input of generalized force element.

Here we consider some features of the spring description only.

1. Some equivalent information is entered instead o the point B_1: direction of the spring axis in SC of the first body (radio group *Direction*) and the length of the spring under the static load, which is set in the *Stationary force* group. If this force is zero, the length of free spring is set.
2. Stiffness parameters should be set at the Parameters tab:
   - shear (lateral) stiffness **Cs**,
   - longitudinal stiffness **Cl**,
   - bending stiffness **Cphi**,
   - torsion stiffness **Ca**.

These coefficients can be computed automatically according to spring geometrical and material parameters if the *Calculate stiffness* box is checked. These data can be parameterized.

3.4.10.6.4. Rack and pinion

Rack and pinion is a particular case of a gearing.

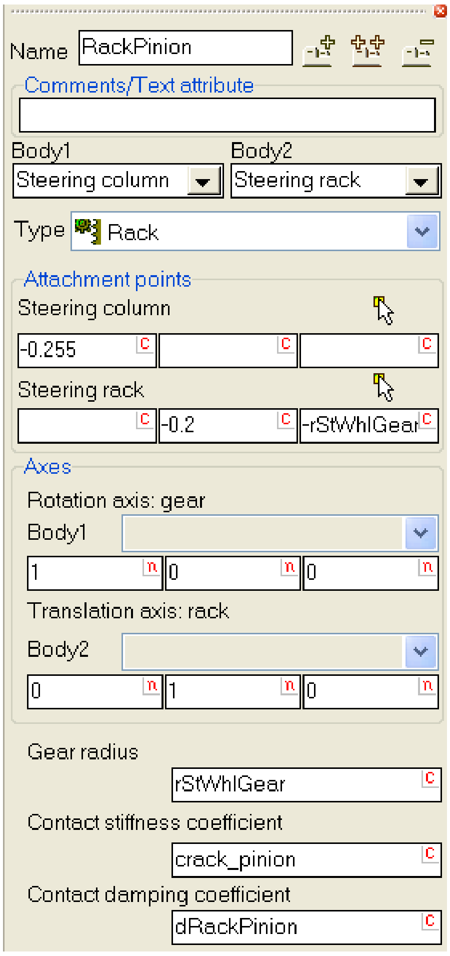


Fig. 3.90. Rack and pinion parameters

The following parameters describe rack and pinion mechanism, Fig. 3.90.

- Attachments points in SC of connecting bodies: center of pinion and point on the axis of the rack.
- Unit vectors along the pinion and rack axes (rotation and translation axes respectively).
- Pinion radius.
- Contact stiffness and damping parameters.

All parameters except unit vectors can be parameterized.

Example. Use of the rack and pinion force element in a car steering system is shown in Fig. 3.91 (see the car model \Samples\Automotive\Vaz21_09).

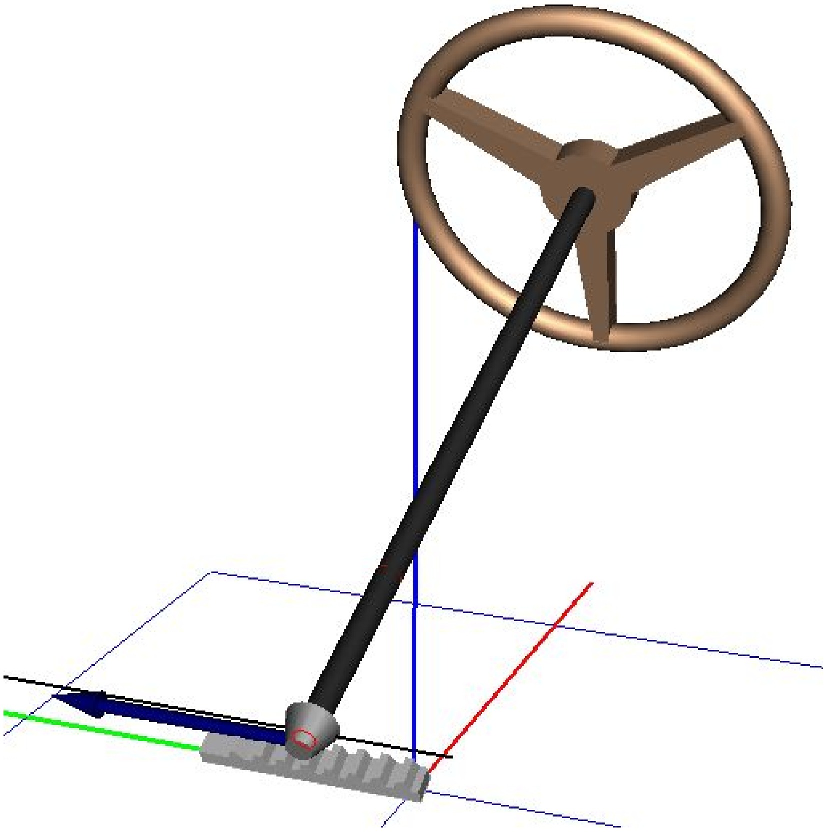


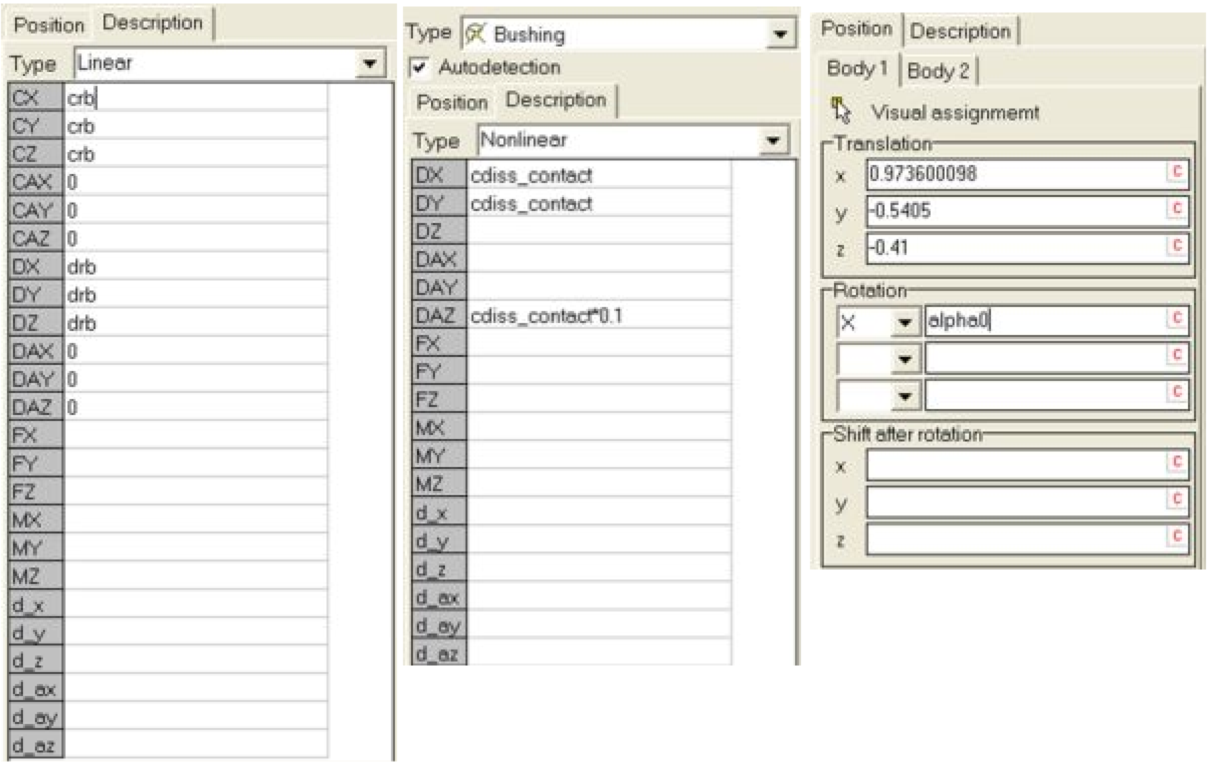
Fig. 3.91. Rack and pinion in the car steering system

3.4.10.6.5. Bushings

The mathematical model of the element is described in Chapt.2, Sect. *Special forces/Bushings*.

To describe a bushing

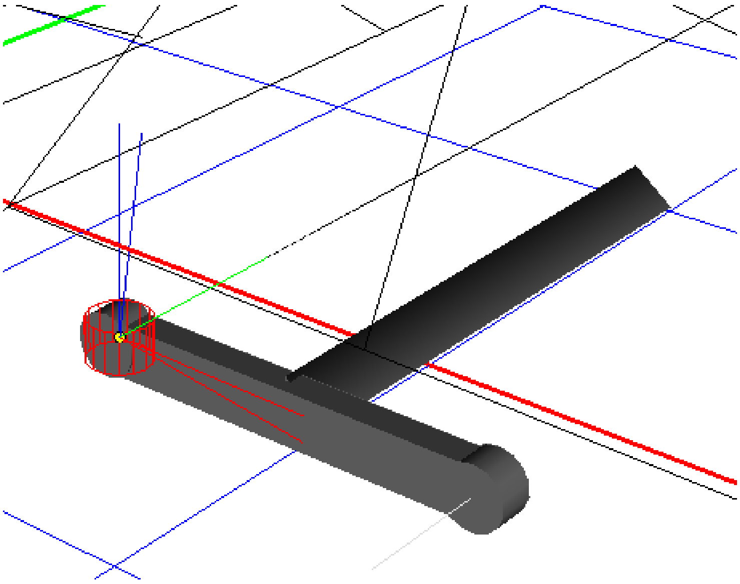
- set positions of SCB1 (Body 1) and SCB2 (Body 2) with a standard interface for specifying positions of local system of coordinates;
- select element type **Linear/Nonlinear**;
- in case of linear bushing: enter stiffness and damping constants for shifts (CX, CY, CZ) and rotations (CAX, CAY, CAZ) relative to axes of CSB1;
- in case of nonlinear bushing: enter damping constants and nonlinear plots for force and torque components versus the corresponding displacements and rotations;



a) b) c)

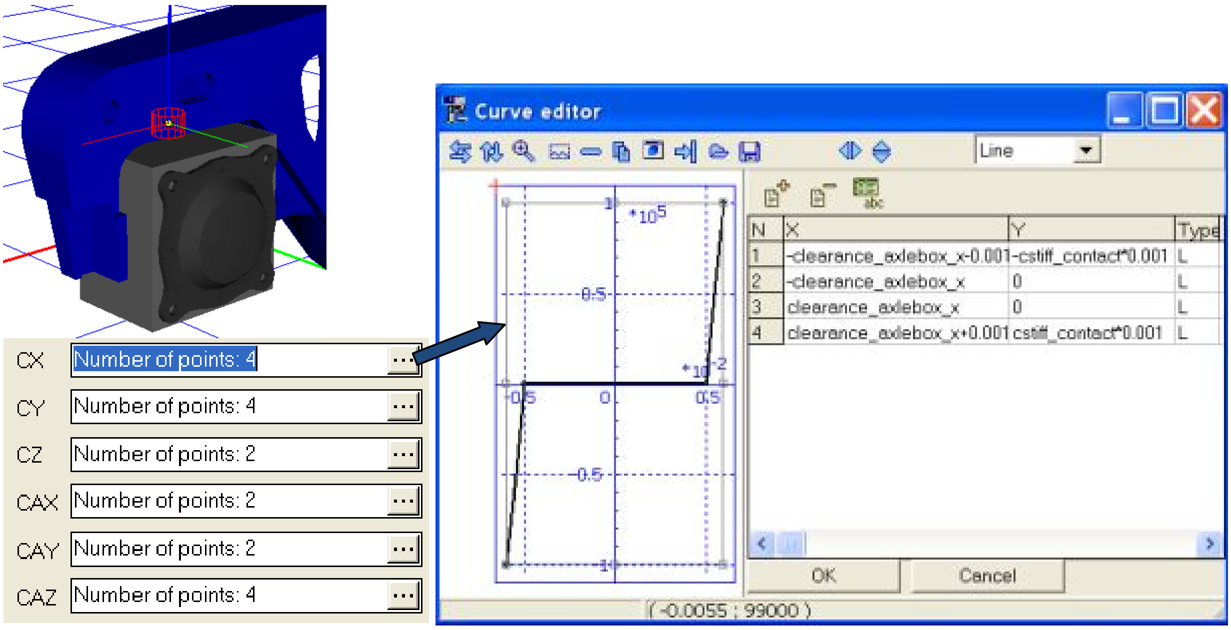
a) Linear bushing: compliant ball joint
b) Nonlinear bushing. Autodetection mode is on.
c) Position of SCB1

- if necessary set static values of force and torque F_0, M_0 (FX, FY, FZ, MX, MY, MZ) and/or static offset for SCB2 Δr_0, $\Delta\pi_0$ (d_x, d_y, d_z, d_ax, d_ay, d_az).



Example of a bushing: model VAZ21_09 from then Samples/Automotive directory

Busing icon is visible in the animation window in the single element mode as a red wired cylinder like in the figure above. SCB1 and SCB2 are drawn as well.



Example of a nonlinear bushing, which is used for modeling support and gaps between a side frame and an axle-box in the model of a three-piece bogie of a freight car

Remark 1. The following agreement about signs is assumed by description of nonlinear force and torque components. Positive value of elastic force/torque in a plot corresponds to positive value of displacement/rotation, see the above plot.

Remark 2. The **autodetection** mode is often can be recommended. At this mode position of SCB2 is computed automatically coincident with SCB1 *for zero values of object coordinates.*

All the parameters including angles of rotations are constant symbolic expression, Sect.0.

3.5. UM Components

3.5.1. Basic notions

UM components give an efficient tool for development of models. The following elements and substructures can be converted into a component form:

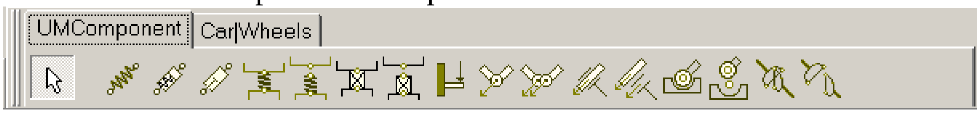
- body with/without image
- joint with/without image
- force element with/without image
- images
- subsystem
- object

Two files are assigned to any UM component: a text file with description of the component on UM language, and a bitmap (*.bmp) file with the component icon.

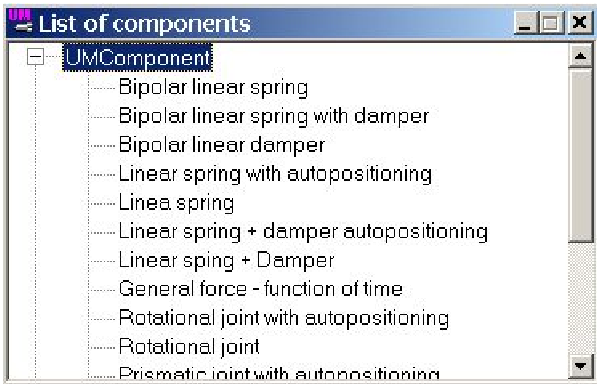
The standard extensions for the component text files are

- Joints: *.jnt
- Bodies: *.bdy
- Bipolar force elements: *.bfc
- Images: *.img
- Subsystem (UM object): *.sbs
- Generalized linear force element s: *.lfrc
- Contact forces: *.cfrc
- General type forces: *.afrc
- Special forces: *.sfrc

Each UM component can be parameterized. The corresponding identifiers and their default values are included in the component description file.



Component panel



List of components

A set of component can be grouped in a *component library*, which description is stored in a *.umc file. A tab on the tool panel corresponds to each of the *linked* component libraries. The library tabs or the list of component window are used for both visual and non-visual adding to the active object all elements included in the component. The component list window is available by then **Tools | List of components** menu command.

The button  is visible in the visual mode otherwise it is invisible. To switch between the modes

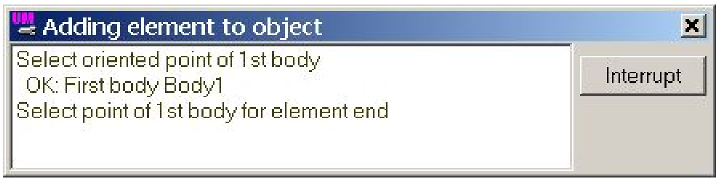
- click the right mouse button on the tab with components;
- use the **Visual design** menu command in the pop up menu.

3.5.2. Adding a component in visual mode

Visual adding components requires a preliminary description of connection point for bodies, Sect. 3.4.7.4. In this mode the components can be connected with the elements already presented in the object by a very simple and intuitively clear manner. This is the advantage of visual adding in comparison with the non-visual one.

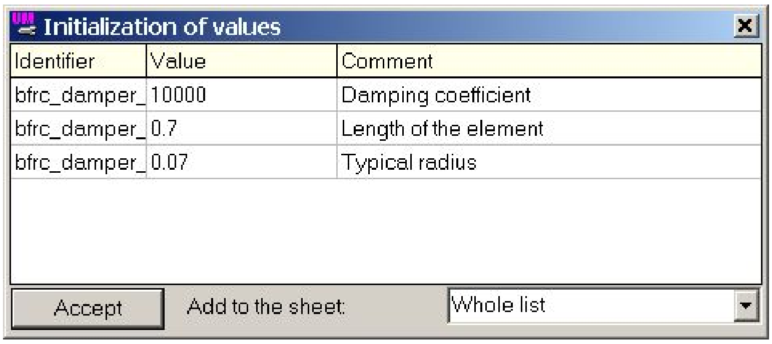
To add a component in the visual mode

- Click by the left mouse button on the component button or double click on the component name in the component list window. The full object mode of the animation window is switched on automatically, Sect. 3.3.1.2.2, and connection points are visualized.



Design help window

- Follow instructions in the design help window by selecting connection points.



List of identifiers of a component

- If necessary, set desired values of identifiers included in the component

To cancel the process of visual adding a component clicks either the  button on the component panel or the **Interrupt** button on the report window.

3.5.2.1. Visual adding generalized linear elastic or viscous-elastic forces

The generalized linear force element is an important tool for description of springs and viscous-elastic elements. We recommend to study the mathematical model of the element before start its usage because the model in quite not trivial, See Chapter 2.

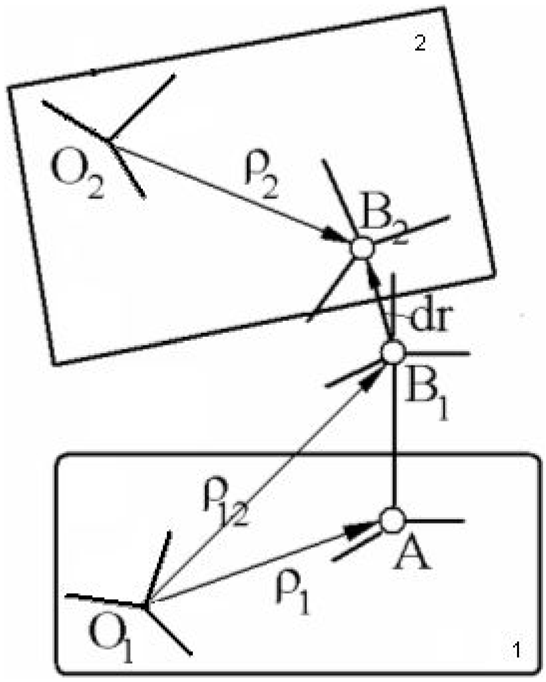


Fig. 3.92. Systems of coordinates related to linear force elements

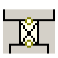
Description of geometric data for an elastic force element includes the following systems of coordinates (SC, **Fig. 3.92**):

- SC1 - local SC of body 1 with origin O1
- SC2 - local SC of body 2 with origin O2
- SCA - fixed relative to body 1, begin of the linear force element, origin at A
- SCB1 - fixed relative to body 1, end of the linear force element in unloaded state or under the static load, origin at B1
- SCB2 - fixed relative to body 2, end of the linear force element in unloaded state or under the static load, origin at B2

Automatic positioning mode

The **linear spring with autopositioning**  or the **Linear spring + damper with autopositioning**  components.

This mode is usually used for dymanic objects created as a result of data conversion from the CAD programs.

1. Add to the first body a connection point corrsponding to point **A** or an oriented point for **SCA** (see **Fig. 3.92**).
2. Add to the **first body** a connection point corrsponding to point **B1** or optionally add to the **second body** a connection point corrsponding to point **B2** or an oriented point for **SCB2** (see **Fig. 3.92**)
3. Click one of the   buttons on the component panel. The design help window opens containingh instructions and comments to the element adding process:

3.1. "Select point/oriented point at 1st body" - select by the left mouse a point for the point **A** or an oriented point for **SCA**. If the selected point is not an oriented point, axes of **SCA** are set to those of **SC1** (the body1 - fixed SC, see the figure.

3.2. "Select element end point (first body) or point/oriented on second body".

If a point at the **second** body is selected, the point **B2** or **SCB2** is assigned. If the selected point is not an oriented point, axes of **SCB2** are set parallel to those of **SC2** (the body2 - fixed

SC). Point **B1** is computed automatically coinsiding with **B2** (see **Fig. 3.92**) and the process of selection geometric paremeters is over. Otherwise the next step is necessary:

3.3. "Select the second body" - click by the mouse on the image of the second body. Point **B2** and **SCB2** are computed automatically conisiding with **B1, SCB1** (Note that axis of **SCB1** are parallel to **SCA**), see the **Fig. 3.92**.

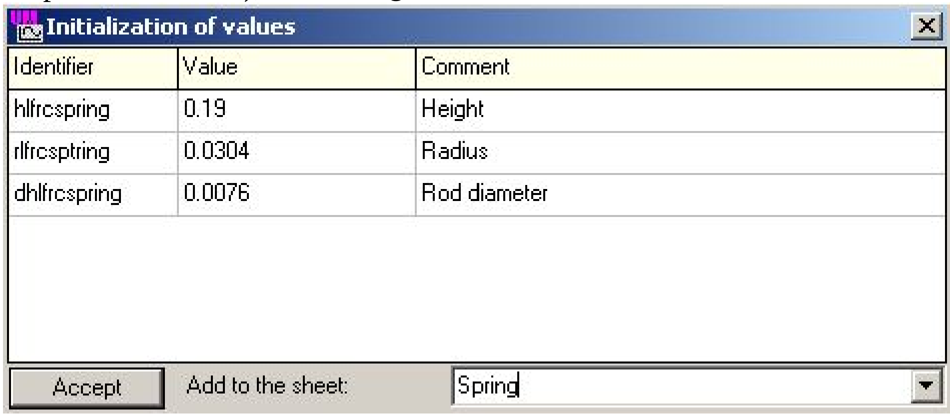
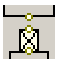
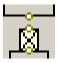


Fig. 3.93. Identifiers parameterizing a force component

4. Correct names and values of identifiers, parameterizing the force element (Fig. 3.93)

The User's mode

The **linear spring**  or the **Linear spring + damper**  components correspond to linear force components without automatic positioning.

1. Add to the first body a connection point corrsponding to point **A** or an oriented point for **SCA** (see **Fig. 3.92**).
2. Add to the **first body** a connection point corrsponding to point **B1**
3. Add to the **second body** a connection point corrsponding to point **B2** or an oriented point for **SCB2** (see **Fig. 3.92**)
4. Click one of the   buttons on the component panel. The design help window opens, the window contains instructions and comments to the element adding process:

   4.1. "Select point/oriented point at 1st body" - select by the left mouse a point for the point **A** or an oriented point for **SCA**. If the selected point is not an oriented point, axes of **SCA** are set to those of **SC1** (the body1 - fixed SC), see **Fig. 3.92**.
   4.2. "Select point at 1st body for element end" - select a connection point for B1 (see **Fig. 3.92**).
   4.3. "Select point/oriented point at 2nd body". This stage selects point **B2** or **SCB2** is assigned. If the selected point is not an oriented point, axes of **SCB2** are set parallel to those of **SC2** (the body2 - fixed SC), see **Fig. 3.92**.

5. Correct names and values of identifiers, parameterizing the force element

Remarks

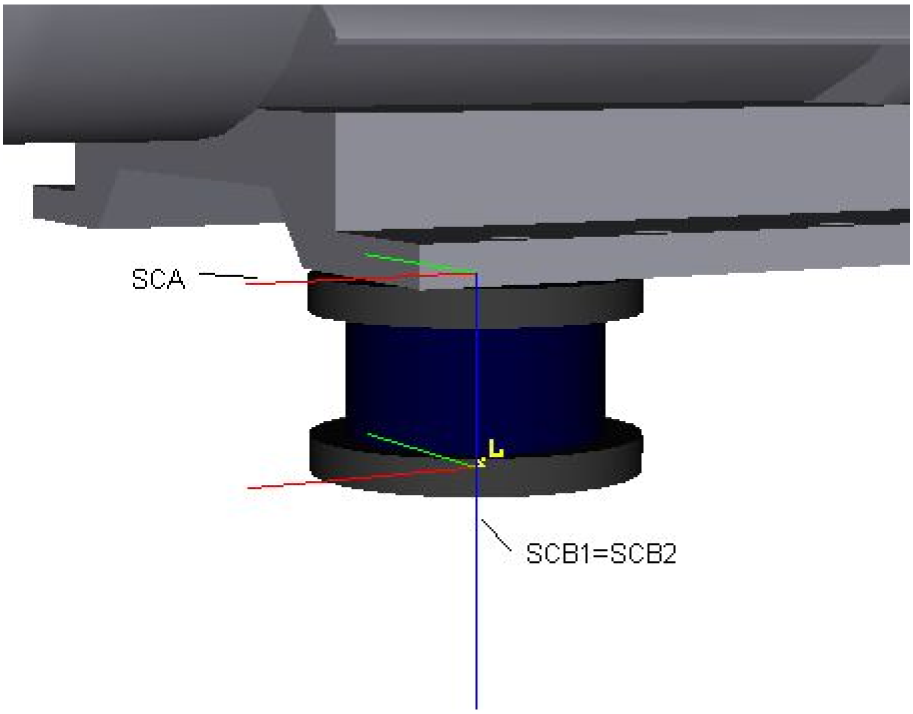


Fig. 3.94. Visualization of element SC

1. In the single element mode of the animation window, **SCA**, **SCB1** and **SCB2** are visualized, the origin of **SCB$_1$** is marked by the icon, Fig. 3.94. Images of **SCB1** and **SCB2** should usually coincide when the geometrical data of the element are correct.

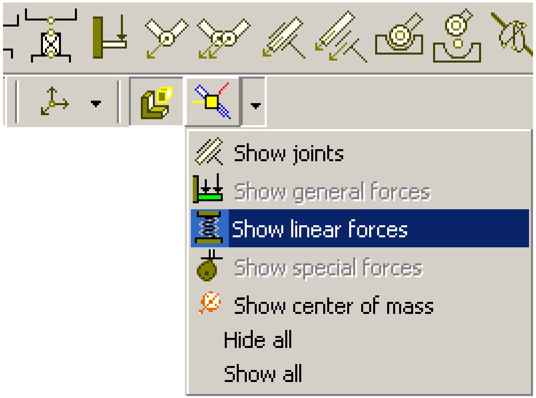


Fig. 3.95. Turning on auxiliary drawings for linear force elements

2. In the single element mode of the animation window these systems of coordinates can be visualized if the corresponding option is on, Fig. 3.95.

3.5.2.2. Saving object data

Use the main menu **File | Save as…** command or the button to save the active object for the first time or to make a copy of the object (Sect. 3.2.1). Just here a name is assigned to the object.

To save a modified object use:

- the **File | Save** command of the main menu;
- the *Ctrl+S* hot key;
- the button.

Data are stored in the *input.dat* file located in the object directory.

3.6. Generation of equations of motion

Universal Mechanism supports two methods: *symbolic* and *numeric-iterative*. Let us consider them more detailed.

Before generation of equations UM saves modified object and verifies correctness and fullness of the object description.

If the object description contains errors or not full, the program opens the **Protocol** tab of the object inspector. The protocol contains a list of errors and warnings. Click a line with an error or a warning to go to the corresponding element of the object.

Zero mass and moments of inertia are errors by default. Use the **General** tab of the UM option window (Sect. 3.1.4) to change the status of this error to a warning and back.

Symbolic method assumes generation equations of motion as source files in C or Pascal with posterior their compilation by one of the supported external compilers. As a result of compilation the *UMTask.dll* appears. This *.dll is used by **UM Simulation** program for numerical integration of equations of motion.

A dynamic linked library (dll), which contains the object equations, must be created for each UM object as a result of generation and compilation of equations of motion.

Use the **Tools | Generate equations** command of the main menu to generate and (optionally) compile equations of motion with the help of the built-in specialized computer-algebra system.

Numeric-iterative method assumes generation of equations of motion on each step of numerical integration directly in UM Simulation program.

Let us consider advantages and disadvantages of both methods.

In terms of CPU efforts the symbolic method is faster. It provides decreasing CPU efforts up to 10-30% for complex (more than 10-20 degrees of freedom) models. For rather simple models CPU efforts for both methods are roughly the same. The symbolic method during generation of source code fulfils its optimization from the point of view of CPU-efforts.

On the other hand the symbolic method of generation of equations of motion expects any external compiler to be installed on the same computer. Universal Mechanism supports Borland Delphi, Borland C++ Builder, Microsoft Visual C++ as external compilers.

At the same time the numeric-iterative method does not suppose explicit steps of generation and compilation of equations of motion and seems to be simpler in usage.

For beginner users it is recommended to use the numeric-iterative method of generation of equations of motion as simpler in usage. The symbolic method might be recommended for more experienced users which work with more or less complex models.

3.6.1. Numeric-iterative method

To set *numeric-iterative* method of generation of equations of motion select **Object** in the tree of elements and then set **Generation of equations** to **Numeric-iterative** (see Inspector window in the right part of the constructor window).

3.6.2. Symbolic method

To set *symbolic* method of generation of equations of motion select **Object** in the tree of elements and then set **Generation of equations** to **Symbolic** (see Inspector window in the right part of the constructor window).

Generation and compilation of equations of motions are performed within **UM Input** program.

Choice of an algorithm for generation the equations allows optimizing the number of floating-point operation in the equation codes.

The group **Language for output files** lets you to specify the program language for output files. You should select that language which compiler is installed on your computer.

The **Compile equations** checkbox presents an option for the user. If it is checked, the compilation will run right after the successful generation of equations (most often used).

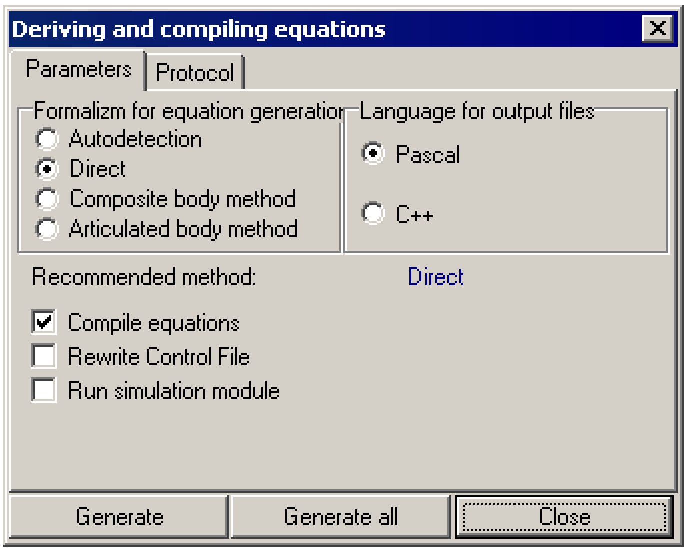
If the **Rewrite Control File** checkbox is checked, the new version of the Control File will replace the old one. The old Control File will be renamed as Cl[NameOfObject].old. If the box is not checked, the new file is created as Cl[NameOfObject].new. This is important if the object description contains external functions or/and the user write its own procedures in the Control file.

Run simulation module if on will start **UM Simulation** program with automatical loading the current model.

The **Generate** button starts the derivation of equations for the active object.

Use the **Generate all** button to derive equations for the object as well as for all external subsystems added to the object.

Use the the **Object | Compile equations** or the *Ctrt-F9* hot key to compile the equations if the Control file has been modified but the equations have not been changed.



3.7. Compilation of equations of motion

If you chosen *symbolic* method of generation of equations of motion you need to compile generated equations with the help of one of supported compilers. Universal Mechanism supports using Borland Delphi, Borland C++ Builder, Microsoft Visual C++ as external compilers.

To compile equations of motion use **Object/Compile equations** menu item or check **Compile equations** flag in the **Deriving and compile equations** dialog, see Sect. 3.6.2.

To setup external compiler paths select **Tools/Options** menu item. Your further actions depend on what external compiler you are going to use:

Delphi

1. Select **Paths/Delphi** tab.
2. Click **Search Delphi** button.

Borland C++ Builder, Microsoft Visual C++

2. Select **Paths/C++** tab.
3. Click one of the following buttons **Search Visual C** or **Search Borland C++ Builder** depending on which C compiler is installed on your PC.

If UM successfully detects external compiler all paths are set automatically. If not, you should set all paths manually.