UNIVERSAL MECHANISM 6.0

Development of Models and Dynamic Analysis of Tracked Vehicles

Getting started

2010

Basic principles of development of models of tracked vehicles and their dynamic are discussed.

Contents

Getting started: development and dynamic analysis of tracked vehicles in UM

Fig. 1 Model of TV

This document helps the user to get experience in development of models and simulation of tracked vehicle (TV) in UM. The model, which development is discussed, is shown in Fig. 1.

It is assumed that the user has already studied the document devoted to introduction in UM (file **gs_UM.pdf**[1]**)** and can create and analyze simple models.

This document does not contain complete information about simulation of TV in UM. More detailed information can be found in Chapter 18 of the user's manual, file **18_UM_Caterpillar.pdf**.

The ready TV model considered in this document is located in the directory

{Path to UM}\Samples\Tracked vehicle\gsTV

[1] http://www.umlab.ru/download/50/rus/gs_um.pdf

1. Development of TV model

1.1. Prototype

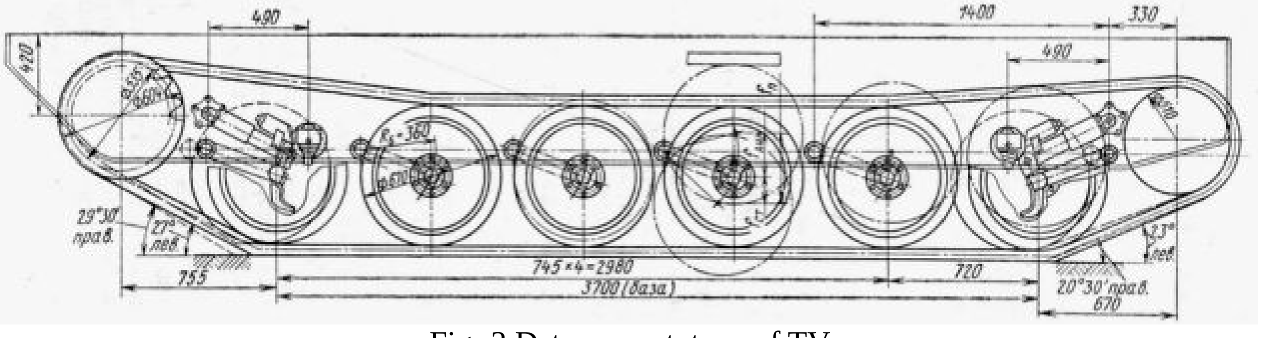


Fig. 2 Data on prototype of TV

A Russian light crawler transporter is considered as the prototype of the model. Fig. 2 shows some geometric data related to the tracks [1].

We would remind that this document is developed to help the user in studying UM Caterpillar module. That is why we will not follow the exact design data of the prototype.

1.2. Creating new object and track subsystem

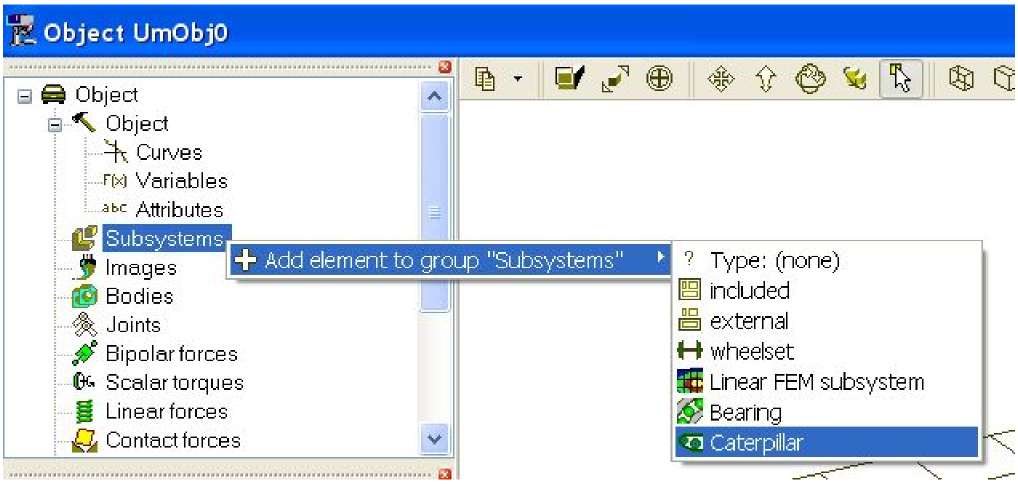


Fig. 3 Adding new subsystem “Caterpillar”

1) Run UMInput.exe and create a new UM object by **File | New object** menu command or by the button on tool panel.
2) Save the model by the **File | Save as** command or by the button.
3) Add a track as a subsystem of the **Caterpillar** type
   - select the **Subsystems** item in the element list
   - click the right mouse button on this item and select the **Add element to group “Subsystems” | Caterpillar**, Fig. 3.

As a result, the **Track wizard** appears in the object inspector.

4) Rename the subsystem to **Left track**.

1.3. Track structure

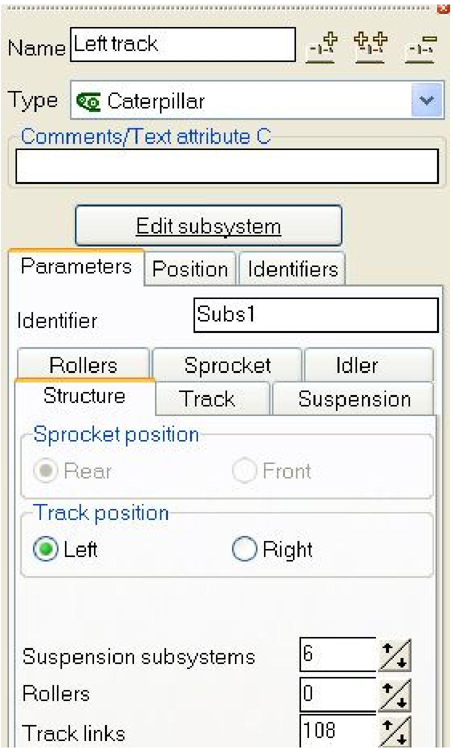


Fig. 4 Parameters of track structure

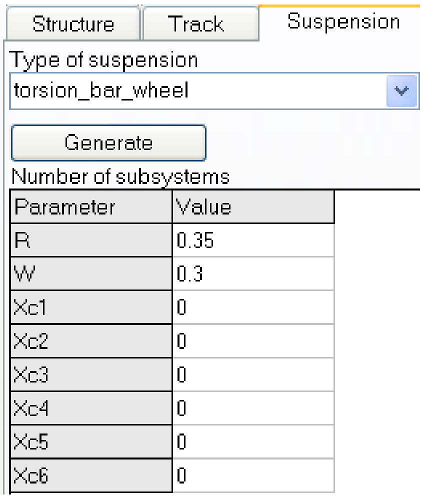
Open the **Parameters | Structure** tab of the wizard, Fig. 4.

1) The modeled TV has a torsion bar suspension with six road wheels. Each of the wheels is described by a standard subsystem, Chapter 18, Sect. Torsion bar suspension. Thus, number six must be set in the **Suspension subsystems** box.

2) The TV has no support rollers; zero value is set in the corresponding box.

3) Number of track links is 108.

1.4. Adding suspension

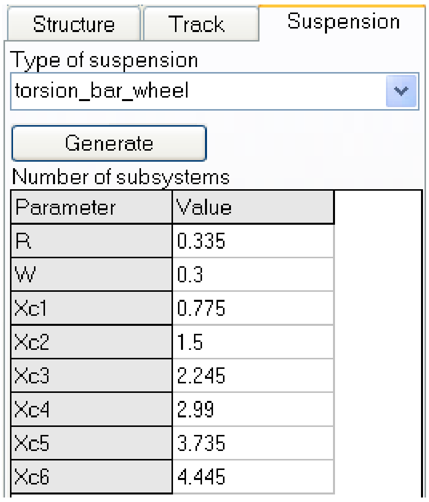


Parameter	Value
R	0.35
W	0.3
Xc1	0
Xc2	0
Xc3	0
Xc4	0
Xc5	0
Xc6	0

Fig. 5 Uninitialized values of suspension geometry parameters

Open the **Parameters | Suspension** tab, Fig. 6.

1) As we have pointed out six suspension units (subsystems), the table of geometrical parameters of suspension contains the same number of longitudinal coordinates of the subsystems (Xc1…Xc6). Besides, the road wheel radius (R) and width (W) must be set in this table. All parameters are in meters. The suspension unit type is specified on the same tab as torsion_bar_wheel, i.e. the default value.



Parameter	Value
R	0.335
W	0.3
Xc1	0.775
Xc2	1.5
Xc3	2.245
Xc4	2.99
Xc5	3.735
Xc6	4.445

Fig. 6 Value of suspension geometry parameters for the MT-L transporter

Following the data in Fig. 2 fill in cells of the tab as in Fig. 6. Note, that the origin of SC0 in the X-direction is located on the level of the sprocket center.

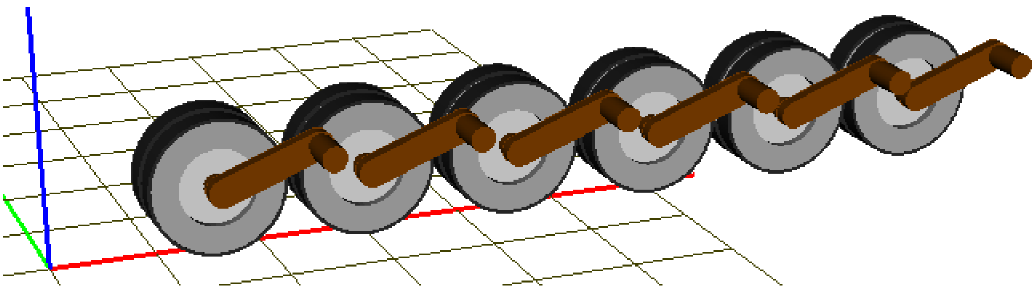


Fig. 7 First variant of suspension

2) Click the **Generate** button to create the suspension according to the specified parameters; the suspension appears in the animation window, Fig. 7

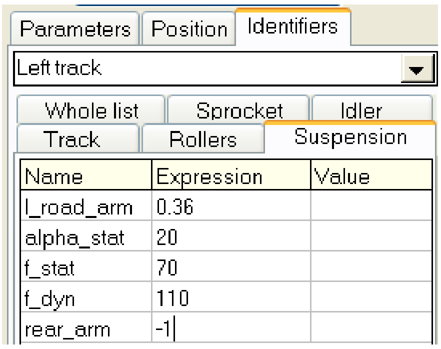


Fig. 8 Selected identifiers of torsion bar suspension

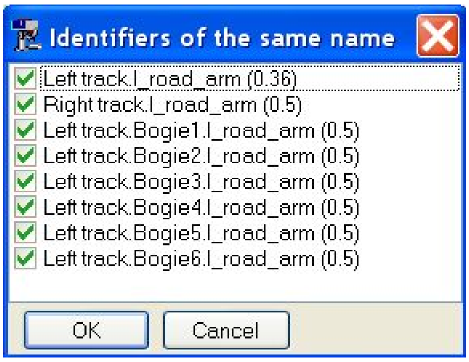


Fig. 9 Assignment of numeric values for identifiers in subsystems

3) Now some parameters of the suspension must be modified. Open the **Identifiers** | **Suspension** tab of the wizard, Fig. 8. Set the length of the torsion arm 0.36m (the identifier *l_road_arm*). All the suspension subsystems contain identifiers with the same name, a window appears in which the user must check the subsystems, for which the identifier value will be changed by the new one, Fig. 9. By default, the new value is assigned to all identifiers of the same name.

We will not change the default values of identifiers, which define the position of the suspension in static state (*alpha_stat*) as well as the static and dynamic travel of wheels (*f_stat*, *f_dyn*, Chapter 18, Sect. *Torsion bar suspension*).

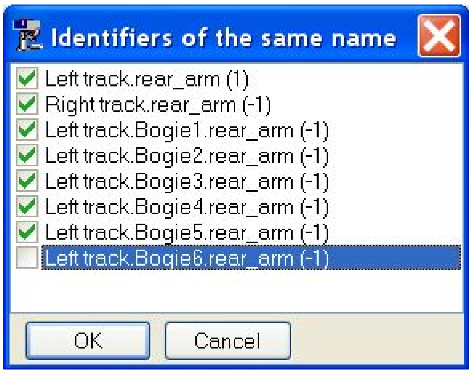


Fig. 10 Road arm orientation

As it is shown in Fig. 2, five road arms has a backward orientation but the front one, which has a forward orientation. So far, all arms in our model are oriented forward. The orientation is defined by the identifier *rear_arm*=±1. The value +1 corresponds to the backward orientation. To set the necessary values of this identifier in the subsystems, set *rear_arm* =+1 in the cell in Fig. 8 and press Enter. Uncheck the assignment of the new value in the lower row, Fig. 10. As a result, orientation of five road arms will be changed, Fig. 11.

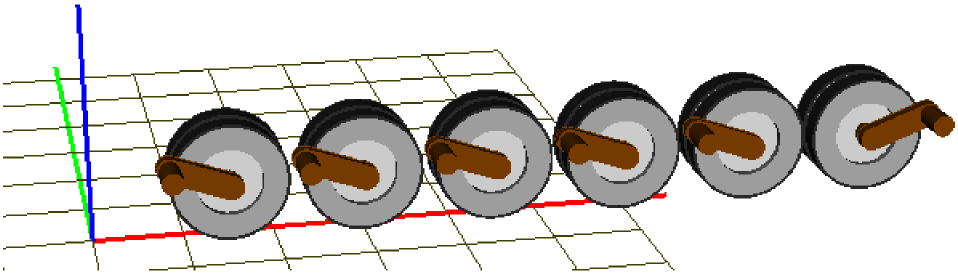


Fig. 11 Suspension with modified parameters

1.5. Adding sprocket

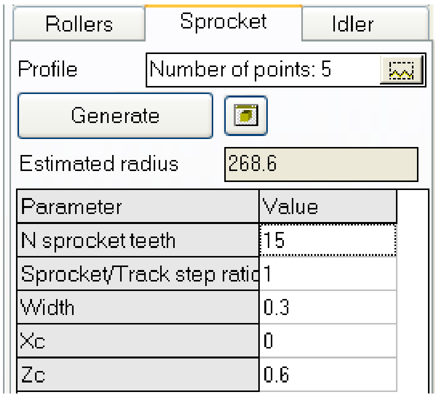


Fig. 12 Geometric parameters of sprocket

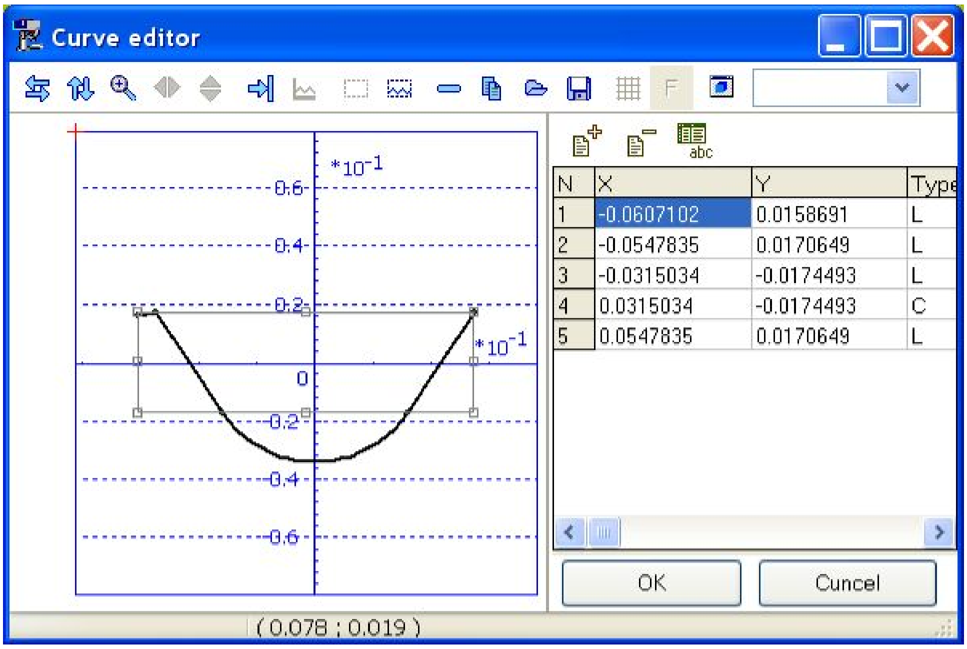


Fig. 13 Tooth profile

Open the **Parameters | Sprocket** tab, Fig. 12.

1) Assign a tooth profile by the built-in curve editor:

- open the editor by the button, Fig. 13
- read the preliminary created file with profile

{Путь к UM}\bin\Caterpillar\Profiles\Sprocket1.spf

by the button.

2) Set number of teeth, t_w / t_t ratio and geometric parameter: width of the wheel, the vertical and longitudinal coordinates of the wheel center, Fig. 12.

3) Use the button to preview the sprocket, Fig. 14. Note the sprocket radius is computed automatically by the link length, t_w / t_t ratio and number of teeth so that the final variant can differ from the current one.

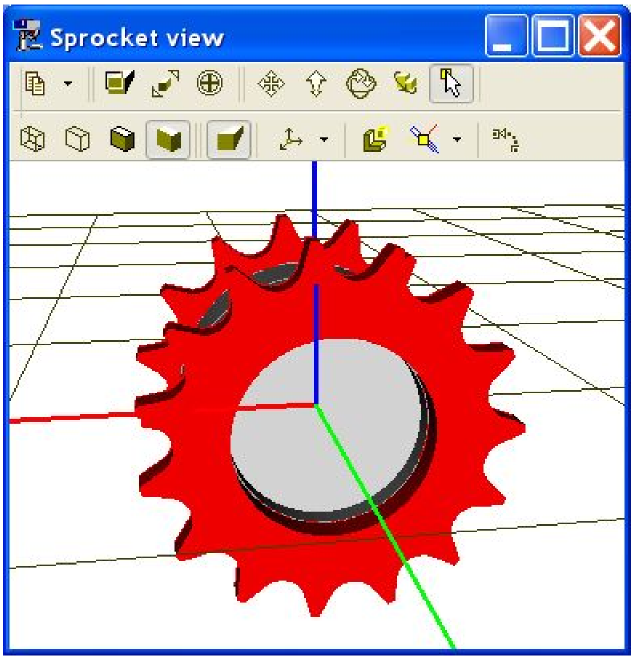


Fig. 14 Sprocket preview

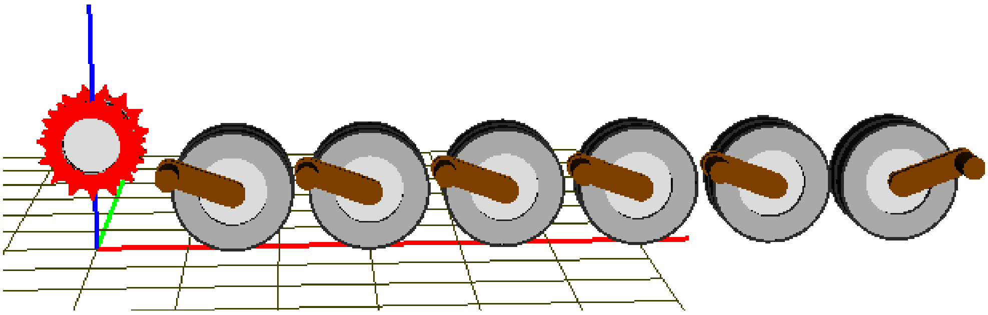


Fig. 15 Adding sprocket

4) Add the sprocket to the model by the **Generate** button, Fig. 15.

1.6. Adding idler

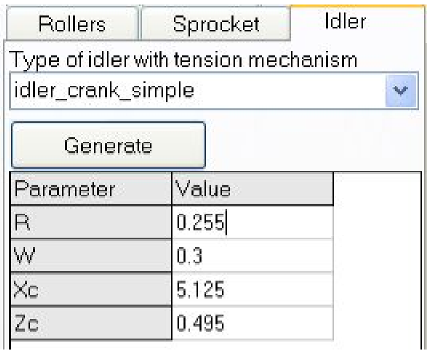


Fig. 16 Parameters of idler

Open the **Parameters** | **Idler** tab, Fig. 16

1) Select a simplified model of the idler on a crank: idler_crank_simple.

2) Set geometrical parameters of the idler in meters as in Fig. 16: radius, width and coordinates of the center.

3) Add the idle to the model by the **Generate** button, Fig. 17.

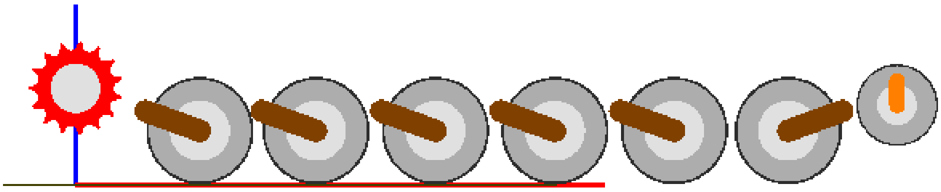


Fig. 17 Adding idler with tension device

1.7. Adding track chain

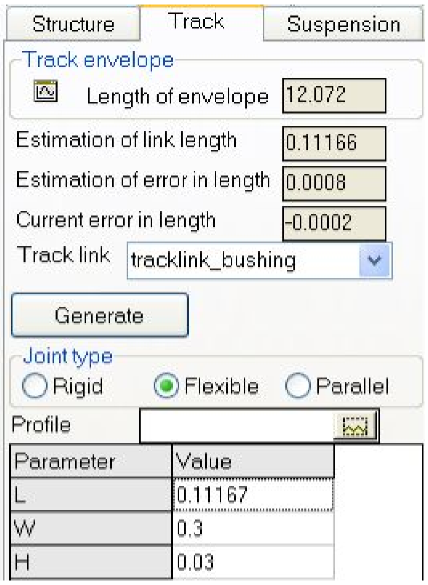


Рис. 18 Tack chain parameters

Open the **Parameters | Track** tab, Fig. 18.

- Use **tracklink_bushing** joint type.
- Set track link length, which is evaluated by the program in the ‘Estimation of link length’ box.
- Click the Generate button, Fig. 19.

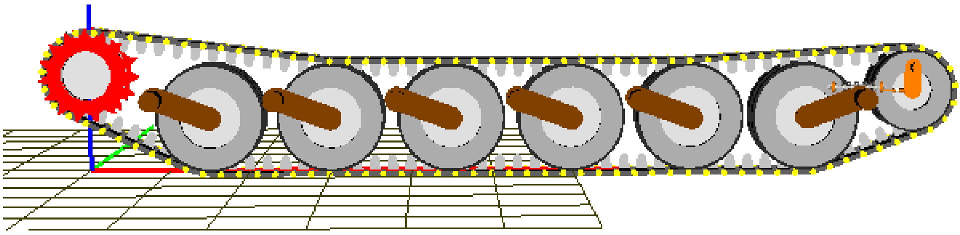


Fig. 19 Adding track chain

1.8. Adding shock absorbers

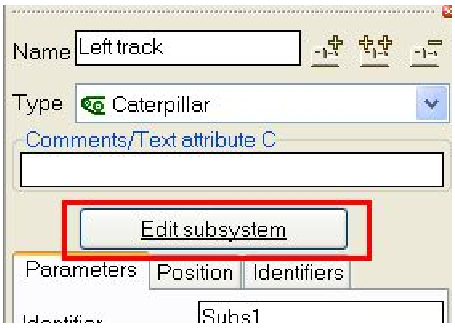


Fig. 20 Button for editing the subsystem

Description of process.

1) Use the **Edit subsystem** button to open a window with description of the track, Fig. 20.

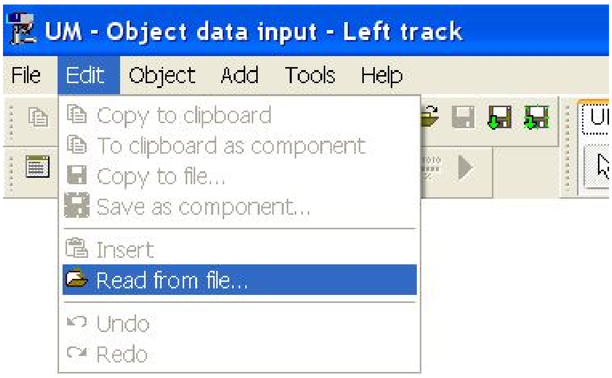


Fig. 21 Menu command for adding an element from file

2) Add a shock absorber model from the UM database by the **Edit | Read from file** command, Fig. 21. Select the file

{Path to UM}\bin\Caterpillar\Dampers\Damper1.

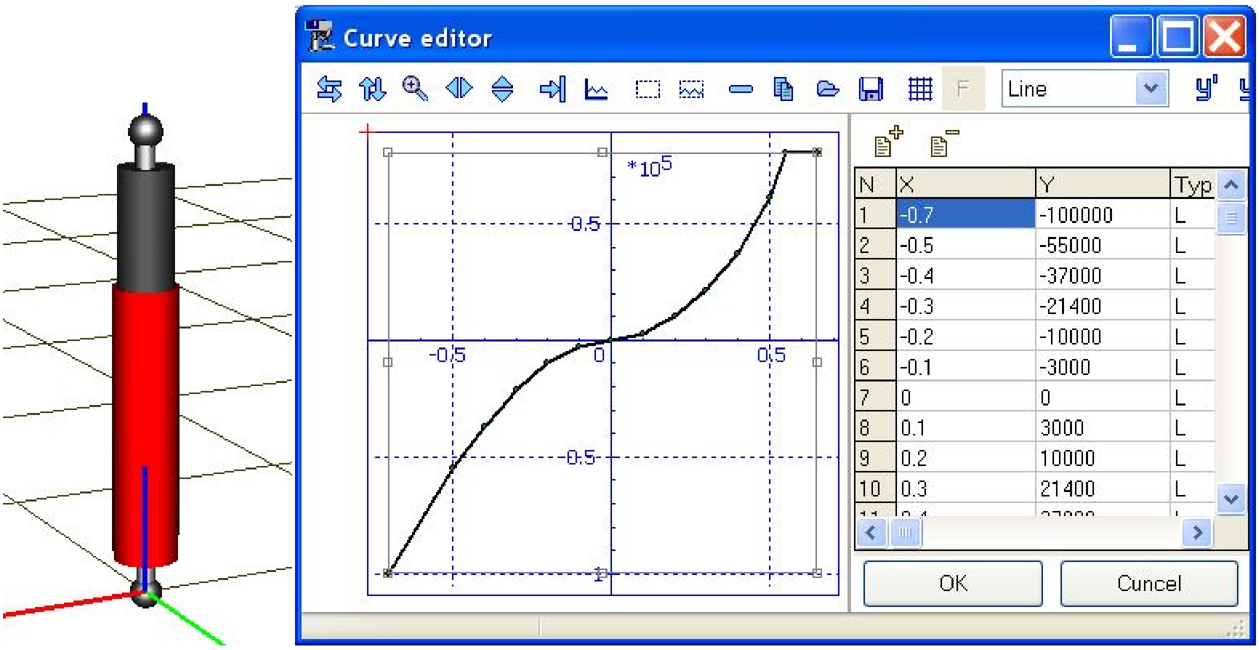


Fig. 22 Image and nonlinear characteristics of shock absorber

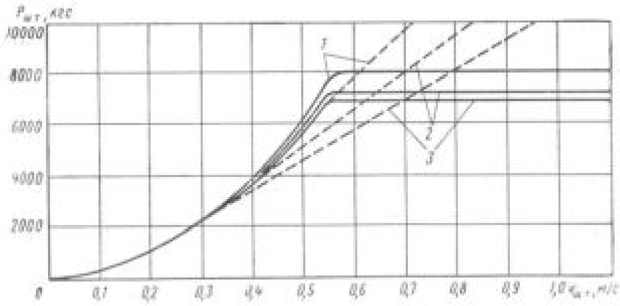


Fig. 23 Shock absorbers characteristics form [1]

The file contains the description of a nonlinear shock absorber as well as its image, Fig. 22. The force vs. velocity characteristics of the element is similar to one of that in [1], Fig. 23.

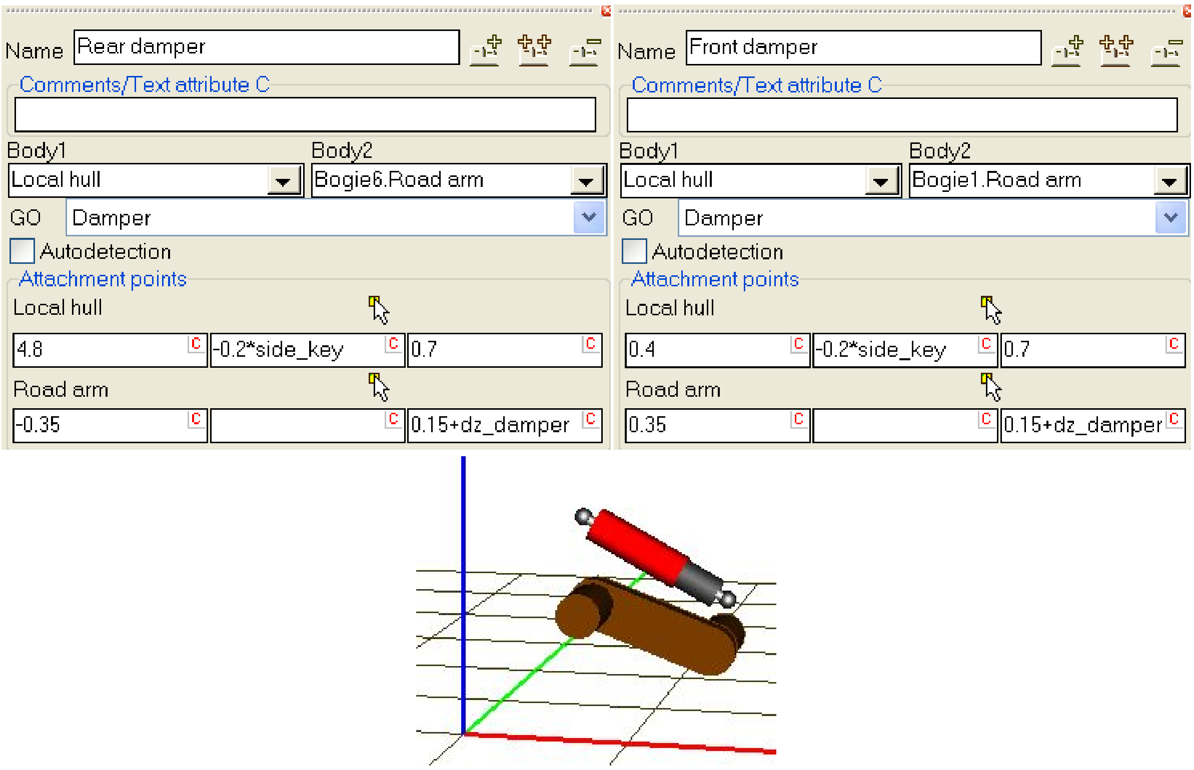


Fig. 24 Assignment of bodies and coordinates

Rename the element; assign bodies and coordinates of attachment points, Fig. 24 left. Note that the *side_key* is used for the lateral coordinate to change the coordinate sign in case of the left and right tracks.

To add the rear shock absorber, copy the front on by the button, rename it, change the second body and coordinates of attachment points as in Fig. 24 right.

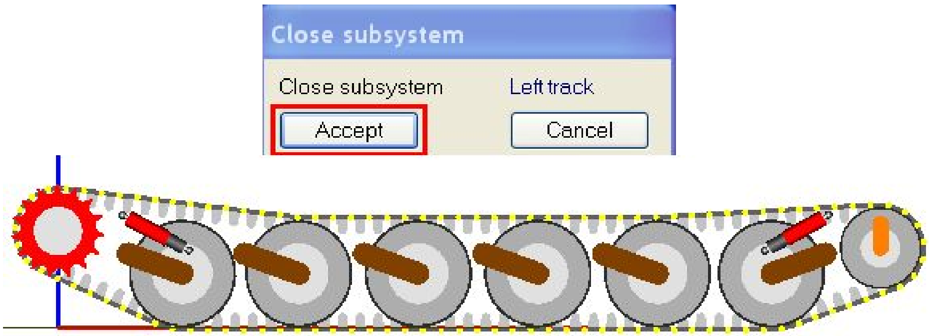


Fig. 25 Model of track with shock absorbers

To finish the process of adding the shock absorbers, close the subsystem by the **Accept** button, Fig. 25.

Save the ready mode of the left track to file.

Remark. We have developed a simplified track model. Several elements are not included in the model.

1.9. Development of full TV model

To finish the model development, we must add a hull and the second track.

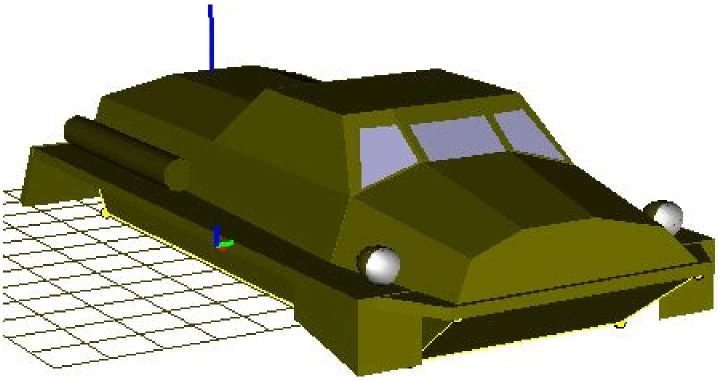


Fig. 26 Hull image

1.9.1. Adding hull

1) Read an image of the hull from the UM database, Fig. 26 by the **Edit | Read from file** command, select the file

{Path to UM}\bin\Caterpillar\Profiles\Hull1.img

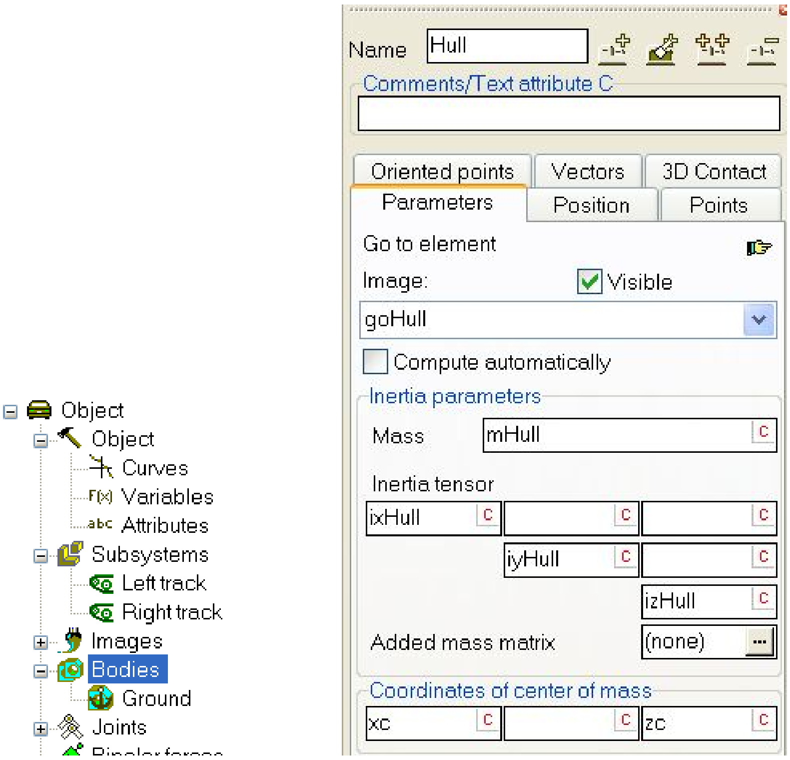


Fig. 27 Adding a body

2) Add a body to the model:

- select the **Bodies** item of the element list, Fig.27;
- create a new body by the  button in the inspector;
- set a name, image and inertia parameters; mass, moments of inertia relative to central axes, coordinates of center of mass (gravity).

mhull	8000
ixhull	5000
iyhull	4.0000000E+4
izhull	4.0000000E+4
xc	2.605
zc	0.6

Fig. 28 Example of hull inertial parameters

It is recommended to parameterize the inertia parameters like in Fig. 27. An example of numeric values of inertia parameter is shown in Fig. 28.

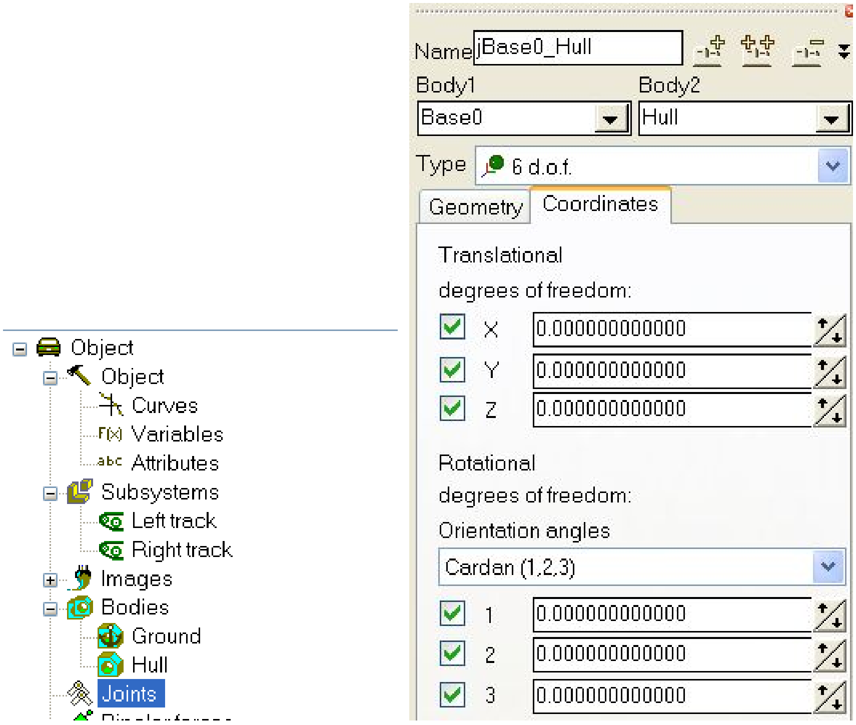


Fig. 29 Adding a joint for hull

3) Add a joint to the model. The joint introduces six degrees of freedom of the hull relative to Base0 (SC0):

- select the Joints item in the list of elements, Fig. 29;
- create a new joint by the button;
- set the joint type **6 d.o.f.**

Remark 1. Note that it is important which body in the joint description is the first one (Body1), and which is the second one (Body2). According to the UM rules, the joint introduces coordinates of the *second* body relative to the *first* one, i.e. coordinates of the hull relative to the inertial frame SC0.

Remark 2. As it is known, any three orientation angles have a singular position. For instance, the Euler angles are singular for zero values of coordinates, and these angles practically do not used in technical applications. We do not recommend the user to use the angles, which are singular at zeroes, i.e. angles corresponding to sequences of rotations in which the first and the third rotations axis are of the same name: are 3, 1, 3; 1, 2, 1 and so on. In the example in Fig. 29, we have assigned the Cardan angle with the sequence of rotations 1, 2, 3, which are singular for the second rotation angle (rotation about the Y-axes) equal to 90 degrees, i.e. in fact by the overturning of the TV. As well, it is recommended to use the angles 3, 1, 2 (yaw, pitch, and roll angles).

1.9.2. Coupling hull and track

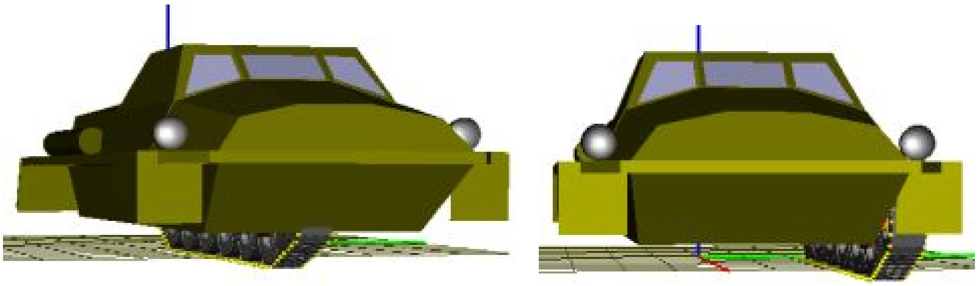


Fig. 30 Uncoupled and coupled hull and track

So far, the track in the current model is not connected with the hull, Fig. 30 left.

To connect some elements of the track with the hull, it is necessary to fix the local hull of the track with the hull body. To do this, we introduce a joint with zero degrees of freedom between these bodies. There are several ways for adding such the joint: a 6 d.o.f. joint with disabled coordinates, a generalized joint with one elementary transformation of the **tc** type (translation on a constant vector).

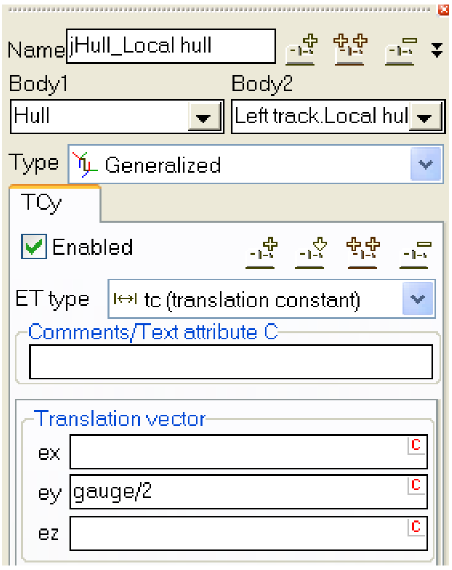


Fig. 31 Joint rigidly connecting hull of TV and local hull of left track

- Add a joint.
- Assign connecting bodies (Hull and Left track.Local hull).
- Select the joint type **Generalized**.
- Add an elementary transformation be the lower button.
- Set the lateral shift of the track. In example in Fig. 31 the gauge is set by the identifier *gauge*=2.6 m.

As a result, we have rigidly connected the local hull of the track with the hull of TV, Fig. 30 right, and now all the joints and force elements connecting track bodies with the local (fictitious) hull are coupled with the real hull of TV.

1.9.3. Adding the second track

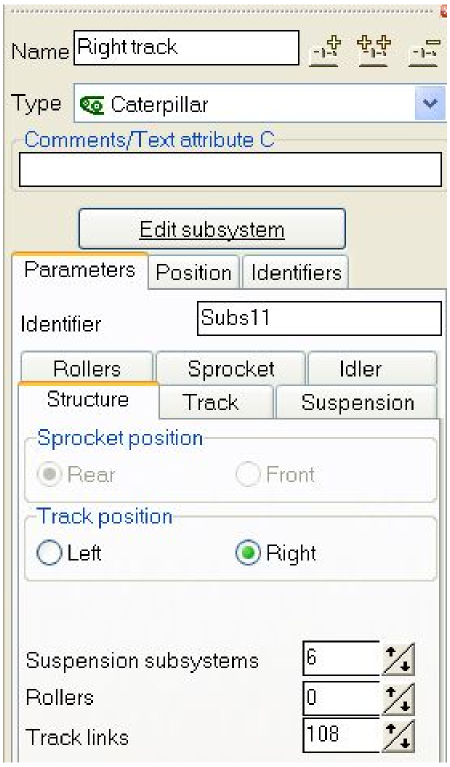


Fig. 32 The right track

Open the left track subsystem and copy it by the button. Rename the subsystem and set the track position **Right**, Fig. 32.

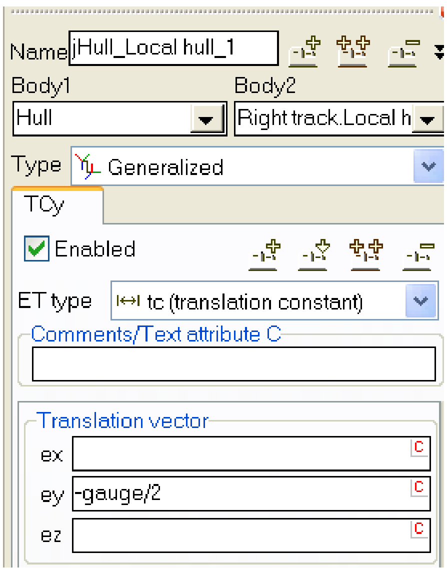


Fig. 33 Joint rigidly connecting the hull of TV with the local hull of the right track

Similar to Sect. *Coupling hull and track* create a joint fixing he local hull of the right track with the hull of TV, Fig. 33. Note that in this case the lateral shift is negative.

1.9.4. Correction of vertical TV position

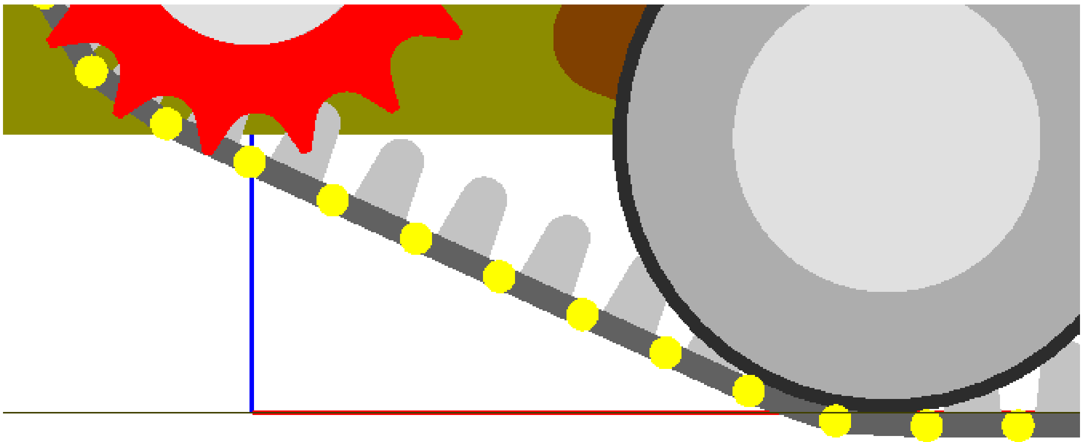


Fig. 34 Links are under zero level

Note that track links are still located under the zero level in the vertical direction, in fact they are ‘under the ground’, Fig. 34. To avoid intensive transient processes by simulation, it is recommended to shift the TV model upwards on the link height.

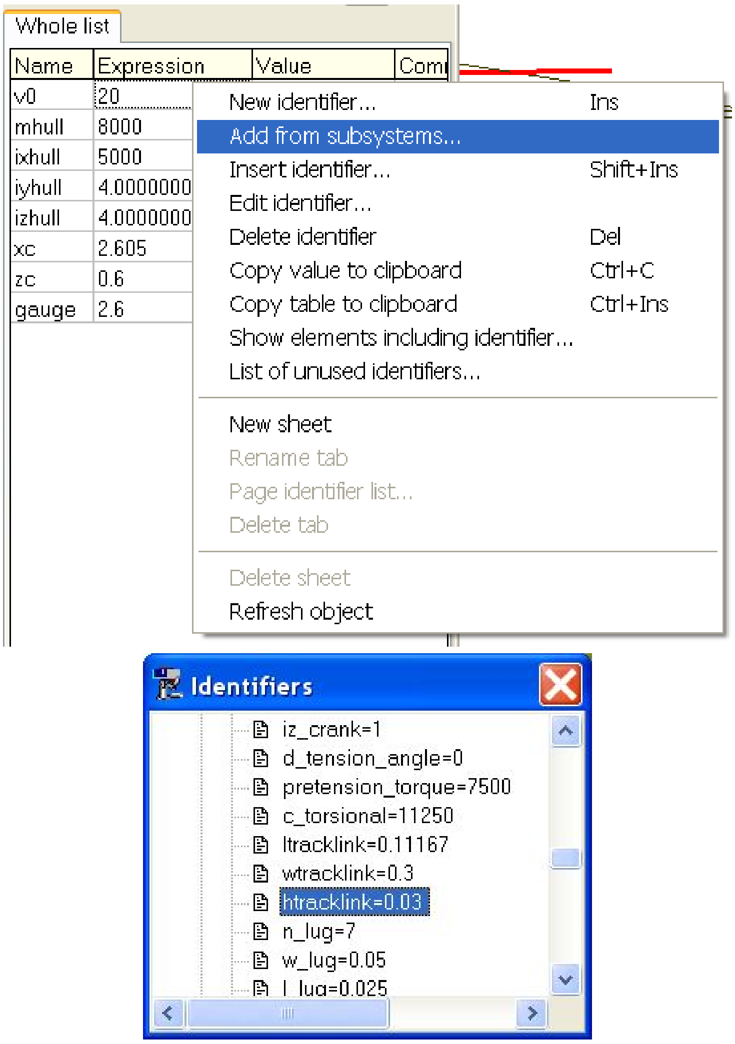


Fig. 35 Adding an identifier from subsystem

At first note that by default the track link height is set by the identifier *htracklink*, which is defined in track subsystems, and not ‘visible’ in the head part of the TV model. It is recommended to add an identifier with the same name in the head part, Fig. 35:

- click by the right mouse button on the list of identifiers and select the **Add from subsystems** command;
- select the *htracklink* identifier in one of the track subsystems and click on it;
- make sure that the identifier appears in the list.

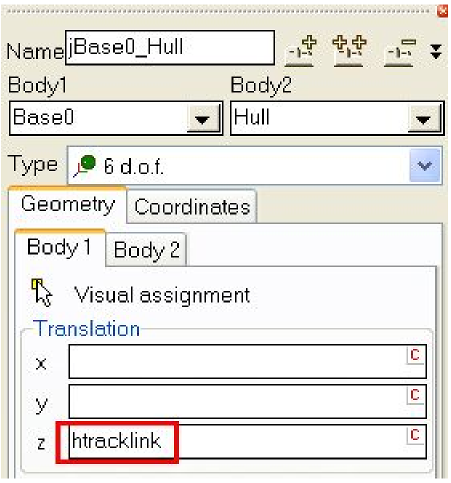


Fig. 36 Vertical shift of TV model

To shift the model upwards, open the joint specifying coordinates of the TV hull relative to the SC0 and set the vertical coordinate in the **Geometry | Body1** tab, Fig. 36. The result is shown in Fig. 37.

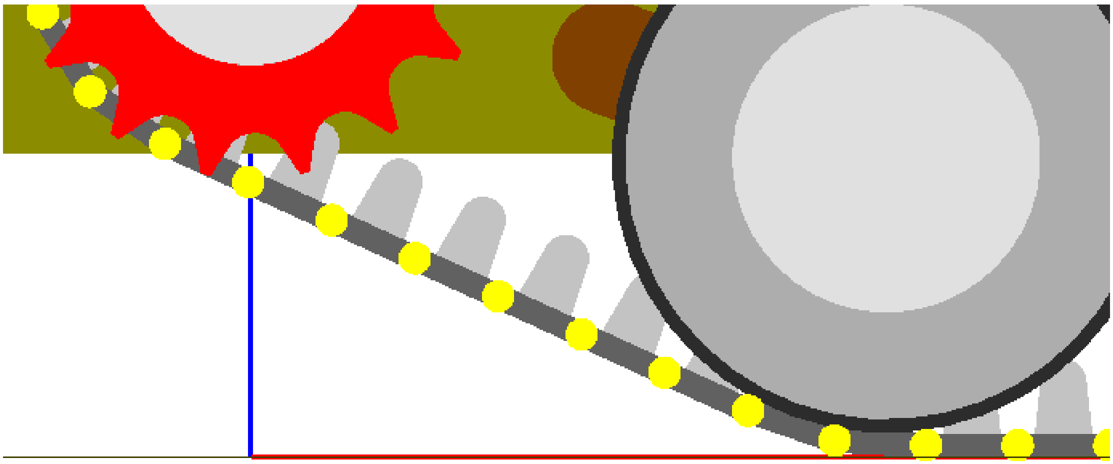
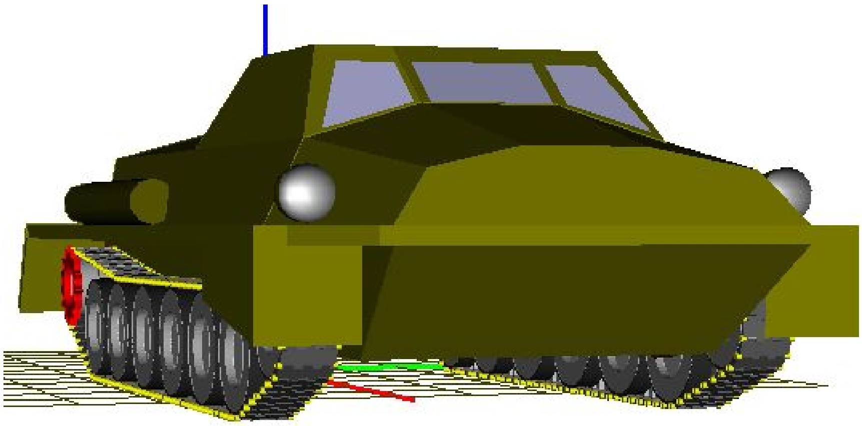


Fig. 37 Links are located on zero vertical level

Now we can start dynamic tests with the developed model of TV.



2. Simulation of TV dynamics

2.1. General remarks

Computer model of TV has usually a large number of degrees of freedom and requires of high performance computers. For instance, the developed model of TV has 1332 degrees of freedom. It is recommended to use computers with multi-core physical processors and apply the multithread solver realized in UM6.0.

As a rule, the model of TV is fully parameterized. It is important that some of the identifiers cannot be changed in the simulation module and requires regeneration of the track models in UMInput. These are identifiers, which influence the track chain and sprocket geometry:

- wheel radii;
- coordinates of wheel centers;
- track height.

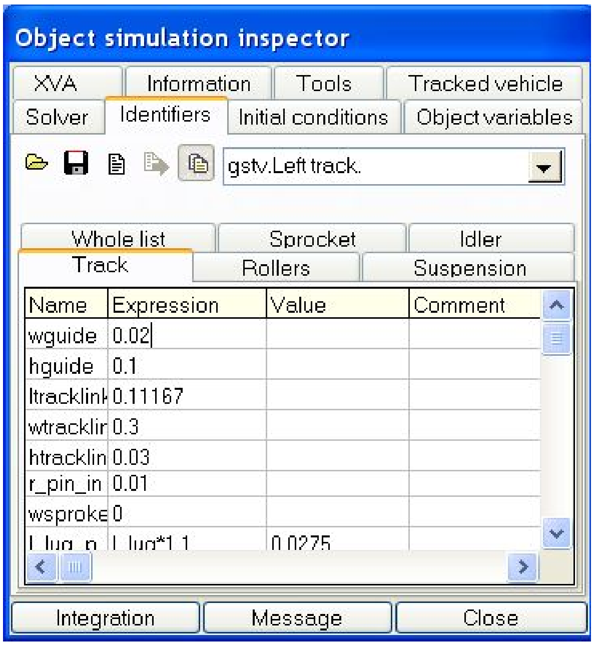


Fig. 38 List of identifiers in UMSimul

Other parameters can be modified without regeneration of the track models. In particular, these are parameters used in the description of force elements (stiffness, damping constants etc.) and inertia parameters. To change values of these identifiers, the user must not come back to the UMInput. Usually, these changes are made on the **Identifiers** tab of the **Object simulation inspector**, Fig. 38. Modifications in parameter values are saved in special *.par files and can be used in simulations.

The user can apply the preliminary prepared configurations for each of the tests described below. The list of configurations is available by the **File | Read configuration | {Test name}** command, Fig. 39.

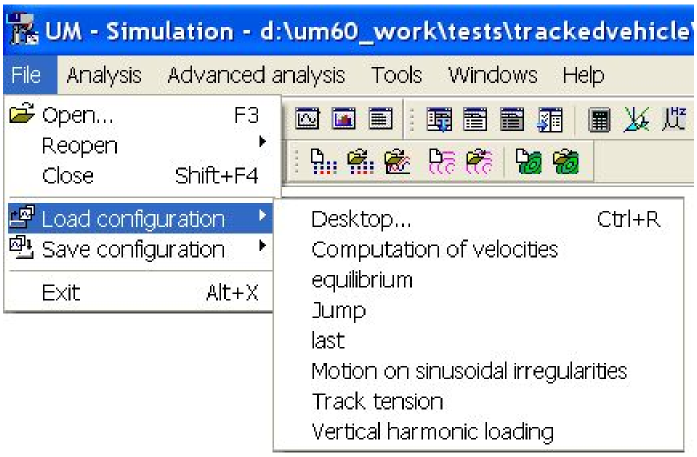


Fig. 39 List of configurations for tests

2.2. Auxiliary tests

The auxiliary tests are used for preparing the model to analysis of its dynamics. In particular, one of such the tests is used for getting a desired tension of track chains.

2.2.1. Test: equilibrium

Consider an auxiliary test «Equilibrium» as the first dynamic test with the TV model. The objective of the test is to compute positions of bodies near the equilibrium state because the positions of bodies after the automatic generation of tracks do not correspond to the TV equilibrium.

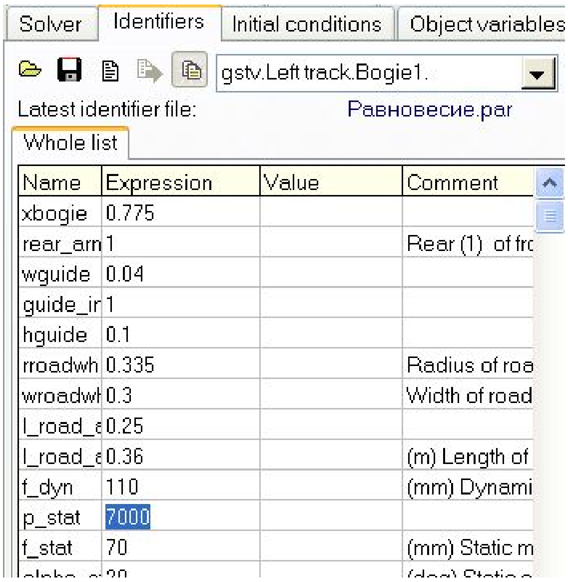


Fig. 40 Modification of parameters

Before start of the test, the user must verify numeric values of identifiers and their correspondence to the real values. In particular, one of the important parameters is the value static load on a road wheel, which is specified by the identifier *pstat*. Value of this parameter depends on the track tension. Let the design value of this parameter be 7 kN. Setting this value to the identifier can be done on the **Identifier** tab of the inspector. Note that the *pstat* identifier is defined in suspension subsystems. Open the list of identifiers for one of the suspension subsystem by the drop-down list, Fig. 38.

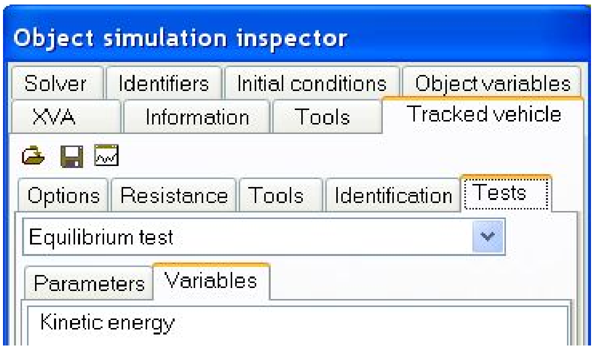


Fig. 41 Equilibrium test

1) Load the model of TV in UMSimul. Open the Object simulation inspector by the **Analysis | Simulation** menu command. Open the **Tracked vehicle | Tests** tab. Select the **Equilibrium test** from the drop-down list, Fig. 41.

2) Open a graphic window by the button on the tool panel. Drag the **Kinetic energy** variable prom the **Variables** tab into the graphic window.

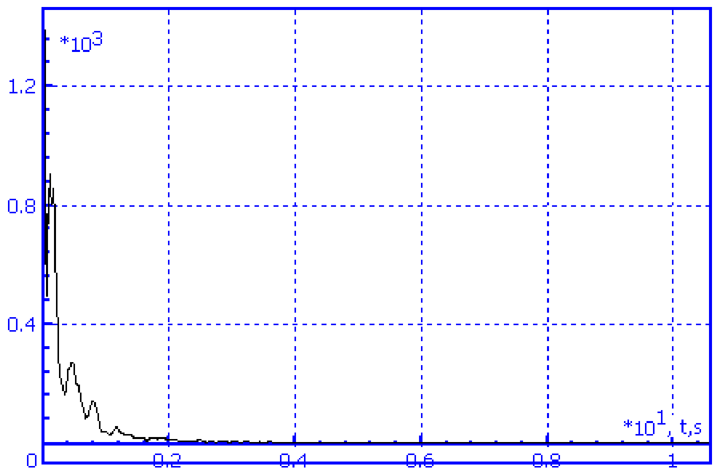
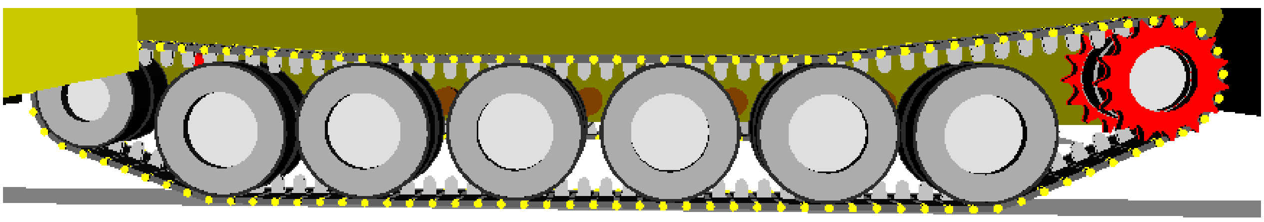


Fig. 42 Plot: kinetic energy vs. time

3) Run the simulation by the **Integration** button in the bottom of the inspector. In our test the energy value decreases to the value lower than 1 J after 7 seconds of simulation, Fig. 42, i.e. the TV is nearly the equilibrium.

4) Start the pause mode after 7 s of simulation by the button in the window of integration process parameters or by the Esc button. Save the final values of coordinates in the *.xv file with any name by the **Save** button in the bottom of the pause window. Break simulation by the **Interrupt** button.



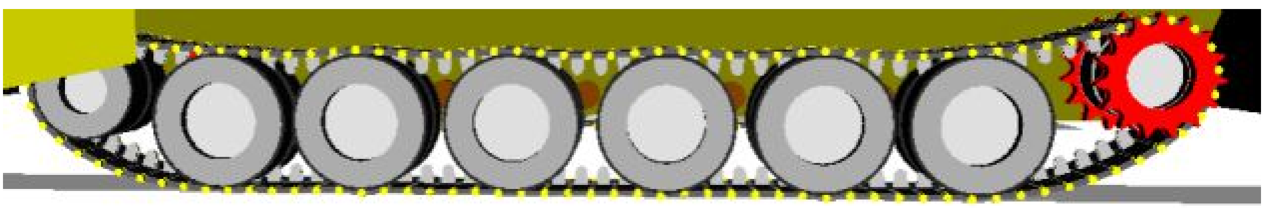


Fig. 43 Track before and after the equilibrium test

5) Read the saved file by the button on the **Initial conditions | Coordinates** tab of the inspector. Set zero values for velocities by the button. It is recommended to save the found coordinates in a file by the button for the next tests. Positions of track bodies before and after the test are shown in Fig. 43. Remember that the necessary track tension is still not set.

2.2.2. Track tension

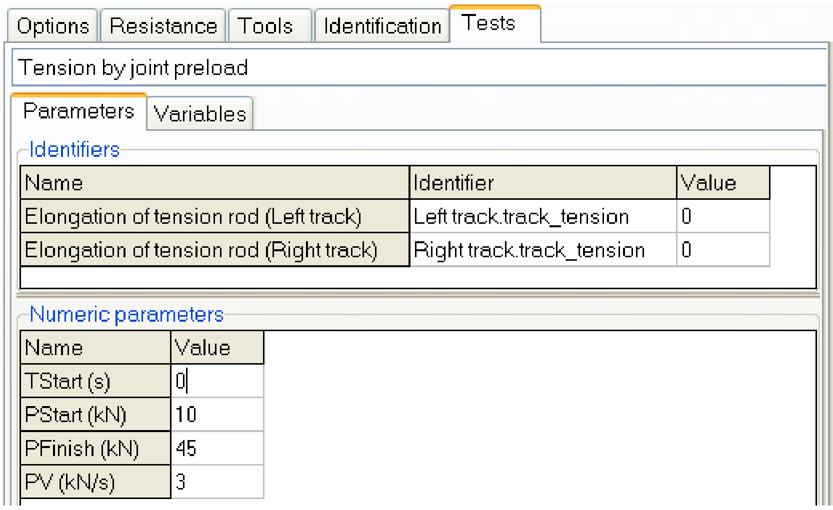


Рис. 44 Parameters of the test

1) Select the '**Tension by joint preload**' test. In this test, a value of the preload force in bushings can be found, which gives the desired value of the track tension. Note that there exists a test 'Track tension' where the tension value is obtained by elongation of the tensions rod, but this method is usually used for track links with rigid joints.

Test parameters are presented in Fig. 44. First, identifiers of preload force in bushing models are specified in the **Identifiers** group. Increase of the value of these identifiers leads to the growth of the track tension. Note that these identifiers were found automatically because the standard name *track_tension* was used.

2) Set numeric parameters of the test as in Fig. 44. A uniforms increase of the preload force in bushings starts from 10kN to 45 kN with the rate 3 kN/s.

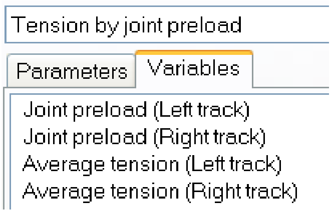


Fig. 45 List of standard variables of the test

3) Open a new graphic window and drag two variables from the list by the mouse into the window: preload and tension, Fig. 45.

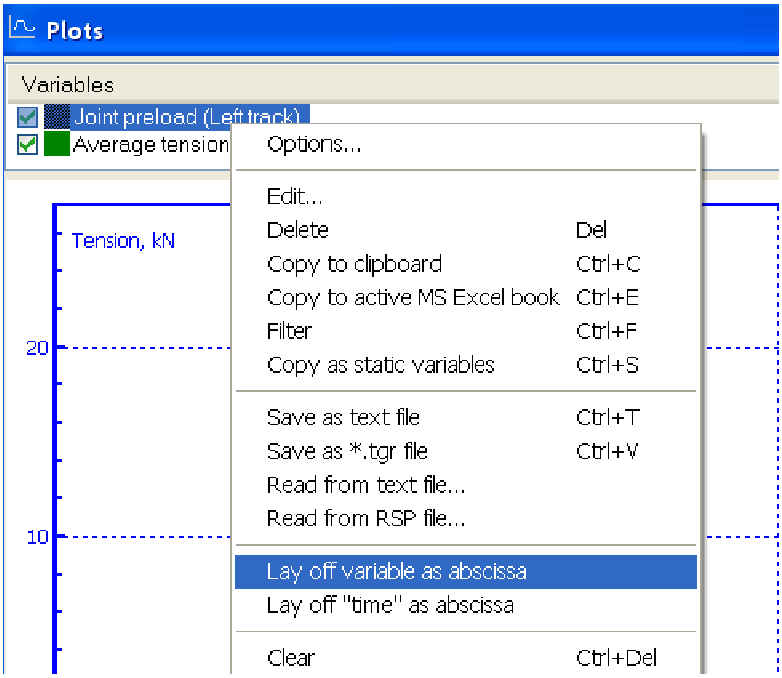


Fig. 46 Preload must be laid off as abscissa

Lay off the preload as abscissa: select the variable in the list of graphic window, call the context menu by the right mouse button and select the menu command, Fig. 46.

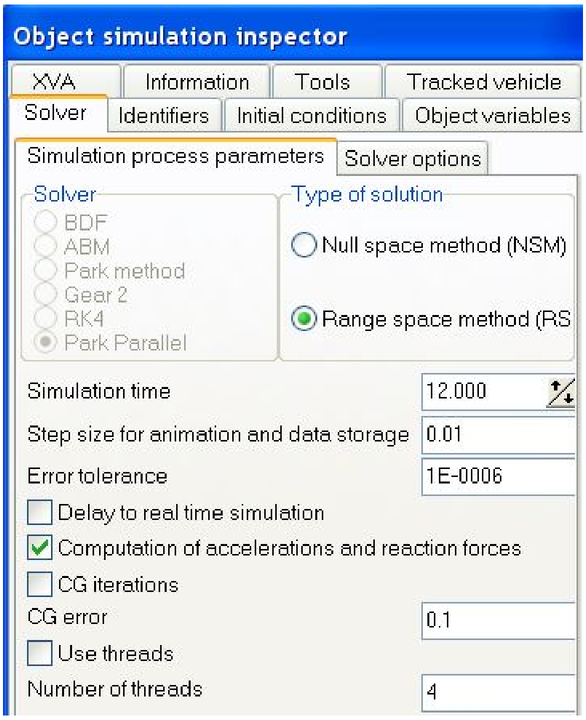


Fig. 47 Setting simulation time

4) Set simulation time 12 s on the **Solver | Simulation process parameters** tab and run simulation by the **Integration** button.

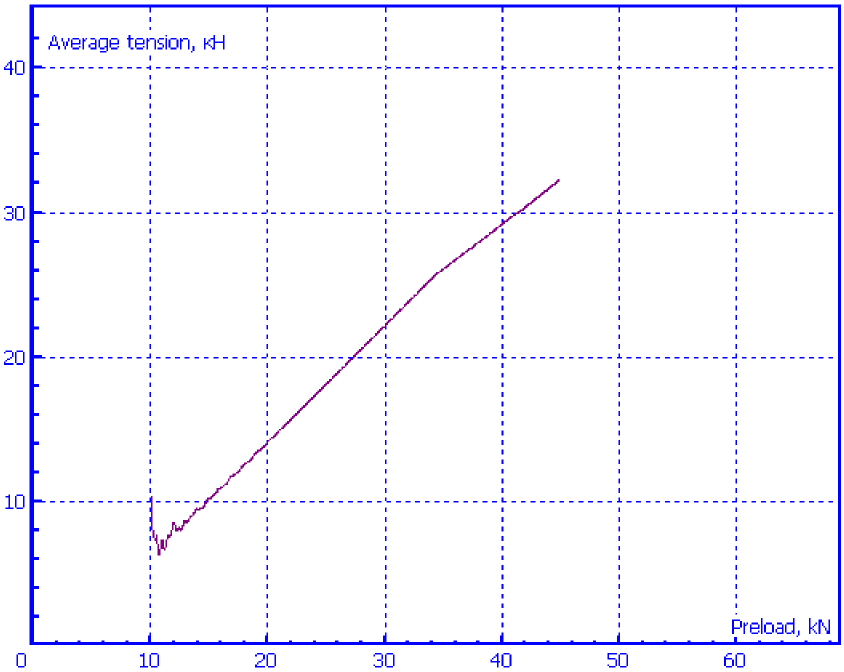


Fig. 48 Average track tension vs. preload

Let us discuss the main result of the test: dependence of the average track tension on the preload in bushings, Fig. 48. The plot has two straight sections: the first section (tension is lower 35 kN) when the load on the tension device is less than the tension spring preload and the second section when the tension spring compressed. In our model the preload of the tension spring is 50 kN.

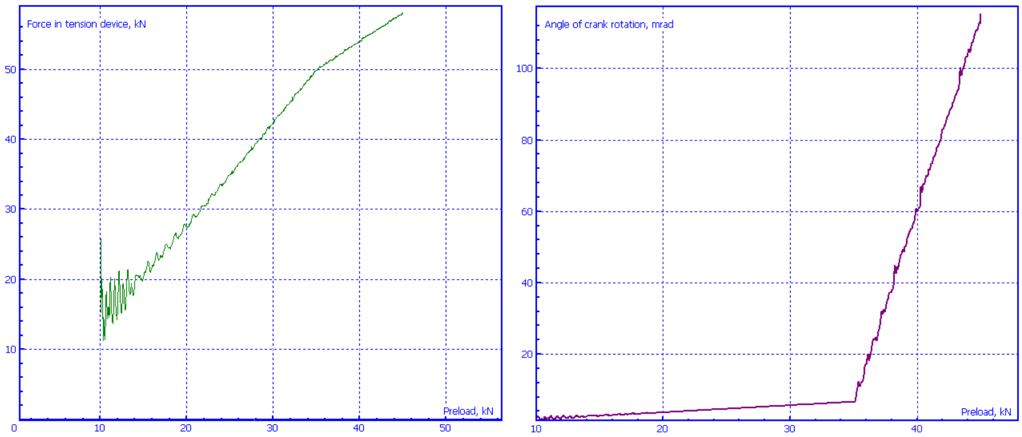


Fig. 49 Force in tension spring (left) and angle of the tension crank rotation (right) vs. bushing preload

These conclusions are confirmed by the plots in Fig. 49.

5) Now the preload in bushings can be evaluated from Fig. 48 by the desired track tension. Let the track tension must be 20 kN. The corresponding bushing preload is approximately 26.6 kN.

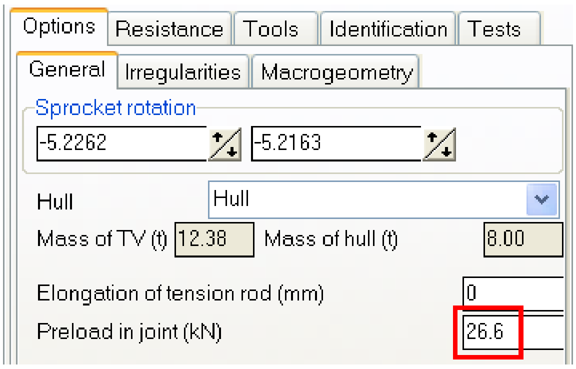


Fig. 50 Setting joint preload for the further use

Break the pause mode and set the found preload value in the **Tracked vehicle | Options | General** for use in other tests.

6) Now we must solve the last problem. Positions of TV bodies for the given track tension must be computed and stored:

- set the Equilibrium test
- run test during 7 seconds
- save coordinates in the pause mode by the **Save** button**;**
- break simulation, read the saved coordinates on the **Initial conditions** tab, set zero values for velocities, and save the coordinates by the button.

Use this coordinates any time when the test requires an equilibrium state of the TV by the given value of the track tension.

2.2.3. Vertical harmonic loading

The test allows the user to get nonlinear vertical characteristics of the suspension by a slow harmonic excitation

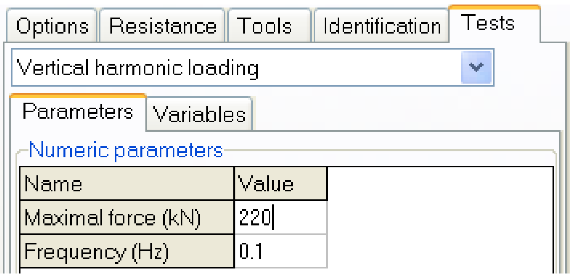


Fig. 51 Test parameters

1) Select the corresponding type of the test and set parameters of the harmonic vertical force, Fig. 51.

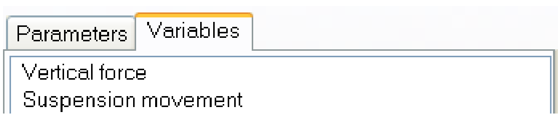


Fig. 52 Test variables

2) Open a graphic window and drag in it the test variables, Fig. 52. Lay off the suspension movement as abscissa.

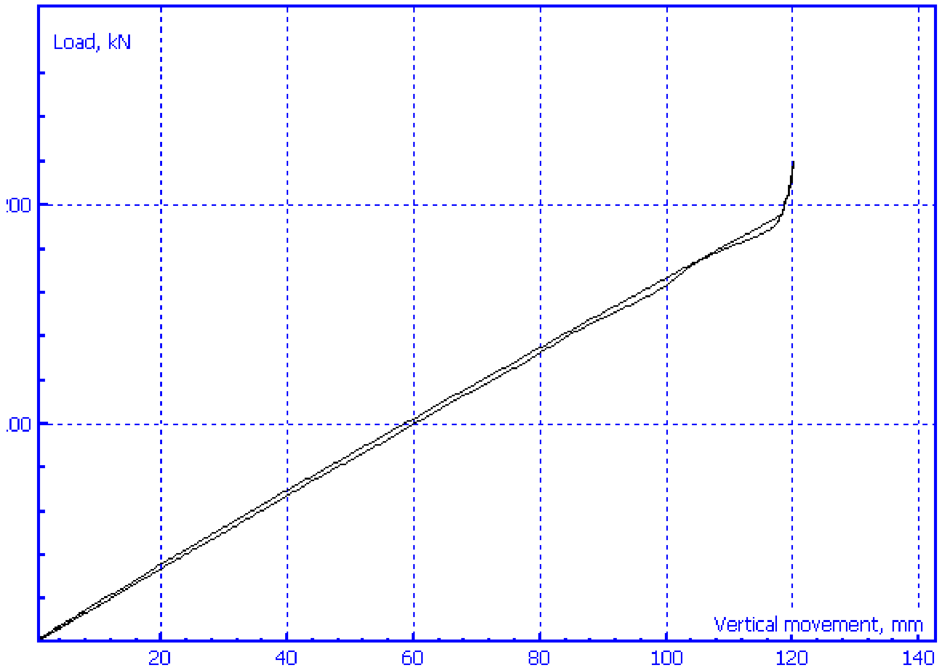


Fig. 53 Test result: Load vs. vertical movement

3) Run the test. The results are shown in Fig. 53. Increase of the suspension stiffness corresponds to the vertical movement exceeding the road wheel dynamic travel 110 mm parameterized by the identifier *f_dyn*, Fig. 40.

2.2.4. Test: initial velocities

The test is necessary for automatic computation of initial velocities of TV bodies by the given value of the TV speed, when one of the main dynamic tests is executed. As a rule, it is enough to create a file of initial conditions corresponding to one speed, e.g. 5 m/s. With this file, the program computes start velocities for any speed of TV using a scale factor.

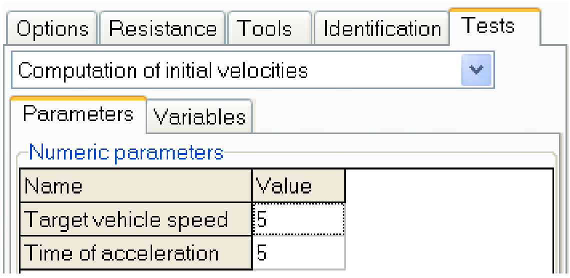


Fig. 54 Test parameters

1) Select the corresponding type of the test; assign the target speed and time interval for acceleration, Fig. 54.

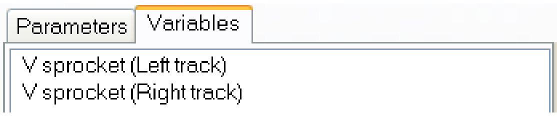


Fig. 55 Test variables

2) Open a graphic window and drag in it the test variables, which are circular velocities of sprockets, Fig. 55.

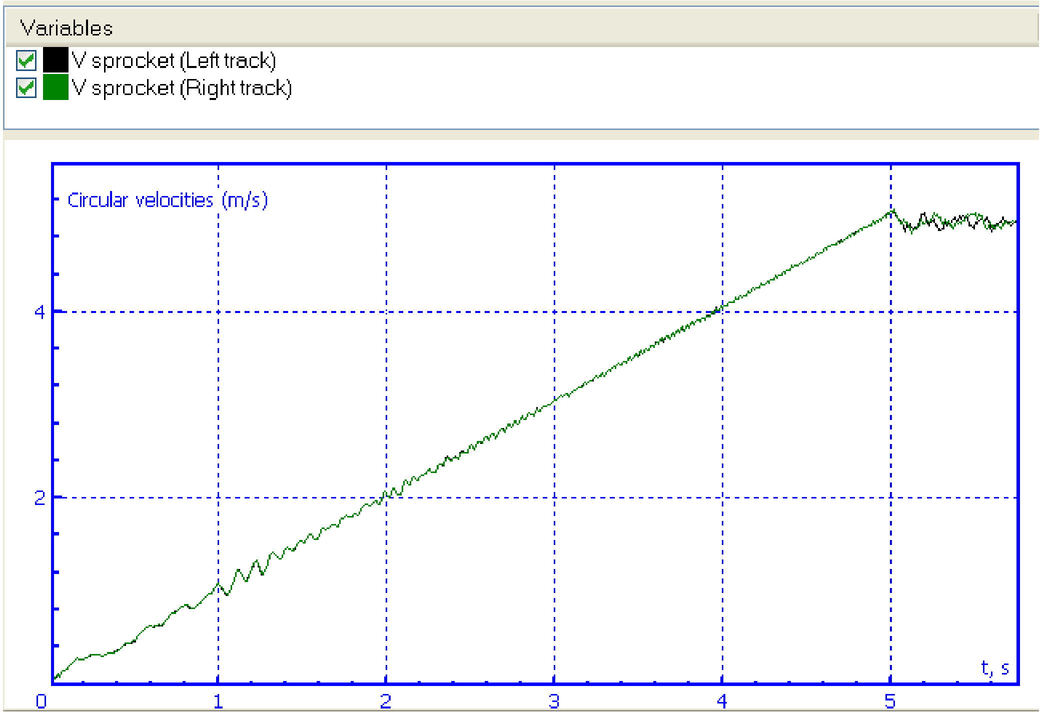


Fig. 56 Circular sprocket velocities vs. time

3) Run the test. The plot of circular sprocket velocities vs. time is shown in Fig. 56.

4) **Confirm saving the results** after finishing the test. The values of coordinates and velocities of all he bodies are saved in the 50.tvv file and will be used in any main dynamic test, in which the TV speed differs from zero.

2.3. Straight motion of TV

This is the main test for analysis of dynamics of a TV by straight motion without turn. Here we consider two examples of such the test.

2.3.1. Motion on sinusoidal road profile

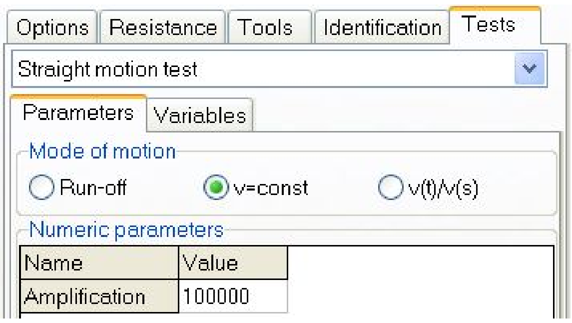


Fig. 57 Test parameter

1) Select the corresponding type of the test, Fig. 57. The test parameter is used in control of the speed history, which will be constant in our test. The amplifier is not used if the ‘Run-off’ speed mode is set.

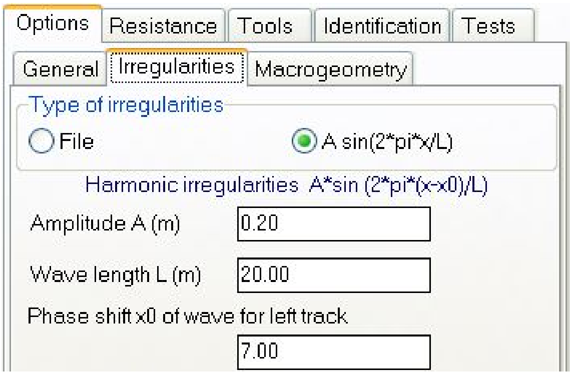


Fig. 58 Parameters of sinusoidal road profile

2) Use the **Tracked vehicle | Options | Irregularities** tab to set parameters of sinusoidal irregularities, Fig. 58**.** By *x*0=0, the irregularities for the left and right tracks are equal, by *x*0>0 the left road curve passes ahead of the right one. Use the button to visualize the curves, Fig. 59.

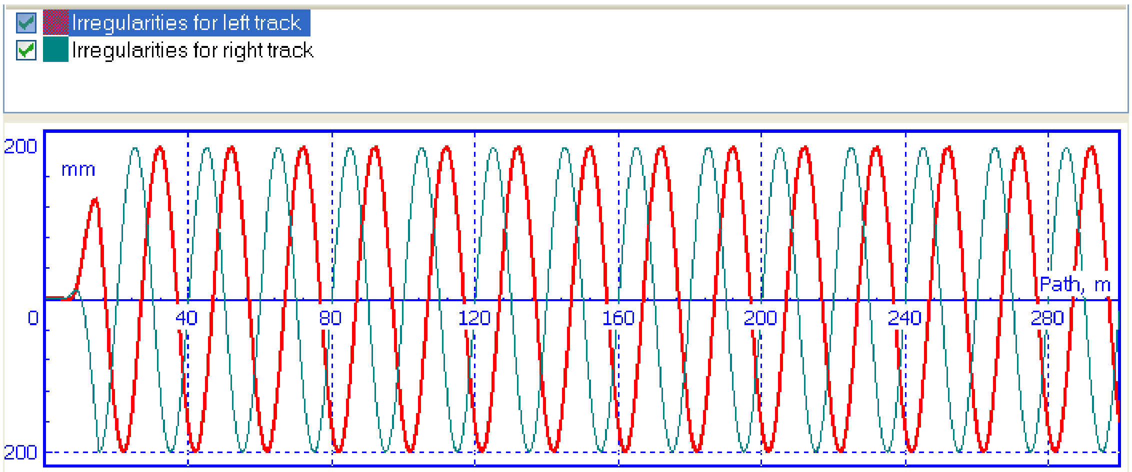


Рис. 59 Sinusoidal irregularities for the left (thick) and right tracks

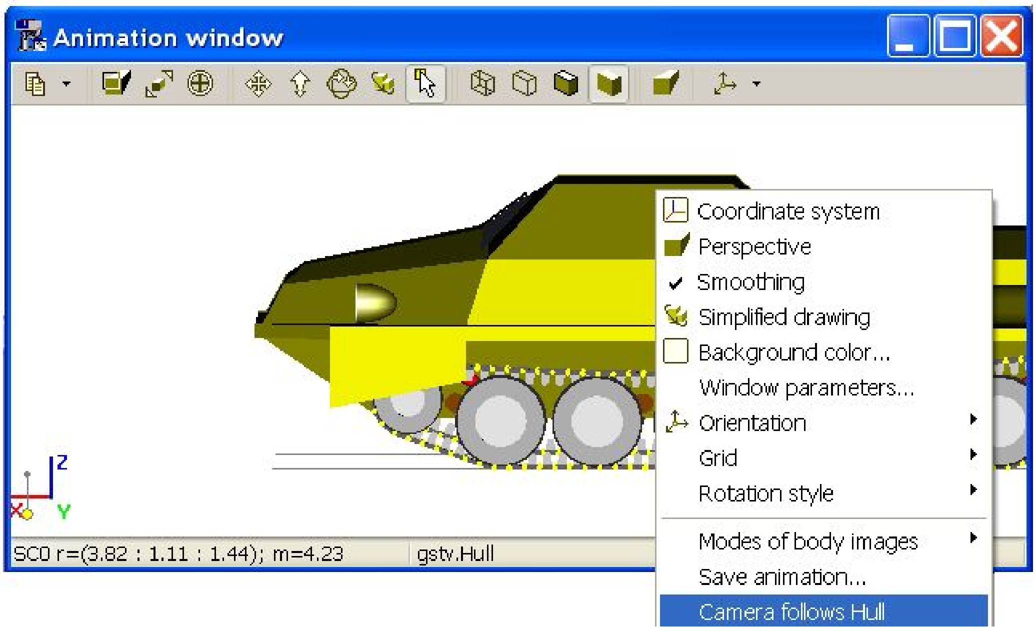


Fig. 60 Setting camera motion

3) Open an animation window and assign the camera motion mode to keep the TV within the window. Move the mouse cursor to the hull image, click the right mouse button, and select the **Camera follows Hull** command, Fig. 60.

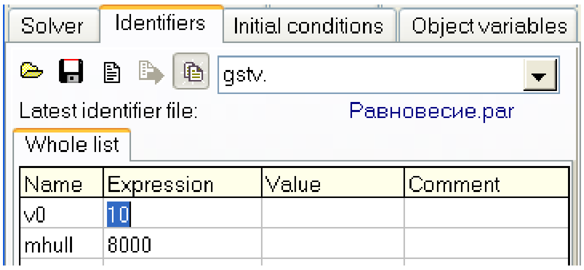


Fig. 61 TV speed

4) Set 10 m/s speed of the TV on the **Identifiers** tab of the inspector, Fig. 61.
5) Open a graphic window and create some variables, which could be useful for dynamic analysis of the TV, e.g. the longitudinal and vertical acceleration of the hull center of gravity.
6) Run simulation.

2.3.2. Modeling of jump

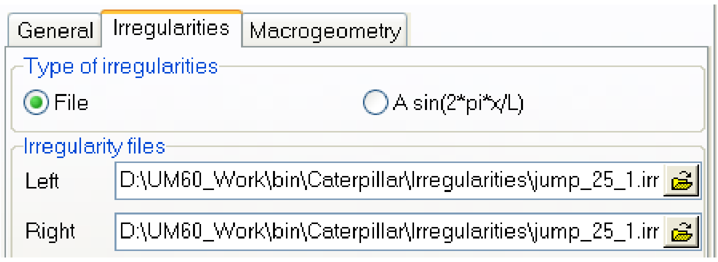


Fig. 62 Setting irregularity files

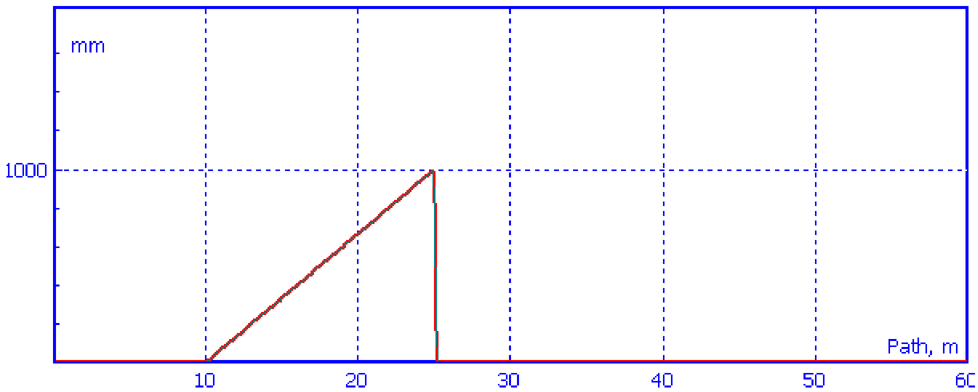


Fig. 63 Road profile for the jump

1) Use the preliminary created road profile

{Path to UM}\bin\caterpillar\Irregularities\jump_25_1.irr.

The file must be assigned by the buttons to the left and right tracks on the **Options | Irregularities** tab, Fig. 62**.** Use the button to visualize the road profile, Fig. 63.
2) Assign speed 10 m/s and run simulation.

References

1. Crawler transporters / Platonov W.F. (Ed.). Moscow: Mashinostroenie. 1972 (Rus).