**UNIVERSAL MECHANISM 9** 



User`s manual



## Simulation of Monorail Train Dynamics

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## 26. UM Module for simulation of monorail trains

## 26.1. General information

Program package Universal Mechanism includes a specialized module **UM Monorail Train** for analysis of 3D dynamics of both single vehicle and trains. The module includes additional tools integrated into the program kernel.

The module is available in the UM configuration if the sign + is set in the corresponding line of the **About** window, the **Help** | **About...** menu command, Figure 26.1.

<b>N</b>	Universal Mechanism Simulation program
	Version 7 All rights reserved (c), 1993-2013 Computational Mechanics Ltd.
	Configuration
	UM Base (+)
	UM Control Panel (+)
	UM Training Ground (+)
	UM Subsystems (+)
	UM Monorail Train (+)
	UM Caterpillar (+)
	UM Loco (+)
	UM Driveline (+)
	UM Rail/Wheel Wear (+)
	UM Train (+)
	www.universalmechanism.com
	e-mail: um@universalmechanism.com

Figure 26.1. UM Monorail Train module is available

**UM Monorail Train** contains the following main components:

- tools for generation and visualization of guideway structure (bridge) geometry;
- tools for generation and visualization of guideway roughness (irregularities);
- mathematical models of tire forces (tire/road contact forces);
- set of typical dynamic experiments.

**UM Monorail Train** allows the user to solve the following problems:

- estimation of vehicle vibrations due to irregularities;
- estimation of vehicle dynamic performances on curving;
- parametric optimization of vehicle elements according to various criteria;
- longitudinal forces and vibrations for trains.

# 

## 26.2. Base system of coordinates

Figure 26.2. Base system of coordinates (SC0)

Inertial system of coordinates (SC0) in UM Monorail Train meets the following requirements (Figure 26.2).

- Axis Z is vertical, axis X coincides with the vehicle longitudinal axis at its ideal position at the moment of motion start; direction of X axis corresponds to the motion direction of the vehicle.
- Origin of SC0 lies at the centerline of the ideal upper surface of track beam, i.e. the surface for driving wheels.

## 26.3. Development of vehicle model

The user develops the vehicle model in UM Input.exe program. The model consists of bodies, joints and force element. We recommend to start the model development with studying the model delivered with UM <u>{UM Data}\Samples\Monorail\Monorail vehicle</u>.

Variables	Curves	Attributes	T-Forces	*
General	Options	Sensors/LSC	A Special forces	-
Transform into subsystem		DriveTire_FL		
		DriveTire_FR		
Object identifie	O_WORK(Te:	sts (monoral) Test	DriveTire RR	
UMObject identilie			StabTire_L	
OMODJECT			- O StabTire_R	=
Comments			GuideTire_FL	1
Monorail			- GuideTire_FR	
Train 3D			GuideTire_RL	
Generation of e	quations		GuideTire_RR	-
Symbolic				
0-1				
<ul> <li>Numeric-ite</li> </ul>	rative			
Numeric-ite Direction of gra	rative avity			
Numeric-ite     Direction of gra     ex:	ative avity	c	Name: DriveTire FL	.e 99 .c
Numeric-iter Direction of gra ex: ey:	rative avity	C	Name: DriveTire_FL Comments/Text attribute	<u>·추 한 · ·</u> C
Numeric-ite Direction of gra ex: ey: ez: -1.0	rative avity	C	Name: DriveTire_FL Comments/Text attribute	<u></u>
Numeric-iter Direction of gra ex: ey: ez: -1.0	rative avity	C C	Name: DriveTire_FL Comments/Text attribute Body1: Body1: Body1:	<u>- :</u> 축 <u>축</u> - := C ody2:
Numeric-iter     Direction of gra     ex:     ey:     ez:     -1.0 Characteristic si	ze: 1.00	C C C	Name: DriveTire_FL Comments/Text attribute Body1: Base0 J	C C ody2: riveWheel_FL ▼

## 26.3.1. Monorail identification

Figure 26.3. Text attribute 'Monorail'. Special forces 'Tires'

UM identifies the model as a monorail vehicle or a monorail train if the following two requirements are met in the model description:

- The standard text comment 'Monorail' must be set in the **Comments** box on the **General** tab of the data inspector, Figure 26.3, left;
- Special forces of the **Tire** type are assigned to the wheels, Figure 26.3, right.

## 26.3.2. Modeling wheels



Figure 26.4. Model of a wheel as a body

A wheel in the UM model of a vehicle is a usual rigid body with assigned image and inertia parameters, Figure 26.4. The following special features distinguish the wheel from other bodies in the model.

- Center of mass is located at the origin of the wheel-fixed system of coordinates (SC).
- Wheel rotation axis coincides with the Y-axis of the wheel-fixed SC.
- A special force element of **Tire** type should be created for each of the wheel, Figure 26.3, right.
- The wheel should be connected to the vehicle by a rotational joint; increment of joint coordinates must correspond to the motion of the vehicle ahead.

In case of guiding and stabilizing wheels, the last requirements can be met if one of the joint vectors has opposite directions for the left and right wheels because the wheels rotate in different directions. Examples of rotational joints for the left and right guiding wheels are shown in Figure 26.5, Figure 26.6. Bogie-fixed joint vector for the left wheel is directed downwards whereas for the right wheel it is directed upwards.

Universal Mechanism 9	26-7	Chapter 26. Simulation of monorail
		Name: jBogie_GuideWheel_FL
		Body1: Body2:
		Frame  GuideWheel_FL
		Type: \land Rotational 👻
	$F \leq $	Geometry Description Joint force
	$\leq$	Joint points
$\overline{\mathcal{A}}$	$\leq$	Frame 💦
		x_guide_v c y_guide_v c -z_guide_v c
	$\sim$	GuideWheel_FL 🖏
		Joint vectors
		Frame axis Z : (0,0,1)
		0 n 0 n -1 n
	<hr/>	
		GuideWheel_FL axis Y : (0,1,0) ▼

Figure 26.5. Joint for the left guiding wheel

	Name: jBogie_GuideWheel_FR 박 박 후
	Body1: Body2:
1	Frame
	Type: \land Rotational 👻
	Geometry Description Joint force
	Joint points
	Frame 🕵
	x_guide_v c -y_guide_v c -z_guide_v c
	GuideWheel_FR
	C C C
	Joint vectors
	Frame axis Z : (0,0,1) ▼
	0 <u>n</u> 0 <u>n</u> 1 <u>n</u>
	GuideWheel_FR axis Y : (0,1,0)
	0 <u>n</u> 1 <u>n</u> 0 <u>n</u>

Figure 26.6. Joint for the right guiding wheel

We could recommend the following method for verification the correctness of joint description, Figure 26.7.

- Set the contour type of graphics in the animation window by the  $\square$  button in the top of the window.
- Open the **Description** tab in the data inspector. Change the value of the coordinates 1,2,3... degrees and watch the direction of the wheel rotation.

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• If the direction is false, change the direction of the bogie-fixed joint vector on the **Geometry** tab.



Figure 26.7. Increase of the joint coordinate

## 26.3.3. Suspension springs and shock absorbers

Linear suspension springs can be modeled by the *generalized linear force elements* (Chapter 2) if a stiffness matrix describes their stiffness properties.

Both linear and nonlinear bipolar springs and shock absorbers can be modeled by *bipolar force elements* (Chapter 2).

## 26.3.4. Air springs

The air springs are modelled with the help special force of **Airspring** type (<u>Chapter 2</u>, Sect. *Special forces/ Air springs*) or **Pneumatic subsystem** (<u>Chapter 31</u>).

## 26.3.5. Bushings

UM supports both linear and nonlinear bushings. The mathematical model of bushings is described in <u>Chapter 2</u>, Sect. *Special forces/Bushings*. Input of the element parameters see in <u>Chap-</u> <u>ter 3</u>, Sect. *Data Input / Input of force elements / Special forces / Bushings*.

Name: jBogie_DriveWh	eel_FL <u>· 호 한 · 드</u> 두
Body1:	Body2:
Frame	DriveWheel_FL -
Type: \land Rotational	<b></b>
Geometry Descriptio	n Joint force
a+b Expression	-
Description of force Pascal/C expression: F	F=F(x,v,t)
Example: -cstiff*(x-x0)-cdiss	*v+ampl*sin(om*t)
F= MLongitudinalCo	ontrol

## 26.3.6. Longitudinal velocity control

Figure 26.8. Joint torque for longitudinal velocity control

To make possible a control of the vehicle longitudinal velocity, the model of a vehicle needs a special traction joint torque. In the simplest case the torque is introduced in the driving wheel joint, which is a rotational joint connecting the driving wheel, Figure 26.8. The model of the control torque is described as a joint torque of the *Expression* type by one and the same identifier for all of the driving wheels. The default identifier is (recommended) *MLongitudinalControl* 

The user may introduce another name of identifier.

## 26.4. Track macro profile and roughness

Guideway geometry is composed of two components: macro profile, and roughness.

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## 26.4.1. Track macro profile

Track macro profile contains 3D information about the geometry of the centerline on the top of guiding beam. The centerline is composed of the horizontal (X-Y) and vertical profiles, which assumed to be independent. Both horizontal and vertical profiles are stored in \*.mcg text files located by default in the **{UM Data}\Monorail\Macrogeometry** directory.

The **horizontal profile** includes any number of tangent sections, standard curves and plane curves specified by a set of points with optional smoothing by splines. The **standard curve** consists of two **transient sections** and a **steady section** with constant radius. The transient sections are the Euler's (Cornu's) spiral (clothoid), i.e. a plane curve whose curvature changes linearly with the curve length. Thus, the curvature increases from zero to the given value at the start transient section, is constant within the steady section, and finally decreases to zero at the end transient section.

The **horizontal profile** consists of any number of sections with constant slope and sections specified by a set of points with optional smoothing by splines. Coupling of sections with constant slopes is smoothed by circles with the given radii.

To generate a macro geometry file use the **Tools** | **Create macrogeometry...** menu command in **UM Simulation** program. The wizard of macro geometry appears (Figure 26.9).



Figure 26.9. Wizard of macro geometry. Horizontal (upper plot) and vertical (lower plot) profiles

## 26.4.2. Track macrogeometry in horizontal plane

The upper part of the window in Figure 26.9 is used for description of the track geometry in the horizontal plane.

• To *add* a section, click on the  $\mathbf{B}^{+}$  button and select the section type in the menu.



Figure 26.10. Section menu

- To *edit* the section parameters double click on the corresponding line of the section list or select the line and press Enter.
- To *insert* a section before the selected one, click on the  $\mathbb{B}^{\mathsf{t}}$  button.
- The button **removes** the selected section from the list.



Figure 26.11. Additional plot information about profile

• The 🖾 button allows the user to get some useful information about the horizontal profile like curvature and superelevation.

## 26.4.2.1. Tangent section

Section parameters		
Length	100.00	
	Apply	Cancel

Figure 26.12. Parameters of a tangent section

Tangent section window contains the values of section length.

## 26.4.2.2. Curve section

Curve	parameters
Type O Lo	e of curve eft
P1	50
s	200
P2	50
R	300
H(%	)0.09
L	300
	Apply Cancel

Figure 26.13. Window with curve parameters

Curve parameter window includes

- type of curve (left or right);
- geometric parameters of the curve: lengths of transient sections (P1, P2), length of steady curve section (S), radius (R), superelevation (H).

## 26.4.2.2.1. Point curve

Pointwise curve	×
Curve XY	5
Superelevation (%)	2
Принять	Отменить

Figure 26.14. Point curve parameter window

Point curve can be used for the pointwise description of guideway horizontal geometry. Press button for editing of the curve parameter in the curve editor.

• Curve XY

Curve editor is used for setting the guide beam centerline projection in XY plane. The section length is evaluated automatically as a length of XY curve.

## The first point must have zero coordinates. The tangent to the curve at the first point must be equal to the positive direction of X axis.

Number of points and curve length are not limited. For example, it can be measured field data or analytically computed coordinates of nonstandard transient curve section. The point list can be as follows:

Х	Y	Х	Y
0	0	26	0.4394
2	0.0002	28	0.5488
4	0.0016	30	0.675
6	0.0054	32	0.8192
8	0.0128	34	0.9826
10	0.025	36	1.1664
12	0.0432	38	1.3718
14	0.0686	40	1.6
16	0.1024	42	1.8522
18	0.1458	44	2.1296
20	0.2	46	2.4334
22	0.2662	48	2.7648
24	0.3456	50	3.125
26	0.4394		

The list is recommended to be prepared in MS Excel as a two-column table. Than it is copied to clipboard and pasted to the curve editor (all other points must be preliminary deleted from the curve editor list!). The curve is shown in Figure 26.15. B-Spline smoothing is recommended for the curve approximation. Automatically evaluated curve length is shown in Figure 26.16.



Figure 26.15. XY curve editor

Plane B <sup>4</sup> B <sup>4</sup>	
S	Macrogeometry XY
0	Tangent: L=100.00
100	Curve(Left): R=300; H=0.0
400	L=50.17; Points: 26
450.17	Tangent; L=100.00

Figure 26.16. Point curve length



Figure 26.17. Direction of positive superelevation

## • Superelevation

Superelevation is a function of the XY curve length. The user may use the length data evaluated in the last column in point table, Figure 26.15.

The positive direction of superelevation is show in Figure 26.17.

**Remark.** The user should take care of the continuity of superelevation function.

## 26.4.3. Track macrogeometry in vertical plane

The lower part of the window in Figure 26.18 is used for description of the track geometry in the vertical plane.

• To *add* a section, click on the  $\mathbf{B}^{\bullet}$  button and select the section type in the menu.

Add constant slope section Add pointwise section

Figure 26.18. Section menu

• To *edit* the section parameters double click on the corresponding line of the section list or select the line and press Enter.

## 26.4.3.1. Constant slope section

Gradient	×
Length, m	100.00
Gradient, ppt	9.00
Next radius, m	25000
	Apply Cancel

Figure 26.19. Constant slope section parameters

The following parameters can be set in Gradient window (Figure 26.19):

- length of section (m);
- gradient in ppt (parts per thousand or meters per kilometer);
- radius of circle on smoothing the gradient change.

## 26.4.3.2. Point section

Point curve can be used for the description of vertical guide beam centerline coordinate as a function of the XY curve length. Curve editor is used for description of functions, see Figure 26.20. Curve editor opens when section editing starts.



Figure 26.20. Parameters of point section

X parameter corresponds to curve length value; Y parameter – to Z coordinate of track axis. B-Splines are recommended for approximation.

**Remarks.** Use zero smoothing radius value for constant slope section if point section is next to it, otherwise the vertical profile will have a break of tangent.

## 26.4.4. Track roughness (irregularities)

Development of track roughness (irregularities) files \*.irr is considered in details in <u>Capter</u> <u>12</u> file, Sect. *Micro profile (irregularities)*.

Here we consider some features related to monorail trains.

## • Driving wheels

Unlike the road vehicles, equal irregularities are assumed to the left and right driving wheel, i.e. only one \*.irr file is required for the vertical track roughness description.

## • Guiding and stabilizing wheels

Solve	er		Identifiers	Ir	nitial conditions				
Object vari	iables	XVA	Information	Tools	🚍 Monorail train				
🖻 🖪   j	Å.								
Tools	Ident	ification	Resistance	Speed	Flexible track				
Tires		Options and	parameters	Geometr	y, irregularities				
Use irregularities Macro-geometry C:\Users\Public\Documents\UM Software Lab\Universal Mechanism\8\Monorail									
Irregularities:									
Driving (left)		C:\	Jsers\Public\Docume	ents\UM Softwa	are Lab \Univers 🛃				
Driving (right)		C:\	Jsers\Public\Docume	ents\UM Softwa	are Lab \Univer: 🔂				
Guiding (left)		C:\L	Isers\Public\Docume	ents\UM Softwa	re Lab \Univers 🥩				
Guiding (right)		C:\L	Isers\Public\Docume	ents\UM Softwa	re Lab \Univers 🥳				
Stabilizing (left)	)	C:\L	Isers\Public\Docume	ents\UM Softwa	re Lab \Univer: 😹				
Stabilizing (righ	t)	C:\L	Isers\Public\Docume	ents\UM Softwa	re Lab \Univers 🛃				
Factor		1.00	00						
🔽 Coherent rig	ght irreg	ularities							
File with special track deviations           Image: Special track deviations									

Figure 26.21. Parameter "Coherent right irregularities"

Description of irregularities for the left and right wheels depends on the key **Coherent right irregularities**, Figure 26.23. This key affects the sign of the irregularity height for the right wheels only. If the key is checked, positive directions for the left and right irregularities are the same. If not, the direction for the right irregularities changes to opposite one, Figure 26.22.



Figure 26.22. Positive direction of left and right irregularities for different values of the key "Coherent right irregularities"

One of the possible ways to define the horizontal beam irregularities is to consider them as a sum of two functions: horizontal irregularities of the beam centerline  $y_c(s)$  and deviation in the beam width from the constant value  $y_w(s)$ . In this case the irregularities for the left and right wheels are

$$y_l(s) = y_c(s) + y_w(s)/2$$
  
 $y_l(s) = y_l(s) - y_l(s)/2$ 

$$y_r(s) = y_c(s) - y_w(s)/2$$

if the key Coherent right irregularities is checked and

$$y_l(s) = y_c(s) + y_w(s)/2$$
$$y_r(s) = -y_c(s) + y_w(s)/2$$

otherwise.

If the irregularities for the left and right wheels are independent stochastic functions, the key value can be ignored.

## 26.4.4.1. Assigning irregularities

Use the **Monorail train** | **Options and Parameter** tab of the **Object simulation inspector** to select the irregularity files for the wheels by clicking the 🖻 buttons (Figure 26.21). Paths to selected files are stored in the configuration file \*.mrt.

Current irregularities are visualized by clicking the 🖾 button.

Irregularity profiles are corrected at the first two-meter distance to provide a smooth run of a vehicle on the irregularities, Figure 26.23. Thus, the vehicle at start is always on an absolutely even horizontal plane.



Figure 26.23. Correction of irregularities

## 26.4.5. Special track deviations



Figure 26.24. Track beam joint

Special track deviations (STD) are geometric deviations of beams from ideal state, which cannot be considered as smooth and small irregularities. For example, a beam joint in Figure 26.24 can be considered in UM as a special track deviation only. We consider a plane model of STD only, and the deviations are considered for the driving wheels only, not for the guiding and stabilizing wheels.

Object simulation inspector											
Solv	/er		Identifiers	In	itial conditions						
Object va	Object variables		Information	Tools	🚝 Monorail train						
Tires		Options and	d parameters	Geometry, irregularities							
Tools	Identi	fication	Resistance	Speed	Flexible track						
	Special tra	ack deviatio	ns		•						
Name	NO Hame										
Abscissa type	2										
📗 🔘 Time			Oistan	ce							
Data input/ed	lit		Curves: 1	•							

Figure 26.25. Tool for STD description

Plane STD are described by a plane curve with the tool, located on the **Monorail train** | **Tools** tab of the Object simulation inspector. Select the Special track deviations item of the pull-

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down menu and click on the 🛄 button to open the curve editor for description of the STD, Figure 26.26.

	1	1	<b>♣</b> ♣	1 Lin	e	-		Ų,
0	20	40	N	x	Y	Туре	Smoothing	
			⊡ Cur					
-			- 1	0	0	Line	Yes	
			- 2	8	0	Line	Yes	
			- 3	8.001	-0.1	Line	Yes	
-			- 4	8.05	-0.1	Line	Yes	
04			5	8.051	0	Line	Yes	
			- 6	28	0	Line	Yes	
			7	28.001	-0.1	Line	Yes	
			8	28.05	-0.1	Line	Yes	
- 1			9	28.051	0	Line	Yes	
			- 10	48	0	Line	Yes	
			- 11	48.001	-0.1	Line	Yes	
)8-	·		- 12	48.05	-0.1	Line	Yes	
-			- 13	48.051	0	Line	Yes	
				50	0	Line	Yes	

Figure 26.26. STD curve with three beam joints

Use the 💾 button on the **Tools** tab to save the curve as a \*.trp file.

Object varia	ables	XVA	Information	Tools	🚍 Monorail train						
🖻 🖻   🎙	£_i										
Tools	Ident	ification	Resistance	Speed	Flexible track						
Tires		Options and	d parameters	Geometr	y, irregularities						
🔲 Use irregulari	ities										
Macro-geometry											
C:\Users\Public\Documents\UM Software Lab\Universal Mechanism\8\Monorail											
Irregularities:											
Driving (left)		C:\L	C:\Users\Public\Documents\UM Software Lab\Univers								
Driving (right)		C:\L	C: \Users \Public \Documents \UM Software Lab \Univer: 🚘								
Guiding (left)		C:\U	C: \Users \Public \Documents \UM Software Lab \Univers 🧟								
Guiding (right)		C:\/	C: \Users \Public \Documents \UM Software Lab \Univers 🛃								
Stabilizing (left)		C:\/	Jsers \Public \Docume	nts\UM Softwa	re Lab\Univer: 🛃						
Stabilizing (right	t)	C:\L	Isers \Public \Docume	nts\UM Softwa	re Lab\Univer: 💕						
Factor		1.00	00								
Coherent right irregularities											
File with special	l track d	eviations									
Use special to	rack de	viations									
C:\Users	C: \Users \Public \Documents \UM Software Lab \Universal Mechanism \8 \SAMPLES										

Figure 26.27. Choice of file with STD

To run simulation with a STD curve, select a \*.trp file with the  $\mathbf{\vec{B}}$  button and check the Use special track deviations option.

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The **Use special track deviations** option allows the user to compare promptly simulation results with and without STD.

Object va	Object variables X		Information	Tools	肩 Monorail train					
	<u>Å</u> .									
Tools Identification			Resistance	Speed	Flexible track					
Tires		Options and	d parameters	Geometr	y, irregularities					
Type of track  Undeformed  Flexible										
<ul> <li>Ire contact m</li> <li>Single poin</li> </ul>	iodel It		Multipo	bint						
-Parameters of	fmultipoi	nt contact								
☑ Distributed flexible contact										
Discretization step (mm) 5.0										

Figure 26.28. Parameters of tire contact model

Tune the tire contact model according to the selected STD. Look at <u>Chapter 12</u> (file 12\_um\_automotive.pdf), Sect. *Single point and multipoint normal contact models* for detailed description of the tire contact model.

If the **Distributer contact model** option is unchecked, the *discrete point contact* is used, which usually used for rolling up a step. In the case of beam joints it gives wrong simulation results.

Remark One additional advantage of use the STD consists in drowing the corresponding deviations in animation window. Usual irregularities are not drawn, and if the user wants to see a short vertical irregularity during the animation, he should describe the vertical irregularity as STD.

## 26.5. Tire models

Models of tire/road interaction forces are considered in details in <u>Chapter 12</u> file, Sect. *Tyre models*. Parameters describing the models are stored in \*.tr files. The default directory for these files is {**UM Data**}**monorailtire**. The user may use the built-in **Wizard of tire models** for changing model parameters.

## 26.6. Track models

There are two types of monorail track models: an **undeformed or rigid track** and a **flexible** one. Undeformed track cannot move and fixed relative to the SC0. In the case of a flexible track, it is modeled as a sequence of FE (finite element) Timoshenko beams with the same section. Each of the beams consists of several sections with different length and with different FE mesh. Beams are connected with neighbor ones and with SC0 by linear viscous-elastic force elements of bushing type, Figure 26.29.



Figure 26.29. Model of a flexible monorail track

You can choose a track model on the tab **Monorail train** | **Options and parameters**, Figure 26.30.

Solve	r	Identifiers	Initial	conditions		Object va	riables		XVA			
	Info	rmation	Tools			Monorail train						
🖻 E												
Tires	Optic	ons and parameters	Tools	Identification	Re	sistance	Speed	FI	exible track			
🔲 Use i	irregul	arities										
Type o	Type of track											
O Uno	leform	ned	Flexible									

Figure 26.30. Type of monorail track

## 26.6.1. Flexible track parameters

The **Flexible track** parameters are described on the corresponding tab and on the **Tools** tab (item *Beam section profile*), see Sect. 26.7.1.3. The **Flexible track** tab includes two groups of parameters **Beams** and **Links**, see Figure 26.31. In the **Beams** group, a sequence of beams is described with the following buttons:

 $\bullet$  is used to add beam to the list;

is used to remove selected beam from the list;

 $\Phi \overline{\Xi}$  is used to insert beam before the selected one.

The following parameters relate to the flexible track:

No. is the beam sequence number;

*L* is the total length, i.e. the length of the beams from the first one to the current one; *Span lengths*. The following syntax is used:

SpanLength1[RepeatCount1], SpanLength2[RepeatCount2], ...;

FE count is the number of FE for a section. The following syntax is used:

FECount1[RepeatCount1], FECount2[RepeatCount2], ...;

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*No. support* assigns indices of force elements from the set **Support**. The force elements connect beams with SC0. Syntax is

SupportID[RepeatCount1], SupportID[RepeatCount2], ...;

*No. coupling* is the index of force element from the **Coupling** set connecting the beam with the next one. Set **-1** if are beams not coupling.

*Damping ratio* is the damping parameter for a beam; this parameter is equal to the damping ratio related to the first mode of the beam.

	Solver Identifiers			ers	Initial conditions			Object va	riables	XVA
		Inf	ormation			Tools		5	Monorai	train
G	<b>₽</b> 8	4 8								
Т	ires	Options a	nd parameters	Tools	Identification	Resistance	Speed	Flexible tr	ack	
F	Beams	;						-		
	+	() ⊕-								
	No.	L	Span lengths		FE count	No. suppor	t No	. coupling	Dam	ping ratio
	1	110.0	30, 40[	[2]	10	1,2,	3	-1		0.002
l[r	inks	-								
	+	<u> </u>								
	Suppo	ort Couplin	ng							
	1	2	3							
	Num	eric parame	eters							
	Имя		Значение							
	Сх		1E8							
	Су		1E8							
	Cz		1E8							
	Cax		1E8							
	Cay		1E8							
	Caz		1E8							
	Dx		1E8							
	Dy		1E8							
	Dz		1E8							
	Dax		1E8							
	Day		1E8							
	Daz		1E8							

#### Figure 26.31. Flexible track tab

The buttons Add link + and Remove selected link m are used for development of **Support** and **Coupling** force lists.

## 26.7. Simulation of monorail dynamics

## 26.7.1. Preparing for simulation

301	ver		Identifiers	I	nitial conditions					
Object va	riables	XVA	Information	Tools	📄 🚍 Monorail traii					
<b>₽</b> 8	£.									
Tools	Identific	cation	Resistance	Speed	Flexible track					
Tires	0	)ptions a	nd parameters	Geomet	ry, irregularities					
Type of track			Classi	ala						
Terrentert	eu		U FIEX	DIE						
Single poir	nodel ht		Multi	point						
Parameters of multipoint contact										
☑ Distributed flexible contact										
Discretization step (mm) 5.0										
Type of bogie	2									
Lower     Oupper										
Tire force visualization										
Longitudina	al force (Fx)									
Longitudina Lateral for	al force (Fx) ce (Fy)									
<ul> <li>Longitudina</li> <li>Lateral for</li> <li>Normal for</li> </ul>	al force (Fx) ce (Fy) ce (Fz)			_						
<ul> <li>Longitudina</li> <li>Lateral fore</li> <li>Normal fore</li> <li>Vector length</li> </ul>	al force (Fx) ce (Fy) ce (Fz) in wheel radi	lius	2.0	]						
<ul> <li>Longitudina</li> <li>Lateral ford</li> <li>Normal ford</li> <li>Vector length</li> <li>Lateral displace</li> </ul>	al force (Fx) ce (Fy) ce (Fz) in wheel radi	lius	2.0	]						
Longitudina     Lateral for     Lateral for     Normal for     Vector length     Lateral displace     Wired bean	al force (Fx) ce (Fy) ce (Fz) in wheel radi rement n image	lius	2.0 0.00	]						
Longitudina     Lateral for     Lateral for     Vector length     Lateral displace     Wired bean     Parameters	al force (Fx) ce (Fy) ce (Fz) in wheel radi ement n image	lius	2.0	]						
Longitudina     Lateral for     Lateral for     Normal for     Vector length     Lateral displace     Wired bean     Parameters     Numeric para	al force (Fx) ce (Fy) ce (Fz) in wheel radi ement n image ameters	lius	2.0 0.00	]						
Longitudina     Lateral fore     Normal fore     Vector length     Lateral displace     Wired bean     Parameters     Numeric para     Name	al force (Fx) ce (Fy) ce (Fz) in wheel radi ement n image ameters	ius	2.0	Value						
Longitudina     Lateral for     Lateral for     Vector length     Lateral displace     Wired bean     Parameters     Numeric para     Name     Guideway ba	al force (Fx) ce (Fy) ce (Fz) in wheel radi mement n image ameters ase (m)	lius	2.0 0.00	Value 0						
Longitudina     Lateral fore     Lateral fore     Vector length     Lateral displace     Wired bear     Parameters     Numeric para     Guideway ba     Bridge pillar	al force (Fx) ce (Fy) ce (Fz) in wheel radi mement n image ameters ase (m) base (m)	lius	2.0 0.00	Value 0 30						
Longitudina     Lateral ford     Lateral ford     Vector length     Lateral displace     Wired bean     Parameters     Numeric para     Name     Guideway ba     Bridge pillar     Shift along Z	al force (Fx) ce (Fy) ce (Fz) in wheel radi mement n image ameters ase (m) base (m) ? of pillar GO	lius (m)	2.0 0.00	Value 0 30 -1.5						
Longitudina     Lateral for     Lateral for     Vector length     Lateral displace     Wired bear     Parameters     Numeric para     Name     Guideway ba     Bridge pillar     Shift along Z     Beam-image	al force (Fx) ce (Fy) ce (Fz) in wheel radi mement n image ameters ase (m) base (m) ? of pillar GO step (m)	lius I (m)	2.0 0.00	Value 0 30 -1.5 1						
Longitudina     Lateral fore     Lateral fore     Vector length     Lateral displace     Wired bean     Parameters     Numeric para     Numeric para     Bridge pillar     Shift along Z     Beam-image     Kinetic energy	al force (Fx) ce (Fy) ce (Fz) in wheel radi ement n image ameters ase (m) base (m) ? of pillar GO step (m) gy for stop (.	lius (m)	2.0	Value 0 30 -1.5 1 0.001						
Longitudina     Lateral for     Lateral for     Normal for     Vector length     Lateral displace     Wired bean     Parameters     Numeric para     Name     Guideway ba     Bridge pillar     Shift along Z     Beam-image     Kinetic energ     Guiding whee	al force (Fx) ce (Fy) ce (Fz) in wheel radi ement n image ameters ase (m) base (m) t of pillar GO step (m) gy for stop (, el contact Y	lius (m) (J) (m)	2.0 0.00	Value 0 30 -1.5 1 0.001 0.425						
Longitudina     Lateral for     Lateral for     Vector length     Lateral displace     Wired bear     Parameters     Numeric para     Numeric para     Bridge pillar     Shift along Z     Beam-image     Kinetic energ     Guiding whee     Stabilizing w	al force (Fx) ce (Fy) ce (Fz) in wheel radi mement n image ameters ase (m) base (m) c of pillar GO step (m) gy for stop ( el contact Y heel contact	lius (m) (J) (m) t Y (m)	2.0 0.00	Value 0 30 -1.5 1 0.001 0.425 0.425						
Longitudina     Lateral ford     Lateral ford     Vector length     Lateral displace     Wired bean     Parameters     Numeric para     Numeric para     Name     Guideway ba     Bridge pillar     Shift along Z     Beam-image     Kinetic energ     Guiding whe     Stabilizing w     Contact shift	al force (Fx) ce (Fy) ce (Fz) in wheel radi ement n image ameters ase (m) base (m) t of pillar GO step (m) gy for stop ( el contact Y heel contact t for lower v	ius (J) (m) (t Y (m) vertical w	2.0 0.00	Value 0 30 -1.5 1 0.001 0.425 0.425 0.2						

Figure 26.32. Object simulation inspector

The most part of the monorail specific data is entered and modified with the help of the **Monorail train** tab in the **Object simulation inspector**, Figure 26.32. Use the **Analysis** | **Simulation...** menu command of the **UM Simulation** program to open the inspector. The data can be saved in monorail vehicle configuration files \*.mrt. Use the  $\cong$  I buttons on the tab to read/write data.

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The monorail configuration data is saved automatically in the *last.mrt* file if the **Monorail train configuration** key is on in the options of the **UM Simulation** program, Figure 26.33. Use the **Tools | Options...** menu command to call this window.

Options				X						
Export to	MS Excel		Bug reports							
General	Autosave	Fo	rmat of numb	bers						
Save										
Configuration										
✓ Initial conditions										
Identifiers										
🔽 Rail vehicle co	onfiguration									
🗷 Road vehicle	configuration									
Tracked vehi	cle configuration									
🗹 Well drilling o	onfiguration									
📝 Monorail train	o configuration									
		ОК	Ca	ncel						

Figure 26.33. Options of UM Simulation program

General information about **UM Simulation** program and its tools are concentrated in <u>Chap-</u> ter 4.

The user should follow some definite steps to make a new created monorail model ready for simulation.

- 1. Create a monorail train model in **UM Input** program.
- 2. Run the **UM Simulation** program.
- 3. Assign tire models to the wheels on the **Monorail train** | **Tires** tab. If necessary, create new tire models.
- 4. Assign a preliminary created file of macro-geometry by the <sup>i</sup>∋, Figure 26.32. Use the <sup>i</sup>≤ button to view/modify the macro-geometry.
- 5. If necessary, check the option **Use Irregularities** and assign irregularity files, Figure 26.32. The **Factor** increases (<1) or decreases (>1) assigned irregularities.
- 6. Set the guideway structure geometrical parameters, Figure 26.32:
  - $\circ$  Guiding wheel contact Y (m) a half of guiding beam width on the level of guiding wheels.
  - Stabilizing wheel contact  $\mathbf{Y}$  (m) a half of guiding beam width on the level of stabilizing wheels.
  - **Guideway base (m)** distance between two parallel guiding beams, has a visual effect only.

- **Bridge pillar base** (m) distance between bridge pillars in longitudinal direction, has a visual effect only.
- Shift along Z of pillar go (m) allows matching the pillar vertical position.
- **Beam image step (m)** is the discretization step of the longitudinal beam image. Decrease of this parameter makes smother the beam curve in animation window, has a visual effect only.
- 7. Set the **Kinetic energy for stop** parameter (Figure 26.32), which is used in equilibrium simulation (speed mode v=0).

## 26.7.1.1. Identification of longitudinal velocity control

Use the **Monorail train** | **Identification** tab of the **Object simulation inspector** to identify the *longitudinal velocity control* parameters. Select the '*Control* V' data type in the drop-down menu

Object va	ariables	XVA	Info	ormation	Tools	Monorail train					
📤 🛃 🖾	1										
Units	T	res	Opt	ions and Pa	arameters	Tools					
Identific	ation	Resistan	ice	Speed	Guide	eway structure					
Control V						•					
Parameters											
Identifiers											
Name			Ident	ifier							
Longitud	inal contr	ol torque	Bogie	e1.mlongitu	ıdinalcontr	ol					
Numeric parameters											
Name	Name Value										
Gain	5000										

Figure 26.34. Identification of longitudinal velocity control parameters

Identification of the longitudinal velocity control parameters of the model requires selecting of one identifier, Sect. 26.3.6, Figure 26.34:

- Longitudinal control torque as well as one numeric values
- Control gain

Double click be the left mouse button on the corresponding table row to assign a model identifier. Use the direct input to set the gain value.

The control of the longitudinal velocity is realized to the proportional control law

$$M = -K(v - v_d)$$

where M is the torque (the value of the torque identifier), K is the gain, v is the current velocity of the vehicle, and  $v_d$  is the desired velocity, which can be both constant and some function of time.

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## 26.7.1.2. Creating longitudinal velocity functions

Use the **Monorail train** | **Tools** tab of the **Object simulation inspector** to specify the desired *longitudinal velocity* functions.

Using this interface the user specifies a dependence on time or distance of the desired longitudinal speed, Figure 26.35.

Object varia	bles	XVA	Information		Tools	Monorail train				
📤 🛃 🖂										
Identification Re		Resista	ance	Speed	Guide	way structure				
Units	Units Tires			ions and Pa	rameters	Tools				
📤 🖬 Long	Longitudinal speed history									
Name (no)										
Abscissa typ	e									
🔘 Time				Oistan	се					
Data Input/Edit				Points: 0		·				

Figure 26.35. Interface for functions of time and distance

The function is a set of points with a possible spline smoothing. To set the function, the user calls the curve editor by clicking the 🛄 button.



Figure 26.36. Setting functions with the curve editor

Use the 🔁 🖬 buttons to read/save data from/to file.

**Remark.** If initial speed is zero, dependence of the speed on time must be used (not on distance).

#### 26.7.1.3. Creating beam section profile

Solver Identi	fiers Initial con	ditions Obj	ject variables	VA Infor	mation	Tools	Monorail train		
🖻 🖻 🗎									
Tires Optio	ons and paramet	ers Tools	Identification	Resistance	Speed	Flexibl	e track		
🛱 🛱	Beam section p	rofile					•		
Name	(no)								
Data Input/E	Data Input/Edit Points: 13								
Material	1	<b>a</b> ==							
Young's modu	lius -	3.55	E10						
Poisson's rati	0	0.2							
Density		2500	)						
Cross-section	Value								
A	1 215								
Tv	0.238212								
IZ	0.0675828								
Ivz	ol								
Ix	0.160873								
Ку	0.847316								
Kz	0.797009								
Fastenings p	oints								
+ 🗊									
No.	X Y								
1 -(	).425 -1.5	5							
2 (	.425 -1.5	5							

Figure 26.37. Tool for setting beam section

Use the **Monorail train** | **Tools** tab of the **Object simulation inspector** to specify the desired guiding *Beam section profile*, Figure 26.37. Click on the  $\square$  button to open the Curve editor. The profile is described by a closed line be a set of points, see Figure 26.38.

In the case of a flexible track, Sect. 26-24, the beam parameters **Young's modulus**, **Poisson's ratio** and **Density** are set in the **Material** group, as well as geometric section parameters are specified in then **Cross-section properties** group, Table 26.1.

In the **Fastenings points** group, fastenings points of the beam to the pillar can be define. The fastening points are defined in the local system of coordinates of the beam cross-section, see Figure 26.38. If the fastening points are not defined, then are assigned automatically depending on the beam type according to Figure 26.39. The buttons Add point + and Remove selected point 1 are used for development of Fastenings points list.

Table 26.1

Parameter	Description
A	Cross-section area
I <sub>y</sub>	Moment of inertia relative to Y axis
Iz	Moment of inertia relative to Z axis
I <sub>yz</sub>	Product of inertia
I <sub>x</sub>	St. Venant torsion constant
k <sub>y</sub>	Shear correction factor in principal planes Y
k <sub>z</sub>	Shear correction factor in principal planes Z



Figure 26.38. Beam section description



Figure 26.39. Location of default fastening points for different types of monorail beams

#### Monorail beam cross-section parameters

## 26.7.2. Modes of longitudinal motion of monorail

Object variables	XVA	Information	Tools	Monorail train
📤 🔛 🖂				
Tires	Opt	ions and Paramet	ers	Tools
Identification	n	Resistance		Speed
Speed mode				
Neurtal		🔘 Profile	e	
v=const		© v=0		

Figure 26.40. Longitudinal motion modes

Modes of longitudinal motion of the monorail are set on the **Monorail train** | **Speed** tab of the inspector.

#### 26.7.2.1. Neutral

In this mode the initial speed value is set by the v0 identifier, Figure 26.41. The speed decreases due to resistance forces.

Object simulation inspector								
Rail/W	'heel		/A	Informa	ation	Tool	s	
Solver	lder	ntifiers	Initi	ial conditions	Obje	ct varia	bles	
🗁 🔒 Whole li	🖹 🗄		ac4.				•	
Name	Expr	ession		Value	Com	ment	^	
V0	20							

Figure 26.41. Identifier of speed

#### 26.7.2.2. v=const

Constant speed mode. The nearly constant value of the vehicle speed is supported automatically by the torque applied to the driving wheel, see Sect. 26.3.6, 26.7.1.1

$$M = -\mathbf{K}(v - v\mathbf{0}),$$

where v0 is the desired speed, v is the current speed, and K is the amplifier.

In this mode the desired speed value is set by the **v0** identifier, Figure 26.41.

## 26.7.2.3. Profile

The speed is controlled according to a dependence on a time or distance. The control force is similar to that in the previous mode (v=const). The  $\bigtriangleup$  buttons are used for reading previously created profiles (Sect. 26.7.1.2) and for saving the current curve.

Identification	Identification Resistance			
Speed mode				
Neurtal	Profile			
© v=const	─ v=0			
Speed profile				



## 26.7.2.4. v=0

Identification	Resistance	Speed					
Speed mode							
Neurtal	Profile						
© v=const	● v=0						
Automatic termination of equilibrium test							

Figure 26.43. Zero speed test

Zero velocity mode.

If the key 'Automatic termination of equilibrium test' is checked, the simulation runs until the kinetic energy decreases to the minimal value specified by the user, Sect. 26.7.1, the parameter **Kinetic energy for stop**. After success of the test, the program automatically accepts the coordinate values as standard ones and stored static deflections of tires and static tire loads, Figure 26.44. It is recommended to run this equilibrium bests before other simulations.

If the key 'Automatic termination of equilibrium test' is not checked, automatic actions are skipped. In this simulation, the user can e.g. apply periodic excitations to get the system response.

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XV	A	Information		Tools		Monorail trair		train
ے چ	~~							
Tires	Options	and Parameters Te	ools	Identificati	on	Resista	ince s	Speed
Co	mbined sli	ip						
Set of	f tire mod	els						
<u></u> _+	c:\users\	public\documents\u	m sof	tware lab∖u	inive	ersal me	echanis	sm\7\tir
E	c:\users\	public\documents\u	m sof	tware lab\u	inive	ersal me	echanis	sm\7\tii
È								
Wheel			Mod	el	St	at. load	Deflec	tion
monor	ail vehicle	.Bogie1.DriveTire_Fl	fialan	nrdrive04	17	7.93kN	35.9n	nm
monor	ail vehicle	.Bogie1.DriveTire_F	fialar	nrdrive04	17	7.93kN	35.9n	nm
monor	ail vehicle	.Bogie1.DriveTire_R	l fialan	nrdrive04	17	7.93kN	35.9n	nm
monor	ail vehicle	.Bogie1.DriveTire_R	l fialan	nrdrive04	17	7.93kN	35.9n	nm
monor	ail vehicle	.Bogie1.StabTire_L	fialar	nr_guide03	3.	25kN	10.0n	nm
monor	ail vehicle	.Bogie1.StabTire_R	fialar	nr_guide03	3.	25kN	10.0n	nm
monor	ail vehicle	.Bogie1.GuideTire_F	l fialan	nr_guide03	3.	25kN	10.0n	nm
monor	ail vehicle	.Bogie1.GuideTire_F	l fialan	nr_guide03	3.	25kN	10.0n	nm
monor	ail vehicle	.Bogie1.GuideTire_R	fialar	nr_guide03	3.	25kN	10.0n	nm
monor	ail vehicle	.Bogie1.GuideTire_R	fialar	nr_guide03	3.	25kN	10.0n	nm
monor	ail vehicle	.Bogie2.DriveTire_Fl	fialan	nrdrive04	17	7.93kN	35.9n	nm
monor	ail vehicle	.Bogie2.DriveTire_F	fialan	nrdrive04	17	7.93kN	35.9n	nm
monor	ail vehicle	.Bogie2.DriveTire_R	l fialan	nrdrive04	17	7.93kN	35.9n	nm
monor	ail vehicle	.Bogie2.DriveTire_R	l fialan	nrdrive04	17	7.93kN	35.9n	nm
monor	ail vehicle	.Bogie2.StabTire_L	fialan	nr_guide03	3.	25kN	10.0n	nm
monor	ail vehicle	.Bogie2.StabTire_R	fialar	nr_guide03	3.	25kN	10.0n	nm
monor	ail vehicle	.Bogie2.GuideTire_F	l fialan	nr_guide03	3.	25kN	10.0n	nm
monor	ail vehicle	.Bogie2.GuideTire_F	l fialar	nr_guide03	3.	25kN	10.0n	nm
monor	ail vehicle	.Bogie2.GuideTire_R	fialar	nr_guide03	3.	25kN	10.0n	nm

Figure 26.44. Tire static deflections and loads

## 26.7.3. Monorail train specific variables

## 26.7.3.1. Tire/road contact variables

🔄 Wizard of variables					8		
Track coordinate system User variables	Reactions	Coordinates	Solver parameters	All forces	Identifiers		
Variables for group of bodies Monorail train	Linear forces	Joint forces	Angular variables	Linear variables	Expression		
🖃 🔳 monorail vehicle	Selec	ted (total 2)					
🖨 🔳 Bogie1	mono	rail vehicle.Bogi	e1.DriveTire_FL, mono	orail vehicle.Bogie1	.DriveTire_FF		
monorail vehicle.Bogie1.DriveTire	_FL Name	2	Comment				
monorail vehicle.Bogie1.DriveTire	_FR	_	Longitudinal force				
monorail vehicle.Bogie1.DriveTire	_RL		Longitudinariorce				
monorail vehicle.Bogie1.DriveTire			Vertical force				
monorail vehicle.Bogie1.StabTire_			Tilting torque				
monorail vehicle.Bogie1.StabTire_	R My		Rolling resistance torg	110			
monorail vehicle.Bogie1.GuideTire	FL M7		Alianing torque	lac			
monorail vehicle.Bogie1.GuideTire	FR Sy		Longitudinal slin				
monorail vehicle.Bogie1.GuideTire			Lateral slin				
monorail vehicle.Bogie1.GuideTire	RR Gam	na	Camber angle				
Bogie2	dz		Roughness height und	ler wheel			
monorail vehicle.Bogie2.DriveTire	FL ddz		Roughness derivative				
monorail vehicle.Bogie2.DriveTire	FR Defle	ection	Tire deflection				
monorail vehicle.Bogie2.DriveTire	RL Dista	nce	Vehicle distance from	the simulation star	t		
monorail vehicle.Bogie2.DriveTire	RR Area		Contact patch area (n	n^2)			
monorail vehicle.Bogie2.StabTire	L Temp	perature	Tire surface temperat	ure (°C)			
monorail vehicle.Bogie2.StabTire	RW		Tire wear rate (mm/10	000km)			
monorail vehicle, Bogie 2. GuideTire	FL dyBri	idge	Bridge deflection unde	er tire Y			
monorail vehicle.Bogie2.GuideTire	FR dzBri	dge	Bridge deflection unde	er tire Z			
monorail vehicle.Bogie2.GuideTire	RL						
monorail vehicle.Bogie2.GuideTire	RR						
Objects: monorail vehide.Bogie1.D	Objects: monorail vehicle.Bogie 1.D (none)						
Fz (monorail veh Fz (monorail veh							

Figure 26.45. Variables related to tire/beam interaction

Variables related to the tire/beam interaction are available on the **Monorail train** tab of the **Wizard of variables**, Figure 26.45. Use the **Tools** | **Wizard of variables...** menu command to open this window. The **Distance** variable is also available on this tab.

Use other tabs of the wizard to create kinematic and dynamic variables different from the tire variables.

See <u>Chapter 4 to get detailed information about creating variables and their use</u>.

#### 26.7.3.2. Kinematic characteristics relative to track system of coordinates

Kinematical variables of bodies should be often projected on the track system of coordinates (TSC). The X-axis of the TSC is the tangent to the guiding beam centerline including the beam vertical slope, Sect. 26.4.3; the Y-axis is perpendicular to the X-axis taking into account the superelevation, Sect. 26.4.2.

Note that axes of the TSC and SC0 in a straight track are parallel, and projections of vectors on these SC are the same.

🔄 Wizard of variables								×
🔺 🖨 monorail vehicle	Expression	Identifie	er	Spec	cial F	All forces	Joint	force
Base0	Coordinates	Angular va	ar. F	Reactio	on F L	inear var.	Linear F	User
CarBody	Track SC	Monorai	train	1	Solver	FEA col	ouring scl	heme
▷ 🗳 Bogie1	Body							
Dogiez	CarBody				0	0		0
	Type Coordinat Velocity Component X Uncompe	e (	<ul> <li>Ac</li> <li>An</li> <li>Y</li> <li>xeleration</li> </ul>	ccelera ngles tion	tion	© Ang © Ang © Z	g.veloc. g.accel.	

Figure 26.46. Kinematic characteristics of bodies in the track SC

Use the **Track SC** tab of the Wizard of variables to get any kinematic variable in projection of the TSC. To create a variable, perform the following steps:

- select a body in the list in the left part of the wizard;
- select the type of variable: a linear variable (Cartesian coordinates, velocity or acceleration) or an angular variable (angles, angular velocity and angular acceleration);
- set a point in SC of the body, which coordinate, velocity or acceleration should be computed, if a linear variable is selected;
- set an axis of the TSC for projection.

For the lateral component of acceleration, either the uncompensated acceleration or the usual acceleration is selected (Figure 26.46).

## 26.8. Simulation of track as FEM subsystem

Some parts of a track can be simulated as FEM subsystems if UM FEM/Monorail track presents in UM Configuration (see Figure 26.47). In this chapter, the features of description and simulation of such models are presented.

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About			×
۲	Universal Mechanism Simulation program		
	Version 7.5.0.0 32bit All rights reserved (c), 1993-2016 Computational Mechanics Ltd.		
	Конфигурация         UM User Routines       (+)         UM Block Editor       (+)         UM FEM       (+)         UM FEM/Vehicle-Bridge Interaction       (+)         UM FEM/Monorail       (+)         UM Ballast       (+)         UM Durability       (-)         UM 3D Contact       (+)		
	UM Rolling Contact Fatigue (+) UM Flexible Railwav Track (+)	•	
	www.universalmechanism.com		
_	e-mail: um@universalmechanism.com		

Figure 26.47. Window "About...": UM FEM/Monorail tool is available

## 26.8.1. Development of FEM subsystem

A FEM subsystem is created in accordance with <u>Chapter 11</u>. Except monorail track, it can include any parts simulating real construction, for example, supports. In order to **UM** consider the subsystem as monorail track, the subsystem comment should contain key string **@monorail=true@** in any place, no case sensitive (see Figure 26.48). For example, "The subsystem simulates monorail track from 30 to 90 meters @monorail=true@".

Geometry of the FEM subsystem must correspond to the track part that it simulates. In **UM Simulation** program, positions of car wheels are calculated using track macrogeometry data. The FEM subsystem must have such geometry and must be placed so that the wheels go on surface of the subsystem.

Let us consider the recommendations for development of the subsystem and matching its geometry and axis of the track.

Creation of 3D FE model of the track part is advised by dragging plane mesh of a crosssection along a track axis (Figure 26.49). If FEM subsystem has simple form like a straight line or a curve with constant radius, it can be easy put to the required place of track macro profile. Otherwise, the way axis lying on the subsystem surface can be included to the description of a whole macro profile as pointwise curves describing horizontal and vertical profiles (Figure 26.50). Let us consider one of the possible methods of preparing data for these curves.

		×								
Name: Monorailflex		- 								
Type: Linear FE	M subsystem	<b>•</b>								
Comments/Text att	ribute C									
Monorail track from	Monorail track from 30 to 90 meters @monorail=true@									
Solution	Coordina	te systems								
General	Position	Image								
Identifier: s	ubs12									
Ancestor:										
E:\Simulation\TESTS	Monorail MONORAIL	EXTERNAL SAMPLI								
Orientation angles:										
Cardan (1,2,3)		•								
Subsystems inform	ation									
File of subsystem:		EXTERNAL SAMPL								
Data imported from	program:									
NX NASTRAN 8.0										
Name of solution:										
CurveBeam3D										

Figure 26.48. Definition Linear FEM subsystem as monorail track via comment string



Figure 26.49. Position of the monorail track section relative to the drive wheels



Figure 26.50. Description of macrogeometry including pointwise curves created via finite element mesh of FEM subsystem

1. Load the flexible subsystem and place it in accordance with the position and orientation of simulated part of the monorail track in **UM Input** or **UM Simulation** program (Figure 26.51).

2. Open an animation window and then open the **Selection of nodes** form using **Select FE nodes...** item of the popup menu (Figure 26.52).

3. Push button and select by mouse two nodes defining the way axis as a line of regular FE mesh of the subsystem. The following rules should be meant for the selection (Figure 26.52, step 3).

- the nodes should belong to an one finite element;

- the selection sequence should correspond to increase of the way coordinate, i.e. the second node should have greater coordinate than the first one.

4. Choice nodes on regular mesh with constant step in meters (Figure 26.52, steps 4, 5).



Figure 26.51. General view of the model in animation window



Figure 26.52. Choice of nodes on line of regular mesh of FEM subsystem

If the selection of the nodes was incorrect, the following message is outputted on the screen. In such cases delete all nodes from the list and repeat the selection more carefully.



Figure 26.53. Diagnostic message on incorrect choice of nodes

If the selection is correct, the state of the screen will be similar to Figure 26.54.

5. Use the **Save macrogeometry profiles to files \*.crv** item to create the files with horizontal and vertical profiles data. Input file name into the **File name** field of the **Windows** dialog form and push **Save** button. As the result, two files will be created. The strings "horizontal profile" and "vertical profile" will be added to the file names correspondingly. For example, a user inputted "Macrogeometry 5" in the **File name** field. Then **Macrogeometry 5 horizontal profile.crv** and **Macrogeometry 5 vertical profile.crv** will be created.

List of nexcile subsystems       Nodes in group: 61         innonralifiex       Nodes selected: 61         List of nodes:       List of nodes:         © by index       © by coordinates         Node number:       437         Node coordinates:       9. Node 18721 (55.239, -7.756, 2.538)         V 1. Node 18721 (53.316, -7.253, 2.534)         V 3. Node 18721 (53.316, -7.253, 2.534)         V 9. Node 18721 (53.316, -7.253, 2.534)
Search node       Ist of nodes:
Search node       ✓       1. Node 20412 (\$9,070, -8,940, 2.726)         ✓       by index       ✓       by coordinates         ✓       3. Node 19732 (\$5,157, -8,558, 2.662)         ✓       3. Node 19732 (\$5,157, -8,558, 2.662)         ✓       4.37L         Node coordinates:       ✓         ✓       1.249 N         ✓       0.072 N         ✓       9. Node
1       12.12       0.004       0.722       ✓ 10. No       Unselect all         Selected node       ✓ 11. No       Delete node       ✓ 12. No       Delete node         N: 437       X: 1.249       Y:-0.004       Z: 0.792       ✓ 15. No       Delete unselected nodes         ✓ 15. No       Delete unselected nodes       ✓ 16. No       Delete all nodes         ✓ 17. No       ✓ 17. No       ✓ 18. No       Save list of nodes to file         Save list of nodes to file       Save list of nodes to file       Load list of nodes to file         Choose nodes on line regular mesh       Choose nodes on line regular mesh

Figure 26.54. General view after choice of nodes on regular mesh

These files should be used for description of a track macrogeometry. Open editor of macrogeometry using main menu item **Tools** | **Macrogeometry editor...** | **Railway or monorail track** 

... or by button on the tools panel. Add sections preceding the part simulated by the flexible subsystem. Then the following steps should be carried out.

1. Add a pointwise curve (Figure 26.55, 1-2) and open curve editor (Figure 26.55, 3).

2. Load the curve from the created earlier file by 🗁 button, for example, Macrogeometry 5 horizontal profile.crv (Figure 26.56).

3. Push Ok button and then push Apply on Pointwise curve form.

4. Repeat these steps for the vertical profile and save macrogeometry to the file by  $\mathbf{E}$  button on macrogeometry editor form.

5. Choose this file in **Macrogeometry** field on **Monorail train** | **Options and Parameters** tab of **Object simulation inspector**.

<u>Note</u>. Connecting curves inputted manually can be added to the loaded ones (Figure 26.57). If maximal abscissa value of the resulting curve  $X_{max}$  is changed, lengths of the neighboring sec-

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tions should be corrected. An abscissa value of the start of the curves loaded from the files in the macrogeometry profiles should correspond to the position of the simulated section of the track.



Figure 26.55. Add pointwise curve and start editing



Figure 26.56. General view of loaded curve in editor window

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Figure 26.57. Loaded curve is added by connecting curves inputted manually

## 26.8.2. Simulation of vehicle-track interaction

Let us consider the key features of simulation of vehicle-track interaction.

A FEM subsystem simulates a part of a monorail track if value **Type of track** on tab **Monorail train** | **Options and parameters** is **Undeformed** (see Figure 26.30). Otherwise, the track is simulated as it is described in Sect. 26.6. In this case, the FEM subsystem is present in the model, but it does not interact with the vehicles and they do not influence on each other.

If the flexible subsystem is considered as a monorail track then the **FEM subsystems** | **Simulation** | **Monorail** tab appears on the FEM subsystem tab of the **Object inspector** window (Figure 26.58). It includes two tabs: **General** and **Image**.

bject simul	ation inspector					
Solver	Identifiers	Initial conditio	ns Object v	ariables	XVA	Information
F	EM subsystems		Tools		Monora	ail train
Subsystem:	Monorailflex					
General Sir	mulation Image :	Solution				
Options D	amping Monorail	1				
General	[mage					
Subsys	tem is monorail					
_Options_						
Consta	ant mass matrix					
C Separa	ate simulation					
🔽 Simula	tion of entry on edg	je				



On tab General the following screen components are placed.

- Flag **Subsystem is monorail** switches the flexible subsystem to be considered as a monorail track. It is intended for quick estimation of the influence of track flexibility on vehicle dynamics. A researcher can execute two numerical experiments for comparison of the simulation results. It can be diagrams of displacements, accelerations of vehicle points, force values in force elements and so on. In the first experiment, the flag should be switched on. Results of this experiment should be saved (via copy as static variables, for example) and then the simulation should be repeated with the switched off flag. Difference in the graphs determined by track flexibility.
- Flag **Constant mass matrix** means simulation without recalculations of the mass matrix on every integration step. It can reduce simulation time appreciable if the flexible monorail model has large number of coordinates. Use of the flag is not recommended if this number is less than 100.
- **Separate simulation** flag switches on the simulation mode when flexible displacements and velocities of the monorail track are not taken into account for simulation of vehicle dynamics. However, forces in the wheel-track contacts are applied to the part of flexible track.
- Simulation of entry on edge flag turns on gradual application of forces to FEM part when a vehicle runs over its edge. If this flag is switched off, entry of wheels on the edge of FEM track leads to impact, that it instant application of the interaction forces between wheels and the track. This effect is observed for any speed even near to zero. In this case, the forces are approximately equal to vehicle weight distributed between wheels. In order to avoid the impacts, the forces increase linearly in accordance to length of the contact spot (see Figure 26.59). The influence of the flag is more evident under small speed. In



#### Distance, m

Figure 26.60, the diagram of acceleration in the center of track section 30 meters in length under entry of the vehicle on the edge is shown as example.



Distance, m

Figure 26.60. Acceleration in the center of track section 30 meters in length. Speed is 5 m/s. Black diagram is obtained with flag **Simulation of entry on edge**, red is calculated without one.

Object simulation inspector						
Solver	Identifiers	Initial conditions	Object variable	es XVA	Information	
FEM subsystems			Tools	Monora	Monorail train	
Subsystem: Monorailflex						
General Simulation Image Solution						
Options D	amping Monorail	1				
General I	image					
Bridge image						
☑ Draw control areas						
✓ Scale up flexible displacements						
Scale: 100 n						
Step of image calculation						
C Calculate on every time step						
Set step of calculation						
Step of image calculation: 0.05 n						

Figure 26.61. Tab Image of monorail track

On tab Image the following screen components are placed.

- **Draw control areas** flag shows control areas around the wheel interacting with the flexible track (Figure 26.62). A contact point is located into control polygon having red color. The yellow polygons are so called surrounding ones i.e. they are neighboring to the control polygon. This capacity allows detecting discrepancy in description of the macrogeometry and form of flexible subsystem simulating monorail track. If control area does not appear under the wheel placed on the subsystem surface, description of the model should be checked. In the current release, colors of the control area cannot be changed.
- Scale up flexible displacement flag allows displaying deflection with the scale specifying in the Scale field (Figure 26.63).
- Components in group box **Step of image calculation** allows to refresh the flexible track image with the step different from **Step size of animation data** inputted on the **Simulation process parameters** tab of **Object inspector**. If FE model of a monorail track consists of great number of finite elements, refresh of the image can take significant time. In this case, step of image calculation can be chosen greater than step size of animation and data storage. For example, if size of animation storage is 0.01 seconds and **Step of image calculation** is 0.05, the image of the FEM subsystem will be refreshed one time per 5 animation steps.



Figure 26.62. Control areas under wheels



Figure 26.63. Flexible deflections of the monorail track are scaled in 200 times.

All analysis tools used for FEM subsystems and described in <u>Chapter 11</u> can be applied for study characteristics of the flexible monorail track section that it simulates. Besides, the special variables **dyBridge** and **dzBridge** created on tab **Monorail train** of the **Wizard of variables** are also supported.

## 26.8.3. Examples

Two examples of simulation of flexible track parts of monorail are available in site <u>www.universalmechanism.com</u> by link <u>um samples fem monorail.zip</u>. They present supporting and suspended variants of monorail systems. Screen copies are shown in Figure 26.64 and Figure 26.65.



Figure 26.64. Model of supported monorail system from the set of UM samples



Figure 26.65. Model of suspended monorail system from the set of UM samples