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RTire

Rigid Ring Tire Model
Documentation and User's Guide

Contents

General Remarks

This documentation describes the modelization and parameters of the Rigid Ring Tire Model (*RTire*), which is a member of the *FTire* tire model family. For more material about this model family and related tire simulation tools, please visit www.cosin.eu.

1 Aims and Scope of *RTire*

The tire model *RTire* (Rigid Ring Tire Model) serves as a fast and efficient tire force element for many dynamic simulation tasks. It can be used in MBS models for handling and ride comfort investigations on moderate uneven roads, and for 4-post test-bench simulations.

In contrast to *FTire*, it does not describe high-frequent belt deformations, and thus is limited to excitations where the influence of these phenomena is negligible. On the other hand, these restrictions allow for a tremendous reduction of computational effort, and such to essentially shorter CPU times. *RTire*, even when called with 4 instances, is real-time capable on many platforms.

RTire is interface-compatible, without any restriction, to *FTire*. Furthermore, data have been chosen to be as far-reaching as possible identical to those of *FTire*. For those parameters that are only used by *RTire*, a tool will be developed for calculation, using only *FTire* data.

When accepting that few parameters might not been needed for one or the other model, *RTire* and *FTire* can share the same data files. Moreover, during a running simulation it is intended to enable smooth switching from *FTire* to *RTire* and vice versa.

2 Modeling Approach

The modeling approach of *RTire* is as follows:

- The tire belt is approximated by a rigid body, which can move relative to the rim with all six degrees of freedom. This body, the **'rigid ring'** part of *RTire*, is elastically coupled to the rim by both translational and rotational stiffnesses in all three directions, with some appropriate damping in parallel. The rigid ring geometry is curvilinear in lateral direction, assuming a constant but typically large curvature radius (which might even be infinite as well).
- A certain part of the belt, near the **contact patch**, is allowed to be quasi-statically distorted relative to the belt's 'rigid-body' position. This distortion includes
    - a small additional longitudinal shift,
    - a small additional lateral shift,
    - a small additional torsion angle about the vertical axis, and
    - a small amount of bending deformation, leading to a deviation from the straight longitudinal axis, and being approximated by a second order polynomial.
- All dynamic and quasi-static stiffness and damping coefficients, mentioned so far, are calculated during pre-processing, fitting the prescribed modal and static properties (cf. list of data below).
- Similarly as with *FTire*, per belt length unit a certain number of mass-less **'tread blocks'** is associated. The tread blocks are located along several parallel lines. Alternatively, they can be placed randomly. These blocks carry nonlinear stiffness and damping properties in longitudinal and lateral direction. The radial deflections of the blocks are determined by the local value of the ground pressure distribution (see below). On the other hand, tangential and lateral deflections are determined by the sliding velocity on the ground and the local values of the sliding coefficient. The latter depends on ground pressure and sliding velocity. 'Radial', 'tangential', and 'lateral' is to be understood relatively to the orientation of the distorted belt section near the contact patch, whereas 'sliding velocity' is the block end point velocity, projected onto the road surface tangent plane.

- Global tire deflection, tire deflection velocity, camber angle, and other **kinematic values** are calculated relative to the road tangential plane. This plane is approximated near the foot-print center (which is called 'contact point'), by numerical differentiation. The contact point, in turn, is iterated by Newton's method. It is defined to be that point in the intersection line between belt mid-plane and road surface, which is closest to the geometrical belt center. In the numerical differentiation process for determining the contact plane, a relatively large step size (100 mm) is used. This results in a certain filter effect, filtering out short-waved road irregularities which are not taken into account by *RTire*.
- On basis of these kinematical values, the **dynamic wheel load** is calculated as function of global tire deflection, tire deflection velocity, camber angle, rolling speed, and inflation pressure. Here, *RTire* takes into account the displacement of the belt relative to the rim as function of the elastic foundation. This elastic foundation is only one share of the radial tire stiffness. In contrast to the total radial stiffness, the stiffness of the elastic foundation is determined by prescribing a respective eigenfrequency of the vibrating tire.
- In contrast to FTire, the **ground pressure distribution** is not a consequence of the flexible belt distortion near the contact patch, but rather described by an appropriate mathematical shape function. This shape function is calculated in three steps:
  - in the first step, the boundary of the contact patch is estimated by calculating the geometrical intersection contour between the rigid ring (disregarding the local contact patch distortion), and the road tangent plane;
  - in the second step, this first estimation of the contact patch is corrected by an empirical 'shortening' factor (which is typically near 60 to 90 %);
  - in the last step, the resulting pressure distribution is calculated by constructing a certain polynomial with the following properties: (a) it is the product of one-dimensional polynomials in longitudinal and lateral direction, (b) these polynomials are such that the shape function is zero along the estimated contact patch boundary, (c) the integral over the shape function equals the dynamic wheel load, calculated as described above, (d) the exponents that are determining the shape functions might depend on tire deflection, inflation pressure, and road curvature both in longitudinal and lateral direction.
- Finally, the 6 components of the tire forces and moments acting on the rim are taken to be the reaction forces and moments of the elastic belt foundation.

RTire is accurate up to moderate frequencies both in longitudinal and in lateral directions, and for road excitation wave-lengths that are greater or equal about twice the contact patch length. *RTire* works out of, and up to, complete stand still, with no additional computing effort, and no model switch.

Optionally, *RTire* can take into account radial and tangential tire non-uniformity, which is a harmonic variation of vertical or longitudinal stiffness, as well as static or dynamic imbalance and geometrical excentricity.

3 Implementation and Interfaces

RTire provides exactly the same program interfaces as *FTire*. Only obvious exception: the basic program interface uses the program and header file names `rtmr`, `rtpi`, and `rtp1.H` instead of `ftmr`, `ftpi`, and `ftp1.H`. For a description of the available interfaces, please refer to chapter 3 of the *FTire model* documentation, and the *FTire interfaces* documentation.

4 *RTire* Parameters

The following is a list of the most important parameters the actual version of *RTire* uses as input data:

- **rolling circumference** under normal running conditions,
- **rim diameter** and **width**,
- **width of tread** that comes into contact with road under normal running conditions without camber angle,
- **tire overall mass**,
- **wheel load** at two different tire deflection values, on flat surface,
- increase of overall radial stiffness at high speed as compared to radial stiffness during standstill, and wheel speed, at which this **dynamic stiffening** reaches half of the final value,
- **natural frequencies and respective damping rates of first, second, third, and fourth vibration mode** of inflated, but unloaded tire with fixed rim, cf. fig. 1,
- at least one out of:
  - **natural frequency of sixth mode** (out-of-plane bending), or
  - **belt out-of-plane bending stiffness** of inflated but unloaded tire,
- the total **longitudinal stiffness** of the tire, which is the force per displacement unit that is needed to move the rim in forward direction while tire contact patch is sticking to ground,
- the total **lateral stiffness** of the tire, which is the force per displacement unit that is needed to move the rim in lateral direction while tire contact patch is sticking to ground,
- the total **torsional stiffness** of the tire, which is the moment about vertical axis per torsion angle unit that is needed to rotate the rim about vertical axis while tire contact patch is sticking to ground,
- **tread depth** = mean groove depth in tread
- **rubber height over steel belt for zero tread depth** = distance between steel belt and grooves
- **stiffness of tread rubber** in Shore-A,
- **percentage of net to gross contact area („tread pattern positive")**
  (the last four parameters together, after pre-processing, actually result in only two values used in *RTire*: compression and shear stiffness of the idealized „blocks" that represent tread rubber),
- quotient of **tread rubber damping modulus** and tread rubber elasticity modulus (remark: deflection/force phase-lag of elastomers is said to be independent on excitation frequency. This behavior is not yet implemented in RTire; instead, viscous damping is used so far),
- coefficients of **maximum friction and sliding friction** that occurs between tread rubber and road, both at very low, at moderate, and at very high ground pressure values.

Most of the *RTire* parameters are also needed for *FTire*. Only important exception is the global longitudinal, lateral, and torsional stiffness which can be estimated using *FTire/tools*, merely on basis of *FTire* data. In other words: any *FTire* data file is sufficient to derive an *RTire* data file. For this reason, please refer to *FTire model* documentation, chapter 4, and *FTire paramaterization* documentation on how to determine *RTire* parameters.

The RTire model data are contained in the *RTire* data file. This data file is given in **TeimOrbit** syntax, with file-extension **.tir** (alternatively, *RTire* supports several other formats, including *cosin/io* and **Tydex/STI**). The following is the contents of a typical (but not the most general one) *RTire* parameter file:

```
$--------------------------------------------------------------------MDI_HEADER
[MDI_HEADER]
FILE_TYPE    = 'tir'
FILE_VERSION = 3.0
FILE_FORMAT  = 'ASCII'
(COMMENTS)
{comment_string}
'Tire Manufacturer    - unknown'
'Tire Type            - unknown'
'Tire Dimension       - 195/65 R 15 on rim 6.5 J'
'Pressure             - 2.0 bar'
'File Generation Date - 15/02/03 11:45'
$-------------------------------------------------------------------------SHAPE
[SHAPE]
{radial width}
 1.0    0.0
 1.0    0.4
 1.0    0.9
 0.9    1.0
$-------------------------------------------------------------------------UNITS
[UNITS]
FORCE   = 'NEWTON'
MASS    = 'GRAM'
LENGTH  = 'MM'
TIME    = 'MILLISECOND'
ANGLE   = 'DEGREE'
$---------------------------------------------------------------------DIMENSION
[DIMENSION]
UNLOADED_RADIUS =    326.0          $ [mm]
$----------------------------------------------------------------------VERTICAL
[VERTICAL]
VERTICAL_STIFFNESS = 170.0       $ [N/mm]
VERTICAL_DAMPING   = 0.0         $ [Nms/mm]
$-------------------------------------------------------------------------MODEL
[MODEL]
PROPERTY_FILE_FORMAT =      'RTIRE'   $
SEPARATE_ANIMATION   =      0         $ [0/1]
$----------------------------------------------------------OPERATING_CONDITIONS
[OPERATING_CONDITIONS]
inflation_pressure = 2.0         $ [bar]
tread_depth        = 8.0         $ [m]
model_level        = 4           $ [-]
$---------------------------------------------------------------------PARAMETER
[RTIRE_DATA]
tire_section_width             =   195      $ [mm]
tire_aspect_ratio              =    65      $ [%]
rim_diameter                   =   381      $ [mm]=[25.4 * 15 inch]
rim_width                      =   165.1    $ [mm]=[25.4 * 6.5 inch]
rolling_circumference          =  1975      $ [mm]
tread_width                    =   160      $ [mm]
tire_mass                      =  9000      $ [g]
lat_belt_curvature_radius      = 10000      $ [mm]
$
first_deflection               =    10      $ [mm]
second_deflection              =    20      $ [mm]
stat_wheel_load_at_first_defl  =  1690      $ [N]
stat_wheel_load_at_second_defl =  3600      $ [N]
dynamic_stiffening             =    20      $ [%]
speed_at_half_dyn_stiffening   =     5.55   $ [mm/ms]=[m/s]
$
inflation_pressure             =     2.0    $ [bar]
$
f1                             =    62.1    $ in-plane rotat. [Hz]
```

```
f2                             =    81.4    $ in-plane transl. [Hz]
f3                             =    76.0    $ out-of-plane transl. [Hz]
f4                             =    80.0    $ out-of-plane rotat. [Hz]
D1                             =     0.05   $ in-plane rotat. [-]
D2                             =     0.08   $ in-plane transl. [-]
D3                             =     0.08   $ out-of-plane transl. [-]
D4                             =     0.05   $ out-of-plane rotat. [-]
$
belt_out_of_plane_bend_stiffn  =   200.0e6  $ [N*mm^2]=[10^6*N*m^2]
$
tread_depth                    =     8.0    $ [mm]
tread_base_height              =     3.0    $ [mm]
stiffness_tread_rubber         =    64      $ [Shore A]
tread_positive                 =    65      $ [%]
damping_tread_rubber           =     0.025  $ [ms]
$
long_stiffness                 =   200.0    $ [N/mm]
lat_stiffness                  =   200.0    $ [N/mm]
tors_stiffness                 =    50.0    $ [Nm/deg]
$
rim_inertia                    =     0.25e9 $ [g*mm^2]=[10^9*kgm^2]
$
sliding_velocity               =   100      $ [mm/s]
blocking_velocity              = 50000      $ [mm/s]
low_ground_pressure            =     0.01   $ [bar]
med_ground_pressure            =     2.0    $ [bar]
high_ground_pressure           =    10.0    $ [bar]
mu_adhesion_at_low_p           =     1.3    $ [-]
mu_sliding_at_low_p            =     1.1    $ [-]
mu_blocking_at_low_p           =     0.8    $ [-]
mu_adhesion_at_med_p           =     1.3    $ [-]
mu_sliding_at_med_p            =     1.0    $ [-]
mu_blocking_at_med_p           =     0.8    $ [-]
mu_adhesion_at_high_p          =     1.3    $ [-]
mu_sliding_at_high_p           =     1.0    $ [-]
mu_blocking_at_high_p          =     0.8    $ [-]
$
excentricity_percentage               0.0    $ [%]
excentricity_ang_position           0.0    $ [deg]
static_balance_weight          =     0.0    $ [g]
static_balance_ang_position    =     0.0    $ [deg]
dynamic_balance_weight         =     0.0    $ [g]
dynamic_balance_ang_position   =     0.0    $ [deg]
radial_non_uniformity          =     0.0    $ [%]
radial_non_unif_ang_position   =     0.0    $ [deg]
tang_non_uniformity            =     0.0    $ [%]
tang_non_unif_ang_position     =     0.0    $ [deg]
$
tread_block_distance           =     1.0    $ [mm]
number_tread_strips            =     8      $
maximum_time_step              =     0.2    $ [ms]
BDF_parameter                  =     0.505  $ 0.5 .. 1.0 [-]
```

As for all TeimOrbit files, the physical units of all parameters are defined by the entries in section `[UNITS]`. The meaning of the parameters in the `[RTIRE_DATA]` section is as follows:

Name in input file	Unit in cosin/io input file	Unit in TeimOrbit input file	Symbol
`rolling_circumference`	mm	length	$2\pi r_{belt}$

This is the rolling circumference of the tire under normal running conditions at small load and low speed. After dividing by 2π, this parameter approximately equals the distance of belt nodes to rim center before inflating the tire, at zero speed and without load.

`tire_section_width`	mm	length	w_{tire}

This is the maximum tire width, at inflated, but unloaded operating conditions. Typically, this value is the first number in the tire dimension string.

`tire_aspect_ratio`	%	%	a_{tire}

This is the percentage of tire height to tire width. Typically, this value is the second number in the tire dimension string.

`rim_diameter`	inch	length	d_{rim}

This is the rim diameter. It is used for estimating the moment of inertia of the 'nonvibrating' parts of the tire (those parts that are assumed to be fixed to the rim), as well as the maximum possible tire deflection. Typically, this value is the third number in the tire dimension string.

`rim_width`	inch	length	w_{rim}

This is the rim width. Currently, it is used only for determining the size of the animation model of *RTire*.

`tread_width`	inch	length	w_{tread}

This variable is the width of the tread that comes into contact with road under normal running conditions, if tire is running without camber. It is needed to estimate the longitudinal and lateral stiffness of the discrete tread blocks that represent the stiffness of the tread area. For this, the following formulae are used:

$$c_{radial} = \frac{P}{100}\frac{\triangle A}{h}E, \quad c_{tangential} = \frac{1}{3}c_{radial}$$

where

$$\triangle A = \frac{2\pi r_{belt} w_{tread}}{n_{seg} n_{blocks}}$$

$$h = d_{tread} + d_{tread,0}$$

$$E = 218300 \cdot 1.0482792^S \frac{N}{m^2} = 10^{5.33905+0.020477\cdot S}\frac{N}{m^2}$$

and

P	tread positive
r_{belt}	belt radius if tire is not inflated and not loaded, at zero speed
n_{seg}	number of belt segments
n_{blocks}	number of contact points per segment
d_{tread}	tread depth
$d_{tread,0}$	rubber height over steel belt, at zero tread depth
S	Shore-A stiffness of tread rubber under the operating conditions the model will be used in

`tire_mass`	kg	mass	m_{tire}

m_{tire} is the tire's total mass. After subtracting the mass of the belt segments, this value is used to determine (or estimate) mass (and moments of inertia) of those tire parts that are to be added to the rim mass

`inflation_pressure`	bar	force/length^2	p_{meas}
`inflation_pressure_2`	`bar`	force/length^2	$p_{meas,2}$

p_{meas} and $p_{meas,2}$ are two inflation pressure values, at which tire data measurements have been taken. Certain modal and static data (see below) are pressure-dependent. Their actual value is determined by linear interpolation between the values for the two inflation pressures.

`first_deflection`	mm	length	d_1
`second_deflection`	mm	length	d_2
`stat_wheel_load_at_first_defl`	N	force	$F_{z,1}$
`stat_wheel_load_at_second_defl`	N	force	$F_{z,2}$

These parameters, together with natural frequency f_2 and actual inflation pressure, largely determine the radial element stiffness cbelt,radial between belt and rim, as well as the mass of the belt. They define the total radial stiffness characteristic of the tire and allow for prescribing the non-linearity of that characteristic in an easy way.

- $F_{z,1}$ is the static wheel load on flat surface, zero camber angle, and inflation pressure p_{meas}, if tire is deflected by d_1 mm;
- $F_{z,2}$ is the static wheel load under the same conditions, if tire is deflected by d_2 mm.

d_2 and $F_{z,2}$ are optional and can be omitted. In that case, the tire is assumed to have a linear radial characteristic. 'Deflection' is defined to be the vertical wheel displacement, starting with value zero when tire first touches ground.

`dynamic_stiffening`	%	%	S_{dyn}
`speed_at_half_dyn_stiffening`	`km/h`	length/time	$v_{dyn,0.5}$

To describe the increase in vertical tire stiffness at higher rolling speeds, a spring-damper series connection is placed between each belt node and rim, in radial direction, parallel to $c_{belt,radial}$. Stiffness and damping coefficient of that series connection are chosen to match the following conditions. The radial stiffness asymptotically reaches a final value for very largespeeds. S_{dyn} defines the percentage of increase of that final stiffness, as compared to radial stiffness at zero speed. $v_{dyn,0.5}$ is the rolling speed where the radial stiffness is estimated to be the arithmetic mean of stiffness at zero speed and maximum stiffness at very high speed. Note that the basis for these calculations is only approximately correct, so the results in the actual *RTire* version cannot be very precise. It is proposed to check the radial stiffness as function of rolling speed by simulation, and eventually adjust the two parameters in an iterative manner to finally get the desired characteristic.

`f1`	Hz	Hz	f_1
`f2`	Hz	Hz	f_2
`f3`	Hz	Hz	f_3
`f4`	Hz	Hz	f_4
`D1`	-	-	D_1
`D2`	-	-	D_2
`D3`	-	-	D_3
`D4`	-	-	D_4

These numbers describe the rigid-body modes of the tire, when the rim is totally fixed, and the tire is inflated with pmeas but has no contact to ground.

f_1 is the natural frequency of the in-plane 'rigid-body' rotation about wheel spin axis, f_2 is the natural frequency of the 'rigid-body' movement in longitudinal or vertical direction, f_3 is the natural frequency of the out-of-plane 'rigid-body' movement in axial (transveral) direction, and f_4 is the natural frequency of the out-of-plane 'rigid-body' rotation about any axis perpendicular to wheel spin axis (cf. fig. 1).

D_1, D_2, D_3, and D_4 are the respective modal damping values, expressed in absolute numbers between 0 (= completely undamped case) and 1 (= aperiodic limit case). In many other sources, modal damping is expressed in percentage of the aperiodic damping. To be used here, these values have to be divided by 100.

The actual implementation of *RTire* uses viscous damping between belt and rim to match these modal values. Due to the fact that rubber damping is more accurately described by frequency-independent hysteresis cycles, this damping model is of limited accuracy. Damping tends to be too small for low-frequent excitation. This is why for some conditions a better coincidence between measurement and model can be gained by increasing the model damping values above those gained by modal analysis. In future, it is intended to using a more accurate time-domain description of material damping.

`long_stiffness`	N/mm	force/length	$\overline{c}_{long}$
`lat_stiffness`	N/mm	force/length	$\overline{c}_{lat}$
`tors_stiffness`	Nm/deg	force*length/angle	$\overline{c}_{tors}$

$\overline{c}_{long}$ is the total **longitudinal stiffness** of the inflated tire, which is the force per displacement unit that is needed to move the rim in forward direction while tire contact patch is sticking to ground,

$\overline{c}_{lat}$ is the total **lateral stiffness** of the inflated tire, which is the force per displacement unit that is needed to move the rim in lateral direction while tire contact patch is sticking to ground,

$\overline{c}_{tors}$ is the total **torsional stiffness** of the inflated tire, which is the moment about vertical axis per torsion angle unit that is needed to rotate the rim about vertical axis while tire contact patch is sticking to ground,

`belt_out_of_plane_bend_stiffn`	Nm^2	force*length^2	$\overline{c}_{bend,out}$

$\overline{c}_{bend,out}$ is the bending stiffness of the belt/sidewall structure (about the radial axis), if the tire is inflated.

For an identification of the out-of-plane bending stiffness, it is advantageous to use steady state side force and aligning torque characteristics. Bending stiffness has a strong impact to several aspects of the shape of these characteristics.

`number_tread_strips`	-	-	n_{strips}

n_{strips} is the number of strips in which the contact blocks are arranged, using an equal spacing. If n_{strips} is greater or equal to 1000, the contact points are distributed randomly over the tread.

`belt_lat_curvature_radius`	mm	length	$r_{belt,lat}$

This variable describes the geometrical curvature radius of the belt cross section perpendicular to the rim mid plane. It affects the approximation of the contact patch shape, and thus at the same time the ground pressure distribution in the contact patch.

`f1_p2`	Hz	Hz	
`f2_p2`	Hz	Hz	
`f3_p2`	Hz	Hz	
`f4_p2`	Hz	Hz	
`D1_p2`	-	-	
`D2_p2`	-	-	
`D3_p2`	-	-	
`D4_p2`	-	-	
`stat_wheel_load_at_first_d_p2`	N	force	
`stat_wheel_load_at_second_d_p2`	N	force	
`belt_out_of_plane_bend_st_p2`	Nm^2	force*length^2	
`long_stiffness_p2`	N/mm	force/length	
`lat_stiffness_p2`	N/mm	force/length	
`tors_stiffness_p2`	Nm/deg	force*length/angle	

If measurements for a second inflation pressure (`inflation_pressure_2`) are available, the above values are the respective ones of

- `f1`
- `f2`
- `f3`
- `f4`
- `D1`
- `D2`
- `D3`
- `D4`
- `wheel_load_at_first_defl`
- `wheel_load_at_second_d_defl`
- `belt_out_of_plane_bend_stiffn`

- `long_stiffness`
- `lat_stiffness`
- `tors_stiffness`

taken at that pressure. **These data is optional**. The actual pressure-dependent values of the respective eigenfrequencies, modal damping values, and stiffness values are determined by linear interpolation between the values for the two inflation pressures.

`tread_depth`	mm	length	d_{tread}
`tread_base_height`	mm	length	$d_{tread,0}$
`stiffness_tread_rubber`	Shore A	Shore A	S
`tread_positive`	%	%	P

d_{tread} is the tread depth: the mean groove depth in tread. dtread is assumed to be that value of tread depth during the measurement or identification of all other basic data. During a simulation,thisvaluecaneasilybemodifiedbyusinganactualvaluedtread,act instead.

$d_{tread,0}$ is the height of rubber below the steel belt, if tread depth is zero. The value coincides with the distance between steel belt and greatest depth of the tread grooves.

Both d_{tread} and $d_{tread,0}$ influence vertical stiffness, shear stiffness, and damping of the contact blocks (cf. explanation of wtread above), as well as the geometrical maximum tire radius.

S is a commonly used measure for the modulus of elasticity of the tread rubber. It is assumed

$$E = 218300 \cdot 1.0482792^{S} \frac{N}{m^2} = 10^{5.33905+0.020477 \cdot S} \frac{N}{m^2}$$

The 'tread positive' P is defined as the percentage of that share of the footprint that actually has road contact, relative to the overall footprint area.

`damping_tread_rubber`	s	time	τ_{tread}

τ_{tread} is the quotient of tread rubber damping modulus and tread rubber elasticity modulus. The physical dimension of that quotient is time, sometimes referred to as 'relaxation time'. If a tread rubber block is elongated, then it will theoretically creep back into its initial position, following the exponential displacement law

$$s = s_0 e^{-\frac{t}{\tau_{tread}}}$$

The above consideration only holds if stiffness follows Hooke's law, damping is viscous and linear, and mass can be neglected. In that case, the phase lag between displacement and force, if a rubber block is displaced harmonically, is proportional to the displacement frequency.

In contrast, deflection/force phase-lag of elastomers often is nearly **independent** on excitation frequency. This behavior is not yet implemented in *RTire*; instead, ideal viscous damping is assumed.

`rim_intertia`	kgm^2	mass*length^2	j_{rim}

$j_{rim}$is the total of the inertia of rim and other rotating parts, but without tire, with respect to wheel spin axis. **This parameter is only needed and used if rim rotation is integrated inside *RTire*.** It is not used and can be omitted, if RTire is called by MSC.ADAMS.

`sliding_velocity`	m/s	length/time	v_{slide}
`blocking_velocity`	m/s	length/time	v_{block}
`low_ground_pressure`	bar	force/length^2	p_{low}
`med_ground_pressure`	bar	force/length^2	p_{medium}
`high_ground_pressure`	bar	force/length^2	p_{high}
`mu_adhesion_at_low_p`	-	-	$\mu_{adh,0}$
`mu_sliding_at_low_p`	-	-	$\mu_{slide,0}$
`mu_blocking_at_low_p`	-	-	$\mu_{block,0}$
`mu_adhesion_at_med_p`	-	-	$\mu_{adh,1}$
`mu_sliding_at_med_p`	-	-	$\mu_{slide,1}$
`mu_blocking_at_med_p`	-	-	$\mu_{block,1}$
`mu_adhesion_at_high_p`	-	-	$\mu_{adh,2}$
`mu_sliding_at_high_p`	-	-	$\mu_{slide,2}$
`mu_blocking_at_high_p`	-	-	$\mu_{block,2}$
`frict_temp_fact_minus_20_degC`	-	-	$f_{T,-20}$
`frict_temp_fact_plus_20_degC`	-	-	$f_{T,+20}$
`frict_temp_fact_plus_80_degC`	-	-	$f_{T,+80}$

This group of variables describes the dry friction characteristics of the friction couple tread rubber / road surface under normal road conditions.

RTire assumes the friction coefficient being a function of the three independent variables **sliding velocity**, **ground pressure**, and **tread rubber temperature**.

This general function is approximated by a certain bilinear one, using only very few data. A function value $\mu_0\left(v, p_{ground}\right)$ is given for any of the combinations of three different sliding velocities: $v = 0$, v_{slide}, v_{block}, and three different ground pressure values: $p_{ground} = p_{low}, p_{medium}, p_{high}$. The prescription of these pressure values is optional; default values are 0.01 bar, 2 bar, and 10 bar.

The piecewise bilinear interpolated friction coefficient value then is multiplied by a temperature-dependent correction factor, being itself a quadratic function of temperature:

$$\mu = f\left(T\right) \cdot \mu\left(v, p_{ground}\right) = \Big(a_0 + a_1 T + a_2 T^2\Big) \cdot \mu\left(v, p_{ground}\right)$$

This quadratic polynomial will interpolate the data pairs $(-20degC,\ f_{T,-20})$, $(+20degC,\ f_{T,+20})$ and $(+80degC,\ f_{T,+80})$.

During a simulation, the friction value can be adapted to actual road conditions by using an additional correction factor that is defined in the road data file. For details, please consult the separate road description documentation.

`static_balance_weight`	g	mass	w_{stat}
`static_balance_ang_position`	deg	angle	α_{stat}
`dynamic_balance_weight`	g	mass	w_{dyn}
`dynamic_balance_ang_position`	deg	angle	α_{dyn}
`radial_non_uniformity`	%	%	$\triangle c_{rad}$
`radial_non_unif_ang_position`	deg	angle	α_{rad}
`tang_non_uniformity`	%	%	$\triangle c_{tang}$
`tang_non_unif_ang_position`	deg	angle	α_{tang}
`conicity`	deg	angle	α_{cone}
`ply_steer_percentage`	%	%	α_{ply}
`run_out`	mm	length	$s_{run-out}$
`run_out_ang_position`	deg	angle	$\alpha_{run-out}$

By that group of data, certain optional tire imperfections can be defined:

- **static imbalance** is defined by mass w_{stat} and angular position α_{stat} of a balance weight that would compensate the imbalance;
- **dynamic imbalance** is defined by mass w_{dyn} and angular position α_{dyn} of a balance weight. If two of these weights are placed at inner and outer rim flange, 180 deg apart from each other, this would compensate the imbalance;
- **radial non-uniformity** in terms of a harmonic variation of the radial stiffness along the tire circumference. The non-uniformity is defined in terms of the maximum percentage of the deviation of the mean value ($\triangle c_{rad}$), and in terms of the angular position α_{rad} where this value is achieved;
- **tangential non-uniformity** in terms of a harmonic variation of the tangential stiffness between belt and rim, along the tire circumference. The non-uniformity is defined in terms of the maximum percentage of the deviation of the mean value ($\triangle c_{rad}$), and in terms of the angular position α_{tang} where this value is achieved;
- **conicity**, in terms of a rotation angle α_{cone} of all belt segments around the circumferential belt axis in unloaded tire condition. Conicity, besides ply-steer, is one of the reasons for non-zero side forces at zero side-slip angle. This residual side force does not change sign in a vehicle-fixed co-ordinate system when the tire rolling direction is reversed;
- **ply-steer**, in terms of a percentage α_{ply} of lateral belt displacement relative to radial belt displacement, when a radial force is applied. Ply-steer, besides conicity, is one of the reasons for non-zero side forces at zero side-slip angle. This residual side force changes sign in a vehicle-fixed co-ordinate system when the tire rolling direction is reversed;
- **run-out**, in terms of a maximum deviation $s_{run-out}$ of the local tire radius from the mean tire radius. Run-out is assumed to be a harmonic function of the angular position. $\alpha_{run-out}$ is the angular position where the maximum positive run-out occurs.

`tread_block_distance`	mm	length	d_{blocks}
`number_tread_strips`	-	-	n_{strips}
`maximum_time_step`	s	time	h_{max}
`BDF_parameter`	-	-	β

This is the set of data that control the numerical properties of *RTire*:

- d_{blocks} is the tread block distance in longitudinal direction;
- h_{max} is the maximum internal time step that is allowed to be chosen by *RTire*. *RTire* may be called with very large external time steps, no matter whether this makes sense. Internally, *RTire* uses multi-step integration with an internal time step that is chosen on basis of h_{max}. This internal time step is kept constant if the external time step does not change. Changing external time-step may result in considerable longer computation time, because certain time-consuming pre-processing calculations have to be repeated. Try to avoid changing external time step;
- β is a numerical parameter to control implicit (BDF) integration scheme. $\beta = 0$ chooses the explicit Euler scheme, $\beta = 0.5$ the trapezoidal rule, and $\beta = 1$ the implicit Euler scheme. Theoretically, every value between 0 and 1 is allowed; 0.505 or larger is recommended.

5 Operating Conditions

As with *FTire*, certain tire data can be controlled during a simulation experiment. These parameters are called **operating condition parameters**. *RTire* uses the same operating conditions as *FTire*. For a description, please refer to the respective chapter of the *FTire* model documentation.