VORtech Computing

the Scientific Software Engineers

P.O. Box 260
2600 AG Delft
The Netherlands

tel. +31(0)15-285 0125
fax. +31(0)15-285 0126
vortech@vortech.nl

MEMO EV/M12.022
Date June 1, 2012
Author(s) Edwin Vollebregt
Subject Release-notes for CONTACT version 12.2

Table of contents

Overview

These release-notes document the changes in CONTACT version 12.2 with respect to the previous version 12.1, which are substantial:

- Improved capabilities for reproducing measured creep force curves;
- Innovative extensions for investigating the effects of velocity dependent friction;
- Multiple improvements with respect to the ease of use and documentation of the program.

In the past few years a lot of changes were made to CONTACT. These concern improvements of the program code and documentation, fast iterative solvers that form the core of the computational model, and in this release, extension of the model formulation itself as well. This is reflected in how the program is denominated: “CONTACT: Vollebregt & Kalker’s rolling and sliding contact model”.

Premium version

There are two versions of CONTACT: a free and a premium version. The two versions are both comprised in the same code. The premium version contains all basic functionality

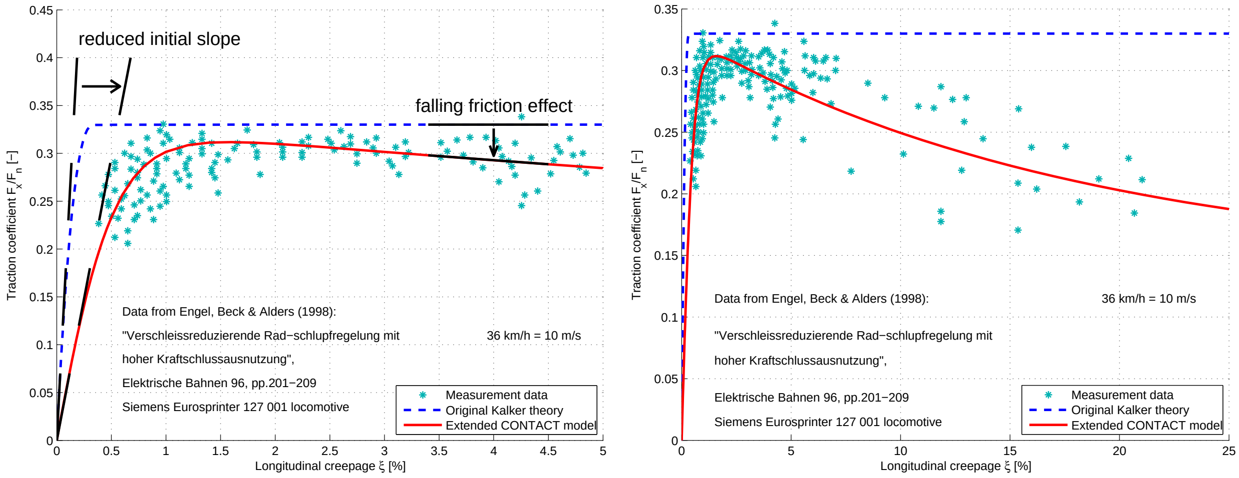

Figure 1: *Measured and computed creep forces for the Siemens locomotive Eurosprinter 127 001 for pure longitudinal creepage.*

plus several extended features, marked blue in these release notes and in the User guide. Licenses are provided for this extended functionality; see the `download` section of our website `www.kalkersoftware.org`. If no license file is found by the program then it still provides the free functionality.

1 Computation of realistic creep force curves

A comment on Kalker's rolling contact theories is that they describe well only the situation for *scrupulously clean surfaces* [1]. In many measurements of traction curves a reduced initial slope is found, as illustrated in Figure 1, left. This is generally attributed to the effects of contamination and of surface roughness. A second effect that is missing in Kalker's original theories is a decrease of the creep force with increasing creepage after attaining a maximum. This is called "falling friction". It is generally attributed to the effects of temperature and may further be due to the effects of fluids in the interface. The two effects are of considerable importance for instance in the design of traction control strategies.

The main result of our recent developments is the improved capability to reproduce creep force measurements, including these two effects. This is illustrated in Figure 1 for measurements presented by Engel et.al. These measurements were used before by Polach for testing his approach [2]. The improvement relies on two extensions [3]:

1. Adding a model for a *third body layer*, i.e. an interfacial layer of variable composition (debris, contaminants, surface roughness);
2. Making the coefficient of friction *dependent on the slip velocity*, regularized using so-called *friction memory*.

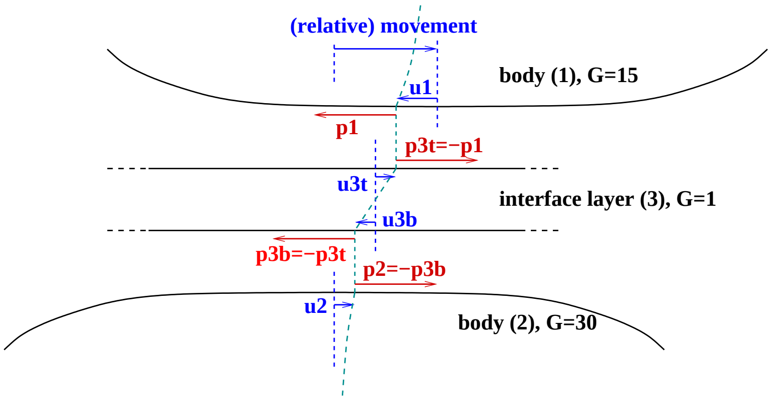

Figure 2: *Illustration of tractions* $\mathbf{p}_t^{(a)}$ *acting on bodies* $a = 1..3$ *and displacements* $\mathbf{u}_t^{(a)}$ *in the bodies as a result of (gross) relative movement, when using material model* $\mathtt{M} = 4$*.*

The interfacial layer is illustrated in Figure 2. This is activated in CONTACT using material model $\mathtt{M} = 4$. The elastic deformation at a point $\mathbf{x}$ now consists of three parts, for the two bulk materials and for the third body layer in between. The deformation in the layer is described by:

$$\mathbf{u}_t^{(3)}(\mathbf{x}) = \frac{\mathbf{p}_t^{(1)}(\mathbf{x})\, h^{(3)}}{G^{(3)}}. \tag{1}$$

The strength of the interfacial layer is thus described by two parameters. By increasing the thickness $h^{(3)}$ or reducing the shear modulus $G^{(3)}$ we increase the amount of deformation taken up by the layer instead of by the bulk materials. This reduces the tractions that are required and thereby reduces the slope of the traction curve. For more information refer to Section 4.1.4 of the User guide.

2 Exciting experiments with velocity dependent friction

Falling friction must not only be considered in traction control strategies, but is also thought to be an important factor in the generation of squeal noise. Therefore it is investigated what the impact of velocity dependent friction is on the model results. This appears to be quite spectacular. In transient rolling scenarios, instabilities are found that consist of a sudden collapse of the shear tractions and corresponding peak in the slip velocity. This gives peaks in the traction distribution that travel through the contact area (Figure 3, left).

Velocity dependence is incorporated in CONTACT by assuming the friction coefficient μ to be dependent on the absolute local slip velocity $s_a = V \cdot \|\mathbf{s}(\mathbf{x}, t)\|$. A typical friction law that is used is

$$\mu_s(s_a) = \mu_{kin} + (\mu_{stat} - \mu_{kin}) \cdot e^{-\log(2)\, s_a / s_{hlf}}. \tag{2}$$

Here μ_{kin} is the asymptotic value of the friction coefficient for $s_a \to \infty$, and s_{hlf} is the slip velocity at which the contribution $\mu_{stat} - \mu_{kin}$ of the second term is halved. Three different forms of friction laws are provided (linear+constant, rational and exponential), which are

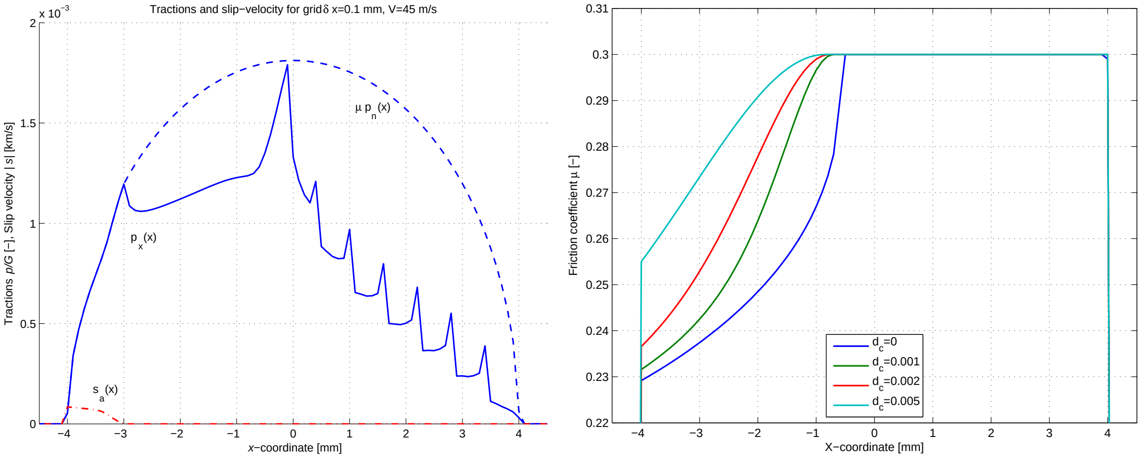

Figure 3: *Left: tangential traction distribution for a rolling cylinder with falling friction, illustrating instabilities in transient rolling scenarios. Right: typical effect of friction memory: gradual instead of abrupt change of the friction coefficient* μ.

activated by the `L`-digit, using $\texttt{L} = 2 - 4$. For more information consult Section 4.2 of the User guide.

The mechanism that governs the peaks is analyzed in detail in [4]. It is mainly attributed to the instantaneous reaction of the friction law (2) to the instantaneous local slip velocity. The model behavior is regularized by introducing *friction memory*. The friction coefficient μ_s is interpreted as the steady state friction that arises at continuous sliding at velocity s_a. It is distinguished from the actual coefficient of friction $\mu = \mu(\mathbf{x}, t)$. The actual friction evolves in time towards the steady state friction, with the rate of change dependent on the slip velocity. This process is governed by the characteristic slip distance d_c over which the relaxation occurs. The effect of this is illustrated in Figure 3, right.

This friction memory is implemented together with the velocity dependent friction laws $\texttt{L} = 2 - 4$. The input parameters are described in Section 4.2 of the User guide. It is de-activated by setting $d_c = 0$, in which case the steady state friction coefficient is used instantaneously.

3 Substantial improvements w.r.t. usability

It is liberally acknowledged that CONTACT is not the easiest program to get acquainted with. In part this is due to the complexity of the subject field itself, but it is further attributed to the way that the program is set up and how it is documented. Several steps were taken to alleviate this and make our contact theories more easily accessible.

- An introduction is written to the field of contact mechanics as a whole, particularly for the situation of wheel/rail contact analysis (User guide, Section 2.1; see also “Frictional contact mechanics” in Wikipedia). This illustrates the relation between the overall situation covered by multi-body simulation and the local contact problems. Further, the main principles with respect to creepage are described.

- The notations in the User guide are simplified (see Section 2.3), particularly by no longer using Einstein's summation convention. Further, the main equations and quantities of the contact problem are explained in relation to the more well-known quantities and equations of continuum mechanics (viz. linear elasticity).

- The specification of the input and interpretation of the output results is simplified by using naturally dimensioned quantities everywhere. We abandoned scaling of forces and tractions by shear modulus G, such that the normal load is now in N and surface tractions are in N/mm^2 (see "Compatibility" below). Particular attention was paid to the slip velocity, such that it is made clear at all times whether absolute or relative values are used and whether this concerns the velocity or resulting shift distance (see for instance Section 4.8).

- Documentation is added for the Matlab plot-routines (Chapter 6). A separate control digit `A` ("MATFIL") is introduced that governs the creation of the Matlab file (simplifying the use of the `O`-digit). The loading and plotting of subsurface stresses is improved, particularly by avoiding the compounded structure for multiple blocks of subsurface points.

- The formula for the profile `IBASE` = 2 ("circular in x, pointwise given in y") is simplified and its documentation is improved (Section 4.4). Particularly with respect to the effective radius of curvature $R_m = R/\sin(\delta)$, with δ the contact angle.

These improvements are substantial and significantly lower the barriers of working with CONTACT. One situation that remains cumbersome though is the application of CONTACT for wheel/rail contact with actual profiles. This requires location of the initial contact points, rotation and interpolation of the profile data, computing the creepages, etc. Note that these calculations are all taken care of automatically by the CONTACT add-on to SIMPACK Rail [5]. For information on this you may contact us at `feedback@kalkersoftware.org`.

4 Resolved problems

No serious bugs were found in CONTACT in the past period. The largest "resolved problems" concern the ease of working with CONTACT as described above.

5 Compatibility w.r.t. previous versions

In order to change from the previous to the current release, a few changes should be made to the user's input files.

- Module 2 is renamed to module 0 ("end-of-file", stop program), so you should change "`2 module`" at the end of the file to "`0 module`".

- The third line with control digits is changed, from `G I O W R` to `G I A O W R`. Insert the `A`-digit (0 or 1) in the third position and reduce the `O`-digit by 4 if it was ≥ 4.
- In cases where the normal force is prescribed (`N` $= 1$), the value `FUN` $= F_n$ must be multiplied by G, the combined modulus of rigidity.
- In case you use the detailed control over the iterative solvers (`G` ≥ 1), add a fourth value `OMGSLP` to the corresponding input line.

There have been changes to the output-files as well.

- The dimensions have changed for multiple values in the output-file, such as `ELEN`, `FRIC`, etc. (User guide Sections 4.5, 4.7-4.9). A second line of aggregate outputs is added to provide true and scaled forces side by side.
- The von Mises stress σ_I is printed (detailed output of subsurface stress calculation) instead of its square (`SIJSIJ`).
- The residuals printed by the iterative solvers now concern rms differences such that the values can be more easily interpreted.
- The format of the `.mat`-file is extended: more problem data are conveyed to Matlab in the first few lines (such as the parameters of the friction law used), and an additional column is introduced for the space-varying friction coefficient μ.
- The tractions that are written to the `.p`-file changed dimension from $[-]$ to $[N/mm^2]$.

6 Known problems and restrictions

The Windows uninstaller does not support multiple versions (v11.1, v12.1) side by side. If you want to uninstall a previous version then do it first, before installing a newer version. If an installation is broken, consult the "Installation" section in the file `README.txt` for manual installation tips.

One feature that is not treated well is the rolling direction parameter `CHI`. It is generally advised to use `CHI` $= 0°$ or restrict `CHI` to at most a few degrees.

The results may contain a significant discretisation error when a small number of elements (7×7, 15×15) is used. Particularly the frictional work appears to be susceptible to this.

Further information

For more information concerning the program (questions, remarks, suggestions), appraisal, publications, possible trainings and materials, information w.r.t. licences, consultancy, research proposals, etc, you may contact us at `feedback@kalkersoftware.org`.

References

[1] E. Magel and Y. Liu. Study of friction - measurement, analysis and practical implications for the wheel/rail contact. In A. Bracciali, editor, *Proceedings of the 8th International Conference on Contact Mechanics and Wear of Rail/Wheel Systems*, pages 239–245, Firenze, Italy, 2009.

[2] O. Polach. Creep forces in simulations of traction vehicles running on adhesion limit. *Wear*, 258:992–1000, 2005.

[3] E.A.H. Vollebregt. 100-Fold speed-up of the normal contact problem and other recent developments in "CONTACT". In W. Zhang, editor, *Proceedings of the 9th International Conference on Contact Mechanics and Wear of Rail/Wheel Systems*, Chengdu, P.R. China, 2012.

[4] E.A.H. Vollebregt and H.M. Schuttelaars. Quasi-static analysis of 2-dimensional rolling contact with slip-velocity dependent friction. *J. of Sound and Vibration*, 331(9):2141–2155, 2012. doi:10.1016/j.jsv.2012.01.011.

[5] E.A.H. Vollebregt, C. Weidemann, and A. Kienberger. Use of "CONTACT" in multi-body vehicle dynamics and profile wear simulation: Initial results. In S.D. Iwnicki et.al., editor, *Proceedings of the 22nd International Symposium on Dynamics of Vehicles on Roads and Tracks*, 2011.