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Subject	Release-notes for CONTACT version 15.1

Summary

These release-notes document the changes in CONTACT version 15.1 with respect to the previous version 14.1.

- The main change in the program itself concerns the new solver TangCG for transient shifting and rolling contact problems.
- The main other development is that the computational core is provided as a library, accessible among others through a Matlab interface.

1 Anisotropy of the contact problem

The understanding of the contact problem is improved by a schematic picture illustrating what's going on (Figure 1, from Section 2.1 of the User Guide). This emphasizes that the physical processes for normal and tangential contact are different. In the normal direction the contact acts like a stiff nonlinear spring, with a small dashpot in parallel (not shown) when material damping is of concern. In rolling contact, the tangential contact force is mainly related to the creep velocity, and should hence be considered as a dashpot element. This dashpot allows for indefinite creeping of one surface with respect to the other. The corresponding force results in the creep versus creep force relationship.

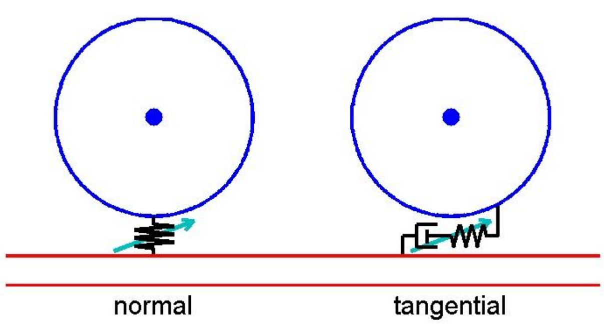

Figure 1: *Schematization of the wheel-rail rolling contact forces: acting like a spring in normal direction, Hertzian or non-Hertzian, and like a variable spring and dashpot tangentially.*

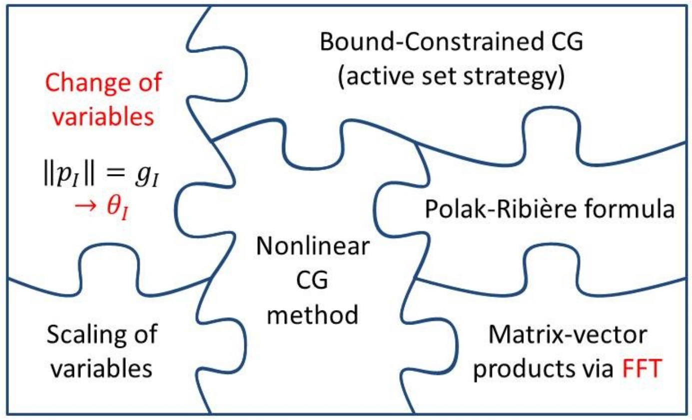

Figure 2: *The new iterative solver TangCG uses several tricks in order to be able to use the Conjugate Gradients method with FFTs for the tangential contact problem [3].*

A new observation is that there's a spring in series with the dashpot as well. This spring plays up in time-varying circumstances; in a steady state it is held at constant elongation such that its effect is unnoticeable. The tangential contact spring allows for tangential oscillations to occur. This is the basis of the so-called rocking phenomenon [2], where the contact force oscillates, resulting in oscillating translational and angular velocities.

2 Fast solution of the tangential contact problem

It is often said that CONTACT is "too slow to be implemented in a MBS environment". This is no longer true, because of tremendous performance improvements achieved in the past few years. It is now feasible to use on-line integration of CONTACT in multi-body simulation. Tens to hundreds of contact problems are solved per second, allowing for the detailed investigation of scenarios involving a modest running distance.

The main algorithmic improvement consists of using the Fast Fourier Transform (FFT) during the iterative solution of the contact equations. This was implemented previously (v13.1, v12.1) in the NormCG solver for the normal contact problem. A related algorithm that's called TangCG has is now implemented for the transient tangential contact problem. The algorithm is presented in the scientific paper [3]. Its main trick is to reformulate the equations for a slipping element using polar coordinates (Figure 2). This allows to incorporate the traction bound inside the numerical algorithm, and adjust the adhesion and slip areas along the way.

TangCG gives a six-fold speed-up for `catt_to_cart` example, reducing the calculation time from 34.4 to 5.7 s. This is accomplished by cutting the number of iterations by half, from 5680 to 2850, and performing each iteration three times faster than before. Similar improvements are obtained for other test problems, with bigger speed-ups for problems where finer grid discretizations are employed.

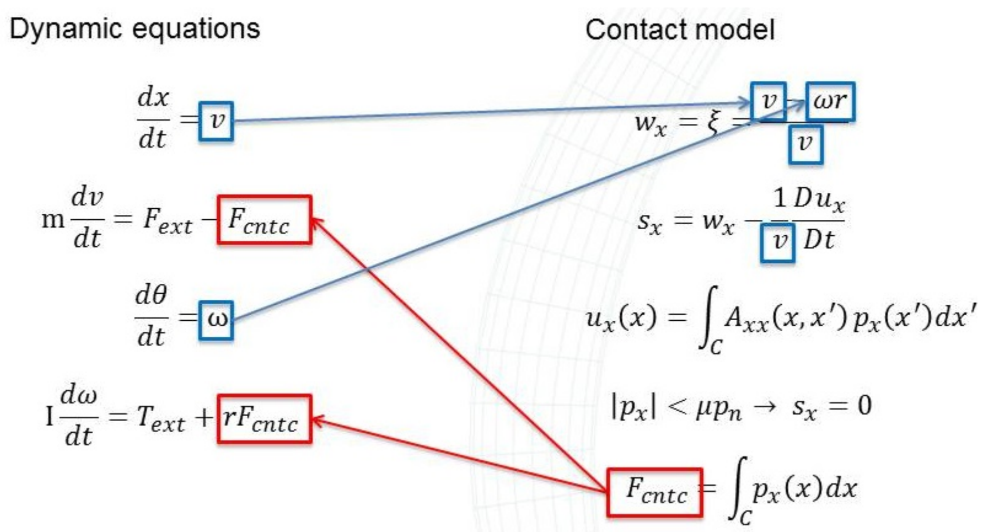

Figure 3: *Illustration of the on-line coupling of MBS (dynamic equations), providing the creepage ξ, with CONTACT, providing the contact force.*

3 Matlab interface for the CONTACT dll

The computational core of CONTACT is provided as a library that can be integrated in other software – that is provided as an add-on to SIMPACK Rail as well. For Windows this is a dll, for Linux an so-file is provided. Through a series of wrapper functions, this library is now also accessible in Matlab. This allows to run a large number of cases easily, for instance for building a table of contact results. Further this allows to use the output of one case to determine the input for the next one. This is needed among others for numerical time integration of dynamic equations, as illustrated in Figure 3 for the translation (x, v) and rotation (θ, ω) of a cylinder.

The interface consists of about 30 routines that allow setting different aspects of the contact problem, solving the case and retrieving the results. For example,

```
%  preparations, set up the fixed part of the contact problem

   ... your preparations here ...
   iwheel = 1; ipatch = 1;
   cntc_setflags(iwheel, ipatch, length(flags), flags, values);
   cntc_setmaterialproperties(iwheel, ipatch, gg1, nu1, gg2, nu2);
   cntc_setnumelements(iwheel, ipatch, mx, my);
   cntc_setgriddiscretization(iwheel, ipatch, dx, dy);
   ... more preparations here ...

%  time integration
```

```
while (time<t_end)
   time = time + dt;

   ... your calculations here ...
   cntc_setcreepages(iwheel, ipatch, cksi, ceta, cphi);
   ierror = cntc_calculate(iwheel, ipatch);
   [fn, tx, ty, mz] = cntc_getforces(iwheel, ipatch);
   ... your calculations here ...
end
```

These library routines provide access to all major features of the input file of the stand alone program. Practically no overhead is added by the wrapper functions. Therefore this provides an easy and powerful way to access the contact problem from the Matlab prompt.

4 Improvements

Several smaller extensions are made to improve the functioning of CONTACT in different circumstances:

- A new example is added for the Bentall-Johnson test-case for rollers of dissimilar materials [1], reproducing the theoretical results.
- The algorithms that required rolling in positive x-direction are extended to allow for rolling in negative x-direction as well ($\chi = 180°$).
- A new option $\texttt{G} = 3$ is added for specifying `INISLP` and `OMGSLP` without having to specify relaxation parameters for ConvexGS and SteadyGS.
- The stopping criterions in the iterative solvers are changed such that they truely check rms-differences. This makes the criterions a little more relaxed, stopping one or two iterations earlier than before.
- Parallel computing, disabled for Windows since v12.2, is enabled again on the Windows platform.

5 Resolved problems

No serious bugs were found in CONTACT in the past period. A few smaller problems that are resolved are as follows:

- Previously it was possible to specify a negative approach in Hertzian problems, resulting in an empty contact area. This is now detected and reported via an error message.
- The extra term to the tangential right hand side ($\texttt{E} = 9$) is now written correctly to the input-file.

6 Compatibility w.r.t. previous versions

No changes are needed to the user's input files in order to change from the previous to the current release. There are a few minor changes to the output-files.

- The word "penetration" is replaced by "approach" on most occurrences.
- One additional line is printed to `mat`-files, which is meant particularly for storing meta-data in the Simpack add-on.

7 Known problems and restrictions

The Windows uninstaller does not support multiple versions (v14.1, v15.1) 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 $180°$ 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.

Premium version & CONTACT library

The basic version of CONTACT is freely available in binary form, and can be downloaded from `www.kalkersoftware.org`. Extended features are provided commercially through a premium version and through the CONTACT library. These features concern fast calculation, conformal contact, third body layer, extended support, etc.. They are marked blue in the release notes and in the User Guide. For information on licenses you may contact us at `support@kalkersoftware.org`.

References

[1] R.H. Bentall and K.L. Johnson. Slip in the rolling contact of two dissimilar elastic rollers. *Int.J. of Mechanical Sciences*, 9:380–404, 1967.

[2] E.A.H. Vollebregt. New insights in non-steady rolling contact. In M. Rosenberger, editor, *Proceedings of the 24th International Symposium on Dynamics of Vehicles on Roads and Tracks*, Graz, Austria, 2015. IAVSD.

[3] J. Zhao, E.A.H. Vollebregt, and C.W. Oosterlee. A fast nonlinear conjugate gradient based method for 3D concentrated frictional contact problems. *Journal of Computational Physics*, 288:86–100, 2015.