Vtech CMCC

Contact | Mechanics | Computing | Consulting

P.O. Box 27097
3003 LB Rotterdam
The Netherlands
info@vtech-cmcc.nl

MEMO	EV/M24.006
Date	June 21, 2024
Author(s)	Edwin Vollebregt
Subject	Release-notes for CONTACT version 24.1

Summary

These release-notes document the changes in CONTACT version 24.1 with respect to version 23.1. The main changes are as follows.

- Added a new User subroutine for on-line integration of CONTACT in Simpack Rail [1, 2].
- Added non-steady ('transient') rolling in module 1.
- Added variable wheel profiles for the simulation of wheel out-of-roundness.

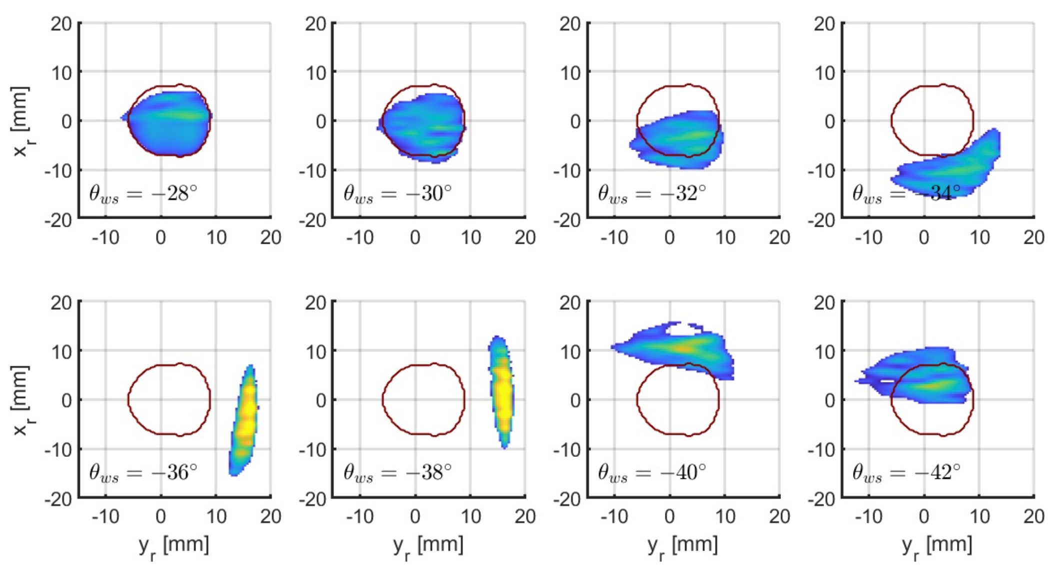

Figure 1: *Computed contact patch shapes and pressures p_n for Chalmers' measured wheel flat approaching, passing through and leaving contact at constant vertical force. Contour: corresponding contact patch on nominal wheel profile without out-of-roundness [3, §5.8].*

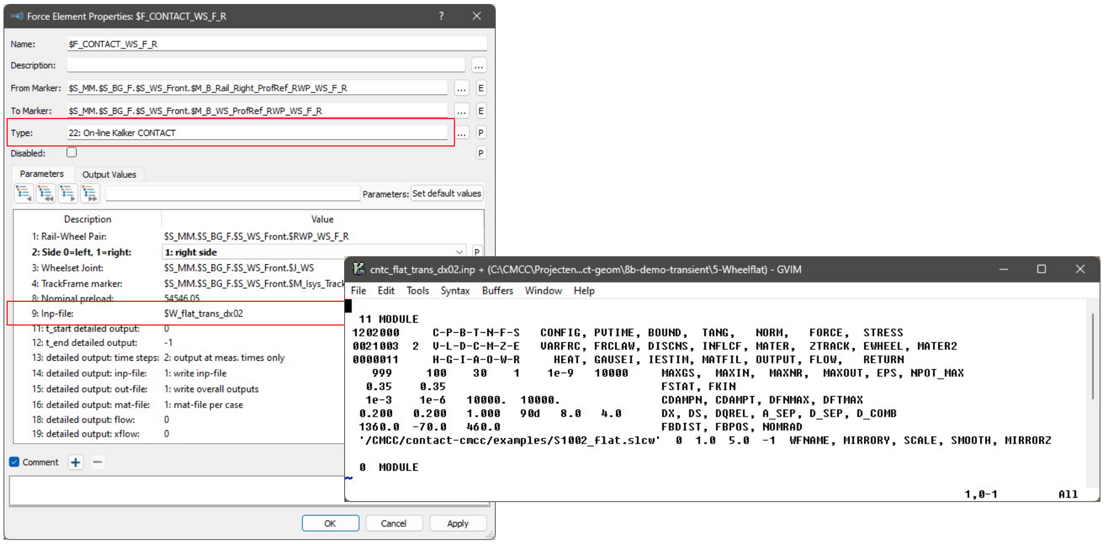

Figure 2: *Dialog box for the Kalker CONTACT force element in Simpack Rail, using an auxiliary input-file to access the advanced features of CONTACT.*

1 User subroutine for on-line integration of CONTACT in Simpack Rail

A user subroutine has been established that provides an interface between CONTACT and Simpack Rail, replacing Simpack's internal wheel-rail contact methods. Contrary to our previous works ([4, 5]), this provides a complete implementation including CONTACT in the dynamic time integration, and supporting advanced features like elasto-plastic third body layers, conformal contact, non-steady contact analysis, and detailed handling of wheel flats and switches and crossings.

The new user subroutine is used as a replacement for one or more rail-wheel pairs defined in the Simpack model. The original rail-wheel pair needs to be kept in the model such that CONTACT can access its information, especially the rail and wheel state parameters and the profiles used. The forces of the rail-wheel pair are disabled by reducing its elastic modulus E to a tiny value.

An auxiliary input-file is used to override default values of the user subroutine and to configure specialized features of CONTACT, see Figure 2 for an example. This is based on a new function `cntc_readinpfile` in the CONTACT library version. A new 'module 11' is introduced for configuring inputs and performing checks for the Simpack user subroutine.

A damping mechanism is added to CONTACT aimed at the integration in multibody simulation via module 1. This damping mechanism takes the contact forces F_n^{el}, F_τ^{el} computed by CONTACT for the previous and current times and sets

$$F_n^{tot} = F_n^{el} + F_n^{damp}, \quad \text{with} \quad F_n^{damp} = C_{damp,n} \frac{\mathrm{d}F_n^{el}}{\mathrm{d}t}, \tag{1}$$

$$F_\tau^{tot} = F_\tau^{el} + F_\tau^{damp}, \quad \text{with} \quad F_\tau^{damp} = C_{damp,t} \frac{\mathrm{d}F_\tau^{el}}{\mathrm{d}t}, \;\; \tau = x, y. \tag{2}$$

This 'force-based proportional damping' relies on the correspondence between force and approach,

F_n^{el} and δ_n, by which dF_n^{el}/dt corresponds to a velocity term. The parameters $C_{damp,*}$[s] correspond to the time-scales of the fluctuations of normal and tangential forces that will be suppressed. The mechanism is activated using a new control digit $\mathtt{M}_2$, see Sections 2.3.2 and 4.1.7 in the User guide [3] or function `cntc_setmaterialparameters` in the CONTACT library version.

The paper [1] presents results obtained from the user subroutine for a measured wheel flat, computing the impact forces for a range of circumstances. The 3D approach shows how the contact patch moves backward and forward on the flanks of the flat, and how the dynamics are altered if the flat is partially missed, not struck at its deepest contour. Non-steady contact calculations show a slower build-up of tangential forces than are predicted using the steady rolling assumption.

2 Non-steady contact modeling in module 1

CONTACT is extended to support 'transient shifts' (`T` = 1) and 'transient rolling' (`T` = 2) in module 1. These methods account for the detailed time-evolution of the contact stresses instead of approximating the stresses on the basis of steady rolling. Transient (non-steady) contact is appropriate in case of rapid changes in circumstances like the geometry, loading, or creep situation, especially in the integration in a dynamic multibody simulation.

Whereas steady rolling permitted each time-step to be solved independently, non-steady contact requires each time-step to be connected to a previous case. This requires that the contact grids of successive steps are attuned to each other. The main conceptual change concerns the introduction of a 'super-grid' fixed to the rail material instead of a grid floating along with the contact reference marker [6]. This super-grid brings a distinction between the origin of the contact grid and the reference marker, requiring further changes at various places in the calculations and plotting routines.

A new marker $\mathbf{m}_{pot}$ is introduced to designate the origin of the contact grid, defined separately from $\mathbf{m}_{ref}$, the contact reference marker. In transient shifts (`T` = 1), the grid origin $\mathbf{m}_{pot}$ may be considered fixed to the rail at track position $s_{fc} = 0$ as illustrated in Figure 3. An infinite grid is considered with the 'active window' moving along with the contact position. In transient rolling (`T` = 2), the grid origin moves along with the wheelset center such that $x_{pot(tr)} \equiv 0$.

An optional 'spin center' is introduced in module 3 to accomodate the offset from $\mathbf{m}_{ref}$ to $\mathbf{m}_{pot}$ in the creep calculation.

Facilities are added in module 3 for growing and shrinking the potential contact area, using different numbers of elements $m_x \cdot m_y$ in successive cases. The grid sizes $\delta x, \delta y$ must be held constant in a transient simulation. The example `catt_to_cart` shows a possible application ([3, §5.5]), with a tight potential contact moving along with the actual contact area.

Procedures are added in module 1 to establish the connection between new contact patches and the contact patches of the previous case, supporting situations where contact patches appear or dissolve, are splitted or combined together.

Non-steady contact is supported in the user subroutine for Simpack Rail using a co-simulation approach, with Simpack and CONTACT marching forward in time together. In this case, CONTACT requires that the contact grid moves no more than one or two grid spaces per time step, imposing a

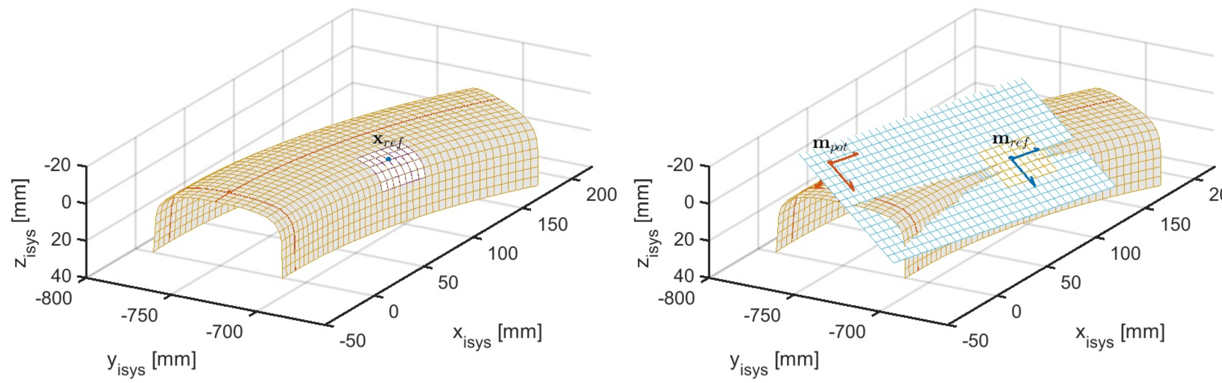

Figure 3: *Left: conceptual super-grid on the rail surface. Right: infinite contact grid with active window.*

time step restriction $\delta t \leq 2\delta x/V$.

3 Simulation of wheel out-of-roundness

Support is added to CONTACT for the detailed modeling of wheel out-of-roundness. Generic algorithms are used to analyze the wheel/rail contact geometry based on a full 3-dimensional wheel representation, capable of predicting contact at any location along the wheel's surface. This development is part of a project supported by the US Federal Railroad Administration (FRA).

The surface for an out-of-round wheel is input to CONTACT using a wheel slices-file with `slcw` filename extension. Wheel slices-files are structured similarly as rail slices-files that were introduced previously for modelling of switches and crossings [7], except that longitudinal s_{fc} positions along the track curve are replaced by angles $\theta_{wc} \in [-\pi, \pi)$ around the circumference of the wheel, and vertical heights z are replaced by radial heights dr with respect to the nominal radius.

In rail slices-files, the keywords `S_OFFSET`, `S_SCALE`, and `S_SLC` are renamed to `U_OFFSET`, `U_SCALE`, and `U_SLC`. Keyword `S_METHOD` is renamed to `U_INTPOL`.

Wheels with out-of-roundness cannot be computed using the contact search method based on the contact locus. CONTACT automatically switches to use the grid-based method instead. This grid-based contact search is rather slow. New contact search methods are needed to speed up this calculation.

The algorithms for combination or separation of contact patches are extended for configurations where two contact patches lie on opposite sides of the flat in running direction. The distance component d_x between the patches is included in the distance d that is used in the criterions for separation or combination ([3, §3.5]).

Results are shown in Figure 1 for a measured wheel flat at eight wheelset pitch angles θ_{ws}. Dynamic effects are excluded using a constant prescribed vertical force $F_z = 125\,\text{kN}$. The dark-red contour shows the outline of the contact patch for the nominal profile. From this we see how the contact patch shifts back at first, moves sideways and then advances ahead of the nominal patch, after which it finally comes back to the reference shape and position. Measurement data for this wheel-flat were provided thanks to prof. Nielsen of Chalmers University of Technology [8, 9], see the example `wheelflat.inp` in the User guide [3], Section 5.8.

4 Resolved problems and general improvements

Several smaller extensions and improvements are made, the main ones being

- An issue is corrected regarding the rail position RAIL_Y0 on left-side configurations.
- Improvements are made for wheel-on-roller contact situations ($\mathtt{C}_1 = 4, 5$) at larger yaw angles ψ_{ws} introducing longitudinal shift of the contact position.
- Issues are solved in the KPEC algorithm regarding the initial estimate and small contact patches.
- An additional control integer X (XFLOW) is introduced to provide access to developer print-output.
- The CONTACT library will reset the output-file when initialized anew after `cntc_finalize-last` has been called, i.e. restarting without unloading/loading the dll.
- A new function `cntc_initializefirst_new` is added introducing the 'effective working folder', overriding the actual working folder where the program is started.
- A new function `cntc_getprofilevalues_new` is added with options for resampling and inteprolation in running direction.
- The Matlab function `cntc_getcpresults.m` is extended to deliver the rail and wheel profile data, facilitating making pictures using `plot3d`.

5 Compatibility w.r.t. previous versions

No changes are needed to user input files to upgrade from the previous release to the current one. New features in the input are as follows.

- Added `slcw`-files for wheel out-of-roundness.
- Added parameters for the force-based proportional damping scheme.
- Permitting growing and shrinking of the contact grid between consecutive cases.

Minor changes are made to the output-file.

- Removed computation/printing of the average contact position.

- Reduced the amount of flow output of iteration procedures.

The format of the mat-file is changed with respect to version 23.1.

- Added the wheelset pitch angle θ_{ws}.
- Added the spin center xo_spin, yo_spin.

Minor changes are needed to user programs calling the CONTACT library version.

- Function `cntc_settrackdimensions_new` is renamed to `cntc_settrackdimensions`. The `_old` version has been deleted.
- A new subroutine `cntc_getprofilevalues_new` is added with additional options and additional inputs compared to `cntc_getprofilevalues`. This can be used safely instead of the original version.

  The interface of `cntc_getprofilevalues` will be changed in version 25.1.
- A new function `cntc_initializefirst_new` is added in Fortran/C with input argument `wrkdir`, effective working folder. This can be used easily with `wrkdir=' '`.

  The interface of `cntc_initializefirst` will be changed in version 25.1.
- The function `cntc_initlibrary` is changed in Matlab/Python, requiring an additional input `wrkdir`.
- The signs of creepages are reversed in the outputs from `cntc_getcreepages` when using Simpack's unit convention.
- The average contact position is no longer available from `cntc_getglobalforces`.

The Matlab-scripts for plotting have been extended in several places.

- `make_2dspline`: added optional inputs `xij`, `use_insert`, `use_cylindr`;
- `eval_2dspline`: added optional input `x_in` and optional output `x_out`;
- `plot_2dspline`: removed the first argument `sol` and reorganized the options: `x/urange` are renamed to `u/vrange`, `coordsys` is removed, `typplot` and `reflec_a` are added.
- `plot_update`: added an optional argument `show_angl`.

6 Known problems and restrictions

- Computations using variable rail or wheel profiles are rather slow, compared to computations with constant profiles.
- The contact locus method (`D` = 2) is not fully robust for variable rail profiles with rapid fluctuations, especially related to poor feature information. This may be circumvented using the grid based approach (`D` = 5).
- Subsurface stresses are computed using elastic influence functions, also when the problem uses the viscoelastic material model.

References

[1] E.A.H. Vollebregt. Detailed contact geometry processing for 3D wheel and rail surfaces. In J. Pombo, editor, *Proceedings of the Sixth International Conference on Railway Technology: Research, Development and Maintenance*, Edinburgh, UK, 2024. Civil-Comp Press.

[2] E.A.H. Vollebregt. User-subroutine for on-line integration of CONTACT in SIMPACK Rail. Memo EV/M24.004, version 24.1, Vtech CMCC, June 2024.

[3] E.A.H. Vollebregt. User guide for CONTACT, Rolling and sliding contact with friction. Technical Report TR20-01, version 24.1, Vtech CMCC, 2024. See `www.cmcc.nl/documentation`.

[4] 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, editor, *Proceedings of the 22nd International Symposium on Dynamics of Vehicles on Roads and Tracks*, pages 1–6, Manchester, 2011. IAVSD. Open access.

[5] E.A.H. Vollebregt and C.D. van der Wekken. Advanced modeling of wheel-rail friction phenomena. Technical Report DOT/FRA/ORD-24/17, Federal Railroad Administration, May 2024.

[6] E.A.H. Vollebregt. Final report for Task 5.b: transient contact in 'module 1'. Memo EV/M23.-012, Vtech CMCC, January 2024. FRA project.

[7] E.A.H. Vollebregt, P. Klauser, A. Keylin, P. Schreiber, D. Sammon, and N. Wilson. Extension of CONTACT for switches and crossings and demonstration for S&C benchmark cases. In W. Huang and M. Ahmadian, editors, *The 28th IAVSD Symposium on Dynamics of Vehicles on Roads and Tracks (IAVSD2023)*, Lecture Notes in Mechanical Engineering, page paper 236, Cham, 2023. Springer.

[8] M. Maglio, T. Vernersson, J.C.O. Nielsen, A. Ekberg, and E. Kabo. Influence of railway wheel tread damage on wheel-rail impact loads and the durability of wheelsets. *Railway Engineering Science*, 2023.

[9] Klara Mattsson. Wheel-rail impact loads generated by wheel flats. Master's thesis, Chalmers University of Technology, 2023.