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Stress-strain analysis for the wheel-railtrack assembly at urban passenger transport

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Abstract
The analysis of the stress-strain state which occurs in the wheel-railtrack assembly of the common mean of urban passenger transportation (tram) represents an issue of high interest due to the fact that the mentioned assembly is subjected to high level of wear resulting in high costs for maintenance and operation at optimum parameters. The high level of wear represents an important source of vibrations. Vibration transmission through the railtrack infrastructure to the surrounding buildings and thus sound pollution represents the main weakness of this mean of transportation.
This paper presents an analysis of the stress-strain state that occurs in the wheel-railtrack assembly, the study being conceived upon a FEA (Finite Element Analysis) calculus model. The FEA calculus model was then subjected to confirmation with strain gauge measurements on the railtrack in connection with various run speed values of the tram.
Keywords: Railtrack infrastructure, wheel-railtrack assembly, stress-strain state, strain gauge measurements

1. Generals

The tram, as a common mean of urban passenger transportation, presents a series of advantages such as: low air pollution, energy effectiveness, large transportation loads. There is also a disadvantage mainly in high level of vibration that is transmitted through the railtrack infrastructure to the surrounding buildings.

From this point view the analysis of the stress-strain state which occurs in the wheel-railtrack assembly at the common mean of urban passenger transportation (tram) represents an issue of high interest due to the fact that the mentioned assembly is subjected to high level of wear resulting in high costs for maintenance and operation at optimum parameters.

The high level of wear represents an important source of vibrations. Vibration transmission through the railtrack infrastructure to the surrounding buildings and thus sound pollution represents the main weakness of this mean of transportation.

This paper presents an analysis of the stress-strain state that occurs in the wheel-railtrack assembly, the study being conceived on a FEA (Finite Element Analysis) calculus model. The FEA calculus model was then confirmed with strain gauge measurements on the railtrack in connection with various run speed values of the tram.

Also, the FEA calculus model represents a key step in developing new optimized design solutions that lead to increased durability of the components subjected to high level wear in the wheel-railtrack assembly.

2. Wheel-railtrack interaction modelling studies

The FEA calculus model has been conceived regarding several actual design solutions of the wheel and railtrack assembly used in tram transportation. The COSMOSWorks FEA software package has been used in developing the FEA calculus model that has allowed a global assessment of the stress-strain state. The 3D parts involved in the wheel-railtrack assembly have been designed in SolidWorks CAD software package. Taking these facts into account, all the design details of the involved 3D parts have been modelled without the need of any simplified geometrical model. In conducting the FEA study, tetraedrical solid 3D finite elements have been used.

For example, figure 1 presents the meshing used in the FEA study and figure 2 shows the distribution of the equivalent stress state, calculated according to the theory of maximum shape modification specific energy (Von Mises), at the level of the wheel-railtrack assembly in static conditions (the tram lying on the railtrack).

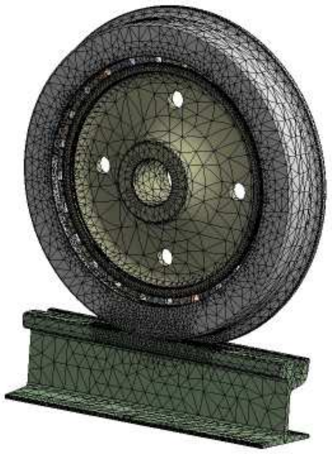

Figure 1. Meshing used in the FEA calculus model.

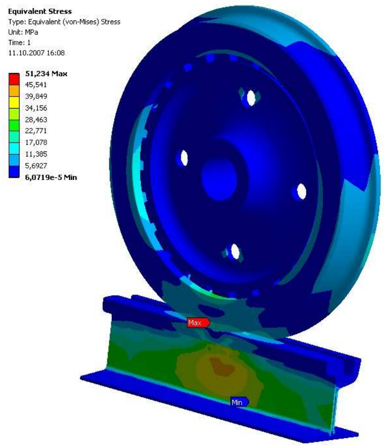

Figure 2. Von Mises stress distribution.

Figures 3 and 4 present a different FEA calculus model in which the cross-beams supporting the railtrack are taken into account.

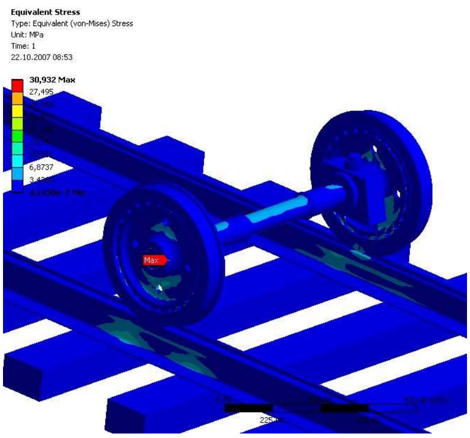

Figure 3. FEA calculus model taking into account the cross-beams supporting the railtrack.

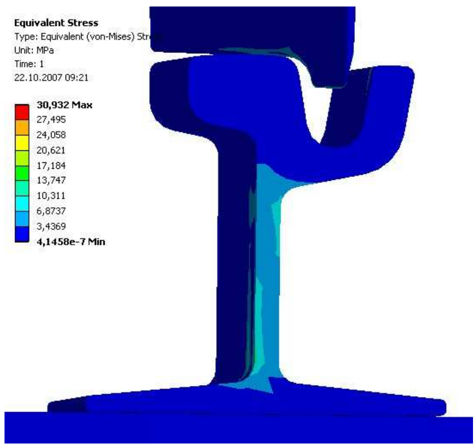

Figure 4. Von Mises stress distribution in FEA calculus model taking into account the cross-beams supporting the rail track.

As a consequence of the finite element analysis the critical areas involving high level stress have been focused. The confirmation of the FEA calculus model has been accomplished by comparing the resulted stress state with the one from experimental strain gauge measurements on the rail track.

3. Experimental study of stress-strain state in wheel-rail track assembly

The critical areas in the cross-section of the rail track are shown in Figure 5. Figure 6 displays the Delta type rosette strain gauge bonded to one of the critical areas of the rail track.

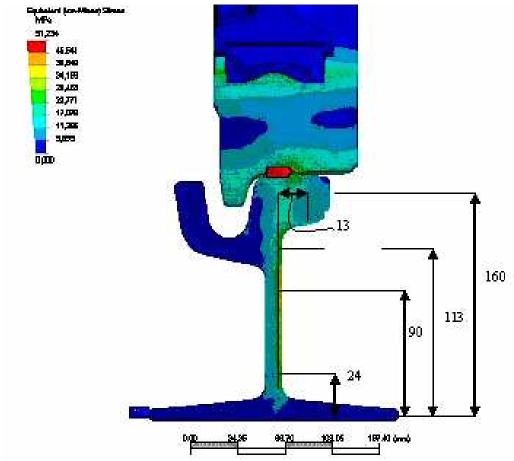

Figure 5. Critical areas in the cross-section of the rail track.

Figure 6. The Delta type rosette strain gauge bonded to one of the critical areas of the rail track sample.

The equipment used has allowed the measurement of the stress state in both static and dynamic conditions for different running speed values of the tram (0; 5 km/h; 10 km/h; 15 km/h; 20 km/h; 25 km/h; 30 km/h; 40 km/h). In these conditions, time variation diagrams for the linear specific deformations have been recorded. Figure 8 shows one of these diagrams corresponding to critical area no. 4 of the rail track sample (measured at 90 mm against the base - Figure 5), for v = 10 km/h running speed value for the tram.

Also, for the same running speed values of the tram, mentioned above, measurements of the stress-strain distribution at the level of the wheel-rail track assembly have been performed, but in braking conditions. The braking procedure has been performed in three ways: with braking shoes, with braking shoes and skating pad and only with skating pad.

The usage of the ESAM Traveller 1 measurement equipment together with its own data acquisition software has led to a fairly high sampling rate and thus measurements of the stress-strain distribution at the level of the wheel-rail track assembly in dynamic conditions has been possible.

Regarding these measurements the principal stress values in the key points of the rail track sample (where resistive strain gauges have been bonded - corresponding to the critical areas depicted in figure 5) have been calculated for all the running speed values of the tram. These values have led to the diagrams displayed in figures 9-12 that show the variation of the principal stress values with running speed values of the tram for different key points of the rail track sample.

Figure 7. Experimental measurements of the stress-strain state of the wheel-rail track assembly through resistive electric gage principle: a) rail track sample with bonded resistive strain gauges; b), c) positioning of the rail track sample in a railway route for measurements of the stress-strain state at the wheel-rail track assembly; d) overall picture above the in-site experimental measurements.

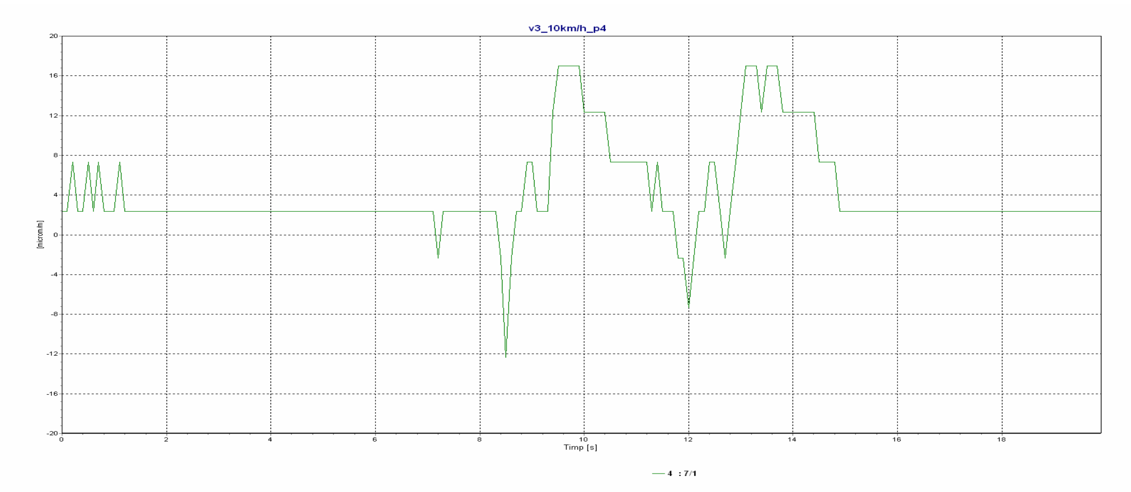

Figure 8. Time variation diagram for the linear specific deformations corresponding to critical area no. 4 of the railtrack sample (measured at 90 mm against the base - Figure 5), for v = 10 km/h running speed value for the tram.

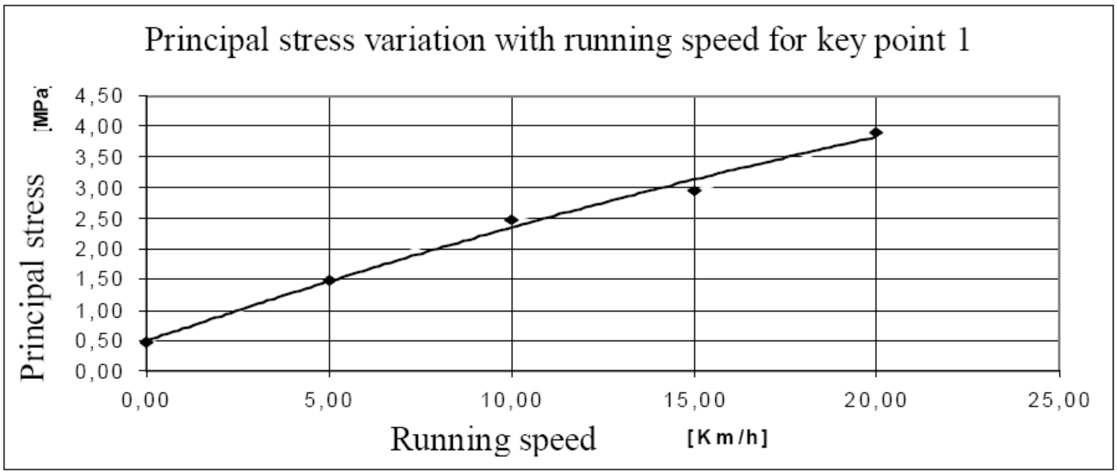

Figure 9. Principal stress variation with running speed for key point 1 (see figure 5).

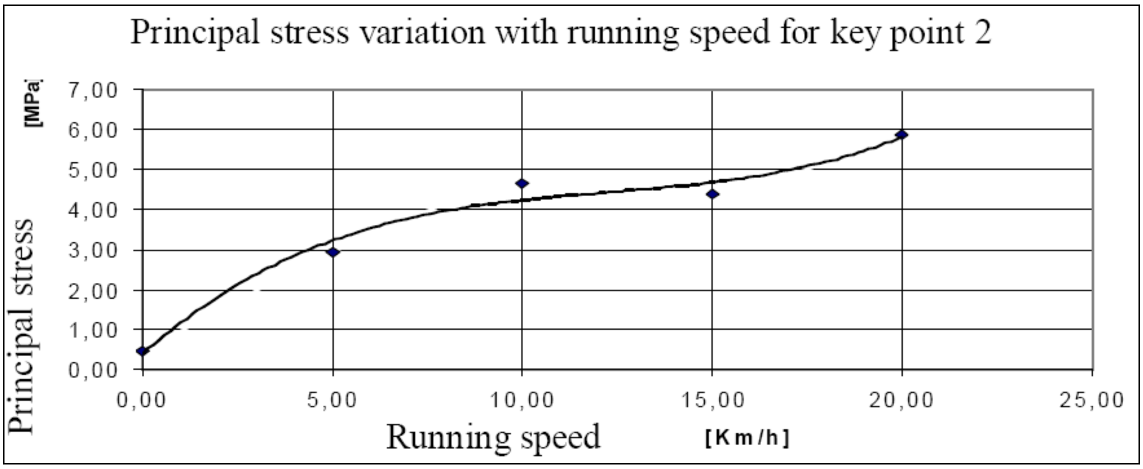

Figure 10. Principal stress variation with running speed for keypoint 2 (see figure 5).

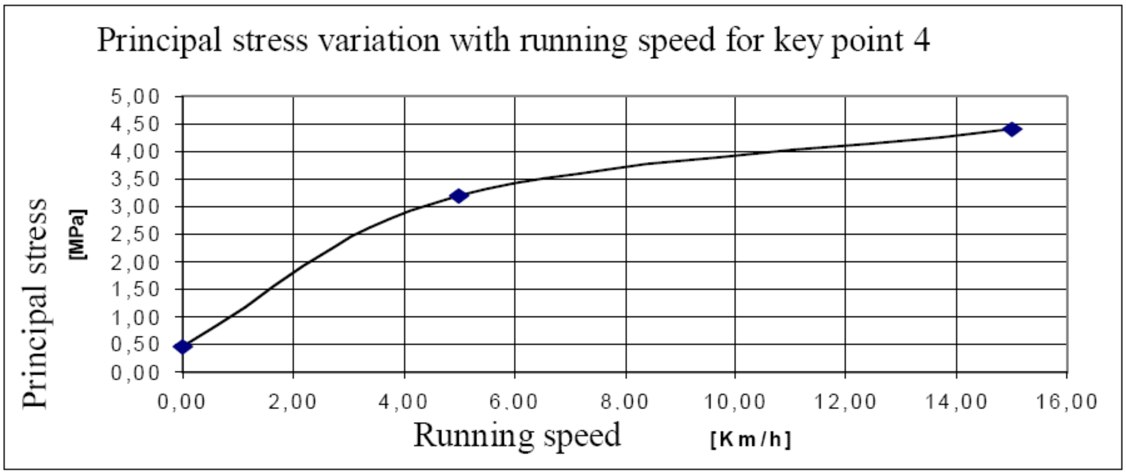

Figure 11. Principal stress variation with running speed for keypoint 4 (see figure 5).

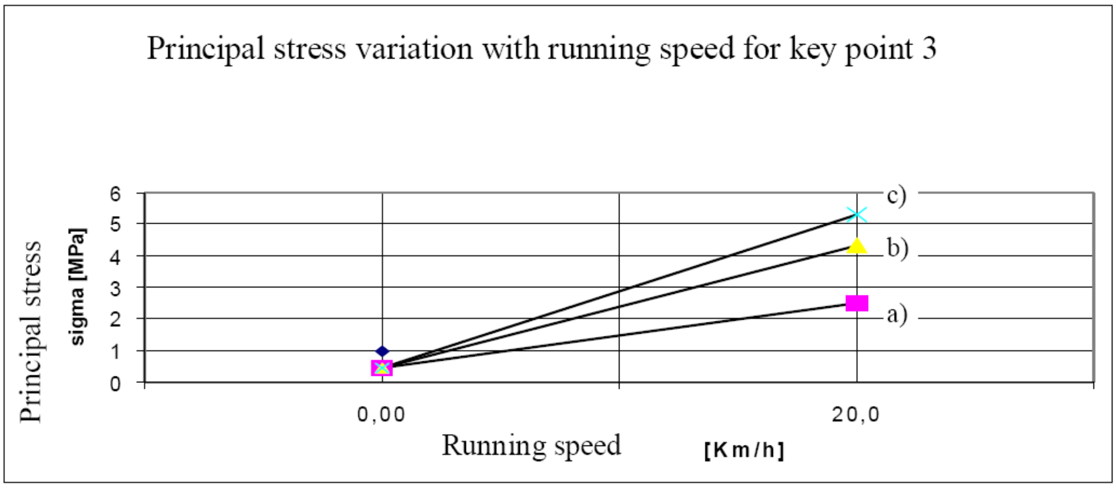

Figure 12. Principal stress σ_x variation with running speed for key point 3 (see figure 5) in comparison with static load of the rail track sample: a) constant running speed of 20 km/h; b) brake procedure with braking shoes from 20 km/h until stop; c) brake procedure with braking shoes and skating pad from 20 km/h until stop.

The experimental data records have confirmed the FEA calculus model for the stress state in the wheel-rail track assembly.

In addition, by analyzing the diagrams of principal stress variation with running speed of the tram for different key points of the rail track sample, it can be concluded that they have different shapes. Therefore, the stress variation with running speed of the tram for key point 1 (figure 9) has a linear shape. For key point 2, that is placed in the filleted zone between the rail head and the central part, which in fact is a stress amplifying zone, the stress variation with running speed of the tram (figure 10) has a totally different shape than in key point 1's case.

Figure 12 shows the principal stress variation with running speed of the tram for key point 3 (figure 5) in comparison with static load of the rail track sample: a) constant running speed of 20 km/h; b) brake procedure with braking shoes from 20 km/h until stop; c) brake procedure with braking shoes and skating pad from 20 km/h until stop. It can be concluded that a constant running speed of the tram has less effect upon the rail track than in braking procedure. The emergency stop procedure (with braking shoes and skating pad) leads to higher level stress state.

The obtained results allow the lifetime assessment of various design solutions for the wheel-rail track assembly and decisions upon optimal design.

4. Conclusions

On the basis of bibliographical surveys and researches conducted, the following conclusions can be drawn:

- Most studies take into account both the contact area between wheel and rail track, and respectively the nearby areas, in the static load case.
- During the run of the tram on the rail track, by applying high torque values upon the wheel, the loads at the wheel level (in the nearby zone of the contact area

between wheel and rail track), are different in traction and respectively braking condition. In addition, on the contact plane between wheel and rail track, a shearing strain state occurs as a consequence of opposite direction forces on the two bodies' surfaces. Under the action of these forces, the wheel and respectively the rail track will stand unequal deformations, these resulting in micro-sliding phenomenon. The micro-sliding phenomenon induces a division of the contact area into an adherent area (for which the sliding value is zero) and a sliding area according to Kalker's linear theory.

- In order to assess the stress-strain state, most of the theories accept the elliptical shape of the wheel-rail track contact area, as well as the hemi-elliptic distribution of the normal pressure.
- The large amount of wheel-rail track contact theories, stated along time, were directly influenced or mutually confirmed.
- At the point of establishing the FEA calculus models, several design solutions were kept in view.
- The FEA calculus models were confirmed by experimental measurements performed in site.

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