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Experimental Stress Analysis

Influence of stress waves to cracked railroad wheel

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Abstract: The FEM study presented in this paper deals with a continuum and fracture mechanics. The stress-strain behaviour in the railroad wheel with primary crack in case of a straight ride can be assessed. The primary cracks are often in the rail wheels; therefore, impact behaviour is common plot. For this reason, the influence of impact behaviour on the railroad wheel has been observed. The analysis will affect some selected cases of straight ride which are important in terms of loading.

Keywords: Railroad wheel, Stress-waves, Transient analysis, Wheel hub

1. Introduction

During the service of traction unit the crack in railroad wheel may appear, this can cause derailing of the train. The crack can appear in different locations of the railroad wheel (further referred as RW). The most common location is in the RW rim and in the RW hub. In this paper, the crack in the RW hub has been closely studied. The crack in hub is usually initiated due to industrial process of pressed joint wheel and shaft. For this reason, the continuum and fracture mechanics approach has been used to clarify the situation of crack in the RW hub in case of activity of the stress waves, which represent impact behaviour between the RW and the rail. This state has been compared with steady state of the rail and the RW interaction.

2. Methods

In order to determine crack behaviour, the finite element method for the computational simulation is used. The FEM is the most common, numeric method used for solving the problems of solid mechanics. For all analyses, the Ansys software (Ansys Inc., Canonsburg, PA, USA) is used. The model is defined from different points of view: the model of geometry, model of materials, model of boundary conditions and loads.

2.1. Model of geometry

As a model of geometry of the wagon RW, the common wheel profile according to European standards is used. Next part of geometry is wheel shaft. It is modelled as a simple cylindrical part. The rail is assumed to be UIC 60 standard with 1:40 cant to the RW. All parts are modelled as parametric bodies in Ansys software. The main aim of this paper is to study quarter-of-penny-shaped primary crack located in the RW hub. The two ways of rail topology are assumed. In the first case, rail is located bellow crack tip in radial direction. In the second

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case, rail is located below fracture area of the crack; see Fig. 2. For FEM mesh, common contact elements and 3D quadratic 20 node solid elements known as SOLID 186 are used.

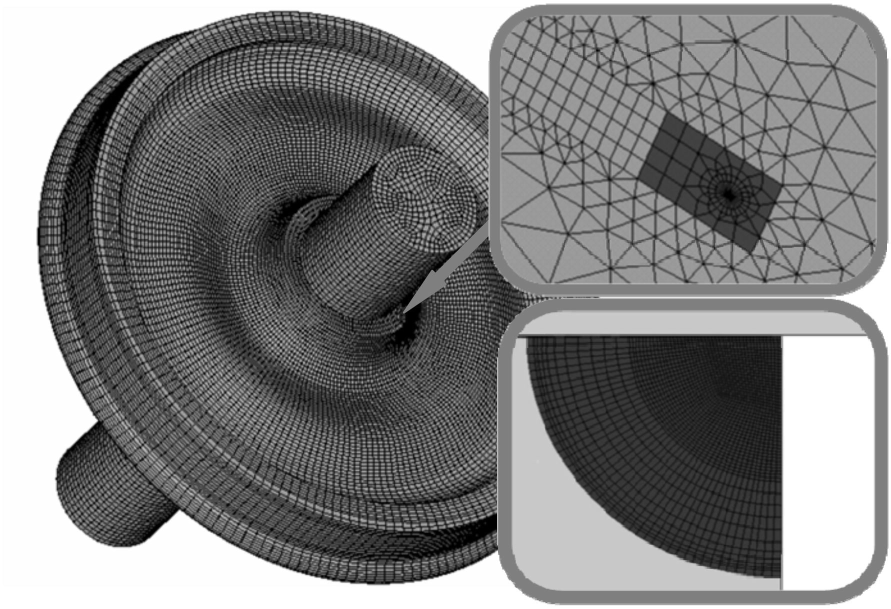

Fig. 1. Meshed railroad wheel set (wheel, shaft, rail, and crack in a cut)

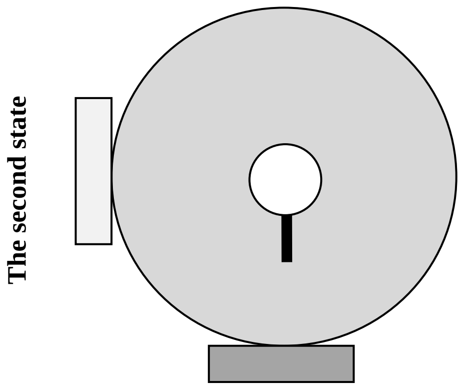

Fig. 2. Topology states – The rail position due to wheel

2.2. Model of materials

The material of the wheel and wheel shaft is assumed to be homogeneous, isotropic and linear elastic. The rail is assumed as rigid. Material characteristics used were following: Young's modulus E = 210 000 MPa Poisson's ratio ν = 0.3.

2.3. Model of boundary conditions and loads

There are three basic types of boundary conditions and loads in our simulations; therefore, three types of simulations are computed. The first type of the simulation is computed as a static analysis of the RW set with take of the influence of interference fit in the simulation. The value of interference is considered to be H7/u6. In this simulation, an influence of inertia forces caused by wheel rotation is considered. The speed of the train is assumed to be 100 km/h.

In the first simulation case, influence of normal load is not included. This influence is caused by wagon weight.

In the second simulation case, the interference fit and inertia forces caused by rotation of the RW are not considered. In this simulation case, influence of 10 tons load to one railroad wheel is taken note of, i.e. 10^5 N value of normal force loading, which can be seen in Fig. 3.

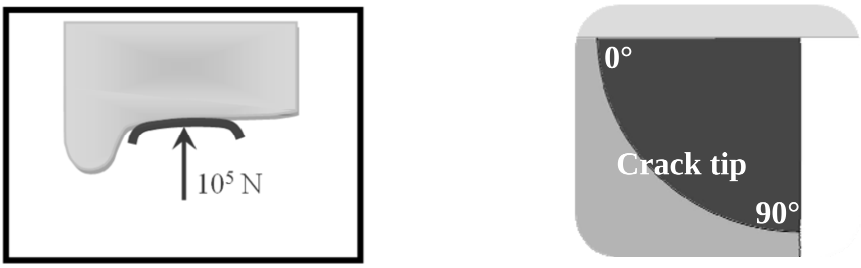

Fig. 3. Expression of force loading and crack tip position

The last, third simulation case, influence of interference fit and inertia forces caused by rotation of the RW are not considered as well as in the previous case. A normal load is taken in account, which can be seen in Fig. 3 and Fig. 4. The third simulation case is different, because of the consideration of influence of the stress waves. This means that simulation isn't steady but transient. In this simulation case, behaviour of the stress waves in case of impact of the RW on the rail is simulated.

For most of simulation cases, the boundary conditions used are of the same characteristic. In the position of the PLC bearing, radial and tangential displacement is set to zero. In case of interference fit of the influence simulation, the interference fit is set as H7/u6, which corresponds with value of 265 μm, in other cases, this condition are not used. At the end of the half wheel shaft, the boundary condition of zero axial displacement is set. Used boundary conditions can be observed in Fig 4.

3. Results

The aim of this study was to get data of stress intensity factors and equivalent stress intensity factor [1, 2], which would show dependence of separate load states on the crack behaviour. The separate modes of the stress intensity factors acquired from different simulation sets can be put together to evaluate equivalent stress intensity factor [1], because linear behaviour of all simulations without stress redistribution is assumed. The two main simulation states has been studied and compared. Firstly, it is the case of steady state and secondly, the case of stress waves, i.e. transient state. The study has been focusing on influence of the stress waves and the difference in behaviour of both simulation states on the crack tip in the RW hub. For the better lucidity, a scheme of the quarter-penny crack has been placed, as it can be seen in Fig. 3.

3.1. Results of steady state loading

In the first part, graphs of steady state of loading are presented. There is rail located bellow crack tip in radial direction. These sets of results of steady state of loading can be seen in following figures, i.e. Fig. 5 and Fig. 6. In these graphs, very high influence of first mode of stress intensity factor [1-3] can be observed. This influence educt of interference fit in the RW hub.

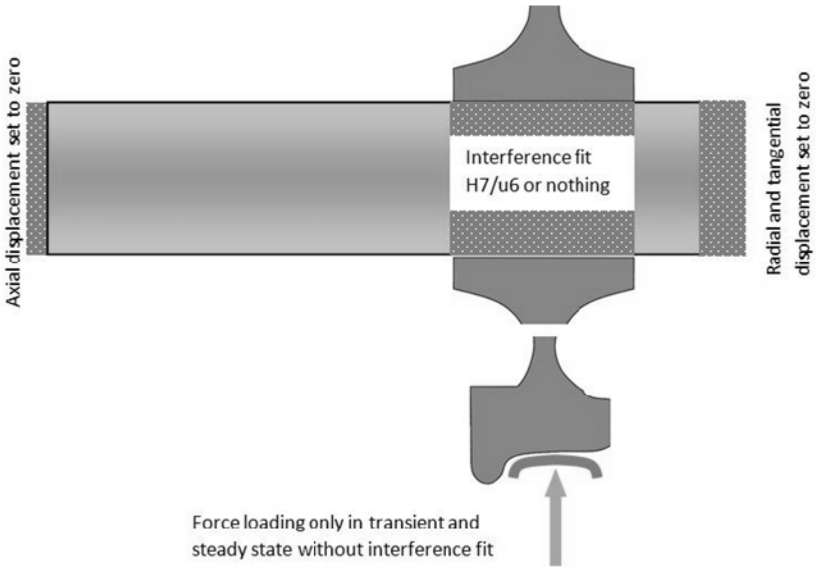

Fig. 4. Boundary conditions of the railroad wheel set

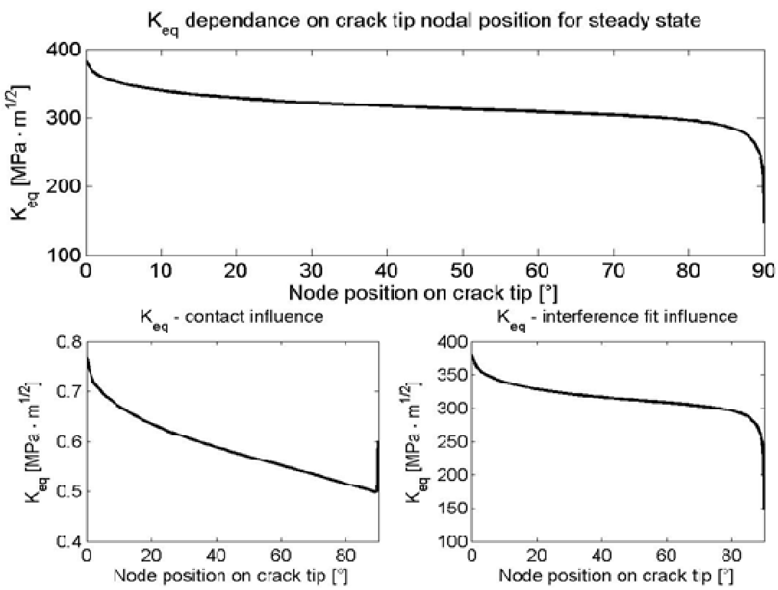

Fig. 5. Graphs of load influence for steady state of loading

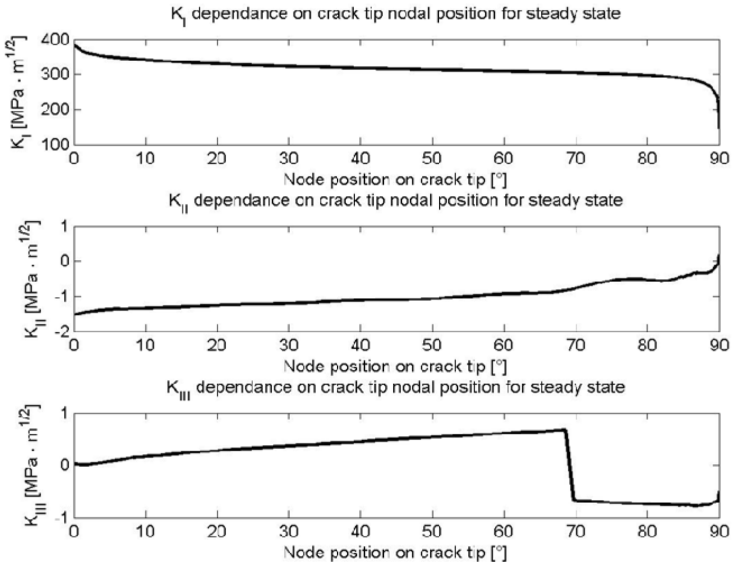

Fig. 6. Graphs of load influence for steady state of loading

In this case, the rail is located below fracture area of the crack. The similar curves can be seen also for other cases of topology. These results can be found in following figure, i.e. Fig. 7.

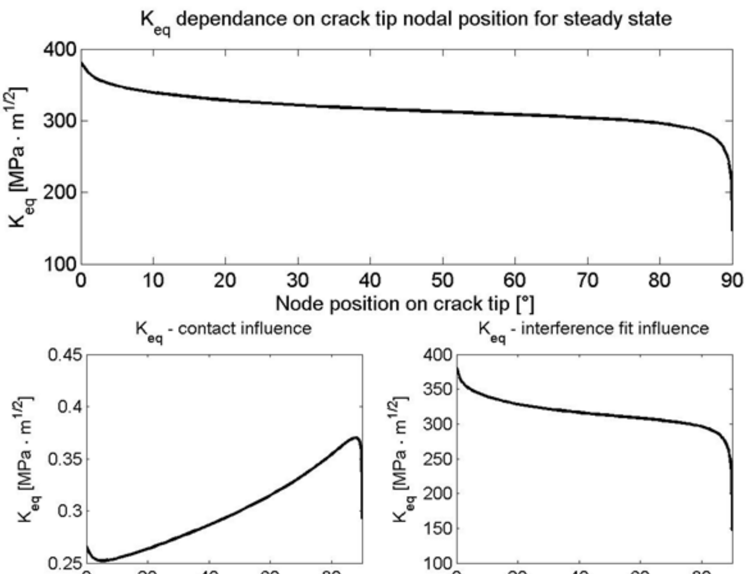

Fig. 7. Graphs of load influence for steady state of loading

3.2. Results of transient loading

The second set of graphs has been aimed to show transient process. In this case, it means an influence stress-waves loading. These sets of results of loading can be seen in following figures, i.e. Fig. 9 and Fig. 10. In these graphs, insignificant influence of stress waves to crack tip can be observed as well as the main influence educt of interference fit in the RW hub, which corresponds with previous loading type.

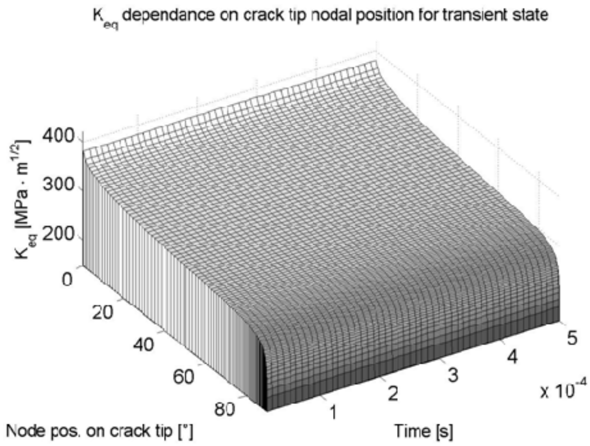

Fig. 9. 3D graph of Keq for transient state

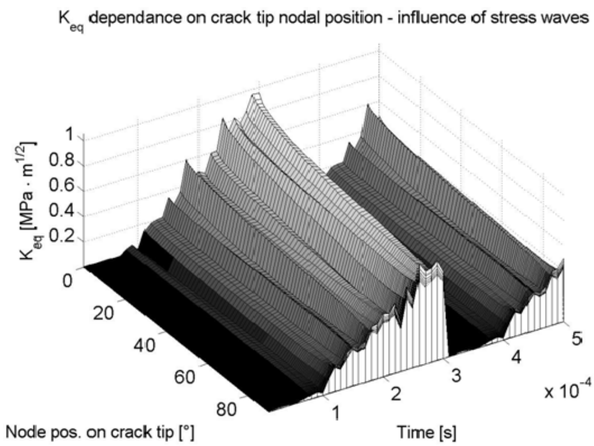

Fig. 10. 3D graph of Keq only for stress waves influence on crack tip (2^{nd} topology state)

In this case, there is rail located below fracture area of the crack. The similar graphs can be seen for other case of topology. The graph which represents K_{eq} is particularly the same as the graph in Fig. 9. The graph, which shows only influence of stress waves, can be observed in Fig. 11.

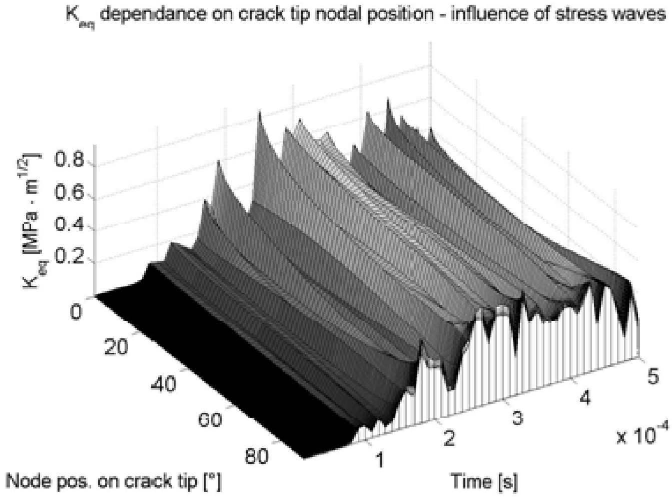

Fig. 11. 3D graph of K_{eq} only for stress waves influence on crack tip

4. Conclusions

In this paper the transient state, stress waves, steady state, as well as loading states of the railroad wheel with the primary "penny" crack, has been studied. Two essentials topology configurations were worked with. For both of them, as well as for both simulation states, i.e. steady and transient state, it can be said that interference fit has major influence on stress distribution and stress intensity factors near railroad wheel hub, which can be seen in Fig. 5 to Fig. 11. The stress waves caused by transient contact loading don't have essential influence on stress intensity factors. All results stem from FEM simulations. This conclusion might also stem from analytical stress solution of cylindrical pressure vessel for steady state of loading. The study has proven that the conclusion is valid for stress-waves loading, too.

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References

[1] Richard, H. A., Sander, M., Fulland, M., Kullmer, G.," Development of fatigue crack growth in real structures," in *Engineering Fracture Mechanics*, ed. (Elsevier, 2008), pp. 331–340. ISSN: 0013-7944

[2] Soh, A. K., Bian, L. Ch.," Mixed mode fatigue crack growth criteria," in *Engineering Fracture Mechanics*, ed. (Elsevier, 2001), pp. 427-439. ISSN: 0013-7944

[3] Janíček, P., *Systémové pojetí vybraných oborů pro techniky* (CERM, Brno, 2007) ISBN: 978-80-7204-554-9