Mechanics Transport Communications
Academic journal

ISSN 1312-3823
issue 1, 2007
article № 0082
http://www.mtc-aj.com

SUGGESTIONS FOR DEVELOPMENT OF SENSORS FOR MEASUREMENT OF FORCES AT WHEEL-RAIL CONTACT

Zlatan Šoškić, Dragan Petrović, Nebojša Bogojević, Ranko Rakanović
soskic.z@maskv.edu.yu , *petrovic.d@ maskv.edu.yu*, bogojevic.n@maskv.edu.yu, rakanovic.r@ maskv.edu.yu

Faculty of Mechanical Engineering Kraljevo, Dositejeva 19, Kraljevo, Serbia

Key words: *Wagon, force, wheel-rail contact, sensor.*
Abstract: *Safety testing of railway vehicles is, according to international regulations, based on measurements of accelerations of axis and forces acting at rail-wheel contact. While acceleration measurements represent standard methodology, only small number of countries has developed methodologies for measurement of forces acting at wheel-rail contact. This paper presents analysis of stresses and deformations of wheelset and standard wheels needed for design of new type of sensors which will efficiently measure forces in wheel-rail contact.*

1. Introduction

All countries that are members of International Union of Railways are obliged to perform investigations and testing of railway vehicles running behavior and safety according to regulations of the Union [1]. Along with increase of knowledge and experience as well as advance in possibilities of measurement equipment, requests posted by those regulations are frequently changing.
Current procedure for such investigations and testing, defined in relevant documents, considers:

- testing conditions,
- measured quantities,
- automatic and statistical data processing,
- assessment quantities and
- limit values.

This paper considers measured quantities with special attention devoted to measurement of forces acting in wheel-rail contact.

2. Measured quantities describing wheel-rail contact

A basic issue related to the wheel-rail interaction is load distribution in wheels of rolling stock in static position [5, 8], as well as in movement [6, 9]. Stands have been developed and implemented designed for the measuring of wheels' load and also for the characteristics of springs' suspension determination [7, 10].
Depending on technical characteristics of vehicle, maximum running speed and the fact that vehicle under investigation may be new or altered there are two investigation procedures, denoted as normal and simplified procedure. Procedures define type and number of measured quantities. While simplified method allows for measurement of lateral forces at wheelsets (usually referred to as H force) for altered vehicles with exploitation speeds less than 120 km/h, normal method, applicable in all other cases, comprises measurement of lateral wheelset accelerations and the following measured quantities

- Sum of guiding forces per axle $(\sum Y)_{2m}$,
- Ratio of the lateral to the vertical force per wheel for the guiding wheelset $(Y/Q)_{2m}$,
- Vertical force between wheel and rail Q,
- Quasi-static force between wheel and rail Y_{qst} and Q_{qst}.

It is clear that in vast majority of cases measurement of H forces is not applicable [4], so contemporary laboratories for railway vehicle testing have to develop sensors and methodologies for measurement of forces in wheel-rail contact.

3. Wheelset loads

From the point of view of derailment safety, dynamical loads of wheelsets are schematically presented at Fig.1 [3]. Figure presents cross-sections of wheelset and rails. Points of wheel-rail contact are denoted by A and B, and center of gravity of wheelset (coinciding with center of gravity of axle) is denoted by T.

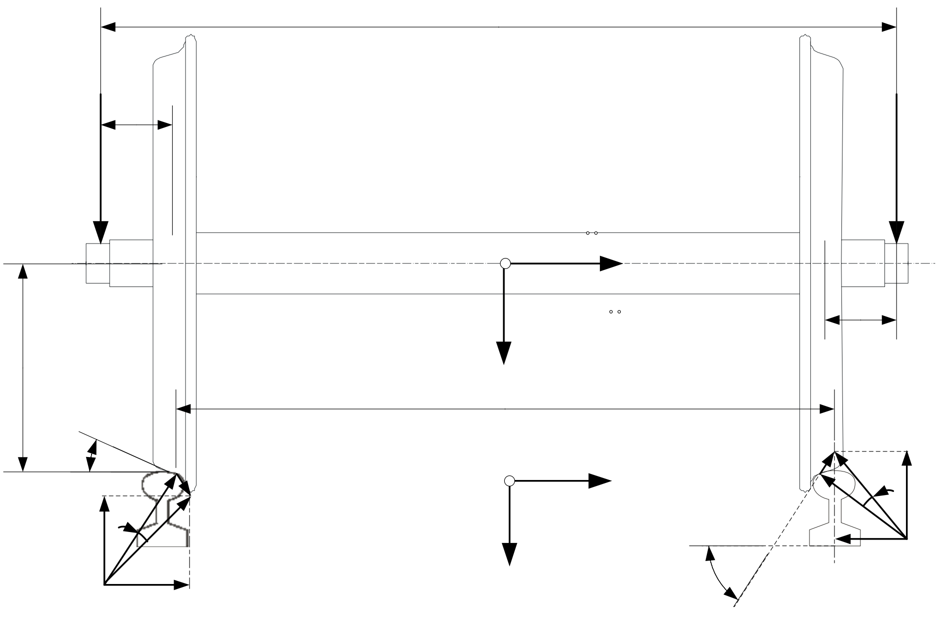


Fig. 1

The influence of vehicle body is presented through forces $F_1(t)$ and $F_2(t)$ acting at axle sleeves and lateral force H(t) acting at point T.

At wheelset center T also act wheelset forces of inertia in lateral ($m_o \cdot \ddot{y}$), and vertical ($m_o \cdot \ddot{z}$) directions, where symbols represent the following:

m_0 - wheelset mass,

$\ddot{y}, \ddot{z}$ - wheelset center of gravity accelerations in lateral and vertical directions.

Due to lateral displacement of wheelset, in points of wheel-rail contacts act normal reaction forces N_1 and N_2 as well as forces of friction

(1) $$F_{\mu 1} = N_1 \cdot \mu_1; \qquad F_{\mu 2} = N_2 \cdot \mu_2$$

where μ stands for coefficient of friction.

Resultant forces in wheel-rail contacts are now:

(2) $$N_{R1} = \sqrt{N_1^2 + F_{\mu 1}^2} = N_1 \cdot tg\,\rho_1$$
$$N_{R2} = \sqrt{N_2^2 + F_{\mu 2}^2} = N_2 \cdot tg\,\rho_2$$

where ρ_1 and ρ_2 stands for friction angles at wheel-rail contact, former describing climbing of one wheel on rail head and later describing slipping of the other wheel from rail head. Force of friction on climbing side makes an angle β_1 with horizontal plane, while on slipping side force of friction makes angle γ_2 with horizontal plane.

Total force in rail-wheel contact N_R is usually described through its vertical (denoted by Q) and lateral (denoted by Y) component.

Static equilibrium conditions can then be expressed as:

(3) $$Y_1 = Q_1 \cdot tg\left(\beta_1 - \rho_1\right)$$
$$Y_2 = Q_2 \cdot tg\left(\gamma_2 - \rho_2\right)$$

while dynamic equilibrium equations are:

$$\sum Y = 0 \Leftrightarrow H + m_o\left(-\ddot{y}\right) - Y_1 + Y_2 = 0$$
$$\sum Z = 0 \Leftrightarrow Q_1 + Q_2 - \left(F_1 + F_2\right) - m_o\left(g \pm \ddot{z}\right) = 0$$

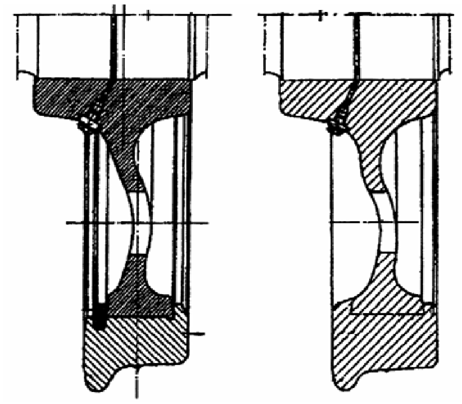
(4) $$\sum M_A = 0 \Leftrightarrow -F_1 \cdot \left(a + 2s\right) + a \cdot F_2 -$$
$$-\left[H + m_o\left(-\ddot{y}\right)\right] r - m_o\left(g \pm \ddot{z}\right) \cdot s + Q_1 \cdot s = 0$$

Aforementioned international regulations define limiting values for measured quantities that must not be exceeded during test rides. Being that it is possible to avoid derailment if those limiting values are exceeded during short periods of time, instead of limiting measured quantity, international regulations are limiting mean values of measured quantities during path length of 2 m.

4.Railway vehicles wheels

Further discussion is based on analysis of the influence of forces acting at wheel-rail contact on railway vehicle wheel. Therefore, railway vehicles will be discussed in short notes. There are two types of constructions of railway wheels: wheels with bandage and monoblock wheels.

Monoblock wheels are used almost exclusively nowadays: exploitation analysis showed that they are not only much more reliable but are also more cost-effective. Fig. 2 presents cross-sections of wheel with bandage (a) and monoblock wheel (b).



(a) (b)

Fig. 2

5. Experimental measurement of forces at wheel-rail contact

There is only small number of institutions nowadays that have developed methodologies for direct measurement of forces acting at wheel-rail contact, and usual practice is to measure H force , static Q force and axle accelerations and calculate forces Y(t) and Q(t) by application of equations (3) and (4). On the other side, international regulations insist on direct measurement of the quantities.

The most renowned methods for direct measurements rely in measurement of deformation of the wheelset under action of forces at wheel-rail contact. Measurement is performed by application of strain gauges: methodology developed in France uses strain gauges sealed to wheel rim, while German methodology uses strain gauges sealed to axle. Both solutions have common technical problem connected with signal transfer but also common principle objection that measurement points are far from wheel-rail contact, making measurement almost indirect.

Contemporary development of sensor technology lead to development of new kind of transducers that measure deformation on different principle comparing to strain gauges: those sensors are inserted within tiny holes bored in sample which deformation is measured; after it they are deformed due to deformations of sample.

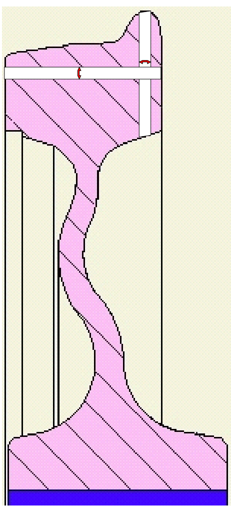


Fig. 3

If such sensor is inserted in hole bored within test wheel immediately under rim (Fig. 3) it will measure deformations caused by wheel-rail contact forces in close vicinity of the contact point. For application of such sensors for measurement of wheel-rail contact forces, it is necessary to study the influence of those forces on deformations of holes bored into wheel.
The first problem that is to be solved is to estimate the order of magnitude of deformations to which holes will be subjected in order to determine measurement range of sensor which should be applied. In this purpose, series of calculations of stress-deformation state of railway vehicle wheel were performed.

6. Calculation of stress-deformation state of railway vehicle wheel

Geometry and stress distribution of railway vehicle wheel are so complex that analytic solution of problem is not possible. It is clear that introduction of holes in structure makes problem even more complex, so that numerical calculations were performed in order to solve problem.

7. Calculation of influence of heat

Large number of vehicles with running speeds up to 160 km/h and practically all vehicles with running speeds less than 120 km/h use brake slippers for braking. In braking process kinetic energy of braked vehicle is transferred to heat energy at slipper-wheel contact surface leading to increase of wheel temperature and thermal deformation of wheel. Railway vehicle wheel profile has shape of letter "S" in order to compensate for this deformation.

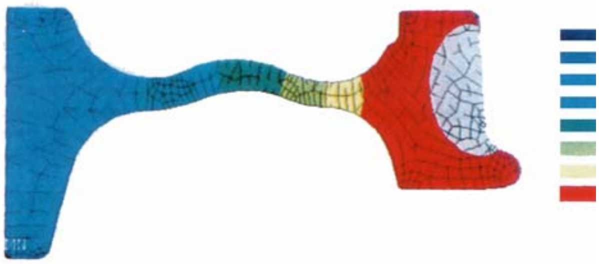


Fig. 4

As an illustration, here are presented some results of investigations [2] of the influence of braking heat on stress-deformation state of railway vehicles wheel. Fig. 4 presents temperature distribution (maximum temperature of 350^0C is reached at the rim of the wheel) and Fig. 5 presents stress distribution (maximum stress of 750 MPa is present at lightly shadowed parts of the wheel) over wheel body during intensive braking.

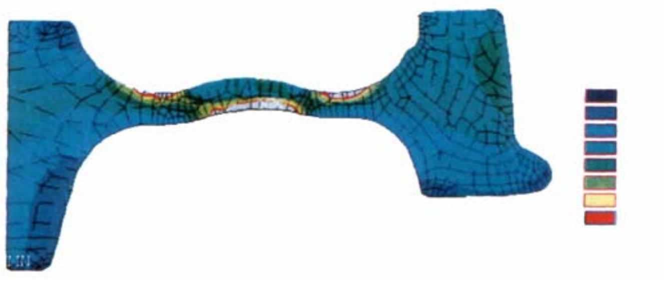


Fig. 5

All results of performed investigations clearly show that thermal stresses are high and non-uniformly distributed. Therefore all measurements of wheel-rail contact forces that rely on stresses caused by those forces must consider thermal stresses.

8.Calculation of influence of wheel-rail contact forces

Influence of wheel-rail contact forces on stress-deformation state of railway vehicle wheel is performed by calculation of stress and deformation of wheel that has holes bored through its rim at positions similar to those depicted at Fig. 3. This paper presents the first results obtained in course of investigations.

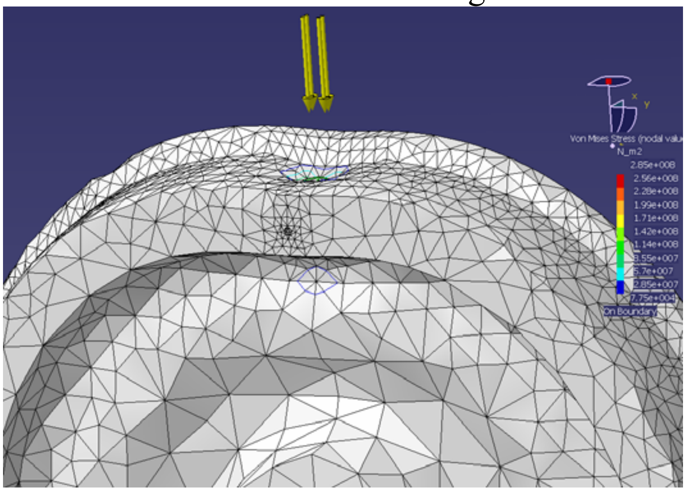


Fig. 6

Calculations are performed on model of standard monoblock wheel [3] with diameter of 920 mm. Hole with 10 mm diameter was inserted at wheel rim with hole center placed at 420 mm from wheel center. Volume model of the wheel is formed with non-uniform net of over 5000 finite elements with element density higher in vicinity of hole where object is modeled by tetrahedrons with 3 mm side length (Fig. 6).
The influence of wheel-rail contact forces is estimated by calculation of influence of force normal to wheel rim (equivalent to influence of vertical component of wheel-rail contact force Q). The intensity of the force is taken to be 30% larger than static load, which, for axle load of 225 kN, amounts to be equal to 146.25 kN per wheel.

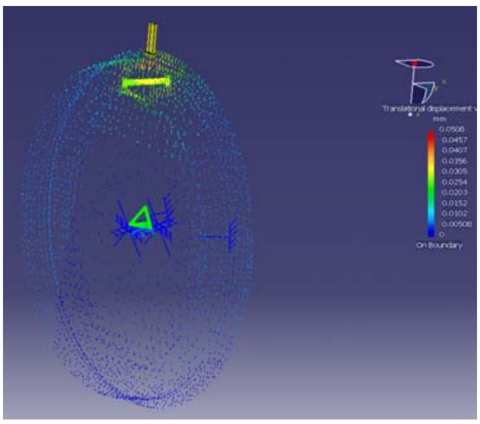


Fig. 7

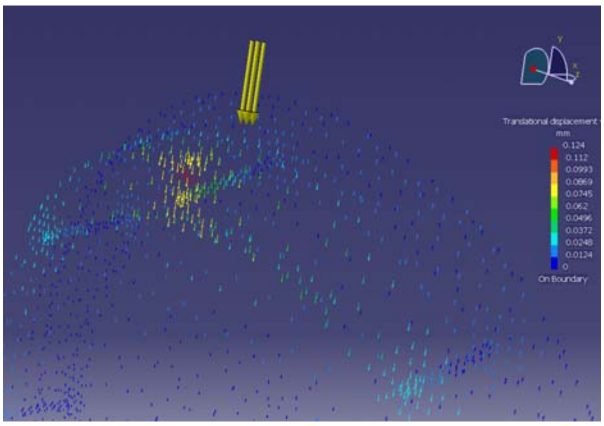


Fig. 8

Calculations are performed by application of program package KATIA. Calculated values of stresses are less than 100 MPa, so that they don't have substantial influence on increase of stresses caused by hole boring.
Calculations also revealed vector of total deformation of the wheel as well as vertical component of deformation vector (Fig. 7).
The most important result for sensor design is deformation of hole, which is equal to difference in displacements of points belonging to hole diameter parallel to direction of applied force. Maximal calculated hole deformation is 2.2 μm.
It is also important to investigate the influence of position of wheel-rail contact on hole deformation. In order to estimate it, calculations were performed for point of attack of the force moved to edge of the rim. Hole deformations are changed and deformation field is presented at Fig. 8

9. Conclusion

The first investigations performed in analysis are giving the first suggestions on sensor for wheel-rail contact forces design:

- Design of sensor for wheel-rail contact forces is immediate necessity.
- Wheel-rail contact forces measurement methodology has to have temperature compensation.
- Holes with diameter of 10 mm for sensor for wheel-rail contact forces do not influence on stress-deformation state of railway vehicle wheel.
- Optimal measurement sensor range is around 5 μm.
- Position of sensor for wheel-rail contact forces within sensor hole is so important that it seems optimal to have several sensors within the same hole.

LITERATURE

[1] UIC Code 518, "Testing and approval of railway vehicles from the point of view of their dynamic behavior – Safety-Track fatigue-Ride quality" 2nd edition, April 2003.

[2] Becejac Lj. , "Investigation of possibility for prediction of thermal overload of wheel of railway vehicle braked by slippers on basis of characteristics of rail and train ", Master thesis, Nis 2003.g. (in Serbian)

[3] Jovanovic R. , "Railway vehicles wheelsets", Saobracajni institut CIP, Beograd, 1996.

[4] Atmadzhova D. B. , "A Model for dynamics of Wagon-Track Systems", V international conference Heavy Machinery HM 2005., Kraljevo, 28 June - 03 July 2005. p. C29-C3

[5] НЕНОВ Н., Система за измерване статичното натоварване на колелата на локомотивите и методика за намаляване на техните разлики, сп. „Механика, транспорт, комуникации”, 2007, №1, BG-2.1

[6] НЕНОВ Н., Система за измерване в движение натоварването на колелата от една колоос на железопътни возила, сп.”Железопътен транспорт”, 2007, №6

[7] NENOV N., DIMITROV. E., MIHOV G.,. RUZHEKOV T, Electronic test equipment for determining parameters of railway rolling stock spring elements,

XI International Scientific Conference “Science, education and society”, Vol. III, pp. 55-58, 15-17 september, Zilina, Slowak Republic, 2003
[8] NENOV N.,. RUZHEKOV T, MIHOV G., DIMITROV, E. Technology of locomotive spring system adjustment, XI International Scientific Conference “Science, education and society”, Vol. III, pp. 51-54, 15-17 September, Zilina, Slovak Republic, 2003
[9] NENOV, N., RUZHEKOV T., MIHOV G., DIMITROV E., Technology for Dynamic Wheel Load Measuring of Railway Carriages, The 12th International Scientific and Applied Science Conference “Electronics ET’2003”, Sozopol 24-26 September, book 1, p64-69
[10] NENOV N., DIMITROV E., RUZHEKOV T., GEORGIEV E., System of Hydraulic Dampers Diagnostics, 29th International Spring Seminar on Electronics Technology “Nano Technologies for Electronics Packaging”, May 10th to 14th, 2006, International Meeting Centre of St. Marienthal, Germany.