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METHODOLOGIES OF EXPERIMENTAL DETERMINATION OF WHEEL-RAIL CONTACT FORCES

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Abstract *– This paper analyses the most relevant methodologies of experimental determination of wheel-rail contact forces. The basic principles of realization of measurement systems, as well as advantages and disadvantages of different methodologies and technical solutions are considered. The special attention was paid to the technical solutions of instrumented wheelsets which are nowadays usually used for measurement of wheel-rail contact forces. The contemporary trends and the most important problems in development of instrumented wheelsets are identified and discussed. The basic guidelines and directions for resolution of key problems in order to obtain high sensitivity and measurement accuracy are given.*

Keywords – Methodologies, experimental determination, wheel-rail contact forces, instrumented wheelset.

1. INTRODUCTION

The derailment mechanism is very closely connected with forces in the wheel-rail contact which is realized via the contact area of a few square centimetres. There are very intensive forces which cause vibrations, wear, thermal effects, noise, fatigue, failure, and the other adverse effects on elements of vehicles and track. Of utmost importance are vertical force Q and lateral force Y whose relation Y/Q is crucial for assessment the safety against derailment (Fig. 1).

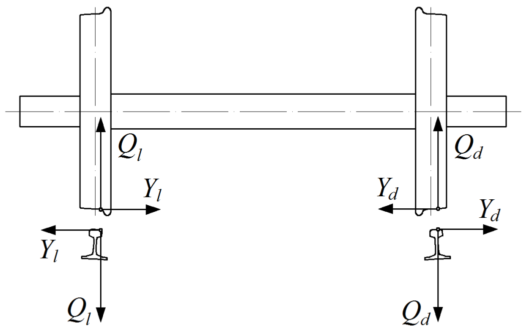

Fig.1. The wheel-rail contact forces

Given in mind their dominant influence on the railway vehicle dynamics, determining wheel-rail contact forces is of great importance. Due to the complexity of the wheel-rail geometry, precise determination by analytical way is very heavy and in many cases impossible. The analytical methods are usually based on large number of approximations in order to solve the very complex equations. In addition, wheel-rail contact forces can be determined numerically using specialized software for simulation of railway vehicle dynamics. However, their algorithms are also based on certain approximations. Also, there are problems of verification of models and numerical results. Consequently, the most reliable way for determination of wheel-rail contact forces is their experimental examination or measurement [1, 2]. International regulations UIC 518 and EN14363 in certain cases require measurement of wheel-rail contact forces as mandatory testing during the certification process of newly-designed or modified railway vehicles [3, 4]. It is important to note that the exact way of carrying out of this experimental testing is not defined by standards. For this reason, the individual railways and test centres are in the past developed their own methods which are largely differed. Even today there is no unique method that can be declared as the best. Each method has certain advantages and disadvantages compared to the others. In that sense, the aim of this paper is analysis of the most relevant approaches and methodologies for experimental determination of the wheel-rail contact forces. The paper can be very useful for researchers and engineers dealing with these and similar problems, or entering into the development of system

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for measurement of the wheel-rail contact forces.

2. BASIC APPROACHES

All methods of experimental determination or measurement of wheel-rail contact forces are based on the two basic approaches: measurement from the track side and measurement from the vehicle side. These approaches are stemmed from the impossibility to measure forces directly in the place of their existence - wheel-rail contact. The problem solving lies in the fact that forces causing certain deformations of structures in its vicinity during the train running. By measurement deformations of these structures (elements of track or vehicle) forces in wheel-rail contact can be determined in an indirect way.

3. TRACK-SIDE MEASUREMENT

The technical solutions of track-side measurement are usually based on checkpoints placed at certain points along the track. They are equipped with sensors (usually strain gauges) placed on the track elements (usually rails), which measure strains during the train passing. The first steps in introduction of track-side measurement have been made by ORE (later ERRI). In report published 1970. ORE has identified the key problems and gave general guidelines for their solution, but without defining of unique measurement method. Since then, different technical solutions of such measurement systems are developed. The most of them are based on the measurement of rail strains using the strain gauges. The typical solutions are based on the application of strain gauges placed on the rail and connected in the Wheatstone bridges (Fig. 2).

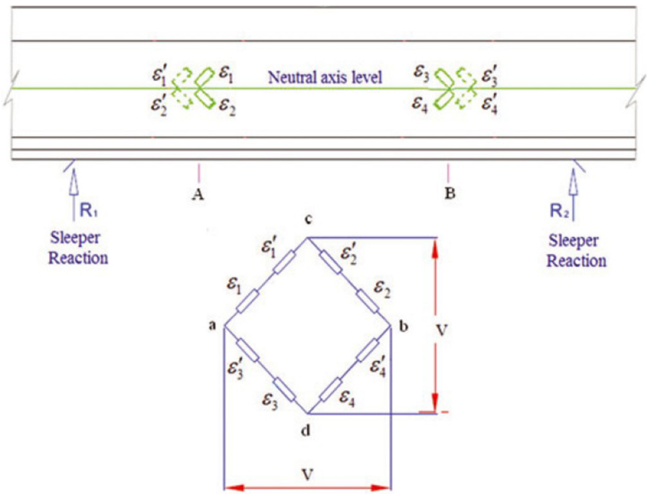

Fig.2. The example of measurement of wheel-rail contact forces using the strain gauges on the rail [5]

Determination of strain gauges positions is usually based on the FEM analysis of rail strains. The key problem is to find locations with the highest sensitivity on Q and Y forces, as well as minimal crosstalk. Calibration of measurement system can be based on the FEM results or can be done using special tools and equipment in near-real conditions. The main task of calibration is identification of individual influences of Q and Y force and changes of contact point position on strains of the rail.

The main advantage of track-side method is that the measurement is performed for each wheelset of any train that passes through the checkpoint. The main disadvantage of this method is that it does not allow continuous measurement during the train running. Measurements are carried out only at discrete points on the line which are estimated as critical from the point of quality of dynamic behaviour of vehicles. However, the process of certification of railway vehicles in accordance with mentioned international standards involves the continuous measurement of parameters of dynamic behaviour of vehicles along the certain track sections. Therefore, the application of track-side measurements is limited on the field of monitoring of vehicles that are already in exploitation. It is important to emphasize that contemporary solutions of track-side systems, in addition to the measurement of wheel-rail contact forces, provide the measurement of contact point position during the wheels passing. The current problems related to these measurement systems are finding the optimal number, layout and way of connection of strain gauges, as well as algorithm of inverse identification and way of calibration in order to obtaining the highest possible sensitivity and accuracy of measurement.

4. VEHICLE-SIDE MEASUREMENT

Vehicle-side measurements of wheel-rail contact forces are usually based on instrumented wheelsets. They are equipped with sensors (usually strain gauges) which measure certain strains during the running of tested vehicle, on the basis of which wheel-rail contact forces can be determined in an indirect way. Generally, all technical solutions of instrumented wheelsets are based on two approaches: measurement over the axle and measurement over the wheel.

The first solutions of measurement over the axle appeared in early seventies of the 20th century. Although they are in the meantime significantly improved, their main characteristic is based on the measurement of the bending and torsion moments in certain sections of the axle. A typical example of such instrumented wheelset is shown in Fig. 3.

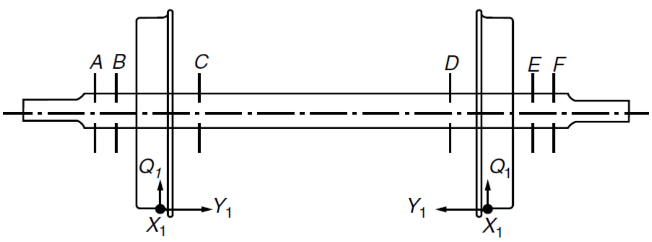

Fig.3. The example of instrumented wheelset based on the measurement over the axle [6]

The solution in the Fig. 3 is based on the measurement of bending and torsion moments in six different sections of the axle. In this way it is possible to determine the approximate values of the six wheel-rail contact forces that caused the measured moments. Moments are measured using the strain gauges connected in the proper configurations of Wheatstone bridges. Advantages of these solutions are based in relative simple measurement system and in possibility for changing wheels of instrumented wheelset. The more important are their disadvantages which are primarily reflected in the impossibility to compensate measurement error due to changing the contact point position. The measurement over the axle was used a long time in German Railways. Because the mentioned disadvantages, this method is replaced with the modern solutions.

First concrete solutions of measurement over the wheel of instrumented wheelset emerged in the fifties of the 20th century. From that time until today, the large number of technical solutions of measurement over the wheel of instrumented wheelset is developed. All solutions are based on two approaches: measurement over the wheel with spokes and measurement over the standard monoblock wheel.

The largest contribution to the development of instrumented wheelsets with spoked wheels gave the British Railways during the seventies and eighties of the 20th century. The solution is based on measurement of strains using the strain gauges placed on the certain sensitive locations of spokes (Fig. 4). The strain gauges are in certain configurations connected into the Wheatstone bridges in order to obtain the highest possible sensitivity and measurement accuracy.

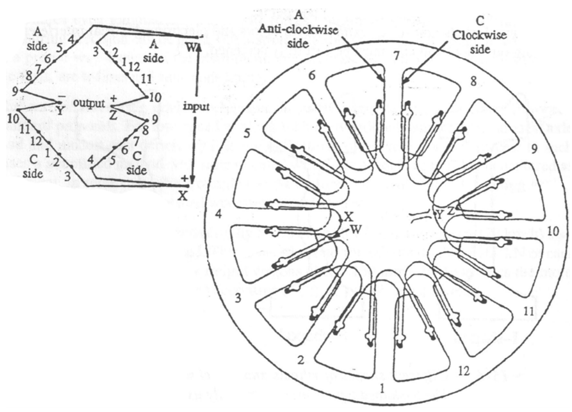

Fig.4. The example of instrumented wheelset based on wheels with spokes [7]

With intelligent selection of spokes and locations of strain gauges it is possible to obtain the signals which are approximately proportional to the wheel-rail contact forces. The advantage of this method is in better sensitivity on the effects of Q force due to the higher elasticity in the vertical direction. In addition, these solutions allow to achieve high measurement accuracy. The main drawback is a very complex and expensive machining of spokes that require high precision. This method is rarely used today, although it has long been in use in the UK and Switzerland.

Instrumented wheelsets with measurement over the standard monoblock wheels appeared in the fifties of the 20th century. After the occurrence of method of Olson and Johnsson, the development of such instrumented wheelsets flowed upward with the increasing of sensitivity and accuracy of the measurement. In the eighties of the 20th century in this area a significant step forward is made in region of former Yugoslavia. At that time, Prof. Jovanovic and colleagues developed instrumented wheelset based on the application of strain gauges placed on the standard monoblock wheels. The measurement of wheel-rail contact forces using the instrumented wheelsets based on the standard monoblock wheels is today most common method that is widely used in countries such as France, Germany, USA, Japan, Sweden, China, etc.

The key advantage of vehicle-side measurement is that it allows continuous measurement. The main disadvantage is that the measuring system is connected with the one wheelset. Since the design of wheelsets for different types of railway vehicles can vary significantly, the instrumented wheelsets must be adapted to the specific types of vehicles or bogies. This cause the high costs of their development and production.

5. CONTEMPORARY INSTRUMENTED WHEELSETS

In contemporary solutions of instrumented wheelsets, the strain gauges can be placed on inner or outer side of wheel disc on the certain radial distances (Fig. 5). The optimal radial distances are selected on the basis of FEM analysis of the wheel (Fig. 6). This is one of the most significant problems to be solved in development of instrumented wheelset.

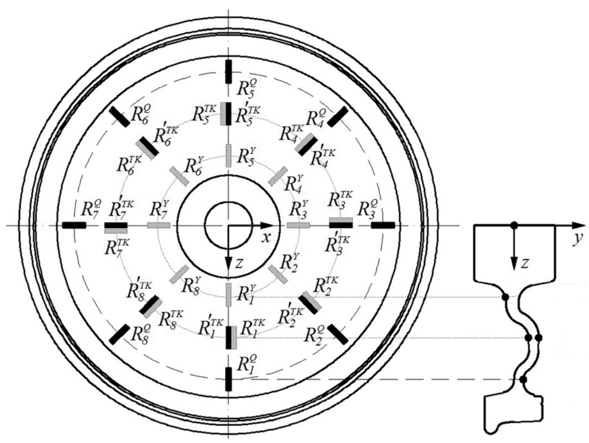

Fig.5. The example of strain gauges layout on the instumented wheelest with monoblock wheels

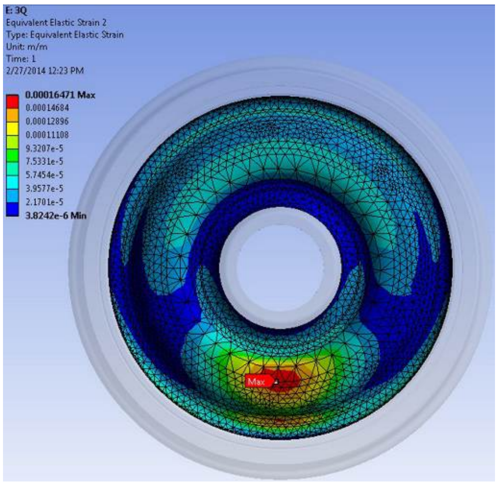

Fig.6. The FEM analysis of the wheel

Finding locations with highest sensitivity on parameters being measured and minimal crosstalk should be based on detailed stress-strain analysis of the wheel. The FEM model also enables solution of very important problems such as finding of optimal number, layout and way of connection of strain gauges in the Wheatstone bridges. The centrifugal and temperature effects should be taken into account and compensated. In order to increase the sensitivity on Q force, in the wheel disc very often there are circular holes for strain gauges placing. In the last time, this solution is very rarely and the tendency is to use the standard monoblock wheel without any additional machining (Fig. 7).

Fig.7. The instrumented wheelset with standard monoblock wheels

In addition to the measurement of wheel-rail contact forces, the contemporary instrumented wheelsets allow measurement of the contact point position. The most significant problems to be solved are also the development of algorithm for inverse identification of measured parameters, the development and production the test stand for calibration, data transmission, etc. This process requires the systematic approach and participation of experts from the different sectors of technique. The key task is providing the highest sensitivity and accuracy of measurement system.

6. CONCLUSION

During the last decades, many different methods and technical solutions for experimental determination of wheel-rail contact forces has been proposed. Each of them has certain advantages and disadvantages. Track-side measurements are more used in monitoring while vehicle-side measurements via the instrumented wheelsets are primarily used in certification process of railway vehicles. Standards do not define technical solution of instrumented wheelset as well as the necessary accuracy. The most of contemporary solutions are based on the standard monoblock wheels equipped with the strain gauges. There are many different approaches when it comes to locations of strain gauges, their layout, number, way of connection, signal transmission, etc. Also, there are many different approaches of calibration and the algorithm of inverse identification. There is no universal solution for which can be said that is the best. Each manufacturer has its own solution of instrumented wheelset that is more or less different from the others, and that has certain advantages and disadvantages. In every case, the key problem in development of every measurement system or instrumented wheelset for experimental determination of wheel-rail contact forces is obtaining the highest sensitivity and accuracy.

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