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Wayside system for wheel–rail contact forces measurements

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ABSTRACT

The system for assessment of the wheel–rail contact forces can be used for multiple purposes, among them for estimation of the train running safety, for train axle load measuring or wheel flats detection, as well as for the other research analyses. As the wheel–rail rolling contact moves along the track during train motion, it is very difficult to establish a reliable and accurate system for measuring of contact forces. Measurement principle of the wayside system, presented in this paper, is based on rail strains measurements using strain gauges, connected into the Wheatstone bridges in a smart way, in order to achieve signal proportional to applied load. This principle uses independent component analysis (ICA) model in combination with system calibration for successful separation of vertical and lateral contact forces from recorded strain signals. In addition, the system provides identification of the contact point position on the rail during train passing over it, which further expands the possibilities of its application to wheel–rail wear analysis, contact geometry optimization etc.

1. Introduction

Systems for measurement of the wheel–rail contact forces are indispensable information provider in studying of railway vehicle dynamics. These systems could be used for multiple purposes, among them for health monitoring of the rolling stock, as well as for the train axle load measurements, without interrupting train regular service. Measurements of the wheel–rail contact forces are also important in the process of experimental verification of the dynamic behaviour of rail vehicles, as some of the criteria for evaluating the dynamic behaviour and train running safety are based on the values of these forces [1]. For example, derailment mechanism is based on the analysis of the ratio between lateral and vertical forces.

As the wheel–rail contact during train motion travels along the track, it is very difficult to establish a measuring device or a system that would enable acceptably accurate measurements of the contact forces. So far developed methods and principles of measurements can be classified into two categories:

1. Vehicleside methods – allowing continuous measuring of the forces during train motion, using specially adapted wheels and/or wheelset [1,2],
2. Wayside methods – allowing discrete contact forces measurements, using devices installed on track [3–8].

Vehicleside methods are mainly based on measuring strains using special instrumented wheelset. Systems based on these methods provide measuring with one vehicle over the whole railroad network. The system drawback is the volume of work required for its preparation including calibration process, as well as the high costs related to the requirement of the expert knowledge and usually specific design of the wheelset, dependant on the vehicle type.

Wayside methods are less expensive, consequently providing less research possibilities. Wayside systems are utilized for measuring of contact forces at single point, or at relatively short rail length, with all vehicles passing over

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the measuring track section. Depending on the application or due to the complex and/or unsuccessful minimisation of cross talk between the vertical and horizontal components, the most of the wayside systems are focused only on vertical force measuring. On the other hand the systems presented in [7,8] provide more information required for assessment of derailment safety, or for dynamics acceptance testing of the new railway vehicles. Measurement principle of the majority of existing wayside systems is based on the measurements of rail strains using: strain gauges [3,9,10], optical fibres [4], piezoelectric sensors [5] or intrusive quartz sensors [6]. Some of the existing devices, within preparation phase, require significant changes to be done on the track, e.g. supporting the rails on the ground over special transducers instead over the sleepers [8], the others require drilling holes in the rail web [6,10], etc. All these modifications are related to increased costs and possible interruption of the train regular service and/or track maintenance.

In this paper we propose the wayside system for wheel–rail contact forces measurements based on measurements of rail strains ε using strain gauges installed on track. The device does not disturb rail or track integrity, nor requires any changes on them. The system is intended primarily for research of some aspects of dynamic behaviour of the railway vehicles that are passing over the equipped track section. With our system we successfully decouple vertical and lateral forces using independent component analysis (ICA). In addition utilizing the benefits of this technique, we propose a method for detection of the contact point position based on strain measurements only.

2. Measurement principle of the proposed system

The proposed measurement principle is based on strain measurements, using strain gauges, evolving in the rail due to the train passing over the equipped measuring track section.

The first phase of development was to numerically evaluate possible solution of the strain gauges positioning, providing the most sensitive and acceptably accurate system for measuring of wheel–rail contact forces. We defined and checked the location of measuring points and directions for strain measurements by static analysis using finite element method (FEM). To include as realistically as possible bending and torsioning of the rail cross-section in the middle between two adjacent sleepers and appropriate boundary conditions, we modelled the track section with the finite length corresponding to four sleepers (three spans) (Fig. 1).

The rail supports were modelled as elastic and clamped, with vertical stiffness according to [11] corresponding to equivalent stiffness of rail, sleeper and ground. We used vertical stiffness equal to 32 kN/mm obtained during performed in situ measurements. This value is very close to the typical value reported in [11] for similar track type. In lateral direction equivalent stiffness of fastening system, sleeper and ground equal to 37 kN/mm was adopted based on the typical value used in [20]. Considering the fact that braking and traction, during which significant longitudinal forces appear were not in the focus of this analysis, to balance the model, we only prevented degree of freedom of one node at one end of the rail in longitudinal direction.

The goal of finite element analysis (FEA) was to find position of the two groups of strain gauges, connected in a smart way to measure separately vertical Q and lateral Y forces. The arrangement of measuring points similar to one given in [3], presented in Fig. 1, was further investigated. The main drawback of the system given in [3], was the complicated and unsuccessful minimisation of cross talk between vertical and lateral forces.

The first assumption was that the strain gauges installed on the rail web were intended for measuring of vertical forces, while the strain gauges installed on the rail foot were for lateral forces measuring. For illustration of measuring points sensitivity and possibility to separately

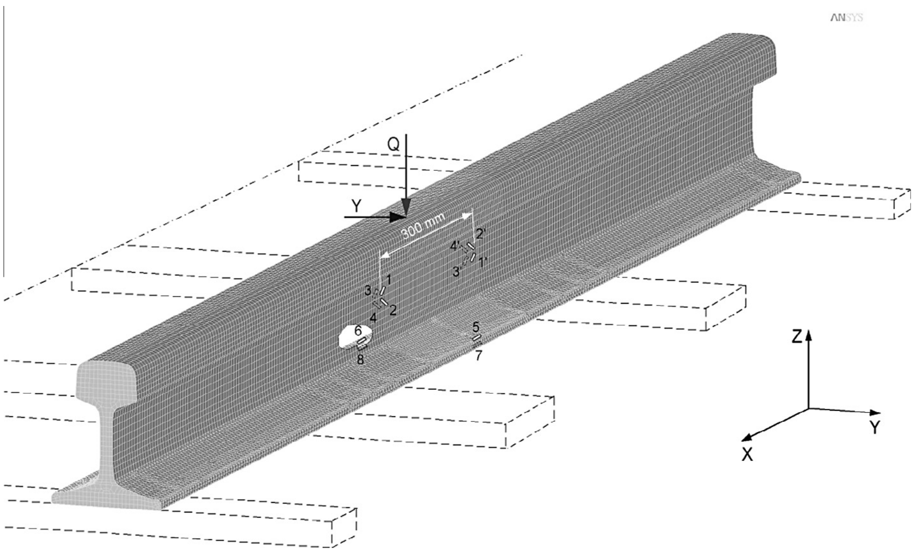

Fig. 1. Strain gauges disposition.