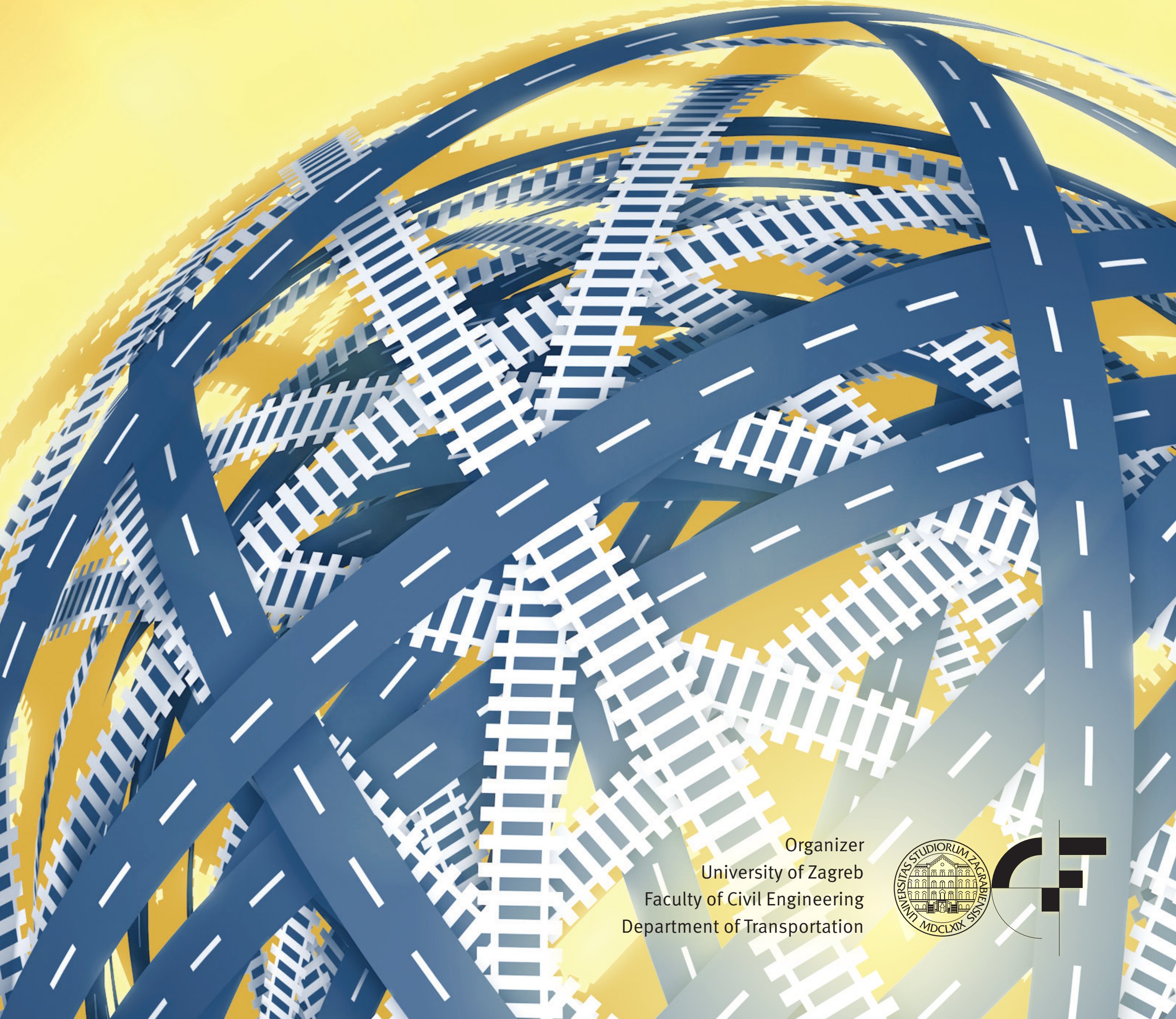
CETRA[2016]

4th International Conference on Road and Rail Infrastructure
23–25 May 2016, Šibenik, Croatia

Road and Rail Infrastructure IV

Stjepan Lakušić – EDITOR



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Road and Rail Infrastructure IV

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DEVELOPMENT OF SPECIALIZED FORCE SENSOR FOR RAILWAY WAYSIDE MONITORING SYSTEMS

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Abstract

The paper is dedicated to the development of a specialized tensometric force sensor which will be implemented in railway wayside monitoring systems. The developed sensor will be a basis to implement number of facilities for control on wheel load of railway vehicles in motion. The global goal is the improvement of the main engineering and economic indicators: reducing wear of wheel and track; reducing failures and damages in the wheeled part of rail vehicles, increasing the inter-repair runs; improving the comfort of riding, etc.
The innovation aspect in the paper is optimization in the sensor structure by mathematical modelling and numerical examination on its behavior by varying geometric parameters and under different model of loading. The optimization of the sensor structure is achieved by: creating of a 3D model of the sensor; determining deformation and stress states of the sensor under load; optimizing the sensor geometric dimensions in order to increase its sensitivity; extending the measuring range of the sensor and accuracy of measurement. Simulation of the sensor model is performed with characteristics modes of loading. Also a new technology for management and control on the process of polymerization of strain-gauge rosettes is developed. The technology includes low temperature curing process with precise computer control system, developed specially for this purpose. The results obtained from the advanced sensor have confirmed the possibility to measure the loads of railway vehicles in motion at an operating speed. The force sensor has been tested under laboratory conditions and is fir for implementation in practice.

Keywords: force measurement, railways, modelling, numerical analysis, monitoring systems

1 Introduction

Taking into account the present-day operating conditions of the railway transport we are able to distinguish two major trends in the roadside inspection and monitoring of trains and railway infrastructure.
The first trend is associated with the continuous increase in the volume of freight and passengers, while increasing vehicle speeds, i.e. there is a constant increase in the intensity of transport activity.
The second trend is associated with reducing (and in some railway administrations to even complete removal) of the staff employed for roadside control and observation of trains and railway infrastructure. The trend is due to the fact that this activity has low performance and low efficiency. Many of the damages to the rolling stock cannot be detected and promptly addressed in such a way.
Combining the two trends and at the same time preserving the level of safety and operating reliability of the railway transport is impossible without using modern automated systems

for wayside monitoring. These systems have to be able to detect most of the defects in the passing trains, which could lead to severe accidents, and in the same time to generate an alarm in order quick addressing of the issues.
In order to detect wheel defects in the passing trains such as flat spots, out of roundness, polygonization, etc. and to measure the current load distribution between the wheels and the vehicle weight, the research team has developed a specialized force sensor, which will be implemented in a wayside monitoring system for the needs of the railway in Bulgaria.

2 Measuring principle and modelling of the force sensor

2.1 Measuring principle

The measuring principle is based on measuring of the deformation of a beam on two supports. The beam represents a 1140 mm long P49E1 rail section. The deformation is measured in two sensitive areas of the rail web. The areas are at the same distance from the middle of the rail section. In order to increase the deformation in these areas, the web of the rail is milled on both sides. The linear deformation in these areas is measured by XK11K-3/350 strain-gauge rosettes – Fig. 1. The force applied by the wheel on the rail is determined by the deformation measured in the two sensitive areas. The strain-gauge rosettes are connected in a full bridge connection – Fig. 2.

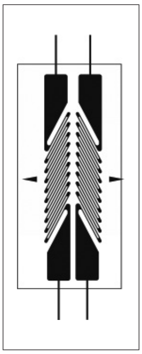

Figure 1 XK11K-3/350 strain-gauge rosette

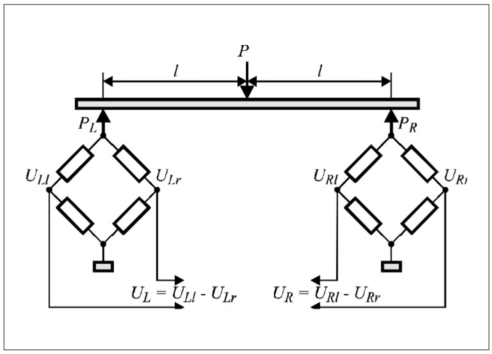

Figure 2 Full bridge connection of strain gauge rosettes

Depending on the location of the force, there are two cases of stress state of the sensor. The first case is pure lateral bending – when the resultant force acts in a vertical plane of symmetry, passing through the longitudinal axis of the rail section. The second case is lateral oblique bending – when the force is in common position on the head of the rail section. The trajectory of the principal stress is a line which tangent in every single point coincides with the direction of one of the principal stresses in this point. It gives clear idea of the stress flow in the loaded body. In each point of the rail section exist two perpendicular directions of the principal stresses. Fig. 3 shows two families of curves, representing the trajectories of the principal stresses.

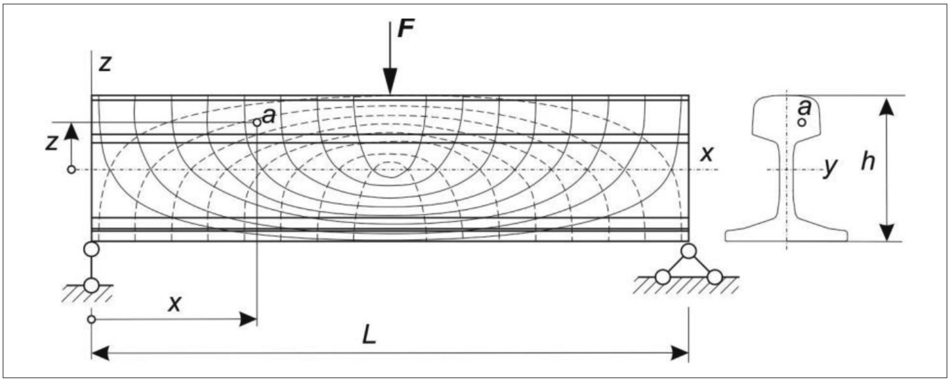

Figure 3 Trajectories of principal stresses in the sensitive rail section

From the foregoing it is clear that making only one sensitive area on the rail section is not very appropriate decision. This is due to the fact that while moving the force and positioning it over the sensitive area it will not be possible to correctly register it. The use of two sensitive areas would eliminate this inconvenience and at the same time will limit the length of the linear portion of the rail section (located between the two sensitive areas) in which it will be possible to achieve accurate measurement of the force.
The two sensitive areas (left and right) are located at 130 mm from each end of the rail section which overall length is 1140 mm. After milling the web of the rail its thickness at the sensitive areas has become 6 mm. For each of the sensitive areas two strain-gauge rosettes are used. Each rosette is installed on one side of the sensitive area – left and right. The rosettes for each sensitive area are connected as a full bridge. Fig. 4 clearly shows the rail section with its sensitive areas and the connection of the strain-gauge rosettes.

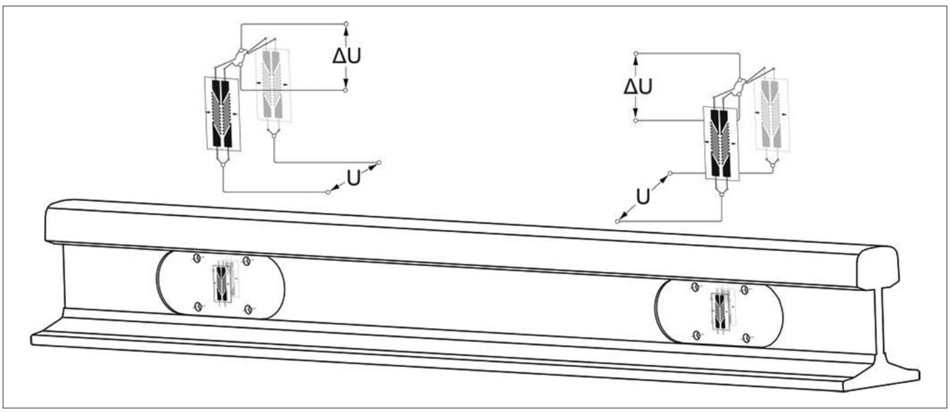

Figure 4 Installation and connection of the strain-gauge rosettes at the sensitive areas of the rail section

2.2 Modelling of the force sensor of rail type

In order to examine the behaviour and optimize the performance of the force sensor the research team has developed a 3D model which was subjected to finite element analysis. The modelling of the force sensor includes several stages.
The first stage is 3D modelling of each solid part, needed for construction of an assembly. The assembly comprises of three solid parts – Fig. 5 – the rail section with its sensitive areas, a loading element for applying force to the rail section, and a ribbed pad of rail type P49E1. To create the 3D models, SIEMENS NX 9.0 software is used [1], [2].
The second stage is assembling the 3D models. The goal is to achieve equivalence between the model and the loading conditions of the force sensor.
The third stage is approximation of the 3D models with finite element meshes. This stage is crucial for achieving accurate results of the finite element analysis [3]. Each of the 3D models of the assembly is approximated by a single 3D mesh of finite elements. The creation of the meshes includes: selection of mesh type – 3D tetrahedral; selection of finite element type – CTETRA (4) and CTETRA (10); specifying of finite elements size – 3 mm; selection of physical properties; specifying the links between the individual meshes of finite elements – Glue Coincident and Free Coincident. In this stage a selection of Solver (software for calculation of the strength-strain state) is also made – SIEMENS NX Nastran 9.0 [4].

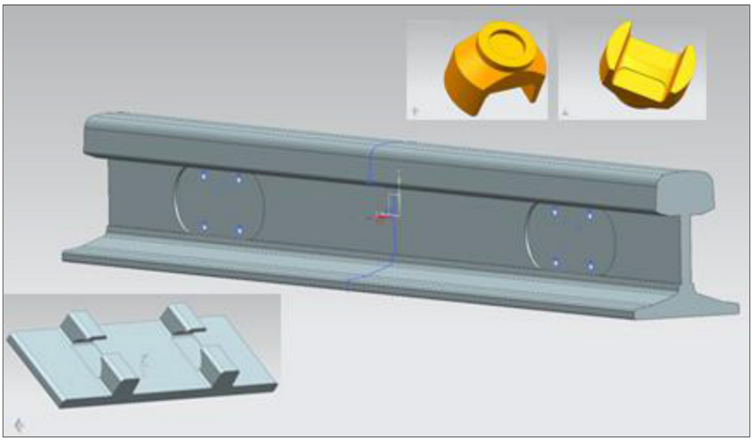

Figure 5 3D models of the force sensor assembly

The final – fourth – stage includes specifying the loading and boundary conditions and specifying how the load is transmitted between the individual meshes, i.e. 3D models, during the analysis – Surface to Surface Contact and Surface to Surface Gluing. Fig. 6 shows the model of the sensor ready for analysis.

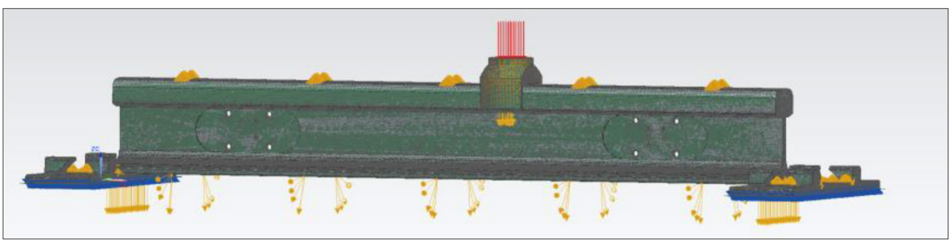

Figure 6 3D model of the force sensor ready for analysis with defined finite element meshes, loading and boundary conditions, and mating conditions

3 Examination of the force sensor

As mentioned above, two sensitive areas are created in the rail section body by milling the rail web. In these areas the strain-gauge rosettes are installed.

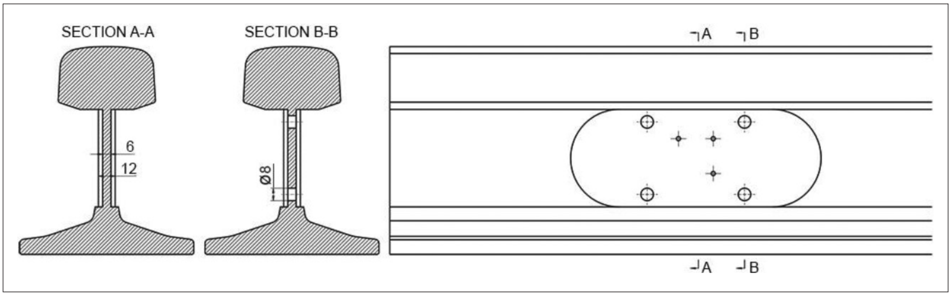

Figure 7 View of a sensitive area with technological holes and cross section of rail, showing the thickness of the web

The selection of the thickness of the rail web in the sensitive areas is a major step of the construction of the force sensor of rail type. The thinner rail web leads to higher values of the principal stresses at the areas where the strain-gauge rosettes are installed and also to higher coefficient of sensitivity. There are two reasons with negative influence in the desire for making the rail web thinner in the sensitive areas. The first is related to the possibility the sensitive areas to loose stability and to begin to behave as a "fictitious holes" in the material. The second is related to the influence of the technological holes in the sensitive areas. They act as stress raisers, which distorts the principal stresses field in the immediate vicinity to the holes. By using the 3D model described above, several numerical experiments were conducted in order to determine the influence of the web thickness in the sensitive areas. The experiments were conducted for web thickness from 3.0 to 8.0 mm in increments of 0.5 mm. Fig. 8 shows the identified relation of the shear stresses to the thickness of the rail web in the sensitive areas.

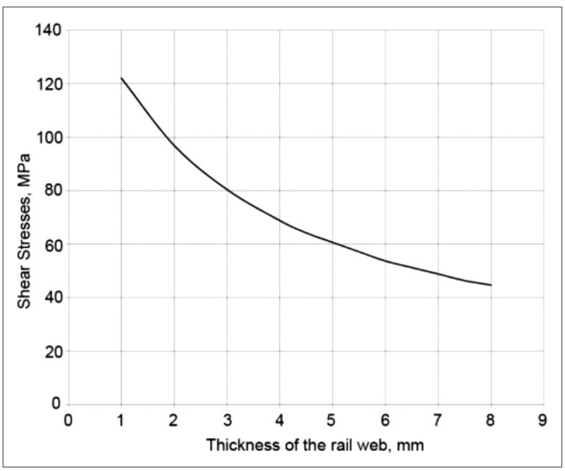

Figure 8 Relation of the shear stresses to the thickness of the rail web in sensitive areas

The shear stress values at small thickness of the rail web are under the critical stress value for rail type P49E1, but for thicknesses under 4.0 mm a stress concentration in the vicinity of the holes is observed, which could lead to metal fatigue, cracking and as a result – damage to the sensor. While the rail web thickness is between 4.0 and 8.0 mm, the stress concentration around the holes does not influence the stress state in the zones where the strain-gauge rosettes are installed.

4 Technology of polymerization of the strain-gauge rosettes

The process of polymerization of the strain-gauge rosettes is carried out in a low temperature chamber with a maximal temperature of 170°C. As the force sensor of rail type is positioned vertically in the chamber, the installation zones of the rosettes are conventionally marked as lower and upper. Forced ventilation ensuring internal circulation of heated air is used. As shown in Fig. 9, after initial heating to about 80°C (taking 1 hour) heaters are switched off, which allows to keep the temperature in the range 60°C ÷ 80°C for about 2 hours and 45 minutes. Then heaters are switched on again for about 3.5 hours, followed by switching off for 45 minutes and switching on for about 45 minutes last. Polymerization of strain gauge rosettes is obtained at temperatures above 130°C for not less than 5 hours.

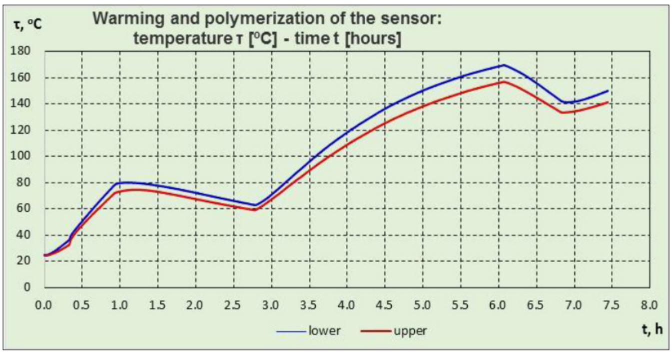

Figure 9 Diagram of polymerization of strain-gauge rosettes

5 Results

Results from the finite element analysis of the force sensor of rail type are shown on Fig. 10. As it is shown, the point of applying the force is slightly moved to the right of the center of the sensor of rail type. It is clear how the stress values of the left and the right sensitive areas differs and the closer the force is to the corresponding area, the higher the stresses are there.

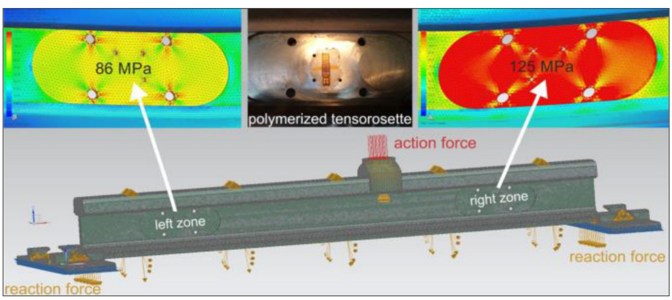

Figure 10 Stress states of left and right sensitive areas with asymmetric force application

A study on the sensor carried out by changing the point of applying force measured along the length of the sensor within ±350 mm from the center has been performed. The signal measured in the left and right sensitive areas and totally for the sensor as well as deviation of measured values from mathematical expectation in the sensor sensitivity are shown in Fig. 11. It was found that within ±200mm from the sensor center the deviation of the measured values from mathematical expectation (err) varies from -0.2% to +0.4%. Therefore the accuracy of measurement in the so-defined area of sensor sensitivity is ensured. Fig. 12 shows the newly-developed advanced force sensor of rail type.

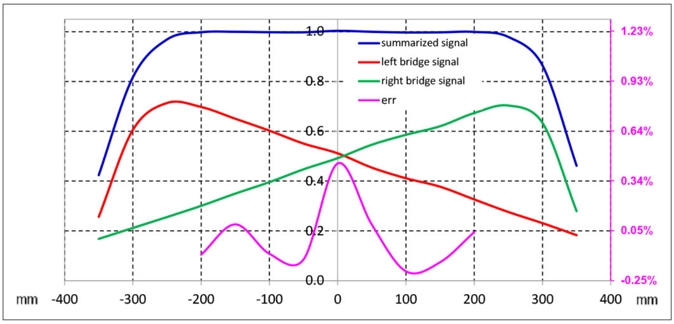

Figure 11 Diagram of polymerization of strain gauge rosettes

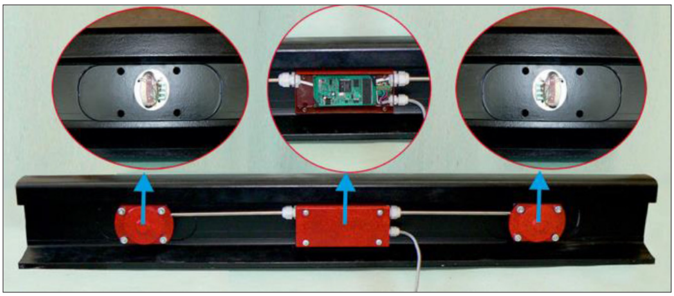

Figure 12 General appearance of the force sensor of rail type

6 Conclusion

It should be noted that the objectives of this study have been fully achieved. An advanced specialized force sensor of rail type intended to measure the vertical load on wheels of rail vehicle in motion at operating speed is designed. The sensor metal structure is optimized and strength-strain state is examined with varying geometric parameters and different modes of loading. New technology for management and control on the process of polymerization of strain-gauge rosettes is developed. The force sensor has been tested under laboratory conditions and is fit for implementation in wayside monitoring systems in practice.

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