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ANALYSIS OF INDUCTIVE SENSOR FIXING CLAMP IN RAILWAY APPLICATIONS

Barbara Schürger
Technical University of Košice, Faculty of Mechanical Engineering, Institute of Design Machine and Process Engineering, Department of Applied Mechanics and Mechanical Engineering, Letná 9, 042 00 Košice, Slovak Republic, EU, barbara.schurger@tuke.sk

Michal Kicko
Technical University of Košice, Faculty of Mechanical Engineering, Institute of Design Machine and Process Engineering, Department of Applied Mechanics and Mechanical Engineering, Letná 9, 042 00 Košice, Slovak Republic, EU, michal.kicko@tuke.sk

Vojtech Neumann
Technical University of Košice, Faculty of Mechanical Engineering, Institute of Design Machine and Process Engineering, Department of Applied Mechanics and Mechanical Engineering, Letná 9, 042 00 Košice, Slovak Republic, EU, Vojtech.Neumann@grob.de

Peter Frankovský
Technical University of Košice, Faculty of Mechanical Engineering, Institute of Design Machine and Process Engineering, Department of Applied Mechanics and Mechanical Engineering, Letná 9, 042 00 Košice, Slovak Republic, EU, peter.frankovsky@tuke.sk (corresponding author)

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Abstract: This paper provides static, modal and dynamic analysis of the assembly consisting of fixing clamp, inductive sensor, two fixing bolts and frame applied on railway stock. All the necessary tests to perform this analysis are in accordance with the standard EN 61373: 2010 or the Slovak standard STN EN 61373: 2011. In the next part, a simulation of the tests required for the dynamic analysis of the modelled assembly is performed. For each analysis, von Misses stress is evaluated and then compared to the yield strength of used material. Finally, this work provides a proposal for new design solutions of the fixing clamp based on the obtained results. All analyses were performed in ANSYS Workbench programme using finite element method.

1 Introduction

The rising standard of living increasing demands on the creation of optimal product design regarding the amount of time, money and material used. With the help of computer software, we can combine knowledge from several scientific disciplines, and thus create methods of solution and analysis in order to create the most optimal design solution [1]. Such solutions are particularly important in the areas of dynamic stress, to which the components on rolling stock are exposed as a result of their operation on railways. The force effect of dynamic loading varies in both magnitude and direction, and the nature of these changes affects how reliably the component will operate until the end of its expected life.

The aim of this paper was a dynamic analysis of the clamp fixing the OsiSense XS inductive proximity sensor from Telemecanique Sensors. This line of sensors provides functional and easy-to-install sensors that help to create much safer operation of the rolling stock.

2 Railway application

The sensors (Figure 1) with their fixing clamp applied to rolling stock are subjected to a deterministic harmonic load during operation as the railway wagon moves on smooth rails.

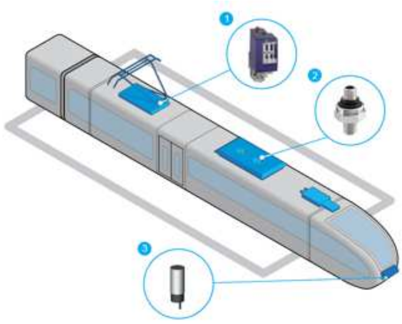

Figure 1 Types of sensor used in railway applications

For this reason, these parts must be subjected to the tests defined in standard EN 61373: 2011. This International Standard specifies requirements for the testing of components for use on railway vehicles that are subsequently exposed to vibration and shock due to the operating environment of the railway.

To ensure that the quality of the element is acceptable, it must withstand tests of a reasonably long time that simulate conditions throughout its expected life.

The test simulations were performed according to the procedures defined in the standard [2], specifically for two categories that were required in advance for fixing clamp analysis:

- **Category 1, Class B:** equipment mounted on the body of the rolling stock,
- **Category 2:** equipment mounted on the bogie of a rolling stock.

Table 1 Engineering data: Material properties

	Structural Steel 13 240	***Aluminium Alloy 6061***	***Plastic ABS***
Density (kg.m^{-3})	7850	2770	1050
Young's Modulus (MPa)	$2,1.10^5$	$0,71.10^5$	$0,024.10^5$
Poisson's Ratio (-)	0,3	0,33	0,4078
Tensile Yield Strength (MPa)	250	164,8	36,13
Tensile Ultimate Strength (MPa)	460	246,1	38,73

Furthermore, it was necessary to define the individual excitation directions, namely:

- **Transverse direction:** in the direction of the X axis.
- **Longitudinal direction:** in the direction of the Y axis.
- **Vertical direction:** in the direction of the Z axis.

The aim of the research was to perform numerical simulations of random vibration tests and shock tests of a fixing clamp made of 3 different materials.

The basic model of fixing clamp is made of structural steel, while 2 other materials were designed during optimization, namely aluminium alloy 6061 (more expensive, but lighter than steel) and plastic Acrylonitrile-butadiene-styrene (cheaper and lighter than steel). Material properties of used materials are defined in Table 1.

3 Problem definition

The aim of the work was to perform numerical simulations of random vibration tests and impact tests, which are defined by the standard EN 61373: 2011 for equipment mounted on rail vehicles. In order to assess the quality of a component, it is necessary for the component to withstand, for a reasonable period, tests simulating the operation of the vehicle over its expected service life [3].

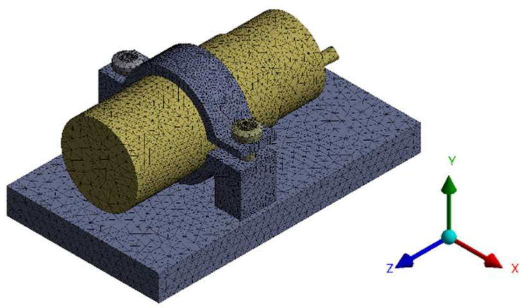

Figure 2 Analysed assembly

In the ANSYS Workbench program, a model of the fixing clamp with a sensor OsiSense XS, fixing bolts M5x40 and a frame was built. Then the model was discrete by quadratic hexagonal finite elements (Figure 2). Dimensions of the sensor and mounting bracket were given by the manufacturer.

4 Static analysis

After creating the finite element network, a static analysis was performed on the original structural steel. In the first step of the static calculation the fixed support and the bolt pretension was defined by calculating axial forces (1) based on the formula [4]:

$$F = \frac{M}{k.d} = \frac{2,68}{0,2.5.10^{-3}} = 2680\ N \qquad (1)$$

where M is maximum torque required to tighten the screw, k is material constant and d is nominal diameter of the bolt thread.

In the next step, we analysed the maximum deformations and stresses.

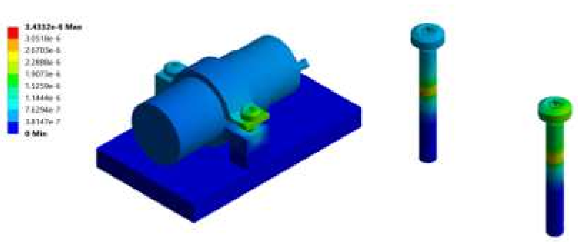

Figure 3 Total deformation of the assembly

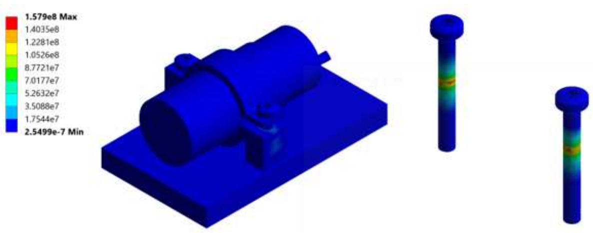

Figure 4 Von Misses stresses of the assembly

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The largest deformations occur at the outer face of the bolts, where they reach a value of 0.0034 mm (Figure 3). The stress concentration occurs at the outer face of the bolts where they reach a value 157,9 MPa (Figure 4).

Static analysis provided required data for further modal analysis [4].

5 Dynamic analysis

5.1 Modal analysis

This analysis is one of the most widely used types of dynamic analysis. According to the author [5], we can characterize it as a part of dynamics, which defines modal parameters and dynamic behaviour of structures.

If we assume the linear behaviour of the material, then the basic equation of motion of the dynamic analysis will be in the form of a system of linear differential equations of the second order in the matrix form (2):

$$[M]\{\ddot{u}\} + [C]\{\dot{u}\} + [K]\{u\} = \{F\} \quad (2)$$

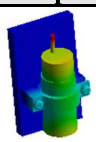
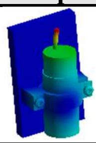
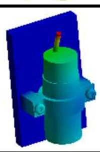
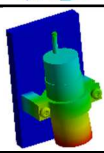
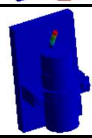
In the case of modal analysis, we neglect both external load and viscous attenuation, so we can write equation (2) in the form (3) [6]:

$$[M]\{\ddot{u}\} + [K]\{u\} = 0 \quad (3)$$

The results of the modal analysis in the form of mode shapes with the corresponding natural frequency for the original structural steel model are in Table 2.

Comparison of the natural frequencies results for all three applied materials are shown in Figure 5.

Table 2 Results of modal analysis

	ω (Hz)	Mode shape		ω (Hz)	Mode shape
1.	1701		2.	3905	
3.	4520,7		4.	4820,4	
5.	6367		6.	7606,5	

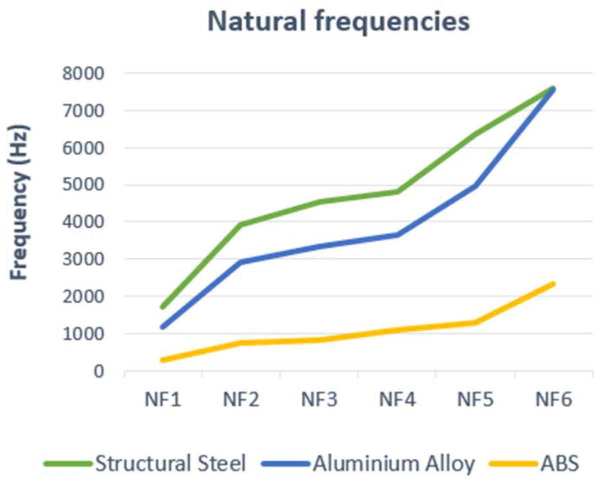
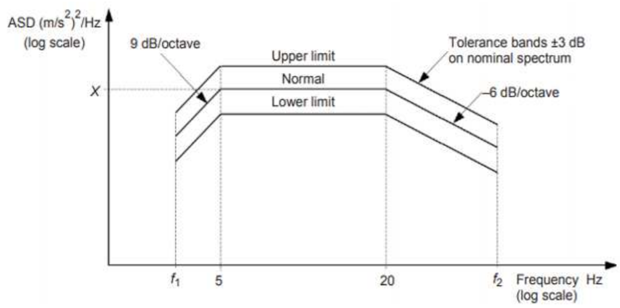


Figure 5 Natural frequencies of the assembly

The performed modal analysis determined the first six mode shapes with corresponding natural frequencies. These first six modes are enough to perform further analyses as it provides input information for both the random vibration testing and the shock testing [7-20].

5.2 Random vibration testing

To simulate the tests, linear dynamic calculations were performed in a predefined frequency range [2].



		Direction		
		X	Y	Z
Category 1B	Functional test ASD level (m/s²)²/Hz	0,0060	0,0144	0,0301
	Effective value m/s²	0,45	0,70	1,01
Category 2	Functional test ASD level (m/s²)²/Hz	0,144	0,0414	0,190
	Effective value m/s²	4,70	2,50	5,40

Figure 6 Parameters of random vibration testing [2]

This range was used to obtain vibration responses caused by random vibration excitation. This excitation was defined by accelerated power spectral density (ASD) curves with the prescribed frequency range and root mean square spectrum values given in the standard [2].

All values used in excitation process with the corresponding course of the graph are shown in the Figure 6.

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5.2.1 Results

The result of the random vibration tests for Category 1B (Table 3) and Category 2 (Table 4) are the RMS von Mises fields with the specific values given in the tables.

Table 3 Random vibration testing: Results for category 1B

Direction	Structural Steel 13 240	Aluminium Alloy 6061	Plastic ABS
X_norm. (MPa)	0.0053682	0.0052499	0.034317
X_incr. (MPa)	0.009758	0.0061394	0.051746
Y_norm. (MPa)	0.0095404	0.0095111	0.025356
Y_incr. (MPa)	0.015117	0.013135	0.080164
Z_norm. (MPa)	0.021856	0.018751	0.1159

Table 4 Random vibration testing: Results for category 2

Direction	Structural Steel 13 240	Aluminium Alloy 6061	Plastic ABS
X_norm. (MPa)	0.055436	0.054317	0.35735
X_incr. (MPa)	0.10098	0.063717	0.58978
Y_norm. (MPa)	0.034331	0.034	0.090949
Y_incr.. (MPa)	0.053884	0.046807	0.31477
Z_norm. (MPa)	0.11617	0.073302	0.67856

The results are given for the X direction, the Y direction and the Z direction. The highest effective excitation value occurring in the vertical Z direction. This value is then also used for the transverse direction X and the longitudinal direction Y as an increased excitation level [2].

The comparison of the results of the maximum reduced stress values for all three materials and for each direction are shown in Figure 7 for Category 1B and in Figure 8 for Category 2, evaluating the state where the value of maximum reduced stresses is greater than the yield strength of the material used.

Such a condition is considered unsatisfactory because undesired deformations are expected.

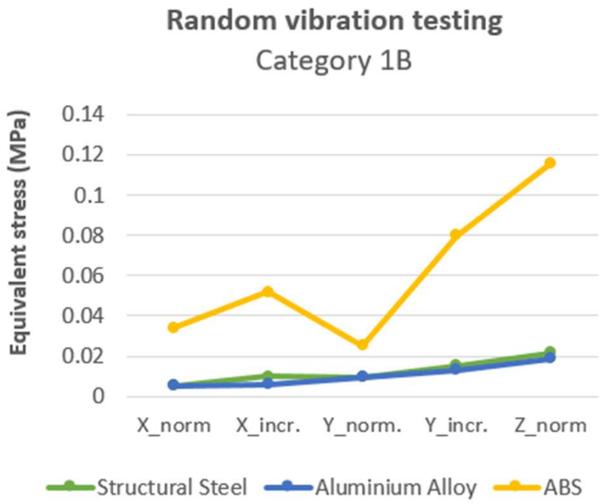

Figure 7 Random vibration testing: Comparison of the results for Category 1B

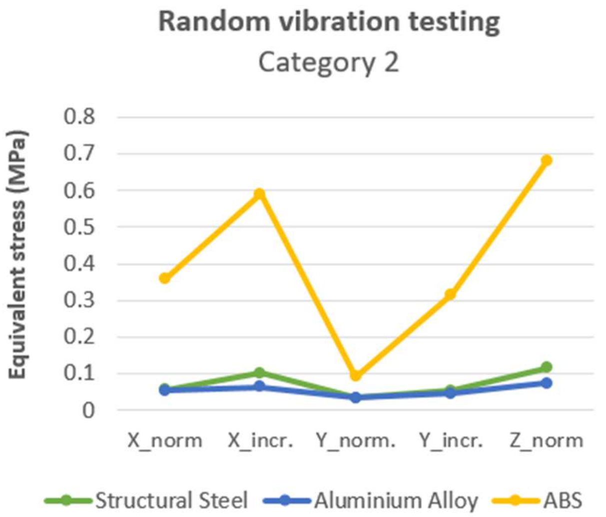

Figure 8 Random vibration testing: Comparison of the results for Category 2

It is clear from the results that the yield strength was not exceeded in any direction of stress for individual materials, so we can say that the item under test conformed with the performance tests after the vibration testing identified in standard [2].

5.3 *Shock testing*

To simulate the tests, linear dynamic calculations were performed in a predefined time domain, which were used to obtain vibration responses during shock excitation. This excitation was defined by acceleration time courses using three positive and three negative pulses and the time required for the responses to subside. It was also necessary to define the amplitude and width of the pulses (Figure 9).

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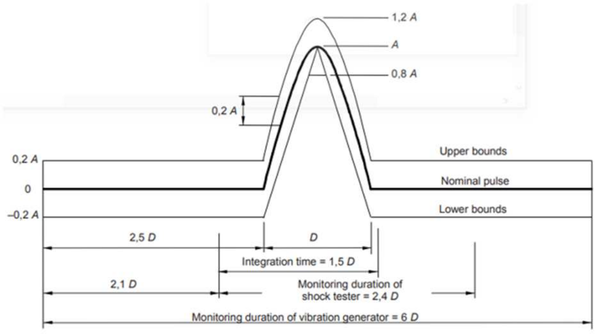

		Direction		
		X	Y	Z
Category 1B	Peak acceleration (m/s²)	30	50	30
	Nominal duration (ms)	30	30	30
Category 2	Peak acceleration (m/s²)	300	300	300
	Nominal duration (ms)	18	18	18

Figure 9 Parameters of shock testing [2]

5.3.1 Results

The result of the shock tests for Category 1B (Table 5) and Category 2 (Table 6) are the RMS von Mises fields with the specific values given in the tables.

Table 5 Shock testing: Results for category 1B

Direction	***Structural Steel 13 240***	***Aluminium Alloy 6061***	***Plastic ABS***
X_norm. (MPa)	0.0005067	0.0006767	0.020885
X_incr. (MPa)	0.0008445	0.0011279	0.034808
Y_norm. (MPa)	0.0011277	0.0014311	0.086949
Z_norm. (MPa)	0.0036982	0.003909	0.19823
Z_incr. (MPa)	0.0061636	0.006515	0.33038

Table 6 Shock testing: Results for category 2

Direction	***Structural Steel 13 240***	***Aluminium Alloy 6061***	***Plastic ABS***
X_norm. (MPa)	0.0064913	0.00883	0.68591
Y_norm. (MPa)	0.010594	0.019368	0.4245
Z_norm. (MPa)	0.060216	0.10024	2.6137

The results are given for the X direction, the Y direction and the Z direction, with the highest excitation effective value occurring in category 1B in the longitudinal direction Y. This value is then also used for the transverse direction X and the vertical direction Z as an increased excitation level. For category 2, the effective excitation values are the same in all directions [2].

The results of the maximum reduced stress values for all three materials and for each direction are shown in Figure 10 for Category 1B and in Figure 11 for Category 2, evaluating the state where the value of maximum reduced stresses is greater than the yield strength of the material used. Such a condition is considered unsatisfactory because undesired plastic deformations are expected.

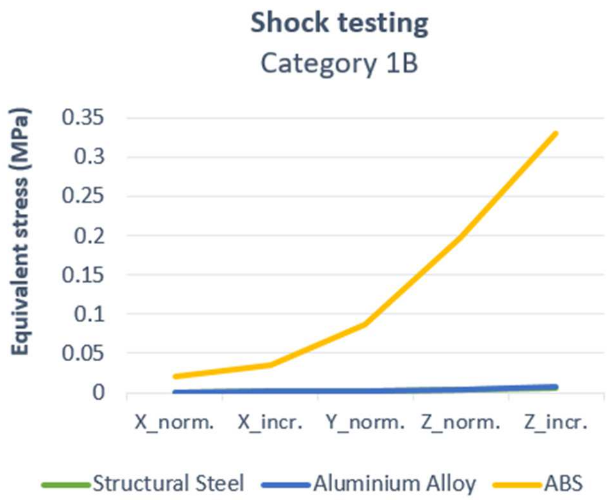

Figure 10 Shock testing: Comparison of the results for Category 1B

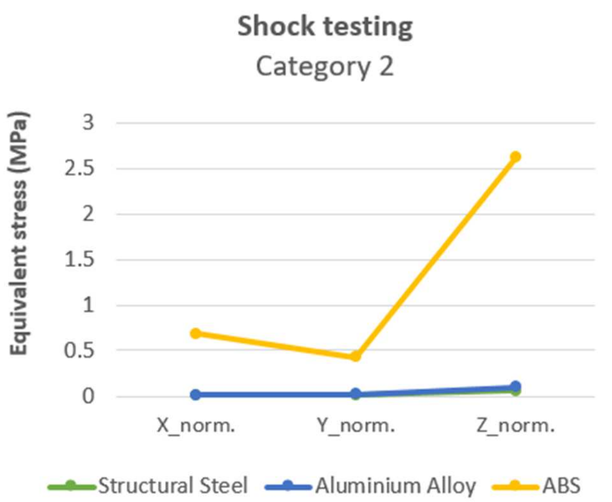

Figure 11 Shock testing: Comparison of the results for Category 2

It is clear from the results that the yield strength was not exceeded in any direction of stress for individual materials, so we can say that the item under test conformed with the performance tests after the vibration testing identified in standard [2].

6 Conclusion

The topic of this article was the dynamic analysis of the sensor OsiSense XS mounting bracket in accordance with the standard EN 61373: 2010.

The aim of the analysis was to assess the suitability of the bracket design. In developing this issue, theoretical knowledge about the finite element method and the subsequent use of the optimization process to improve the final design of the solution were used.

By evaluating the results of the maximum reduced stresses obtained in the random vibration tests as well as in the shock tests, it is obvious that neither material has reached its yield strength. Therefore, all three material designs meet the standard. However, in terms of weight and economic aspect, the best design is the mounting bracket model made of ABS Plastic, which, despite its low specific weight, is an extremely durable material and therefore met all testing parameters [3-20].

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