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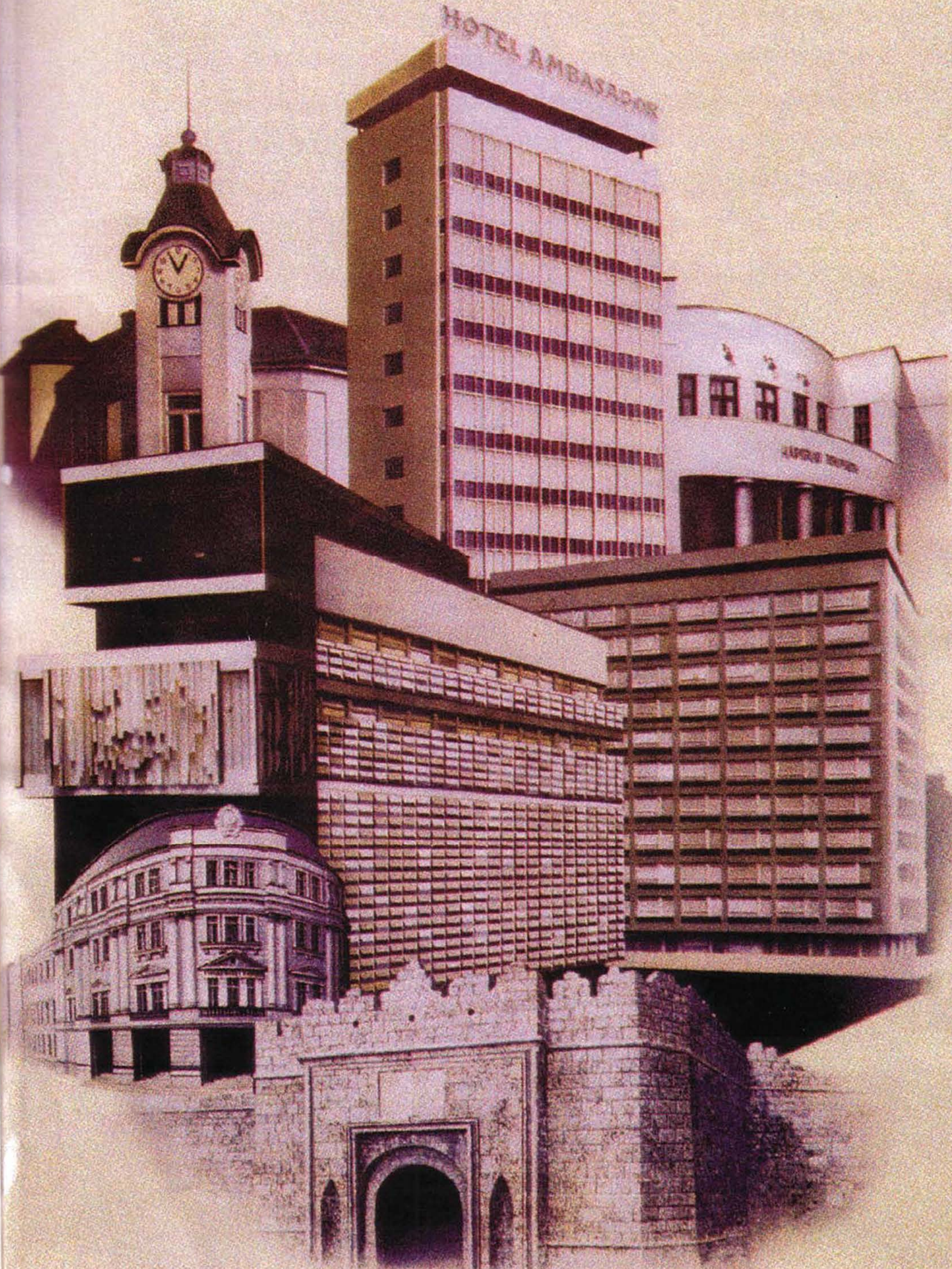
HOTEL AMBASADOR

XIX SCIENTIFIC-EXPERT CONFERENCE ON RAILWAYS RAILCON '20

DEVELOPING ADVANCED SUBSYSTEM FOR SECURING STEEL COIL CARGO ON SHIMMNS WAGON CRADLES

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Abstract *– In this paper design improvement on assembly used for securing steel coils on Shimmns wagon is presented. The main disadvantage of current solution is that it is very slow for securing coils with smaller width, since safety mechanism is positioned manually for each coil. We needed to solve this issue without compromising function and reliability of the current locking mechanism. In the current design spindle rotation causes coupled movements of securing arms which constrain lateral movement of coils by applying significant force, but if the coil is not adequately centered, the arms on one side will not come in the contact with the coil, as arms on both sides are coupled on the same spindle and are moving symmetrically. The Finite Element Method is used to analyze the new solution and verify that it meets all the safety requirements prescribed in the standards. The improvement of existing solution is done with the half-nut mechanism which enables arbitrary, decoupled initial positioning of arms and clamping with threaded spindle when the arms are brought in contact with the coil. The new solution is implemented, and has proven to be practical and reliable in the exploitation.*

***Keywords* – Shimmns wagon, Steel coils, Securing mechanism, FEM analysis**

1. INTRODUCTION

The Shimmns freight wagons are used for transportation of steel coils which can vary in diameter, width and weight. These coils are placed into five cradles, and each coil is fixed using four securing arm subsystems. Proper positioning and secure fastening of these coils are essential for safety during the exploitation. During their lifetime, Shimmns wagons are subjected to different forces and strains, and must be able to withstand a wide range of load cases defined in the standards. Particular standards used are TSI [1] and BS EN 12663-2 [2]. Currently, each coil is secured manually, which is a slow process performed on many wagons, so the efficiency of this securing subsystem needed to be increased.

3D CAD model of the securing mechanism is created using provided technical documentation, and the numerical analysis of the worst case scenario, according to standards [1] and [2] was performed using the Finite Element Method (FEM) [3]. FEMAP software [4] is used as pre and post-processor for the FEM mesh generation and display of the results. FEM analysis was performed using NX Nastran solver, which is built in FEMAP. The results show that the maximum calculated stress is below permissible stress, and based on these conclusions, modifications to existing wagons were performed. The upgraded wagons perform well in the exploitation, and the new securing mechanism behaves like predicted.

In the next section, we will describe the loading of analyzed Shimmns wagon, and show the required service (fatigue) load case that wagon securing arms need to withstand. After that, we will describe in detail FEM model of this assembly, and will present analysis results. Based on these results, we will draw a conclusion that the proposed new design is safe for the exploitation, which is proven on the real wagons.

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2. THE SHIMMNS WAGON LOADING

A technical description of four-axle bogie wagon type Shimmns is given in [5]. The wagon is designed for transportation of sheets coils that are loaded in the horizontal position onto five cradles. The maximum total weight of all steel coils combined is 68 tons. This weight can be achieved using different combinations of coil width and diameter, but for the purpose of analysis of the assembly for coil securing, we must consider the worst case scenario [6], which is shown on Fig. 1.

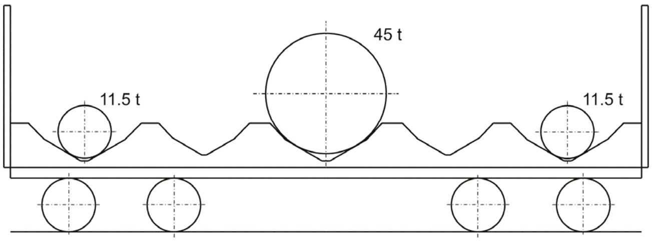

Fig.1. Big coil in the middle, smaller on front and back cradle

In this load case, a coil weighing 45 tons, which is the maximum coil weight, is placed in the middle crate, so redesigned securing mechanism must hold this big coil firmly secured to the wagon structure. Service (fatigue) loads of securing pin assembly in lateral direction are specified by TSI [1] and BS EN 12663-2:2010 [2], Clause 5.2.5.1, Tab. 13. Loading scheme of securing pin assembly is shown in Fig. 2.

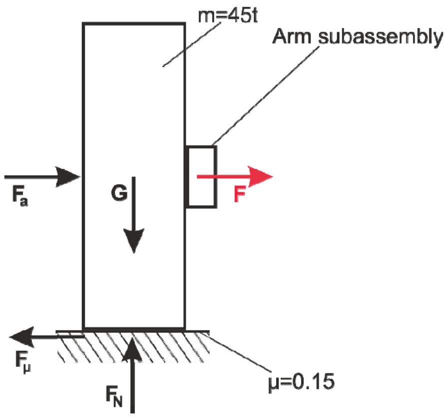

Fig.2. Scheme of model loading

According to loads shown in the previous figure and friction coefficient (steel-steel, lubricated and greasy) according to [7], forces acting on the coil are given in the next table.

Tab. 1. Forces acting on the largest coil (45 t)

G=mg=450 kN	F_a=0.2 m g=90 kN
F_N=G=450 kN	F_μ=μ F_N=67.5 kN
F=F_a- F_μ=22.5 kN	F_1=F_2=F/2=11.25 kN

Force in the lateral direction is divided in two equal parts F_1 and F_2 acting on two arm mechanisms.

3. FEM MODEL OF SECURING ARM SUBSYSTEM

The securing arm mechanism of the Shimmns wagon is shown in Fig. 3.

Fig.3. Securing arm on Shimmns wagon

This assembly is modeled in 3D and analyzed using FEM [4], in order to test the proposed modifications. The new design enables fast decoupled movement of securing arms, and when the arms are in contact with the coil, the mechanism can be used to lock the half-nut with the housing firmly gripping the spindle. Now operators can manually rotate the spindle to tighten the clamp of securing arms on the coils. The FEM model of the whole securing arm assembly is shown in Fig. 4. viewed from the upside down for the best details.

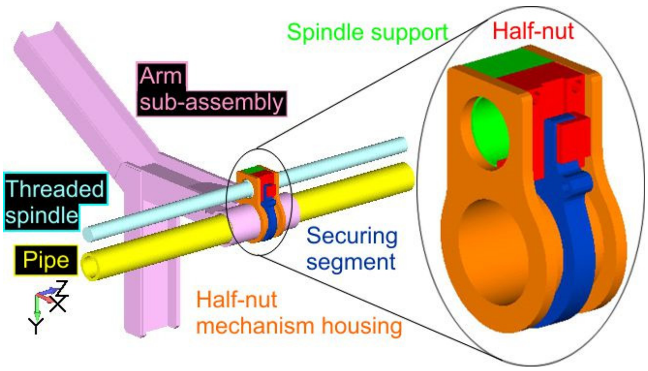

Fig.4. Securing arm assembly

The assembly consists of arm subassembly, pipe, threaded spindle, securing segment, half-nut housing and half-nut, which are shown in Fig. 4.

The arm subassembly, pipe, securing pin and segment, as well as half-nut mechanism housing, are all made of steel S355J2+N (same as the most of the Shimmns wagon). Threaded spindle is made of steel C45E. The Half-nut is made of steel 42CrMo4. The physical properties of steel are given in Tab. 2.

Tab. 2. Physical properties of steel

E [N/mm^2]	ρ [kg/mm^3]	ν
$2.10 \cdot 10^5$	$7.85 \cdot 10^{-6}$	0.3

The values in Tab. 2. are the same for all 3 steels, however, their mechanical properties are significantly different, which can be seen in Tab. 3.

Tab. 3. Mechanical properties of used materials

Nominal thickness, or diameter t [mm], d [mm]	Minimum yield strength, R_{eH} [MPa]	Tensile ultimate strength, R_m [MPa]
S355J2+N		
t≤16	355	470-630
C45E (+QT)		
t≤8, d≤16	490	700-850
42CrMo4 (+QT)		
t≤8, d≤16	900	1100-1300

According to the construction type, 3D elements (tetrahedral elements with midside nodes and linear hexahedral) were used for creating the FEM mesh, Fig. 5. to Fig. 9. The assembly is modelled in details with 397374 nodes and 286981 elements in total. Tab. 4. shows number of nodes and elements per part.

Tab. 4. Number of elements and nodes foe each part

Subassembly name	Number of elements	Number of nodes
Arm subassembly	99492	139992
Pipe	22080	33264
Segment	4898	6801
Threaded spindle	103765	135067
Half-nut housing	30520	38611
Half-nut	26221	42635

Designing the new securing mechanism required special attention to be paid to contacts. The contact between arm sub-assembly and pipe occurs in two places (highlighted blue), Fig. 5.

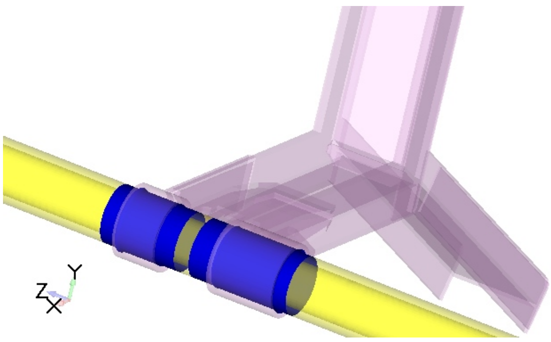

Fig.5. Pipe-arm sub-assembly contact

Since these are just two parts, we could define just one contact pair, however the contact surface would be much greater and calculation time slower, so we defined two contact pairs for pipe arm sub-assembly contact. The entire FEM model contains 25 contact pairs, which is the result of our attention to detailed modelling, focused on both the accuracy, and the analysis time. Fig. 6. shows one of the most crucial contact pairs between threaded spindle, and half-nut.

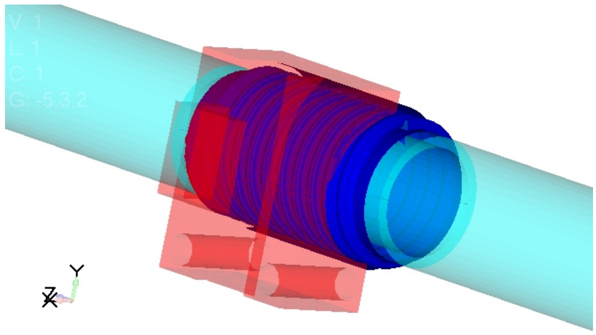

Fig.6. Contact between spindle and half-nut

Two contacts between the half-nut and the spindle support are shown in Fig. 7.

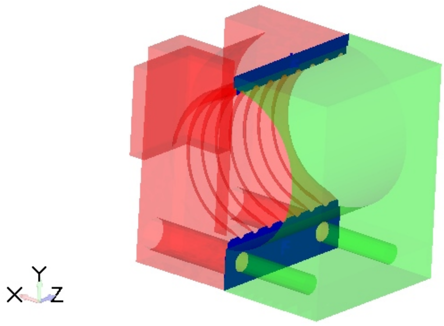

Fig.7. Half-nut spindle support contact

4. FEM ANALYSIS RESULTS

Within the calculation there is a system of two million and four hundred thousand equations being solved. Results show that for every part calculated stress is under permissible stress give in Tab. 3.

For arm subassembly maximum Von Mises stress of 292.9 MPa is shown in Fig. 8.

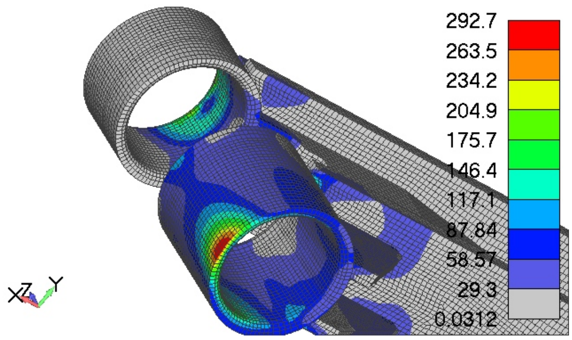

Fig.8. Significant loading zone of arm sub-assembly

Fig. 9. shows Von Mises stress for half-nut housing.

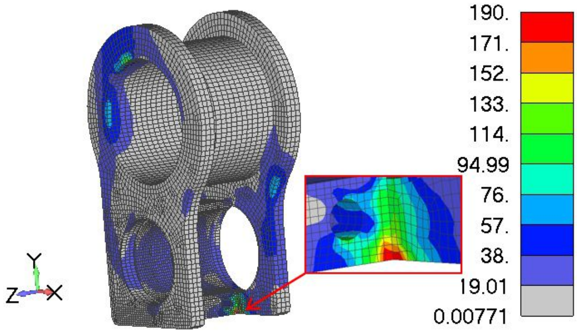

Fig.9. Von Mises stress field – half-nut housing

In case of spindle, the maximum Von Mises stress is 328.1 MPa as seen in Fig. 10., which justifies the usage of stronger, more expensive material C45E.

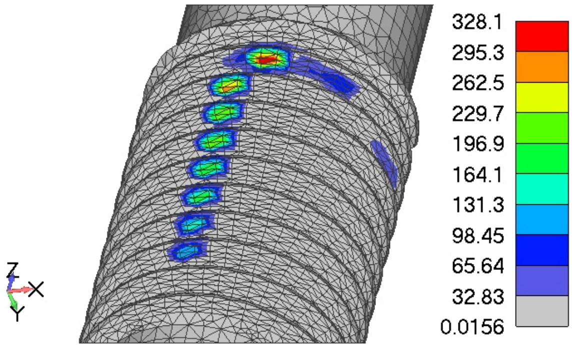

Fig.10. Von Mises stress field – spindle

The most loaded part is the half-nut, which is made of 42CrMo4 so it can withstand maximum calculated stress, shown in Fig. 11.

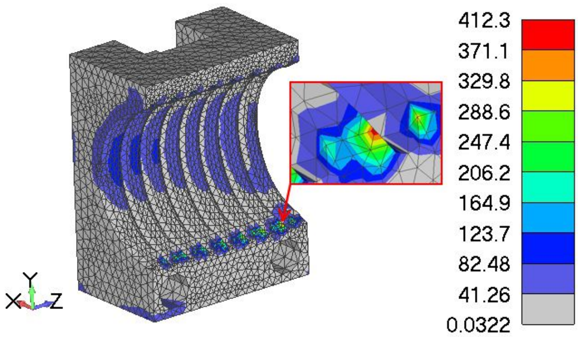

Fig.11. Maximum Von Mises stress half-nut

Half-nut mechanism displacement in the x direction is shown in Fig. 12.

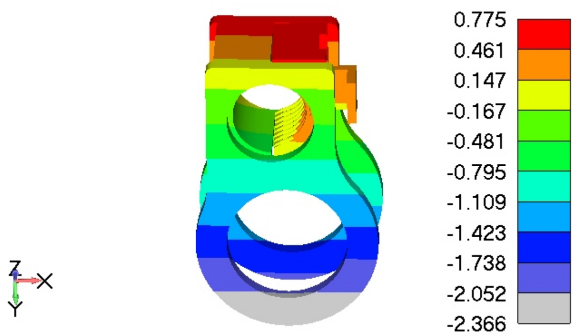

Fig.12. Half-nut mechanism displacement

Fig. 13. shows in more detail the transversal displacement between the half-nut and the spindle support. This displacement is small enough not to cause the mechanism malfunction or failure.

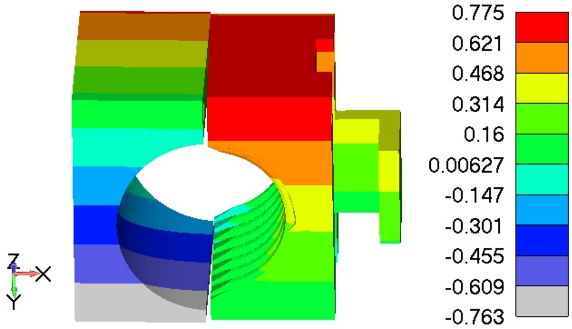

Fig.13. Half-nut and support x displacement

5. CONCLUSION

Based on the results of the FEM analysis described in the previous section, the securing mechanism for Shimmns wagon needed to be made out of 3 different steels in order to withstand service (fatigue) load defined in [1] and [2]. Calculated displacements do not affect functionality of analyzed mechanism.

This solution is already implemented on existing wagons in service, thus improving their functionality and ergonomic quality.

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