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RANDOM VIBRATION ANALYSIS OF THE RAILWAY OBSTACLE DETECTION SYSTEM DEMONSTRATOR HOUSING

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Abstract *–The paper presents random vibration analysis of the railway obstacle detection system (ODS) housing developed in the frame of S2R project SMART. In order to mount obstacle detection system demonstrator onto the vehicle, it was necessary to prove that the demonstrator housing satisfies the demands EN 61373:2010 standard for a Category 1 Class B device. The noted was performed by a numerical analysis of the obstacle detection system demonstrator, according to the demands of EN 61373:2010 standard. The analysis was performed by week coupling of static structural, modal and random vibration analysis. The random vibration analysis results were checked with fatigue analysis to assess the service life of ODS housing components for increased vibratory load. The results of the analysis show that the housing meets the requirements set by the railway EN 61373:2010 standard for a Category 1 Class B device.*

Keywords – Railway Obstacle Detection, Random Vibration Analysis, EN 61373:2010 standard

1. INTRODUCTION

Prototype solution for Obstacle Detection System (ODS) at mid-range (up to 200m) and long range (up to 1000m) was developed in the frame of project SMART (http://www.smartrail-automation-project.net) as a prerequisite for Autonomous Train Operation (ATO). A novel integrated multi-sensor on-board ODS for freight trains combines different vision technologies to identify obstacles up to 1000m. The obstacle detection system sensors are mounted into device housing for different evaluation tests in static and moving vehicles.

Fig.1. CAD model of the ODS housing

To obtain permits for evaluation it was necessary to prove that ODS demonstrator housing (Fig.1) is resistant to vibrations and it is designed to satisfy requirements by EN 61373:2010 – Rolling stock equipment – Shock and vibration tests for a Category 1 Class B device.

The simulation was performed as random vibration simulation in ANSYS Workbench 19.2 [2] software according to the demands of EN 61373:2010 as well as by the same procedures defined by standard. According to the noted standard, the housing must sustain increased vibratory loads which simulate service conditions for a period of 5 hours which correspond to normal service life of vehicle (25 years) [3].

For a Category 1 Class B device Table 1 defines the Acceleration Spectral Density (ASD) values, while Figure 2 defines frequency range which should be used during testing.

To complete above mentioned random vibration analysis, it is necessary to preform four linked analysis in ANSYS software. The first analysis is used to determine stress-strain state of the housing during normal service load and its deformed shape when subjected to service loads. In the second step, the modal analysis is performed for a deformed shape (under service loads) of ODS housing in order to determine primary natural frequencies. In the third

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step a random vibration analysis is performed to determine the stress-strain state under increased vibratory load and finally a fatigue analysis is performed in order to assess the service life of ODS housing components for increased vibratory load.

Tab. 1. ASD and RMS values for simulated long life testing at increased vibration levels for a Category 1 Class B device [4]

	Vertical	Transverse	Longitudinal
Long life ASD level $(m/s^2)^2/Hz$	6.12	4.62	1.32
RMS value 2 to 250 Hz	30.6	26.6	14.2

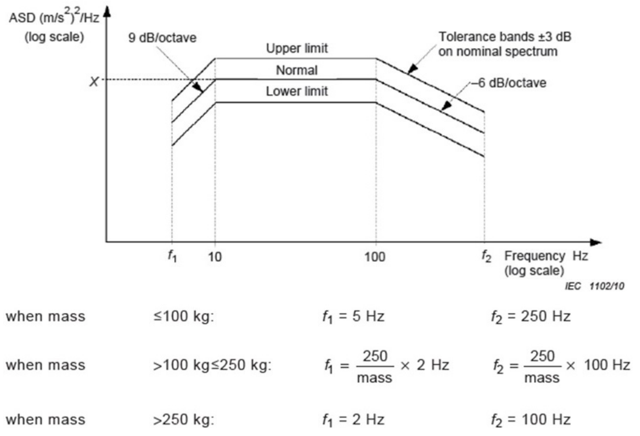


Fig.2. Frequency range for simulated long life testing at increased vibration levels for a Category 1 Class B device [3]

2. RANDOM VIBRATION ANALYSIS

To perform all above mentioned analyses firs it was necessary to prepare the FEM model. In order to prepare the noted FEM model internal components and sensors were removed from the geometrical model as they were not a subject of analysis. According to the standard EN 61373 the internal components of the housing mounted on a vehicle body are not tested as they cannot fall of the vehicle as they are already located in protective case (housing). The ballasts used to increase the mass for vibration isolation purposes were added to the model of the housing.

The reduced geometric model of the redesigned housing was transformed into the discretized Finite Element Model FEM with the application of advanced meshing tools. The discretized model consisted of 2661038 nodes, forming 510620 finite elements.

Connection between ODS housing parts were taken as bonded as they are joined by bolted connections or by welding which corresponds to noted contact condition. The contact stiffness was updated in every simulation iteration and the contacts were defined by a pure penalty method. All contacts were treated as asymmetric to avoid errors in calculation of contact parameters.

The materials were assigned to the model components according to the design documentation. In total four materials were used:

- steel S355J2GR for all housing elements made as sheet metal components and stiffening profiles,
- aluminium for a sensor rail
- tempered glass for transparent protective windows
- germanium glass for thermal camera protective window.

Material properties were taken from GRANTA material database which is a part of ANSYS 19.2 software [2]. Stress-strain properties of material S355J2G3 were defined with isotropic bilinear hardening in order to more accurately obtain stress state of reliefs (which are characteristic to sheet metal parts) as stress concentrations due to analysis singularity are expected in noted areas.

Figure 3 show the deformed shape of the ODS housing in static structural analysis. The maximal deformation is approximately 0.3 mm which is well below the critical limit.

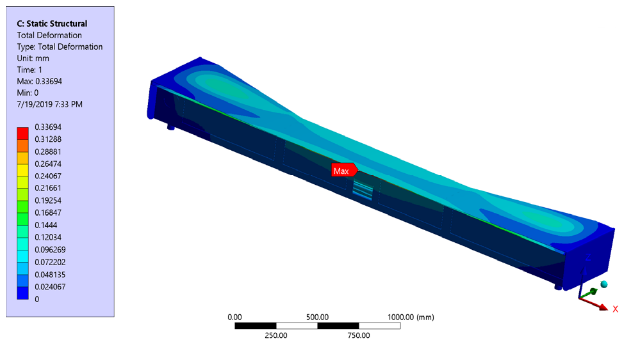


Fig.3. Deformed state of ODS housing

Figure 4 shows the equivalent stress in static structural analysis. The maximal stress is approximately 37MPa which is well below allowable stress for steel S355 J2G3 (355 MPa).

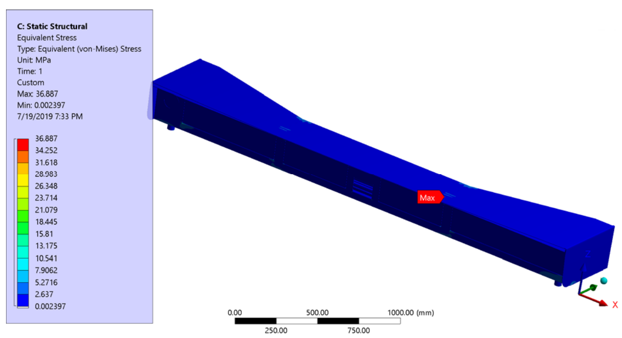


Fig.4. Equivalent stress of ODS housing

Based on preformed static structural analysis it can be concluded that the housing has a satisfactory stiffness and that when subjected to loads, stress and deformations are significantly below the allowable ones.

The second step was to perform a modal analysis of the deformed shape of ODS housing. The modal analysis was performed in range between 0 and 200 Hz. Figure 5 show the natural frequencies of the redesigned ODS housing.

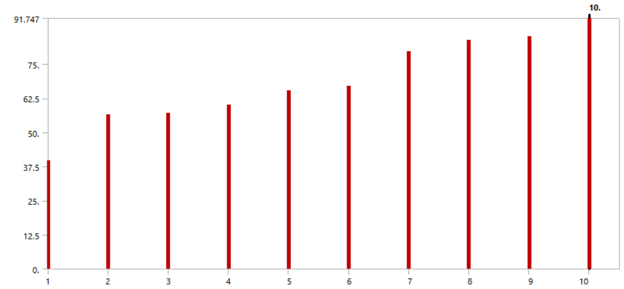
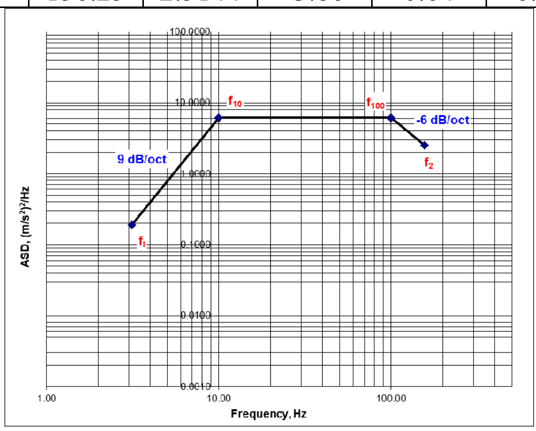


Fig.5. The ODS redesigned housing natural frequencies determined by modal analysis in the loaded state

The modal results were transferred to random vibration analysis. The random vibration analysis was performed by exciting the fixed supports defined in static structural analysis with vibration load in vertical, transverse and longitudinal directions as defined in Table 1. For a housing mass of 160 kg with ballasts installed, the limiting frequency were calculated and ASD curves were formed for all three loading directions as shown in Tables 2-4.

Tab. 2. ASD load at base excitation in vertical direction

Frequency, Hz		ASD, $(m/s^2)^2/Hz$	dB	OCT	dB/OCT (Slope)
f_1	3.13	0.1889	*	*	*
f_{10}	10.00	6.1200	15.11	1.68	9.00
f_{100}	100.00	6.1200	0.00	3.32	0.00
f_2	156.25	2.5144	-3.86	0.64	-6.00

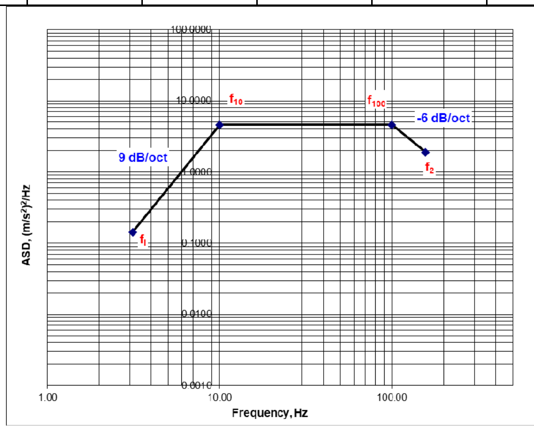


Figures 6-8 show the 1σ, 2σ and 3σ equivalent stress results obtained by postprocessing the random vibration analysis results.

From noted figures for almost all parts of the ODS housing the probabilistic stresses are below allowable ones for materials used in analysis. The very high stresses values occur due to singularity at sharp corner of relief at back side sheet metal part (Fig. 9).

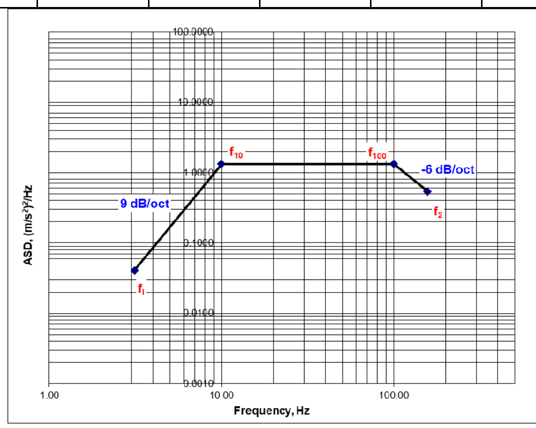
Tab. 3. ASD load at base excitation in transverse direction

Frequency , Hz		ASD, $(m/s^2)^2/Hz$	dB	OCT	dB/OCT (Slope)
f_1	3.13	0.1425	*	*	*
f_{10}	10.00	4.62	15.11	1.68	9.00
f_{100}	100.00	4.62	0.00	3.32	0.00
f_2	156.25	1.8969	-3.87	0.64	-6.00



Tab. 4. ASD load at base excitation in longitudinal direction

Frequency, Hz		ASD, $(m/s^2)^2/Hz$	dB	OCT	dB/OCT (Slope)
f_1	3.13	0.0408	*	*	*
f_{10}	10.00	1.3200	15.10	1.68	9.00
f_{100}	100.00	1.3200	0.00	3.32	0.00
f_2	156.25	0.5425	-3.86	0.64	-6.00



As this is a consequence of numerical problem at noted spot they can be neglected. Even if high stress values at single point occur, material will yield and plastically deform thus scientifically lowering the stress levels.

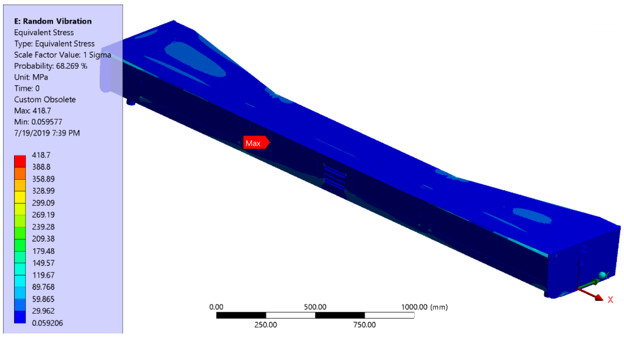


Fig.6. 1σ equivalent stress of ODS housing

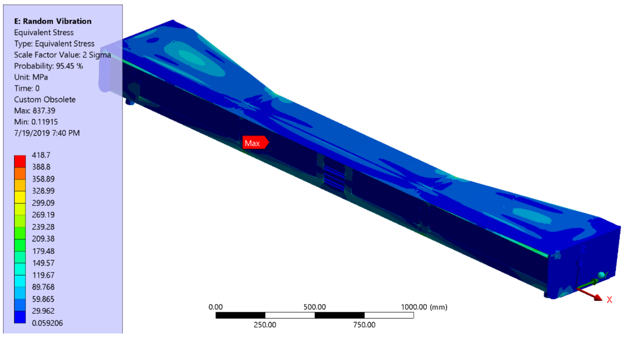


Fig.7. 2σ equivalent stress of ODS housing

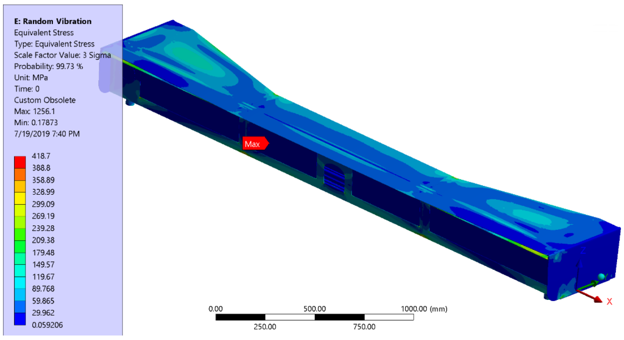


Fig.8. 3σ equivalent stress of ODS housing

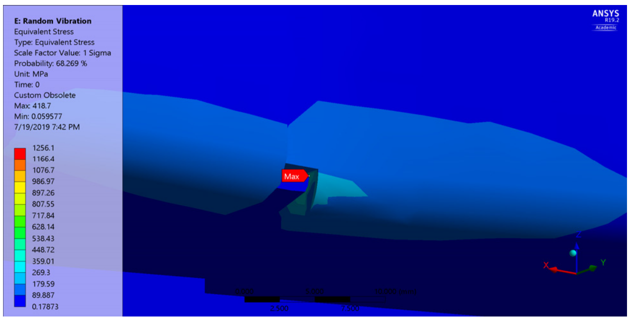


Fig.9. 1σ equivalent stress of back side of ODS housing

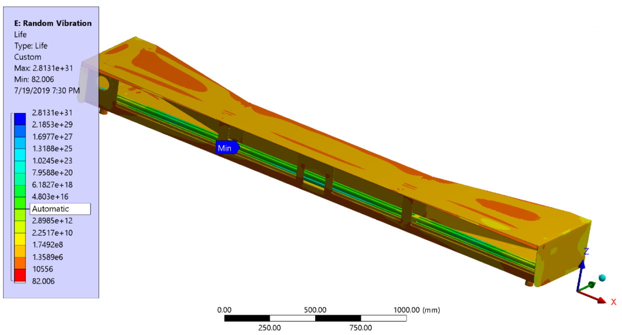


Fig.10. Random vibration fatigue life

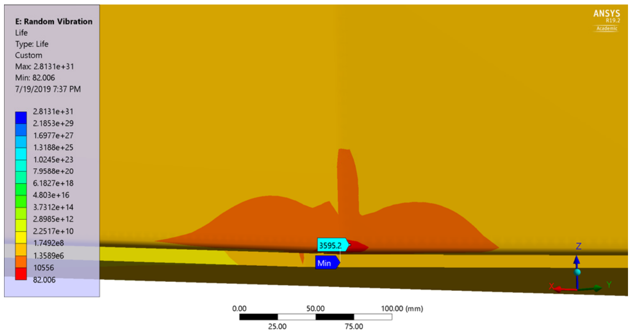


Fig.11. Random vibration fatigue life at back side of ODS housing

Based on obtained probabilistic stress results a fatigue analysis was performed in the last step based on S-N curves defined in GRANTA material database for materials used in analysis.

Results of fatigue life analysis are shown on Figure 10. Expected life during testing at increased vibration levels is well above 5h which correspond to expected vehicle service life of 25 years. The singularity occurrence at relief of back side sheet metal part resulted in lower life expectancy but noted results can be neglected as it is well known that stresses due to singularity tend to infinity (known limitation of Finite Element Method). Even if noted results are taken as realistic, the life expectancy in noted area is larger than 3000 h which correspond to 4.2 years in service (Fig.11). As ODS demonstrator will not be mounted for more than several days on a vehicle, noted life expectancy is more than sufficient.

3. CONCLUSION

Based on above preformed analysis it can be concluded that design of ODS housing satisfies the requirements imposed by EN 61373:2010 for a Category 1 Class B device. Results of the above performed analysis were submitted to owner of the vehicle, who accepted it as a proof that designed housing will not disassemble or fall od from the vehicle body during evaluation.

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