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Finite element analysis of new failure indication device of air suspension systems

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ABSTRACT

This paper presents FEA results carried out in Housing and Bracket of Failure Indication cum Brake Application device (FIBA). FIBA device is a critical item, used to initiate service brake application in case of any failure in Air suspension bellows presently used by Indian Railways.

The Housing is modeled with realistic details like internal pressure routings. The results are obtained from a 3D finite element analysis. The rigid body motion is carried out prior to structural analysis to ensure the stability of the model after meshing in FEA. The results of structural analysis indicate stress distribution in the housing. Analytical calculations also carried out to verify the results. Fatigue analysis is also carried out to predict the life of the Housing (No of cycles) during its zero based cyclic loading. Three different materials are used in the investigation to assess the effects of material properties on the stress and strain variation. This comparison displays a generous life cycle variation due to material itself. The natural frequency of the body is found out using modal analysis. Different Mode shapes are obtained at the end of Modal analysis. Based on the above said analysis material selected for making a prototype.

Bracket is a simple mechanical member -'L' Channel. One side is mounted on the coach & the other side is used to carry the FIBA device itself. As the member is subjected to higher vibration, modal analysis is taken in to priority than structural loading. Modal analysis indicated that the natural frequency falls in the range of excitation frequency. To counter check, random vibration analysis as per IEC 61373 is carried out in all the three directions – Vertical, Longitudinal & Transverse in order to find out the stress distribution using FEA.

KEY WORDS: Component, Finite Element Analysis, Static structural subjcted to Internal Pressure, Random vibration, Fatique & Modal Analysis.

1. INTRODUCTION

Housing is a material block machined suitably to accommodate parts, which is subjected to varying pressure i. e fatigue loading. Housing is similar to pressure vessels. The ASME pressure vessel code does not provide specific design procedure for the Pressure vessel design or the Induced stresses. Pressure vessel works in a severe cycle of pressurization/depressurization (from maximum to minimum in about 30 min). Theoretical study of stress analysis was carried out for thick-walled cylindrical pressure vessels subject to both cyclic internal pressure and temperature in journals. Our Housing is also subjected to pressurization/ depressurization during its operation or in its ideal position. Finite element analysis of pressure vessels with attached nozzles, and concluded that isoparametric solid elements with eight nodes and incompatible modes were the most appropriate. High end meshing element is used for carrying out analysis i.e. 20 Node Hexahedral element. Giving insight in the spring performance under cyclic loads considering as parameters: material type, wire diameter, recommended time and other Specifications It has been shown experimentally as well, that Static limit depends on the Torsional stress field.

Basic Theory for the analysis:

Pressure vessels: The Pressure vessels, according to their dimension, maybe classified as thin shell or thick shell. If the wall thickness of the shell (t) is less than 1/10 of the radius of the shell (r), then it is called a thin shell, Otherwise it is called as thick shell.

Thin Walled cylinder: Young– Laplace equation for estimating the hoop stress created by an internal pressure on a thin wall cylindrical pressure vessel:

$$\sigma_\theta = Pr / t \qquad (1)$$

Where

P: Internal pressure in N/m^2

T: Wall thickness in m

r: Inside radius of the cylinder in m

σ_θ: Hoop stress in N/m^2

Thick Walled Cylinder: In order to calculate the stresses and strains here a set of equations known as the Lame equations must be used.

$$\sigma_r = A - (B / r^2) \qquad (2)$$

$$\sigma_\theta = A + (B / r^2) \qquad (3)$$

A and B are constants of integration, which may be discovered from the boundary conditions.

r is the radius at the point of interest (e.g. at the inside or outside walls)

Thick Cylinder subjected to Internal Pressure:

Radial Stress $\sigma_r = -P\,\{(R_2 / r)^2 - 1\} / \{k^2 - 1\}$ (4)

Hoop Stress $\sigma_\theta = P\,\{(R_2 / r)^2 + 1\} / \{k^2 - 1\}$ (5)

Where

k is the diameter ratio $D_2 / D_1 = R_2 / R_1$

R_1, R_2 – Inner & outer Radius of the cylinder in m

P – Internal Pressure in N/m^2

r - Radius of interest in m.

Finite element analysis of housing:

Methodology adopted for FEA:

- Rigid Body Motion (Free – Free Analysis)
- Static structural & Fatigue Analysis
- Modal Analysis & comparison with IEC 61373

Rigid Body Motion: This Rigid body motion analysis is also called as Free –Free Analysis as the body is not constrained by the boundary condition. This is to ensure the model hygiene after importing and meshing by the FEA Software (ANSYS). Without boundary condition, modal analysis will be carried out. Condition for hygiene is 1st mode to 6th mode frequency must be less than 10^{-3} Hz. It ensures that Housing is having free translation along X, Y & Z and also having the free rotation about X, Y & Z after meshing. 7^{th} Mode to 10^{th} mode frequency must also raise & there should not be any fall in the frequency.

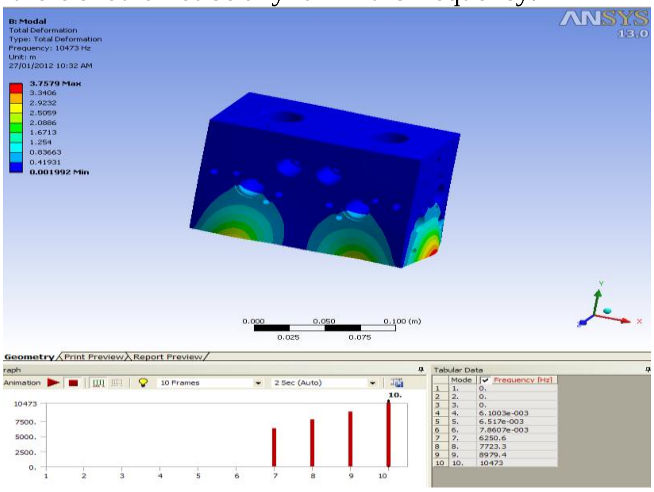

Figure.1. Rigid Body Motion

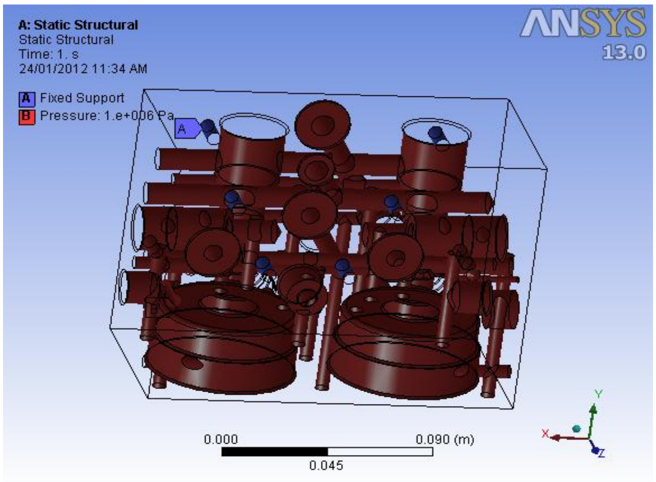

Figure.2. Boundary condition & Internal pressure loading applied

Conclusion: Refer Figure 1, 1st to 6th modes frequency is 7.8 x 10-3 Hz (0.0078Hz) – Acceptable, 7th Node to 10th mode frequency is higher & in increasing mode only, hence Model hygiene is maintained by FEA in importing as well as meshing.

Static Structural Analysis: Housing is subjected to Internal Pressure of 10x105 N/m2 max. As per Pascal's law, all the surfaces selected. No of Surfaces – 271 faces. Refer Figure 2.

Stress distribution & Max stress at the support:

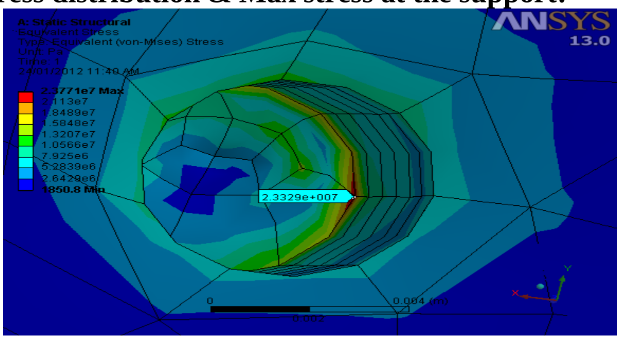

Figure.3. Stress distribution & Max stress at the support

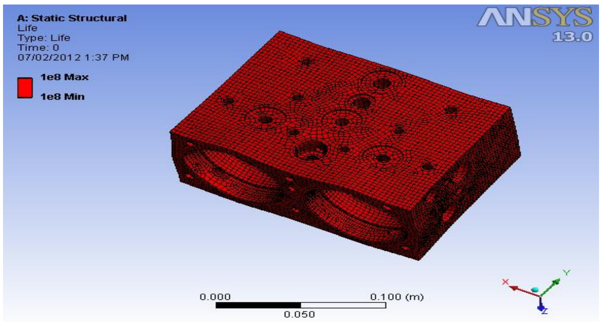

Figure.4. Life of the Housing predicted by FEA

Fatigue Analysis: Fatigue is the progressive and localized structural damage that occurs when a material is subjected to cyclic loading. Fatigue occurs when a material is subjected to repeat loading and unloading. If the loads are above a certain threshold, microscopic cracks will begin to form at the surface. Eventually a crack will reach a critical size, and the structure will suddenly fracture. Housing is subjected to varying pressure from 0N/m^2 to 10x10^5 N/m^2.Hence zero based loading is taken in to account for carrying out the stress analysis in ANSYS.

Table.1. Results – Static structural & Fatigue Analysis with Different material

Material	Aluminium alloy	Mild Steel	Grey Cast Iron
Yield Strength (x10^6 N/m^2)	240	230	NA
Ultimate Strength (x10^6 N/m^2)	310	410	240
Young's Modulus (x10^6 N/m^2)	7.1x10^4	2.1x10^5	1.1x10^5
Mass of the Housing (Kg)	3.13	8.88	8.14
Max Stress Induced (x10^6 N/m^2)	23.77	26.88	26.32
Max Strain Induced (m/m)	3.35x10^{-4}	1.2 x10^{-4}	2.39 x10^{-4}
Deformation (µm)	7.40	2.48	4.73
Factor of Safety (Y.S)	9.33	8.55	NA
Factor of Safety (U.S)	12.05	15.24	9.11
Fatigue Life (Cycles)	1.0x10^8	1.0 x10^6	NA

Static Structural & fatigue analysis with various materials: The above said static structural Analysis & fatigue analysis was carried out with various materials like Aluminium alloy, Mild Steel & Grey Cast Iron as these materials are readily available. Housing model kept as same. Along with material properties, Results of FEA are listed down in Table.1. Stress Variation is due to meshing & strain variation is due to material.

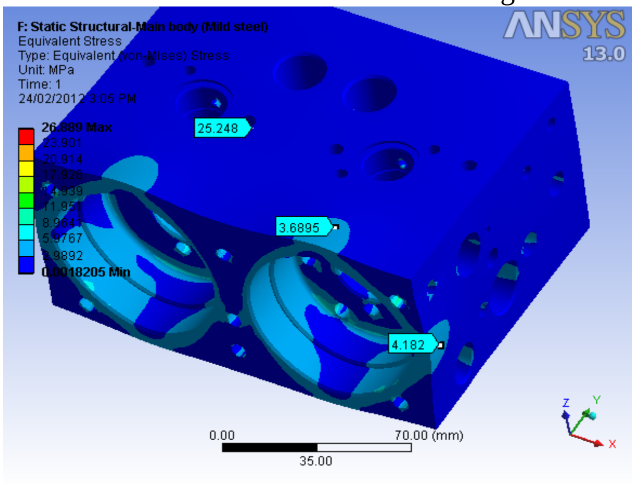

Figure.5. Comparison of Analytical results

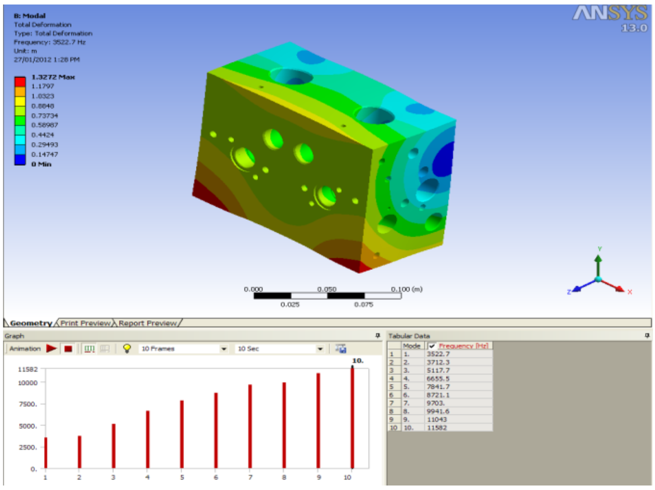

Figure.6. Nodal Analysis of Housing

Comparison of Analytical results with FEA: By using equation 5, ANSYS results were verified for the given cross section, assuming as a cylinder.

Conclusion: In FIBA, more rubber parts are used, which used to have contact with the Housing. These rubber parts (Diaphragm & 'O' rings) are going to work in static as well as dynamic condition. Better surface finishes should be maintained as rubber parts are very week in wear. In Aluminium alloy better surface finishes can be achieved, when compared to Mild steel & Grey cast iron. From Table.1, Infinite life can be achieved while using Aluminium alloy. Even though deformation is occurring max in Aluminium alloy; the area in which max deformation occurring is nonfunctional one.

Material selected for Housing – Aluminium alloy:

Modal Analysis & comparision with IEC 61373: Housing is getting bolted with Pipe bracket in the assembly of FIBA using six M6 Bolts, these M6 Holes are assumed to be fixed as shown in Figure.2.

IEC 61373 covers the requirement of Random vibration and shock testing items of Mechanical, Pneumatic, electrical and electronic equipment/ components to be fitted on to Railway Vehicles.

The Valve is getting mounted directly in the Body & Hence following category is chosen for comparison.

- Mounting - Body Mounted
- Type of Mount - Direct Mounting Type
- Vibration Class - Class A

As per class 'A' Excitation frequency will be 5 to 150 Hz.1st Natural frequency of the Body - 3522.7 Hz (Refer Figure.6). As excitation frequency is not matching with natural frequency of the Housing, Housing is very safe.

Finite element analysis of bracket:

Methodology adopted for FEA:

- Modal Analysis of Bracket & Comparison with IEC 61373
- Random Vibration of Bracket

Modal Analysis of Bracket & Comparison with IEC 61373:

Boundary Condition Applied: As shown in Figure 7, Displacement is fixed for the top surface of the bracket (Hence this top surface will move along with bracket fixed in the coach). Washer area is alone fixed in the bottom of this bracket. Point mass of 9.8 Kg applied at the Centre of gravity of assembly.

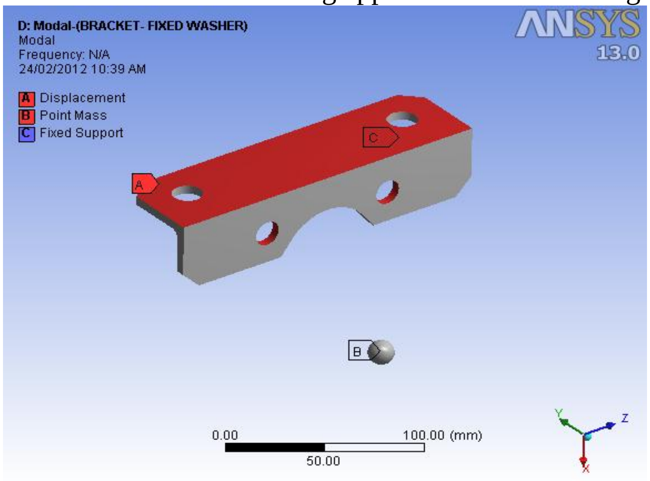

Figure.7. Boundary condition

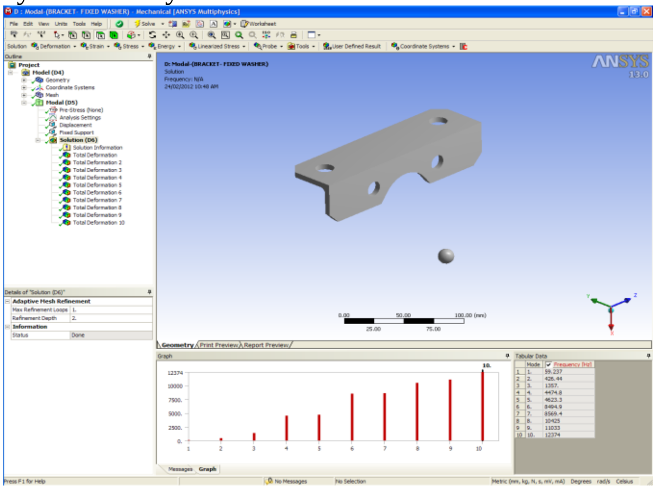

Figure.8. Modal Analysis of Bracket

Result of Modal Analysis: The Valve (FIBA) is getting mounted directly in the Body & Hence following category is chosen for comparison.

- Mounting - Body Mounted
- Type of Mount - Direct Mounting Type
- Vibration Class - Class A

Excitation frequency is 5 to 150 Hz. 1st Natural frequency of the Bracket – 59.23 Hz. As excitation frequency is matching with natural frequency of the Bracket, Bracket is not safe. Random vibration must be carried out for this part.

Random Vibration: Random vibration is motion which is non-deterministic, meaning that future behaviour cannot be precisely predicted. The randomness is a characteristic of the excitation or input, not the mode shapes or natural frequencies. Some common examples include an automobile riding on a rough road, wave height on the water or the load induced on an airplane wing during flight. Structural response to random vibration is usually treated using statistical or probabilistic approaches. In mathematical terms, random vibration is characterized as an ergodic and stationary process.

A measurement of the acceleration spectral density (ASD) is the usual way to specify random vibration. The root mean square acceleration (Grms) is the square root of the area under the ASD curve in the frequency domain. The Grms value is typically used to express the overall energy of a particular random vibration event and is a statistical value used in mechanical engineering for structural design and analysis purposes.

Power Spectral Density: In physics, the signal is usually a wave, such as an electromagnetic wave, random vibration, or an acoustic wave. The spectral density of the wave, when multiplied by an appropriate factor, will give the power carried by the wave, per unit frequency, known as the power spectral density (PSD) of the signal. Power spectral density is commonly expressed in watts per hertz (W/Hz) or dBm/Hz. For random vibration analysis, units of g^2Hz^{-1} are sometimes used for acceleration spectral density. Although it is not necessary to assign physical dimensions to the signal or its argument, in the following discussion the terms used will assume that the signal varies in time.

ASD from IEC 61373: Calculated values of ASD for Class 'A' are shown in Table.2.

Table.2. ASD from IEC 61373

Frequency (Hz)	ASD Values $((mm/s^2)^2/Hz)$		
	Vertical	Transverse	Longitudinal
5	1.034×10^6	2.5×10^5	4.52×10^5
20	1.034×10^6	2.5×10^5	4.52×10^5
150	18637	4506.2	8147.1

Random Vibration of Bracket: As shown in Figure 9, Frequency & ASD feed into ANSYS for analysis.

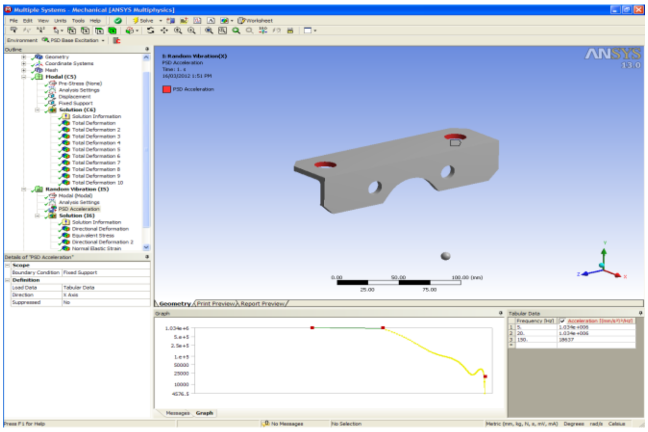

Figure.9. Random Vibration of Bracket

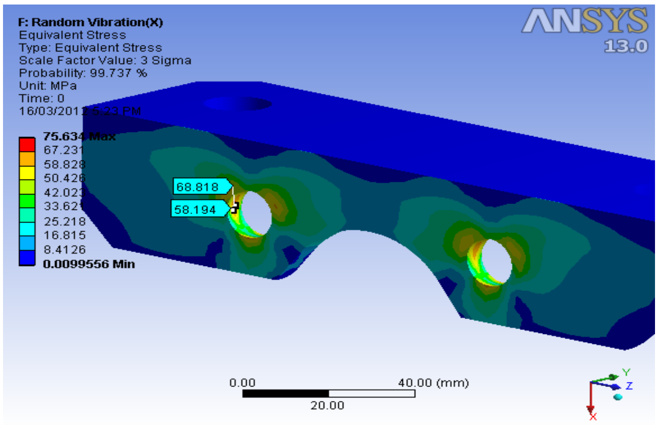

Figure.10. Stress Distribution in Random vibration

Results of Random Vibration:

Table.3. Result of Random Vibration

Description	Vertical	Longitudinal	Transverse
Stress (MPa)	75.63	50.00	37.19
Deformation (mm)	3.26×10^{-3}	2.1×10^{-3}	1.6×10^{-3}
Strain	2.75×10^{-4}	1.82×10^{-4}	1.35×10^{-4}

Conclusion: As shown in Table.3, Stress Induced in Vertical Random Vibration is 73.63×10^6 N/m^2.
Material Selected – Mild Steel
However Material Yield Strength = 230×10^6 N/m^2.
Hence design of bracket is safer.

2. CONCLUSION

Housing: Structural & fatigue analysis carried out on Housing. Based on the results material selected for the housing as aluminium alloy. Modal analysis also carried out on housing which shows that the natural frequency is not matching with the excitation frequency. It is concluded that Housing is totally safe during its cycling operation (Approximately infinite life – 1×10^8 cycles).

Bracket: Modal analysis on Bracket shows that the natural frequency is matching with excitation frequency. In continuation, Random vibration of Bracket carried out. Stress induced during random vibration is lower than yield strength of the material. Hence bracket is also safe

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