Analysis of Air Cleaner for an Automobile Subjected to Different Engine Loads

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Abstract:- **Air cleaner and its support bracket is mounted on the engine at different attachment locations. The air cleaner and its support bracket is subjected to dynamic loads arising from engine vibrations along all the three vehicle axes of X, Y and Z. Apart from the dynamic loads, the static gravity load for which vehicle undergoes are also considered. The basic objective of the study is to perform fatigue life estimation for an air cleaner support bracket of an automobile at the design stage of development process for the engine forcing input data. The finite element modeling and analysis is carried out for the air cleaner support bracket using Hypermesh for Finite Element Model generation and Nastran for analysis. The frequency response is simulated efficiently by employing Nastran frequency response module. The total damage and durability life of an air cleaner due to engine loading input are then calculated by the Palmgren Miner's accumulated damage rule.**

Keywords: Support bracket, frequency response, damage rule.

1.INTRODUCTION

Engineering machines and structures in service experiences vibration to some degree, and their design generally requires consideration of their dynamic behaviour. The type of input forces /loads experienced by different components of an automobile in service is dynamic and time dependant in nature. Materials and particularly metals are prone to a cyclic load degeneration failure mechanism usually called fatigue. Hence, Fatigue and Durability design of any component of an automobile structure plays an important role to ensure reliability. The total damage and durability life of an Air cleaner support bracket depends on the loads subjected to a combination of static and dynamic loads arising from engine vibrations.

Brain.j.Schwatz et.al., explained majority of structures can be made to resonate under the proper conditions and structure can be made to vibrate with *excessive, sustained, oscillatory motion*. Resonant vibration is caused by an interaction between the *inertial* and *elastic* properties of the materials within a structure. Resonant vibration is often the cause or

at least a contributing factor to many of the vibration related problems that occur in structures and operating machinery.

Bishop et.al., demonstrates the Benefits of frequency domain fatigue analysis by comparison with more conventional time series transient fatigue analysis. Many engineering applications such as offshore engineering and wind turbine engineering have got the benefits of using frequency response analysis for reliability assessment and also briefly explained about S-N curve and Palmgren Miner's Accumulated damage rule.

Andrew Halfpenny explains the available methods for performing fatigue analysis from PSDs and shows that the Dirlik method gives the best comparable results with the traditional time domain approaches. Each cycle will induce a certain amount of fatigue damage on the component. The total damage caused by the time history can be obtained by summing the damage caused by each cycle. This approach is known as the Palmgren-Miner accumulated damage rule after the two independent people who proposed it.

Neil Bishop et.al., demonstrates an analysis of a Missile Shaker Table Mounting Bracket subjected to a significant fatigue loading. The analysis demonstrates that fatigue calculation results should be seen as point results from a multidimensional distribution of all possible events. For instance, loading level, residual stress level, material quality, surface treatment and surface finish are just a few of the inputs that could exhibit statistical variation.

Hong Su has given a procedure for automotive CAE durability analysis using the random vibration approach. Two example results of automotive structures, a rear axle assembly made of metals, and a headlamp assembly made of plastics, are given to demonstrate the approach and their applications. The results show that the random vibration approach costs less CPU time and memory.

2 .FINITE ELEMENT MODELING OF AIR CLEANER

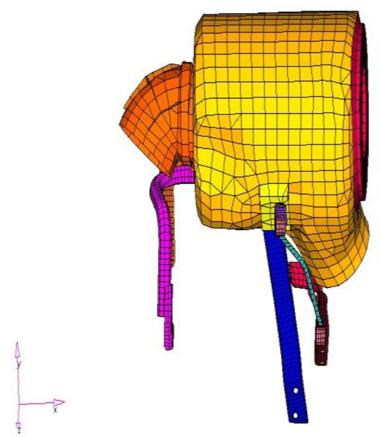

Figure 1: Geometric CAD model of an Air cleaner & its support bracket

The 3D model was provided for the analysis, which includes the air cleaner & its support structural bracket as shown in fig.1. Meshing was done using Hypermesh and analysis was carried using NASTRAN.

Model Summary:

Number of Grid Points = 7057

Number of Hexa Elements = 1573

Number of Penta Elements = 32

Number of Quad4 Elements = 4019

Number of Tria3 Elements = 317

Number of RBE2 Elements = 132

Finite element model generated 42342 degrees of freedom.

Total weight of the structure = 13 Kgs

Weight of the support bracket = 4.275 Kgs

Boundary Conditions (Constraints)

The boundary conditions for the model are as follows:

For Static and Modal analysis:

- The Engine is constrained for all six degrees of freedom at three engine excitation locations.
- The Air cleaner support bracket is mounted on the engine is connected by one dimensional Rigid elements called RBE2 elements.

For Frequency Response analysis:

- The Engine excitation locations are constrained such that they are free in the direction of excitation and the rest of the degrees of freedom are fixed.
- The Air cleaner support bracket is mounted on the engine is connected by one dimensional rigid elements called RBE2 elements.

3. ANALYSIS OF AIR CLEANER AND ITS SUPPORT BRACKET

A static load case can easily be obtained through the GRAV entry in Msc / Nastran. The GRAV entry is used to define the direction and magnitude of a gravity vector in any user-defined coordinate system. Acceleration due to Gravity (g) = 9810 mm/s^2 is provided. Static analysis is analysed in all the three directions.

Dynamic forcing functions:

The forcing dynamic load profiles extracted from the vibration velocity at the front engine suspension, rear right engine suspension and rear left engine suspension are given below as function of frequency. Refer figure 3.1 to 3.3.

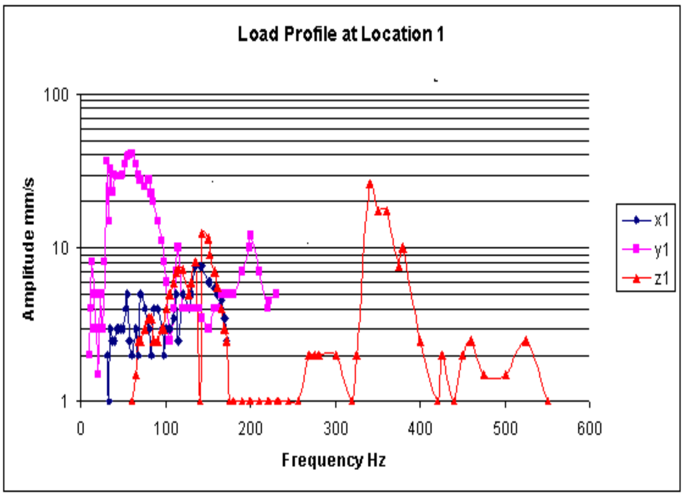

Figure3.1 Load profile at Front engine suspension

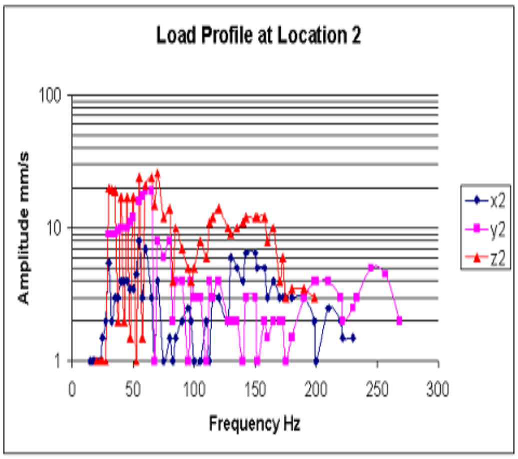

Figure 3.2: Load profile at Rear right engine suspension

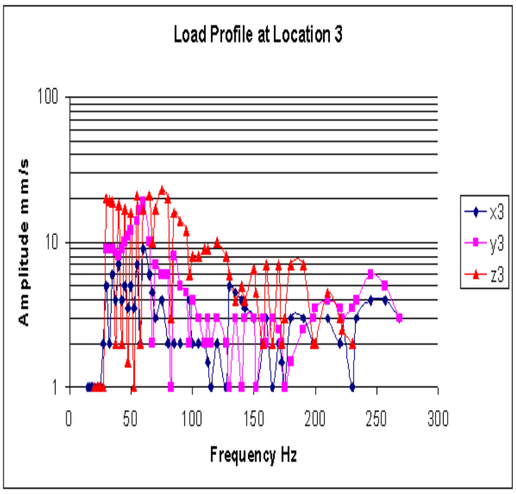

Figure3.3: Load profile at Rear left engine suspension.

Fatigue Life (Durability) Estimation
Palmgren Miner's accumulated damage rule:

The total damage caused can be obtained by summing the damage caused by each cycle. The high stressed element is considered for the fatigue life estimation.

Accumulated Damage, $E(AD) = \Sigma N_i / N_f$

$= \Sigma D_i$

Where N_i is the number of cycles with a particular stress range.N_f is the number of cycles to failure for a particular stress range.

D_i is the individual damages caused at each stress level S-N Curve for steel(1045) is shown in the figure 3.4. From this curve number of cycles to failure can be obtained for the particlar stress range.The curve has been extrapolated to obtain the number of cycles for the low stresses and high stresses.

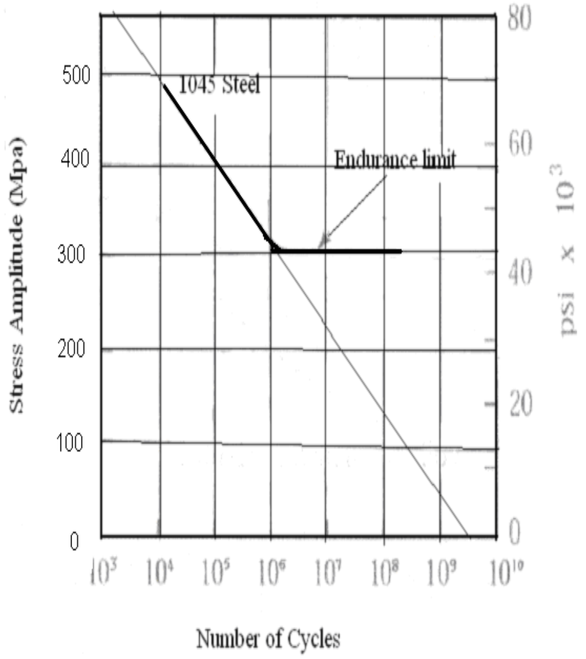

Figure 8.1: S-N curve of 1045 steel

Fig.3.4 S-N curve for steel(1045)

The accumulated damage for the time 500 hours is calculated at first peak stress of the element is as follows:

The support bracket is exposed to both the engine vibrations and road loads. Assuming

that the vehicle durability is for 2,00,000 km running at an average speed of 40 km per hour.

The engine will be running for 5000 hours..

Assuming that the vehicle will be running 10% of the time on rough road when the load levels are severe, then the cumulative time to be considered for the damage is 5000 /10=500 hours.The damage is calculated given below.

Accumulated Damage,

$E(AD) = \Sigma N_i / N_f = \Sigma D_i$

$D_1 = 5.47 (500 \times 60 \times 60) / 10^9 = 0.00984$

4. RESULTS AND DISCUSSION

The static gravity load experienced by the Air cleaner support bracket in global X, Y and Z axes is considered. The Finite element static analysis is performed for the gravity loads along X,Y and Z axes individually as well as the combined X,Y and Z axes loading .The Maximum stress induced in each case is determined. The stress induced during combined gravity loading is severe and the maximum stress is 446 Mpa. Considering the yield strength of the steel material for the support bracket , the design is safe and has a factor of safety of 1.2 on the yield strength of the material.

The first step in performing normal mode analysis is determining the natural frequencies and associated mode shapes of the Air cleaner and its support bracket with damping neglected. These results characterize the basic dynamic behaviour of the structure and shows how the structure will respond to dynamic loading. The results of the normal mode analysis shows that first natural frequency is 5.46 Hz corresponding to the global mode of Aircleaner .The first global frequency associated with the support bracket is 15.1 Hz.

The dynamic response analysis is performed for the engine loads excited by the engine vibrations in order to calculate the response of a structure specifically at characteristic resonant frequencies. The excitation was imparted along X, Y and Z-axes combinedly at the attachment points. The modal method utilizes the mode shapes of the structure to reduce and uncouple the equations of motion of the solution for a particular forcing frequency is obtained through the summation of the individual modal responses.

The frequency resolution selected for the dynamic response prediction has been verified to be adequate capturing sufficient number of peaks in the response around resonance. A small enough Δf is used in order to capture the peak response appropriately. Analysis contains enough modes in order to ensure accurate results for the highest frequency. The peak stress responses at different locations are plotted for the complete frequency range of 3-600 Hz.

The results of induced stress for the air cleaner support bracket were used to establish the fatigue life. As mentioned earlier in the static analysis and modal analysis, highly stressed zones in the air cleaner support bracket are identified. The responses for the input of engine load excitation are extracted from the results at all the identified elements where the stress spectrum is significant. The maximum induced dynamic stress in the support bracket is 124 Mpa.

The approach of fatigue life estimation by Palmgren Miner's rule is adopted to calculate the accumulated damage and Residual life for the support bracket. It is clear, from the accumulated damage estimation considering damage due to engine loads along X, Y and Z axes that the worst damage for the Accumulated damage for the element is 0.813 and The residual life is 0.187. The Air cleaner support bracket can survive the engine loads excitation safely.

5. CONCLUSION

Finite element technique has been successfully used to understand the behaviour of an Air cleaner support bracket for static and dynamic loads. Fatigue life (Durability) has been estimated based on the induced stresses due to dynamic loads arising from engine vibrations.

Based on the results of the analysis, following conclusions are made

Static analysis was performed for the specified gravity loads on the Air cleaner support bracket. The maximum stress induced for the combined gravity loading in the support bracket is 446.7 Mpa. The location of maximum stress is on the bracket which is close to the Rear left engine suspension. The Factor of safety in the design for the combined gravity load case is 1.2 on yield stress of the material. Hence the design is safe from the gravity loads.

- Normal mode analysis is performed for the Air cleaner support bracket. The first natural frequency of the Air cleaner and its support bracket is 5.46 Hz, corresponding to the global mode of the Air cleaner tank. The first global mode associated with the support bracket and the Air cleaner is at 15.1 Hz.
- Dynamic response analysis performed on the Air cleaner support bracket for the excitation due to engine vibrations. The maximum induced dynamic stress in the bracket is 124 Mpa in the same zone as the gravity load case, that is closed to the Rear left engine suspension.
- Durability analysis for the Air cleaner support bracket is performed by the Palmgren Miner's Accumulated damage rule. The Accumulated damage for the support bracket is 0.813 and The Residual life remaining in the support bracket is 0.187, for the assumption that engine operates at full power for 500 hours.

In general, the design of the support bracket is safe not only for the defined static gravity loads and also for the dynamic loads. The residual life of the support bracket from fatigue (Durability) considerations shows about 19%.

REFERENCES

1. Brain.j.Schwatz & Mark H.Richardson, Experimental modal analysis", Vibrant Technology, Inc.James town, California, October1999.
2. NWM. Bishop, IW Lack, T Li, SC Kerr, *"Analytical Fatigue Life Assessment of Vibration Induced Fatigue Damage"*, Paper presented to MSC World Users Conference, Universal City, Los Angeles, 1995.
3. Neil Bishop and Andy Woodward, *"Fatigue Analysis of a Missile Shaker Table Mounting Bracket"*, RLD Limited and MSC Software, UK. 1993.
4. Andrew Halfpenny, *"A Frequency Domain Approach for Fatigue Life Estimation from Finite Element Analysis",* Presented at International Conference on Damage Assessment of Structures, Dublin, 1999.
5. NWM. Bishop and F. Sherratt, *"A Theoretical Solution for the Estimation of Rainflow Ranges from Power Spectral Density Data"*, Fatigue & Fracture of Engineering Materials & Structures, Vol 13, No 4, 1991, pp 311-326.
6. Walter Schutz,"A history of Fatigue", JABG, D5521, Hobrunn, Germany, vol-54, pp.263-300, 1996.
7. Walter H. Lowe, *"Comparison of Experimental Shaker Table Results with Classical FEA Frequency Response Analysis Vs Mechanical Event Simulation",* Sierra Nevada Corporation, Algor Inc, 2005.
8. Andrew Halfpenny, *"What is the Frequency Domain and how do we use PSD?"* nCode International Ltd., Sheffield UK. 1999.
9. Hong Su, *"Automotive CAE Durability Analysis Using Random Vibration Approach"*, Visteon / Ford CAE forum, Nov1999.
10. NWM. Bishop and F. Sherratt, *"Fatigue Life Prediction from Power Spectral Density Data"*, Part 1, Traditional Approaches, Environmental Engineering, Vol.2,1989.
11. Peter Avitabile, "Experimental modal analysis (A simple non mathematical presentation)", MACL, University of Massachusetts Lowell, Draft document for Sound and Vibration magazine.