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ESTIMATION OF HARMONIC RESPONSE CONSIDERING THE TRANSFER FUNCTION RESULTED FROM FEA ANALYSIS

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Abstract: - *In the paper a method for evaluating the behavior of a mechanical structure subjected to harmonic loading is investigated. Vibration sources are very important in automotive industries. Often it is necessary to do two or more finite element analyses for example random and harmonic. To reduce the computing time we investigate the possibility of evaluating the behavior of a structure under a harmonic loading by using first the random vibration analysis. The main assumption is that both types of analyses are linear and both use the transfer function to calculate the structure's response. A comparison between analytically calculated response and FEA calculation response is done.*
Keywords: - *Power Spectral Density, random vibrations, harmonic response, evaluation method, analytic estimation, Finite Element Analysis.*

1. INTRODUCTION

The design of mechanical components should be done taking in account the static and dynamic forces which are acting on the automobile components.

The dynamic loading is imposed by standards which include a harmonic loading profile and a random vibration profile.

Generally the part is tested for both profiles, then an optimization is done with FEA. This requires two different simulation runs after a modal analysis. However there is a connection between Harmonic Response analysis and Random vibration analysis. Even though harmonic loading describes a well defined sinusoidal load, while random uses a statistical distribution to determine the probability of occurrence of particular amplitudes, both are linear analyses and use the same transfer function of the frequency response function to correlate the output with the input. This means that we can calculate a Power Spectral Density (PSD), extract the transfer function and use it to calculate the harmonic response of the structure. This can be used to quickly evaluate a structure for a PSD and harmonic profile and save time by doing one simulation run instead of two. In the case of large structures, the analysis can be done more than four times faster.

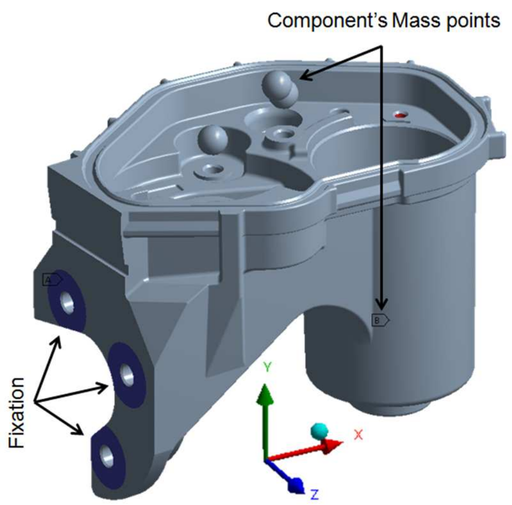

Fig. 1. CAD model of the electromechanical valve

2. CASE STUDY

The investigation is done on an Aluminum housing for an electromechanical valve which controls the airflow in an automobile engine. The CAD model and constrains of the component is shown in figure 1. There are lumped masses which are the equivalent of the other components in valve.

The properties of the material used in the dynamic analysis are: Elastic modulus (E = 70000 MPa), density (ρ = 2700 kg/m2). The part was tested both to a Power Spectral Density (PSD) profile and to a harmonic loading. To optimize the part a few runs are necessary. Through the methodology described below it is possible to evaluate the component by doing only a PSD simulation run.

3. EVALUATION METHODOLOGY

The first step to the performed is the modal simulation to find the eigen frequencies of the structure. (fig. 2). In order to evaluate the component subjected to random and harmonic excitation profile, the transfer function is calculated from only one random simulation run. Then the response for the only harmonic loading is calculated with expression (1) [8]:

$$A_0(\omega) = H(\omega) \cdot A_i(\omega) \qquad (1)$$

where:

- $A_i(\omega)$ is the applied excitation on the component .
- $H(\omega)$ is the transfer function
- $A_0(\omega)$ is the response of the structure

For the random analysis, the expression (2) is used [8]:

$$S_{xx}(\omega) = H^2(\omega) \cdot S_{AA}(\omega) \qquad (2)$$

where:

- $S_{XX}(\omega)$ is the resulting spectrum, with the same units as the input spectrum.
- $S_{AA}(\omega)$ is the acceleration input spectrum
- $H^2(\omega)$ is the square of the transfer function.

Firstly, the PSD with 1 [(m/s)^2 / Hz] following y direction it's applied in the frequency range 10 – 2000 [Hz]. For the component the resulting response is extracted from the point of maximum displacement.

After extracting the square root of the FRF *H(ω) and* taking into account the expression (1), the harmonic response can be calculated for different values of applied harmonic excitation.

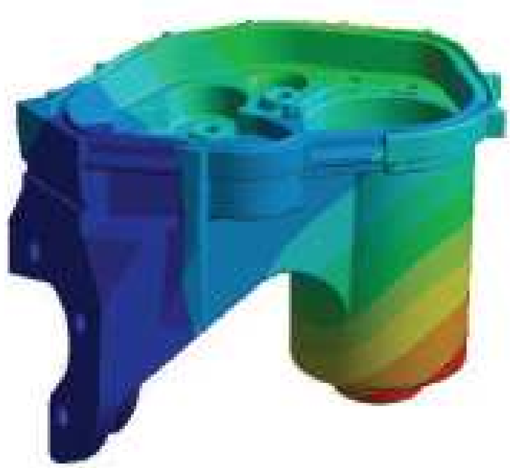

Fig. 2. Second eigen frequency mode at 665 Hz

For the studied CAD model the calculated amplitude of the harmonic response for a 1 g excitation and the simulation with the same excitation input are presented in figure 3.

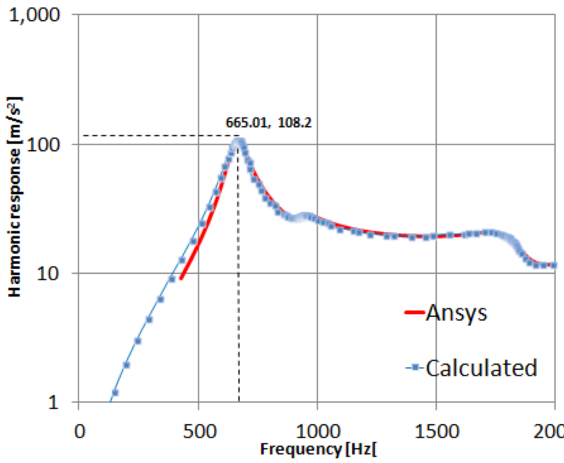

Fig. 3. Harmonic response for 1 g excitation

Based on the acceleration response spectrum, the displacement can be calculated using expression (3):

$$d = \frac{a}{\omega^2} \qquad (3)$$

where:

- *d* is the amplitude of the displacement
- *a* is the acceleration amplitude
- *ω* is the angular frequency

For the maximum value of acceleration in figure 3, the displacement amplitude value will be:

$$d = \frac{108.235}{4\pi^2 665^2} = 6.19910^{-6} m \qquad (4)$$

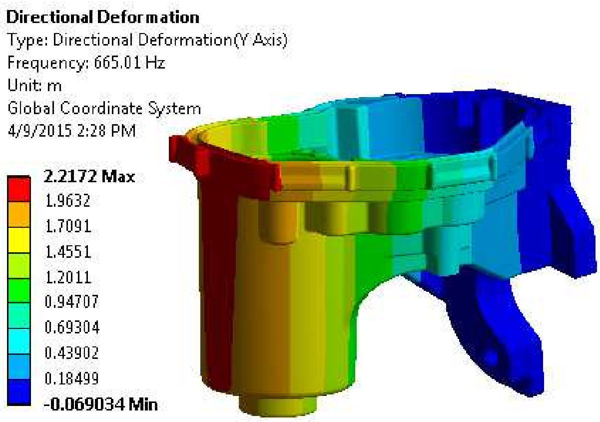

Fig. 4. Deformation in Modal analysis

Using the calculated displacement, the maximum value for von Mises stress on the part can be evaluated from the modal results. This is done by corresponding the displacement and stress in the modal results (fig.4) and (fig. 5) with the calculated displacement, *d*.

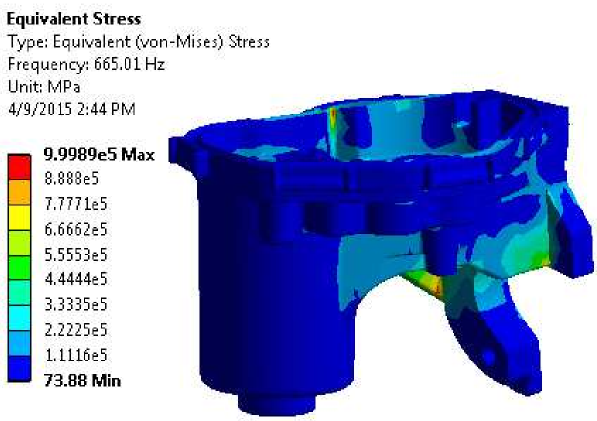

Fig. 5. Stress in Modal analysis

Using the linearity property of the harmonic calculation the Von Mises Stress is:

$$\sigma = \frac{\sigma_m d}{d_m} = \frac{9.99\ 10^5 \cdot 6.19910^{-3}}{2198.3} = 2.812 MPa \qquad (5)$$

where:

- σ is the estimated stress in the harmonic simulation.
- d_m is the amplitude of the displacement at the mode of 665 Hz, at the same point as the measured response.
- *d* is the amplitude of the displacement at the measured response.
- σ_m maximum stress in the modal analysis at the vibration mode of interest, 665 Hz.

The calculated von-Mises stress value is within 0.5 % error as the value from harmonic analysis, (fig.6).

4. CONCLUSIONS

The method can be use to quickly evaluate parts subjected to harmonic loading, based on the transfer function calculated in a PSD analysis. Also in the PSD analysis before software is calculating square transfer function, the module or phase, can be read if is necessary.

The von-Mises Stress maximum value location can be extracted from the modal analysis and using expression (5), the stress in the harmonic analysis can be calculated. The damping of the structure has influence on the value of the amplitude response, therefore the calibration with a tested part is very important. In this case a damping of 6% was used in the random and harmonic analysis.

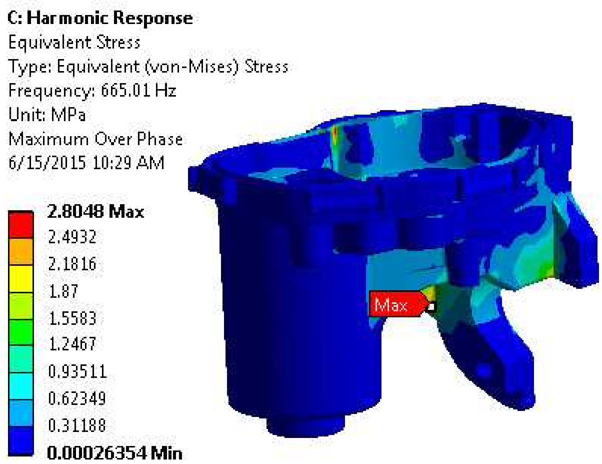

Fig. 6. Von-Mises stress [MPa]

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ESTIMAREA RĂSPUNSULUI LA EXCITAȚIE ARMONICĂ CONSIDERÂND FUNCȚIA DE TRANSFER REZULTATĂ DIN ANALIZA FEA

Rezumat: *În prezenta lucrare este prezentată o metodă pentru evaluarea comportamentului unei structuri mecanice sub acțiunea unei excitații armonice. Sursele de vibrații sunt foarte importante în industria auto. De cele mai multe ori este necesară efectuarea a două sau mai multe analize, de exemplu o analiză aleatoare și una armonică. Pentru a reduce timpul de execuție investingăm posibilitatea de a evalua comportamentul structurii excitate armonic prin utilizarea unei prime analize sub acțiunea unor excitații aleatoare. Pricipala ipoteză utilizată este cea de liniaritate a analizelor dinamice precum și faptul că ambele tipuri de analize folosesc funcția de transfer pentru a calcula răspunsul structurii. Deasemenea se realizează o comparație între metoda FEA și cea analitică.*

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