Resonant Frequency Analysis of the Diaphragm in an Automotive Electric Horn

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Abstract

The resonant frequency of the diaphragm is the important parameter in the design of electric horns. The natural frequency of vibration of the diaphragm is dependent of the stiffness and also the mass attached to it as the diaphragm is designed as a thin plate. A magnetic field is used to produce the excitation of the diaphragm mass and resonance occurs when the two frequencies coincide. It is also important to maintain the air gap between the diaphragm mass and the magnetic core. Presently, the development time used in introducing new horns is high and is mostly based on trial and error. It was therefore decided to try out an analysis using ANSYS to cut down development time. This paper enumerates a design process of horn diaphragm that was carried out using ANSYS. The finite element model of the diaphragm with the mass is subjected to modal and harmonic analyses to determine the natural and the resonant frequency conditions. The stress-strain characteristic of the particular diaphragm design is also analyzed. Variations have also been brought in the diaphragm design and also the mass attached to the diaphragm. The results have corroborated the experimental frequency data obtained using a Fast Fourier Transform (FFT) analyzer. The procedure will be helpful to quickly fine tune electric horns, thereby reducing development time appreciably.

Introduction

The electric horn used in automobiles is an important accessory and their designs are constantly updated. A study carried out by the authors in a local horn manufacturing industry revealed that the conventional approach to developing new horns is time consuming. The mass of the system is adjusted to obtain the required sound level and frequency. The diaphragm design is critical in the electric horns as the resonant frequency of the diaphragm determines the output sound level of the electric horn. The diaphragm is excited by an electro-magnet. The setup consists of copper coil of a specified number of turns and provides the necessary exciting force when current is passed through the coil. The frequency of magnetic force exciting the diaphragm is varied. Resonance occurs when the frequency of the exciting force and the natural frequency of the diaphragm coincide. The resonant frequency also determines the intensity of sound. The magnitude of the diaphragm mass is usually arrived at manually using trial and error procedure, which consumes a lot of time. Thus there is a need to develop a CAE procedure to design and fine-tune these devices. This paper enumerates a procedure, developed by the authors, to carry out the design of the diaphragm in the electric horns using ANSYS.

The natural frequency of a single degree of freedom system is given by

$$\omega = \sqrt{(k/m)} \text{ -----------------1}$$

where k = stiffness of the system (N/m) and m = mass of the system.

Changing stiffness value or the mass could alter the natural frequency. The natural frequency of the diaphragm is altered by the addition of extra masses, to obtain the necessary resonant condition. It is this process that could be replaced with a simple but reliable CAE procedure using ANSYS. A standard horn was used for the study first. This diaphragm of the horn was modeled in ANSYS.

Figure 1 shows the model of the diaphragm and the masses attached. The model properties are given in Table 1.

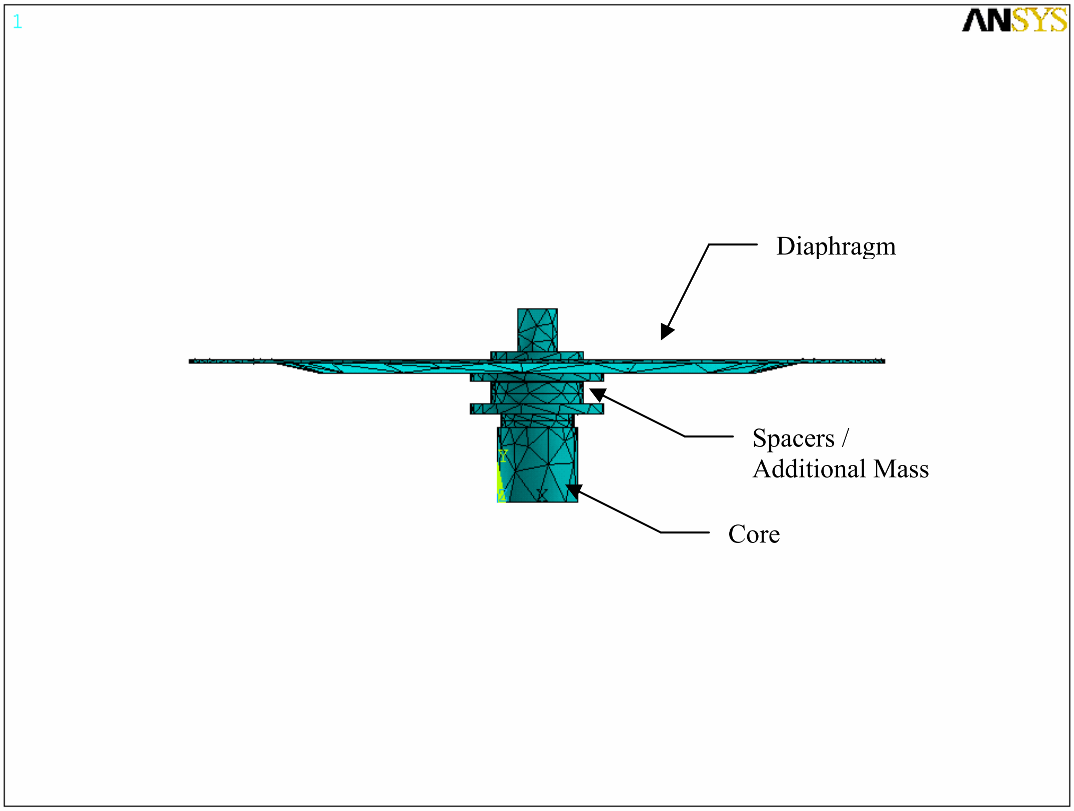

Figure 1. Finite Element Model of the Diaphragm and Attached Mass (shown with part labeling)

Table 1 Model Properties

Total mass of Diaphragm and attached mass	64 g
Input Parameters	12V at 5A
No. of turns of coil	50
Material	Steel

In practice the diaphragm is excited by means of a magnetic coil. The relations given below obtain the electro-magnetic force that excites the diaphragm and the mass. The electromotive force (emf) induced is given by

$$E = N\phi/t \text{ (V)} \text{ -----------------2}$$

where N= no of turns of coil, ϕ = magnetic flux and t= time period. The force generated is given by

$$F = BIL \text{ (N)} \text{ -----------------3}$$

where F= force generated, B=flux density, I = current flowing and L=length of the conductor.

Procedure

The adopted procedure is to perform modal and harmonic analyses on the diaphragm. A study of the geometry of the diaphragm and the pattern of deformation indicated that an element type of Plane2 – Axisymmetric (Triangular element) is adequate to model the diaphragm. The solid model of diaphragm 1 is shown in fig.2. The appropriate FE model is created (FE model of diaphragm 2 is indicated in Fig 3 and the FE model of diaphragm 1 is similar to diaphragm 2) and modal analysis is carried out on this model. The significant modes of vibration were extracted using modal analysis. In actual use, an electro-magnetic force excites the diaphragm. The magnitude of this force is calculated using the equation given above and is used as the input. This force will depend on the mass attached to the diaphragm. The diaphragm is then subjected to harmonic analysis. The resulting amplitude plot will yield the resonant frequencies and amplitudes of the response of the diaphragm. The result of the finite element analysis was compared with the experimental values obtained by using a FFT analyzer. The procedure is repeated by modeling additional mass in order to vary the frequency. The diaphragm of a different model electric horn (Fig. 3) was also analyzed using the same procedure to confirm the reliability of the method. The diaphragm shown (Fig. 3 is shown as meshed) is of different dimension and the extra mass attached to the diaphragm varies in different models of electric horns, depending on the frequency required (calculated using eq.1). The resonant frequency of diaphragm 2 is different from the model (diaphragm 1) shown in fig.2. The other properties such as material of the diaphragm remain the same. A study of the stresses developed in the diaphragm was also carried out to ensure that the stresses induced in the diaphragm are within safe limits (Fig. 6).

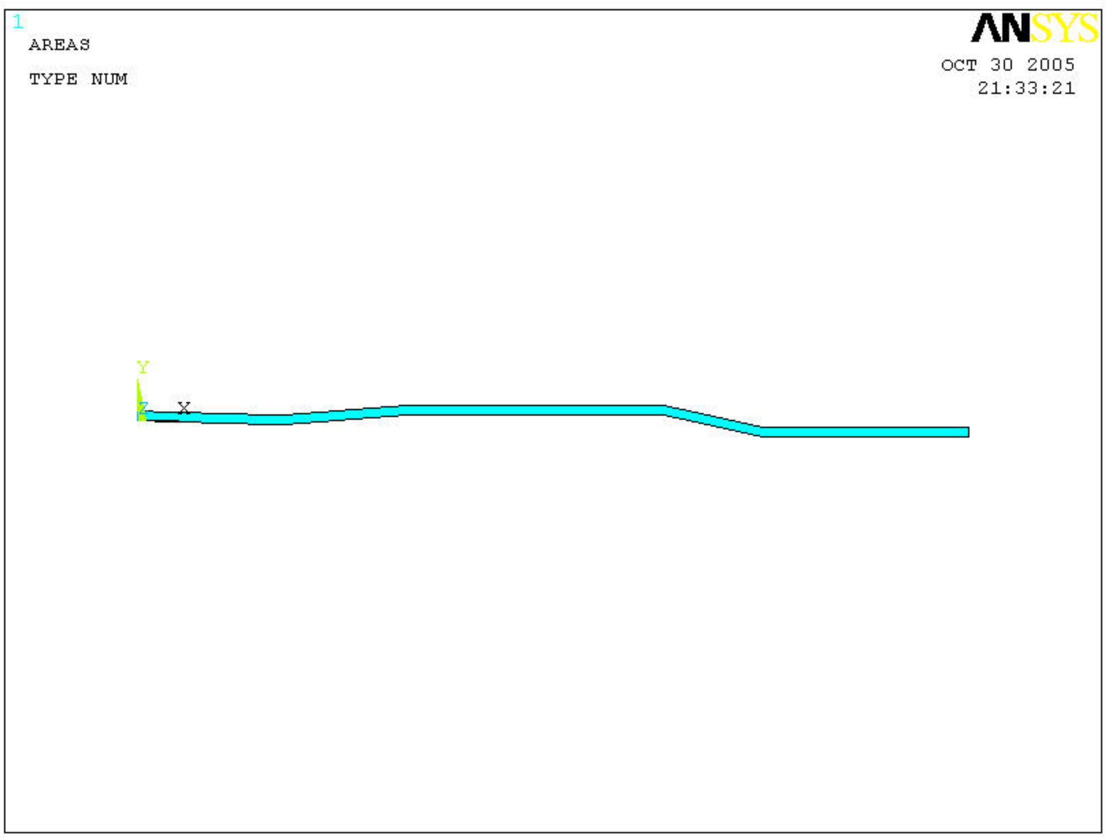

Figure 2. Solid model of Diaphragm 1

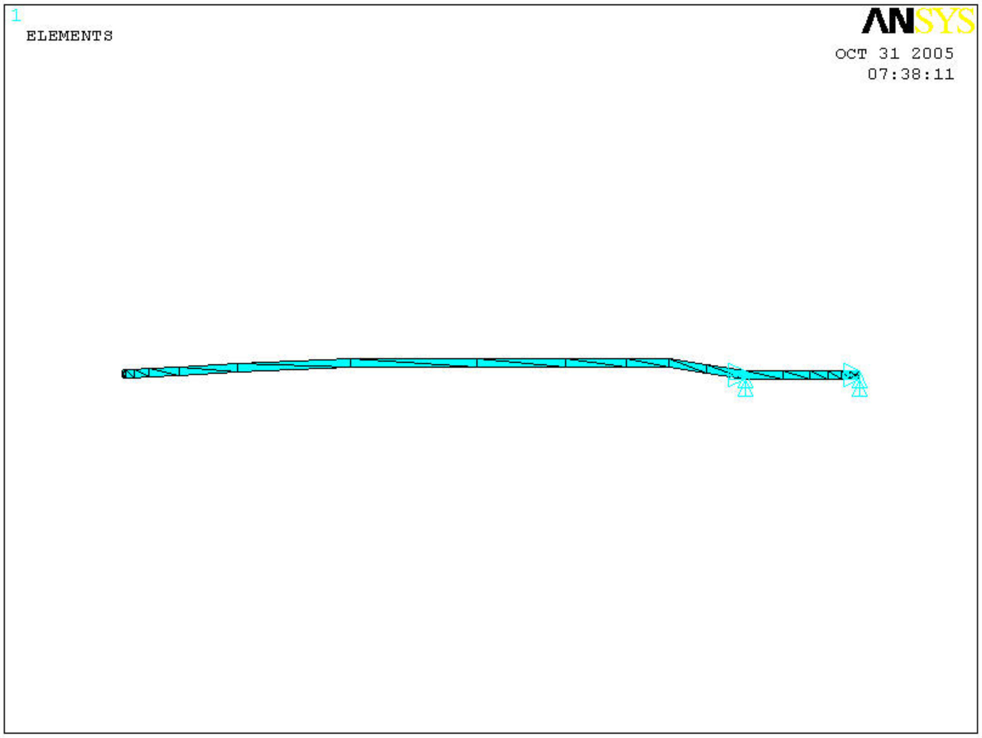

Figure 3. Axisymmetric FE model of Diaphragm 2

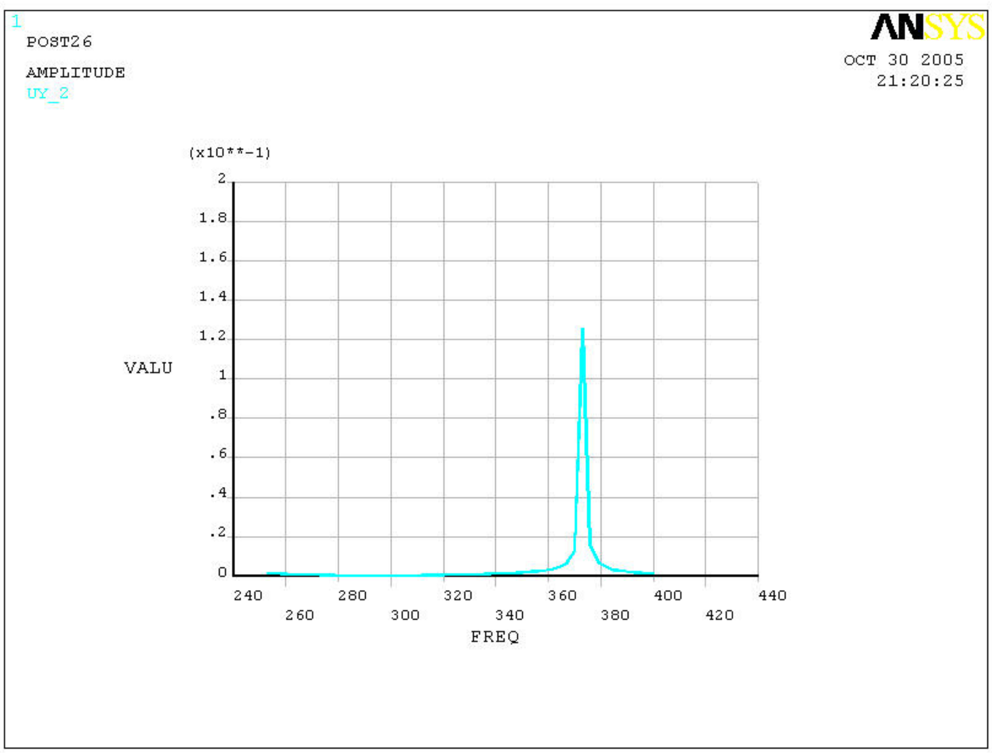

Figure 4. Harmonic Analysis Results of Model 1 (amplitude in mm)

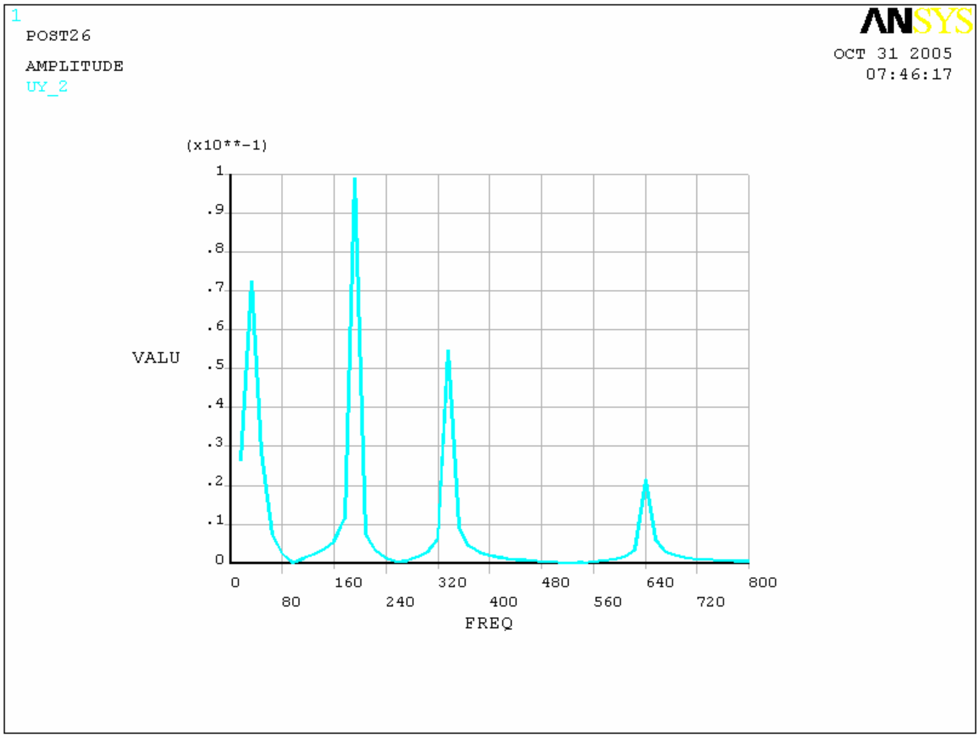

Figure 5. Harmonic Analysis Results of Model 2 (amplitude in mm)

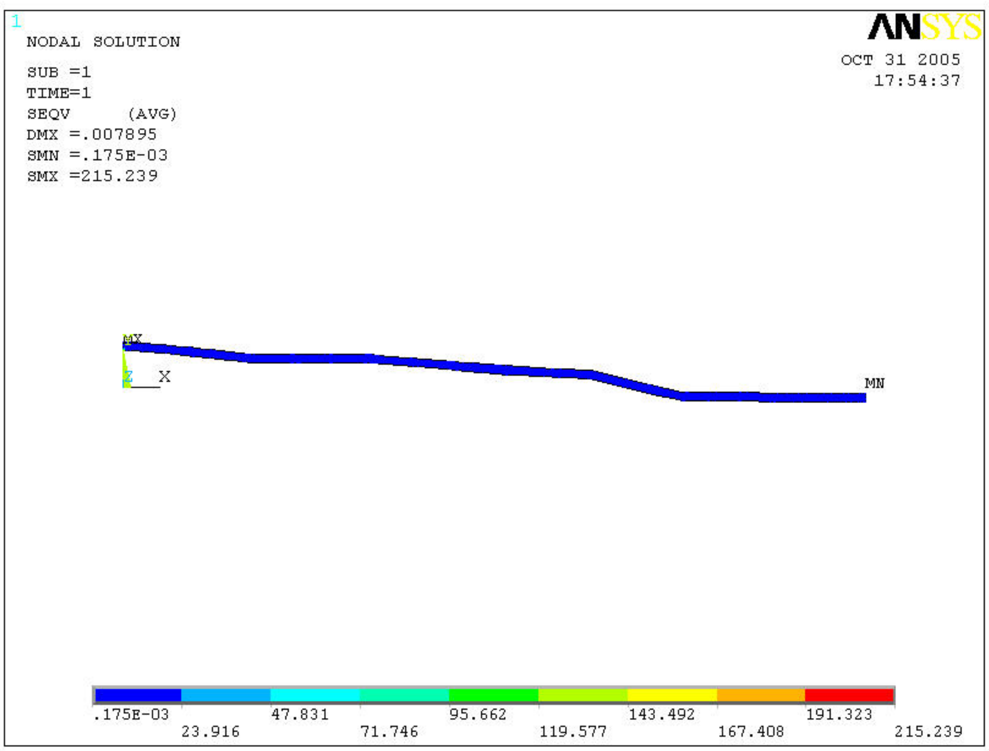

Figure 6. von-Mises stress Distribution

Analysis & Results

The F.E. model of diaphragm (Fig. 2) has the following properties.

Table 2 Analysis Variables

Element type	Plane2 – Axisymmetric (Triangular element)
No. of Nodes	8390 nodes
Constraints	Edge – All DoF, Center – UX
Electro-magnetic excitation force	1.66 N

The modal analysis of the diaphragm (fig.2) yielded in the following frequencies.

Table 3 Modal Analysis Results

1.	16.80 Hz
2.	156.68 Hz
3.	227.72 Hz
4.	385.47 Hz
5.	456.62 Hz

The harmonic analysis carried out on the same diaphragm model using the force of 1.66 N, resulted in the amplitude given in fig.4. The harmonic response shows that the significant amplitude of vibration is 385 Hz. The noise frequencies could be the second or third harmonic of this frequency. The amplitudes at other frequencies are negligible The table below indicates the frequency of maximum amplitude (resonance condition) and also the deviation in the results from the actual value obtained from a FFT analyzer. The results of the two diaphragm models are given in the table below (Table 4) and the corresponding amplitude plots are given in Fig. 4 and Fig. 5.

Table 4 Comparison of the Analytical and Experimental Values

Diaphragm Model	Analytical (ANSYS)	Experimental (FFT Analyser)	% Deviation
Fig.2	385 Hz	390 Hz	1.28
	373 Hz (additional mass)	380 Hz	1.84
Fig.3	192 Hz	190 Hz	1.05

The results show that the experimental and the theoretical resonant frequencies of the two diaphragm models match. The axisymmetric models appear to yield satisfactory results for the resonant frequency of the diaphragm of the electric horn. The stress distribution of the diaphragm (Fig.2) is also given in fig.6. The stress diagram shows that the stress values are well within permissible limits and particular diaphragm under study can survive longer cycles of operation. In case of very high stresses, the diaphragm could be remodeled and the resonant frequency analysis could be carried out using the procedure indicated in this paper.

Conclusion

The resonant frequency of an automotive electric horn obtained from the experiments show close agreement with the analytical results obtained using ANSYS. This result is very significant as it opens up a new method to synthesize the design of horns using the CAE approach compared to the time-consuming trial and error approach. Apart from the reduction in the development time for new horns, this method can also be extended to evolve alternative designs to arrive at an optimized solution.

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