

Investigation of Natural Frequency and Modal Analysis of Disc Brake rotor of Cast Steel Material using FEA and EMA

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ABSTRACT:- This study incorporates the FEA and EMA analysis of squeal which is disc brake rotor of Cast steel material, the different parameters which are responsible for squeal in the braking system have been analysed with the help of experimental modal analysis for Free-free condition and FEA is done with their boundary conditions. “Brake squeal” means noise occurs when the speed of the vehicle is below 30km/h and braking pressure is below 2Mpa, which radiates the noise in 1kHz to 16 kHz audible frequency range. As increasing the demands of vehicle gives understanding of disc brake importance squeal tends to affect human comfort and vehicles warranty by minimizing the squeal. This Experimental work is accomplished with the help of FFT analyser. The obtained results are validated with these two techniques.

KEYWORDS – Disc brake, Brake squeal noise, FEA analysis, Cast steel, FFT analyser.

I. INTRODUCTION

A disc brake is wheel brake which slows the rotation of the wheel by the friction caused by pushing brake pads against a brake disc with a set of callipers. Disc brake noise and vibration generating during braking is an important economic and technical issue in the automotive industry. In fact brake noise is not safety issue and also the little impact on braking performance, it gives customers the impression of underlying quality problems of the vehicle. Basically, squeal noise which usually occurs in the frequency range between 1 kHz to 16 kHz. It is probably generated at low vehicle speed (below 30km/h) and at low brake pressures (brake line pressure below 2 MPa).^[5] The squeal noise in disc brake is produced by instability due to the friction forces leading to self excited vibrations that result in audible noise. In last few years, researches were directed towards understanding, identifying critical factors and possibly in reducing the effect of squeal. It is essential to get knowledge of mechanisms generating squeal to the extensive research and development work to reduce this problem. Grate efforts had been made in gaining physical insight into brake squeal mechanisms and causes in earlier years and present brakes have become quieter. However, squeal still occurs frequently in brake system and therefore much work required to carry out. Thus the disc brake squeal has been a challenging problem due to its immense complexity which is very delicate to variables including corner component design, component interaction, usage history and many operating and environmental condition.

Generally, brake noise can be classified into many categories based on either the occurring frequencies or excitation sources. So brake noise is classified as a function of frequency and there are three groups introduced by namely; low frequency noise, low-frequency squeal and high-frequency squeal.

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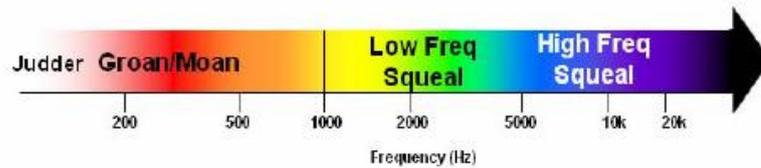


Fig.1. (a) Classifications of brake noise

Fig.1. (a) Shows the Classifications of brake noise with different range of squeal frequencies as per their classifications.

- Low-frequency disc brake noise typically occurs in the frequency range between 100 and 1000 Hz and has different types namely; groan moan and howl. This type of noise is caused by friction material excitation at the rotor and lining interface. The energy is transmitted as a vibratory response through the brake corner and couples with other chassis components.
- Low-frequency squeal is generally classified as a noise having a narrow frequency bandwidth in the frequency range above 1000 Hz.
- High-frequency brake squeal is defined as a noise which is produced by friction induced excitation causing by coupled resonances of the rotor itself as well as other brake components. It is typically classified as squeal noise occurring at frequencies above 3 kHz.

Among the different types of brake noise, squeal noise, because of its higher frequency contents, is the most troublesome and irritant one to car passengers and the environment, and is expensive to the brakes and car manufacturers in terms of warranty costs.^[5]

II. MATERIALS AND METHODS

A detailed three dimensional FE model of a commercial disc brake rotor was developed considering the realistic dimensions for better correlation of the consequences with the experimental. The Disc brake rotor was examined considering the free-free boundary conditions as it allows the structure to vibrate freely without interference of the other parts. It also facilitates better visualization of mode shapes associated with natural frequency. For validation of FE model one must recognize the dynamic properties as modulus of elasticity, density and Poisson's ratio of the components. Only linear behaviour is viewed in a modal analysis while Non-linear properties are neglected.^[6]

III. FE MODAL ANALYSIS OF BRAKE ROTOR

Modal analysis of disc brake rotor has been carried out for the materials Cast steel (CS) as it is one of the most essential part of the brake system which contributes more participation percentage in the generation of squeal noise. First Fifteen modes are extracted for the disc brake rotor for predicting the natural frequencies. Solid 45-3D structural solid element is utilized for the three-dimensional modelling of structure. The element is defined by eight nodes having three degrees of freedom at each node. Role of element shape and order of interpolation decides the element selection.

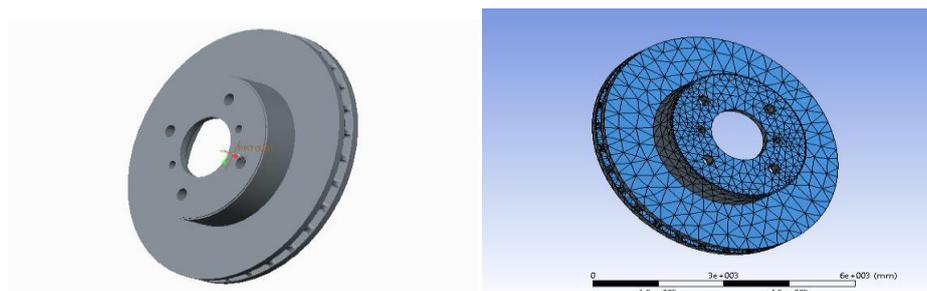


Fig. 2 (a) CAD model of Disc brake rotor (b) FEA model of Disc brake rotor

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This fig.2 (a) shows the CAD model of Disc brake rotor which is created in the Pro-E software which used for analysis. (b) shows the FEA modal of Disc brake rotor with meshing of disc brake rotor which is made in Ansys13.

IV. EXPERIMENTAL MODAL ANALYSIS (EMA) PROCEDURE

The disc of a brake rotor was tested through the FEA & EMA with free – free boundary conditions. The observational approach to investigate the way patterns and natural frequencies of the structure through impact hammer test consists of the next steps.

1. Generation of model.
2. Model test setting
3. Divide the structure inadequate number of points with the appropriate special distribution.
4. Shake up the structure with impact hammer.
5. Taking the measurements
6. Analysis of measured output data.
7. Establishment with the FEM data.

The test equipment used for the experimentation is the Fast Fourier Transform (FFT) with sixteen channels along with data acquisition system made of Scadas Front End. The structure was excited using impact hammer (Dytran Make 5800B3) at all predefined locations as indicated in fig. 3 and the response was collected using tri-axial accelerometer (PCB T356A02 & 356B21) at an identified driving point transfer function (DPTF) location. The type of EMA is known as the Frequency Response Function (FRF) method which evaluates the input excitation and output response simultaneously. The essence of all frequency response functions (FRF's) was resolved to extract natural frequencies and mode shapes. Fig.3 shows the experimental modal analysis set up for rotor.

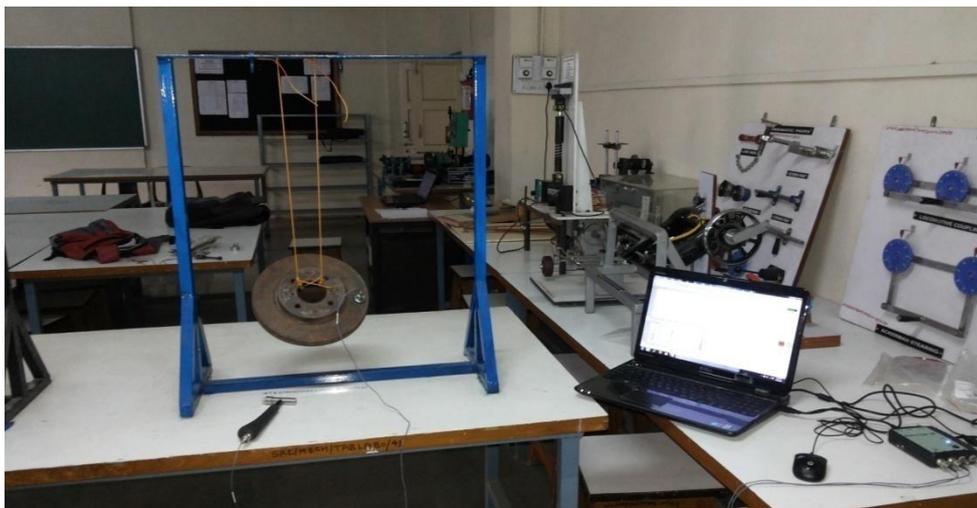


Fig. 3 (a) Experimental setup with Free-Free condition for Disc brake rotor for EMA

Fig.3 (a) Shows the Experimental setup with Free-Free condition for Disc brake rotor for EMA which is done by using the impact hammer (Dytran Make 5800B3) and tri-axial accelerometer (PCB T356A02 & 356B21) with Fast Fourier Transform (FFT) with sixteen channels along with data acquisition system made of Scadas Front End.

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V. RESULTS AND DISCUSSION

Natural frequencies obtained for disc brake rotor of cast steel material using FEM for fourteen modes are presented in the table 1. It is observed that the Cast steel has acceptable lower natural frequency for fourteen modes with the help of FEA. In fact, as per the definition of squeal range prescribed by the various researchers and experts found in the literature, Cast steel does not much contribute to the generation of brake squeal. Finally, it is noted that Cast steel is considered as the suitable material for the disc brake rotor.

Table 1. (a) Natural frequency of CS material of Disc brake rotor.

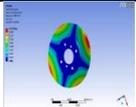
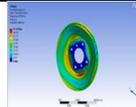
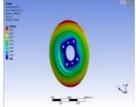
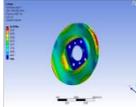
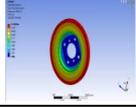
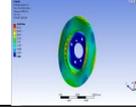
Mode	Natural Frequency(Hz)	Mode	Natural Frequency(Hz)
1	1370	8	3151.5
2	1498.1	9	4174.9
3	1648.9	10	4203.1
4	2386.1	11	4240.2
5	3006.4	12	4761.7
6	3020.7	13	4780.3
7	3126.3	14	4784.8

Above table 1, (a) Shows the natural frequency of Cast steel material of disc brake rotor with their each different mode shapes.

Confirmation has also pulled in for the effects of natural frequencies of CS materials of the same model (Mode1) obtained in the FEA in terms of damping ratio coefficients which is the ratio of modulus of elasticity and compactness. For Gary C.I, modulus of elasticity (E_b) = 205Gpa and density (ρ_b) = 7800 Kg/m³. Thus the ratio of natural frequencies and damping ratio coefficient of the materials is equal to 0.7 and are calculated by using the relation f_a/f_b and $\sqrt{E_a \times \rho_b} / \sqrt{E_b \times \rho_a}$ respectively.

As the ratio between natural frequencies of CS is equal to the damping ratio coefficient, which is the ratio of modulus of elasticity and density, therefore the modes of frequencies obtained through Finite element modelling are correct.

Table2. (a) Comparison of FEM and EMA Results for a Disc material Cast steel.

Mode No.	Natural Frequency FEA	Natural Frequency EMA	Mode shapes	Mode No.	Natural Frequency FEA	Natural Frequency EMA	Mode Shapes
1	1370	1355		8	3151.5	3180.4	
2	1498.1	1464.7		9	4174.9	4130.7	
3	1648.9	1630.6		10	4203.1	4199.3	

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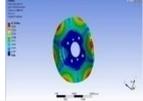
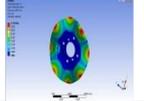
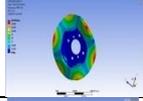
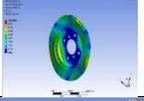
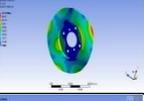
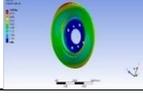
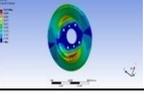
4	2386.1	2367.6		11	4240.2	4215.8	
5	3006.4	2990.5		12	4761.7	4698.6	
6	3020.7	3012.8		13	4780.3	4774.6	
7	3126.3	3092.2		14	4784.8	4860.6	

Table 2. (a) Shows the comparison of FEA and EMA results for a disc material Cast steel for different fourteen modes. The FEM analysis deviation is considered acceptable as it fits within the scope. (Most of the deviation is zero) Small deviation is noted due to component production variability. (Geometric and material variations).

VI. CONCLUSION

The material properties of cast steel disc brake play an very important role towards the vibration mode patterns. From this finite element analysis, the result proves that the ratio between Young's modulus over density increases the natural frequencies of the disc with respect to the number of modes shapes and disc stiffness. From above comparing results of FEA and EMA analysis we conclude that the range of natural frequency of cast steel material does not much contribute to the generation brake squeal. So cast steel material is considered as best suitable material for disc brake rotor.

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