ISSN 2395-1621

Optimization and Analysis of Disc Brake Rotor to Supress Squeal

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ABSTRACT

This paper reviews the most important research work carried out on the disc brake squeal and find the factors affecting on it. This study incorporates the FEA analysis of squeal, the different parameters which are responsible for squeal in the braking system have been analyzed for different working conditions and effort were been carried out to reduce the squeal noise by minimizing given condition. Also FFT analysis is carried out for disc rotor to find out the natural frequencies."Brake squeal" is a noise occurs when the speed of the vehicle is below 30km/h and braking pressure is below 2Mpa. Disk brake squeal noise is generated due to friction-induced vibration caused by the dynamic instability of the brake system, 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. So it is important factor which we reduce both. The present work shows the study of the disc brake rotor materials which is of cast iron, cast steel and carbon-carbon composite.

Keywords— **Disc brake squeal, FEA, EMA, Cast iron, Cast steel, Carbon-Carbon composite.**

ARTICLE INFO

Article History

Received :18th November 2015

Received in revised form :

19th November 2015

Accepted : 21st November , 2015

Published online :

22nd November 2015

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 calipers. 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.

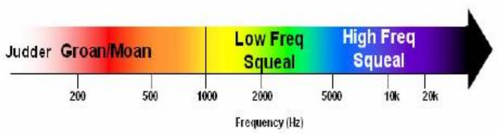


Fig.1. Classifications of brake noise

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]

I. MATERIALS OF DISC ROTOR

Generally in the all vehicle disc brake rotor is of cast iron material, because this material gives better performance than other material. So in this study we use three different materials i.e. 1) Cast iron

2) Cast steel

3) CC- Composite materials

II. MATERIAL PROPERTY TABLE

TABLE 1

PROPERTIES OF MATERIALS

Material properties	Cast iron	Cast steel	CC-Composite
Density (kg/m^3)	7100	7800	1800
Specific heat (J/Kg k)	540	420	1420
Poisons ratio	0.25	0.3	0.33
Thermal conductivity (W/m K)	57	47	50
Thermal expansion (10^{-6}/k)	11	15	0.31
Young modulus (MPa)	103000	205000	50200
Coefficient of friction	0.0667	0.0667	0.0667

III. DISC BRAKE ROTOR

The disc brake rotor is created in Pro-E CAD software with specific dimensions which is having for actual disc. Fig 2 (a) shows the 2D model of rotor with specific dimensions, (b) shows the 3D model of rotor which developed in Pro-E, (c) shows the FEA disc brake rotor model with meshing.

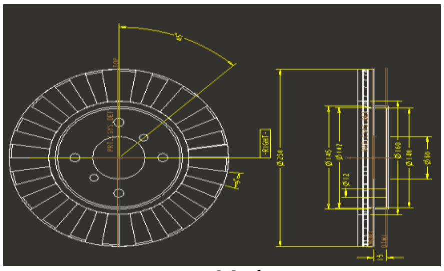


Fig. 2 2D model of Disc rotor

Fig. 3 3D model of Disc rotor

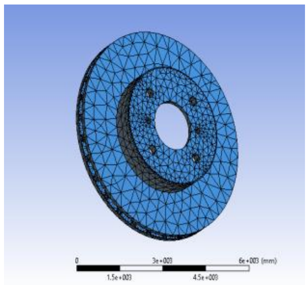


Fig. 4 FEA model of Disc rotor

IV. FE MODAL ANALYSIS OF BRAKE ROTOR

Modal analysis of disc brake rotor has been carried out for the materials Cast iron, Cast steel and CC-composite 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 Fourteen 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 modeling 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.

VI. NATURAL FREQUENCIES OF CAST IRON, CAST STEEL AND CC-COMPOSITE MATERIALS (FEA)

TABLE 2

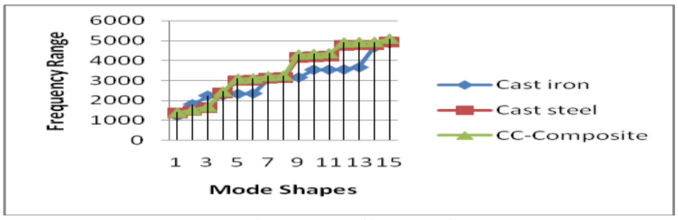
Natural frequency of each material with mode shapes.

Mode shapes	Cast iron	Cast steel	CC-Composite
	Natural frequencies of materials		
1	1212.1	1370	1412.2
2	1803.2	1498.1	1543.2
3	2236.6	1648.9	1698.6
4	2246.7	2386.1	2458
5	2321.3	3006.4	3096.9
6	2341.3	3020.7	3111.7
7	3077.6	3126.3	3220.4
8	3123.2	3151.5	3246.4
9	3152.9	4174.9	4300.6
10	3540.5	4203.1	4329.7
11	3542.3	4240.2	4367.9
12	3554.1	4761.7	4905.1
13	3662	4780.3	4924.3

14	**4672.4**	**4784.8**	**4928.9**

Table 2 shows the natural frequency difference of each material with same mode shapes. Also this following chart Graph (a) shows that the actual difference in the natural frequency of materials. With natural frequency range Vs mode shape.

A]Natural frequency comparison graph of materials (FEA)



Graph 1 Natural frequency difference of all materials.

VII. RESULTS AND DISCUSSION

Natural frequencies obtained for disc brake rotor of Cast iron, Cast steel and CC-Composite materials using FEM for modes are presented in the table 1. From this, it is observed that the Cast iron, Cast steel and CC-Composite materials 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, All these three materials does not much contribute to the generation of brake squeal.

Graph 1 shows the actual difference in their natural frequency for all three materials with their specific range of mode shapes.

VIII. EXPERIMENTAL MODAL ANALYSIS (EMA) PROCEDURE FOR CAST STEELMATERIAL[10]

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.5 shows the experimental modal analysis set up for rotor.

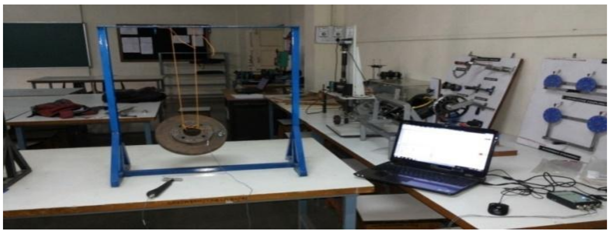


Fig. 5 Experimental setup with Free-Free condition for Disc brake rotor EMA[10]

IX. COMPARISON OF DISC BRAKE ROTOR RESULTS.

Natural frequencies obtained for disc brake rotor of all materials using FEM for modes are presented in the table 1. While table 2 shows the comparison of mode shapes with their FEM and EMA natural frequency results. From this study, 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.

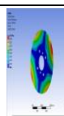
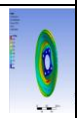
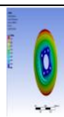
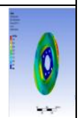
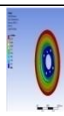
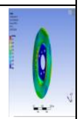
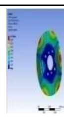
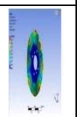
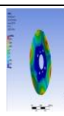
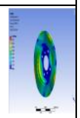
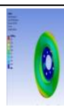
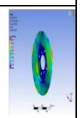
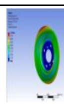
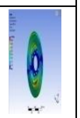
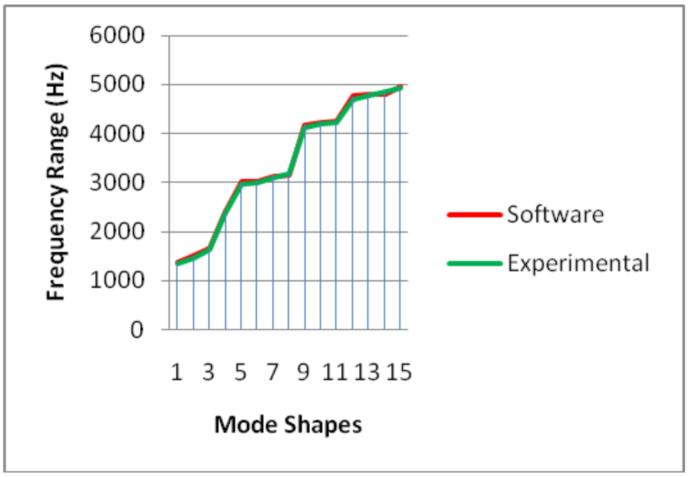
Mode No.	**Natural Frequency FEA**	**Natural Frequency EMA**	**Mode shape**	**Mode No.**	**Natural Frequency FEA**	**Natural Frequency EMA**	**Mode Shapes**
1	**1370**	**1355**		**8**	**3151.5**	**3180.4**	
2	**1498.1**	**1464.7**		**9**	**4174.9**	**4130.7**	
3	**1648.9**	**1630.6**		**10**	**4203.1**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

Comparison of FEM and EMA Results for a disc material Cast steel.

A. Comparison graph of FEM and EMA Results for a Cast steel material.



Graph 2 Comparison graph of FEM & EMA results.

X. WEIGHT OPTIMIZATION

Carbon–carbon composites use carbon fibers in a carbon matrix. These composites are used in very high-temperature environments of up to 6000°F, (3315°C), and are 20 times stronger and 30% lighter than graphite fibers.

Carbon is brittle and flaw sensitive like ceramics. Reinforcement of a carbon matrix allows the composite to fail gradually and also gives Advantages such as:-

1. Ability to withstand high temperatures
2. Low creep at high temperatures
3. Low density
4. Good tensile and compressive strengths
5. High fatigue resistance
6. High thermal conductivity
7. High coefficient of friction.

Drawbacks include:-

1. High cost
2. Low shear strength
3. Susceptibility to oxidations at high temperatures.

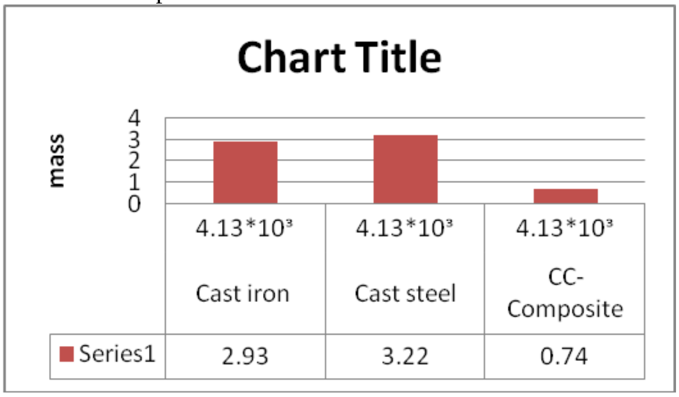
TABLE 4

Comparison for mass properties of all materials

	Materials		
	Cast iron	**Cast steel**	**CC-composite**
Volume	**$4.13*10^5$ mm^3**	**$4.13*10^5$ mm^3**	**$4.13*10^5$ mm^3**
Surface area	**$1.90*10^5$ mm^2**	**$1.90*10^5$ mm^2**	**$1.90*10^5$ mm^2**
Mass	**2.93 kg**	**3.22 kg**	**0.74 kg**
Weight	**28.74 N**	**31.58 N**	**7.25 N**

As the table 4 shows that the volume, Surface area, Mass and Weight of the disc brake rotors for all these three materials. So from table and the literature we found that the after comparison of all three material CC-Composite material have an lightweight material than other two materials, so its help to reduce the weight of the disc brake assembly with this consideration overall weight of the vehicle wheels is also optimize. Graph 3 shows the graphical representation of the all three materials Mass Vs volume of disc brake rotor material.

B. Comparison graph of Cast iron, Cast steel and CC-Composite materials mass.



Graph 3Comparison of Mass Vs Volume of all materials

XI. CONCLUSION

Based upon above study results the following conclusions are made

- Looking to the observed natural frequency of these three materials shown in table 2, frequency are within the limit. i.e. under the natural frequency range of squeal frequency 1KHz.
- From the experimental investigation of natural frequency is found to be within the range. i.e. under 1KHz.
- From the optimization study we conclude that the CC-Composite material is better for future use due to its advantages and weight.

Overall it is concluded that the cast steel and CC-Composite materials frequency are within the squeal frequency range, so this two materials are best suitable materials.

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