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Vibration Analysis of Disc Brake by Using FEA and FFT Analyzer

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Abstract – *A disc brake is a type of brake that uses calipers to squeeze pairs of pads against a disc or rotor to create friction. This action retards the rotation of a shaft, such as a vehicle axle, either to reduce its rotational speed or to hold it stationary. The energy of motion is converted into waste heat which must be dispersed. The disc brake is a device for slowing or stopping the rotation of a wheel. Repetitive braking of the vehicle leads to heat generation during each braking event. In our project topology optimization and modal analysis of existing 2-wheeler disc brake is performed. The 3D model will be drawn with the help of CATIA software. In modal analysis disc brake with three different shape holes are performed namely original, elliptical and larger circular hole. Hence, modal analysis is performed on three different shapes to evaluate mode shapes and natural frequency. So, optimum model is selected from these analyses. Also, experimental analysis using FFT technique (impact hammer test along with accelerometer) to determine mode shapes and natural frequency and comparison with FEA results are performed. Modal Analysis and of the Rotor Disc of Disk Brake is aimed at evaluating the performance of disc brake rotor of a car under severe braking conditions and there by assist in disc rotor design and analysis. Similar testing will be done using FFT analyzer method for experimental stress analysis.*

Key Words: **Repetitive Braking, Vibration, FEA, ANSYS.**

1.INTRODUCTION

In today's growing automotive market, the competition for better performance vehicle is growing enormously. The racing fans involved will surely know the importance of a good brake system not only for safety but also for staying competitive. The disc brake is a device for slowing or stopping the rotation of a wheel. A brake disc usually made of cast iron or ceramic composites includes carbon, Kevlar and silica, is connected to the wheel and the axle, to stop the wheel. A friction material in the form of brake pads is forced mechanically, hydraulically, pneumatically or electromagnetically against both sides of the disc. This friction causes the disc and attached wheel to slow or stop. Generally, the methodologies like regenerative braking and friction braking system are used in a vehicle. A friction brake generates frictional forces as two or more surfaces rub against each other, to reduce movement. Based on the design configurations, vehicle friction brakes can be grouped into drum and disc brakes. If brake disc is in solid body the heat transfer rate is low. Time taken for cooling the disc is low. If brake disc is in solid body, the area of contact between disc and pads are more. In disc brake system a ventilated disc is widely used in automobile braking system for improved cooling during braking in which the area of contact between disc and pads remains same.

2. LITERATURE REVIEW

Khaled R.M. Mahmoud et al. [1] mathematical models to study the dynamic behavior of a wedge disc brake are presented in this article. The friction coefficient has a significant role in the brake system dynamics especially, self-energized. A set of experiments have been conducted to formulate mathematical equations relating the friction coefficient, normal force and sliding speed. The effect of main operational parameters of a wedge disc brake such as normal force, sliding speed and wedge angle on the dynamic behavior and their comparisons with conventional disc brake system are investigated. Setting time and frequency response are the main performance indicators to investigate the dynamic behavior of a disc brake. The results indicate that friction coefficient significantly influence the resonance frequency and setting time of wedge disc brake shoe factor. However, the coefficient of friction has a negligible effect on setting time or resonance frequency of conventional disc brake. The effect of sliding speed on a wedge disc brake dynamic is somewhat considerable but it has a little effect on the dynamics of a classical disc brake.

Daanvir Karan Dhir et al. [2] the kinetic energy of the vehicle is converted into mechanical energy while braking which leads to heat dissipation and temperature rise of the disc and the disc-pads. The aim of this investigation was to study the rise in temperature of an automotive disc brake at the time of braking and its effect on disc durability using finite element method. Application of a specified braking torque on the rotor led to generation of heat flux. The heat flux generated and the heat transfer coefficient taken into consideration were numerically analyzed, which were then used to calculate the rotor rigidity, maximum temperature rise on the disc rotor. The rotor was further loaded with thermo-mechanical cyclic stresses which were used to analyze the durability and fatigue factor of safety of disc. The influence of variations in disc rotor geometry i.e. holes and airfoil vents in comparison to a simple flange type disc were studied and their effect on maximum temperature rise and disc durability has been investigated by modeling and conducting FEM techniques in Solid works and ANSYS respectively.

Xingwei Zhao et al. [3] creep groan in automotive disk brakes is a prevalent low frequency vibration phenomenon. It may occur when a car accelerates slowly from standstill with slightly operating brake as it might be the case for cars with automatic transmission or at slopes. The origin of creep groan is friction-induced vibrations from the pad-disk contact in the brake resulting in stick-slip limit cycles. These stick-slip limit cycles may excite comprehensive structural vibrations in the car leading to structure-borne sound and passengers' discomfort. The investigations in the present paper focus on the origin of this phenomenon - by considering set-ups concentrating on the pad-disk contact - and the possibility of suppressing the stick-slip limit cycle vibrations by excitation with piezoceramic actuators. Therefore, two test set-ups are investigated. The simpler one just uses disk, brake pads and caliper from an industrial brake, while carrier and suspension are replaced. The other one considers a complete brake including serial carrier and suspension. Low frequency stick-slip limit cycles could be observed in both test set-ups and a corresponding nonlinear model including the bristle friction law is developed for both systems.

Chin An Tan et al. [4] this paper presents a dynamic stability study of a novel brake disc design consisting of periodic lattice truss substructures. An integrated approach of theoretical modeling, experimental modal analysis, and finite elements methods is employed in this investigation to understand the squeal characteristics. The brake system is analytically modeled by a rotating annular disc subjected to in plane frictional loads. Natural frequencies and forced response of the brake disc are obtained and validated by finite elements results. Experimental modal analysis of the lattice brake rotor/pad system with free-free boundary conditions is performed to obtain the modal properties of the brake rotor as inputs to the finite elements model.

Yan Shui et al. et al. [5] the ventilated disc brake of vehicles was selected as the objective of this study, which was built on 3D modeling technology. Through establishing thermo-structural coupling model, this study analyzed the transient temperature field of automobile brake under the condition of hard braking. Meanwhile, the test of hard braking was carried out on professional platform of vehicle test bench in this paper, and temperature curves of brake disc in radial and circumferential directions were obtained. By comparison, the experimental values and simulation values were basically equal. The rationality of the selected finite element analysis (FEA) was attributed, which provided a better theoretical basis for further experimental analysis.

3. EXPERIMENTATION

3.1 Problem Statement

High stresses are seen in brake disk due to friction & also the vibrations will be increased so to reduce the vibrations, optimization & modal analysis will be carried out. So, in current study modal analysis of disc brake with different shape is performed to obtain optimized model without disturbing its existing natural frequency. Hence, FEA analysis results are compared with experimental results using FFT analyzer technique.

3.2 Objectives

- To prepare CAD design of existing disc brake using CATIA V5 software.
- To obtain optimized model of existing disk brake (by making larger holes and elliptical) shape and comparing with original model.
- To determine mode shapes, natural frequency, deformation in disc brake through finite element analysis by modal analysis.
- Experimental analysis of disc brake to obtain mode shapes and natural frequency by modal analysis using FFT analyzer technique.
- Validation of experimental and analytical results.

3.3 Methodology

1. The CAD model is prepared in CATIA V5 R20.
2. The modal analysis is performed in ANSYS 19.0. Modal analysis is performed to determine mode shapes, natural frequency, deformation of all models (by large holes and elliptical) shape to get optimized models.
3. The best optimized is to be obtained and compared to the existing model.
4. Experimental analysis of the disc brake rotor will be performed by fixing one side to determine mode shape and natural frequency using FFT analyser technique.
5. Comparison of experimental and numerical results.

3.4 FEA Analysis

Material selection for disc brake: Grey cast iron

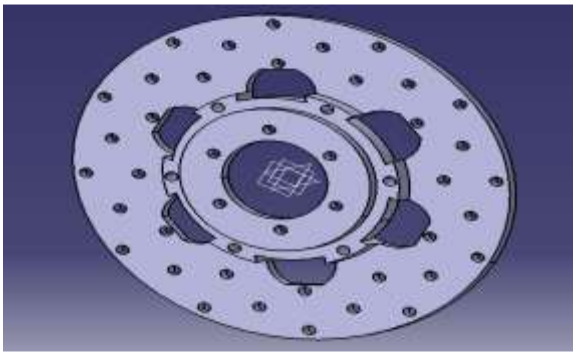

Fig -1: Catia model of disc.

Solid model of the disc brake assembly is shown in fig.1, consisting of brake pad along with arrangement of circular holes.

	A	B	C
1	Property	Value	Unit
2	Material Field Variables	Table	
3	Density	7200	kg m^-3
4	Isotropic Secant Coefficient of Thermal Expansion		
5	Coefficient of Thermal Expansion	1.1E-05	C^-1
6	Isotropic Elasticity		
7	Derive from	Young's Modulus...	
8	Young's Modulus	1.1E+11	Pa
9	Poisson's Ratio	0.28	
10	Bulk Modulus	8.3333E+10	Pa
11	Shear Modulus	4.2969E+10	Pa

Fig -2: Engineering Materials Properties in ANSYS.

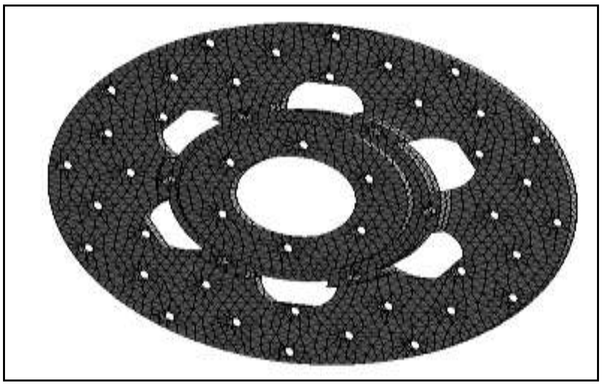

Fig -3: Meshing of Disc Brake.

In meshing of disc brake geometry, we used tetrahedral element type and get 37787 nodes and 19740 elements.

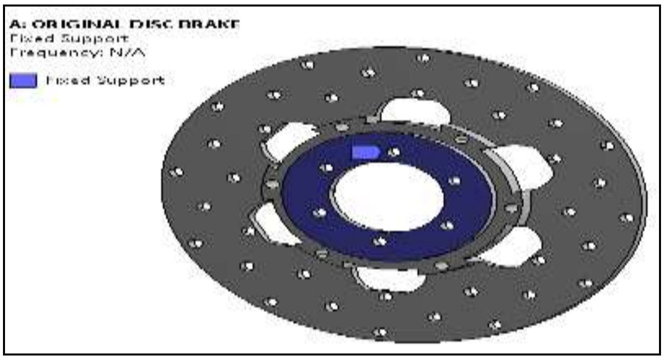

Fig -4: Boundary Conditions.

4. RESULTS AND DISCUSSION

Results for Different mode shapes

At mode 1

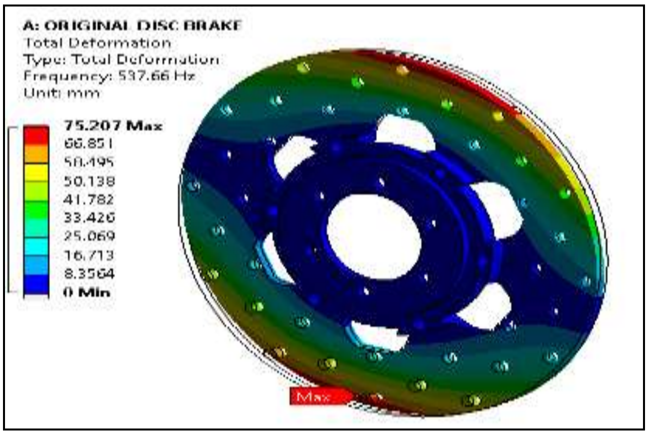

Fig -5: Natural Frequency at Mode 1.

At mode 2

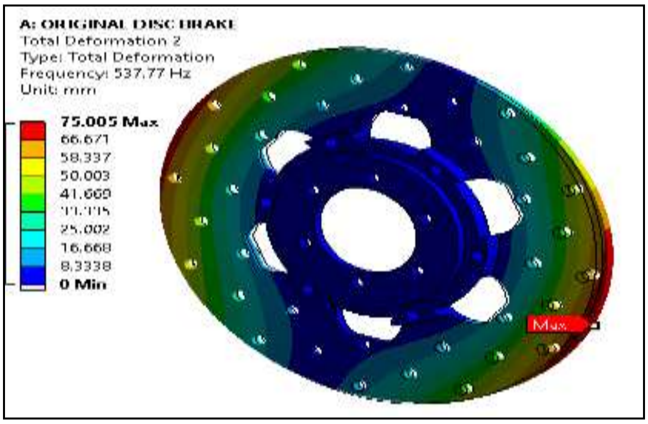

Fig -6: Natural Frequency at Mode 2.

At mode 3

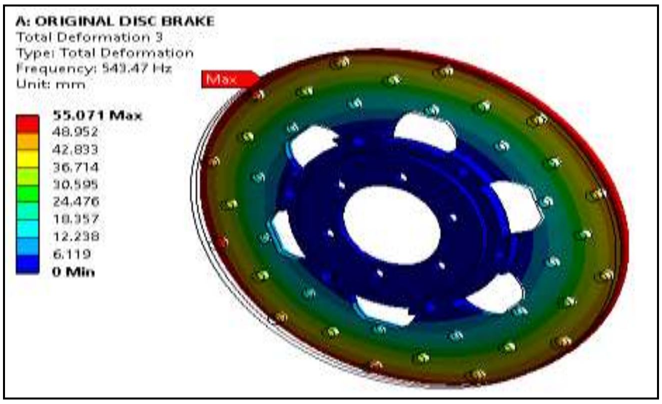

Fig -7: Natural Frequency at Mode 3.

At mode 4

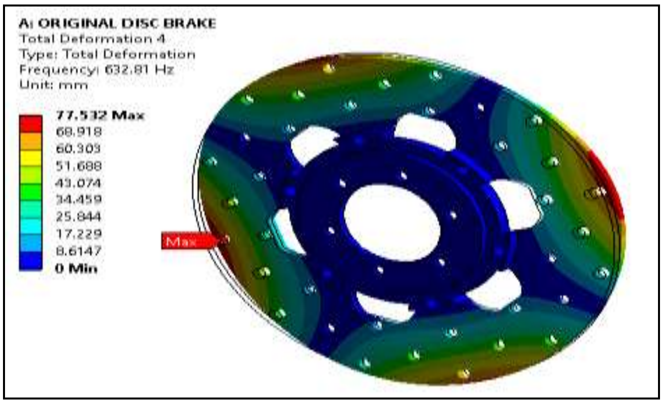

Fig -8: Natural Frequency at Mode 4.

At mode 5

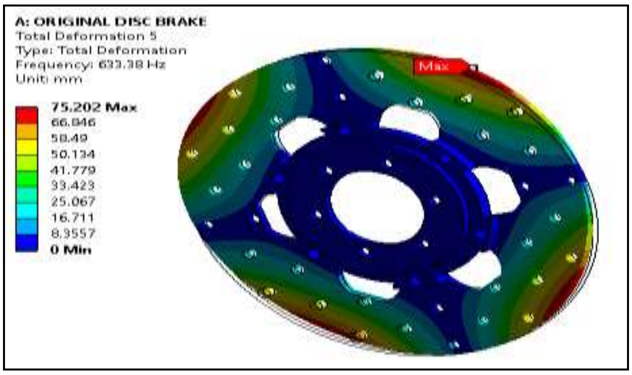

Fig -9: Natural Frequency at Mode 5.

Table -1: Natural frequency reading for 5 mode shape For Disc Brake with Elliptical Hole.

Tabular Data

	Mode	Frequency [Hz]
1	1.	540.48
2	2.	540.72
3	3.	544.36
4	4.	631.64
5	5.	632.11

Table -2: Natural frequency reading for 5 mode shape For Disc Brake with Large Circular Hole.

Tabular Data

	Mode	Frequency [Hz]
1	1.	539.14
2	2.	539.63
3	3.	543.92
4	4.	634.38
5	5.	634.82

Experimental Testing

Experimental modal analysis is performed on disc brake with elliptical shape holes to determine natural frequency and mode shapes. It is observed from above graph obtained by Fast Fourier transform (FFT) technique that maximum frequency is about 556 Hz and from ANSYS it is observed around 544.6 Hz.

Fig -10: Experimental Setup

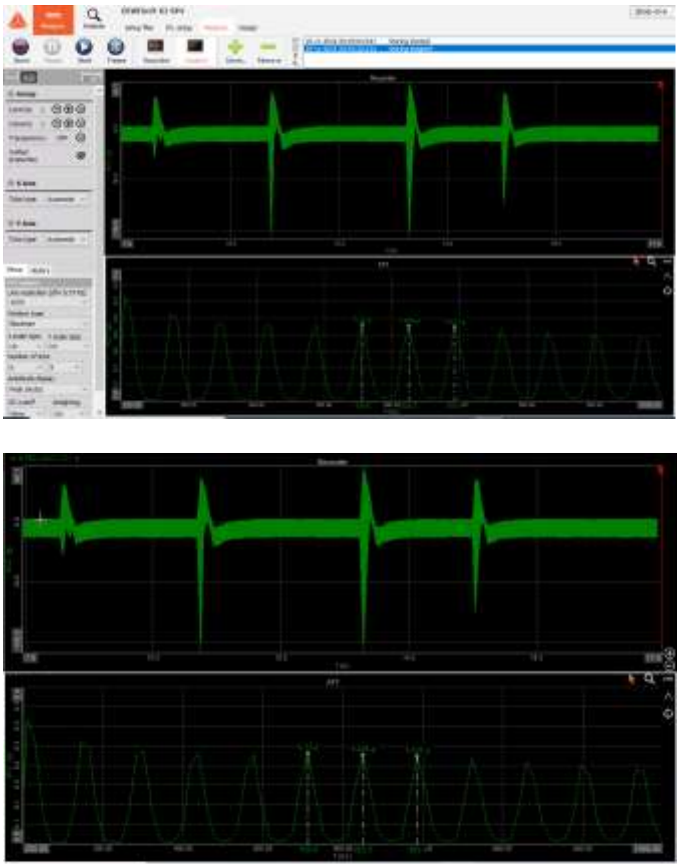

Fig -11: FFT Analyzer Results

5. CONCLUSION

By comparing the different results obtained from FEA and experimental setup, it can be concluded that,

1. Modal analysis of disc brake is performed to obtain optimized model for existing disc brake. It is concluded that after performing analysis on three different shapes (original, large circular holes and elliptical shape) holes the best optimized results are obtained with elliptical shape holes.
2. Disc brake with elliptical shape hole has more weight loss (5%) without disturbing its existing natural frequency compared to original disc, hence heat dissipation is increased and cooling effect is improved.
3. Experimental modal analysis of disc brake provided natural frequency around 556 Hz and ANSYS around 543.6 Hz. So, both frequencies are nearly same. Also, mode shape 3 frequency is observed to be severe as 50 % mass is participated in vibration.

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