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Dynamic Transient Analysis in Predicting Disc Brake Squeal

Prabhu.N[1], Sarathkumar.P[2] & Sivaraja.M[3]

[1] Assistant Professor, Dept. of Mech Engg., N.S.N. College of Engg. & Tech, Karur, India, Mail ID: vnprabhumech @gmail.com

[2] Assistant Professor, Dept. of Mech Engg., N.S.N. College of Engg. & Tech, Karur, India, Mail ID: sarathmech09@gmail.com

[3] Principal, N.S.N. College of Engg. & Tech, Karur, India, Mail ID: m.shivaraj2006@gmail.com

Abstract - *Brakes and tires are the major contributors for catastrophic failure of ground vehicles. Braking system is the utmost important besides tire to ensure the safety of users and vehicle. Automobile brake noise and vibration have become an increasing concern to manufacturers, consumers and investigators. Friction can result in a series of acoustic problems. Brake squeal may be considered to be a type of friction-induced noise. Friction-induced noise is generally divided into two categories: squeal or squeak and chatter, groan, or moan. Many studies have been performed in view to modelling the vibration phenomenon of the piston pad of the disc brake. Two different analysis methodologies using the Finite Element method are available for predicting disc brake squeal, namely complex eigenvalue analysis and dynamic transient analysis. In the present study, transient analysis of piston pad of the disc brake is performed in ANSYS to predict its dynamic vibration and noise characteristics and its dependency on the hydraulic pressure of the system. The prediction would be complete if MATLAB software is used in addition to the ANSYS software. The response signal of the pad against hydraulic pressure is captured in the ANSYS software by performing transient analysis. The captured signal is then processed with the help of MATLAB software by invoking the FFT algorithm to find out the squeal frequency during braking conditions. The present project attempts to develop a novel idea of predicting squeal in the disc brake without experimental work thus by saving money and time this method of using the capabilities of the software to predict the squeal would definitely creates an interesting atmosphere among designers and researchers.*

INTRODUCTION

In the past 30 years the automotive industry has seen a transition from drum brakes to disc brakes. This transition was made with the purpose of improving performance and reducing mass. Concurrent with this transition has been an all out effort to improve perceived quality of automobiles. The most important quality factor of brake systems can be considered brake noise.

Disc brake noise, in general, is one of the major contributors to the automotive industry's warranty costs. In most cases, this type of noise has little or no effect on the performance of brake system. However, most customers perceive this noise as a problem and demand that their dealer's fix it. Customer complaints result in significant yearly warranty costs. More importantly, customer dissatisfaction may result in the rejection of certain brands of brake systems or vehicles. The automotive industry is thus looking for new ways to solve this problem. In order to produce quality automobiles that can compete in today's market the occurrence of disc brake noise must be reduced.

Over the years, disc brake noise has been given various names in an attempt to provide some definitions of the sound emitted such as grind, grunt, moan, groan, squeak, squeal and wire brush. In general, brake noise has been divided into three categories, in relation to the frequency of noise occurrence. The three categories presented are low frequency noise, low-frequency squeal and high-frequency squeal.

Low-frequency disc brake noise typically occurs in the frequency range between 100 and 1000 Hz. Typical noises that reside in this category are grunt, groan, grind and moan. 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, but below the first in-plane mode of the rotor.

The failure mode for this category of squeal can be associated with frictional excitation coupled with a phenomenon referred to as ''modal locking'' of brake corner components. Modal locking is the coupling of two or more modes of various structures producing optimum conditions for brake squeal.

High-frequency brake squeal is defined as a noise which is produced by friction induced excitation imparted by coupled resonances (closed spaced modes) of the rotor itself as well as other brake components. It is typically classified as squeal noise occurring at frequencies above 5 kHz. Since it is a range of frequency which affects a region of high sensitivity in the human ear, high-frequency brake squeal is considered the most annoying type of noise. Brake squeal is a concern in the automotive industry that has challenged many researchers and engineers for years. Considerable analytical, numerical and experimental efforts have been spent on this subject, and much physical insight has been gained on how disc brakes may generate squeal, although all the mechanisms have not been completely understood.

This project is developed a finite element model to examine the dynamic behavior of a brake system for a range of operational parameters. This numerical model is used to investigate the effect of some operational parameters like friction coefficient, temperature and braking pressure. Then the results are validated with the experimental work on the noise study of brake pad.

Element type	Solid-20 node186
Material	1.Back plate-Mild steel(grade C45) 2.Pad- Carbon fiber reinforce carbon
Material Properties or Isotropic Properties	1.Back Plate Young's modulus – 206e3 N/mm^2 Poisson's ratio -0.35 2.Pad Young's modulus – 500 N/mm^2 Poisson's ratio -0.2
Mesh Type	Unstructured (Tetrahedral)
Number of Nodes and Elements	1.Back Plate Max node no-50735 Max Element no-31970 2.Pad Max node no-53913 Max Element no-34086
Load type	Time step load(centre circle)
Displacement	A15,A21 – Fixed All DOF

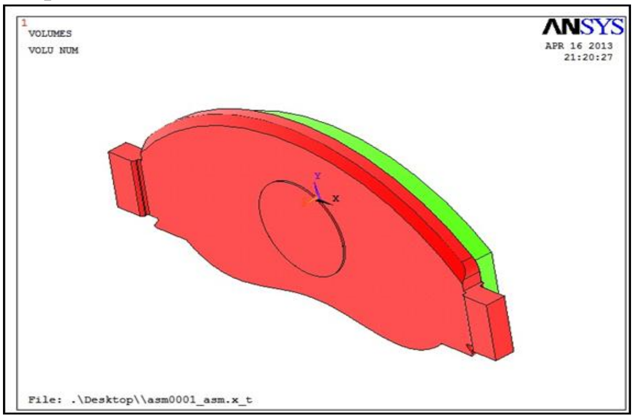
Brake pad material details

RESULTS AND DISCUSSIONS

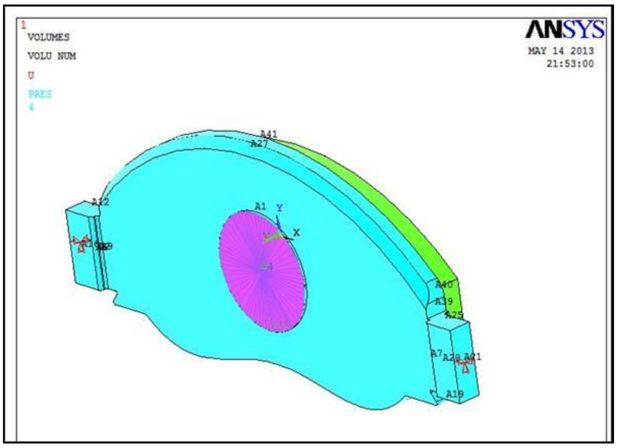
Boundary Conditions

Component	Material	Grade	Young's modulus N/mm^2	Poisson's ratio
Back plate	**Mild steel**	**C45**	**206e3**	**0.35**
Pad	**Carbon fiber reinforce carbon (c/c)**	**CCP-145-12**	**500**	**0.2**

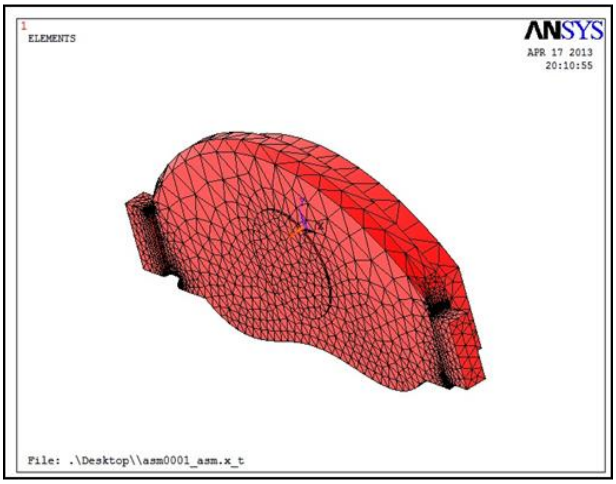
Preprocessor Results:



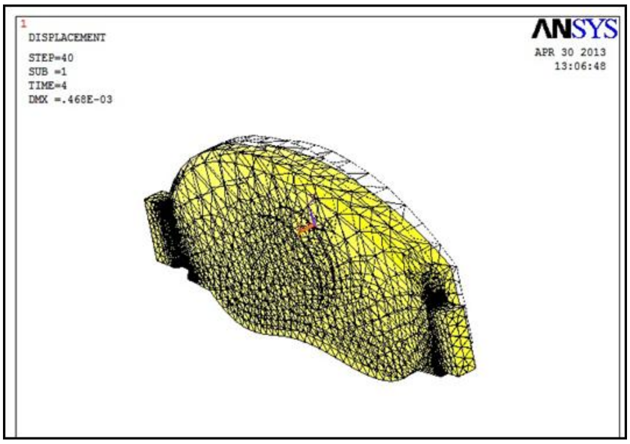
Pad volumes



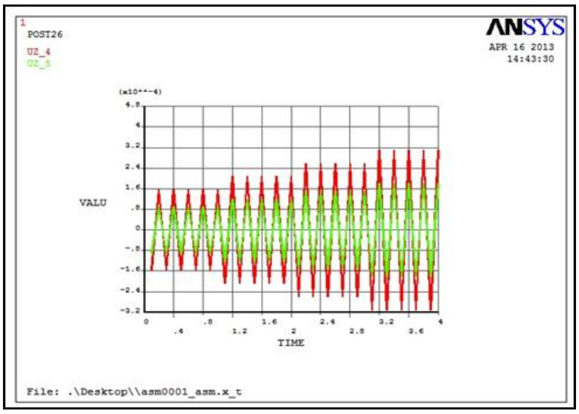
Boundary conditions



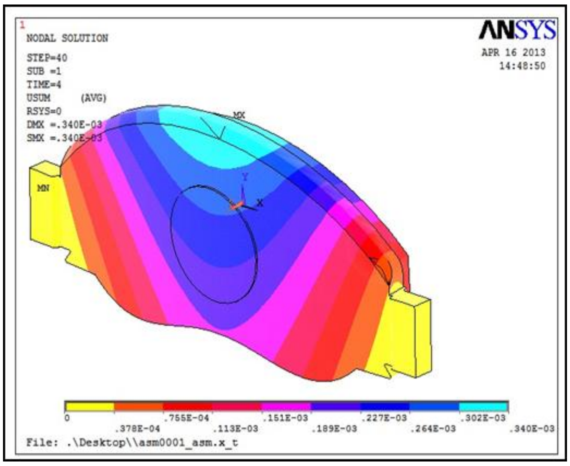
Mesh diagram



Pad deformation shape

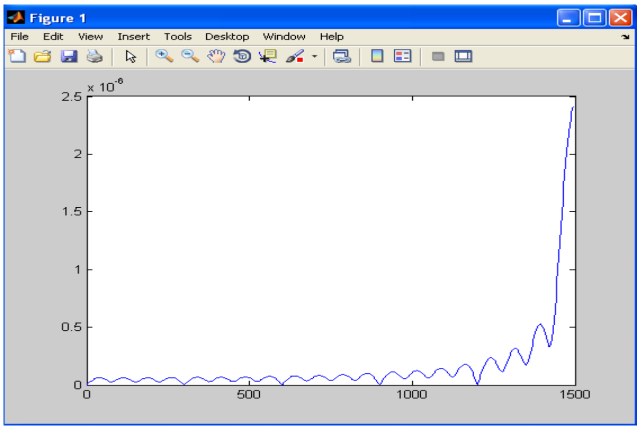


Time Vs Displacement of max node numbers



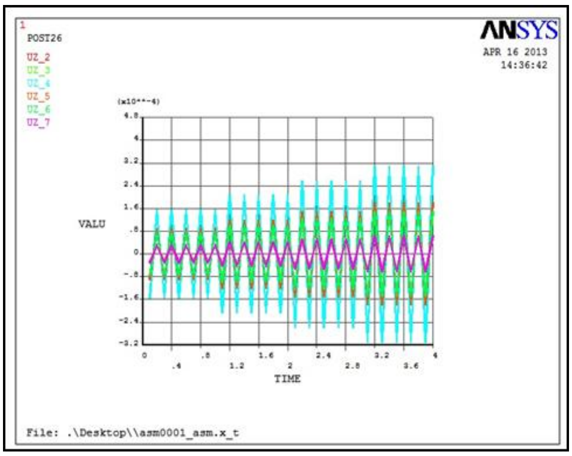
Displacement result

MATLAB Result



Frequency Vs Amplitude of pad

Time History Postprocessor results



Time Vs Displacement of all 6 nodes

Discussion about Experimental Results and ANSYS-MATLAB Results

In the experimental work, accelerometers are mounted at six positions on the pad surface to measure its response under the hydraulic pressure while applying the brake. The variation of acceleration of the pad against time is measured and then signal was processed to find the squeal frequency of the pad. A squeal frequency of 1550 Hz was obtained experimentally. Then the integration is done on the acceleration signals to find out the displacement of the pad or pad deformation as well as its maximum amplitude at the squeal frequency.

As the experimental works involves integration of accelerometers into the brake assembly which is substantially cumbersome and costly. In order to avoid the above disadvantage of the experimental way of finding the squeal frequency of the brake pad, a novel attempt was made to obtain the same objective by using ANSYS and MATLAB software. In ANSYS, the pad was excited by the linearly varying hydraulic pressure and its response against time was found from the time history post processor. The time signal obtained from ANSYS was processed in the MATLAB software by invoking the FFT algorithm to obtain the equivalent frequency response. By carrying out the FFT, squeal frequency obtained was very closer to the experimental results. So this novel method can be extended to find out the squeal frequency of pad made with any materials without requiring experimental work.

CONCLUSION

Brake squeal vibration has been a challenging problem to solve in automotive industry. Many researchers have investigated mechanisms for the generation of squeal; however, a complete explanation of squeal generation has not yet been available due to complexity of the problem. One common direction of study in brake squeal has been the numerical dynamic transient analysis predicting the instabilities of the system equilibrium.

Certain vibrations may only result in minor annoying squeals, while others may be severe enough to result in structural damage or failure. In either case, it is desirable to predict the conditions under which these vibrations arise, so that they may be controlled, or eliminated. Four parameters to vibration response of a brake pad are the applied load/Pressure, the speed of rotation of the disc, the roughness of the disc and pad, and the young's modulus of the disc and pad. Disc tangential velocity, Young's modulus and applied load/pressure are the most significant, in that order. Several interactions and the main effect roughness are suggested to be less significant, but not insignificant.

In the present study, applied load/pressure is considered for the vibration study of the pad by performing transient analysis in ANSYS. From the results of the analysis, it would be concluded that the squeal frequency of the pad is almost closest with the experimentally found squeal frequency. Still it is possible to predict the squeal frequency and its harmonics exactly matches with the experimental one if the sample length of the signal and time step between the applied pressures on the pad face is increased. Using this novel method, squeal effect on the other parameters such as speed of rotation of the disc, the roughness of the disc and pad, and the young's modulus of the disc and pad can also be explored that can be left out for the future work.

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