International Engineering Research Journal Page No 1289-1295

Review on study and analysis of Drum Brake to control Squeal Noise

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Abstract*—The stringent competition in automobile market of passenger vehicle segment exists on account of With respect to critical attributes like vehicle comfort, fuel efficiency, and cost. Noise, Vibration, and Harshness are of critical issues and largely depends upon a number of components in an assembly; their resonances ultimately leads to vehicle comfort. Brake squeal is the major factor for vehicle comfort since it has the wide frequency range from 1 Hz to 12 KHz. In this paper, various parameters like coefficient of friction, an interface between liner and drum, contributions of components to resonant, etc. affecting on Drum Brake squeal are studied. The interface between Liner and drum during braking condition can't have control. Reducing coefficient of friction result in adverse effect on Braking performance. So the finest way to achieve the squeal noise reduction by structural modification of components in the design stage for stiffening and adopting FRF quality check method before manufacturing.

***Index Terms*—NVH, Squeal, Drum brake, FRF, Modal analysis.**

I. INTRODUCTION

Squeal noise is one of the major concerns of automotive brakes systems. It is also a part of standard vehicle evaluation systems/rankings e.g. JD Power ratings. Vehicle manufactures demand minimal possible NVH issues from sub-components, and a brake is no exception. A plenty of literature, case studies and specific mitigation techniques addressing brake squeal have been discussed and presented over the years. Despite it, squeal noise remains a field concern due to various reasons and one of those is consistency in parts manufacturing.

FRF (Frequency Response Function) is a fundamental measurement function for NVH analysis, and it provides displacement output to force input relation in frequency domain like a transfer function for a given structure under test. By virtue of this function, one can determine structural resonances, material damping and deformation pattern at resonances. All these are extremely vital information for NVH analysis and mitigation.

Brake Squeal noise is a sinusoidal characteristic noise typically heard during the end of the stop with lower braking efforts. The audible frequency range for squeal noise in disc and drum brakes ranges from 1 Hz to 15000 Hz, which is quite wide. The squeal is a friction pair (rotor and pads or drum and shoes) induced vibration excitation that passes through a number of components of brake assembly and associated vehicle suspension parts. Typically, assembly parts comprising a disc brake are rotor, caliper, friction pads, mounting bracket, knuckle/axle assembly and vehicle suspension parts. In the case of drum brakes, those are drum friction shoes, torque plate, and other vehicle parts. Each sub-component has many natural frequencies (resonances) by virtue of their material (mass, geometry, and stiffness). Due to assembly boundary conditions, multiple components are connected, and those may have closely spaced resonant frequencies. When frictional forces during braking can excite these closely spaced resonances, those components undergo uncontrolled structural vibration, in-turn produces noise at resonant (specifically a sine wave) frequency which is termed as squeal noise. It is a necessity to control automotive brake squeal. The impact on NVH attributes due to the design change of brake parts has been discussed in the paper.

II. Literature Review:

Vandari(1999), Noise, Vibration and Harshness (NVH) problems in brakes in general and creep-groan in particular manifest in different forms. Creep-groan is an example of self-excited vibration caused by the stick-slip phenomenon. Most researchers to date have been concentrating on the characteristics of the friction material and the contacting surfaces and its effect on creep-groan vibration and describes creep-groan and its relationship to vehicle dynamics response to creep-groan and presents a solution to reduce effects due to creep-groan vibrations.

Nouby M. Ghazaly(2014), During the earlier years, study done on understanding, identifying critical factors and possibly in reducing the effect of squeal noise. Increasing the knowledge of the mechanisms generating squeal is one important contribution to the extensive research and development work being perform in order to solve this problem. From the literature review, it is found that there are six mechanisms of squeal formation namely: stick-slip, negative friction – velocity slope, sprag-slip, modal coupling, splitting the double modes and hammering. These mechanisms are indispensable for a better understanding of squeal. Despite much progress has been made in gaining physical insight into squeal mechanisms and causes in recent years and present brakes have become quieter. However, squeal still occurs frequently, and therefore, much work still needs to carry out. Due to the fact that disc brake squeal has been a challenging problem due to its immense complexity which is very sensitive to variables including corner component design, component interaction, and operating and environmental conditions.

A) Experiments on squeal mechanisms:

Dunlap (1999) investigated various categories of brake noise namely low-frequency noise, low-frequency squeal and finally high-frequency squeal. Low-frequency noise typically occurred at the frequency between 100 and 1000 Hz where grunt, groan, grind and moan generally fall into this category. This class of noise was due to friction material excitation between the disc and pad interface. Low-frequency squeal defined as a noise having a narrow frequency bandwidth in the frequency above 1000 Hz and yet below the first in-plane mode of the disc. The failure mode of this category could be associate with frictional excitation coupled with modal locking of disc brake components. While high-frequency squeal is classified as a noise produced by friction-induced vibration at a frequency above 5 kHz. This kind of squeal was due to in-plane vibration of the disc.

B) Experiments using an accelerometer to identify squeal behavior:

Kumamoto (2004) analyzed brake pad behavior, which focusing on the pad restraint condition, with regards to squeal generation. A small piezoelectric type accelerometer was located on the caliper to measure vibration waveform while the contact load was measure by pressure distribution measurement sensor, which was place between the pad and the caliper. During the experimental tests, they found two remarkable squeals at frequencies of 2 kHz (diametric mode) and 2.5 kHz (diametric and radial in-plane modes). These two squeal noises were observed as a result of a soft connection between the pad abutments and the caliper. In order to confirm the observation, a disc brake finite element model was built. The analysis results showed that the pad had a large displacement in the axial direction both at outer and inner abutment side for 2 kHz squeal while at an inner side for 2.5 kHz squeal. From these results, it was confirmed that pad restraint condition largely contributes to brake squeal. Squeal performance could be improved with a rigid and stable connection between the pad abutment and the caliper. The effective way to doing so was to use the stainless steel contact shim structure.

C) Components and parameters contribution on system instability(Analytical):

Sherif (1991), modeling of friction pad in disc brakes as a distributed parameter system (mass-inherent damping-elasticity) is made in order to show the conditions of stable vibrations, The interface characteristics of the pad/disc assembly beside the negatively sloped friction-velocity relationship are taken into account. The interface characteristics report by the effective contact stiffness as well as the friction damping of both pad and disc surfaces. It is shown that continuous modification of the equivalent contact stiffness by wear mechanism or by any other mechanism, is the mean cause of squeal triggering. The analysis has shown that stability can be attained at all possible squeal frequencies of the friction pad by the good selection of its geometrical configuration (thick, and short brake pad) and its material loss factor within certain limits. It is necessary to choose the appropriate way of pad fixation inside the caliper to give higher modes of vibrations. According to the considered model of longitudinal vibrations, it is found that stability of motion is independent of the value of the coefficient of friction whereas it depends on its negative slope.

D) Follower force and moving load (FEA approach)

Chung (2003), Disk Brake Squeal noise is a problem that continues to confront automobile manufacturers. Customer complaints result in significant warranty costs yearly. Furthermore, customer dissatisfaction can cause a loss of future business. Physically, squeal noise occurs when the friction coupling between the rotor and pad creates a dynamic instability. This result in vibration of the structure, which radiates a high-frequency noise in the 1- 15 kHz range. Many analytical approaches have been proposed in the literature evaluate the Brake Squeal Dynamics, and the most popular approach is the Complex Eigenvalue approach. Root Locus Analysis is a further application of the Complex Eigenvalue approach, which can trace the unstable modes represent meaningful structure mode pairs. While the Root Locus Method provides a way to identify potential critical modes, it suffers from several drawbacks, such as solution long time and lack of resolution to provide the detail mode interaction among complex roots. Chung, et al. presented approach by transferring the brake system equation of motion from transient domain to modal domain. The modal domain transformation significantly reduces the complexity of the Complex Eigenvalue analysis and provides a mechanism of mode coupling phenomenon. The shown approach has been successfully applied to solve Automotive Brake Squeal problem and Motorcycle brake squeal problem. The goal of this paper is to apply the Modal Domain analysis approach to minimize design iterations using FE models and provides a new method to calculate Complex Eigenvalues to reduce solution time.

Saki and Wada (2003), In the studies of disc brake squeal, the vibration modes on squealing were measured, and calculated. By those results to the disk rotor, it is clear that the type of the modes affects the squeal generation. It is not clear whether mounting bracket mode shapes contribute to squeal, because the mounting bracket mode shapes cannot be classified in the same way as the rotor mode shapes. In this paper, by using FEM modal analysis the vibration modes of the mounting bracket are classify systematically. And by adopting this classification to the vibration mode of mounting on squealing, it is confirmed that the specific type of modes of mounting affects the squeal generation.

E) Squeal Reduction Methods:

In a recent review, Chen (2003) provides guidelines to suppress and eliminate squeal occurrence for disc brake. This including optimization of the damping, minimizing the impulsive excitation and reducing the modal coupling. These three guidelines have been adopted by many researchers and thought to be essential for squeal reduction methods.

Liu and Pfeifer (2000) performed several tests on different pad configurations to reduce high-frequency squeal. The configurations were straight chamfer, radial chamfer, diamond chamfer, and center slot. They found that all the configurations effective to suppress squeal at frequencies of 6.1 and 9.5 kHz while no effect at a frequency of 8.1 kHz. In order to address this problem, a combination of chamfer and slot were made. This combination then was proved to suppress squeal at 8.1 kHz.

Von Wagner (2009), the last decades have shown efforts on the investigation of automotive disk brake squeal. The root of brake squeal is seen in self-excited vibrations, cause by the friction forces transferring energy from the rotating disk into the brake system.

Tuma(2009) Gearbox noise is tonal. it represent that the noise frequency spectrum consists of sinusoidal components at discrete frequencies with low-level random background noise. The frequency that is the product of the gear rotational speed in Hz. Produce the idle gear rattle. The dominating components in the frequency spectrum can be identified after averaging either in the time or frequency domain. The modal properties of gearbox housing were identified using operational deflection shapes and experimental modal analysis. The effect of the gearbox load on the vibration response of each gear in the time domain using synchronous averaging with the rotational frequency was analyzed. The "power" can flow through the gearbox in many ways according to the gear used. The components like gearbox housing, shafts, and gears are not an ideally rigid structure. The compliant gearbox structure is deform under load. The responses are differing due to the gearbox deformation. To prevent uncertain tooth contact, the gearbox housing was stiffened by using ribs, inside the housing the ribs perpendicular to the shafts while two massive ribs at the housing surface were parallel to the shafts. The additional ribs ensure that the bearing close to the 21-tooth gear is stiffened enough, and the vibration responses were not differing.

III. *Objective of review:*

To reduce Squeal noise of automotive brake by structural modifications of Backplate and applying FRF quality check method.

IV. *Drum Brake squeal:*

Braking is the mechanism in the vehicle which is used to slowing down and stopping the vehicle to rest in the shortest possible distance.

The main components of drum brakes are as follow:

1. Brake drum
2. Back plate
3. Brake shoes
4. Brake Liners
5. Retaining Springs
6. Wheel Cylinder
7. Anchors

In the above the system, the wheel is attached to drum. there are brake shoe used to contact the rotating drum for braking operation. The shoes provide lining on their outer surface. The Wheel cylinder is used to lift the brake shoes at one end, another end is connected by some method so as to make as the brake sleeve come into contact with the brake drum. The retaining spring is provide for bringing the brake shoes back to its original position, after releasing the brake pedal. All these parts are fitted in the back plate and enclosed with the brake drum.

Brake noise has been divided into three categories, in relation with frequency of noise occurrence. The three categories present in figure 2 are low-frequency noise, low-frequency squeal, and high-frequency squeal.

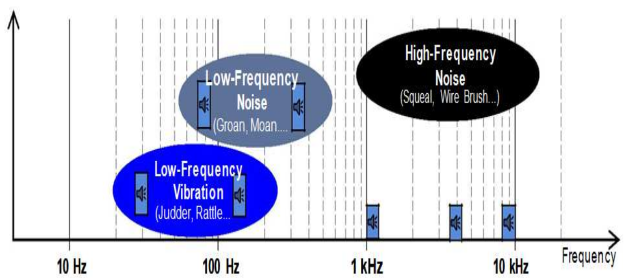


Figure 2: Classification of squeal noise

Low-frequency disc brake noise occurs in the frequency range between 100 and 1 kHz. That reside in this category are a grunt, groan, grind, and moan. This type of noise is cause 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. The Low-frequency squeal is classify as a noise having a narrow frequency bandwidth in the frequency range 1-3 kHz. 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 classify as squeal noise occurring at frequency range 3-12 kHz. 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.

There are two main theories that explains squeal phenomenon occurrence. The first theory is stick-slip theory. This theory states that brake squeal is a result of a stick–slip mechanism. According to the second theory, high levels of vibration result from geometric instabilities of the brake system assembly. Both theories results in the brake system vibration, and the noise is due to variable friction forces at the liner–drum interface.

V. Methodology:

Two methods are chosen to control squeal viz. **Finite element method for natural frequency measurement** and **FRF** (Experimental) measurement of parts. Since two parameters affecting natural frequencies are Stiffness and mass. By finite element method, we will control on natural frequencies by structural modification (stiffening). Using FRF measurement, we will able to detect part before assembling which natural frequencies cause resonant and accepting / rejecting by quality check. FRF is nondestructive method and in current scenario very difficult to control mass distribution in parts which causing NVH.

A) ***Finite Element Analysis Method:***

The finite element method has been apply for brake squeal studies to several ends. It was used to investigate the modes and natural frequencies of the brake rotor. The most common use is to compute the M and K matrices in models of drum brakes. Subsequently, a linear eigen value analysis is conducted to determine the system's frequencies, modes, and stability. As in the other analyses, we have cited lack of (linear) stability evidenced in the form of one or number of dissipating eigen modes are associated with squeal propensity.

To design SolidWorks CAD Software is used and design analysis is conducted using SolidWorks simulation software.

Material- IS1079 EDD,

Yield strength:	280 MPa
Tensile strength:	380 MPa
Mass density:	7.85 g/cm3
Elastic modulus:	200000 MPa
Poisson's ratio:	0.3
Weight:	6.9 N

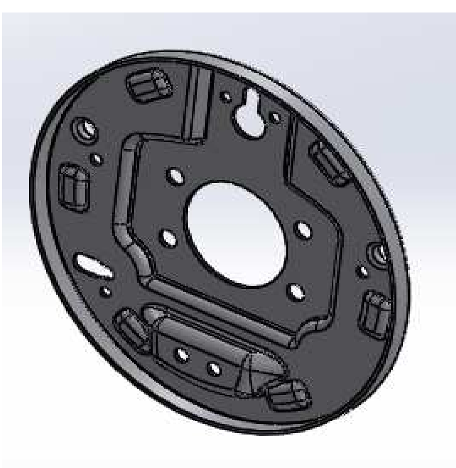


Figure 3: Backplate(Nodes191831, Elements107248)

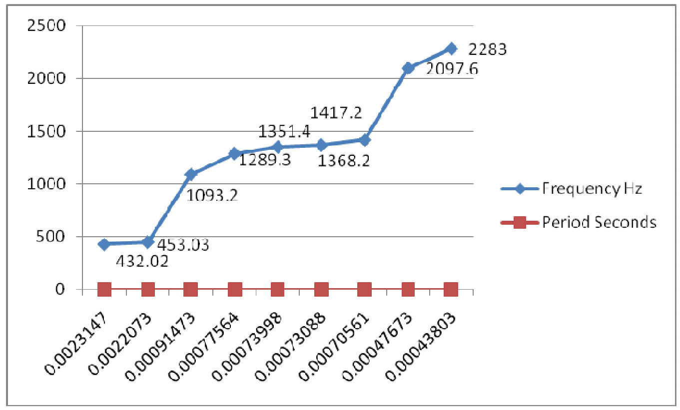


Figure 4: Graph for Backplate

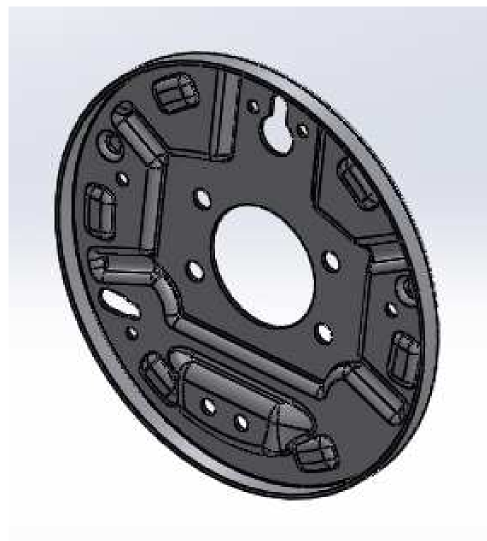


Figure 5: Backplate with Ribs, Nodes1061134, Elements 651749, Weight 7 N

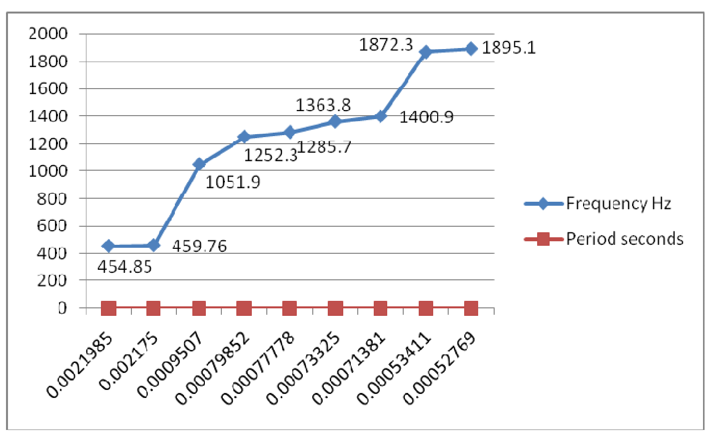
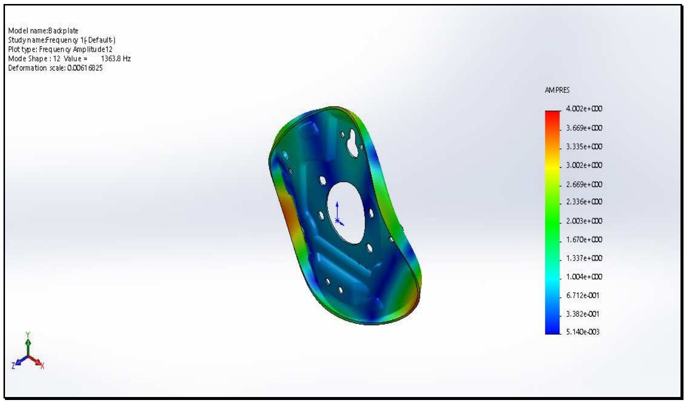
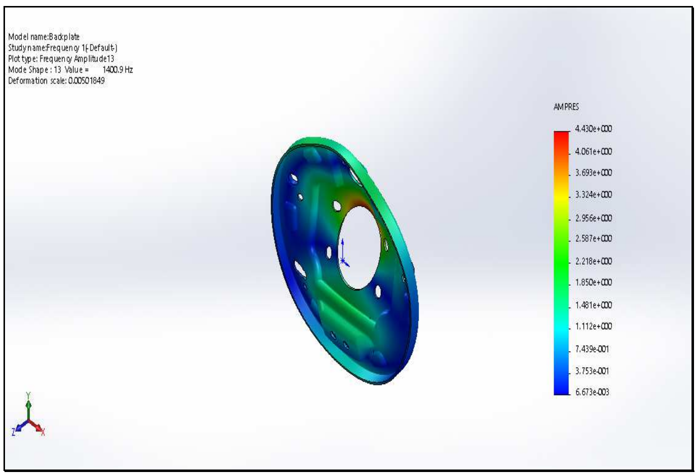


Figure 4: Graph for Backplate with Rib

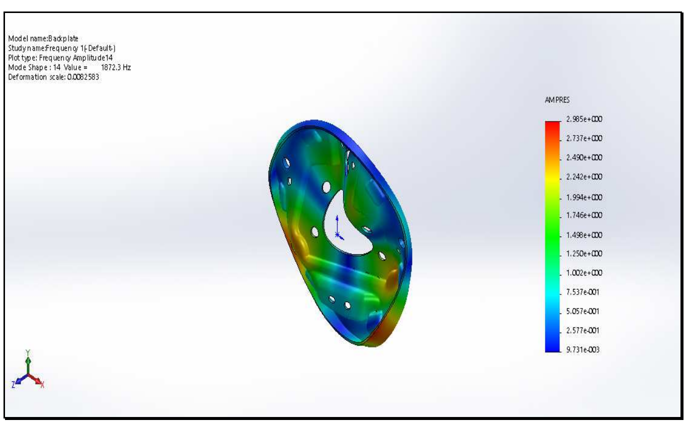
A) Mode Shape for Backplate:



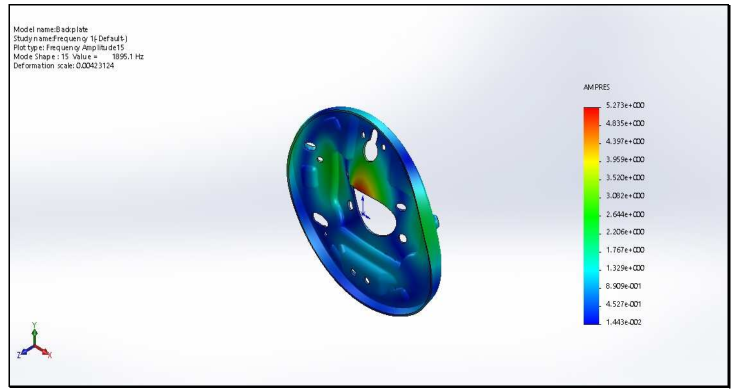
Resultant Amplitude Plot for Mode Shape: 12(Value = 1363.79 Hz)



Resultant Amplitude Plot for Mode Shape: 13(Value = 1400.92 Hz)

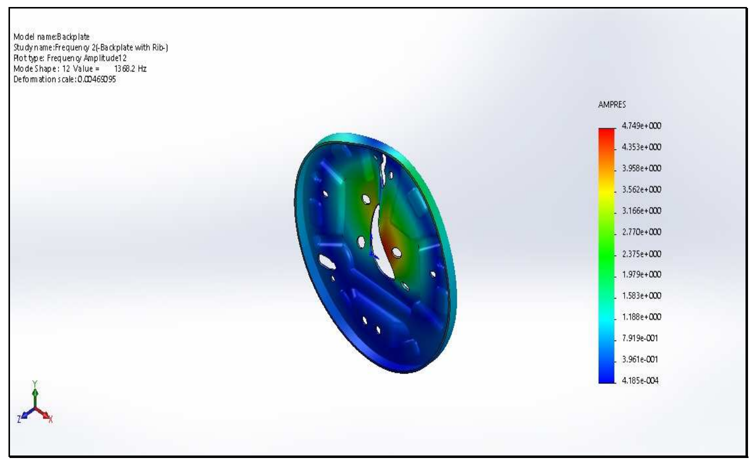


Resultant Amplitude Plot for Mode Shape: 14(Value = 1872.28 Hz)

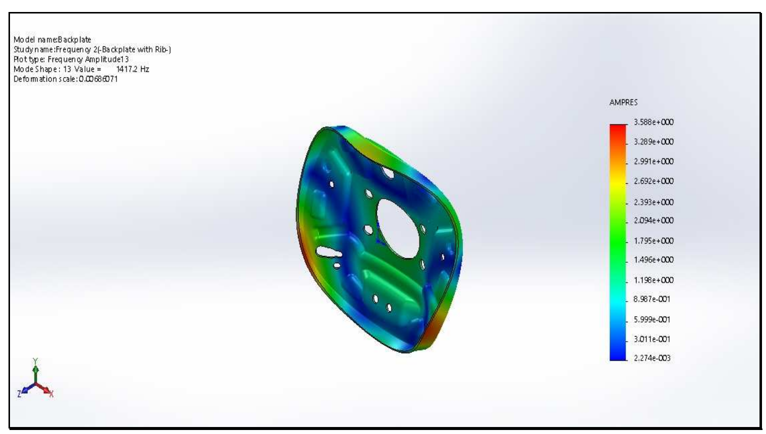


Resultant Amplitude Plot for Mode Shape: 15(Value = 1895.05 Hz)

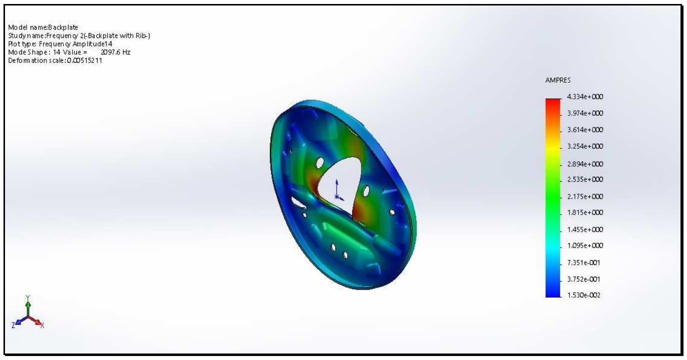
B)Mode Shape after geometry modification of Backplate:



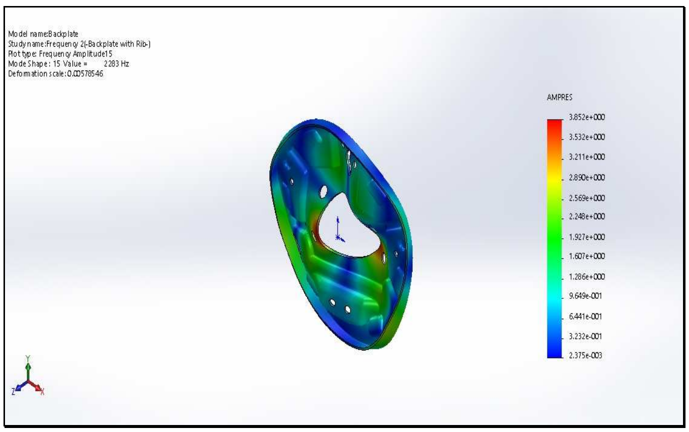
Resultant Amplitude Plot for Mode Shape: 12(Value = 1368.22 Hz)



Resultant Amplitude Plot for Mode Shape: 13(Value = 1417.21 Hz)



Resultant Amplitude Plot for Mode Shape: 14(Value = 2097.6 Hz)



Resultant Amplitude Plot for Mode Shape: 15(Value = 2282.96 Hz)

B) Experimental Modal Analysis:

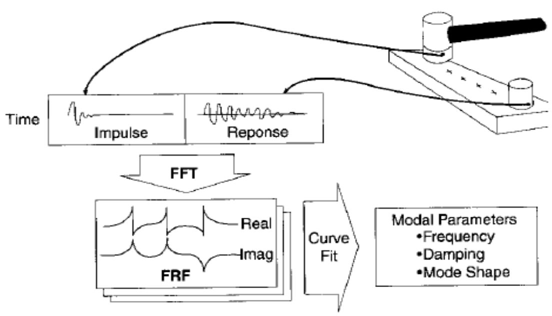


Figure 5: FRF measurement

The Drum of a brake assembly can be test through the free–free boundary conditions. The observational investigate the way patterns and natural frequencies of any structure through hammer impact test. The important part of the test system is the controller, or computer, which is the operator's communication link to the analyzer. The modal analysis software commonly used for analysis of structures for improved modifications. The analyzer provides the data acquisition and signal processing operations. It can be configure with several input channels, for force and response measurements, and with one or more excitation sources for driving shakers. Measurement functions such as windowing, averaging and Fast Fourier Transforms (FFT) computation are usually process within the analyzer.

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Figure 6: Backplate

Figure 7: Backplate with design modification to increase stiffness

Discussion

For reduction of drum brake squeal most important to control two parameters of natural frequencies are Stiffness and mass. By finite element method, we have control on natural frequencies by structural modification (stiffening). By finite element analysis show shift in natural frequency from 2283 Hz to 1893 Hz at mode shape 9^{th}.

Future work will involve four ribs Backplate structure FRF testing validation.

CONCLUSION

Taking all analysis into account shows an easy to way to reduce squeal of Brake to shift Natural frequencies pattern by increasing stiffness. Considering with rib structure of Backplate shows improved results.

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