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Experimental and Finite Element Analysis of Automobile Wheel Hub Plate

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ABSTRACT

In recent years, competition in the automobile market is getting increase with respect to fuel economy, especially for the light commercial vehicles. Moreover, there is a significant necessity about reducing fuel consumption level for automobile companies. The weight of a vehicle is one of the most important factor that affecting the fuel economy. The weight minimization of wheel is more effective than the weight minimization of elsewhere in a vehicle due to the rotational moment of inertia effect during motion(1). Therefore, the wheel design should be optimized by considering fundamental attributes of a light commercial vehicle such as NVH, Durability and Weight. In this study, the modal correlation between CAE simulations and tests is performed. For this purpose, mode shapes and their natural frequencies obtained from CAE simulations are compared with experimental modal analysis results. After the correlation is provided, wheel design optimization proposals are given by considering NVH and Durability criteria. Vibration in automobile wheel is important economic and technological problem in the industry. Improved understanding of disk vibration through research papers offers one opportunity for targeted improvements in wheel design. Depending on the frequency range of interest, the hydraulic system, body panels, steering column, and other vehicle components can also become active from vibrations point of view. In an aggregate sense, the disk wheels of a large percent of new three wheeler vehicles exhibit sufficient vibration to generate significant customer complaints. So this investigation of Mode shape & vibration analysis of wheel disc of automobile is undertaken. The study will be carried by various methods the first method is experimental method to carryout exciter test after this second method consist of identification of natural frequency by FFT analyzer will be done then at last optimization study consist of use of software's such as ANSYS can be done to compare & conclude. The work will be carried out in following stages. The methodology and objectives of these stages are also discussed below.

- **I. To perform experimental modal analysis of wheel disc used in automobile.**
- **II. To investigate effect of structural parameter on natural frequency of automobile disc**
- **III. To perform modal analysis of automobile wheel disc by FEM.**
- **IV. To carry out weight optimization of automobile wheel disc.**
- **V. To compare experimental and FEM result**

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I. INTRODUCTION

Rotor dynamics is a specialized branch of applied mechanics concerned with the behavior and diagnosis of rotating structures. It is commonly used to analyze the behavior of structures ranging from jet engines and steam turbines to auto engines and computer disk storage. At its most basic level rotor dynamics is concerned with one or more mechanical structures (rotor) supported by bearings and influenced by internal phenomena that rotate around a single axis. The supporting structure is called a stator. As the speed of rotation increases the amplitude of vibration often passes through a maximum that is called a critical speed. This amplitude is commonly excited by Unbalance of the rotating structure; everyday examples include engine balance and tire balance. If the amplitude of vibration at these critical speeds is excessive then catastrophic failure occurs. In addition to this, turbo machinery often develops instabilities which are related to the internal makeup of turbo machinery, and which must be corrected. This is the chief concern of engineers who design large rotors. An important part of the inertia effects is the gyroscopic moment introduced by the precession motion of the vibrating rotor as it spins. As spin velocity increases, the gyroscopic moment acting on the rotor becomes critically significant. Not accounting for these effects at the design level can lead to bearing and/or support structure damage.

Accounting for bearing stiffness and support structure flexibility, and then understanding the resulting damping behavior is an important factor in enhancing the stability of a vibrating rotor. Rotor dynamics can be divided into three different types of motion, lateral, longitudinal and Torsional. Lateral is also called bend rotor dynamics and is associated with bending of the rotor. Torsional is the modes when the rotor is twisting around its own axis. Longitudinal modes are when the rotor parts are moving in axial direction. Every system has its own natural frequencies and if the disturbing force's frequency is close to any of the natural frequencies, the amplitude can get very large. This phenomenon is called resonance. To hold the amplitudes on a decent level, damping can be applied to the system. Damping is for example applied with help of the Bearings. When dealing with torsional motion the whole system together with the generator has to be modeled even if there is a gearing between them because the twisting motions are affecting each other. The whole system doesn't have to be modeled when lateral and longitudinal modes should be analyzed. Lateral vibrations, torsional vibrations and longitudinal vibrations cannot always be calculated separately from each other because sometimes they are affecting each other.

II. LITERATURE REVIEW

To help the dissertation; research papers dealing with the vibration analysis of the wheel disc have been studied.

B Sing et al.[1] proposed the investigation of the transverse vibration of skew plate with the help of Rayleigh Ritz method. The two dimensional thickness variation is taken as the Cartesian product of linear variations along the two concurrent edges of the plate. The first three frequencies and mode shapes have been computed by using successive approximations. Convergence of results is ensured by working out several approximations until the results converge to four significant digits. In special cases\ comparisons have been made with results that are available in the literature. Mode shapes have also been plotted for some selected cases[7 0886 Academic Press Limited. Received 08 March 0885 and internal form 19 February 0886.

Mehdi Ahmadian et al.[2] presented an experimental evaluation of the benefits of smart damping materials in reducing structural noise and vibration. The construction of a special test rig for measuring both vibrations and structure-borne noise is discussed. Further, the test results show that the structure-borne noise at the vibration peaks is substantially reduced with the smart damping materials. The results indicate the viability of smart damping materials for many industrial applications where reducing noise and vibrations is desired,with minimal amounts of added weight.

Tsuyoshi Inoue et al.[3] proposed that dynamic characteristics of nonlinear phenomena, especially chaotic vibration, due to the 1 to (−1) type internal resonance at the major critical speed and twice the major critical speed are investigatedfor the rotating machinery. The following are clarified theoretically and experimentally: (a) the Hopf bifurcation and consecutive period doubling bifurcations possible route to chaos occur from harmonic resonance at the major critical speed and from sub harmonic resonance at twice the major critical speed, (b)another chaotic vibration from the combination resonance occurs at twice the major critical speed. The results demonstrate that chaotic vibration may occur even in the rotor system with weak nonlinearity when the effect of the gyroscopic moment is small.

Albert C. J. Luo et al.[4] performed the analytically and investigated the response and natural frequencies for the linear and nonlinear vibrations of rotating disks are. The natural frequencies for symmetric and asymmetric responses of a 3.5-inch diameter computer memory disk as an example are predicted through the linear theory, the von Karman theory and the new plate theory. The hardening of rotating disks occurs when nodal-diameter numbers are small and the softening of rotating disks occurs when nodal-diameter numbers become larger. The critical speeds of the softening disks decrease with increasing deflection

M.M.Alipour et al.[7] investigategd based on zig zag global local plate theory free vibration of functionally graded annular sandwich plates resting on Winkler-type elastic foundations. Material properties of each layer may be graded in the transverse direction according to a power law.It is the first time that a global–local theory is combined with a layer wise analytical solution for analysis of the annular functionally graded sandwich plates.Various edg conditions are considered for the inner and outer edges.

H. Bisadi et al.[8] the exact closed-form solution for freely vibrating annular thick plates is presented on the basis of the Reddy's higher-order shear deformation plate theory. Several combinations of classical boundary conditions including, free, soft simply supported, hard simply supported and clamped, are applied at the inner and outer edges of annular plates. Hamiltonian and minimum potential energy principles are employed to derive the equations of dynamic equilibrium and natural boundary conditions of the plate. In parametric studies, the first eight natural frequencies of annular plates with different combinations of boundary conditions are tabulated for various values of the inner–outer radius ratios and thickness–radius ratios.

Jae-Hoon Kang.[9] stuided three-dimensional vibration analysis of thick, circular and annular plates with nonlinear thickness variation. A three-dimensional (3-D) method of analysis is presented for determining the free vibration frequencies and mode shapes of thick, circular and annular plates with nonlinear thickness variation along the radial direction. Unlike conventional plate theories, which are mathematically two-dimensional (2-D), the present method is based upon the 3-D dynamic equations of elasticity. Displacement components us, and uh in the radial, thickness, and circumferential directions, respectively, are taken to be sinusoidal in time, periodic in h, and algebraic polynomials in the s and z directions. Potential (strain) and kinetic energies of the plates are formulated, and the Ritz method is used to solve the eigen value problem, thus yielding upper bound values of the frequencies by minimizing the frequencies.

Albert C.,J. Luo.[10] investigated an approximate theory of thin plates is developed that is based on an assumed displacement field, the strains described by a Taylor series in the normal distance from the middle surface, the exact strains of the middle surface, and the equations of equilibrium governing the exact configuration of the deformed middle surface. This theory reduces to some existing nonlinear theories through imposition of constraints.

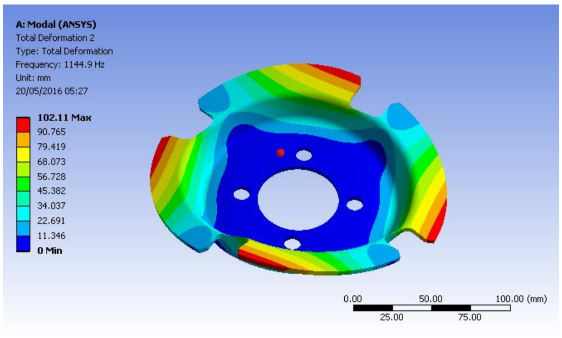
K. Ramesh et al.[11] investigated, the presence of periodic radial cracks in an annular plate introduces additional modes, and these are very significant for the case of cracks emanating from the outer boundary, as the individual sectors are strongly coupled. A split in the resonance frequencies is observed for degenerate modes and these are readily observed for cracks emanating from the outer boundary. However, the change in resonance frequencies due to the presence of cracks is rather too small to develop any condition monitoring technique based on this premise. Nevertheless, the result presented in this paper supports the wave propagation concept for analyzing the dynamic behavior of cyclically symmetric structures.

MODAL ANALYSIS USING ANSYS WORKBENCH

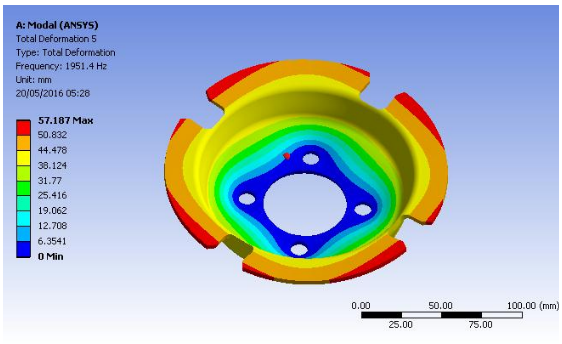
Modal analysis in the ANSYS family of products is a linear analysis. Any nonlinearities, such as plasticity and contact (gap) elements, are ignored even if they are defined. You can choose from several mode extraction methods: subspace, Block Lanczos, Power Dynamics, reduced, un symmetric, and damped. The damped method allows you to include damping in the structure. Details about mode extraction methods are covered later in this section. The procedure for a modal analysis consists of four main steps:

1. Build the model.
2. Apply loads and obtain the solution.

Model 1



Model 2



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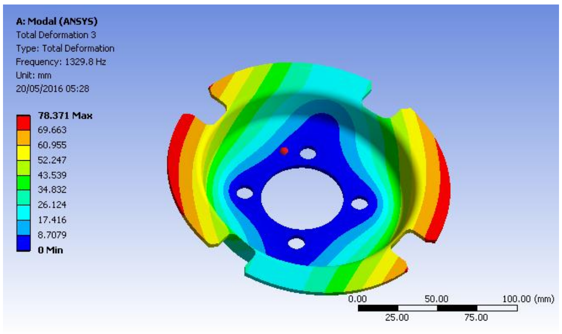

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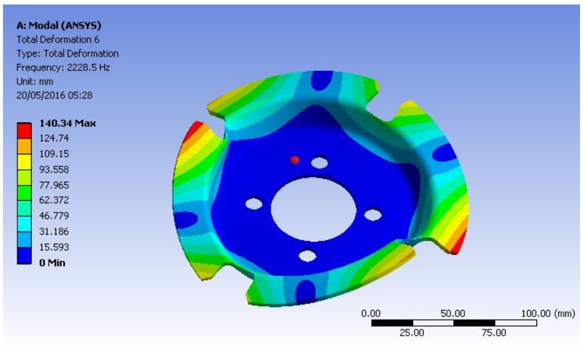


I) METHODOLOGY

The methodology to achieve above objectives is as given below:

Step 1: To perform experimental modal analysis of wheel disc used in automobile:

- Modal analysis of automobile wheel disc will be carried out. Dynamic response and characteristic such as natural frequency, mode shape will be observed
- By using FFT analyzer with impact hammer and exciter machine the modal analysis of automobile wheel disc will be performed.

Step 2: To investigate effect of structural parameter on natural frequency of automobile wheel disc

- The effect of structural parameter such as Number of holes for nut bolt fitting of wheel to vehicle, hole diameter, aspect ratio on natural frequency will be found out

Step 3: To perform modal analysis of automobile wheel disc by FEM

- The modal analysis of automobile wheel disc will be carried out by using FEA.
- The mode shape and natural frequency will be found

Step 4: To carry out weight optimization of automobile wheel disc:

- By investigating different parameter and there effect on natural frequency and mode shape to perform optimization of automobile wheel disc.

Step 5: To compare experimental and FEM result:

- Compare natural frequency and mode shape for automobile wheel disc with experimentation and FEA.

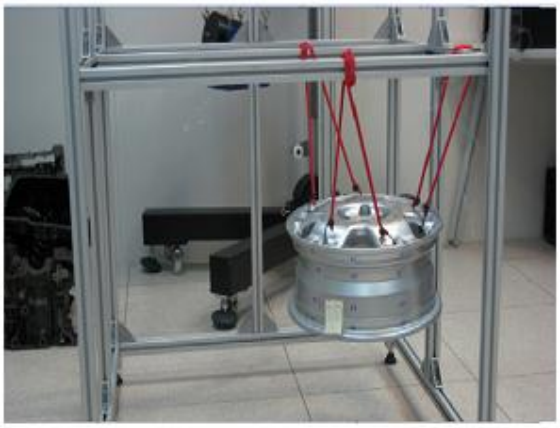
III. EXPERIMENTAL SETUP

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.7 shows the experimental modal analysis set up for rotor

Fig.7. Schematic diagram of the experimental set-up used for modal testing [5].

An excitation signal generated by signal analyzer, then amplified by a power amplifier, and exerted on the tested structure through the exciter. The applied force will be measured by a transducer fixed between the flexible string and the plate. The vibration amplitude at the measuring locations is sensed by a accelerometer, and monitored by a oscilloscope

Fig.. Free Body Condition for Experiment



Fig/9 Wheel Disc

Experimental modal analysis of a system, deals with determination of natural frequencies, damping ratios, and mode shapes through the vibration testing [5]. In the case of forced vibration, the analysis includes the study of acceleration, velocity and displacement responses of the systems. The schematic setup for conducting experiment has shown in Fig. 7.

3.1.1 Basic assumption in experimental analysis

Four basic assumptions are used to perform an experimental modal analysis.

- The structure is assumed to be linear i.e. the response of the structure to any combination of forces, simultaneously applied, is the sum of the individual responses to each of the forces acting alone.
- The structure is time invariant, i.e. the parameters that are to be determined are constants. In general, a system which is time invariant has components whose mass, stiffness, or damping depend on factors that are not measured or not included in the model
- The structure obeys Maxwell's reciprocity, i. e. a force applied at degree of freedom p causes a response at degree of

freedom q that is the same as the response at degree of freedom p caused by the same force applied at degree of freedom q.

- The structure is observable; i. e. the input output measurements that are made enough information to generate an adequate behavioral model of the structure

3.1.2 Instrumentation used for modal analysis

- FFT analyzer
- Accelerometer
- Exciter
- Impact hammer

3.1.2.1 Fast fourier transform

A spectrum analyzer is an electronic device that is capable of taking the time waveform of a given signal and converting it into its frequency domain. Importance of spectrum analyzer by J. B. Fourier mathematician showed that it is possible to represent any time waveform (the plot of a signal whose amplitude varies with time) by a series of sins and cosines of particular frequencies and amplitudes.

3.1.2.1.1 Two channel spectrum analyzer

A Two - channel spectrum analyzer is far more powerful than signal channel analyzer. The two channel analyzer operates in same way as a single channel analyzer with following exception:

- Two input attenuators
- Two input buffers, controlled by the same analyzer in the internal clock
- Half the number of lines of resolution as the same, analyzer in the single – channel mode
- Calculation of cross channel properties such as the transfer function, coherence and coherent –output power.

3.1.2.2. Accelerometer

The benefit of use of accelerometers is that they do not require a calibration program to ensure accuracy. From the accelerometer record, the velocity and displacement are obtained. A wax type material is used to mount the accelerometer on the non-magnetic material. It is a linear seismic transducer utilizing a piezoelectric element in such a way that an electric charge is proportional to the applied acceleration Piezoelectric accelerometers utilize a variety of seismic element configurations. Most are constructed of polycrystalline ceramic piezoelectric materials because of their ease of manufacture, high piezoelectric sensitivity, and excellent time and temperature stability.

3.1.2.3 Vibration exciter

Vibration exciter SI-220 is an electro-dynamic type of device. By controlling the amount of current, the amplitude of vibration is controlled. A powerful magnet placed centrally surrounding which is suspended with the exciter coil. This assembly is enclosed by a high permeability magnetic circuit for optimum performance and enough design care has been observed to minimize the leakage magnetic flux at the top of the vibration table. When an electrical current is passed through the exciter coil, a magnetic field is created around the coil. This field interacts with the field due to the central permanent magnet and these results in the upward or downward movement of the suspended coil depending upon the direction of current flow in the coil. If an alternating current is injected into the coil, it moves up and down continuously. Thus controlling the frequency of the coil current, the frequency of vibration is controlled.

3.1.2.4. Impact hammer

It is a built up force transducer in its head. The impact hammer can be used to hit or impact the structure being tested to excite a wide range of frequencies .The shape of frequency response is dependent on the mass and stiffness of the hammer and structure. The impact force caused by impact hammer, which is nearly proportional to the mass of the hammer head and the impact velocity. It can be found from the force transducer embedded in the structure at an impulse is composed of excitation at each of the natural frequencies of the structure. The impact hammer is simple portable, inexpensive and much faster to use than exciter.

3.2 Vibration Measuring Techniques

3.2.1 Time domain analysis

It uses the history of the signal (waveform). The signal is stored in an oscilloscope or a real-time analyzer and any non-steady or transient impulse are noted.

3.2.2 Frequency domain analysis

Frequency spectrum/domain is a plot of the amplitude of vibration response versus the frequency and can be derived by using the digital fast fourier analysis of the time waveform. Another important characteristic of a spectrum is that each rotating element in a machine generates identifiable frequency. The frequency spectrum provides valuable information about the condition of the machine. The vibration of response of a machine is governed not only by its component but also by its assembly, mounting and installation. Thus the vibration characteristics of any machine are somewhat unique to that of particular machine.

3.3 Measurement Methods

Measurement methods are used to collect data from the tested structure, i.e. to obtain the various mobility properties in the form of a frequency response function. To be able to describe or simulate an existing system accurately, high quality measured data is required. Depending on the type of structure, the time available to perform the tests among others, several methods can be applied for excitation. Some aspects of the measurement process which require particular attention are:

- Mechanical aspects of supporting a structure.
- Mechanical aspects of exciting a structure

- .Correct transduction of the quantities to be measured by the transducers (force, displacement, motion and acceleration).

IV. RESULT & DISCUSSION

Table 1 Result Table

Mode	Experimental Analysis	FEA Analysis			
	Original Thickness	Original Thickness	0.5 mm	1.00 mm	1.5 mm
1	1378.6	1359.7	1349.4	1337.8	1323.4
2	1386.2	1366.5	1355.2	1342.2	1332.7
3	1655.4	1633.9	1614.6	1594.9	1574.2
4	1802.7	1782.6	1757.4	1730.2	1703.2
5	1941.2	1924	1903.8	1881.7	1859.8
6	2954.6	2937.7	2955.3	2973.1	2990.9

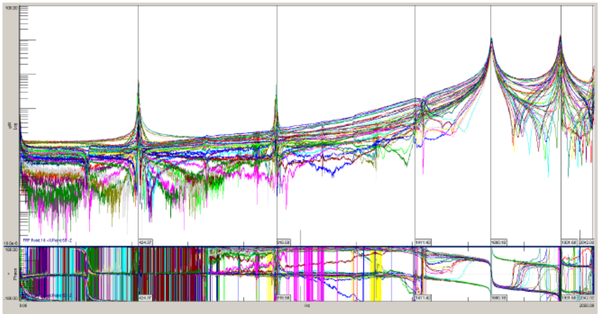


Fig.Frequency Amplitude Graph

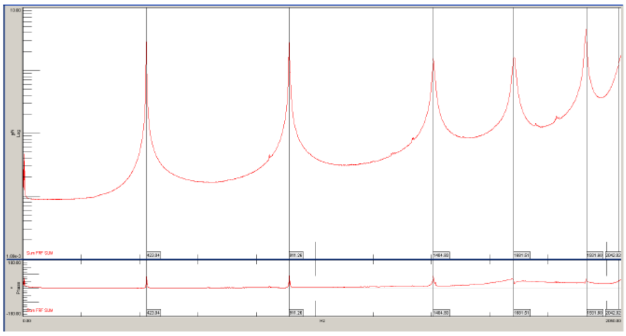


Fig. Average of Frequency Amplitude Plot

V. CONCLUSION

Our work shows the result and discussion on disc brakes with respect to the natural frequency simulation by ANSYS. Based on the results, the reduction of the thickness will be effected on the frequency. The result shows that at the same mode shape the higher reduction of mass becomes the lowest value of frequency. It is suggested that this is due to effect of inertia force. The last mode shape shows that the natural frequency was maximum as predicted due to the instabilities arising from the repetitions of force applied to the rotor area. The results confirmed that more studies are needed to determine the beneficial and cost effective applications of the brake disc system

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