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Experimental and Finite Element Analysis of Automobile Wheel Disc

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ABSTRACT

The 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.

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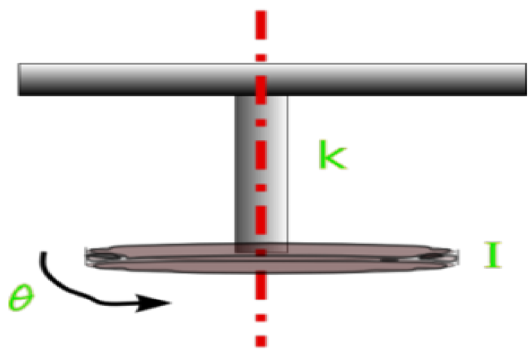
I. INTRODUCTION

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. 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.

II. DIFFERENT TYPES OF VIBRATIONS

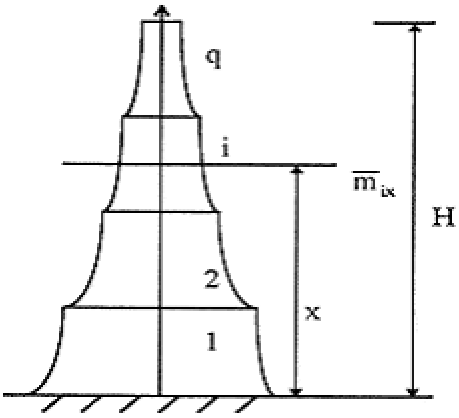
1) Torsional Vibrations

Torsional vibration is when the oscillation motion is twisting the rotor. The oscillations are added to the constant rotational speed of the rotor. When a rotor should be designed with respect to torsional vibrations there are four important analyses which have to be done, static, real frequencies, harmonic force response and transient.



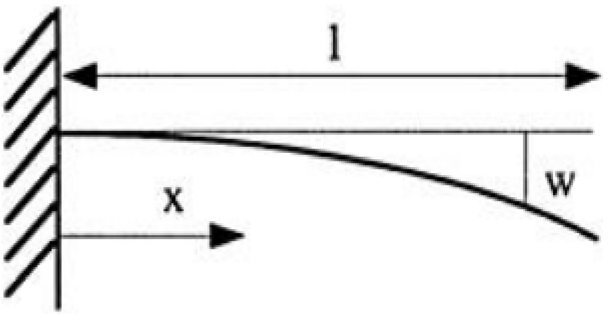
2 Longitudinal Vibrations

Longitudinal vibrations consist of an extension and compression motion of the rotor. The motion can be simplified with two masses with a spring between them. The masses are then moving back and forth from each other.



3. Lateral vibration

Calculations of lateral vibrations are more complex than torsional vibrations and more analyses have to be done. The analyses which have to be done are static, harmonic force response, real frequencies and complex Eigen values. Stator-simulations and bearing calculations have to be done also because they are affecting the lateral vibrations. The static analysis is done to see how much the rotor is deflecting by its own weight.



III. THE GENERAL DYNAMIC EQUATIONS

The general dynamic equation is given by following well known expression

$$[M]\{\ddot{U}\}+[C]\{\dot{U}\}+[K]\{U\} = \{f\}$$

[M], [C], [K] are mass, damping, stiffness matrices In rotor dynamics, equation gets additional contributions from gyroscopic effects [G], rotating damping effect [B] i.e.

$$[M]\{\ddot{U}\}+[(G)+(C)]\{\dot{U}\}+[(B)+(K)]\{U\}=\{f\}$$

In this modal analysis we does not consider damping and other functions, so equation is

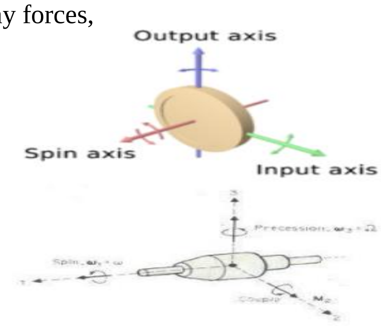
$$[M]\{\ddot{U}\}+[K]\{\dot{U}\} = 0$$

IV. TERMINOLOGY USED IN ROTOR DYNAMICS

a) Gyroscopic effect
b) Whirl
c) Stability
d) orbit
e) Critical Speed
f) Damping
g) Mode shapes

1.3.1 Gyroscopic effect

The gyroscopic stiffening effect has everybody felt, if you are holding a rotating wheel at axis of rotation. If the wheel is held still you will not feel any forces,



1. Whirl

There are two types of whirling, forward and backward. Forward whirling is when the whirling rotation is the same direction as the rotational speed. This type of whirling is the most dangerous one because it is easier to excite the rotor with forward whirling in resonance than with backward whirling . Backward whirling is when the whirling rotation is opposite the rotational speed. Where a forward whirling is increasing the natural frequency with higher rotational speed and backward whirling is decreasing the natural frequency with higher rotational speed.

3) Stability

Self-excited vibrations in a rotating structure cause an increase of the vibration amplitude over time. We have measurement called the log decrement (δ); can be used to decide the stability and that is a better measurement because it is a non-dimensional quantity.

4) Orbits

In most general cases, the steady state trajectory of a node located on spin axis also called as orbit.

5) Critical Speed

A critical speed appears when the natural frequency is equal to the excitation frequency. The excitation may come from unbalance which is synchronous with the rotational velocity or from any asynchronous.

Critical speed of shafts

The magnitude of deflection depends upon the followings:-

(a) Stiffness of the shaft and its support.
(b) total mass of shaft and attached parts.
(c) Unbalance of the mass with respect to the axis of rotation.
(d) The amount of damping in the system Therefore, the calculation of critical speed for fan shaft is necessary. Critical speed can be calculated through Campbell diagram.

6) Damping

Damping is the dissipation of energy which means that energy leaves the system for example as heat. There are a few different types of damping such as viscous, friction and material damping.

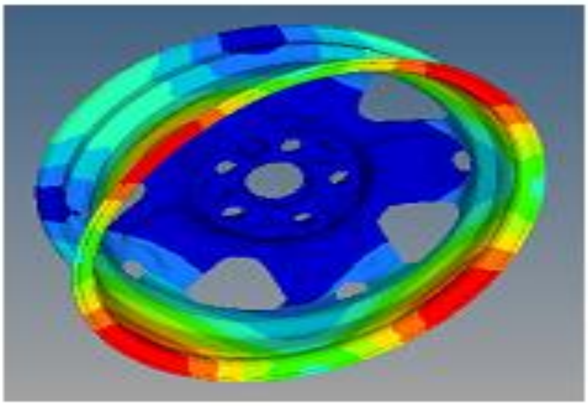
V. MODAL ANALYSIS USING ANSYS WORKBENCH

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.

The procedure for a modal analysis consists of four main steps:

1. Build the model.
2. Apply loads and obtain the solution.
3. Expand the modes & Review of Results



VI.LITERATURE SURVEY

1. **M.M.Alipour et al.[1]**investigategd based on zigzag 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 edge conditions are considered for the inner and outer edges.
2. **H. Bisadi et al.[2]** 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. To validate the accuracy and effectiveness of the present formulation, direct comparisons are made between our results and those from the literature. 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.
3. **Jae-Hoon Kang.[3]**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.
4. **B Sing et al.[4]** 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.
5. **Mehdi Ahmadian et al.[7]** 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. Next, the application of smart damping materials, specifically piezoceramics with electrical shunts, in reducing the vibrations of a test plate is discussed. It is shown that the smart damping materials are able to effectively reduce the vibration peaks at multiple frequencies, with minimal amount of added weight to the structure, as compared to passive viscoelastic damping materials. 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.
6. **Albert C. J. Luo et al.[8]** performed the analytically and investigated the response and natural frequencies for the linear and nonlinear vibrations of rotating disks are. The results for the nonlinear vibration can reduce to the ones for the linear vibration when the nonlinear effects vanish and for the von Karman model when the nonlinear effects are modified. They are applicable to disks experiencing large-amplitude displacement orinitial flatness and waviness. 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
7. **Tsuyoshi Inoue et al.[9]** 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.

8. **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. In this theory, the exact geometry of the deformed middle surface is used to derive the strains and equilibrium of plates. This theory reduces to some existing nonlinear theories through imposition of constraints.
9. **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. Normally, the change in the resonance frequencies is more for circumferential modes than for the diametral modes. The trend is well defined when either the number or the length of the cracks is increased. 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.

VII.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:

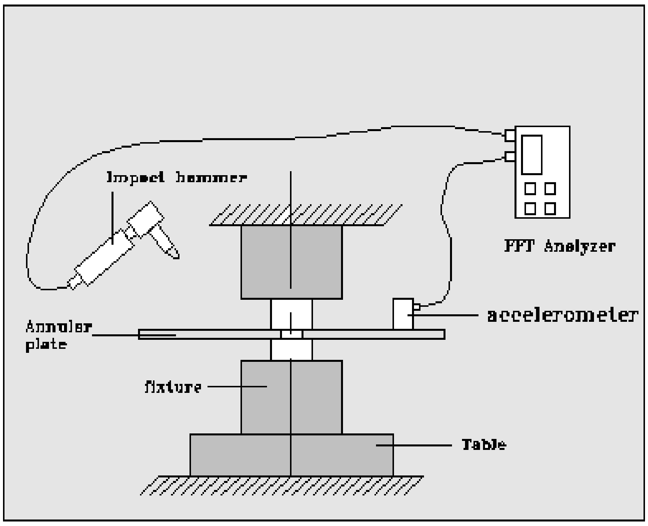
- By investigating different parameter and there effect on natural frequency and mode shape to perform optimization of automobile wheel disc.

Step 5: To compare experimental and FEM result:

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

VIII.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.



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 togenerate an adequate behavioral model of the structure

Instrumentation used for modal analysis

- FFT analyzer
- Accelerometer
- Exciter
- Impact hammer
- 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..

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,

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).

IX.EXPECTED OUTCOME

There are two types of experimental measurements which are conducted. The first is component level measurement using the free-free boundary condition which allows the structure to vibrate without interference from other parts, making easier visualization of mode shapes associated with each natural frequency and validation of corresponding FE model.

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