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Natural Frequency and Mode Shape Analysis of Circular Cutters

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Abstract: - *The objective of current dissertation work is to analysis of vibration characteristics of circular cutters with free boundary condition but having different (numbers of cutting teeth, aspect ratio, effect of radial slots, enlargement of stress concentration holes) is done here. Analysis for circular cutters with inner edge clamped and outer edge free is done here. For same aspect ratio of annular cutter but variable numbers and variable lengths of radial cracks for inner edge clamped and outer edge free boundary condition. When the excitation frequency of any structure matches with one of the natural frequency of the plate then resonance occurs and a damage of plate takes place. So here objective is to determine the modal parameters and an effort can be made to avoid the resonance*

Introduction

The study of the dynamic behavior of circular cutters with free boundary condition but having different (numbers of cutting teeth, aspect ratio, effect of radial slots, enlargement of stress concentration holes) is important, as used in several machine components, such as flywheels circular saw plates etc. The knowledge of natural frequencies of component is of great interest in the analysis of response of structures to various excitations. This study is fundamental for high-risk plants. Unwanted noise, vibration & accidental failure associated with the cutting process has become an important economic and technological problem in the industry that can be solved by this work.

It is well known that the high-speed machining is used widely as one of the key technology in manufacturing. With the use of HSM, we will enhance the productivity and surface quality in great extent. In addition, the operation cost will be reduced largely. The HSM system is the typical and complex dynamic system. The development and applications of its all advantages are depended very closely on the dynamic characteristics and stability of the system .With the enhancement of speed, the dynamic characteristics of the high-speed rotary tools system (for instance milling, drilling, grinding) have a significant effect on the stability of machining process and running-life of machining tools and so forth. So that it is taken into account as the dominating factor. A very serious accident would result from the tools used at increased speed due to the unstable machining process. In order to avoid the accident, the dynamic characteristics of high-speed rotary tools system must be understood. So that analysis exactly of the dynamic characteristics of HSM system has become an important research aspect of dynamic stability of HSM process. In this paper, dynamic characteristics modeling of the rotary tools is performed and natural frequencies and mode shapes of vibration are calculated. In this process, the rotary tools' structural parameters are taken into account. It is testified that the results of calculation are in agreement with those of experiment. And this is very useful for dynamic analysis and optimization of the high-speed rotary tools system

Analysis of vibration characteristics of circular cutters with free boundary condition but having different (numbers of cutting teeth, aspect ratio, effect of radial slots, enlargement of stress concentration holes) is done with the FFT & FEM analysis. Also mode shapes will be compared with FFT & FEM analysis to conclude its effect on cutters. Experimental set up of circular cutter is done for inner edge clamped and outer edge free boundary condition. Results are reviewed in general post-processor and time history in post-processor. The general postprocessor is used to review the results during a particular time step for the whole or part of body. Different results like deformations, stresses, and tabular listings of displacements and animations of vibration can be obtained by using general post-processor. Time-history postprocessor is used to find out results of a particular node through all the time-steps. By using time-history postprocessor, graphs of data vs. time can he obtained. The arithmetic operations can also be performed on graphs .

Using FFT analyzer, natural frequencies are detected by hitting the plate with impact hammer; the response at a point of a plate is measured by using an accelerometer.FFT analyzer analyzed the output of accelerometer. The clamped cutter will be mounted on exciter and different resonance's was detected by varying the exciting frequency. Mode shapes are investigated using coal dust or salt to compare with FEM mode shapes of same test specimens.

Related Work

Vibrating structures are distributed parameter systems. However, due to lack of viable computational methods to handle distributed parameter systems, such systems are usually described to a matrix second-order system of the form by using techniques of finite element as follow in which, the matrices M, K and D are, respectively, known as the mass, stiffness and damping matrices. M is assumed to be positive definite and K is positive semi-definite The mass and stiffness matrices can be obtained accurately by numerical computing and experiment measuring

I. THEROTICAL ANALYSIS

FINITE ELEMENT ANALYSIS

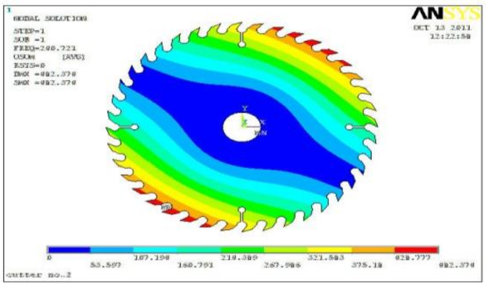
In this method, the actual structure is replaced by several pieces or elements, each of which is assumed to behave as a continuous structural member called a finite element. The elements are assumed to be inter connected at certain point known as joints or nodes. Since it is very difficult to find the exact solution of the original structure under the specified loads, a convenient approximate solution is assumed in each finite element. During the solution process, the equilibrium of forces at the joints and the compatibility of displacement between the elements satisfied, so that the entire model is made to behave as a single entity. The finite element method is a numerical method which can be used for the accurate solution of complex mechanical and structural vibration problems. The analysis capabilities of ANSYS include the ability to solve static and dynamic structural analysis, static or time varying magnetic analysis and various types of field and coupled field applications. This program contains many special features, which allow nonlinearities or secondary effect to be include in the solutions, such as plasticity, large strain, hyper elasticity, creep, swelling, large deflection, contact stress, stiffening, temperature dependency, material anisotropy and radiation.

Same set of command is used for modal analysis that used in any other type of finite element analysis. Likewise, choose similar option from the graphical user interface (GUI) to build and solve models. Modal analysis determines the vibration characteristics (natural frequencies and mode shapes) of a structure or machine components. Experimental modal analysis of a system, deals with determination of natural frequencies, damping ratios, and mode shapes through the vibration testing. In the case of forced vibration, the analysis includes the study of acceleration, velocity and displacement responses of the systems.

Modal analysis is the identification of vibration characteristics of elastic structures. It consists of describing a system by its modal parameters; natural frequencies, natural damping and natural modes. This study enables better understanding of the vibration phenomenon encountered in engineering it's purpose is to get data from experiment in order to determine system characteristics. One can use the data in several ways, depending on the aims to reach.

A reason to make measurements on a real test structure is the need to compare the experimental vibration with the data produced by a simulation program like a FEM program, for instance. The aim is the validation of theoretical model before it's further use, with more; complex excitation like shocks or step changes.Another way of using the information provided by modal analysis is to obtain a frequency response function (FRF) from the theoretical model and real test structure and to compare both results this comparison allows, correcting the model to a certain extent by using a trial and error approach.Modal analysis can be used to quantitatively describe a mechanical element that will have to be part of bigger assembly. Accurate data is required for natural frequencies, damping and mode shapes. This is referred to as a sub structuring process and is in theoretical analysis of complex structures. This method can also be used to predict the vibration behavior of a machinery element that has to be modified for any reason including the one of modifying the vibration properties themselves by reducing the amplitude of vibration at a given frequency or by shifting the resonance frequency of a given mode. Another application for modal testing is that of force determination. Given a theoretical model and measured vibration on a real structure, it is possible to determine the forces that act upon the real structure. Nevertheless this method is very sensitive to modeling inaccuracies and little errors can have huge consequences. Accurate Modal Analysis requires understanding of the theoretical basis of vibration, accurate measurement of vibration, careful and detailed data analysis.

Theoretical analysis of circular cutter by FEM shows the mode shape and gives the natural frequency.



Natural frequency 248.721

Steps of analysis:

1. Model meshing

This step includes the job name and analysis title and then uses PRER7 to define the element types, element real constant, material properties, and the model geometry.

2. Loadings

In this step, define analysis types and options, apply load, satisfy load step options to get the finite element solution for the natural frequency.

3. Expansion of the modes

Specify the number of mode that, you have to expand. If frequency range is selected, only modes within that range mode results are appeared.

4.Results

Results from modal analysis are written to the structural results file. Results consist of natural frequency, mode shapes relative stress and force distribution. Those results wish to see, database must contain the same modal for which the solution was calculated.

II. PROPOSED METHODOLOGY

(A)Test set up:

Total circular cutters of S.S. are chosen with following material properties for the specimen plates.

Young's modulus (E) = 2.1 X 10^{11} N/m^2

Poisson's ratio (γ) = 0 .3

Density of material (ρ) = 7850 N/m^3

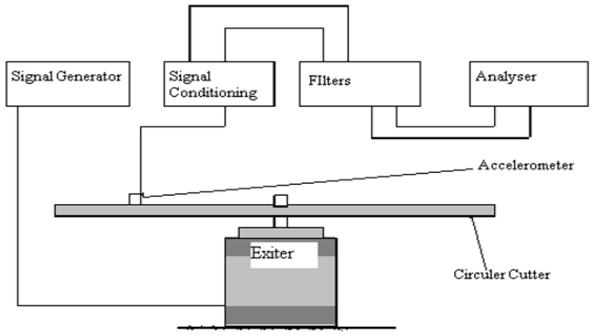
Inner diameter of the disk is 20 mm while outer diameter variable & thickness of the disk is kept 1.5 to 2.5 mm. These specimen sizes are chosen to facilitate the measurements by using the same fixture for all the specimen plates. As boundary conditions for plate specimen are inner edge fixed and outer edge free, with these boundary conditions These specimens prepared were taken one by one for experimental modal analysis.

Test Fixture:

In vibration test annular cutter is fixed in a fixture . As the plates are to be fixed on inner boundary it can be used for two types of tests as below:

I] Clamping was obtained by using two 20mm diameter nuts and one bolt with two washers are fastened above and below the disk for impact hammer test. . Bolt is used to restrict the movement at inner edge of annular plate in x and y and z direction. The fixture was hold in vice, which is rigidly fixed on concrete foundation with nut bolts.

II] Annular plate assembly will be mounted on exciter & pressed by a set of nut and clamping bolts and also in diagram & sufficient care is exercised to tighten the bolts with 3 kg-m constant torque provided by torque range spanner, uniformly to achieve the fixed end Condition.



(B) Basic assumption in experimental analysis

Four basic assumptions to perform an experimental modal analysis.

1. 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.
2. 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 that's mass, stiffness, or damping depend on factors that are not measured or not included in the model.
3. 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.
4. The structure is observable; i.e. the input output measurements that are made enough information to generate an adequate behavioral model of the structure

(C) Instrumentation used for modal analysis

1) FFT analyzer 2) Accelerometer 3) Exciter
4) Impact hammer

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.

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.

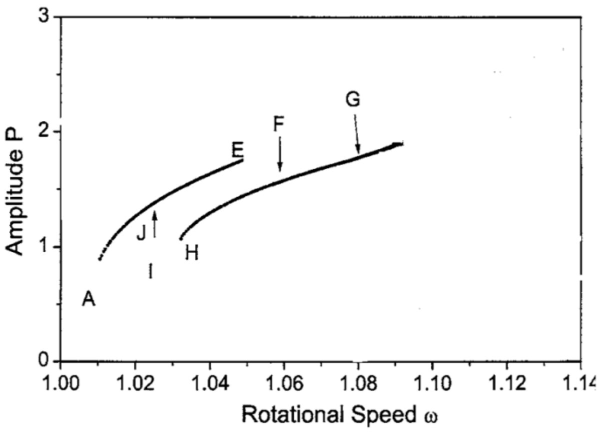
3) Exciter

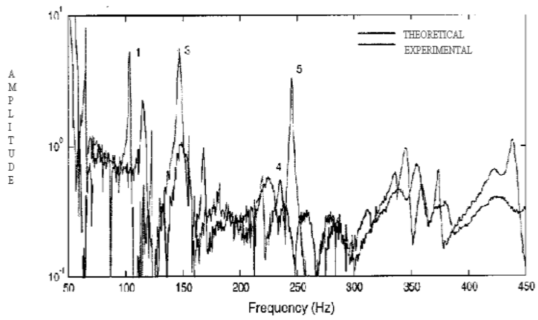
Exciter SI-220 is an electrodynamics type of device. By controlling the amount of current, the amplitude of vibration is controlled. A powerful magnet placed centrally surrounding which is suspended with the exciter coil. This assembly is enclosed by a high permeability magnetic circuit for optimum performance 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.

III. RESULT AND CONCLUSIONS

Following two graphs shows the performance.

Graph 1 shows the variation in rotational speed of brake cutter vs amplitude as speed increases amplitude also increases





Circular cutter which is flexible and symmetric will exhibit both "single" and "double" modes of vibration, due to the circular symmetry of the cutter. A "single" mode is identified as having one natural frequency and a circumferentially symmetrical mode shape. A "double mode" has two natural frequencies which coincide in an axisymmetric cutter. Non-uniformities exist in which introduce a frequency splitting in the double modes giving two, very close natural frequencies.

IV. REFERENCES

[1] H. Jiang, W. X. Tang and Y. P. Qu College of Chemistry and Chemical Eng., Shandong University, NO.27, Shanda South Rd,250100, Shandong, P.R.China, This paper focuses on analysis for the dynamic characteristics of the high-speed rotary tools. In this process, the rotary tools' structural parameters are taken into account, dynamic characteristics analysis of the rotary tools models are performed and natural frequencies and mode shapes of vibration are calculated. It is testified that the results of calculation are in agreement with those of experiment. And the dynamics modeling proposed and the dynamic characteristics obtained in this paper can be used to evaluate and optimize the dynamic behaviors and stability of the rotary tools in high-speed machining (HSM) system

[2] G. N. Weisenel have cutter used the results of an extensive literature search and review of available sources of numerical natural frequency information for stationary circular and annular elastic plates. In addition to source information is given regarding the specific plate theory, boundary conditions, geometric properties and material properties used to determine the natural frequency information Sources of information are tabulated according to the above parameters for easy reference and selection of desired information This information may be particularly useful to experts and designers when frequency data are required without the need for detailed analysis.

[3] C.A. Malfa, C.A.Rossit, P.A.A. Laurahave focused on analytical and experimental investigation on transverse vibrations of solid circular and annular plates carrying a concentrated

mass at an arbitrary position with marine applications.

[4] J.A. Wickert investigated the free vibrations of disk-hat structures such as automotive brake rotors analytically and through laboratory experimentation of particular interest are the role played by the hat element’s depth in influencing the 3D vibration of the cutter and the manner in which the bending and in-plane modes of the cutter alone evolve as a hat of increasing depth is incorporated in the model. The lower vibration modes of cutter-hat structures are shown to be characterized by the numbers of nodal circles (NC) and diameters (ND) present on the disk, as well as phase relationships between the cutter transverse and radial displacements due to coupling with the hat element.

[5] G.frosali, M.K.Kwak studied free vibrations of annular plates coupled with fluids. The natural frequencies of annular plates on an aperture of an infinite rigid wall and in contact with a fluid on one side are theoretically obtained by using added mass approach.

[6] Kristina M. Jeric Daniel J. Inman An Experimental Evaluation of Smart Damping Materials for Reducing Structural Noise and Vibrations An experimental evaluation of the benefits of smart damping materials in reducing structural noise and vibration is presented. The construction of a special test rig for measuring both vibrations and structure-borne noise is cutterussed. Next, the application of smart damping materials, specifically piezoceramics with electrical shunts, in reducing the vibrations of a test plate is cutterussed. 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.