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ANALYTICAL AND EXPERIMENTAL VIBRATION INVESTIGATION OF ROTOR WITH RADIAL SLOT

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Abstract: The slotted discs are important structural elements in engineering application. The turbine, brake disc and diaphragm clutch spring are the well-known examples of industrial application of annular disc with radial slots. Rotor discs with uniform radial slots are extensively used in the construction of aircraft, ships, automobiles, flywheels, circular saw plates, pressure vessel, missiles, ship structures and liquid containers. The knowledge of natural frequencies of components is of great interest in the study of response of structures to various excitations. Hence one of the application of rotor disc i.e. tile cutter with central hole fixed at inner edge and free at outer edge is chosen and its dynamic response is investigated in this present work. The natural frequencies are detected by hitting the disc with impact hammer; the response at a point is measured with the help of accelerometer. The Fast Fourier Transform analyzer analyzes the response given by accelerometer. The Finite Element Method software package *(*ANSYS*)* is used for vibration analysis of tile cutter of the same ratio of inner to outer radius having different number of teeth and different slot end hole diameter with the same boundary condition for determining different parameters such as natural frequency and mode shapes. The analytical and experimental results obtained are compared.

Keywords- **Exciter, FFT, FEM, Mode shapes, Natural frequency, Rotor with radial slot, Vibration analysis.**

I. INTRODUCTION

The study of the dynamic behaviour of tile cutter with free boundary condition but having different number of teeth and slot end hole diameter is important, as used in several cutting machines. Unwanted cutting process 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 dissertation work. The Circular plates with multiple circular holes are widely used in engineering structures, e.g. missiles, aircraft etc., either to reduce the weight of the structure, to increase the range of inspection or to satisfy other engineering applications. These holes in a structure usually invoke natural frequency change and loading capacity decrease. It is important to comprehend the corresponding effects in the process of mechanical design. Circular and annular plates with variable thickness are widely used in many engineering structures and machines. By appropriate variation of plate thickness, these plates can have significantly greater efficiency for vibration as compared to the plates of uniform thickness and also provide the advantage of reduction in weight and size.

ANSYS/CAE is a general purpose finite element analysis tool with a group of engineering simulation programs capable of modeling structures under different loading conditions. It can solve problems of relatively simple structural analysis to the most complicated linear to nonlinear analyses. In a nonlinear analysis ANSYS/CAE automatically chooses appropriate load increments and convergence tolerances and continually adjusts them during the analysis to ensure that an accurate solution is obtained. ANSYS /CAE consist of a widespread library of elements, wherein any type of geometry can be modeled. Apart from solving structural problems, it can also solve problems in other different areas like fracture mechanics, soil mechanics, static analysis, piezoelectric analysis, coupled thermal-electrical analyses, heat problems, and acoustics etc.

Many researchers have studied the vibration of annular plates over a long period of time. Dynamic characteristics of annular plates are of considerable importance in many designs. Circular plates with cutouts are extensively used in mechanical structures. Vibration analysis of this kind of structure is the foundation for structural parameter identification, damage detection and vibration control.

II. TEST FIXTURE

Bolt is used to restrict the movement at inner edge of cutter in x and y and z direction. The fixture was held in bench vice, which is rigidly fixed on rigid foundation with nut bolts. Clamping was obtained by using two 20mm diameter nuts and one bolt with two washers are fastened above and below the rotor disc as shown in fig 1.Secondly cutter with annular disc assembly was mounted on exciter and pressed by a set of nut and clamping bolt. Sufficient care is exercised to tighten the bolts with 3kg-m constant torque provided by torque range spanner, uniformly to achieve the fixed end condition. The clamped disc cutters were excited by electrodynamic exciter.

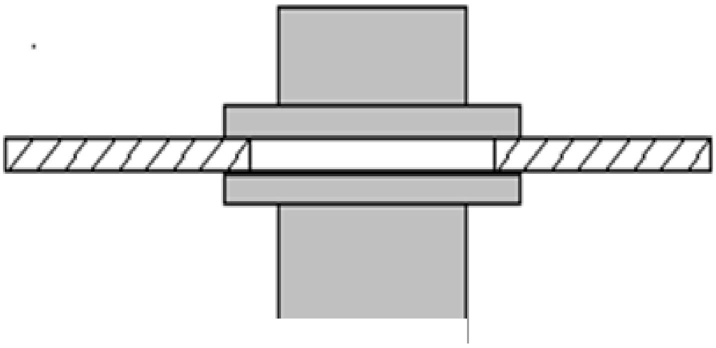


Fig. 1 clamping details of test specimen

III. EXPERIMENTATION

Figure (2). shows schematic representation of the experimental set up to be used, both for impact hammer test along with specialized mounting to simulate the clamped end condition at the inner boundary. **S**pecimens of circular annular cutters of S.S. are chosen for testing. Following are the material properties for the specimen discs. Young's modulus (E) = 2.1 X 10^{11} N/m^2, Poisson's ratio (γ) = 0 .3, Density of material (ρ) = 6250 N/m^3. In analysis, annular cutters are used for investigating the bending modes. The structure is axi-symmetric and formed of an isotropic homogeneous elastic material. Three dimensional parameters represents the disc's inner radius (*b)* outer radius (a) and thickness (h) respectively. Specimens prepared were rigidly fixed in fixture to obtain correct boundary conditions.

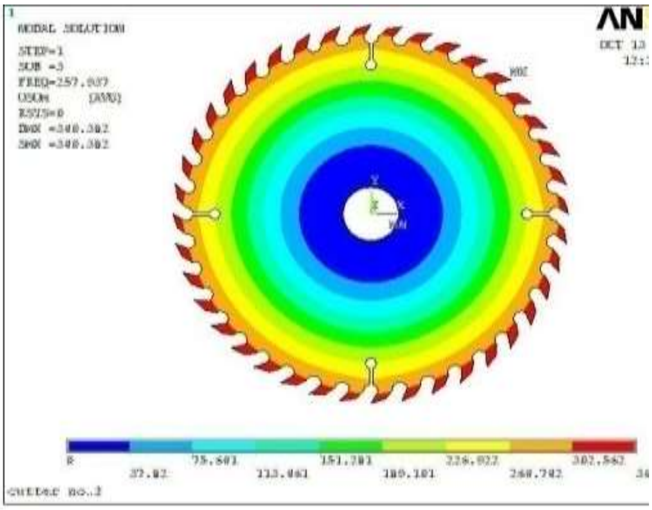
Fig. 2 experimental set up

Experimental Procedure

It is done by two types. In first method, Using FFT analyzer, natural frequencies are detected by hitting the disc with impact hammer; the response at a point is measured by using an accelerometer. FFT analyser analysed the response given by accelerometer. In second method, the clamped cutter is mounted on exciter and different resonance's was detected by varying the exciting frequency. Mode shapes are investigated using sea shore sand, coal dust or salt to compare with FEM mode shape of same test specimen. The annular disc cutter of thickness 1.5mm.The inner diameter of the disc is 25.4 mm and outer diameter is 180 mm with same boundary condition. Analysis is done experimentally with the help of FFT analyzer, accelerometer and impact hammer. Comparison of vibration results is done after experimentation with analysis by three methods as below: i) To find natural frequency and modes by FEM, ii) To find natural frequency by FFT, iii) To find modes by exciter.

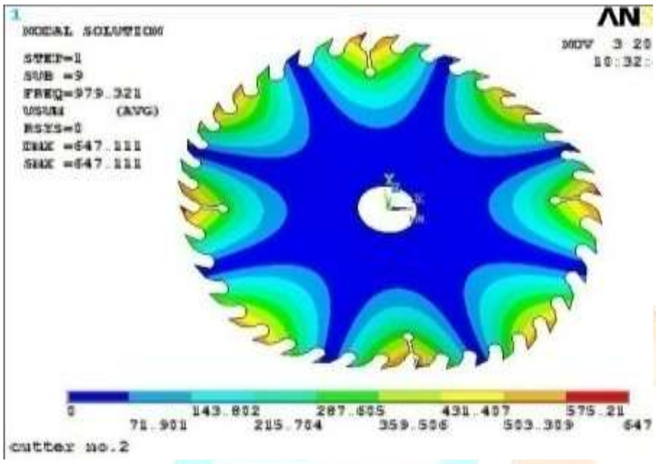
IV. RESULTS AND DISCUSSION

We shall now attempt to compare the predicted and measured results for individual modes or pairs of modes. As these are the modes with a low number of diameter, which are most readily identified to concentrate our interest on those with 2, 3 or 4 nodal diameters. Comparisons on the results, concern the natural frequencies and the mode shapes is done here. Experimental results shows that values of natural frequencies determined experimentally are less than those obtained by FEM analysis. Comparison of mode shapes of annular disc cutter no.1throughFEM (ANSYS) results and exciter results showing similarity are given below.



Mode shapes of annular disc cutter no.1 by <u>FEM (ANSYS)</u> Results-

Mode shapes of annular disc cutter no .1 by <u>Exciter</u> Results-



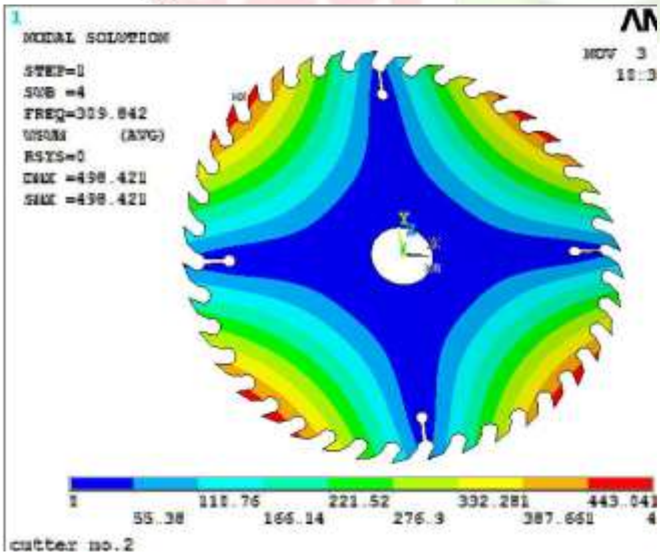
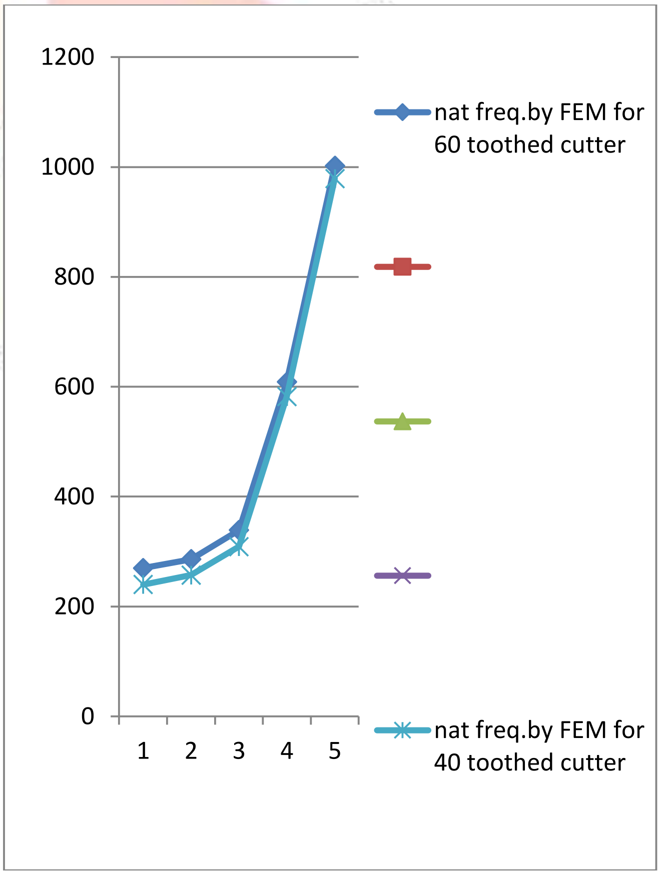


Table (I) - (Toothed cutter – To cut Aluminium)
Thickness–1.5 mm

Specimen	**Aspect ratio b/a**	**Inner diame -ter in (mm)**	**Outer diamet er in (mm)**	**No. of slots of length 22.5 mm**	**No. of teeth**
First Cutter	0.141	25.4	180	4	**60**
Natural frequency by FFT	262	275	323	598	992
Natural frequency by FEM	270	286	339	609	1002
Second Cutter	0.141	25.4	180	4	**40**
Natural frequency by FFT	232	248	301	575	968
Natural frequency by FEM	240	257	309	582	979
% change in FFT frequency due to reduced no. of teeth	12.9%	10.8%	7.3%	4%	2.4%
% change in FEM frequency due to reduced no. of teeth	12%	11.2%	9.7%	4.6%	2.3%

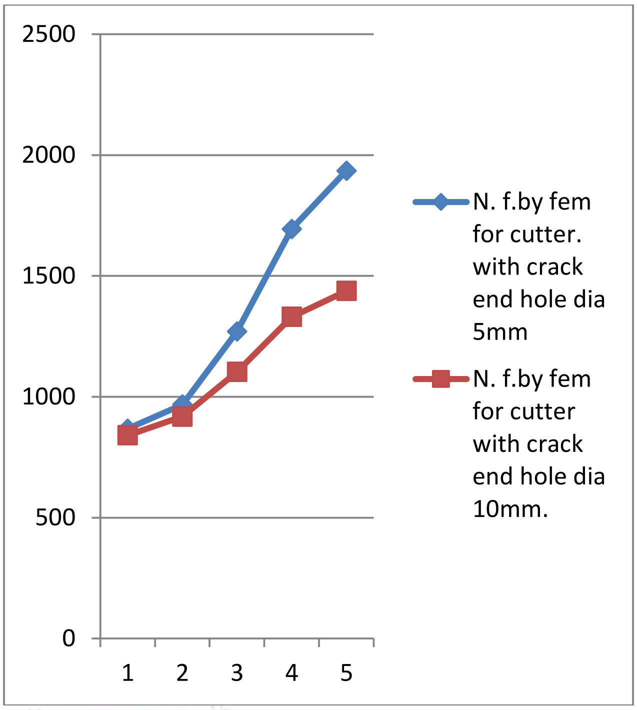


Graph - Comparison graph of FEM natural frequency results for 60 and 40 number of teeth while all other data is same. For cutter no. 1 & 2 (Frequency vs modes)

Concluding Remark- Natural frequency decreases as number of teeth on cutter reduces. 33% reduction in number of teeth gives 2.4 to 12.9% reduction in natural frequency variable as per modes.

Table (II) - (Non Toothed Cutter– To cut Wood)
Thickness–1.5 mm

Specimen	Aspect ratio b/a	Inner diameter in(mm)	Outer diameter in (mm)	No. of slots of length 17.5 mm.	Slot end hole dia.mm
Third Cutter	0.182	20	110	10	**5**
Natural frequency by FFT	851	953	1255	1677	1917
Natural frequency by FEM	868	968	1270	1694	1935
Fourth Cutter	0.182	20	110	10	**10**
Natural frequency by FFT	828	909	1087	1316	1421
Natural frequency by FEM	841	918	1103	1331	1438
% change in FEM frequency due to reduced no. of teeth	2%	1.5%	1.5%	1.2%	1%



Graph - Comparison graph of FEM natural frequency results for cutter showing effect of increased hole diameter of slot end. For cutter no.3&4(Frequency vs modes)

Concluding Remark - Natural frequency decreases as slot end hole diameter increases. 3 to34%reduction in natural frequency is achieved by 100% enlargement of slot end hole diameter.

V. CONCLUSIONS

Conclusion of results common for all specimen types : Vibration analysis of cutters with different aspect ratio, with different number of teeth and with different slot end hole diameter is conducted by FFT and FEM (ANSYS) method to reach the conclusion as:

- Natural frequency increases with increase in nodal diameter and both results FFT & FEM are matched to average of 4% error which is acceptable.
- Comparison of Mode shapes is done for annular disc cutters through exciter results and FEM (ANSYS) results which found, similar modes shape.

Conclusion of results of specimen type I: Vibration analysis of annular disc with four slots for same aspect ratio but variable no. of teeth conducted by FFT and FEM (ANSYS) method to reach the conclusion as natural frequency increases with increase in no. of teeth on cutters.

Conclusion of results of specimen type II: Natural frequency decreases as slot end hole diameter increases. 3 to34%reduction in natural frequency is achieved by 100% enlargement of slot end hole diameter.

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