Vibration Analysis of Circular Plate Having Radial Crack by Experimental and FEM analysis

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Abstract— This paper deals with vibration analysis of circular plate having radial crack in it. The plate is of Alluminium (A-2024) and Steel (AISI 304) material. For testing of plate two-boundary condition are chosen namely: 1. Simply Supported and 2.cantilever boundary condition. The plates are crack with different crack ratios (*c/a*) such as 0.2, 0.4, 0.6, 0.8 and 1.0 (no crack in plate). Then the plates fabricated according to dimensions and crack ratios. The plates are analyzed by using FEM software, find out the natural frequencies for different boundary conditions, and crack ratios. Then same plates analyzed experimentally by using FFT analyzer.

Keywords— Circular Plate, vibration, Radial Crack

INTRODUCTION

The problem of the plate is important since such components are frequently used in engineering applications where dynamic excitation may occur. For this reason, some literature on the subject is discussed in the useful review works by Arthur W. Leissa [1]. However, there is relatively little work reported on the plates with crack. Flat Circular Plates are widely used in practice and they have conspicuous role in the theory of acoustics and vibration. They are common in many structures such as architectural structures, pavements, containers, airplanes, ships, instruments, machine parts such as turbine disks/blades, bulk heads in submarines and airplanes, etc. Because of their distinct advantages, thin plates are extensively use in all fields of engineering [2].

In this paper the circular plate is of aluminium (a-2024) with Young's Modulus of 70 GPa , Poisson's ratio 0.3 , density 2770 kg/m^3 and Steel (AISI 304) with Young's Modulus of 204 GPa , Poisson's ratio 0.33, density 7860 kg/m^3. The plate is of 250mm in diameter and 3mm thick. Two boundary conditions are taken for analysis of plates simply supported and cantilever. The plates were manufacture according to the crack ratios (*c/a*), 'c' is the crack length and 'a' is the radius of the plate. The crack in the plate having length of 25mm, 50mm, 75mm ,100mm and one plate without crack for comparing result. For each crack length and boundary condition find out the natural frequencies are found out by using FEM software such as ANSYS by creating model of the plate in ANSYS and results are compared with the experimental results.

STATEMENT OF PROBLEM

The main objective is to find out the change in the natural frequencies of the plate when the crack size in the circular plate increases. Two boundary conditions used to find out the natural frequencies of the plate with change in crack ratios.

For this study a simply supported and cantilever circular plate of AISI 304 Steel and a-2024 Alluminium with a radial crack originating at the circumference of radius '*a*', thickness '*h*' and edge crack radius '*c*' are considered. The geometry of the plate is shown in Fig 1. The crack is said to be increasing towards the center from the edge of the plate. Therefore different crack ratios (*c/a*) are considered such as 0.2 (c-25), 0.4 (c-50), 0.6 (c-75), 0.8 (c-100), 1.0 (without crack).

FINITE ELEMENT METHOD

Due to geometry of the figure, it is very complicated process to find out the natural frequencies by analytical method. So, numerical methods are used to solve these partial differential equations. One of the most used techniques in engineering is Finite Element Method. ANSYS is the popular software uses Finite Element Technique.

First we have prepared the model in CATIA V5R15 software. So, the total plates are 10 in nos. The plates can be prepared for 5 crack ratios, namely; plate without crack (i.e. Crack ratio c/a 1.0), plate having distance of crack from the center of plate 100mm (Crack ratio c/a 0.8), plate having distance of crack from the center of plate 75mm (Crack ratio c/a 0.6), plate having distance of crack from the center of plate 50mm (Crack ratio c/a 0.4), plate having distance of crack from the center of plate 25mm (Crack ratio c/a 0.2) i.e. it is highest crack size in plate.

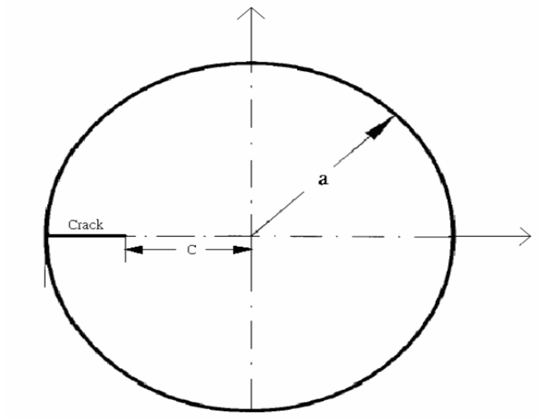

Fig. 1 Geometry of Plate

The prepared model plates are imported into the ANSYS software for obtaining the simulation results. The element type chosen is SOLID95 because SOLID95 is a higher order version of the 3-D 8-node solid element SOLID45. It can tolerate irregular shapes without as much loss of accuracy. SOLID95 elements have compatible displacement shapes and are well suited to model curved boundaries. The element is defined by 20 nodes having three degrees of freedom per node: translations in the nodal x, y, and z directions. The element may have any spatial orientation. SOLID95 has plasticity, creep, stress stiffening, large deflection, and large strain capabilities. Figure 2 shows the plate model mesh in ANSYS. Fine mesh is given in crack area to get accurate result. The results of the ANSYS analysis are shown in Table no. 1

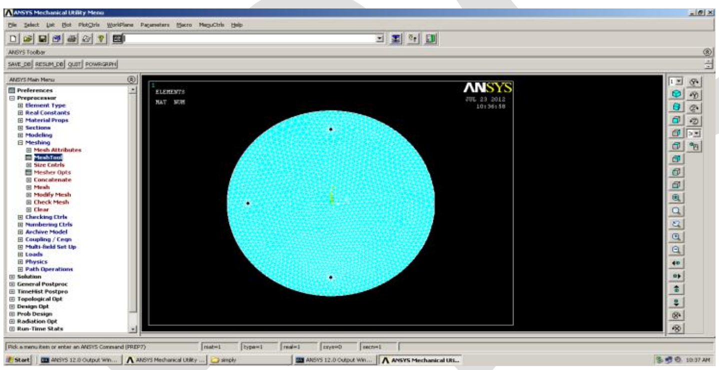

Fig.2 Circular Plate model mesh in ANSYS

EXPERIMENTAL METHOD

The experimental work conducted on FFT (Fast Fourier Transform) Analyzer. Here we use multichannel FFT (4-channel). One channel connected to exciter i.e. to the hammer and other connected to the sensor. During testing, the hammer struck on the plate to get the natural frequency peaks of the plate. The same procedure repeated for other plate. The results of experimentation are shown in Table no.1.

EXPERIMENTAL SETUP

The typical experimental setup is shown in Fig 3 and fixture for clamping of plate and FFT analyzer. The setup consists of hammer, sensor, and FFT analyzer and for display of result laptop. The FFT is multichannel (4 channel) one channel for hammer and one for sensor. The plates excited by hammer and the peak of natural frequency measured by sensor and display the result on laptop screen. The results of measurements are auto generated by FFT software in MS-Word format.

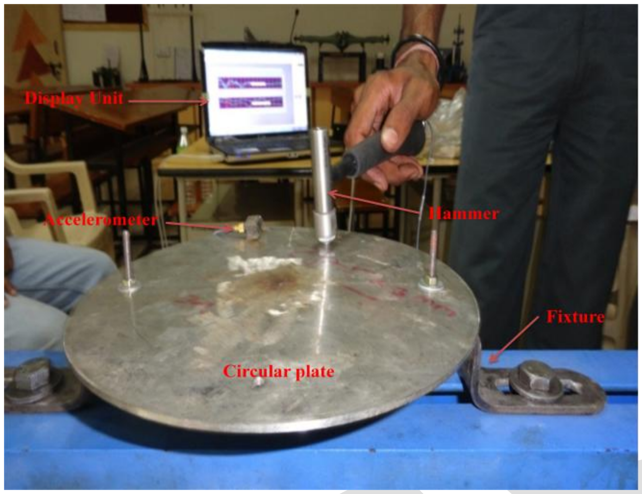

Fig. 3 Experimental Setup for Steel Plate

RESULTS

For AISI 304 steel plate the Young's modulus E=204 GPa, density ρ=7860 kg/m3, Poisson's ratio υ = 0.33, radius a = 0.125m, and thickness h = 0.003 m, without crack (*c/a* 1.0) simply supported the natural frequency ω for first mode by FEM is 120.74 Hz and by FFT 116.69Hz, Similarly for a-2024 alluminium plate, Young's modulus E = 70 GPa, density ρ=2770 kg/m3,Poisson's ratio υ = 0.3 , radius a = 0.125m, and thickness h = 0.003 m, without crack simply supported the natural frequency ω for first mode is 118.76 Hz and by FFT 112.07 Hz. If the crack initiates in steel plate simply supported case (*c/a* 0.8) the plate vibrate with higher natural frequency and it goes up to 630.34 Hz for third mode and similar condition seen in alluminium plate but it less vibrate as compare to steel plate.

The steel plate without crack (*c/a* 1.0) in cantilever case the natural frequency ω for first mode by FEM is 41.682 Hz and by FFT 37.69 Hz, Similarly for alluminium plate without crack (*c/a* 1.0) cantilever case the natural frequency ω for first mode by FEM is 40.939 Hz and by FFT 39.57 Hz. As crack increases in alluminium plates i.e. for different crack ratios of plate *c/a* 0.8, *c/a* 0.6, *c/a* 0.4, *c/a* 0.2 the natural frequencies are somewhat decreases and for highest crack size in plates they are increases. For without crack and for highest crack size in plates the difference between natural frequency ω is 0.99 % for alluminium plate and for steel plate it is for different crack ratios of plate *c/a* 0.8, *c/a* 0.6, *c/a* 0.4, *c/a* 0.2 the natural frequencies are decreases as crack increases in plate.

Finally, it is seen that the natural frequencies are decreases as crack increases in plate. This is due the stiffness of plate decreases. The plate will vibrate for lower natural frequencies ω. The results are tabulated below

Steel Plate Simply Supported Condition

MODE NO.	FEM -0.2	FFT-0.2	% change	FEM-0.4	FFT-0.4	% change	FEM-0.6	FFT-0.6	% change	FEM-0.8	FFT-0.8	% change	FEM-1.0	FFT-1.0	% change	% Ave.
	c/a-0.2			*c/a*-0.4			*c/a*-0.6			*c/a*-0.8			*c/a*-1.0			
1	120.74	116.69	**3.35**	121.85	119.94	**1.56**	123.07	118.56	**3.66**	208.82	201.31	**3.59**	124.45	129.74	**-4.25**	**1.58**
2	167.64	164.15	**2.08**	170.07	166.90	**1.86**	172.37	169.71	**1.54**	292.94	291.48	**0.49**	174.65	170.65	**2.25**	**1.64**
3	210.76	205.99	**2.26**	274.00	271.06	**1.07**	344.15	338.75	**1.56**	630.34	627.15	**0.50**	378.98	380.79	**-0.47**	**0.98**

Steel Plate Cantilever Condition

MODE NO.	FEM -0.2	FFT-0.2	% change	FEM-0.4	FFT-0.4	% change	FEM-0.6	FFT-0.6	% change	FEM-0.8	FFT-0.8	% change	FEM-1.0	FFT-1.0	% change	% Ave.
	c/a-0.2			*c/a*-0.4			*c/a*-0.6			*c/a*-0.8			*c/a*-1.0			
1	41.682	37.69	**9.58**	41.680	40.25	**3.43**	41.654	39.57	**5.00**	41.664	38.56	**7.45**	41.770	39.57	**5.27**	**6.14**
2	70.431	67.41	**4.29**	72.911	68.35	**6.26**	73.983	70.23	**5.07**	74.476	69.29	**6.96**	74.479	73.91	**0.76**	**4.66**
3	150.29	146.48	**2.54**	151.33	146.56	**3.15**	151.05	146.48	**3.03**	151.58	154.85	**-2.16**	150.94	145.54	**3.58**	**2.02**

Aluminum Plate Simply Supported Condition

MODE NO.	FEM -0.2	FFT-0.2	% change	FEM-0.4	FFT-0.4	% change	FEM-0.6	FFT-0.6	% change	FEM-0.8	FFT-0.8	% change	FEM-1.0	FFT-1.0	% change	% Ave.
	c/a-0.2			*c/a*-0.4			*c/a*-0.6			*c/a*-0.8			*c/a*-1.0			
1	118.76	112.07	**5.63**	119.78	117.94	**1.53**	120.94	115.75	**4.29**	121.83	117.62	**3.45**	122.26	118.56	**3.02**	**3.58**
2	164.75	160.40	**2.64**	167.16	162.27	**2.92**	169.42	163.21	**3.66**	170.97	171.58	**-0.35**	171.63	169.71	**1.11**	**1.99**
3	208.23	201.31	**3.32**	271.01	264.00	**2.58**	340.22	331.01	**2.70**	369.41	367.57	**0.49**	373.87	371.48	**0.63**	**1.99**

Aluminum Plate Cantilever Condition

MODE NO.	FEM -0.2	FFT-0.2	% change	FEM-0.4	FFT-0.4	% change	FEM-0.6	FFT-0.6	% change	FEM-0.8	FFT-0.8	% change	FEM-1.0	FFT-1.0	% change	% Ave.
	c/a-0.2			*c/a*-0.4			*c/a*-0.6			*c/a*-0.8			*c/a*-1.0			
1	40.939	39.57	**3.34**	40.829	38.63	**5.38**	40.805	39.32	**3.63**	40.808	36.75	**9.94**	40.909	41.37	**-1.12**	**4.23**
2	69.677	62.42	**10.41**	71.917	68.35	**4.95**	72.949	68.35	**6.30**	73.412	68.35	**6.89**	73.685	69.29	**5.96**	**6.90**
3	150.71	146.56	**2.75**	150.80	145.63	**3.42**	150.64	146.48	**2.76**	151.04	147.42	**2.39**	150.43	147.42	**2.00**	**2.66**

Frequency (Hz)

Table 1 Percentage change in FEM and FFT result of Steel and Allunimium Plates

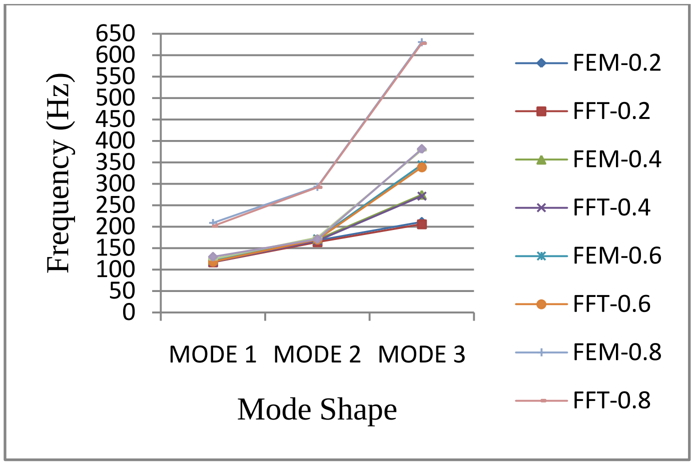

Fig. 4 Steel Plate Simply Supported Condition for different crack ratios of plate

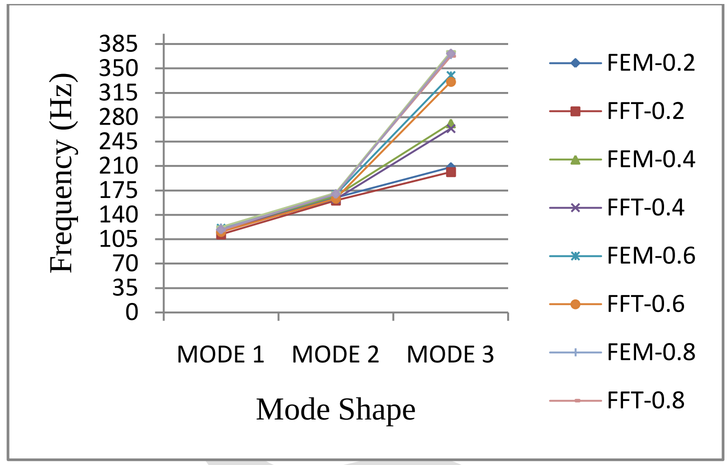

Fig. 5 Alluminium Plate Simply Supported Condition for different crack ratios of plate

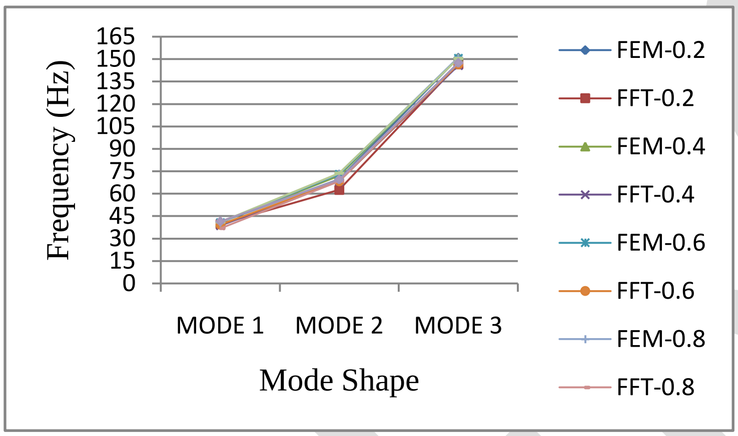

Fig. 6 Alluminium Plate Cantilever Condition for different crack ratios of plate

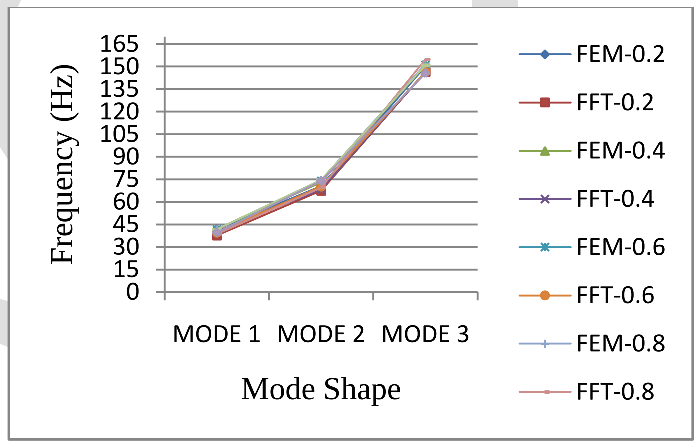

Fig. 7 Steel Plate Cantilever Condition for different crack ratios of plate

CONCLUSIONS

Based on classical plate theory, the vibration analysis of edge cracked circular plate is provided. The analysis results are determined experimentally and numerically by mode shapes. The maximum error of natural frequency is in the range of 1 % to 10 % and average error in the range of 0.9% to 6.9%.

In this study, the natural frequencies are determined for different crack ratios. It is found from graph that as crack increases the natural frequencies somewhat increases and decreases for steel cantilever plate, bur from graph of steel simply supported plate it is seen that natural frequencies decreases as crack in the plate increases. However, for an instance for crack ratio 0.2 of steel simply supported condition the natural frequency increases predominantly and then decreases. As move towards the aluminum plate, the natural frequencies are decreases as crack ratio increase for both cantilever and simply supported condition.

It is observe that when the value of ω is equal to the natural frequency of plate resonance occurs. We can find the difference between the two cases of AISI 304 stainless steel plate and a-2024 aluminum plate.

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