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EVALUATION OF PERFORMANCE AND VIBRATION ANALYSIS OF ANNULAR DISC BY USING FINITE ELEMENT METHOD

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ABSTRACT:The vibration analysis of a circular or annular plate has been a topic of practical interest and attracted much attention. This interest naturally comes from the similarity with industrial application such as compact and computer disks, train wheels, circular saws, etc. Most of this interest, however, has been concentrated on the free vibration. Many researchers have studied the vibration of annular discs over a long period of time. Dynamic characteristics of annular disc 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. However, for engineering applications, many machine elements or structural components can be modeled as a circular plate with central holes, i.e., the annular plate, and has led to a rapid development of analytical or experimental methods, such as the energy approach, the mode subtraction approach, etc.

Keywords- Vibration, Natural Frequency, FFT, FEM, ANSYS.

1. OVERVIEW

In the recent decades, lightweight plate structures have been widely used in many engineering and practical applications. Vibration analyses of plates of different geometries and shapes have been carried out extensively by various researchers throughout the globe. The annular elliptic and circular plates are used quite often in aeronautical and ship structures, and in several other industrial applications. Therefore, the vibration analyses of these shapes are becoming more important. 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. In general, most research work has focused on vibration analysis of circular plates with a central hole, i.e., annular plates, and has led to a rapid development of analytical or experimental methods, such as the energy approach, the mode subtraction approach, etc.

2. OBJECTIVE

The objective of current dissertation work is study of the behavior of Annular plate i.e. Circular plate with centre hole with different boundary conditions, when they are faced to crack is important, as used in several machine components, such as circular saw plates, aeronautical structures, turbine rotors, vehicle disc-brake etc. The knowledge of natural frequencies of component is of great interest in the analysis of response of structures to various behaviors. This dissertation work will help the Engineers to know the Natural frequency changes and will give an idea for values of natural frequency for different material and different conditions, with different crack lengths. The presence of damage is typically confirmed by witnessing changes in the Frequency of the structure before and after damage. The application of vibration analysis techniques, or more specifically the change in natural frequencies, is also one tool that can be also used for damage detection.

3. EXPERIMENTAL ANALYSIS

FFT ANALYSER

The Fast Fourier Transform is a computerized mathematical algorithm for transforming vibration signals from the time domain (time waveform) into the frequency domain. The Fourier Transform, a plot of vibration amplitude vs frequency, is especially useful for frequency analysis which is the analytical method most often used for fault recognition in operational machines.

4. EQUIPMENTS REQUIRED:-

1. Model hammer.
2. Accelerometer.
3. Portable pulse.
4. Connectors
5.Specimen.
6. Display Unit.

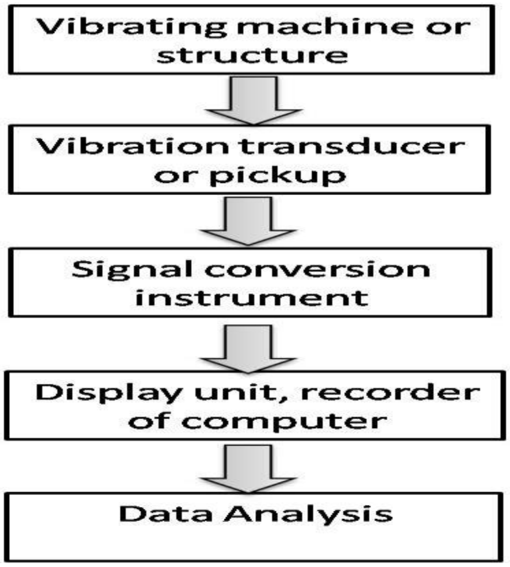

Fig.1. Display Unit

Fig.2.Vibration measurement Scheme

Experimental setup for annular disc

Fig.3.Schematic diagram of experimental setup & Physical modal of annular disc

Fig.3. shows the schematic figure of the experimental set-up used for vibration testing. An excitation signal was generated by a signal analyzer, then amplified by a power amplifier, and exerted on the tested structure through the exciter. The applied force was measured by a transducer fixed between the flexible string and disc. The vibration amplitude at the measuring locations was sensed by a accelerometer, and monitored by a oscilloscope.

5. MODELING AND FINITE ELEMENT ANALYSIS

The designing software used here is CATIA V5 R 16. The model of the Annular Disc having crack and without crack is generated in CAD software i.e. CATIA with different crack distance. The fig. given below are the example of how models are generated in CATIA.

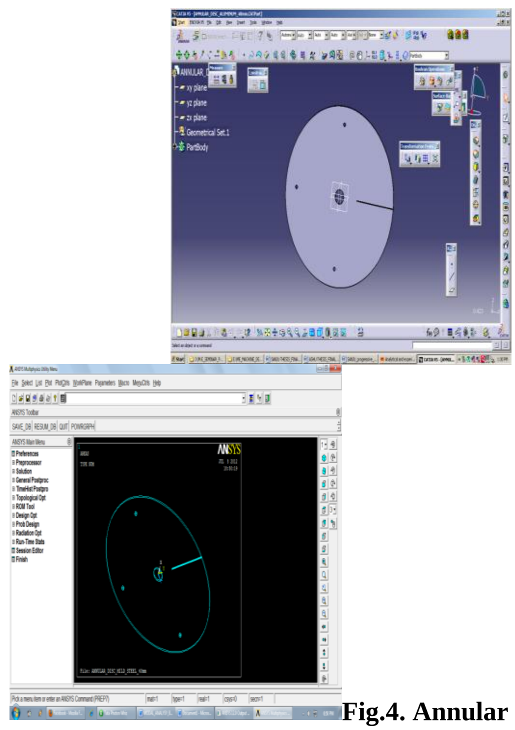

Fig.4. Annular Disc Model in CATIA & Imported Annular Disc CATIA model in ANSYS

6. RESULTS AND DISCUSSION

Specifications and boundary condition

The problem involves calculation of natural frequencies and mode shapes for Annular Disc without a crack and with crack of different crack ratio. The results of ANSYS software are validated with the results obtained by Experimental FFT vibration analysis.

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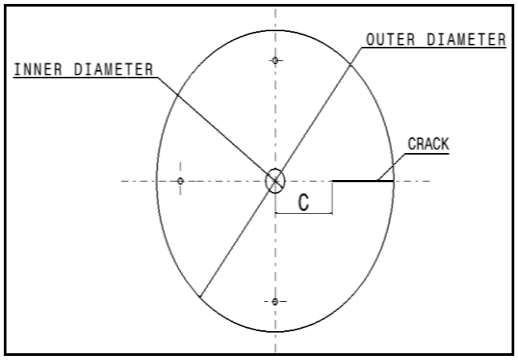

Fig.5. Geometry of Annular Disc.

Table 1. Specification and Boundary conditions for Aluminum and Mild Steel Annular disc		
Outer Diameter (OD)	250mm	
Inner Radius (ID)	20mm	
Thickness (t)	3mm	
Crack Width	0.5mm	
MATERIAL	**Aluminum**	**Mild Steel**
Elastic modulus of the beam	$7.3 \times 10^{11} N/m^2$	$2.1 \times 10^{11} N/m^2$
Poisson's Ratio	0.334	0.3
Density	2713 kg/m^3	7850 kg/m^3
For both Case -I- Aluminum and Case-II- Mild Steel (Total 10 Annular Disc)		
Plate 1.	No Crack	
Plate 2.	Length C form the centre 100mm	
Plate 3.	Length C form the centre 80mm	
Plate 4.	Length C form the centre 60mm	
Plate 5.	Length C form the centre 40mm	
CONDITIONS:- 1). Simply supported 2). Clamped Condition		

Experimental results

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 analyzeranalyzed the output of accelerometer.

Table 2. Experimental result of Natural Frequency for Case –I Aluminum Annular Disc.

Sr.No.	**Condition**	**Crack distance (C) mm**	**Experimental Results for Natural Frequency in Hz**				
			1	**2**	**3**	**4**	**5**
4.	**Simply Supported**	**100**	266.87	368.68	797.84	889.03	1027.93
5.		**80**	264.33	368.68	759.75	870.23	1024.00
6.		**60**	472.48	496.04	873.44	976.29	1159.46
7.		**40**	260.65	354.89	527.81	854.41	971.29
8.		**Without Crack**	1632.68	1635.14	2780.56	3825.92	3826.35
9.	**Inner Edge Clamped**	**100**	327.62	327.62	415.87	545.01	546.21
10.		**80**	324.66	327.63	412.90	527.92	536.72
11.		**60**	466.54	493.07	863.45	972.25	1152.62

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12.		**40**	315.55	322.20	389.91	427.23	517.49
13.		**Without Crack**	102.80	100.62	126.68	171.23	172.01

Table 3. Experimental result of Natural Frequency for Case –II Mild Steel Annular Disc.

Sr.No.	Condition	Crack distance (C) mm	Experimental for Natural Frequency in Hz				
			1	2	3	4	5
1.	**Simply Supported**	**100**	81.25	115.63	256.40	282.92	325.01
2.		**80**	84.16	118.65	242.93	278.96	320.82
3.		**60**	78.23	114.12	208.44	274.17	318.61
4.		**40**	84.85	115.17	169.56	271.85	307.21
5.		**Without Crack**	85.67	115.63	257.80	286.52	324.99
6.	**Inner Edge Clamped**	**100**	102.16	103.67	130.62	175.26	176.62
7.		**80**	100.65	103.67	126.09	168.99	173.84
8.		**60**	102.16	100.65	126.09	157.06	166.27
9.		**40**	102.20	99.14	123.07	136.25	168.35
10.		**Without Crack**	103.67	103.67	133.67	178.27	177.42

7. FEA RESULTS:-

The first, second, third, Fourth, Fifth natural frequencies corresponding to various crack locations and material are calculated. The fundamental mode shapes for transverse vibration of cracked and untracked annular disc are to be plotted and compared. The results obtained from the numerical analysis (FEA) are to be presented in graphical form. Results will show that there is an appreciable variation between natural frequency of cracked and uncracked annular disc.

Table 4. Natural Frequency Results by ANSYS for Simply Supported without Crack Case – I- Al and Case –II – MS.

Without Crack_ Simply Supported_Al

***** INDEX OF DATA SETS ON RESULTS FILE *****

SET TIME/FREQ LOAD STEP SUBSTEP CUMULATIVE

```
1   1634.4   1   1   1
2   1635.8   1   2   2
3   2784.3   1   3   3
4   3825.2   1   4   4
5   3825.6   1   5   5
```

Without Crack_ Simply Supported_MS

***** INDEX OF DATA SETS ON RESULTS FILE *****

SET TIME/FREQ LOAD STEP SUBSTEP CUMULATIVE

```
1   84.842   1   1   1
2   117.65   1   2   2
3   257.89   1   3   3
4   286.24   1   4   4
5   323.76   1   5   5
```

Table 5. ANSYS Results of Natural Frequency for Case –I Aluminum Annular Disc

Sr.No.	Condition	Crack Distance (C) mm	ANSYS Results for Natural Frequency in Hz				
			1	2	3	4	5
1)	**Simply Supported**	**100**	266.32	369.43	799.59	889.05	1026.0
2)		**80**	266.08	367.55	758.50	871.21	1022.9
3)		**60**	471.32	497.53	870.69	979.22	1158.8
4)		**40**	261.03	359.48	525.38	854.83	972.01
5)		**Without Crack**	1634.4	1635.8	2784.3	3825.2	3825.6

6)	**Inner Edge Clamped**	**100**	327.93	328.21	417.36	544.16	544.90
7)		**80**	327.75	327.97	414.82	528.08	535.71
8)		**60**	469.06	495.54	868.48	971.13	1149.1
9)		**40**	317.84	324.62	395.59	426.29	516.64
10)		**Without Crack**	101.79	101.97	129.59	170.03	170.20

Table 6. ANSYS Results of Natural Frequency for Case –II Mild Steel Annular Disc

Sr.No.	Condition	Crack Distance (C) mm	ANSYS for Natural Frequency in Hz				
			1	2	3	4	5
6.	**Simply Supported**	**100**	84.73	117.31	255.27	283.59	323.47
7.		**80**	84.38	116.57	241.88	277.69	321.99
8.		**60**	83.65	115.40	207.77	273.71	317.16
9.		**40 mm**	83.00	114.09	167.82	272.58	307.14
10.		**Without Crack**	84.84	117.65	257.89	286.24	323.76
11.	**Inner Edge Clamped**	**100**	103.34	103.38	130.81	174.62	174.81
12.		**80**	103.10	103.19	129.94	169.43	171.84
13.		**60**	102.60	102.95	127.92	157.05	168.27
14.		**40**	100.16	102.04	124.06	136.69	165.53
15.		**Without Crack**	103.40	103.56	131.08	176.07	176.23

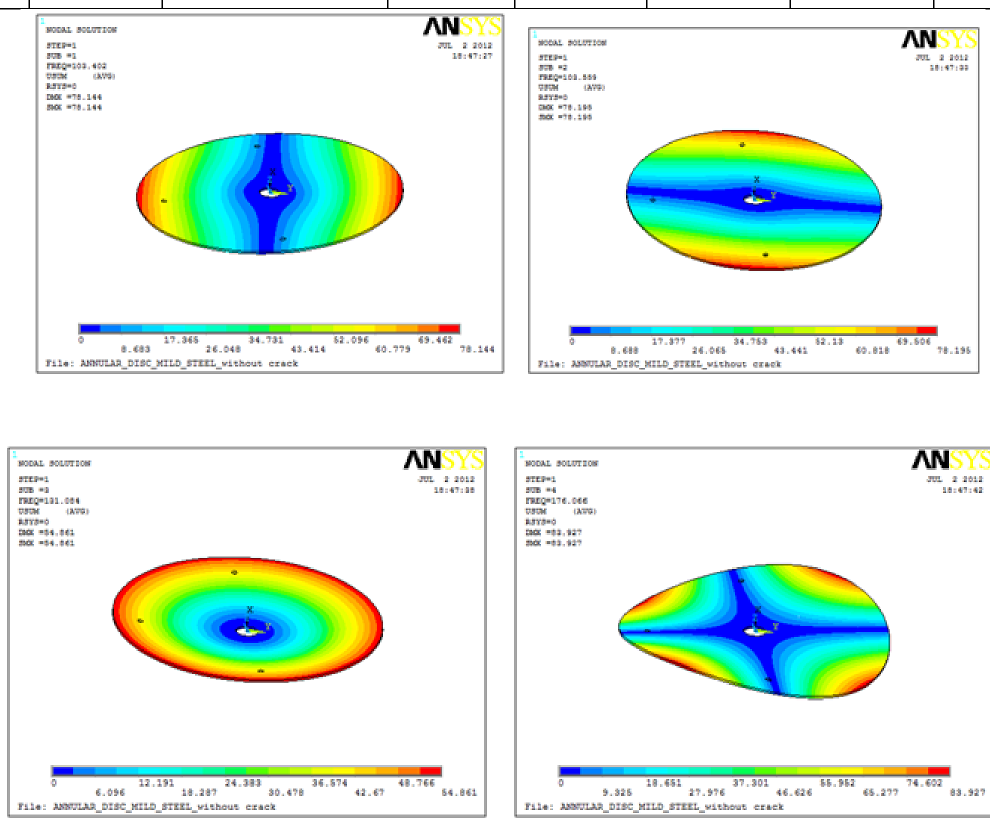

Fig.5.2 ANSYS Mode shapes for Annular Disc without Crack

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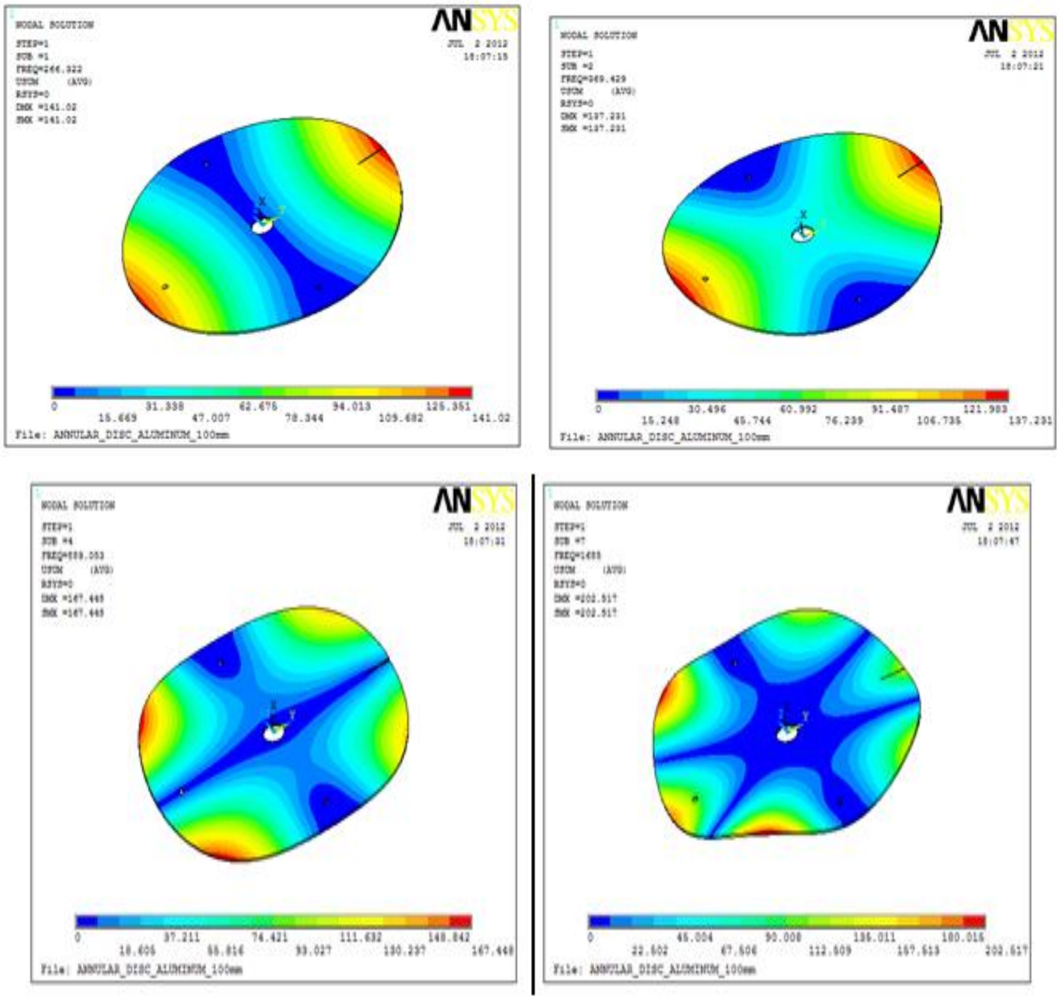

Fig. 6ANSYS Mode shapes for Case - I- Al -Simply Supported - Crack Distance (C)100mm

8.COMPARISON OF EXPERIMENTAL AND FEA RESULTS:-

Experimental results taken from FFT and FEA results from ANSYS are compared in form of tabular and graph. % change in FFT and FEA results are also compared.

Table 7.Comparison of Experimental Results and FEA Results for Case-I A aluminum Annular Disc without Crack.

Mode	Results of Natural Frequency in Hz					
	Simply Supported			Inner Edge Clamped		
	By ANSYS	By Expt.	% Change	By ANSYS	By Expt.	% Change
First	1634.4	1632.68	**0.11**	101.79	102.80	**-0.99**
Second	1635.8	1635.14	**0.04**	101.97	100.62	**1.32**
Third	2784.3	2780.56	**0.13**	129.59	126.68	**2.25**
Fourth	3825.2	3825.92	**-0.02**	170.03	171.23	**-0.71**
Fifth	3825.6	3826.35	**-0.02**	170.20	172.01	**-1.06**
		Average % Change	0.048		Average % Change	0.162

Table. 8 Comparison of FEA and Experimental Results for Case-I Mild Steel Annular Disc without Crack.

Mode	Results of Natural Frequency in Hz

	Simply Supported			Inner Edge Clamped		
	By ANSYS	By Expt.	% Change	By ANSYS	By Expt.	% Change
First	84.84	85.67	**-0.98**	103.40	103.67	**-0.26**
Second	117.65	115.63	**1.72**	103.56	103.67	**-0.11**
Third	257.89	257.80	**0.03**	131.08	133.67	**-1.98**
Fourth	286.24	286.52	**-0.10**	176.07	178.27	**-1.25**
Fifth	323.76	324.99	**-0.38**	176.23	177.42	**-0.68**
		Average % Change	0.058		Average % Change	-0.856

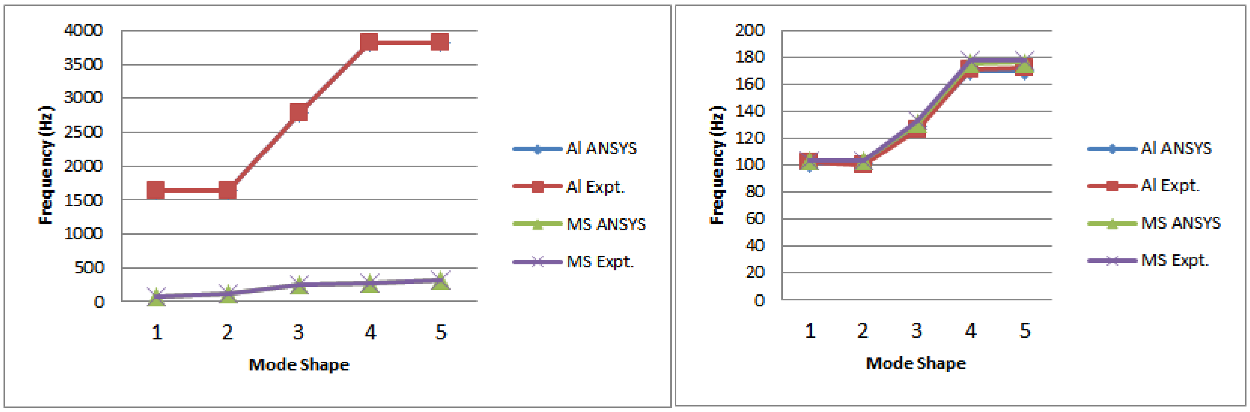

Fig.7 (a). Comparison graph of natural frequency results from FEM and Experimental for Simply Supported Annular Disc without Crack

(b) Comparison graph of natural frequency results from FEM and Experimental for Inner Edge Clamped Annular Disc without Crack

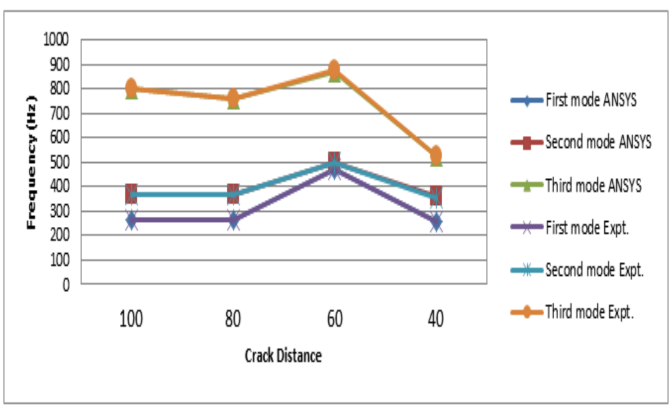

Fig.8 Comparison graph of natural frequency results of Case-I Simply Supported Aluminum Annular Disc

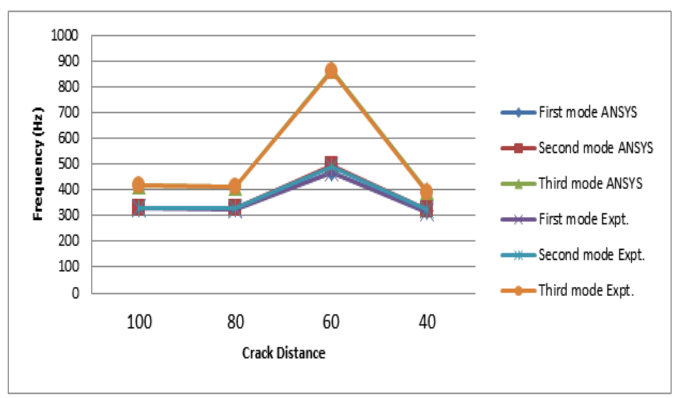

Fig. 9 Comparison graph of natural frequency results of Case-I Inner Edge Clamped Aluminum Annular Disc

Table. 11. Comparison of FEA and Experimental Results for Case-II Simply Supported Mild Steel Annular Disc

Crack Distance (C)	FFT/ANSYS Results	Results of Natural Frequency in Hz (modes)				
		1	2	3	4	5
100	ANSYS	84.73	117.31	255.27	283.59	323.47

	FFT	81.25	115.63	256.40	282.92	325.01
% change		4.11	1.43	-0.44	0.24	-0.48
80	ANSYS	84.38	116.57	241.88	277.69	321.99
	FFT	84.16	118.65	242.93	278.96	320.82
% change		0.26	-1.78	-0.43	-0.46	0.36
60	ANSYS	83.65	115.40	207.77	273.71	317.16
	FFT	78.23	114.12	208.44	274.17	318.61
% change		6.48	1.11	-0.32	-0.17	-0.46
40	ANSYS	83.00	114.09	167.82	272.58	307.14
	FFT	84.85	115.17	169.56	271.85	307.21
% change		-2.23	-0.95	-1.04	0.27	-0.02
Average % change		2.15	-0.05	-0.56	-0.03	-0.15

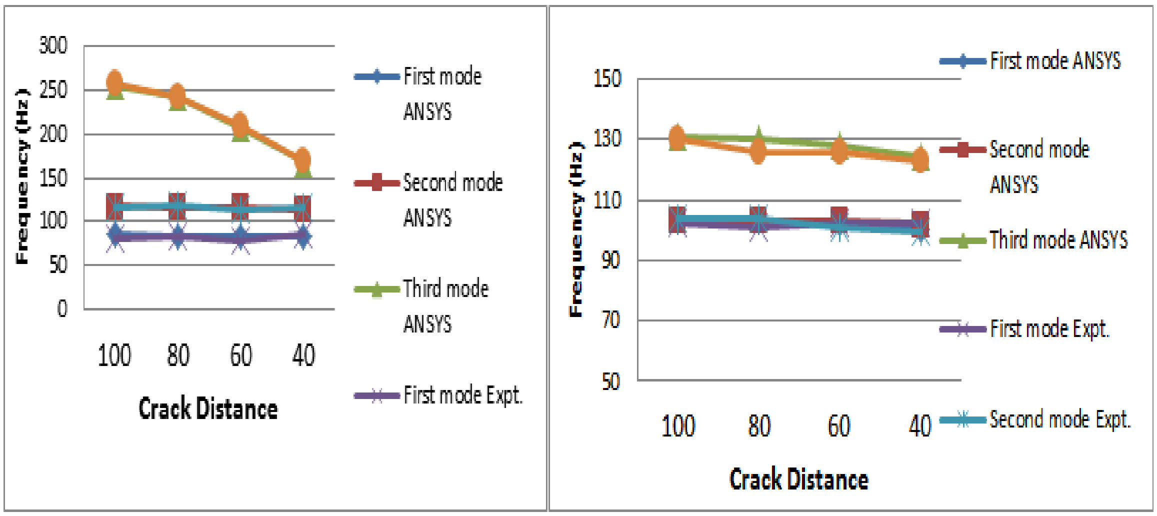

Fig. 10. a. Comparison graph of natural frequency results of Case-II Simply Supported Mild Steel Annular Disc

b. Comparison graph of natural frequency results of Case-II Inner Edge Clamped Mild Steel Annular Disc

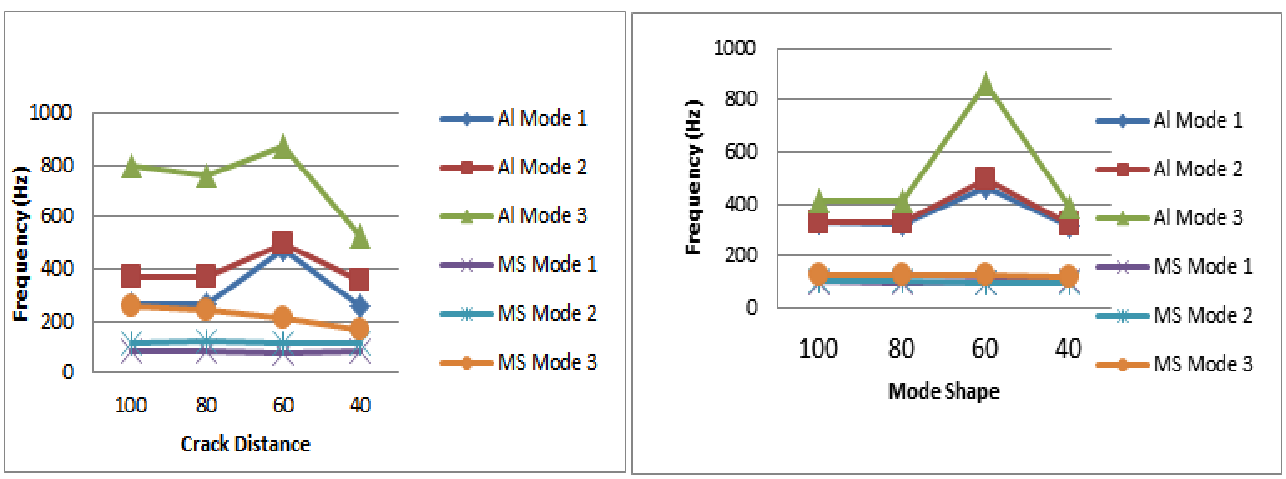

Fig. 11.a. Comparison graph of Experimental Results of simply Supported Aluminum& Mild Steel Annular Disc

b. Comparison graph of Experimental Results of Inner Edge Clamped Aluminum& Mild Steel Annular Disc

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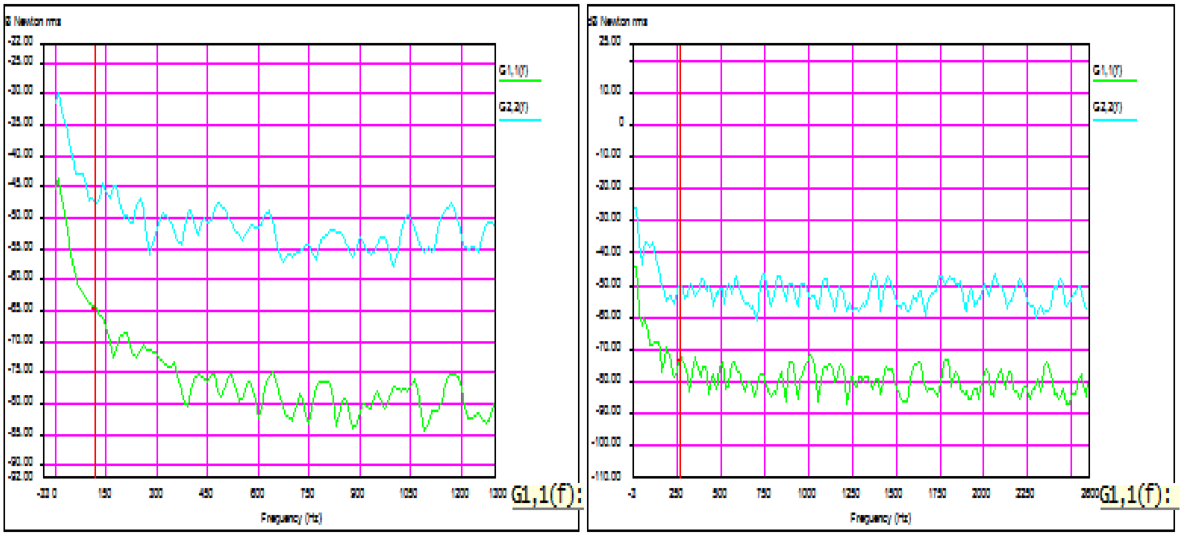

Fig. 12. a. Graph of (By FFT) Frequency (Hz) Vs Amplitude for without crack Mild Steel simply supported Annular disc.

b. Graph of (By FFT) Frequency (Hz) Vs Amplitude for without crack Mild Steel simply supported Annular disc.

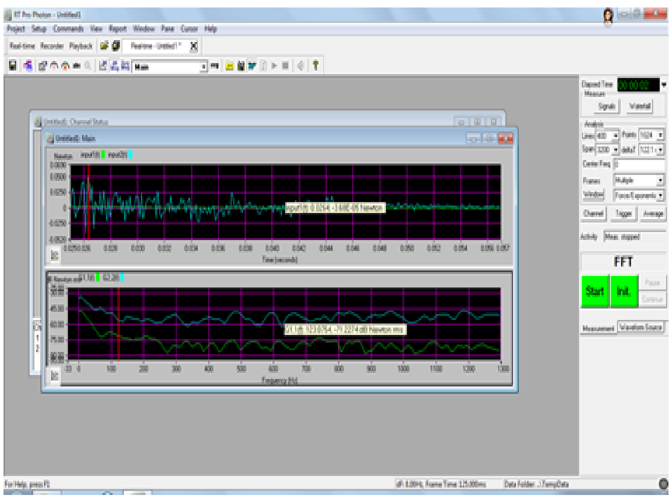

Fig.13. Fast Fourier Transform plot for free vibration of Annular Disc.

9. DISCUSSION AND CONCLUDING REMARK

The natural frequency obtained Experimentally compared with FEM both the results was close agreement.(lowest -0.03% to highest 6.48% change). The variation between Theoretical results and Experimental results are due to different material, Boundary condition and crack distance. The lowest frequency was in mode 1. The frequency was increasing with each subsequent mode of vibration. The percentage of error was also decreasing as frequency is increasing. Results show that there is an appreciable variation between natural frequency of cracked and uncracked cantilever beam.

1). Natural Frequency Results Comparison of Annular Disc without Crack

- Aluminum simply supported and Inner Edge Clamped gives variation of 1634 Hz to101 Hz change in natural frequency variable as per modes1. There is decrease in frequency if Inner edge clamped condition as compared to simply supported condition.
- Mild Steel simply supported and Inner Edge Clamped gives variation of 84 Hz to 103 Hz increase in natural frequency variable as per mode1. There is decrease in frequency at mode 5 as compared to simply supported condition.

2). Natural Frequency Results Comparison of Annular Disc with Crack

Comparison graph of natural frequency results of Simply Supported and Inner Edge Clamped Aluminum and mild Steel Annular Disc gives decrease in natural frequency as the crack distance decreases from the centre. Increase in natural frequency is seen in case of C = 60mm as compared to other crack ratio in case of Aluminum disc.

10. CONCLUSION AND FUTURE SCOPE

Conclusion

Vibration analysis to find out Natural frequency of Annular disc without and with Radial crack is presented with the help of Experimental (FFT) & by FEA (ANSYS). Reading of Natural Frequency are taken for different material (MS & Al), different boundary conditions and different crack length are considered. Both the results from FEA and Experimental Analysis are compared. In this study increasing crack length

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leads to decreasing natural frequency. Also Natural frequency decreases of without crack disc as compared to different crack length disc. Here we can find the difference between two cases of MS and Al. Experimental Results of Aluminum& Mild Steel Annular Disc at two different boundary condition gives higher frequency range for Aluminum as compared to Mild Steel.Good agreement is found between the FEA and Experimental Analysis. It provides a guidance on vibration analysis, FEA & FFT and the method may be applied to damage detection of Annular disc. The results obtained are expected to be useful to other researchers and Engineers for comparison. The study in this work is also necessary for a correct and thorough understanding of the Vibration analysis techniques.

Future Work

We can have the vibration analysis of different materials like composites. Different boundary conditions with different types of crack which are related to real problems, vibration analysis can be carried out with the help of these techniques. Present method can be used for more complex geometrical shapes for various boundary conditions without accessing whole structures. The more precise instrumentation and data acquisition system can be used for determining the natural frequencies to detect the damage and damage size. We can modify the mode shape has an important implication for the design of Annular disc with free edges. We can have the vibration analysis with different specification and different clamping conditions. Further different methods can be find out to carry out vibration analysis of Annular discs.

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