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Crack Detection in Brake Disc By Modal Analysis

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Abstract: The aim of the thesis is to investigate techniques and parameters that could be used to identify crack if it exists in brake disc. Health monitoring for disc brake due to crack using crack detection techniques will minimize or reduce the failure that probably to occur. Crack changes the dynamic behaviour of the structure and by examining this change, crack size and position can be identified. Among few methods of detecting crack components and due to its feasibility of detection of fatigue crack, vibration –based crack detecting techniques through modal analysis are applied in this thesis. This method is based on the fact that change of physical properties(stiffness, mass and damping) due to crack that will manifest themselves as changes in component modal parameters. Experimental Modal Analysis (EMA) was performed on cracked disc and a healthy disc. The first three natural frequencies were considered as basic criterion for crack detection. To locate the crack, 3D graphs of the normalized frequency in terms of the crack depth and location are plotted. The intersection of these three contours gives crack location and crack depth.

INTRODUCTION

Damage identification methods are mainly based upon the shifts in natural frequencies or changes in mode shapes. NDT methods are often employed for detection of cracks in machine and structural components. All of these NDT techniques require that the location of the damage is known a priori and that the portion of the structure being inspected is readily accessible. In order to detect a crack by this method, the whole component requires scanning. The drawbacks of traditional localized NDT methods have motivated development of global vibration based damage detection methods.

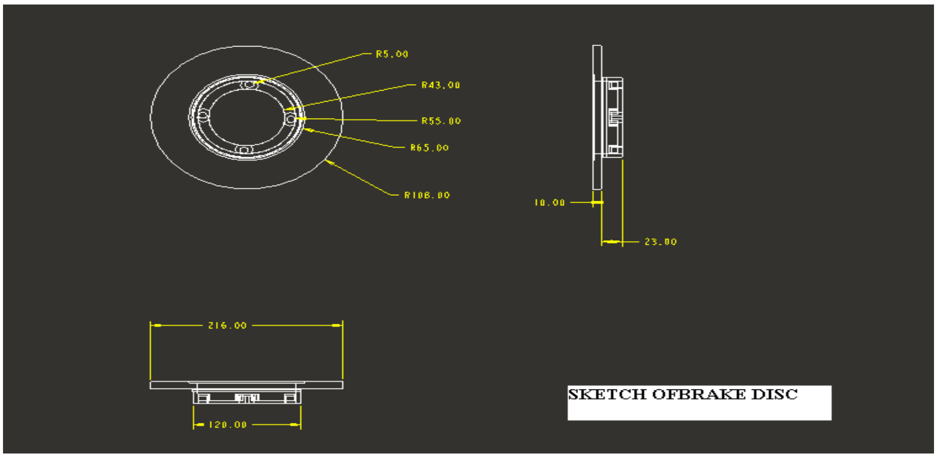

Fig 1. A thick annular disk with a hat structure simulates the brake rotor. Disk is clamped at the inner bolts and free at outer edge

Table 1. Geometric dimensions and material properties of the brake rotor.

Outer radius (a)= 216 mm
Inner radius (b)= 110 mm
Radii ratio (β = b/a)= 0.509
Disk thickness (h)= 10 mm
Hat height (H)= 23 mm
Density (ρd)= 6900 Kg/m3
Young's modulus (E)=110 GPa
Poisson's ratio (ν)= 0.211

Fig.2. Brake Disc in assembly

1. Free Vibration of Circular Disc Without Damping : An Analytical Approach

The equation of motion of a circular Kirchhoff plates in the polar coordinate system reads

$$\rho h w_{,tt} + D\nabla^4 w = 0, \qquad (1)$$

where

$$\nabla^2 = \frac{\partial^2}{\partial r^2} + \frac{1}{r}\frac{\partial}{\partial r} + \frac{1}{r^2}\frac{\partial^2}{\partial \phi^2}.$$

Substituting a solution of the form

$$w(r, \phi, t) = W(r, \phi)\mathrm{e}^{i\omega t} \tag{2}$$

gives

$$\nabla^4 W - \gamma^4 W = 0,$$

$$\text{or} \quad (\nabla^2 + \gamma^2)(\nabla^2 - \gamma^2)W = 0, \tag{3}$$

where

$$\gamma^4 = \frac{\rho h \omega^2}{D}. \tag{4}$$

For a plate with suitable boundary conditions one may assume a separable periodic solution

$$W(r, \phi) = R(r)\mathrm{e}^{im\phi}. \tag{5}$$

Using this in (3) yields

$$\left[\frac{\mathrm{d}^2}{\mathrm{d}r^2} + \frac{1}{r}\frac{\mathrm{d}}{\mathrm{d}r} + \left(\gamma^2 - \frac{m^2}{r^2}\right)\right]\left[\frac{\mathrm{d}^2}{\mathrm{d}r^2} + \frac{1}{r}\frac{\mathrm{d}}{\mathrm{d}r} - \left(\gamma^2 + \frac{m^2}{r^2}\right)\right] R_m = 0. \tag{6}$$

One can find solutions of $R_m(r)$ as

$$R_m(r) = A_m(r) + B_m(r), \tag{7}$$

Where

$$\frac{\mathrm{d}^2 A_m}{\mathrm{d}r^2} + \frac{1}{r}\frac{\mathrm{d}A_m}{\mathrm{d}r} + \left(\gamma^2 - \frac{m^2}{r^2}\right) A_m = 0, \tag{8}$$

$$\text{and} \quad \frac{\mathrm{d}^2 B_m}{\mathrm{d}r^2} + \frac{1}{r}\frac{\mathrm{d}B_m}{\mathrm{d}r} - \left(\gamma^2 + \frac{m^2}{r^2}\right) B_m = 0. \tag{9}$$

The Bessel differential equation (8) has the general solution

$$A_m(r) = C_1 J_m(\gamma r) + C_2 Y_m(\gamma r), \tag{10}$$

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where C_1 and C_2 are arbitrary constants, and $J_m(.)$ and $Y_m(.)$ are, respectively, the Bessel functions of first and second kinds of order m. For the modified Bessel differential equation (9), the solution can be written as

$$B_m(r) = C_3 I_m(\gamma r) + C_4 K_m(\gamma r), \qquad (11)$$

where C_3 and C_4 are arbitrary constants, and $I_m(.)$ and $K_m(.)$ are known as, respectively, the modified Bessel functions of first and second kinds of order m. Therefore, the solution of $R_m(r)$ is given by

$$R_m(r) = C_1 J_m(\gamma r) + C_2 Y_m(\gamma r) + C_3 I_m(\gamma r) + C_4 K_m(\gamma r). \qquad (12)$$

The value of λ, and the constants in (12) are determined from the boundary conditions.

2. FEM Results in ANSYS

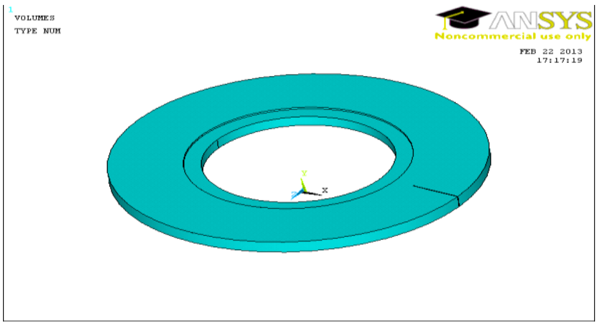

Fig.3. Equivalent Disc Model of Cracked Brake

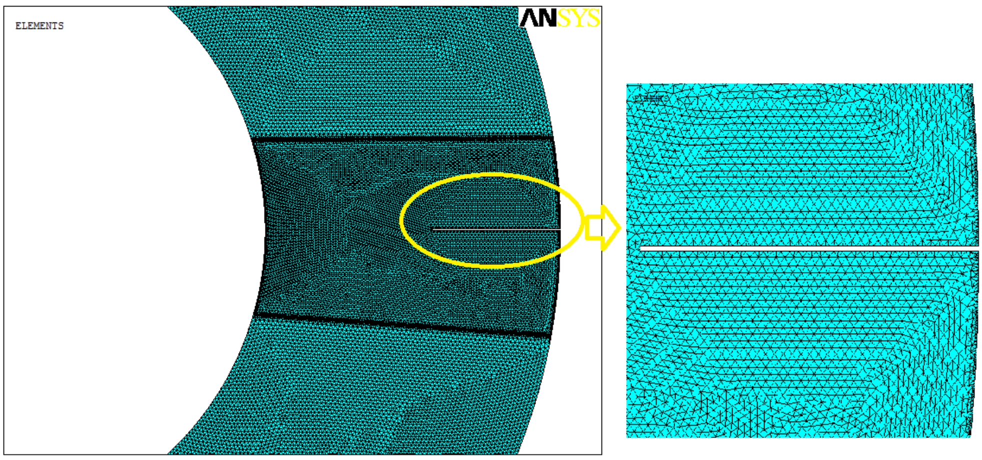

Fig.4. Meshed Model of Rotor with crack

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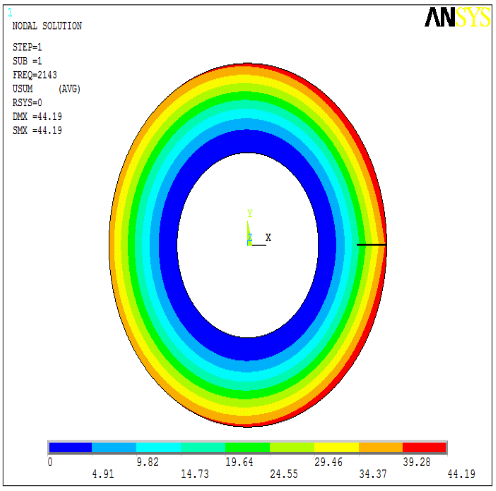

Fig..5. 1ST Mode shape of cracked rotor at 2143 Hz

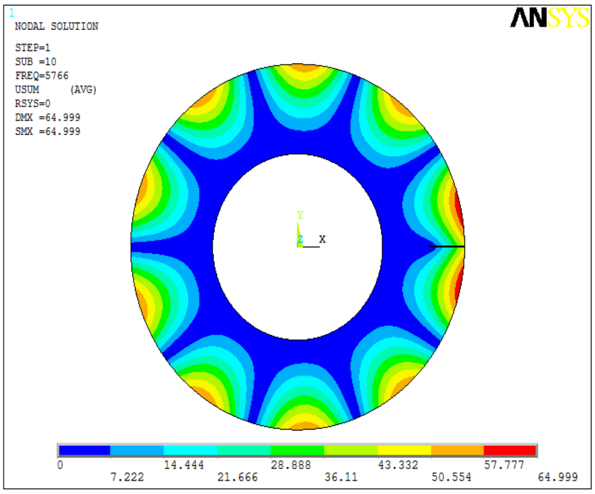

Fig.6. 10th mode shape of 5Nodal Diameters at 5788 Hz

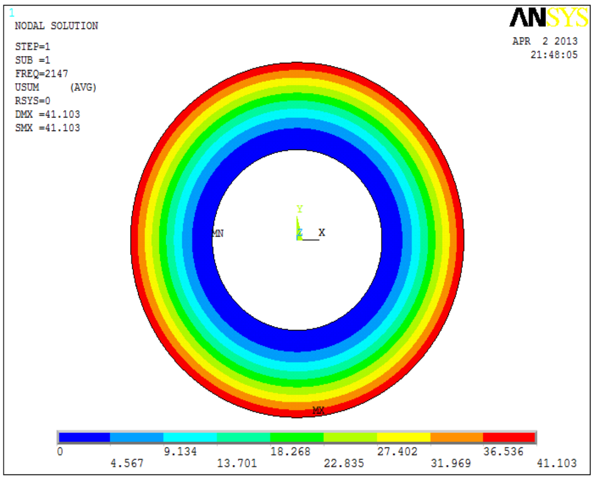

Fig.7. 1st Mode shape of uncracked disc at 2147 Hz

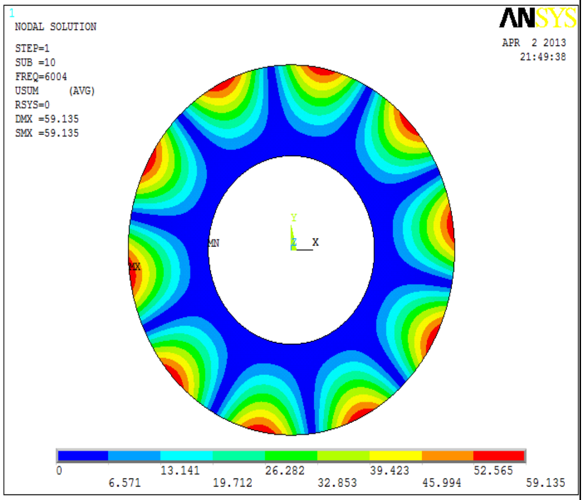

Fig.8. 10th mode shape of 5ND of uncracked disc at 6004 Hz

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3. Experimental Modal Analysis Test

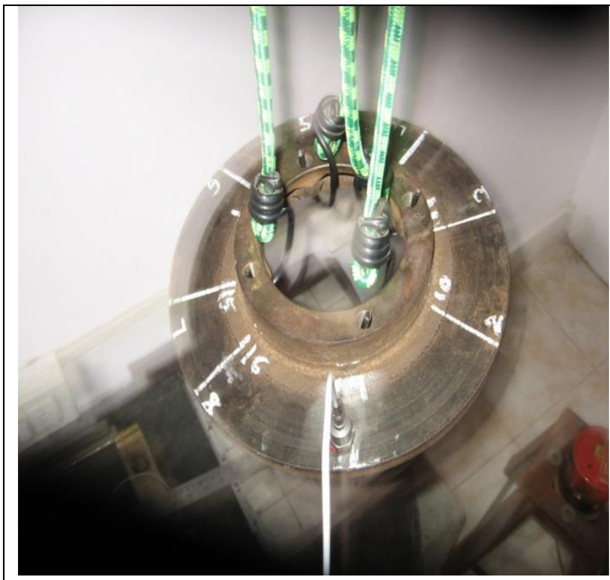	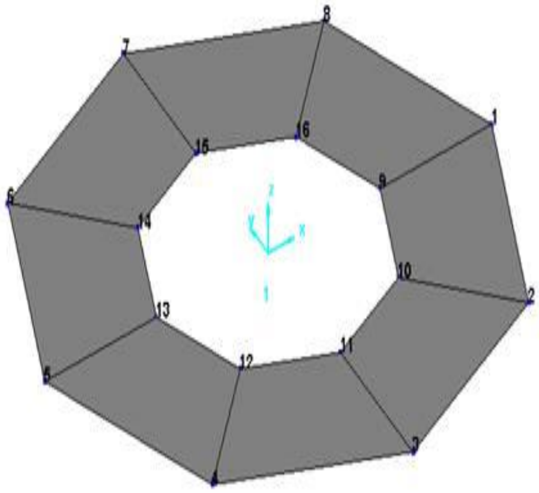
Fig.9. Brake Rotor with accelerometer	Fig.10.Test Node points on the structure

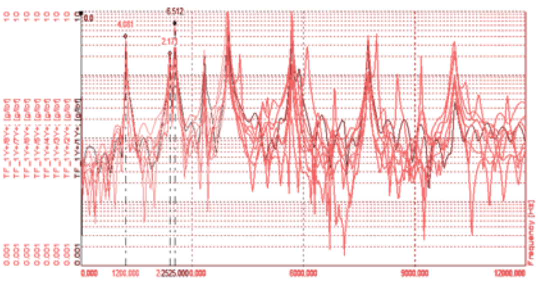	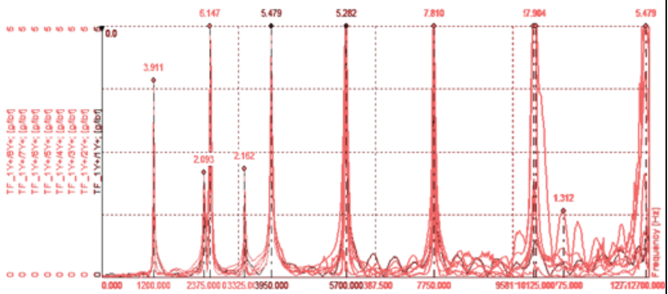
Fig.11.FRF Plot in Y-axis	Fig.12. Disc Modal Peaks

Table.2. Comparison between Experimental and Numerical Results

No	Numerical (Hz)	Experimental (Hz)	% Deviation
1	1682.9	1200	40.24
2	1699.6	2375	39.73
3	2759.6	2525	9.29
4	3268.9	3325	1.716

Change in the Natural Frequencies of Cracked and Uncracked Brake rotor Disc (FEA Results)

Uncracked Disc		Cracked Disc		
Mode No	Natural Frequency(Hz)	Mode No	Natural Frequency(Hz)	%Decrease in Nat Freq (Hz)
1	2146.9	1	2143.2	0.172
2	2210.8	2	2202.7	0.366
3	2210.8	3	2208.2	0.118
4	2490.9	4	2459.6	1.256
5	2490.9	5	2476.3	0.586
6	3166.9	6	3096.1	2.235
7	3166.9	7	3151.3	0.492
8	4339.9	8	4206.2	3.08
9	4339.9	9	4281.5	1.345
10	6004.3	10	5766.1	3.967

Table. 3. Natural frequency result from EMA at free-free BC of disc

S.No	Nat freq(Hz)	TF in g/lbf	Damping coefficient
1	1200	3.11	.011701
2	2375	2.093	.0089
3	2525	6.147	.004514
4	3325	2.162	.006078
5	3950	5.479	.00542
6	5700	5.262	.0029836

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