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Static Analysis of a Rotor System on ANSYS and Its Validation

Jitendra Patil[1], Manoj Chouksey[2], Vijay Jangde[3], Vaibhav Jain[4]
[1,2] *(IPE, SGSITS Indore, India)*

Abstract: *The present work endeavors the analysis of non-spinning rotor system with numerical and theoretical results of deflection, bending moment and stresses. A three disc rotor system is considered for the numerical simulation and the results are presented for non-spinning conditions. Both fixed and simply supported boundary conditions have been simulated as a real case may correspond to the one between these two boundary conditions. The results of ANSYS software are found to be very close to the theoretical results.*

I. Introduction

In this chapter, static analysis of a non-spinning three-disc rotor system has been carried out by finite element method using ANSYS Multiphysics software. In the analysis, shear force distribution, bending moment distribution, deflection, stresses etc have been found out numerically. The same results are also calculated theoretically. The numerical results thus obtained have been compared with theoretical results. In the analysis the rotor system is considered to be supported on rolling element bearings.

II. Theory

If the rotor is considered in a non-spinning condition then its analysis can be carried out in vertical and horizontal planes. In this work, the numerical results for stresses have been obtained by finite element method using the ANSYS software. The theoretical values of bending stress, principal Stresses and Von-misses stress are calculated based on Timoshenko beam theory after following the work of (Stefano Cutrona). The bending stress in beam can be found out using the equation**.**

Bending stress in rotor $\sigma_{xx} = \left(\mathrm{M}_T / \mathrm{I}\right) \mathrm{Y}$ (0.1)

The bending moment at a cross section ($M_T(Z)$) at a distance Z from one of the ends is given by:

Bending Moment $M_T(Z) = M_E + EI_X + (C_2 + 2C_3 Z)$ (0.2)

The vertical deflection as per the Timoshenko beam theory can be obtained after using Equation.

$$\mathrm{V_T}(\mathrm{Z}) = \mathrm{V_E}(\mathrm{E}) + \left\{\mathrm{M_E}(\mathrm{Z}) / \mathrm{GA_S}\right\} + 2\mathrm{C_3}\left\{\mathrm{EI_X} / \mathrm{GA_S}\right\}\mathrm{Z} - \mathrm{C_1 Z} - \left\{\mathrm{C^2}_2 / 2\right\}\mathrm{Z}^2 - \left\{\mathrm{C^2}_3 / 3\right\}\mathrm{Z}^3 + \mathrm{C4}$$
(0.3)

$\mathrm{V_E}(\mathrm{E})$ = Defection at z distance according to Euler's beam theory.

$\mathrm{M_E}(\mathrm{Z})$ = Moment at z distance according to Euler's.

$\mathrm{M}_T(\mathrm{Z})$ = Moment at z distance according to Timoshenko

G = Shear modulus

$\mathrm{V_T}(\mathrm{Z})$ =Defection at z distance according to Timoshenko

Shear Area $\mathrm{A_S}$ = k A (where k is the shear factor)

z = distance from one end of beam

$\mathrm{C_1}, \mathrm{C}_2, \mathrm{C}_3\ \mathrm{C_4}$ are the constants which are dependent on the boundary conditions. These constants for beams with various types of boundary conditions subjected with point load and uniformly distributed load can be found in the work by (Cutrona).

I = moment of inertia.

Y = distance from natural axis.

Principal stress

$$\sigma_{1,2} = (\sigma_x + \sigma_y)/2 \pm \sqrt{\{(\sigma_x - \sigma_y)/2\}^2 + \tau_{xy}{}^2} \qquad (0.4)$$

Von misses stress

$$v = \sqrt{(\sigma_x - \sigma_y)^2 + (\sigma_y - \sigma_z)^2 + (\sigma_z - \sigma_x)^2} \qquad (0.5)$$

σ_x = stress in direction of x axis, σ_y = stress in direction of y axis, σ_z = stress in direction of z axis.

III. Numerical example

For illustration, a numerical example has been considered after following the work of (Lalanne and Ferraris 1998; A.S. Das 2008). The rotor consists of a 100 mm diameter uniform steel shaft of length 1.3 m. It is supported on two identical orthotropic bearings at its ends and carries three rigid discs at different locations within its span. The location, geometry and other properties of the discs are given in

Table **0-1** . Density of the shaft material is 7800 kg/m3 and Young's modulus is 200 GPa. The stiffness and damping coefficients of two identical bearings at each end of the rotor-shaft are:-

$k_{yy} = 7e7 N/m$, $k_{zz} = 5e7 N/m$, $c_{yy} = 700 Ns/m$, $c_{zz} = 500 Ns/m$.

k_{yy} = stiffness in y direction, k_{zz} = stiffness in z direction

c_{yy} = damping coefficient in y direction, c_{zz} = damping coefficient in z direction.

Table 0-1 Details of the discs

Disc	Outside diameter (m)	Thickness (mm)	Density (kg/m3)	Position from the left end of rotor (m)
1	0.24	50	7800	0.2
2	0.4	50	7800	0.5
3	0.4	60	7800	1.0

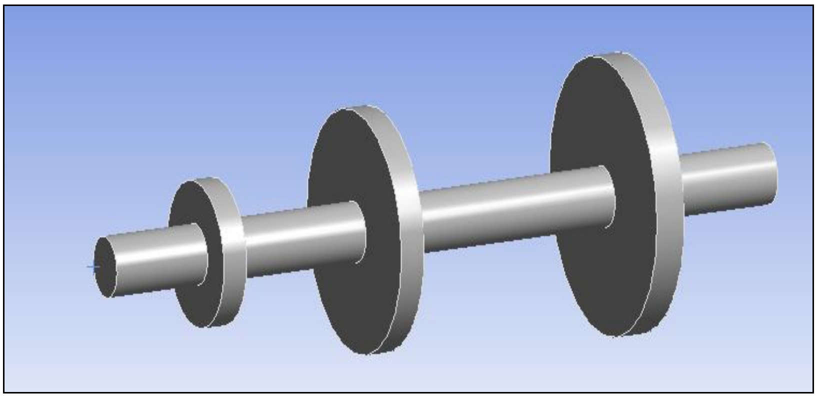

Figure 1 Three disk rotor

- A model generated in ANSYS has been shown in Figure 2. The discs are not visible because these are considered as a mass element.

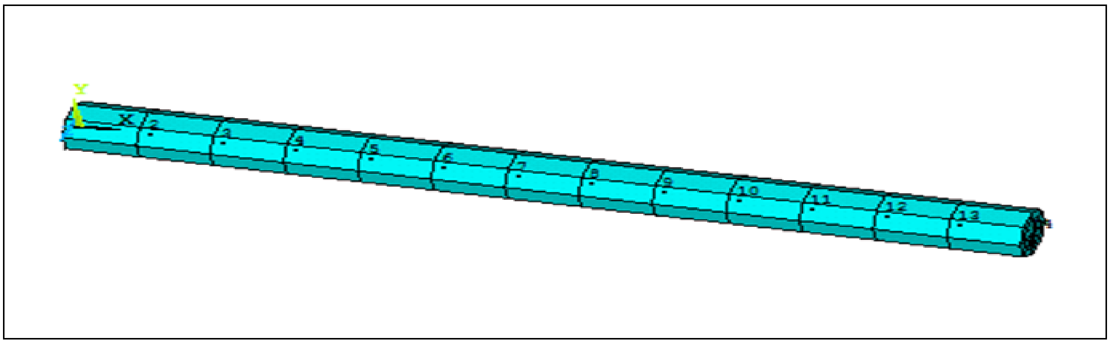

Figure 0-2 model created in ANSYS

IV. Results and comparison

For analysis of the above rotor system the rotor is considered under two support conditions: (i) fixed-fixed (ii) simply supported. Modeling of the same is done in ANSYS and results of deflection, bending moment and stresses are reported.

Before carrying out the detailed static analysis, the finite element model has been checked for convergence. For this the element size has been considered as 0.3 m, 0.1 m, 0.05 m, 0.001 m, 0.0001 m. The results of convergence have been checked for the stresses and are plotted in Figure 2. It has been seen that the results are converging as the element size is reduced and finally it converges with element size of 0.001 m. The results thus obtained have also been compared with the theoretical results calculated. This comparison has been shown in **Figure 3**

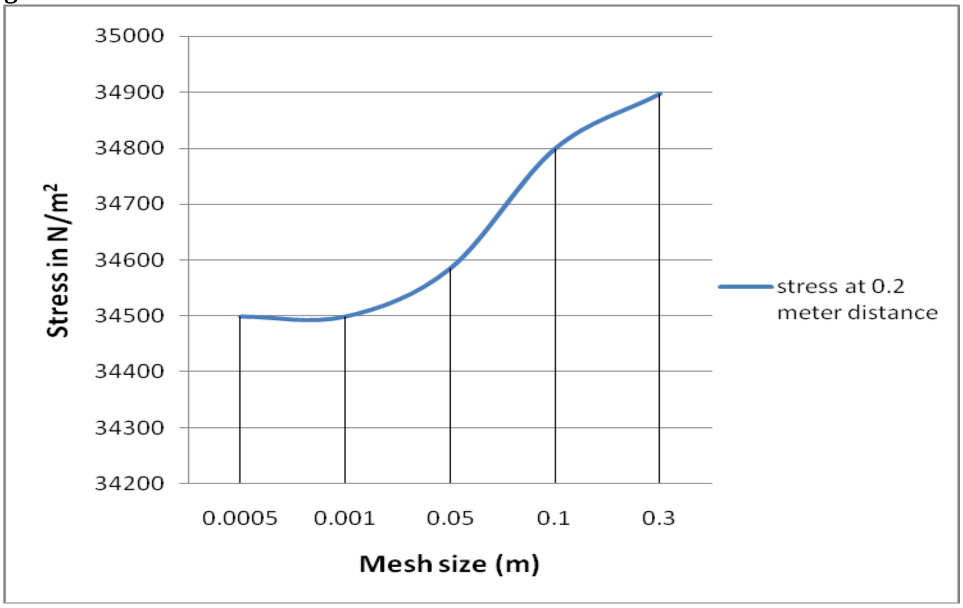

Figure 2 Plot for convergence of results.

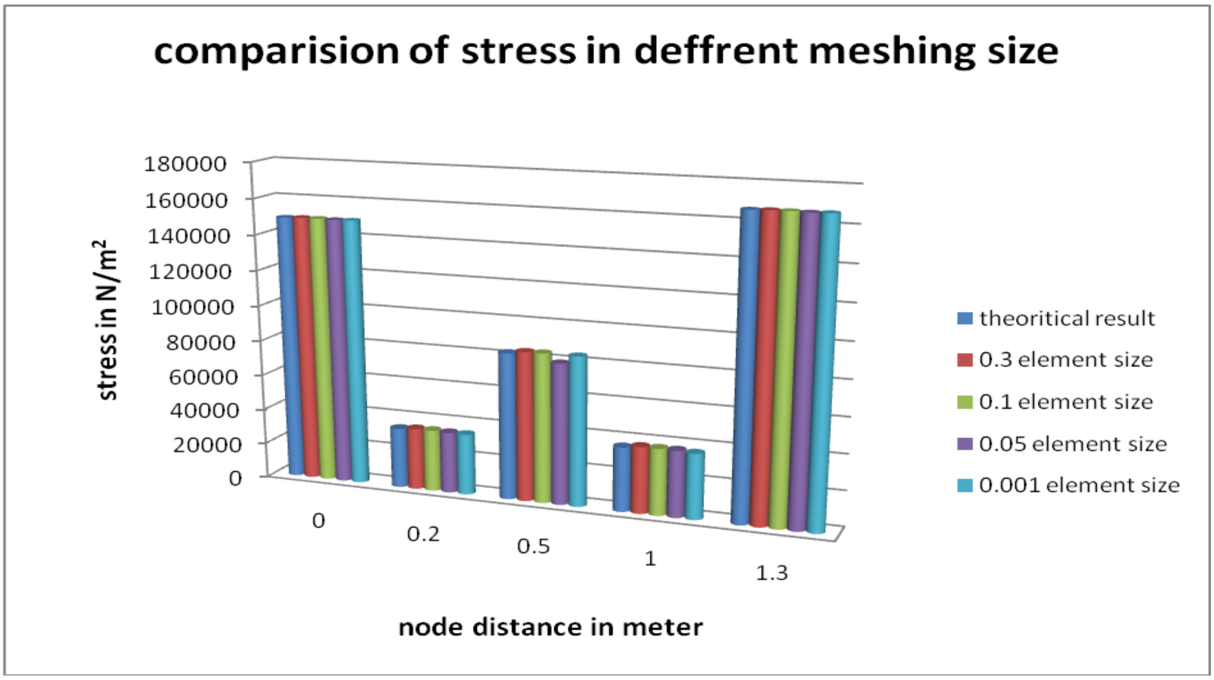

Figure 3 meshing size variation

After the convergence, the detailed static analysis has been carried out. The results of bending moment, deflection, bending stress as obtained in ANSYS and from theory along with the percentage error have been shown in for the rotor-shaft with fixed-fixed end conditions.

Table 0-2 Fixed supported beam:-

	Theoretical values			ANSYS values			Error %		
Distance of node (m)	Bending moment (Nm)	Stress (N/m^2)	Deflection (m)	Bending moment (Nm)	Stress (N/m^{2s})	Deflection (m)	Bending moment	Stress	Deflection
0	-14.656	156571	0	-14.6655	152565	0.000000	0.064	1.98	0
0.2	-3.3545	34168	0.26e-6	-03.3800	35566	-0.2445E-6	0.76	3.8	4e-12
0.5	8.3873	86425	0.80e-6	08.22219	85916	-0.7991E-6	1.9	0.35	9e-10
1.0	3.8538	40148	0.52e-6	03.6832	38315	-0.4836E-6	4	2.5	5e-10
1.3	16.380	175184	0	16.37010	170296	0.000000	0.060	1.8	0

The variation of deflection and bending stress on the rotor-shaft continuum has been shown in Figure 4and Figure 5 respectively.

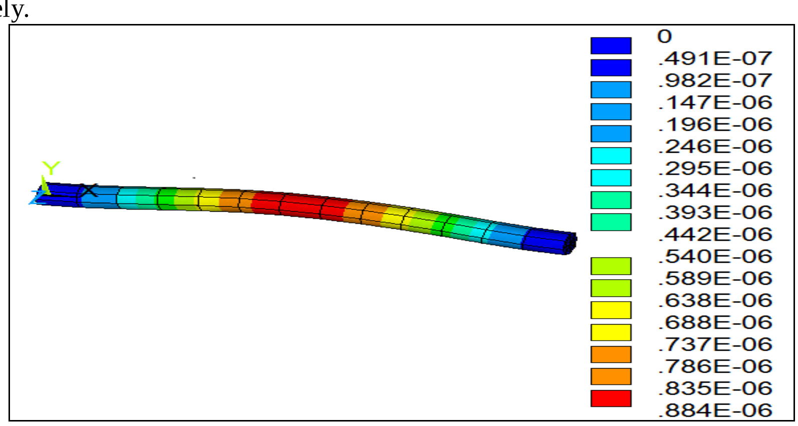

Figure 4 Deflection of beam in meters

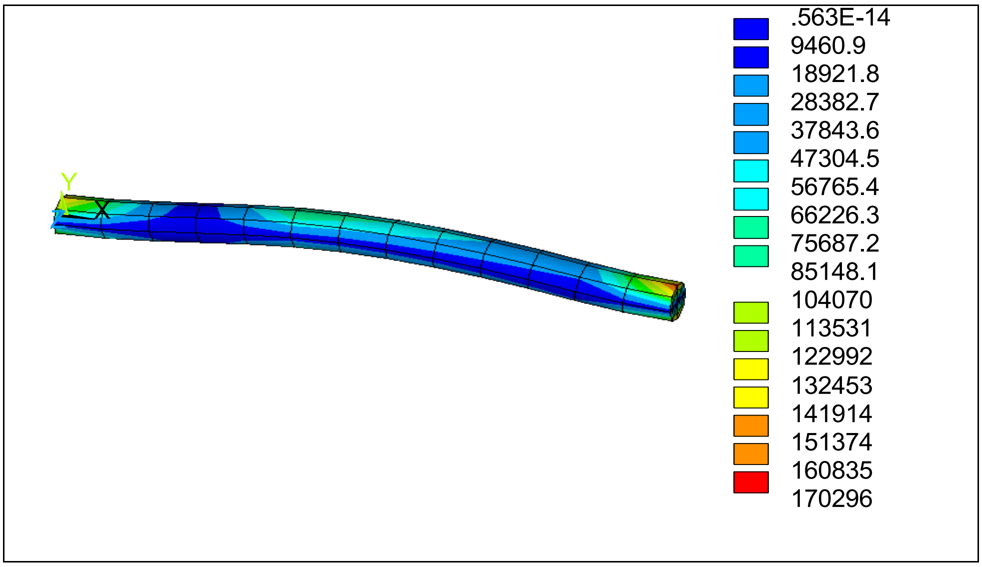

Figure 5 Stress in beam

Table 4.2 simply supported beam

	Theoretical values			ANSYS values			Error %		
distance of node(m)	Deflection (m)	Stress (N/m^2)	Bending moment (Nm)	Deflection (m)	Stress (N/m^2)	Bending moment (Nm)	Deflection	Stress	Bending moment
0	0.00000	0.0000000	0.0000	0.00000	0.0000000	0.0000	0.00	0.00	0.00
0.2	0.094E-5	0.11723E+6	11.509	0.100E-5	0.11745E+06	11.507	6e-8	8e-7	2e-3
0.5	0.376E-5	0.26057E+6	23.581	0.390E-5	0.24065E+06	23.577	4e-10	4e-7	2e-3
1.0	0.270E-5	0.20033E+6	19.660	0.284E-5	0.20066E+06	19.659	5e-10	5e-7	5e-5
1.3	0.00000	0.0000000	0.0000	0.00000	0.0000000	0.0000	0.00	0.00	0.00

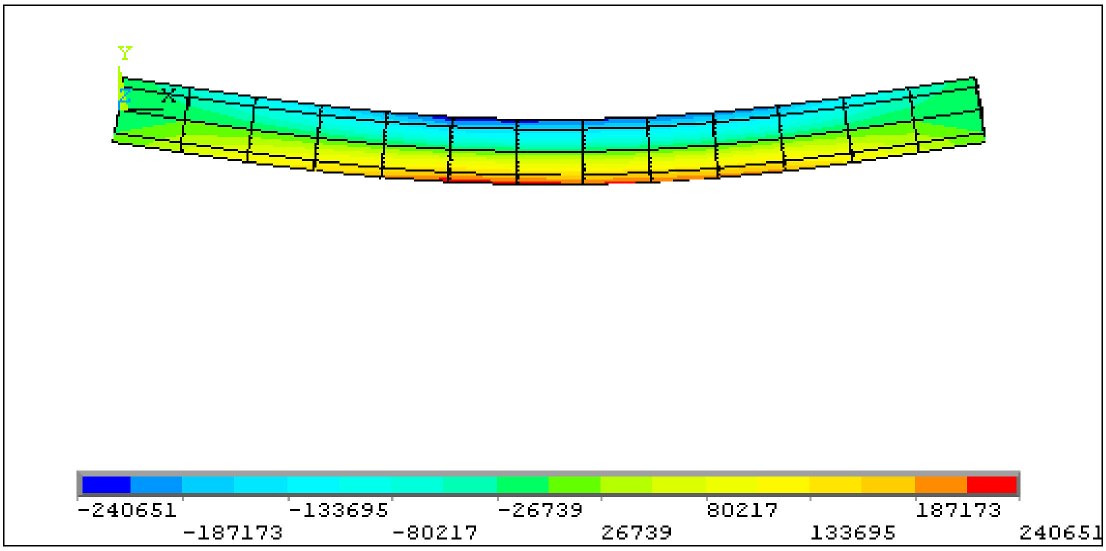

Figure 6 Stress in simply supported beam.

V. Conclusion

The numerical and theoretical results of deflection, bending moment and stresses etc have been reported and correlated for a three disc rotor system for non-spinning condition. Both fixed and simply supported boundary conditions have been simulated as an actual case may correspond to the one between these two boundary conditions. Model of rotor system is created in ANSYS and analysis results are found considering it as fixed beam as well as simply supported beam. Results of the same have been calculated theoretically. It is found that ANSYS results of bending moment, stresses and deflection at the supports as well as interior points almost matches with the theoretical results in case of simply supported beam . In -case of fixed-fixed beam, it is seen that results of deflection from ANSYS closely matches with theoretical results both at supports and interior point and the results of bending moment and stresses are close at the supports in the two cases. However, there is some deviation in the results of bending moment and stresses at interior points in the two cases i.e. using ANSYS and theory, though this deviation is also quite marginal.

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