Stability Model Analysis of Squirrel cage Rotor by Finite Element

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Abstract:
Importance of rotor in the motor is obvious. Transmitting the torque in the motor is compulsory for further action. If torque transmission is without critical speed and with a status of stability then it is the best thing for this action. This analysis aimed at studying and performing an analysis of a Rotor Bearing System i.e. Squirrel cage rotor which have characteristics of bearings at the ends by finite element analysis techniques. Squirrel cage Rotors are generally used in three phase A.C. Induction motors. Design of a rotor bearing system is based upon calculation of various natural frequencies, critical speed and stability analysis. The results for up to 940 rpm were plotted. A computational procedure for finding natural frequencies of vibrating rotors with damping is presented on Campbell diagram. Rotating systems are widely studied under rotor dynamics in industries for designing the systems below critical speeds and stability. The most commonly used material for making rotors are Copper-alloy and Aluminum. Copper-alloy as a material over Aluminum in chosen in this paper.
Keywords – Finite element analysis, Rotor bearing system, critical speeds, damping, stability, Campbell diagram.

1. Introduction:
The rotor is placed inside the stator means stator is wounded on the rotor. The rotor core is also laminated in construction and uses cast irons. It is cylindrical, with slots on its periphery. The rotor conductors or winding is placed in the rotor slots. The two types of rotor constructions which are used for induction motors are,
1. Squirrel cage rotor
2. Slip ring or wound rotor

The squirrel caged rotor is made up of laminated steel core with evenly spaced copper or aluminum bars placed axially around the circumference of core which are permanently shorted at their ends by the end rings. This construction is ideal for various applications as it is simple to build. The assembly has a catch: the bars are slightly skewed in order to reduce magnetic noise, slot harmonics and to prevent the tendency of locking of rotor. Enclosed in the stator, the rotor and stator teeth can magnetically lock themselves when they are equal in number and the magnets aligns themselves equally spaced,opposing rotation in either directions. Bearings are used to mount the rotor at each ends in its housing, with one end of the shaft extendingoutside the housing forproviding the load. Insome motors, there is aprotrusion at the non-driving end as well for measuring speed of motor or for other purposes. The generation of torque drivesthe rotor to rotate which is transferred to load end. The core of rotor is cylindrical shaped and is slotted on its periphery. The rotorcontains noninsulated copper or aluminum bars called rotor conductors. The barsare allocated in the slots. The bars are generally brazed with the end rings to provide ample mechanical strength. The entire assembly forms a cage, in a closed electrical circuit. Thus this rotor is termed as squirrel cage rotor. As the bars are permanently shorted with each other through end ring, the totalrotor resistance is little. Hence this rotor is termed asshort circuitedrotor. As rotor itself is short circuited, external resistance cannot hamper on the rotor resistance. Hence external resistance can't be instigated in therotor circuit. Thus slip ring and brush assembly is not presentin this motor. Hencethe fabrication of motor is very simple.Fan blades are generally provided at the ends of the rotor core. This circulates theair through the machine while operation, providing the necessary cooling. The airgap between stator and rotor is kept uniform and as small as possible.

In this type of rotor, the slots are not arranged parallel to the shaft axis but are skewed. The motor rotor shape is a cylinder mounted on a shaft. Internally it containslongitudinal conductive bars (usually made of aluminum or copper) laid intogrooves and connected at either ends by shorting rings building a cage - like shape.The name is derived from the homogeneity between rings-and-bars and squirrel cage windings.The core of the rotor is formed with stacks of laminated steel. The rotor has lesser slotsthan the stator and mustn't be an integral multiple of stator slots so as to haltmagnetic interlocking of rotor and stator tooth at the starting interval.The rotor bars may be built with either copper or aluminum. A very usualstructure uses die casted aluminum poured into the rotor after the laminations arepiled. Some larger motors have aluminum or copper bars welded orbrazed to end-rings. The voltage developed in the squirrel cage winding isvery low, thus presence of insulation layer between the bars and the rotorsteel is inappropriate.

2. Literature Review:

J.Padovan et.al Presented that a slim sort of ultrasonic engine utilizing longitudinal-torsional cross breed vibration was proposed and explored in this paper. To get reaction and mechanical limit of collected and complete mixture longitudinal-torsional ultrasonic engine, a 3D limited component model had been built up by business FE programming ADINA. numerical outcomes concur with test brings about terms of pattern and significant degree, implying that it was anything but difficult to assess mechanical qualities of engine before model assembling. In meantime, outspread, circumferential and hub removals of contact hubs can be acquired to reenact real curved movements of stator teeth. Moreover, reasonable contact instrument between stator and rotor can be precisely reflected by pressure nephogram of contact surfaces. This examination gives an advantageous strategy to structure streamlining and mechanical limit forecast of half breed longitudinal-torsional ultrasonic engine.

S. Iskierka et.al introduced that utilization of a genuine dissemination of a three-dimensional electromagnetic field in a strong rotor of limited measurements will expand exactness of electromagnetic field counts. This paper presents an examination of a diphase offbeat engine with a strong rotor. estimations have been performed utilizing main request limited component strategy.

J. Xiang et.al analyzed rotor dynamic hypothesis, joined with limited component technique, had been generally utilized in course of most recent three decades so as to ascertain dynamic boundaries in rotor-bearing frameworks. Since wavelet-based components offer multi-scale models, especially in displaying complex frameworks, wavelet-based pivoting shaft components are built to show rotor-bearing frameworks. impacts of translational and rotatory latency, gyroscopic minutes, transverse shear misshapenness, and inside thick and hysteretic damping's are considered in current plan. Numerical models and trial examine show accuracy of wavelet-based limited component model of rotor-bearing framework. Consequences of forward and in reverse spin speeds and damped dependability are given and looked at other distributed works.

Wang et.al presented In rotary compressor, moving cylinder and reached rotor-diary bearing framework are fundamental moving segments. They endure huge occasionally differing loads presented by idleness power, contact power and gas power. These heaps change quickly with speed variety of blower. They generally lead to genuine vibration of framework, and afterward bring about scraped area and execution decrease. In this paper, dynamic conduct of rotor-diary bearing framework were determined by tackling three-dimensional numerical model utilizing limited component technique, and vibration attributes of framework were explored by figuring results. normal frequencies and vibration modes were acquired. pressure, removal and hub circle of rotor community were determined considering speed variety of engine. By means of set up numerical model, vibration qualities of a recently structured blower can be anticipated, and improvement should be possible to decrease vibration.

T. Sun et.al calculated on aeroelasticity investigation of rotor sharp edge and rotor control frameworks. Another multi-body element model was built up to foresee both rotor pitch interface loads and swashplate servo burdens. Two helicopter rotors of UH-60A and SA349/2, both working in two basic flight conditions, rapid flight and high-push flight, are examined. examination shows great concurrences with flight test information and estimation results utilizing CAMRAD II. systems of rotor control loads are then investigated in subtleties dependent on current expectations and flight test information. In fast conditions, pitch interface loads are commanded by necessary of cutting-edge pitching minutes, which are created by cyclic pitch control. In high-push conditions, positive contributing burdens propelling side are brought about by high aggregate pitch point, and dynamic slowdown in withdrawing side energizes high-recurrence reactions.

H.Mama et.al presented technique to research convoluted powerful attributes of a rotor framework with two kinds of limiters under multilateral contact and grating conditions when scouring happens between rotor and limiters. current examination centers around f facts of various stator/limiter structures on vibration reactions of rotor stator coupling framework. In first place, FE models of rotor with two kinds of limiters (four pin molded stators and three pins formed stators) are built up. At that point four- and three-point contact components are utilized to reenact scouring among rotor and two sorts of limiters. These contact components portray coupling of rotor and stators by enlarged Lagrangian technique. Confused vibration reactions of decay or framework with two kinds of limiters under various turning speeds are dissected by range falls, rotor circles, ordinary scouring powers, plentifulness range, time space waveform and stator increasing speed. outcomes show that vibration reactions of rotor under primary sort of limiter are steadier than those under second kind of limiter by watching power and times of scouring, greatness of ordinary scouring power and consistency of recurrence parts brought about by scouring.

M.H. Jalali et.al presented high speed rotors are powerless against vibrations bringing about disappointment of entire working framework. To maintain a strategic distance from full conditions at working velocities, modular investigation of such rotors was significant in plan and advancement of framework. Full rotor dynamic examination during working conditions was likewise required to research dynamic conduct of turning structure. In this paper, full powerful examination of a rapid rotor with certain geometrical and mechanical properties was done utilizing 3D limited component model, one dimensional beam type model and test modular test. Great understanding between hypothetical and trial results demonstrates precision of limited component models. Campbell graph, basic paces, operational avoidance shapes, and unbalance reaction of rotating system.

I. Dirba et.al analyzed and requested to diminish measure of material waste and in this way to utilize valuable uncommon earth component Nd in an increasingly proficient manner, courses for creation of crack NdFeB magnets have been explored. Rather than regular course wherein material streams into a cavity, pressing apparatus had been utilized so as to apply a back weight during in reverse expulsion, prompting crack free and net shape creation of radially arranged ring magnets, without inconvenient effect on attractive properties. Micrographs exhibit in general great arrangement of extended platelet molded grains with radially situated axis in many pieces of ring. A mean remanence Jr = 1.27 T and coercivity μ0iHc = 1.5 T had been gotten. Level of surface stretches around 0.7. Besides, bite dust had been performed for various degrees of disfigurement to get break - upsetting free, precisely and attractively homogenous, pivotally situated tablet magnets.

M.Arias-Montiel et.al examined the issue of demonstrating, investigation and unbalance reaction control of a rotor framework with two circles in a hilter kilter design was dealt with. Finite Element Method (FEM) was utilized to get framework model including gyroscopic impacts and afterward, acquired model was tentatively approved. Rotor dynamic investigation was completed utilizing limited component model getting Campbell chart, common frequencies and basic paces of rotor framework. An asymptotic eyewitness was intended to gauge full state vector which was utilized to integrate a Linear Quadratic Regulator (LQR) to lessen vibration amplitudes when framework goes through principal basic speed. Some numerical recreations are done to check shut circle framework conduct. dynamic vibration control plot was tentatively approved utilizing a functioning suspension with electromechanical straight actuators, getting huge decreases in full pinnacle.

H.H. Hanafy et.al analyzed ABC transient model of three stage enlistment engine was built up that relies upon s and common inductance figuring's dependent on precise limited component investigation (FEA). This model can speak to both solid and broken bars' conditions. impacts of that kind of flaw on stator current, rotor bar flows dissemination, powers applied on rotor bars, engine speed and engine torque are examined. It was seen that messed up bar issues will cause vacillations in stator top current and in engine speed and torque. It was discovered that asymmetry in rotor bar flows will prompt halter kilter appropriation of outspread and extraneous powers influencing bars. asymmetry in extraneous powers causes changes in engine torque, while asymmetry in spiral powers will build mechanical pressure es on rotor.

3. Problem Statement:

Vibration and instability in Rotor shaft is a serious issue when running at critical speed with different frequencies. For continuous and uninterrupted torque transmission proper rotor selection is needed. Objective of this work is to analyze a squirrel cage type Rotor through Finite element Method in which purpose is to do analysis of rotor to check the critical speedand stability of rotor by generating Campbell diagram for Natural frequency(Y-axis) Vs Rotor speed (X-axis).For generating the Campbell diagram Model of a Rotor is needed in assembled form with Bearing. Squirrel cage induction motor is selected in this analysis because of its vital application.

Main disadvantage of squirrel cage induction motor is that they have poorstarting torque and high starting currents. Starting torque will be in the orderof 1.5 to 2 times the full load torque and starting current is as high as 5 to 9times the full load current.Squirrel cage induction motors are more sensitive to the supply voltage fluctuations. When the supply voltage is reduced, induction motor draws more current. During voltage surges, increase in voltage saturates the magnetic components of the squirrel cage induction motor. Speed control is not possible in squirrel cage induction motor. This is one ofthe major disadvantages of squirrel cage induction motors. The total energy loss during starting of squirrel cage motor is morecompared to slip ring motors. This point is significant if the application involves frequent starting.

4. Methodology:

For this Finite element analysis of a squirrel cage type rotor which was related to Design and analysis of rotor, Modeling, Mathematical calculation and simulation is adopted though which stability of rotor is justified for optimize torque transmission by Campbell diagram . Modeling is carried out in SOLIDWORKS and Analysis is carried out in ANSYS Workbench. A mathematical calculation is also used to validate the data.

So to generate the simulated platform in the ANSYS , material definition is added for the rotor and bearing then import the geometry or vice versa (First import the geometry and then define the material forthe imported geometry) and then go for the Modal analysis (Define load, speedand other required parameters) after that Campbell diagram will generated.

5. Solution approach:

5.1 Modeling:

Reference of Teco Company for the particular dimensions of the drawing for the design of the rotor is considered

Rotor dimension are as given below:

Rotor dia., d = 24 mm = 0.024 m

Rotor length, l = 130 mm =0.13 m

Clearances at the rotor ends for bearing assembly = 20-20 mm (From left and right)

Journal Bearings is used to assemble the rotor in which bearings at the ends of the rotor by using the following dimensions is modeled.

Bearing diameter = 24 mm with 2 mm clearance

Bearing diameter length = 20 mm

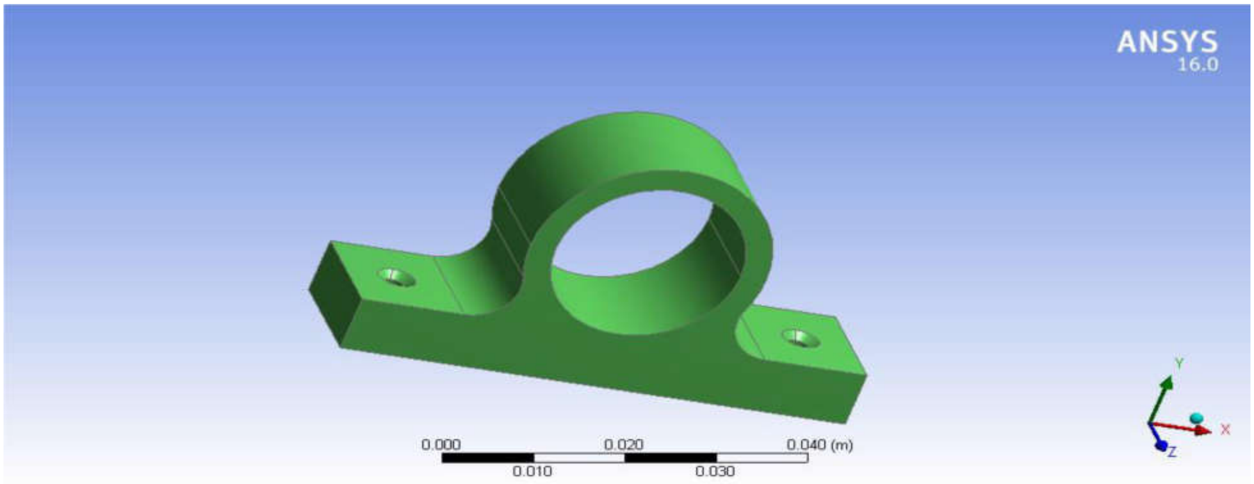


Figure 1: Bearing Design

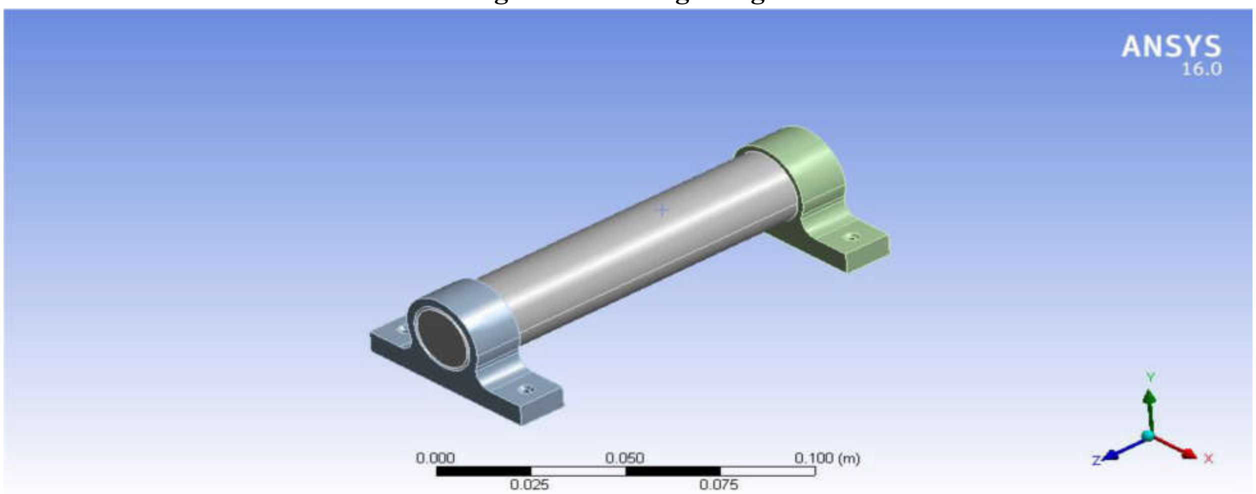


Figure2: Rotor-Bearing Assembly

5.2 Material selection:

After importing the design in ANSYS, material is defined/selected for the imported object. In this case Copper-alloy chosen over the Aluminum for the rotor and steel for the Bearing. Preference is given Copper-alloy over Aluminum Because of the following reasons.

Table1: Comparison of Aluminum and Copper alloy properties

Factors	Aluminum	Copper alloy
Temperature	Low temperature required for Heat up(1200F)	High temperature required for heat up(2000F)
Yield strength	28Mpa	69Mpa
Tensile strength	69Mpa	220.7Mpa

5.3 Mathematical Analysis:

Mathematical Analysis is carried out to by assuming Rotor as Simply Supported Beam.

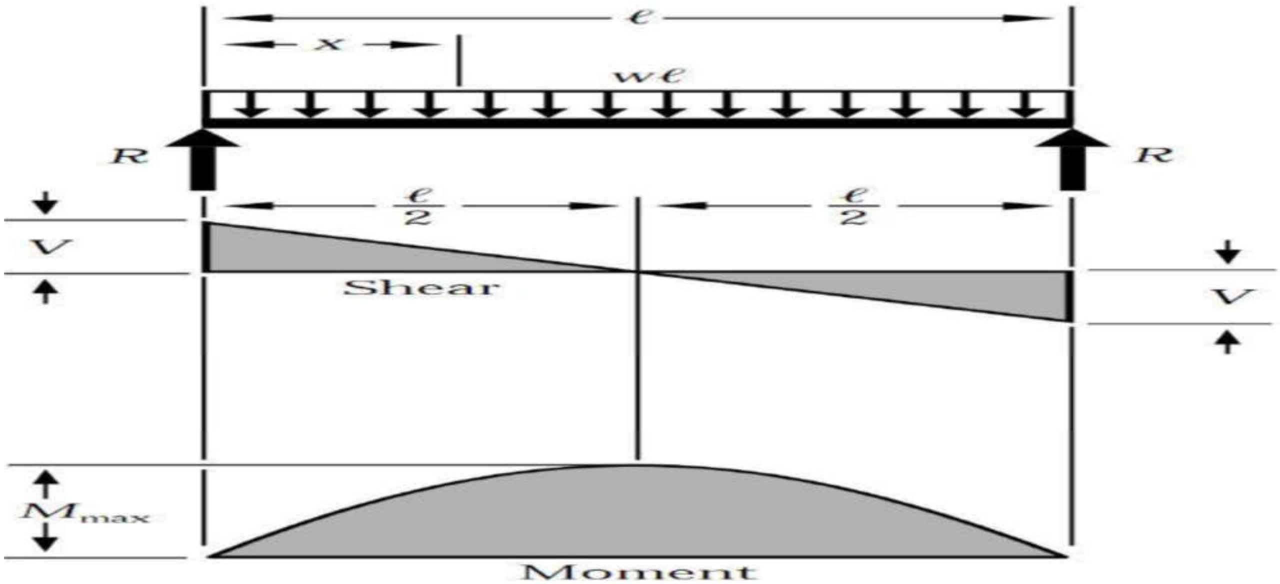


Figure-3: Loading, Shear Stress, Bending Moment Diagram of Simple Supported beam

5.3.1 For 3-phase induction motor

No. of poles, p = 6, Frequency, f = 50 Hz

Rotor speed, N = 940 RPM = 15.67 RPS, Synchronous speed, Ns = (120*f)/P=1000 RPM

Power, P = 0.75 KW, Torque T = 7.62 N-m = 0.00762 N-mm, Efficiency η = 78 %, Current I = 1.97 Amp., Voltage V = 415 volts

5.3.2 For Rotor

Rotor dia., d = 24 mm = 0.024 m, Rotor length, l = 130 mm =0.13 m, Weight of rotor $W = \frac{\pi}{4} * l * \rho * d^2\ (\rho = 8950\ kg/mm^3)$

W = 0.5264 kg = 5.16 N

5.3.3 Static deformation is calculated as $\delta max = \frac{5wl\wedge 3}{384EI}$

$$\delta max = \mathbf{0.0000000755\ m}$$

5.3.4 For Dynamic deformation

$$y = \frac{e}{\left(\frac{\omega n}{\omega}\right)^2 - 1}$$

(Centrifugal force $F_c = m*r*\omega^2$, $F_c = m*(y+e)*\omega^2$, r = y+e, e = 12-y,)

$$y = \frac{12-y}{\left(\frac{11398.85}{98.44}\right)^2 - 1}$$

$$y = \frac{12-y}{13408.46-1}$$

Where ω_n is natural frequency and ω is frequency at given r.p.m. it is calculated as

$\omega n = \sqrt{\ g/\delta max} = \sqrt{\ 9.8/(.0000000775)}$

$\omega_{\mathbf{n}}$ = 113.98 rad/sec.

$\omega = \frac{2*3.14*940}{60} = 98.44\ rad/s$

13408.46 X y = 12
y (dynamic) = 0.000895 mm
Total deformation, Δ_{max} = **δ_{max}(static) + y (dynamic)**
Δ_{max} = 0.0000755 + 0.000895
Δ_{max} (total) = 0.00097 mm

6. Analytical Analysis:

For the analysis in the ANSYS tool There are 3 **stages in the ANSYS** to follow:-
1. Pre-processing
2. Analysis
3. Post-processing

Above mentioned stages consists of the following steps

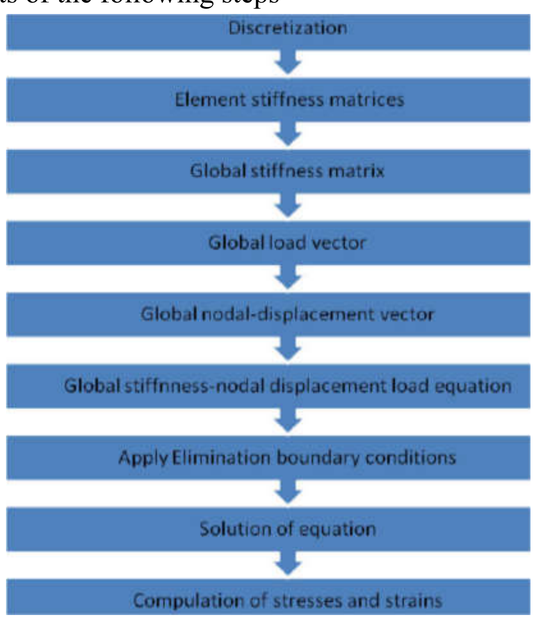


Figure-4: FEA Steps

In this analysis, there is Universal Distributed load (UDL) of 0.5264 kg or 5.16 N on the rotor. We are considering the rotor as a Hinged supported at the ends and this support is provided by bearing by assembling the bearings at the ends. In this case, Triangular meshing is chosen because of the following advantages of

Triangular meshing over the rectangular or other meshing:-
1. High rate of convergence means correct solution faster.
2. Less numerical errors

3. It gives high resolution of deformation

After analysis Static Deformation Due to Self Weight is found as **0.000037466 mm** and Dynamic deformation as **0.5593 mm**

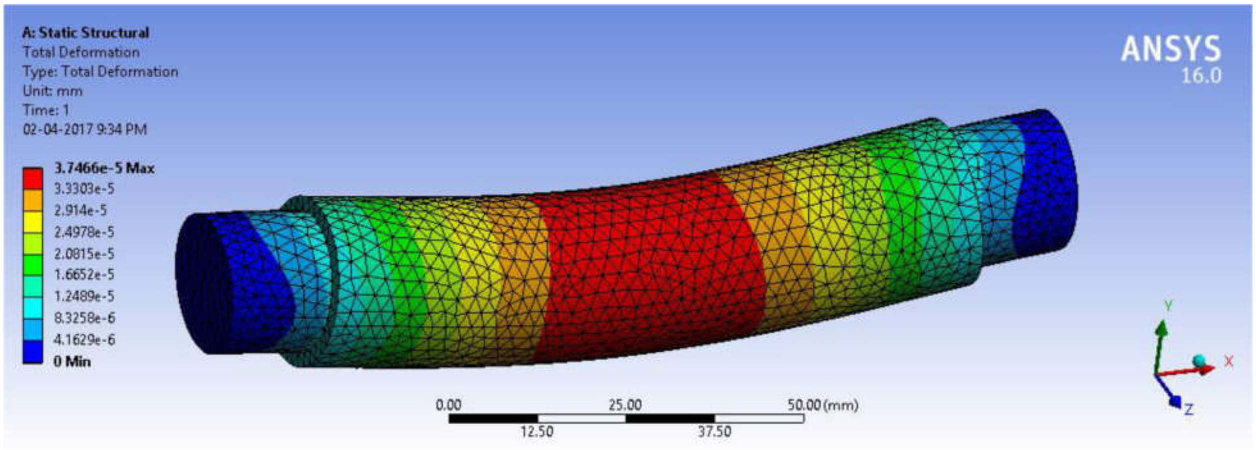


Figure- 5 : Static Deformation Due to Self Weight

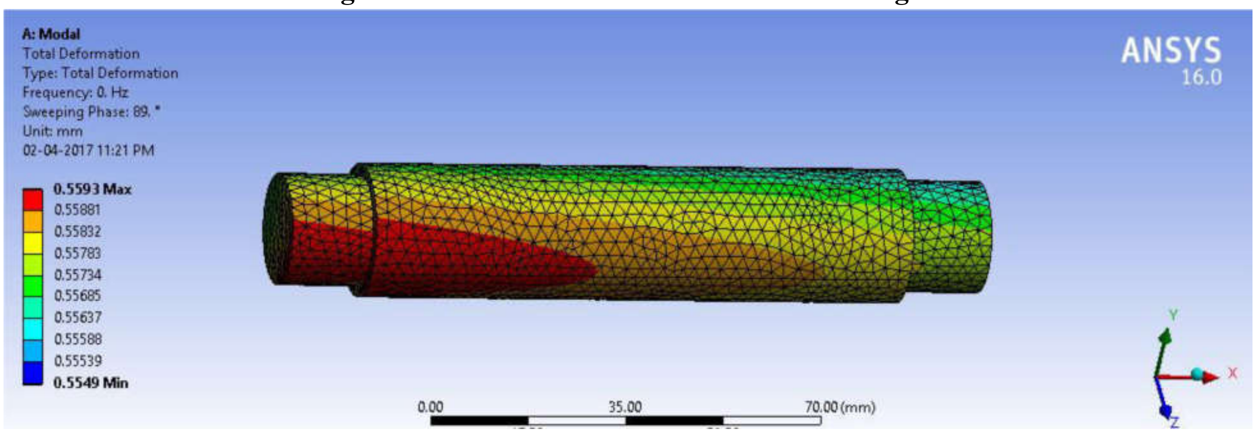


Figure-6 : Dynamic Deformation Due to Rotational Speed Of Rotor

7. Result and Discussion:

While comparing The mathematical and analytical result we find following outcomes

Static deformation by Mathematical analysis = 0.0000755 mm

Static deformation by ANSYS = 0.000037466 mm

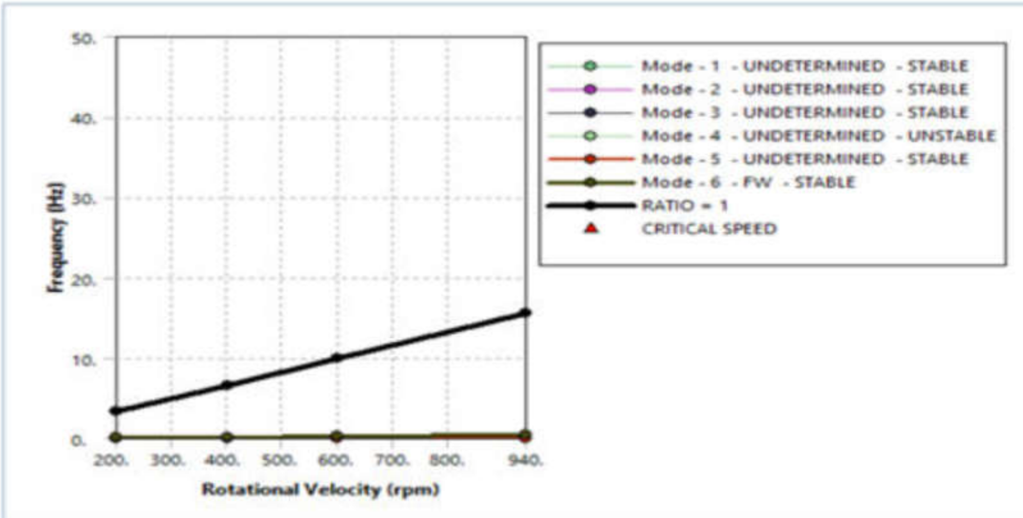
Dynamic deformation by Mathematical analysis = 0.000895 mm

Dynamic deformation by ANSYS = 0.55926 mm

Total deformation by Mathematical analysis = 0.00097 mm

Total deformation by ANSYS = 0.5593 mm

Now the thing is Total or maximum deformation by mathematical/engineering approach and by the ANSYS is within/below 1mm which is indicating the approval of result. So for the maximum deformation of rotor the Campbell diagram is given below.



Model (A4) > Modal (A5) > Solution (A6) > Campbell Diagram

Mode	Whirl Direction	Mode Stability	Critical Speed	200. rpm	400. rpm	600. rpm	940. rpm
1.	UNDETERMINED	STABLE	NONE	3.4996e-005 Hz	1.7337e-005 Hz	1.1539e-005 Hz	7.3591e-006 Hz
2.	UNDETERMINED	STABLE	NONE	7.5942e-004 Hz	7.6614e-004 Hz	7.6737e-004 Hz	7.6796e-004 Hz
3.	UNDETERMINED	STABLE	NONE	1.3092e-003 Hz	1.3099e-003 Hz	1.31e-003 Hz	1.3101e-003 Hz
4.	UNDETERMINED	UNSTABLE	NONE	0. Hz	0. Hz	0. Hz	0. Hz
5.	UNDETERMINED	STABLE	NONE	4.5334e-003 Hz	4.5334e-003 Hz	4.5334e-003 Hz	4.5334e-003 Hz
6.	FW	STABLE	NONE	9.7529e-002 Hz	0.19504 Hz	0.29256 Hz	0.45834 Hz

Figure- 7: Campbell Diagram

8. Conclusion:

If rotor is rotating at a particular dimensions, which are mentioned in thisproject, at the particular speeds with respect to the particular Natural frequencies,which are mentioned in the Campbell diagram, then one can read the status thatthe process is Stable or not also we can check the critical speeds status, is thereany critical speed or not.So Campbell diagram is followed to rotate the rotor at the particular speedwith respect to natural frequencies then we can eliminate the effect of the criticalspeed and Instability of the rotor and one can ensure that maximum deflection ofthe rotor will be within the range of 1 mm.

1. Natural frequency is the number of cycles made in 1 second of the object.It is constant for particular dimensions, when dimensions changes, itchanges accordingly.
2. Cycle is the motion completed during one time period.
3.Period is time interval after which motion repeats itself.
4.Critical speed is defined as the speed of shaft at which the additionaldeflection of shaft from Axis of rotation becomes infinite.

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