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Evaluation of Whirling Speed of an Induction Motor

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Abstract*: *The whirling speed in rotor dynamics, with reference to solid mechanics, is the velocity that excites the natural frequency of rotating object or assembly. Proper estimation of this whirling speed is one of the key factors that are to be considered at design stage of electrical machines as induction motors. This research paper deals with estimation of whirling speed of an induction motor. The work involves theoretical estimation of whirling speed and its validation using ANSYS.

Keywords*: *Whirling speed, Critical speed, Unbalanced Magnetic Pull (UMP), Natural frequency

I. INTRODUCTION TO PRODUCT

The specifications of given induction motor are:

a) Power Output : 630 kW
b) Mass of Rotor : 665.245 kg
c) Bearings
Driving End : 6319.C3 95 x 200 x 45 mm
Non-Driving End : 6319.C3 95 x 200 x 45 mm
Mean diameter of bearing : 147.5 mm

Typical Load pattern of the motor shaft is as illustrated in Figure 1.

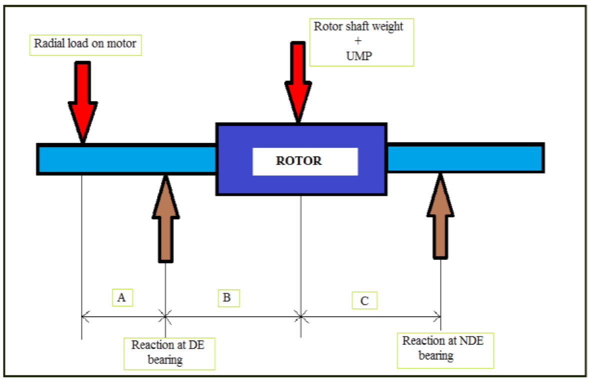

Figure 1.Illustrative Load Pattern on rotor-shaft assembly of Induction Motor

Distance between shaft extension and Driving End bearing (A) : 329 mm
Distance between Driving End bearing and Load (B) : 822 mm
Distance between Load and Non- Driving End bearing (C) : 822 mm

II. PROBLEM IDENTIFICATION

When the rotor mounted motor shaft reaches its critical speed, it starts vibrating violently. This results in excessive noise from rotor bearing assembly. Further, these vibrations may tend to bend the shaft which results in abnormal rubbing of rotor with stator. To avoid such probable conditions, identification of critical speed of given induction motor is necessary.

III. OBJECTIVE

In tune with identified problems, the objectives of the proposed work are:

a) To estimate the critical speed.
b) To corroborate the results of estimated critical speed using suitable software.

IV. PROPOSED WORK

The proposed work includes stepwise study of shaft-rotor assembly of product under consideration.

The methodology includes,

a) Estimation of critical speed by classical techniques.
b) Model the roto-dynamic system using a suitable modelling tool.
c) Estimate the natural frequency of the system using suitable tool.

V. EXPECTED OUTCOME OF THE WORK

The research will provide the safe operating speed for a new variant of induction motor.

VI. PROCEDURE

The procedure involves three stages. First, evaluation of whirling speed of induction motor theoretically using standard formulae and empirical relations, second, modelling of the system / assembly with suitable tool and third, validating the theoretically obtained value with suitable software.

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VII. MATERIAL SPECIFICATIONS AND DIMENSIONS

The shaft- rotor assembly of induction motor is made up of following main components:

a) Shaft

The shaft is made of 40C8 steel with material density as 7850 kg/m^3. The shaft is of circular cross-section having diameter 95mm and length under analysis consideration as 1644 mm.

b) Rotor

The rotor is made up of copper alloy with material density as 8300 kg/m^3. The rotor is of hollow circular cross-section with total mass of 665.245 kg.

VIII. ESTIMATION OF CRITICAL SPEED OF INDUCTON MOTOR (SHAFT-ROTOR ASSEMBLY) ANALYTICALLY

For estimation of critical speed, the mass of rotor and stiffness of shaft is to be calculated.

Now,

A) For mass of shaft (m_s),

Cross- sectional Area of shaft (A_S)

$A_S = \frac{\pi}{4}$ (Diameter of shaft)^2

$= \frac{\pi}{4} (0.095)^2$

$A_S = 7.088 \times 10^{-3}$ m^2

Volume of shaft (V_S)

V_S = Total cross- sectional Area of shaft (A_S) x Length of shaft

$V_S = (7.088 \times 10^{-3}) (1.644)$

$V_S = 0.01165$ m^3

Mass of shaft (m_S)

m_S = Total volume of shaft (V_S) x (Density of shaft material)

$m_S = (0.01165) \times (7850)$

$m_S = 91.45$ kg

B) For Mass of Rotor (m_r),

The total mass of rotor provided is 665.245 kg.

Hence,

$m_r = 665.245$ kg

C) For Stiffness of Shaft (k),

Moment of Inertia of shaft (I)

$I = \frac{\pi}{64}$ (Diameter of shaft)^4

$I = \frac{\pi}{64} (0.095)^4$

$I = 3.9982 \times 10^{-6}$ m^4

Therefore,

Stiffness of shaft (k)

$$k = \frac{48\,E\,I}{L^3}$$

Where,

'E' is Young's modulus for shaft material.

'I' is Moment of inertia of shaft.

'L' is length of shaft or bearing span.

So,

$$k = \frac{48\,(205 \times 10^9)\,(3.9982 \times 10^{-6})}{(1.644)^3}$$

k = 8854298.80 N/m

D) Involvement of UMP

The value of UMP for this particular induction motor is 3656 N i.e. 372.6 kg. This value is provided as a standard design parameter. This UMP is applied as a point mass to the rotor during analysis.

E) For Natural frequency,

Natural frequency (ω_n)

$$\omega_n = \sqrt{\frac{\text{Stiffness of shaft}}{(\text{Actual mass of rotor}) + (\text{UMP})}}$$

$$\omega_n = \sqrt{\frac{8836139.314}{(664.035) + (372.5)}}$$

$\omega_n = 92.36$ rad/s

Therefore,

$f_n = \frac{\omega_n}{2\pi}$

$= \frac{92.32}{2\pi}$

= 14.69 rev/s

$f_n \approx 15$ rev/s

Hence,

Critical speed by analytical method (Nc)

Nc=(f_n x 60) RPM

= (15 x 60)

Nc= 900 RPM

So,

The whirling speed or Critical speed of the induction motor by analytical method is 900 RPM.

IX. ESTIMATION OF CRITICAL SPEED USING ANSYS 15.0 WORKBENCH

A) Modelling the Shaft- Rotor Assembly

For modelling the shaft- rotor assembly, CATIA V5R21 is selected. The diameter and length of shaft, the inner and outer diameter and length of rotor are the basic input parameters. These parameters are able to define the assembly.

The software tool CATIA uses these parameters, in combination with its features to generate the geometry and all essential information to create the model.

The CATIA model was prepared as per the present design parameters and after this, the file is saved in IGES format.

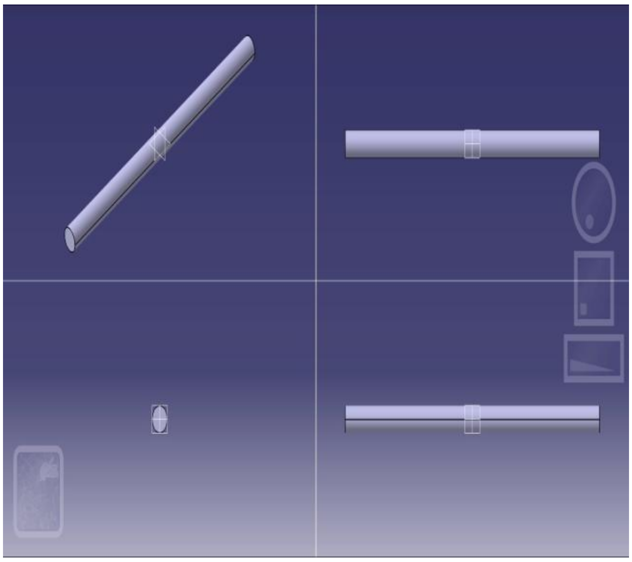


Figure 2. Modelling of Shaft

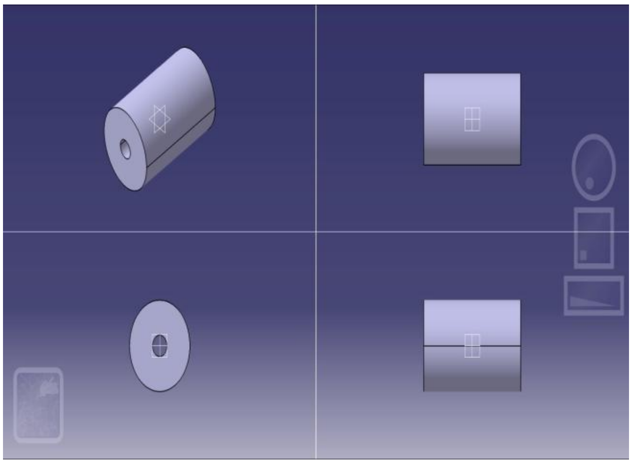


Figure 3. Modelling of Rotor

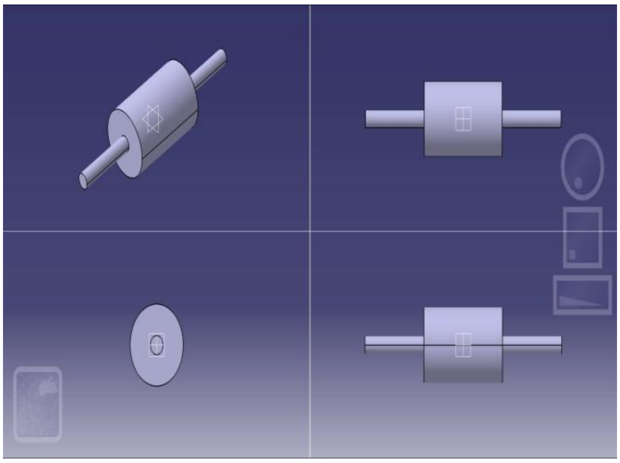


Figure 4. Modelling of Shaft- Rotor assembly

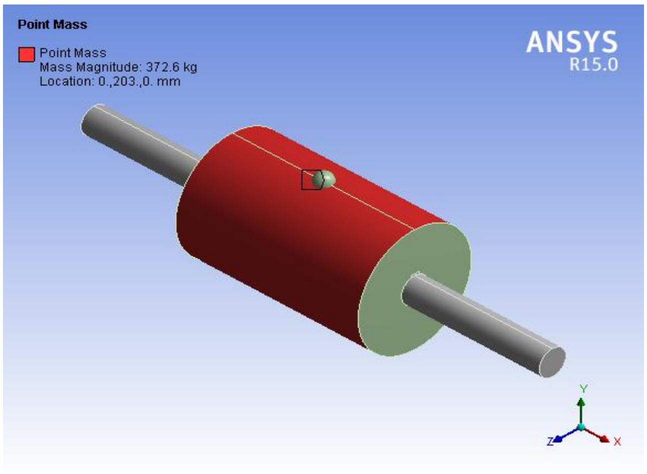
B) Selection of Analysis System

As the project work involves the calculation of natural frequency, the Modal analysis system is selected.

C) Importing the CATIA Model to Ansys and Defining the Materials

The CATIA model file in IGES format is imported to ANSYS workbench and respective model of shaft- rotor assembly is generated for analysis purposes. After generation of model, the different components of assembly are assigned with their respective materials as different components are made up of different materials. The materials and their properties are mentioned in previous headings.

The Unbalanced Magnetic Pull (UMP) is applied in the form of Point Load on rotor geometry.



Point Mass

Point Mass
Mass Magnitude: 372.6 kg
Location: 0.,203.,0. mm

Figure 5. Application of UMP to Shaft- Rotor assembly

The pre-processing and post processing is done in ANSYS workbench for obtaining solution. Meshing is also one of the important stages in this analysis.

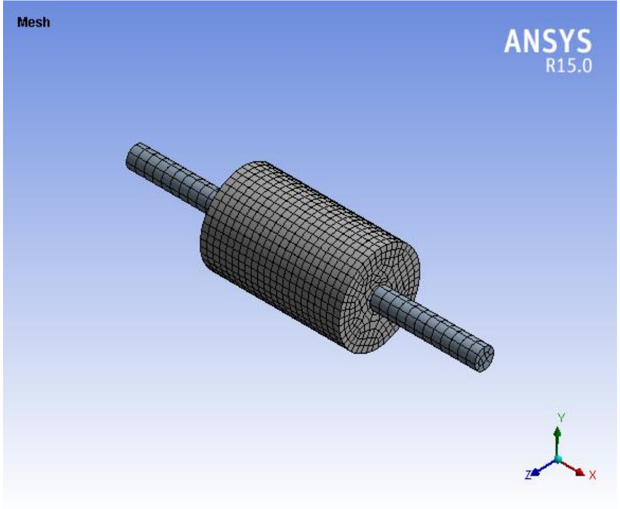


Figure 6. Meshing of shaft- rotor assembly

D) Solution And Results

The result of analysis, the value of natural frequency obtained is 15.17Hz.

Therefore,

$f_A = 15.17\ H_Z = 15.17$ rev/s ≈ 16 rev/s

From this value of natural frequency, Critical speed of motor (N_{CA}) is estimated as:

Critical speed of given motor (N_{CA})

$N_{CA} = (f_A \times 60)$ RPM

$= (16 \times 60)$

$= 960$

$Nc_A = 960$ RPM

So,

The whirling speed or Critical speed of the induction motor using Ansys is 960 RPM.

X. DISCUSSION OF RESULT AND CONCLUSION

The value of critical speed of the induction motor under study is:

- By classic theoretical method N_C = 900 RPM
- By analysis in ANSYS N_{CA} = 960 RPM

The percentage error in obtained values of critical speed is:

Percentage Error =

$$\left[\frac{(\text{Experimental Value})-(\text{Theoretical Value})}{(\text{Theoretical value})}\right] \text{x } 100$$

$$= \left[\frac{(N_{CA})-(N_C)}{(N_C)}\right] \text{x } 100$$

$$= \left[\frac{(960)-(900)}{(900)}\right] \text{x } 100$$

$$= 6.66$$

The percentage error within the limit of 10% is acceptable.

From this, it is clear that the value of critical speed obtained by theoretical method is validated in ANSYS as value of frequency opted among ANSYS results compliments theoretically obtained value. So, with consideration of safety, comparatively lower value is stated as critical value of the induction motor.

Therefore, the Critical Speed of the induction motor under consideration is 900 RPM.

REFERENCES

1. Ziyuan Huang, Bangcheng Han. (2015). “Effective approach for calculating critical speeds of high-speed permanent magnet motor rotor-shaft assemblies”, The Institution of Engineering and Technology 2015, Vol. 9, Iss. 9, pp. 628–633
2. Raj Mistry, Bill Finley, Scott Kreitzer, Ryan Queen. (2013). “Influencing Factors On Motor Vibration & Rotor Critical Speed In Design, Test And Field Applications”, Institute of Electrical and Electronics Engineers 2013, Vol. 5
3. Ankit J.Desai, Devendra A. Patel, Pranav B. Patel. (2014). “Analysis of whirling speed and Evaluation of self-excited motion of the rotating shaft”, International Journal of Engineering Sciences & Research Technology 2014, pp. 784-787
4. C. W. Bert, Chun-Do Kim. (1995). “ Whirling of Composite Material Drive shafts including Bending-Twisting Coupling and Transverse Shear Deformation”, ASME, Journal of vibrationand Acoustics 1995, Vol. 117/17
5. Erik Swanson, Chris D. Powell, Sorin Weissman. (2005). “A Practical Review of Rotating Machinery Critical Speeds and Modes”, cpowell@structuraltechnology.com, Sound and Vibration 2005
6. Chun-Do Kim, Charles W. Bert. (1993). “Critical Speed Analysis Of Laminated Composite Hollow Drive Shafts”, Pergamon press limited, Composites Engineering, Vol. 3, pp. 633-643
7. E. Downham. (2008). “The Critical Whirling Speeds and Natural Vibrations of a Shaft Carrying a Symmetrical Rotor”, London' Her Majesty's Stationery Office, Ministry Of Supply Aeronautical Research Council Reports And Memoranda, 2008
8. Martin Donát. (2012). “Computational Modelling of the Unbalanced Magnetic Pull by Finite Element Method”, SciVerse ScienceDirect, Procedia Engineering 48(2012) 83-89, ELSEVIE R2012
9. G. K. Grover (2014 Reprint). “ Mechanical Vibrations” (Book, Eighth Edition), Nem Chand and Bros., Roorkee(India) ISBN 978-81-85240-56-5

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