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-Driver 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-Driver 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.

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/m³. 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 ($A_s$)

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

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

Volume of shaft ($V_s$)

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

$$V_s = 0.01165 \text{ m}^3$$

Mass of shaft ($m_s$)

$$m_s = (0.01165) (7850)$$

$$m_s = 91.45 \text{ kg}$$

B) For Mass of Rotor ($m_r$),

The total mass of rotor provided is 665.245 kg. Hence,

$$m_r = 665.245 \text{ kg}$$

C) For Stiffness of Shaft ($k$),

Moment of Inertia of shaft

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

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

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

Therefore,

Stiffness of shaft ($k$)

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

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,

$$k = 8854298.80 \text{ N/m}$$

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 ($\omega_n$)

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

$$\omega_n = \frac{5036139.314}{(664.035)+372.5}$$

$$\omega_n = 92.36 \text{ rad/s}$$

Therefore,

$$f_n = \frac{\omega_n}{2\pi} = \frac{92.32}{2\pi} = 14.69 \text{ rev/s}$$

Hence,

Critical speed by analytical method ($N_c$)

$$N_c = f_n \times 60 \text{ RPM}$$

$$N_c = (15 \times 60)$$

$$N_c = 900 \text{ RPM}$$

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 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.

Figure 5. Application of UMP to Shaft-Rotor assembly

D) Solution And Results
The result of analysis, the value of natural frequency obtained is 15.17Hz.
Therefore, 
\[ f_A = 15.17 \text{ Hz} = 15.17 \text{ rev/s} = 16 \text{ rev/s} \]
From this value of natural frequency, Critical speed of motor (\( N_{CA} \)) is estimated as:
Critical speed of given motor (\( N_{CA} \))
\[ N_{CA} = (f_A \times 60) \text{ RPM} = (16 \times 60) = 960 \]
\( N_{CA} = 960 \text{ RPM} \)
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 \( N_C = 900 \text{ RPM} \)
- By analysis in ANSYS \( N_{CA} = 960 \text{ RPM} \)
The percentage error in obtained values of critical speed is:
Percentage Error = \[ \left( \frac{\text{Experimental Value} - \text{Theoretical Value}}{\text{Theoretical value}} \right) \times 100 \]
\[ = \left( \frac{(960) - (900)}{900} \right) \times 100 \]
\[ = \left( \frac{60}{900} \right) \times 100 \]
\[ = 6.66 \]
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


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