Modelling and Analyzing of Induction Motor Using Three-Dimensional Finite Element Method

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Abstract

Induction motors are reliable, efficient electrical machines. So they are widely used in industry. To design more efficient induction motors, accurate predictions of the motor's behaviours are required. Finite element method provides us computing characteristics of induction motors without physically constructing a prototype. In this study, three phase squirrel cage induction motor is modelled. After magnetic flux density and speed parameters are analyzed using three-dimensional finite element method.

Key Words: Three-Dimensional Modelling, Induction Motor, Finite Element Method

1. Introduction

Induction motors can be used almost anywhere. In particular, industrial plants, such as water pumps, industrial tapes, paper mills, fixed speed construction machinery and three-phase turning machines. It is used in refrigerator, washing machine and in similar many devices.

Speed of induction motor varies very little with load. There is a small difference operating speed between load speed and no load speed. This difference is generally negligible. So, these motors are located in the constant speed motors class. Induction motor speed controls are more difficult and expensive than direct current motors .

With computers and power electronics, techniques for designing, analyzing, and driving induction motors are developing rapidly [1]. Take saturation of the motor and rotor skew into account in calculation of the flux distribution by using a static non-linear vector potential solution by Dolinar. The results verified through laboratory measurement of parameters [2]. How to model one slot at the low frequency applications and giving the comparison between one slot and the entire of induction motor results have been showed by Ergene [3].

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2. Squirrel Cage Induction Motors

Classification of induction motors can be made according to the rotor structure, number of phases and operating modes. Induction motors are manufactured as single phase or three phase. Three-phase induction motors are classified according to their rotor structure. These are defined as ring induction motors and squirrel cage induction motors.

In industry and in home areas, mostly used induction motor type is squirrel cage induction motor. These motors are manufactured from a few watts up to 300 MW. Three-phase rotor structure and squirrel cage structure which is designed in Ansys/Maxwell program are shown in figure 1.

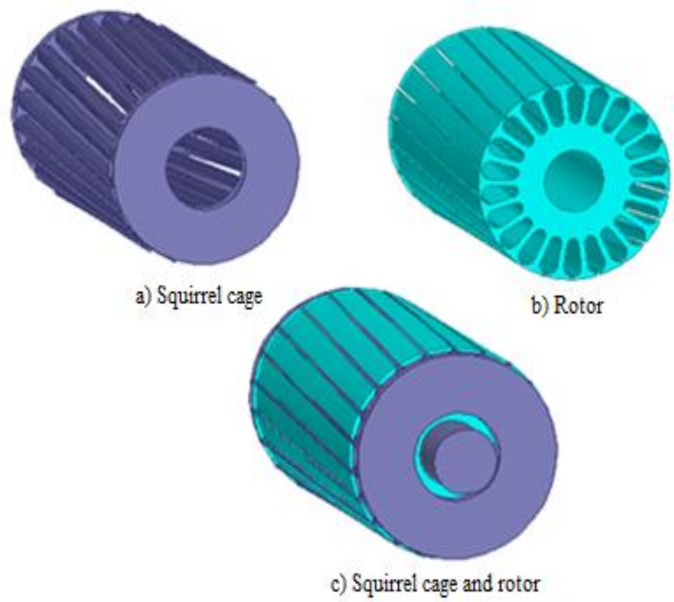

Figure 1. The structure of the three-phase and squirrel cage induction motor

The following methods are used to improve the performance of induction motors [4].
- Using higher quality core material for smaller loss.
- Optimum stator and rotor design.
- Optimum air gap.
- Optimal selection of the package length.
- Reduction of losses.
- Saturation prevention.
- Reduction of leakage reactance, increasing the useful flux.
- Reduction of harmonics.
- Optimization of design parameters.
- Optimization of the equivalent circuit parameters.

3. Finite Element Method

To design induction motor, motor's parameters such as the magnetic flux density, speed parameters requires correctly. Induction motor has two main magnetic flux calculation methods for magneto-dynamic analysis. These are permeance wave method and numerical approximation method (e.g. finite difference or finite element method). Permeance wave method is generally not used for this purpose due to the lack of accuracy, especially with non-linear magnetic core. Because of the flexibility and accuracy in solving electromagnetic problems, finite element method is more applicable [5].

Finite element method (FEM) is used for the analysis of the magnetic field, the behavior of the electric machine calculations and modelling of electrical machines. This method is utilized before the manufacturing and pre-examination of an electrical machine. Thus, using the properties of the material is employed in induction motor and the physical dimensions of motor. We can calculate flux distributions and generated torque in the no load or the load.

To use the finite element method, this principles are needed;
- Solutions the system which will be held on, must be composed of an enclosed area or volume.
- The physical properties of all materials used in the system must be defined.
- Value of required function there must be defined at each point in the system.

For the static magnetic field solution, Ampere's Law and the Maxwell equations used the following equation.

$$\nabla \times H = J \qquad \nabla \cdot B = 0 \tag{1}$$

Calculated quantities by using finite element method are magnetic vector potential values. Relationship between the magnetic vector potential values and current density is shown equation 2. Where, H is magnetic field strength, A is magnetic vector potential, J is current density and μ is magnetic conductivity.

$$\nabla \times H = \nabla \times \left(\frac{1}{\mu}\nabla \times A\right) = J \tag{2}$$

Equation 3 shows analytically three-dimensional plane.

$$\frac{\partial \mathbf{A}}{\partial x}\left(\frac{1}{\mu}\frac{\partial \mathbf{A}}{\partial x}\right) + \frac{\partial \mathbf{A}}{\partial y}\left(\frac{1}{\mu}\frac{\partial \mathbf{A}}{\partial y}\right) + \frac{\partial \mathbf{A}}{\partial z}\left(\frac{1}{\mu}\frac{\partial \mathbf{A}}{\partial z}\right) = -J \tag{3}$$

4. Modelling and Analyzing of Induction Motor

Modelled the induction motor has 24 slots in stator and 22 slots in rotor. Using the parameters from figure 2 we have designed our squirrel cage induction motor model in Ansys/Maxwell program as shown in figure 3.

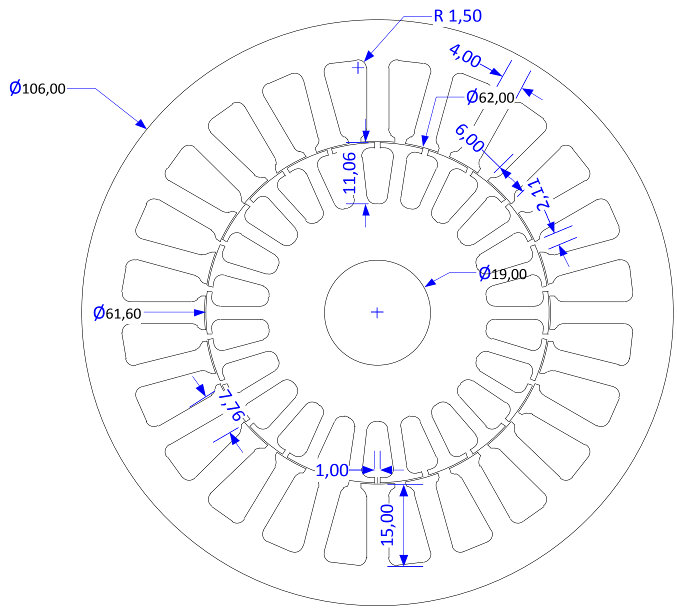

Figure 2. The induction motor size dimensions

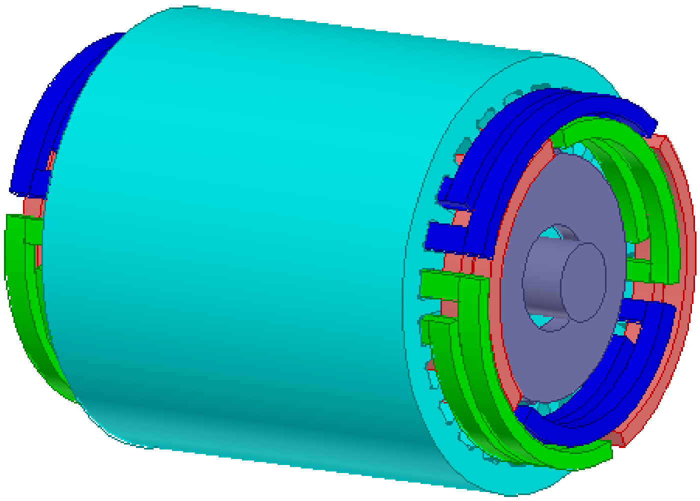

Figure 3. View of the designed three-dimensional induction motor

After drawing model, material identification, assignment of boundary conditions, defining parameters, the process solutions start as shown in figure 4. In this process, the simulator generates meshes and making solutions in these meshes (in figure 5). Being done each solution called iteration. In analysis, the error rate is 1% and the number of iteration is 5 for this model.

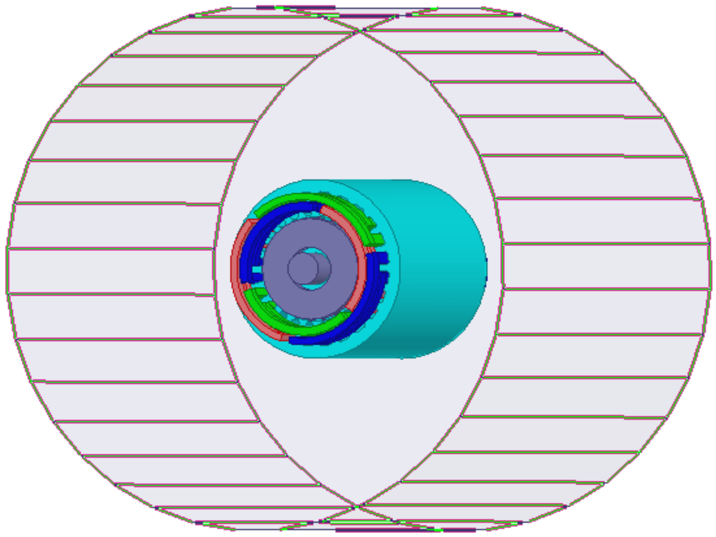

Figure 4. Three-dimensional view of the induction motor model in the boundary condition

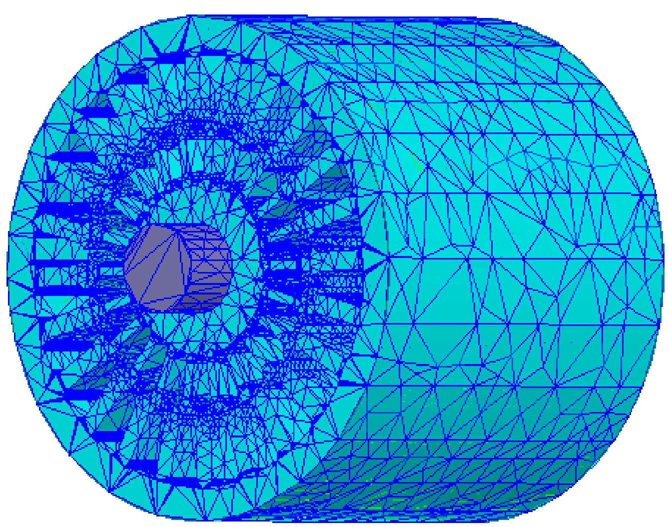

Figure 5. Three-dimensional view of the partitioning induction motor

Studied induction motor has 154 winding per phase. The model is designed for a 1.3 ampere current. So there will be 154 x 1.3 x sin (120) =173,37 ampere turns. The magnetic flux density value for 173.37 ampere turns is shown in the figures 6-7 according to the color code.

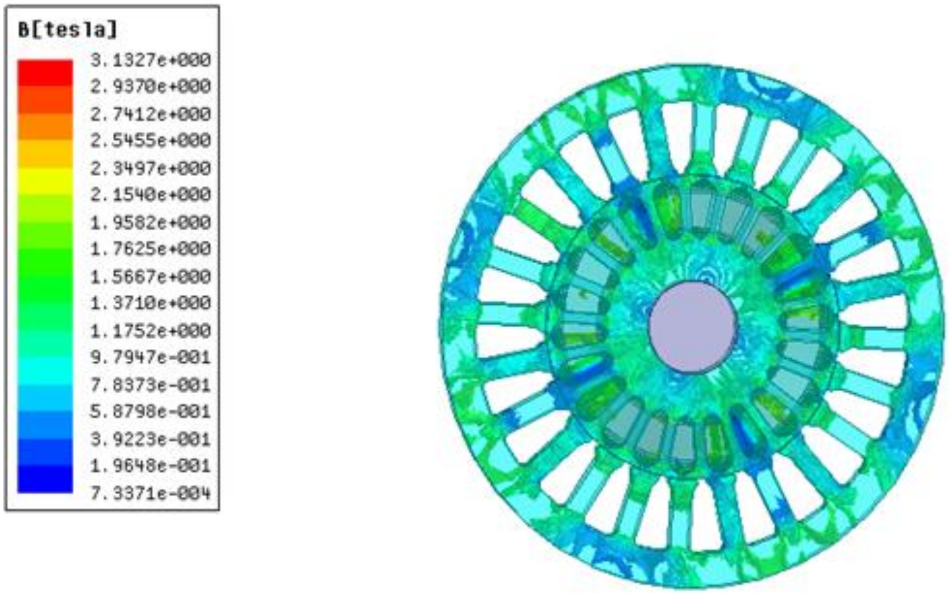

Figure 6. Front view of the magnetic flux density in the induction motor

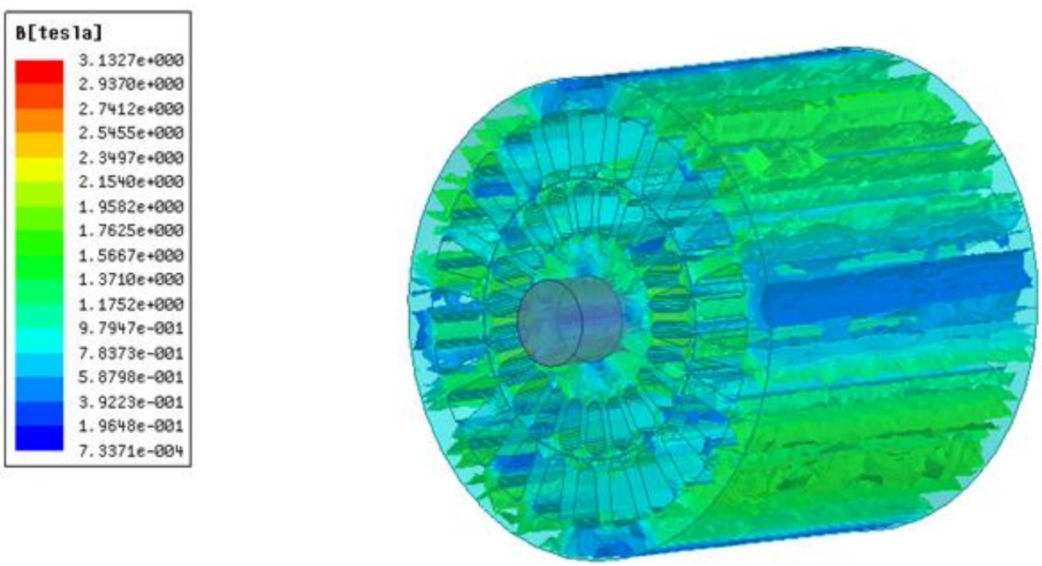

Figure 7. Three-dimensional view of the magnetic flux density in the induction motor

Finite element analysis results are obtained for different speed values. Such as, input current graph is figure 8, output power graph is in figure 9, efficiency graph is in figure 10 and output torque graph is in figure 11.

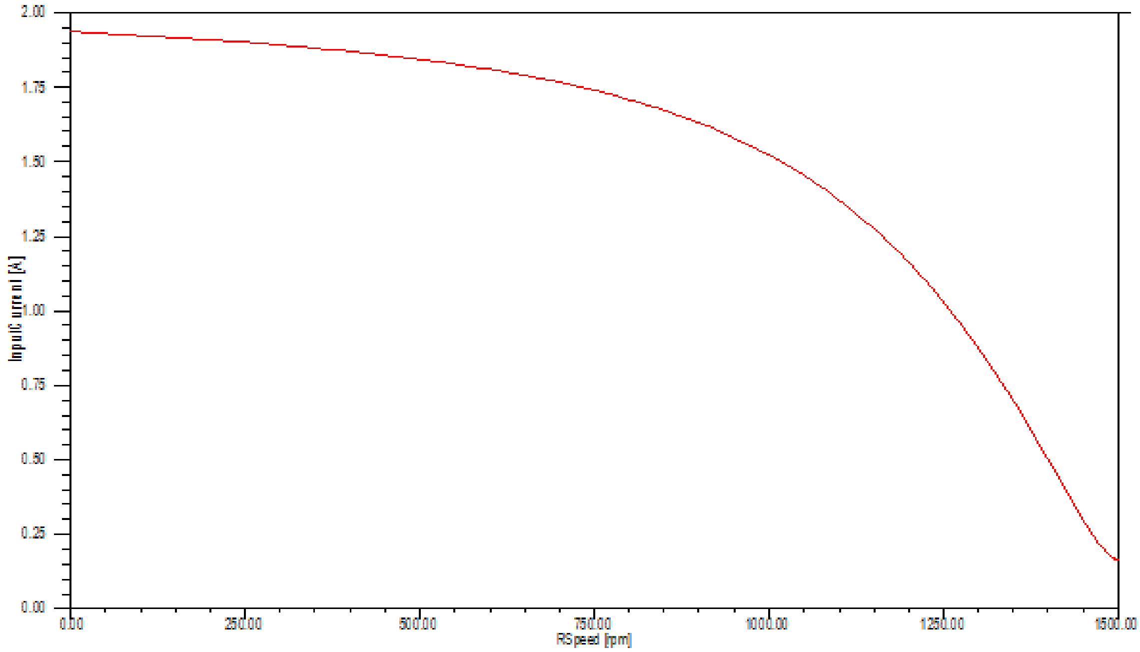

Figure 8. Input current graph for three-phase squirrel cage induction motor with different speed values

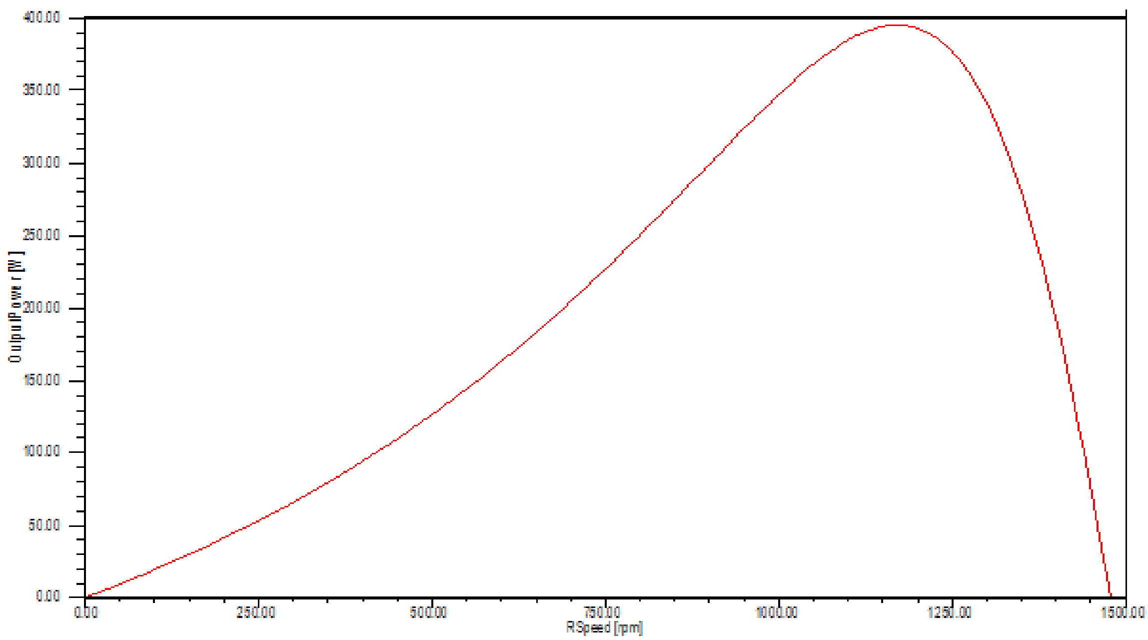

Figure 9. Output power graph for three-phase squirrel cage induction motor with different speed values

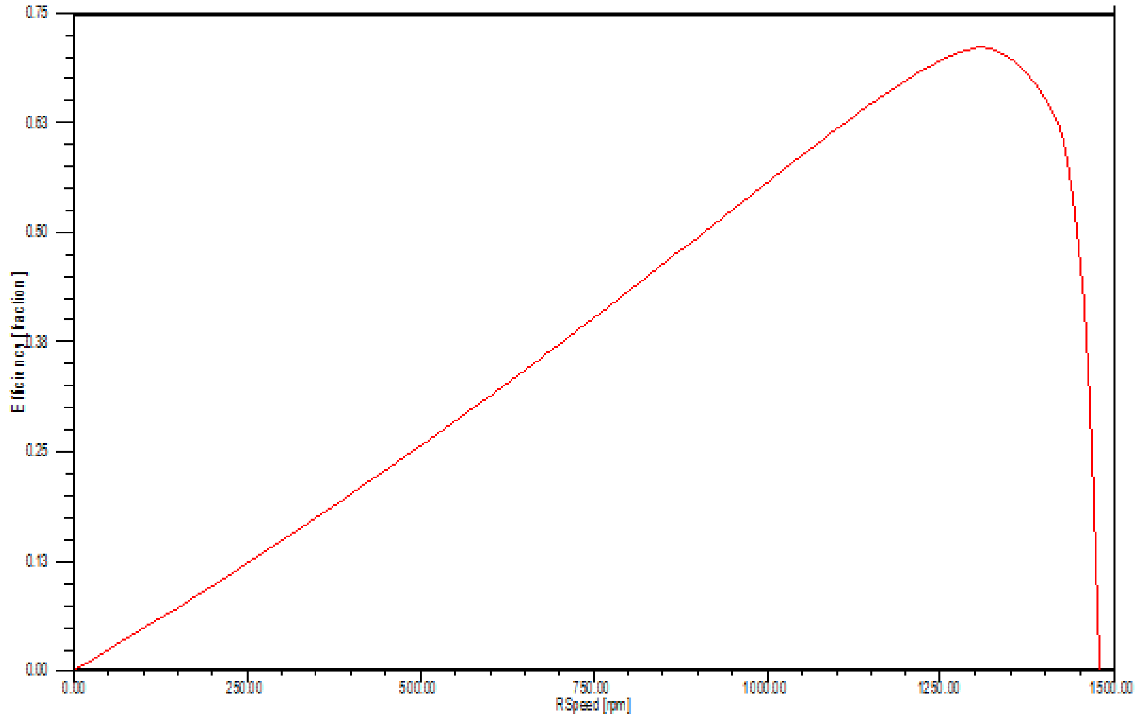

Figure 10. Efficiency graph for three-phase squirrel cage induction motor with different speed values

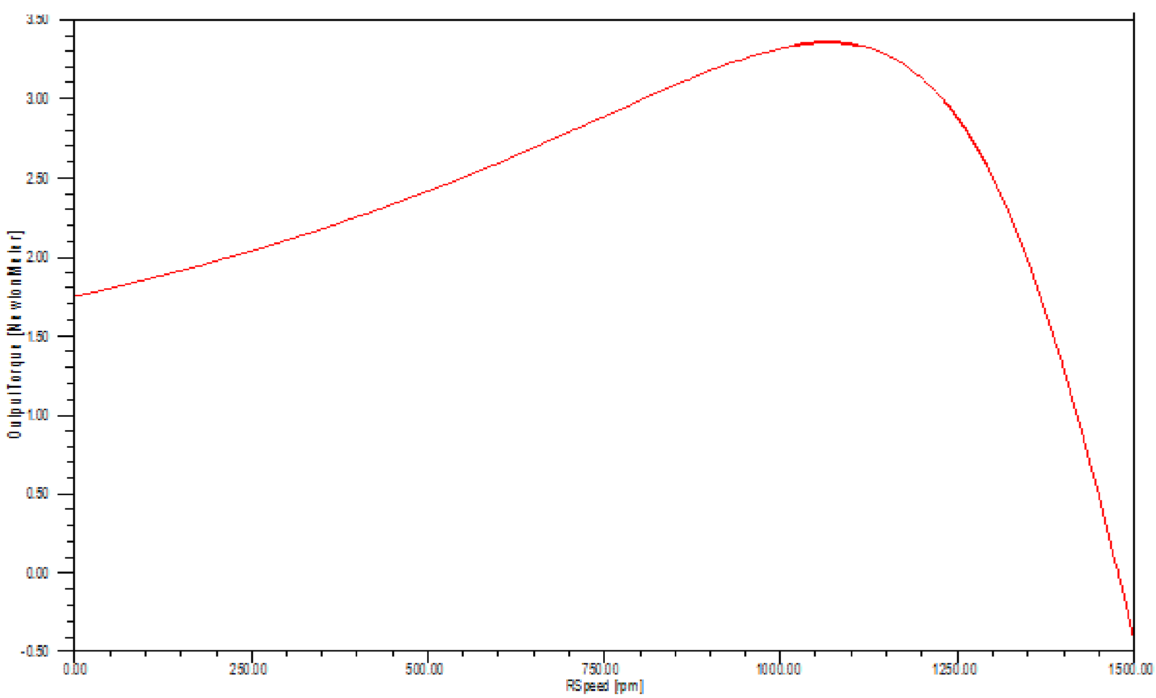

Figure 11. Output torque graph for three-phase squirrel cage induction motor with different speed values

5. Results

In this study, three-phase squirrel cage induction motor has been analyzed using Ansys/Maxwell program by three-dimensional finite element method. Depending on induction motor's different speeds, input current, output power, efficiency and torque changes are obtained. Also, three-dimensional magnetic field distribution is obtained for the induction motor.

While finite element method analysis is used in the Ansys/Maxwell program, if the error rate is selected smaller and if number of iteration is selected larger, the analysis result will be more accurate. But in this case, computer problem solving time and solution file area on the hard disk increase too large. For a better result in following studies, powerful computer hardware should be prefer. Also, this paper show us that modelling and analyzing with finite element method is simple and effective. Disadvantages of this method are harmonics, magnetic noises etc. which are ignored in the Ansys/Maxwell program.

Acknowledgment

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