Finite Element Analysis and Modeling of Three-Phase Induction Motor

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Abstract. As mentioned in this paper that three-dimensional and two-dimensional model of the motor is established and three-dimensional structure of the motor is proposed. The finite element structure of the two-dimensional motor is analyzed by using the two-dimensional finite element analysis method combined with a motor example. The finite element parameters of the motor are designed, and the state parameters of the motor involving flux diagram, magnetic line diagram, magnetic density vector diagram and magnetic density cloud diagram are obtained.

1. Introduction
Motor analysis is abstract in conventional methods, especially involving its numerical analysis operation, it is difficult to understand on the basis of abstraction. By introducing the method of finite element analysis and design in the process of motor analysis, not only the concrete process of motor design can be improved, but also the motor operation problems can be solved to a certain extent, which improves the efficiency of motor design and shortens cycle of motor designing.

On the basis of literature research, according to the specific three-phase induction motor physical model, this paper designs a three-dimensional model via simulation of three-phase induction motor, and structural characteristics analysis. At the same time, two-dimensional section model of the three-phase induction motor is analyzed by the finite element model based on three-phase induction motor model, and the parameters and results of the three-phase induction motor in the operation process are analyzed.

2. Finite Element Analysis of Three-phase Induction Motor
The electromagnetic field is controlled by the Maxwell equations describing the field quantity and the field quantity is described by the continuous boundary conditions. Maxwell's equations are the basis of studying macroscopic electromagnetic field problems. Their differential forms are described as follows:
\[
\begin{align*}
\nabla \times H &= J_s + J_\sigma + \frac{\partial D}{\partial t} \\
\nabla \times E &= -\frac{\partial B}{\partial t} \\
\n\nabla \cdot D &= \rho \\
\n\nabla \cdot E &= 0
\end{align*}
\] 

(1)

\[
\begin{align*}
D &= \varepsilon E \\
B &= \mu H \\
J_\sigma &= \sigma E
\end{align*}
\] 

(2)

In formulas (1) and (2), B is the vector of magnetic induction intensity, H is the vector of magnetic field intensity, E is the vector of electric field intensity, D is the vector of electric displacement, \( \rho \) is the density of charge volume, \( J_s \) is conductive current, \( J_\sigma \) is eddy current density, \( \varepsilon \) is dielectric constant, \( \sigma \) is conductivity and \( \mu \) is permeability.

3. Finite Element Modeling of Three-phase Induction Motor

3.1. Three-dimensional finite element model of three-phase induction motor

By establishing the three-dimensional finite element model of three-phase induction motor and isolating each part, the internal structure of three-phase induction motor can be understood on the whole. Fig. 1 shows the three-dimensional finite element model of the three-phase induction motor, and describes the overall structure of the motor.

![Figure 1. Three-dimensional model of three-phase induction motor](image)

3.2. Three-dimensional Local Finite Element Model of Three-phase Induction Motor

By appropriately splitting each part of the three-dimensional model of the three-phase induction motor in Fig. 1, the discrete structure of each part of the induction motor can be obtained, as shown in Fig. 2. Figure 2 shows the physical structure of each discrete structure of three-phase induction motor, including air gap, permanent magnet, and stator and winding model.
4. Finite element experimental model of three-phase motor

Three-phase motor mainly consists of stator and rotor. The stator of the motor consists of several basic parts, such as stator core, stator winding and permanent magnet material. In the rotor part, there are rotor coils and rotating shafts. The following is a case study of three-phase motor structure parameters as shown in Table 1.

There are several basic points involved in the design of motor. The first is to select the connection form of motor windings, and the second is to select the winding distribution of each phase sequence after the connection form is selected.

The winding wiring diagram of three-phase motor is shown in Fig. 3. As can be detected from the figure, the wiring wiring is arranged in a single-layer way, and each winding slot is arranged with a single coil winding. Each phase in the winding wiring diagram of the motor corresponds to the incoming and outgoing wires in turn. If phase A is taken as A, phase B is taken as B, phase C is taken as C, and phase B is taken as Z. Then the winding in and out and the phase sequence table can accurately determine the routing of each phase line of the motor.

### Table 1. Structure and material parameters of three-phase motor.

| Stator Internal diameter | 74mm | Permanent magnetic materials | P_Mag      | Stator Internal diameter | 74mm |
|--------------------------|------|------------------------------|------------|--------------------------|------|
| Stator Outer diameter    | 120mm| Stator core                  | DW465-50   | Stator Outer diameter    | 120mm|
| Motor pole number        | 4 poles | stator winding              | copper     | Motor pole number        | 4 poles |
| stator slots number      | 24 slots | air gap                    | Air (vacuum) | stator slots number      | 24 slots |
4.1. Two-dimensional finite element model of three-phase motor

Based on the parameter setting and winding structure description of tables 1 and Figure 3, the two-dimensional finite element analysis structure of three-phase motor as shown in Fig. 4 (a) is the basic structure of two-dimensional magnetic field analysis of three-phase motor, and the two-dimensional magnetic field structure of three-phase motor in Fig. 4 (b) is the structure diagram of two-dimensional magnetic field analysis of three-phase motor. The finite element analysis results of the motor can be obtained.

4.2. Finite element analysis experiment of three-phase motor

After modeling, the two-dimensional finite element analysis results of three-phase motor are obtained, as shown in Fig. 5. Fig. 5 gives four variable distributions of finite element analysis of motor, including motor flux, motor flux line, motor flux density vector and motor flux density nephogram.
5. Conclusion

In this paper, three-dimensional and two-dimensional models of three-phase induction motor are established by finite element analysis and simulation, and the two-dimensional model of induction motor is simulated. The two-dimensional model of 24-pole motor is established as the experimental object. Experimental result of steady-state structure diagram, flux density diagram and magnetic circuit distribution diagram of induction motor are obtained.

Theoretical analysis and experimental results show that:

1) The motor model after finite element modeling is intuitive and reflect the motor structure, which is conducive to the further analysis of the motor work and the optimization of motor working process.

2) The model experiment established by the two-dimensional finite element analysis of the motor can observe the state parameters of the motor from various angles, and the observation of motor operation parameters is intuitive and efficient.

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