Characteristics Analysis of Single Phase Induction Motor by Finite Element Method Considering Elliptical Magnetic Field

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Abstract ¾ **This paper presents the characteristics analysis of Capacitor-run Single Phase Induction Motor (SPIM) by time varying field considering the elliptical magnetic filed. The stator of this motor generates the elliptical magnetic field inside the housing by exciting 2-stator windings, a main winding and an auxiliary winding. Therefore, it is difficult to analyze their accurate characteristics. Two winding currents obtained from time varying Finite Element Method (FEM) by voltage driven source are separated into two components: forward and backward MMF, and then the total force is calculated by each component. The validity of the proposed analysis method is verified by experimental values.**

INTRODUCTION

The SPIM is widely used in industrial and household applications. The major reason is that the operation of SPIM fed directly from the commercial single-phase voltage source is more popular in households without any type of control strategy. In addition, it is rugged, maintenance-free and cheap [1,2]. It has a main winding and an auxiliary winding connected with capacitors for the efficiency improvement in steady state and higher starting torque [2]. The stator is capable of generating an unbalanced elliptical magnetic field because 2-stator windings that have different magnitude of current and phase [3]. The elliptical magnetic field caused by the sum of Magneto-motive Force (MMF) of each winding is dependent to the slip. This phenomenon of SPIM makes more difficulty to analyze the characteristics than the balanced poly-phase machine.

The SPIM is generally analyzed by the equivalent-circuit using the symmetrical-coordinate method in order to consider the elliptical magnetic field [4]. As it cannot take into account the magnetic saturation and deep-bar effects varied with any slip, the use of unsaturated leakage reactance in the equivalent circuit will reduce the accuracy with which performance is calculated [5,7]. On the other hand, Finite element analysis is well established as a field analysis technique that is able to model both magnetic saturation and resistance of conductor bars. However, in order to consider an elliptical magnetic field based on FEM, the analysis of SPIM should employ the transient magnetic field. The transient analysis by FEM is complexity and requires much time to obtain a solution.

This paper describes the time harmonic field 2D FEM with aid of double revolving field theory to reduce problem size and improve the accuracy of analysis in the SPIM. First, two winding currents are estimated by the time harmonic field FEM driven by voltage source, and they are separated into the forward and backward MMF components from the double revolving field concept [3][8]. Next, analysis model is analyzed by the time harmonic field FEM driven by the each MMF component respectively. Finally, the total force is obtained by the sum of the tangential force for each component.

The various performances of the SPIM by the proposed analysis method are compared with the experimental results.

ANALYSIS METHOD

Table I presents the specifications of a capacitor-run single-phase induction motor. Fig.1 shows the structure of analysis model and the main and auxiliary winding distribution in the stator.

TABLE I. SPECIFICATIONS OF ANALYSIS MODEL

Item	Value	Item	Value
Input voltage	115(V)	Frequency	60(Hz)
No. of pole	2	Capacitor	12(μF)
No. of stator slot	24	No. of rotor slot	34

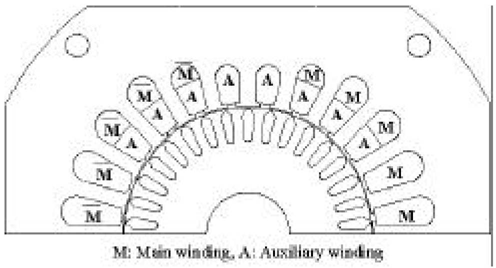

Fig. 1. Analysis model and winding distribution

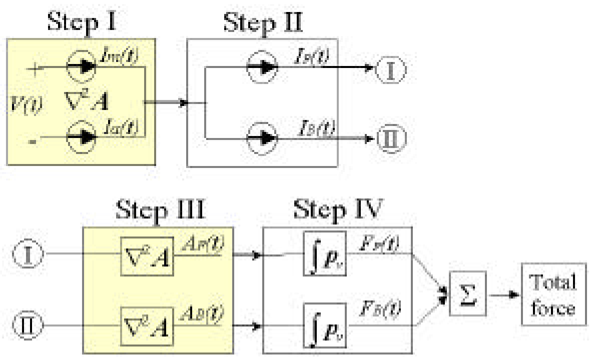

Fig. 2. Analysis procedure

To analysis the SPIM by the proposed method, the analysis procedure as show in Fig.2 is of sequence of steps.

- *Step I*: Extract the main and auxiliary current from the nonlinear analysis of time harmonic field driven by the voltage source. The governing equation with vector potential is as follows:

$$n\nabla^2 \boldsymbol{A} = \boldsymbol{J_0} - jsw\boldsymbol{A} \quad (1)$$

where $\boldsymbol{A}$ is the magnetic vector potential $\boldsymbol{J_0}$ is the current density of the coil, and σ is the conductivity.

Equation (1) is coupled with the voltage equation (2) for voltage source.

$$V = IR + E + L\frac{di}{dt} \quad (2)$$

where I is the current conducted in main and auxiliary winding. R and E are the resistance and back EMF in each winding respectively. ω is slip frequency.

- *Step II*: Separate the forward and backward component into each winding current based on two revolving magnetic field theory. The forward MMF F_a and backward MMF F_b of alternating magnetic field by each winding is as follows [3].

$$F_m = \tfrac{1}{2} i_m N_m [\cos(q - wt - p/2 + a) + \cos(q + wt - p/2 - a)] \quad (3)$$

$$F_a = \tfrac{1}{2} i_a N_a [\cos(q - wt) + \cos(q + wt)] \quad (4)$$

where, F_m, i_m and N_m are the MMF, current, series turns per phase in the main winding. F_a, i_a and N_a are the MMF, current and series turns per phase in the auxiliary winding respectively.

- *Step III*: Analyze the time harmonic field FEM driven by the forward and backward current components respectively. The governing equation for the 2D FE analysis is given by

$$n\nabla^2 \boldsymbol{A} = \boldsymbol{J_0} - jsw\boldsymbol{A} \quad (5)$$

This step is subdivided into three processes for the saturation of core.

(A) Perform a nonlinear field solution with both the forward MMF and the backward MMF. (B) Fix the element reluctivities obtained at the value at step 3(A). And carry out a linear solution driven by the forward MMF. (C) Spte3 (B) is repeated by substituting the backward MMF for the forward MMF.

- *Step IV*: Calculate the tangential force for two components by Maxwell stress tensor. Finally, the total force is obtained from the sum of the force induced by each component.

ANALYSIS RESULTS AND DISCUSSION

Fig. 3 shows the Lissajous elliptical magnetic filed varied with the slip. These results indicate that the shape of magnetic field is not a circular field but an elliptical magnetic field. Table II shows the torque calculated by the proposed method and the experiment result at slip 1.67(%).

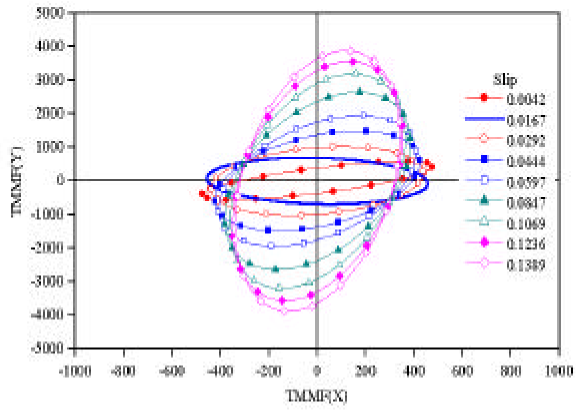

Fig. 3. The shape of magnetic field according to slip

TABLE II. ANALYSIS MODEL

Slip = 1.67(%)	Torque(kgf-cm)
Proposed method	3.50
Experimental value	3.54

CONCLUSIONS

The single-phase induction motor generates an elliptical magnetic field naturally. The transient analysis by FEM is its complexity and the length of time it takes to obtain a solution. Therefore, the SPIM is analyzed by the time varying field 2D FEM based on the double revolving theory. The proposed method can reduce the computation time and error better than a conventional method.

The various performances of SPIM for compressor will be investigated by the proposed method.

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