Shape Optimization Procedure of Interior Permanent Magnet Motors Considering Carrier Harmonic Losses Caused by Inverters

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An automatic shape optimization procedure that estimates the inverter carrier harmonic losses generated at cores and magnets has been developed in order to improve the performance of interior permanent magnet motors used for variable speed/load applications. In the proposed procedure, an electromagnetic field analysis coupled with armature voltage equation is iteratively carried out at each rotor shape. The input of this analysis is the theoretical inverter voltage, which is determined by both the rotor shape and the driving conditions of the motor. The proposed procedure is applied to a 100 kW-class interior permanent magnet motor, in which the carrier harmonic losses become dominant under frequent driving conditions. It is clarified that the carrier harmonic losses can be reduced by more than 10%, while the other important characteristics are not considerably deteriorated.

***Index Terms*—Permanent magnet motors, losses, inverters, finite element methods.**

I. INTRODUCTION

INTERIOR PERMANENT MAGNET MOTORS are widely used with inverters for many industry applications. As the rotor of this motor has very high degree of design freedom, various kinds of rotors have been developed according to applications and driving conditions. In recent years, owing to the progress of computers, a lot of papers related to the automatic shape optimization using electromagnetic field analysis have been published [1]-[5].

In the optimization of this motor, it is very important to consider the driving conditions for each application because the dominant components in the torque and losses considerably vary with the motor speed and load [6]. For example, in the case of automotive traction motors, the term under high speeds and full load condition is limited, whereas that under low speeds and low load conditions is very long. In this case, the iron loss caused by fundamental rotational field, stator slot harmonics, and rotor magnet harmonics become very small as compared to those in high speed conditions. In addition, the copper loss becomes also very small as compared to that under the full load condition because of small armature currents. As a consequence, the iron losses including magnet eddy current loss caused by inverter carrier becomes dominant under low speeds and low load conditions. Therefore, the reduction of the carrier harmonic losses is one of the key issues for these kinds of applications to improve the total performance of the driving system. However, as far as we know, there is no paper related to the automatic shape optimization for the reduction of carrier harmonic losses.

From these viewpoints, we have developed an automatic shape optimization procedure that estimates the inverter carrier harmonic losses generated at cores and magnets in order to improve the performance of interior permanent magnet motors used for variable speed/load applications. In the proposed procedure, an electromagnetic field analysis coupled with armature voltage equation is iteratively carried out at each rotor shape. The input of this analysis is the theoretical inverter voltage, which is determined by both the rotor shape and the driving conditions of the motor. The proposed procedure is applied to a 100 kW-class interior permanent magnet motor, in which the carrier harmonic losses become dominant under low speed and low load conditions.

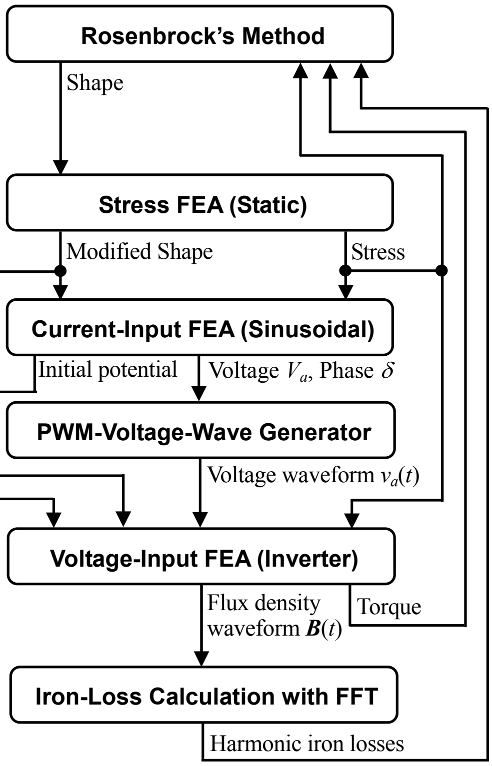

Fig. 1. Block diagram of proposed optimization procedure.

II. OUTLINE OF PROPOSED PROCEDURE

Fig. 1 shows the block diagram of proposed optimization procedure. Finite element analyses (FEAs) are applied for both the estimation of mechanical stress and electromagnetic field [5], whereas Rosenbrock's method is applied for the optimization method. First, the stress FEA is carried out according to the shape determined by Rosenbrock's method to examine the maximum stress in the rotor. If the stress is larger than the yielding stress of the core, the corner radius of the core is enlarged according to the process reported in [5]. Next, the electromagnetic FEA assuming sinusoidal armature current is carried out. The purpose of this analysis is to obtain only the amplitude and phase of the armature voltage. Then, the theoretical voltage wave form of pulse width modulated (PWM) inverter is generated and given to the voltage-input

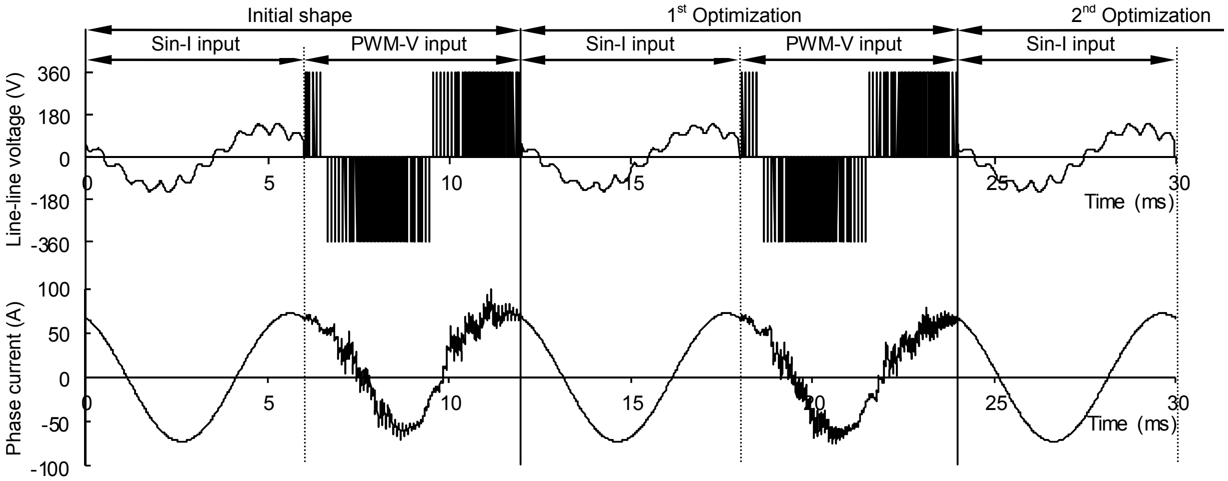

Fig. 2. Variation in armature voltage and current in the proposed optimization procedure.

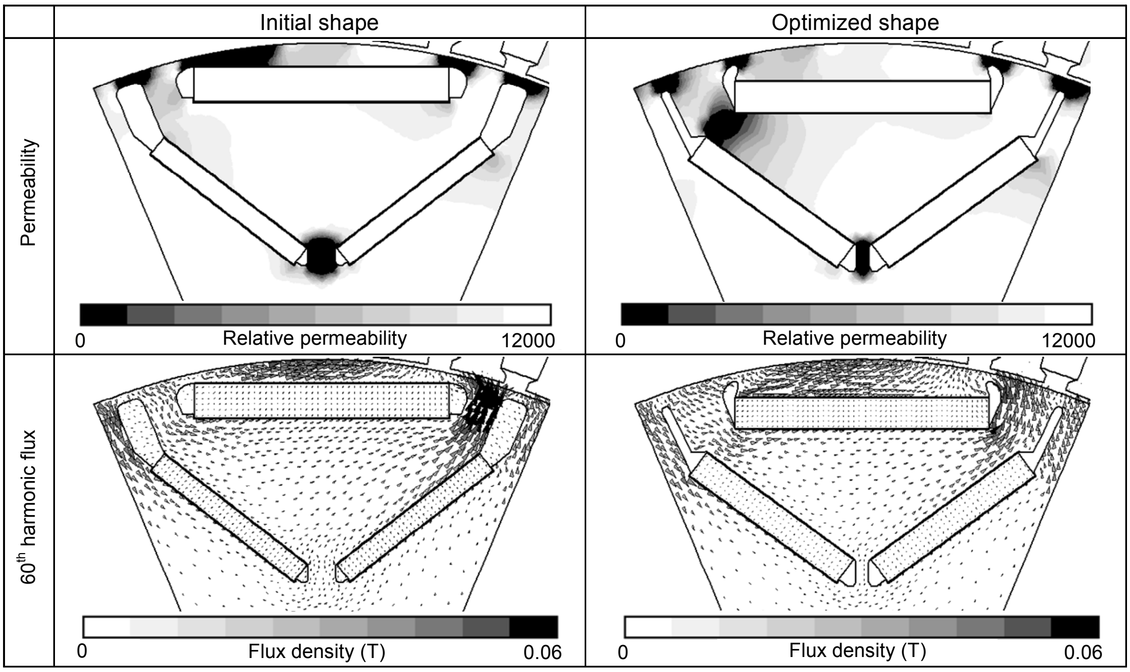

Fig. 3. Distributions of relative permeability and carrier harmonic flux density vector (Low speed and low load condition).

FEA. Finally, the iron loss is calculated by the method reported in [6], in which the accuracy is confirmed. The carrier harmonic losses are separated from the total losses by using Fourier transformation. The objective of this optimization is to minimize the total carrier harmonic loss. The torques of the motor under several important driving conditions, such as the maximum torque and rated high speed conditions, are also estimated as the constraint conditions.

III. Results and Discussion

The proposed optimization procedure is applied to a 100 kW-class interior permanent magnet motor. Fig. 2 shows the variation in the armature voltage and current in the proposed optimization procedure. In the current-input FEA, the current is sinusoidal, whereas it is not sinusoidal in PWM-voltage-input FEA. Fig. 3 shows the distributions of permeability and carrier harmonic flux density in initial and optimized rotors under the typical low speed and low load condition. It is observed that the concentration of the carrier harmonic flux is avoided in the optimized rotor. As a consequence, the rotor and total carrier harmonic losses are reduced by 20.7% and 11.2%, respectively, whereas the other important characteristics, i. e., the maximum torque and the efficiency at high speeds are not deteriorated. More detailed explanation of the results will be described in the full paper.

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