

Optimum Design of a Switched Reluctance Motor Fed by Asymmetric Bridge Converter Using Experimental Design Method

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Abstract— This paper proposes an optimization method for the switched reluctance motor (SRM) fed by the asymmetric bridge converter. It is the experimental design method applied to the two-dimensional finite element method (FEM) coupled with the asymmetric bridge converter circuit. We optimize five geometries of SRM shape and turn-on and turn-off angles of the asymmetric bridge converter by using the proposed method.

Index Terms— Switched reluctance motor, optimization, experimental design method, converter.

I. INTRODUCTION

SRMs have several advantages such as the simple construction of the motor, brushless operation, absence of permanent magnets and windings in the rotor, and low cost. They can be one of substitutes for interior permanent magnet synchronous motors used in home appliances and industrial applications such as air-conditioners and hybrid vehicles and so on. Several shapes of SRM have been analyzed and developed. Rahman et al. have investigated several (8/6) and (6/4) SRM geometries by the FE analysis [1], and have optimized the geometry of (24/16) SRM for high torque density [2]. Oh et al. have proposed a two-phase SRM for high-efficiency operation and full-load starting performance for any initial rotor positions [3]. Lee et al. have proposed a two-phase SRM with a stator composed of E-core structure having minimum stator core iron [4], [5]. Zulu et al. have proposed a three-phase, segmental-rotor, flux-switching synchronous motor with both field and armature windings placed on the stator [6]. Takeno et al. have developed a 400-N·m SRM for hybrid vehicles, and have investigated the effect of its structure on the characteristics and optimized the shape [7]. However, they have optimized a few parameters which define the shape of SRM structure. It is very important to optimize the whole shape of SRM structure considering the drive circuit.

The authors have designed the whole shape of an (18/12) SRM to produce a large average torque at a very low speed [8]. In the optimization, we utilized the experimental design method, where the stator current is assumed to be a rectangular shape with 120-degree width. Unfortunately, the torque becomes small, when the motor speed is high. This paper proposes an improved optimization method in which the FE analysis of SRM is coupled with an asymmetric bridge converter circuit. We optimize five geometries of SRM shape and the turn-on and turn-off angles of the asymmetric bridge converter by using the proposed method.

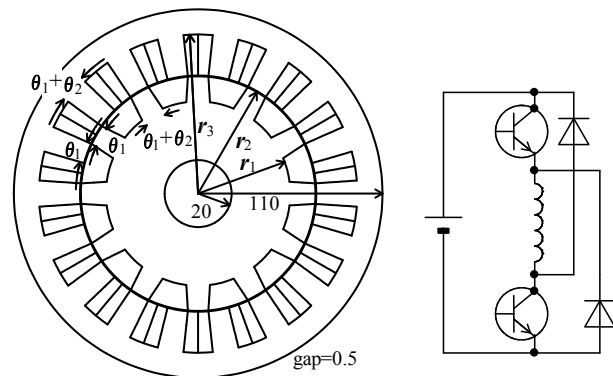


Fig. 1. (18/12) SRM model. Fig. 2. Asymmetric bridge converter (one phase).

II. OPTIMIZATION METHOD FOR SRM

Fig. 1 shows an SRM model to be designed, which has 18 stator teeth and 12 rotor teeth. The outer diameter, the shaft diameter, the stack and coil end length, and the air-gap length are fixed to 200mm, 40mm, 100mm, and 0.5mm, respectively. The space factor of winding is assumed to be about 35%, and the number of stator windings is proportional to the area of slot. Five parameters to be designed are shown in this figure. Fig. 2 shows an asymmetric bridge converter for SRM drive. It has two power switches and two diodes per phase. The motor phases are independently controlled by the turn-on angle β_1 and the turn-off angle β_2 . This paper assumes that the stator current is controlled by a hysteresis comparator. The behavior of the hysteresis comparator circuit is introduced to the programming code of the 2-dimensional nonlinear FEM coupled with voltage equations.

The experimental design method is a well-known technique developed to plan many experimental measurements efficiently, and it can be used to optimize electromagnetic devices. The method evaluates a lot of factors by means of the orthogonal table at the same time. The L18 orthogonal table experiments 18 conditions by allocating three levels to each factor. And then, an optimal condition is selected by analyzing the factor effects. In this paper, according to these factor effects, these parameters are changed, and the width of three levels is narrowed in half. When the dimensions of the motor are changed, a new FE mesh is automatically generated using the Delaunay algorithm. The objective function is the minimum torque in a cycle.

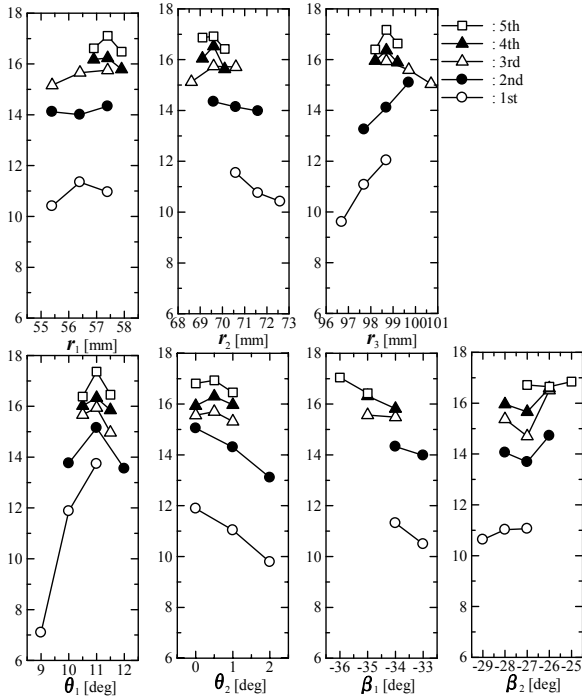


Fig. 3. Factor effects of SRM model.

III. OPTIMIZED RESULTS

The influence of each factor on the objective function is shown in Fig. 3. For example, the angle θ_1 is set to 10 ± 1 deg at the first iteration, and the factor effect says that it should be large. Then θ_1 is set to 11 ± 1 deg at the 2nd iteration, where the width of three levels is not changed. At the third iteration, the width is narrowed in half, and θ_1 is set to 11 ± 0.5 deg. As the obtained objective function at the 6-th iteration is slightly smaller than that at the 5-th iteration, the iteration is converged. Fig. 4 shows the torque and stator current of the optimized motor at a low speed of 400 min^{-1} . As the calculation time step is $25/540 \text{ msec}$, the stator current is controlled to be around $I_{\max} = 35 \text{ A}$, and the torque waveform is approximately constant. However at a higher speed of $2,000 \text{ min}^{-1}$, the current waveform is very different from a rectangle, and the torque is reduced as shown in Fig. 5.

Fig. 6 shows the comparison of torque-speed characteristics of the initial motor and the optimized motor. The average torque of the optimized motor is larger than that of the initial motor when the rotating speed is less than about 1000 min^{-1} . Moreover, the minimum torque in a cycle of the optimized motor is improved from $7.5 \text{ N}\cdot\text{m}$ to $18.9 \text{ N}\cdot\text{m}$, that is, about 2.5 times at 400 min^{-1} .

IV. CONCLUSIONS

This paper has proposed the optimization method for the SRM fed by the asymmetric bridge converter. It utilizes the experimental design method for the two-dimensional FEM coupled with the asymmetric bridge converter circuit. Seven parameters including turn-on and turn-off angles have been optimized to produce the large torque by the proposed method.

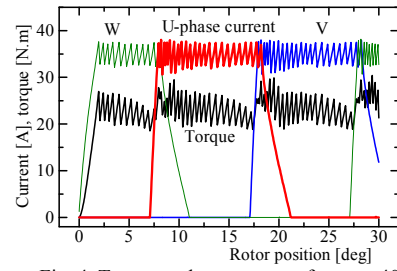


Fig. 4. Torque and current waveforms at 400 min^{-1} .

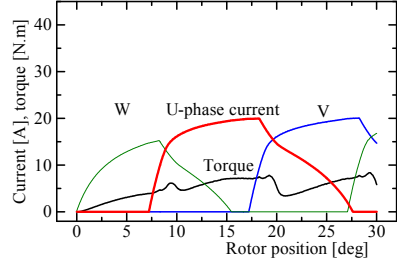


Fig. 5. Torque and current waveforms at $2,000 \text{ min}^{-1}$.

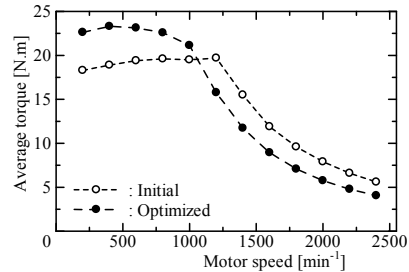


Fig. 6. Torque speed characteristics.

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