Back E.M.F. Waveform Optimization of Magnetically Modulated Motor

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1. Introduction

This paper focuses on improvement of back electromotive force (e.m.f) of a magnetically modulated motor (MMM). The structure of the motor is quite different from standard PMSMs because it has two rotating parts, i.e., an inner PM rotor and an outer modulator. Computer simulations conducted in the open stator winding circuit case show that the induced e.m.f. becomes imbalanced at lower speeds. Therefore, this paper discusses the nature of the induced e.m.f. of the prototype, and improvement of the e.m.f. waveform is achieved by optimizing the modulator shape by introducing air gaps in the iron bridge parts.

2. Waveform of Original Prototype

Fig. 1 shows a cross-section view of the original prototype MMM. The prototype MMM has a relationship among the stator pole-pair number P_s, the inner PM rotor pole-pair numbers P_{pm}, and the number of the outer modulator iron cores P_{mod}, which can be represented by P_s: P_{pm}: P_{mod} = n: $2n$: $3n$ (n is a natural number), respectively. The prototype has been made with n = 4, and the stator has 48 slots with distributed windings. The electrical frequency f_s for this motor is given by the following equation:

$$f_s = P_{mod} f_{mod} - P_{pm} f_{pm}, \tag{1}$$

where f_{mod} and f_{pm} are the mechanical frequencies of the modulator and the inner rotor, respectively. Fig. 2 shows the 2D FEA results of the induced e.m.f. waveforms at various speeds and their FFT results. Here the stator frequency has been kept at 120Hz. The simulation tests reveal that the induced e.m.f. gets distorted at lower speeds. The major harmonic components are the fifth and the seventh, and are generated due to the magnetic paths in the stator-side iron bridge parts of the modulator.

3. Optimization of Modulator

The induced e.m.f. is detrimentally distorted by the harmonic components; hence the modulator shape should be optimally modified to reduce them. The modification has been applied to the stator-side iron bridge parts of the modulator by inserting the air gaps. Fig. 3(a) shows the magnetic flux density along the stator-side air gap for different inserted air gaps. it is possible to improve the symmetry of the waveform. Fig. 4 shows the induced e.m.f. waveforms and the corresponding FFT results of the optimally modified modulator configuration. As can be seen from the simulation results, even a small air gap length such as 1 mm is good enough to reduce the harmonics in the induced e.m.f.

4. Conclusion

This paper discussed improvement of the induced e.m.f. waveform of a magnetically modulated motor by optimizing the modulator shape. The THDs when the modulator is rotating and when it is locked are estimated to be 28 % and 52 % for the prototype, but they can be reduced down to 5.7 % and 6.2 % for the optimized one, respectively.

References

[1] Y. Takeuchi, H. Kato, M. Tago, S. Ogasawara, and H. Sakai, "Operating Principle and Control Method of the Magnetic Modulated Motor," *IEEJ National Convention Record*, no.5-041, 2013, pp. 73-74.

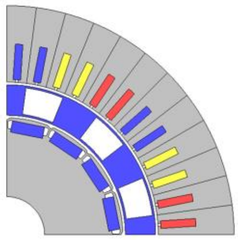


Fig. 1. Cross section of original prototype MMM.

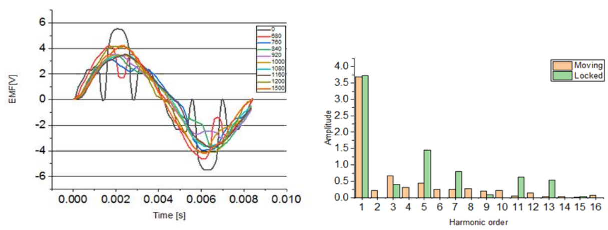
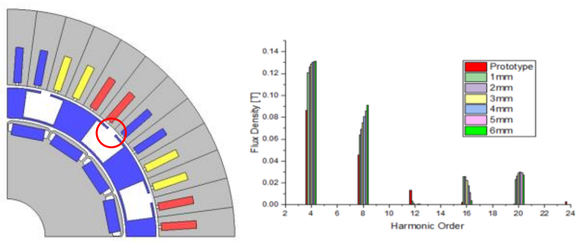


Fig. 2. Induced e.m.f. of prototype MMM.



(a) Modified modulator. (b) Flux density FFT.
Fig. 3. Modulator with modified iron bridge parts.

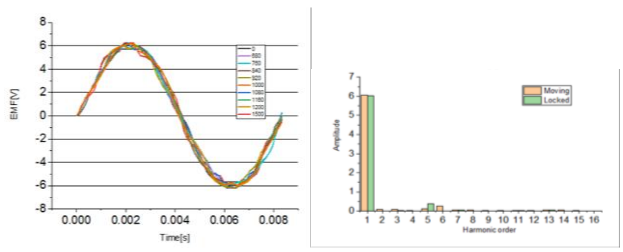


Fig. 4. Induced e.m.f. of optimaized MMM.