Comparison of Core Losses in Switched Reluctance Motors with Different Winding Arrangement and Conduction Scheme

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Abstract. *This paper presents core loss characteristics of Switched Reluctance Motors (SRM) with different winding arrangement and conduction scheme. Four cases of winding arrangement and conduction scheme are studied; concentrated winding driven by unipolar and bipolar conduction, distributed winding, and toroidal winding driven by bipolar conduction. For each case, change of flux density in specific element and core loss are calculated and compared. This study gives a guideline in determining the winding arrangement and conduction sequence for SRM design.*

Keywords: Conduction scheme, Core Loss, Finite Element Analysis, Switched Reluctance Motor (SRM), Winding arrangement

1 Introduction

These days there is a growing interest in the application of Switched Reluctance Motor(SRM) for industry application because of its simple and solid structure. However there is a limitation in improving characteristics of conventional SRM with asymmetric driver. Therefore, there are many reserches about changing not only the driver but also the driving sequence to get lower unit cost of production and higher performance [1,2].

As a part of the studies, this paper deals with a comparison of core losses about SRM with different winding arrangement and conduction scheme. There are possible to be lots of cases to compound winding arrangement and conduction seheme, only four cases are considered in this paper : basically concentrated winding driven unipolar, and bipolar conduction, distributed winding driven bipolar conduction, and toroidal winding also driven bipolar conduction.

For the computation of core losses, the process in [3,4] is used. Core losses are related to both flux density value and frequency of the flux density variation. While the period of flux density variation of each element is identical in brushless motors [5], the period is difficult in SRM. In addition, the period is changed depending on winding arrangement and conduction scheme even in the same part.

Therefore, before calculating core losses, the flux density variation of each representative element for the four cases is investigated, and the computation resluts of core losses according to the four cases are compared.

2 Analysis Model

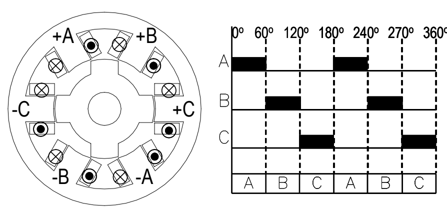
Fig. 1 shows the four cases of SRM with different winding and switching sequence. All these SRMs have 6 stator poles and 4 rotor poles, and only the winding arrangement and conduction scheme are different as listed in Table 1. For the analysis the input current is 1A of ideal square wave, and the magnetic material is S18 in JIS.

3 Theory of Core loss calculation

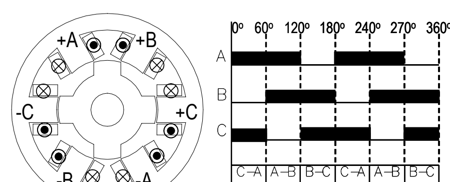
A core loss calculation method using FEA and core loss data is used. The procedure is shown in Fig. 2 and this flow chart is introduced in related paper of the authors in [3,4]. For the calculation, the core loss data of S18 shown in Fig. 3 is used. As mentioned previous, SRM have different periods of flux density variation of each element. However, the magnetic path can be roughly divided into four parts such as stator yoke and pole, and rotor yoke and pole [5,6]. Even though the flux density is calculated for all elements, the period of flux density in one representative element in each four part is examined.

To calculate flux density under the same condition, turn-on time is set from 0 to 30 degree which is general conducting time for 6/4 SRM. The base position 0 degree in the inductance profiles shown in Fig.4 is defined as the position shown in Fig. 1. Input current is set as 1A.

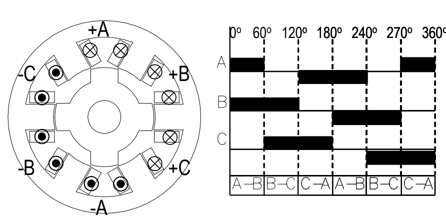
In the consideration of the fact that each inductance profile is different according to only difference of winding arrangement and conduction scheme, it can be expected that the core losses be different.



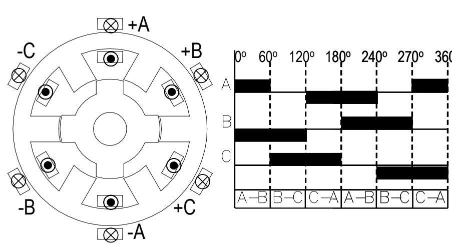
(a) Concentrated winding and unipolar conduction



(b) Concentrated winding and bipolar conduction



(c) Distributed winding and bipolar conduction



(d) Toroidal winding and bipolar conduction

Fig. 1 Four cases of different winding arrangement and conduction scheme

Table 1: Specification of analysis model

Model name	CSRM1	CSRM2	DSRM	TSRM
Magnetic material	S18			
Winding	Concentreted	Concentreted	Distributed	Toroidal
Conduction Scheme (current input sequence)	Unipolar, Fig. 1(a)	Bipolar, Fig. 1(b)	Bipolar, Fig. 1(c)	Bipolar, Fig. 1(d)

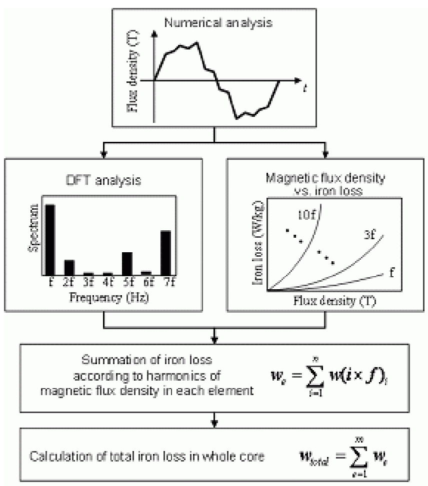


Fig. 2 Core loss calculation process

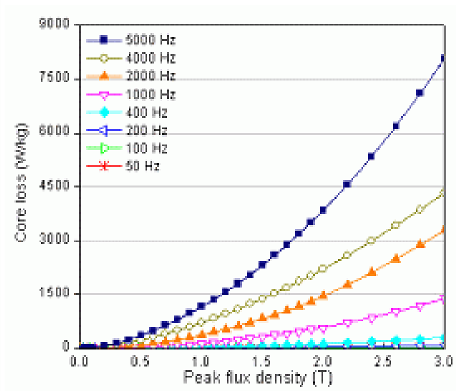
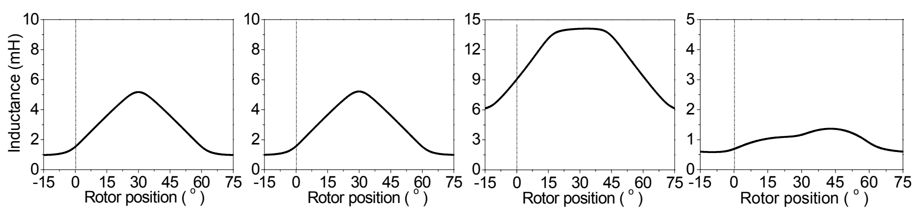


Fig. 3 Core loss data of S18



(a)CSRM1 (b)CSRM2 (c)DSRM (d)TSRM

Fig. 4 Inductance profiles of analysis model

4 Variation of flux density in representative element

Even though each model has the same dimensions and number of turns, the changing aspect of magnetomotive force (MMF) and total flux can be changed for the same input current because the winding and conduction scheme is different.

Therefore before calculating the core loss, each model is divided into four parts (stator yoke and pole, and rotor yoke and pole) and observed the change of flux density of the representative element in each part as shown in Fig. 5.

Fig. 6 shows the variation of flux density in the representitive element for 1A input current as the rotor rotating in CSRM1. The values are quite low because input MMF is not as high as possible to make the core saturated. Consequently, the value 1 is the unit value as meaning of the highest flux density, and the peak value of the DSRM is 1.

The periods of flux density variation per one revolution are different according to part of magnetic flux path and analysis model, and the comparison results are listed in Table 2. [6] gives a fomula to estimate this period, but it can be applied only to the CSRM1. Recently it is possible to directly calculate the changing aspect in each element using FEA, hence this paper only introduces the fact of the different period, and the period is compared.

5 Results of core loss calculation

Fig. 7 is one of the harmonic analysis results. This result is about tangential component of flux density, and the total harmonic distortion (THD) is calculated.

After calculating flux density of all elements, the core losses are calculated. Fig. 8 shows the results according to speed variation. The core losses according to speed is different depending on models because the period of flux density variation is different. However Fig.8 is not obtained by the same input power, but by the same current 1A. Therefore it is needed to calculate the input power to estimate the ratio of the core loss to the same input power. At 2000rpm the output power is calculted using the speed and torque in Fig. 9(a) and (b), and copper loss is calculated using phase resistance for CSRM1 and line to line resistance for other models. Using the estimated input power calculated by the sum of the output power and losses, the ratio of core loss to the input power is shown in Fig.9 (c) and (d)

6 Conclusions

Table 3 shows the summary of Fig. 8 and Fig. 9. CSRM2 has the lowest core losses per input current. However DSRM has the lowest core losses per input power. These comparison results can be a guideline to determine the winding arrangement and driving method in designing the SRM.

Acknowledgements

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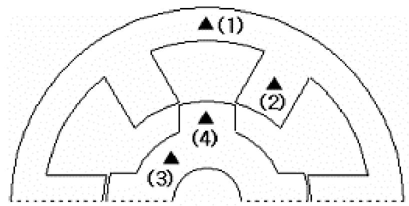


Fig.5 Four representative element; (1)stator yoke (2)stator pole (3)rotor yoke (4)rotor pole

Table 2: Flux density variation per one revolution

	Element No 1 : Stator yoke	Element No 2 : Stator pole	Element No 3 : Rotor yoke	Element No 4 : Rotor yoke
CSRM1	4	4	1	1
CSRM2	4	4	3	3
DSRM	2	2	3	3
TSRM	2	2	6	6

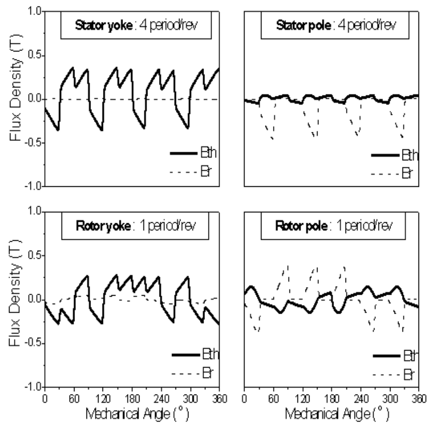


Fig.6 Flux density variation
in representative element in CSRM1

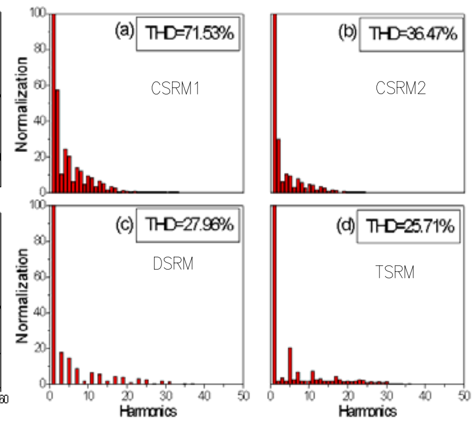


Fig. 7 Normalized harmonic ratio

Table3: Order of the magnitude for each model

	CSRM1	CSRM2	DSRM	TSRM
THD of tangential component flux densityinstator yoke	1	2	3	4
Average torque at the speed	2	3	1	4
Core loss / copper loss	1 / 2	4 / 1	2 / 1	3 / 1
Core loss to the input power	1	3	4	2

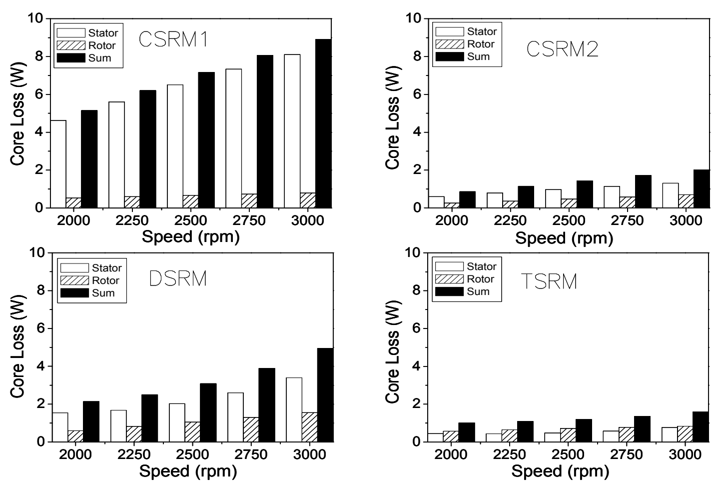
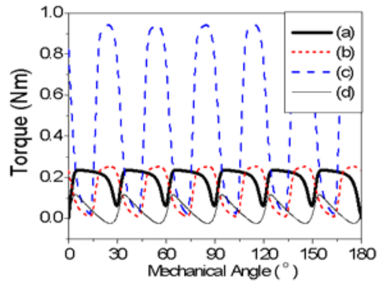
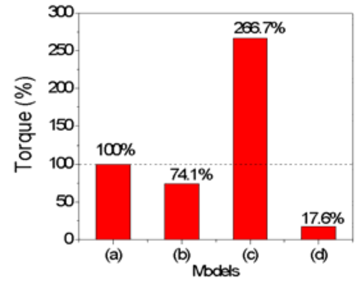


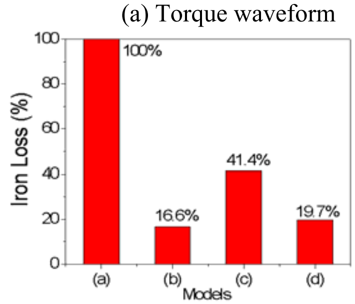
Fig. 8 Core loss variation to speed



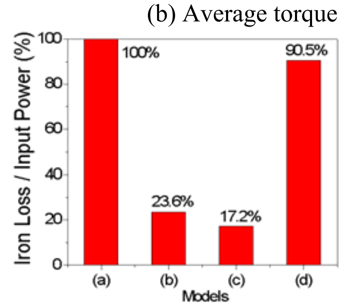
(a) Torque waveform



(b) Average torque



(c) Calculated core loss



(d) Core loss to the input power

Fig. 9 Comparison of torque characteristics and core losses
(graph label : (a)CSRM1,(b)CSRM2,(c)DSRM(d)TSRM)

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13:50–14:10	Zhengang Yang, Jiansheng Yuan, Zhanghong Tang (China) *Three-dimensional finite element mesh generation of models defined by a set of discrete points*
14:10–14:30	T. Yasuda, A. Kawahara, K. Tanaka (Japan) *Obstacle avoidance using virtual sensor of intelligent wheelchair with operation support system*
14:30–14:50	J.-H. Bahn, J.-Y. Lee,J.-P. Hong, J. Hur, B.-K. Lee (Korea) *Comparison of core losses in switched reluctance motor with different winding arrangement and conduction scheme*
14:50–15:10	Z. Zhao, L. Hao, J. Yuan (China) *Calculation of single conductor capacitance by estimating the electrostatic field*
15:10–15:30	**Coffee Break**
15:30–18:30	**Visiting the Temple of Literature**
19:30	**Banquet**