Rare Earth less Traction Motor for Electric Vehicle

Masayuki Morimoto
Department of Electrical and Electronic Engineering, Tokai University,
1117 Kitakaname, Hiratsuka-shi, Kanagawa-ken, 259-1292, Japan, e-mail:morimoto@ieee.org

Abstract

In this paper, rare earth less traction motor for electric vehicles is presented. Almost all HEV's and EV's use rare earth permanent magnet synchronous motor as a traction motor. Nowadays, resource crisis of rare earth materials is coming. This paper proposes novel induction motor made of Soft Magnetic Composite (SMC). The comparison of the load characteristics of SMC induction motor and conventional induction motor is shown. As the result, efficiency difference between SMC motor and conventional laminated motor is only 3.7% in spite of the permeability of SMC is 20% lower than conventional laminated steel iron

Keywords: AC motor, rare earth material, motor design

1. INTRODUCTION

The resource crisis of rare earth materials has broken out in motor industry in the world. The resource of rare earth material is uneven distributed in the globe. The exporting price of these materials is raising high and high strategically. Nowadays, many of electric motors use rare earth permanent magnet (PM) for the source of the magnetic field. The efficiency of PM motors is high even in the partial load condition or at the low speed operation. Moreover, the control of PM motors is simple because it is a synchronous motor.

Nd-Fe-B magnet is mainly used for the motor of small and medium class below 100kW. High efficiency and high power density can be easily realized by using Nd-Fe-B magnet as rotating field magnet. Almost all hybrid electric vehicles in the market use several kilograms of Nd-Fe-B magnet in their traction motor and generator.

Therefore, car industries and motor industries should consider about how to reduce rare-earth magnet and what is the alternative to the PM motors.

In this paper, one solution of rare-earth-less motor for traction will be presented. The motor is a novel induction motor. The induction motor uses iron core of Soft Magnetic Composite (SMC). SMC is compressed iron powder covered by insulation coating which is easy to form by press molding.

Recent advances of SMC materials can be realized motors made of SMC[1]-[3]. All motors proposed in the literatures are PM machines. Because the literatures say that the assistance of magnetic flux by permanent magnet is necessary to attain high performance of the motor[4]. They said that SMC is not suitable for electro magnet motor such as induction motor. The permeability of SMC is still lower than that of conventional electromagnetic steel. The comparison of magnetic flux density is shown in Fig. 1.

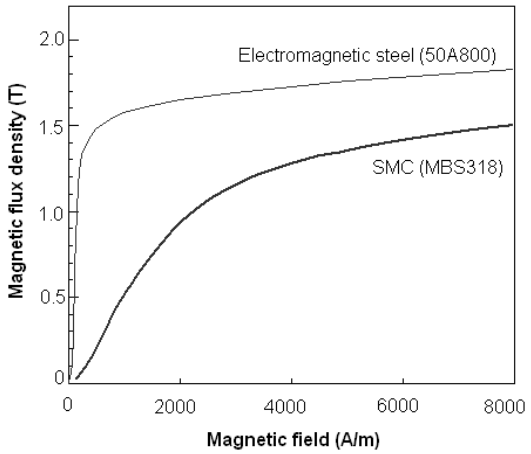


Fig. 1. Comparison of magnetic flux density.

After 1990th, the developing effort of the motor is mainly on PM motors Because almost all newly designed motor use high energy density, Nd-Fe-B magnet. New motor technology of design and manufacturing is applied only to PM motors. Therefore, an induction motor is going to be thought as the past technology. The author believes that the improvement can be realized by the application of new technology to the induction motor. One of new technology is the use of SMC. The use of SMC to the stator of the induction motor has been reported already [5]. This paper is

the first report of The rotor of induction motor made of SMC.

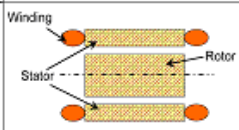
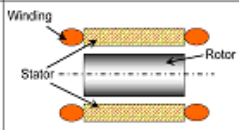
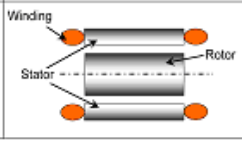
In this paper, the experimental comparison of SMC induction motors and conventional laminated steel iron induction motor will be described.

2. INDUCTION MOTOR MANUFACTURED BY SMC

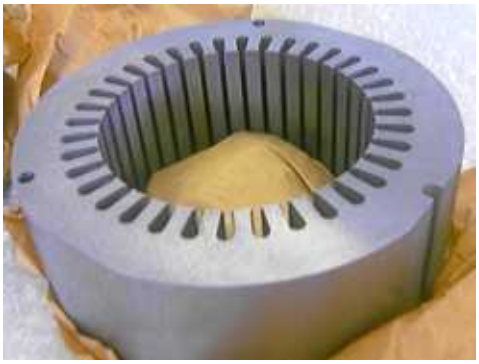
We manufactured three kinds of induction motors experimentally. One is a conventional electromagnetic steel motor. The others are SMC motors. One of the SMC motor uses SMC for stator omly[5], while the other SMC motor uses SMC for stator and rotor. The SMC material used for these motors is MBS318 manufactured by Mitsubishi Materials Corporation.

The material components of these motors are shown in Table 1. The rated output is 750 W. The stator of these motors have same core dimensions and same windings configuration. For motor S and C, the same rotors made of laminated iron is used. The rotor conductor is die-cast Al cage. For motor A, which rotor core is made of SMC, cage conductor is made of soldered copper. Because the heat at Aluminum die-casting will destroy the insulation of SMC powder.

Table 1. Material components of motor.

	Structure	Stator	Rotor
SMC motor (A)		SMC	SMC
SMC motor (S)		SMC	Laminated iron
Conventional (C)		Laminated iron	Laminated iron

Picture of the stator and rotor made of SMC are shown in Fig. 2. Two rotors are shown in Fig.3. Laminated die-cast rotor is shown in (a), and SMC with copper conductor is shown in (b).



(a) stator core made of SMC

(b) rotor core made of SMC

Fig. 2. Picture of the stator core manufactured by SMC.

(a) Laminated iron and aluminum conductor

(b) SMC and copper conductor

Fig.3. Pictures of rotor core.

3. Equivalent Circuit Parameter of the Motors.

At first, the equivalent circuit parameters of these motors are measured. Fig. 4 shows the equivalent circuit of an induction motor. The measured circuit parameter is shown in Table 2.

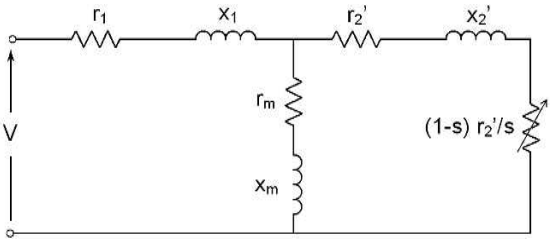


Fig.4 Equivalent circuit of an induction motor

Table 2 Measured equivalent circuit parameter at 50Hz

	All SMC motor	Stator SMC motor	Conventional motor
r_1 (Ω)	2.71	2.69	3.07
x_1 (Ω)	1.84	2.13	2.18
r_2' (Ω)	2.21	2.03	1.98
x_2' (Ω)	1.84	2.13	2.18
r_m (Ω)	2.57	3.12	2.54
x_m (Ω)	26.8	31.3	44.9

The difference of the equivalent circuit parameter should be only at the excitation circuit, because the shape of slots and the number of windings are same. Excitation inductance, X_m, of motor A and S is low, because the permeability of SMC is 20% lower than conventional steel iron at same number of turns of the winding as shown in equation (1),

$$X \propto \mu N^2 \quad (1)$$

where, X: reactance, μ : permeability, N: number of winding.

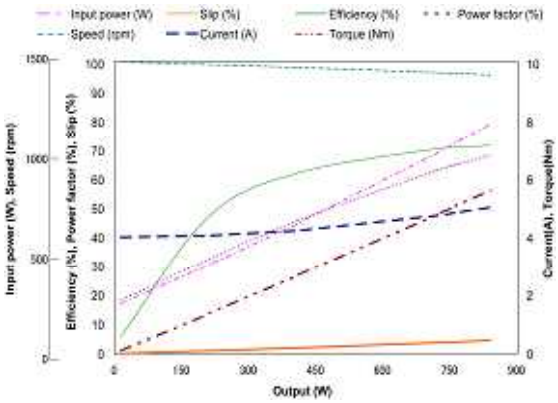
4. EXPERIMENTAL RESULT

4.1 Comparison of Motor Characteristics at 200V

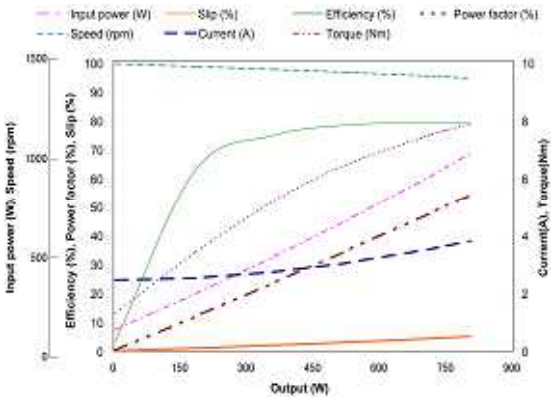
The rating voltage of conventional motor is 200V. Calculated characteristics at 200V using measured equivalent circuit parameter of conventional motor and all SMC motor are shown in Fig. 5.

At the rated output, the current and the input power of SMC motors are larger than conventional motor. Efficiency and power factor of SMC motors are lower.

At no load, the current and the input power of SMC motors are larger than conventional motor. The comparison result expresses that the winding design of SMC motor is not adequate at 200V. SMC motor is thought at the over excitation condition.



(a) All SMC motor



(b) Conventional motor

Figure 5 Calculated characteristics at 200V

4.2 Determination of the Optimum Voltage of SMC Motor

Generally, in the case of over excitation, number of winding will be re-designed. However, the purpose of the study is to know the effect of material difference. Therefore, we reduced applied voltage to the optimum voltage in order to equalize the excitation condition. To determine the optimum voltage of SMC motors, the terminal voltage has varied by the experiment. The optimum voltage here is defined as the lowest current and the highest efficiency at the rated torque (4.8Nm). Fig. 6 shows the experimental result.

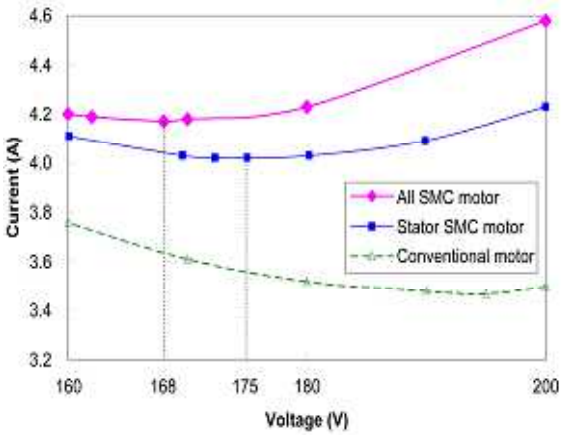


Figure 6 Result of confirmation voltage examination.

The voltage which shows the lowest current in this measured data is 168V for all SMC motor, A, 175V for stator SMC motor, S, and 200V for conventional motor, C. As the result, we decided that these voltages are the optimum voltage for the experimental SMC motors.

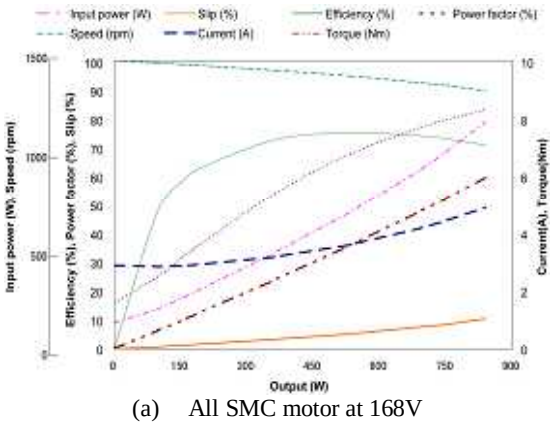
4.3 Performance of SMC Motor at the Optimum Voltage

The result of the load characteristics of three motors at optimum voltages are shown in Table 3 and Fig. 7. Comparison of maximum output at optimum voltage is shown in Table 4.

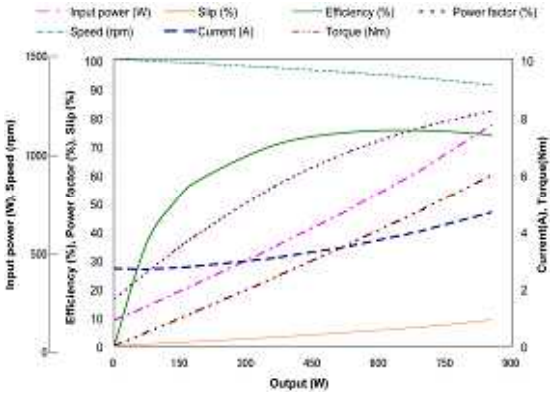
Table 3 Comparison of characteristics at rated torque.

	All SMC motor	Stator SMC motor	Conventional motor
Voltage (V)	168	175	200
Torque (Nm)	4.8	4.8	4.8
Current (A)	4.2	4.0	3.5
Input power (W)	932	931	916
Output (W)	693	700	722
Efficiency (%)	74.3	75.2	78.9
Power factor (%)	76.3	76.8	75.5
Speed (rpm)	1386	1400	1428
Slip (%)	7.6	6.7	4.8

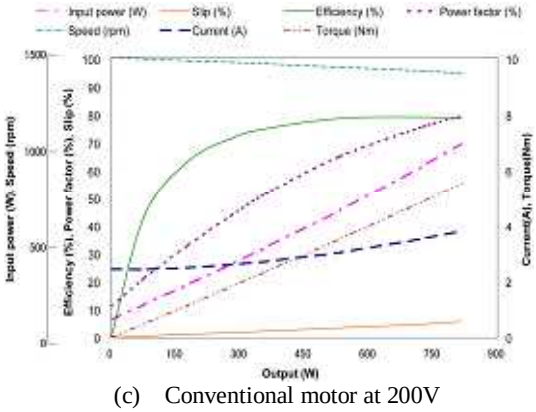
From Table 3 and Fig.7, conventional motor is the most efficient, and, all SMC motor shows the lowest efficiency. Vice versa, the slip at rated torque of all SMA motor is the largest and that of conventional is the lowest. The difference of the slip is come from the difference of voltage. Therefore, maximum output of all SMC motor is low as shown in Table 4 because of low voltage.



(a) All SMC motor at 168V



(b) Stator SMC motor at 175V



(c) Conventional motor at 200V

Fig. 7. Measured load characteristics at optimum voltage.

Table 4 Comparison of maximum output power

	All SMC motor	Stator SMC motor	Conventional motor
Voltage (V)	168	175	200
Output (W)	1089	1149	1400

Fig.8 shows the comparison of efficiency. The efficiency curves of all motors are very similar. And the efficiency of all SMC motor and Stator SMC motor is almost same. This result shows that

laminated rotor can be used with SMC stator. If we use SMC for rotor core material, the die casting of aluminum conductor can not be used for manufacturing the rotor because of the temperature. As a result, the difference of efficiency is only 3.7% even the permeability of SMC is 20% low.

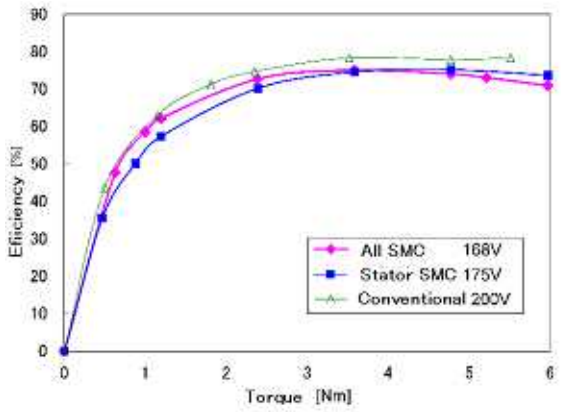


Figure 8 Comparison of efficiency.

4.4 Comparison of SMC Motors and the Conventional Motor

The loss analysis of three motors at no-load condition is shown in Fig. 8. The difference of copper loss for each motor is come from the difference of excitation reactance x_m . Small reactance of SMC motor leads large line current at no-load condition. The difference of mechanical loss comes from bearing alignment at the assembly of the test machine.

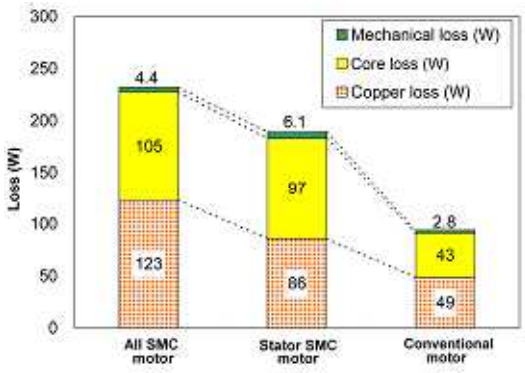


Fig. 8. Comparison of losses at no load test

The difference of core loss comes from the difference of the stator core materials. Therefore, the difference of core loss between SMC motor and conventional laminated steel motor is come from only the core loss of each material.

5. CONCLUSION

In this paper, the induction motor made of SMC core for the stator is described. The characteristics of the test machine are compared. SMC motor at 175V and conventional motor at 200V are very similar characteristics. As the result, the difference of the efficiency between SMC motor and conventional motor is only 3.7%. The induction motor made of SMC has much performance to offset that the permeability is 20% lower than the conventional electromagnetic steel.

The use of SMC to the rotor of an induction motor has a lot of difficulties, such as the efficiency, manufacturing and mechanical strength.

REFERENCES

[1] Y. G. Guo, J. G. Zhu, P. A. Watterson and W. Wu, “Comparative Study of 3-D Flux Electrical Machines With Soft Magnetic Composite Cores”, *IEEE Transactions on Industry Applications*, Vol. 39, No. 6, November / December, 2003.

[2] A. Jack, B. Mecrow, P. Dickinson, D. Stephenson, J. Burdess, N. Fawcett and J. Evans, “Permanent-Magnet Machines with Powdered Iron Cores and Prepressed Windings”, *IEEE Transactions on Industry Applications*, Vol. 36, No. 4, July / August, 2000.

[3] HUANG Yunkai, HU Qiansheng, ZHU Jianguo, GUO Youguang, LIN Zhiwei, “Design and Analysis of a High-Speed Claw Pole Motor With Soft Magnetic Composite Core”, *IEEE Transaction on Magnetics*, Vol.43, No.6, Page.2492-2494 (2007).

[4] H. Amano, Y. Enomoto, M. Ito, R. Masaki, M. Matsuzawa and M. Mita, “Characteristics of a Permanent-Magnet Synchronous Motor with a Dual-Molding Permanent-Magnet Rotor”, *IEEE Power Engineering Society General Meeting*, 2007.

[5] T. Fukuda and M.Morimoto, “Load Characteristics of Induction Motor Made of Soft Magnetic Composite (SMC)", *Proc. of International Conference on Electric Machines and Systems 2008*, CMP-02(2008).

Author

Masayuki Morimoto was born in Tokyo, Japan. He received the B.S., M.S., and Ph.D. degrees all in electrical engineering from Keio University, Yokohama, Japan in 1975, 1977 and 1990, respectively.
From 1977 to 2005, He was with Mitsubishi Heavy Industries, Ltd., where he has been involved in research and development of power electronics and electric machinery. From 1994 to 2004, he was also a Lecturer of the Department of Electrical and Computer Engineering at Nagoya Institute of Technology. From April 2005, he has been a professor of the Department of Electrical and Electronic Engineering at Tokai University. His current research interests are in the area of electric motors, power electronics and vehicle application.

Dr. Morimoto is a member of the Institute of Electrical and Electronic Engineers (IEEE), senior member of the Institute of Electrical Engineers of Japan (IEEJ), Magnetics Society of Japan (MSJ), the Institute Electrical Installation of Japan (IEIJ), and the Society of Instrument and Control Engineers (SICE).