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- Research group Applied Electromagnetics, Faculty of Electrical Engineering and Computer Science, Maribor, Slovenia
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ORAL SESSION:
MAGNETIC MATERIALS MODELLING 1 (MMM-1 [9.00-11.00]
Chairman: Prof. J.K. Sykulski

POSTER SESSION:
MAGNETIC MATERIALS MODELLING 2 (MMM-2) [9.00-11.00]
Chairman: Prof. L. Antunes

CHARACTERISTIC COMPARISONS BETWEEN IRON POWDER MATERIALS AND LAMINATION CORES IN BRUSHLESS MOTORS

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Abstract *– Magnetic materials are used for all kinds of electromagnetic energy-conversion devices to improve the capability of magnetic circuit. Iron Powder Materials are recently received much attention in the electric machine aplications due to their advantages over lamination steels, such as low iron losses and large fill factor. This paper describes an BLDC motor with iron powder materials and its perfomances are compare with the Iron Powder Materials and lamination core in BLDC motor.*

Introduction

Magnetic materials are used for all kinds of electromagnetic energy-conversion devices to improve the capability of magnetic circuit. Most recently, iron powder materials in new magnetic materials have been developed and electric machine designers have an interesting in applying these materials to electric machines [1]. The iron powder materials allows improvements over the lamination core with the respects of design freedom, low manufacturing cost, simple manufacturing processes, and low eddy current losses [1-2].

In this paper, the effects of magnetic properties of iron powder are investigated in the machine performances point of view in order to evaluate the application possibility and appropriate design of BLDC motors. Two different typed 300W rated BLDC motors, such as one is iron power and the other is lamination core, are designed and manufactured to test of their properties and the comparative analysis has been performed. Moreover, practical use of tooth shape in the iron powder BLDC motor is additionally suggested to maximize the effects of end winding in the motor.

Description of the compressed iron powder material

An iron powder, Höganäs manufactured Somaloy 500, is used to produce the Soft Magnetic Composite (SMC). The iron powder materials are confessed iron powder particles insulated form each other epoxy resin and iron flakes. The magnetic properties of iron powder materials depend on shape, size content, and property of the powder particles. These iron powder materials, which are highly pure and highly compressible, ensure good soft magnetic properties. Most of all, an excellent insulation between the particles and a smaller particles size are required to reduce eddy-current losses at the higher frequency applications [1-3].

In this application, the typical particle size that is 212 micron is applied. The particles are high iron content of 99.5(%) with thin insulation layers. Moreover, the particles larger than 150 micron occupy 10 (%) and the one less then 45 micron does 20 (%) of the used metal powders. Table I shows the size of the SMC materials according to a heat treatment and pressing pressure. And Fig. 1 and Fig. 2 show exprememental results of the SMC materials according to a heat treatment and pressing pressure.

Table 1. Size of the SMC materials according to a heat treatment and pressing pressure.

Density (g/cm^3)	Lindberg 275°C/60min, Air				Lindberg 530°C/30min, Air			
	HT (*mm*)		WT (*mm*)		HT (*mm*)		WT (*mm*)	
	Before heat treatment	After heat treatment	Before heat treatment	After heat treatment	Before heat treatment	After heat treatment	Before heat treatment	After heat treatment
6.72 ~ 6.74	7.962	7.972	21.169	21.148	8.010	8.023	21.247	21.159
	7.985	7.998	21.212	21.195	8.024	8.022	21.263	21.175
6.78 ~ 6.85	7.967	7.985	21.535	21.513	8.012	8.016	21.446	21.363
	8.005	8.006	21.414	21.405	8.062	8.068	21.617	21.535
7.17	8.005	-	22.655	22.617	8.014	7.988	22.654	22.547
	7.959	-	22.514	22.475	7.959	7.944	22.496	22.394
7.19	8.004	-	22.701	22.661	7.964	7.963	22.589	22.488
	7.946	-	22.525	22.489	7.947	7.93	22.535	22.435
7.23	7.989	-	22.782	22.747	8.024	8.028	22.905	22.797
	7.950	-	22.683	22.647	7.948	7.963	22.687	22.584

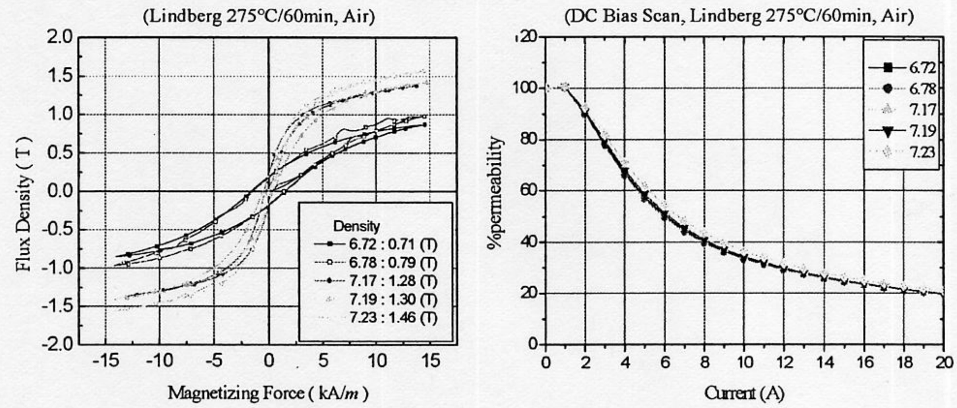


Fig. 1. Hysteresis (Magnetization) curve and Permeability according to and pressing pressure at 275 (°C).

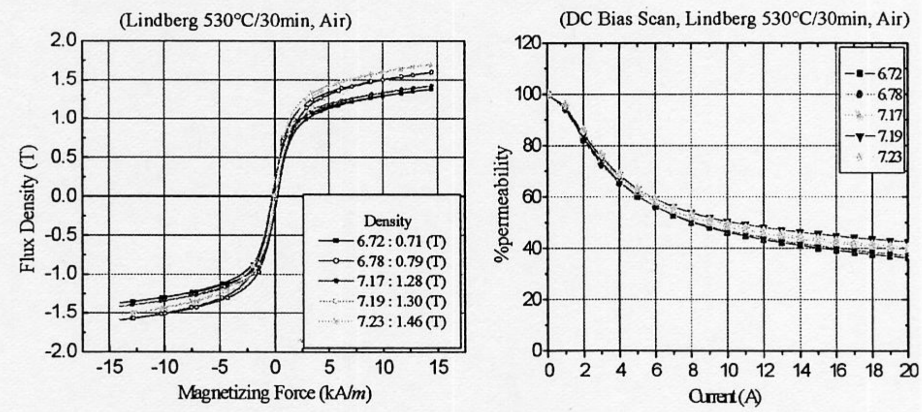


Fig. 2. Hysteresis (Magnetization) curve and Permeability according to and pressing pressure at 530 (°C).

Description of the compressed iron powder material

The applied machine is a 300W BLDC motor, and its stator has 12 slots and the rotor is built of 8 poles of radial magnetic, Ferrite magnet. In order to compare of the iron powder BLDC motor with lamination core one, two BLDC motors are applied in examin iron powder motor of the same dimension as previously designed lamination core one. Fig. 3 shows the design specification of the applied BLDC motor and the summarized procedure of its initial design.

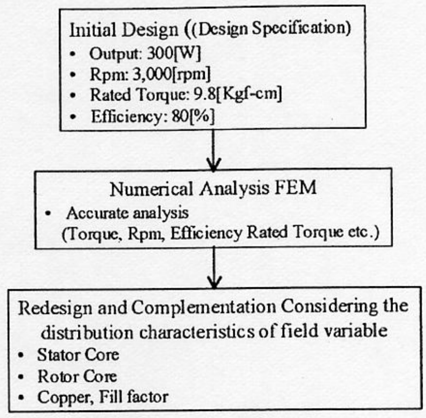


Fig. 3. Flow chart describing design of BLDC motor.

Field computation method

The magnet field within the motor is computed using the two-dimensional finite element method (2-D FEM). The analysis domain comprises an eighth model of the whole motor and periodic conditions are used as boundary conditions of analysis model. The Maxwell stress tensor is used for a resultant forces and torque calculations. Beside many advantages of the iron powder materials, it has a disadvantage of low permeability. This low permeability causes output power density to be reduced, therefore, an overhang, which covers the end winding and is shown in Fig. 4, is proposed to use the leakage component of the end winding to effective components in this paper. To analyze the effect of the overhang, 3D-EMCN [4] is introduced in this paper and its basic concept is illustrated as following.

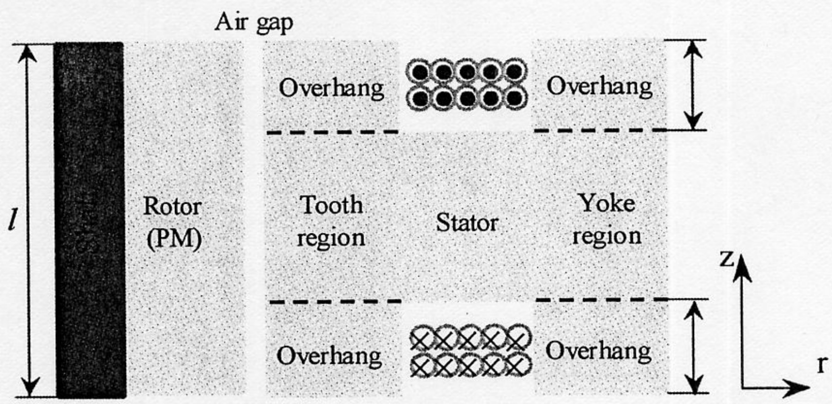


Fig. 4. Flow chart describing design of BLDC motor.

3D-EMCN is a numerical analysis method that can allow modeling of a machine in detail. Each region of the machine is divided into elementary volumes (elements) of hexahedral shape, and then 3-D equivalent magnetic circuit network is built by connecting the centroids (nodes) of adjacent elements with adjacent element's permeance.

In EMCN, Flux flow into the node (*i,j,k*) included in the source region, and the fundamental *r*-directional node equation between node (*i,j,k*) and node (*i,j-1,k*) can be described by using magnetic scalar potential [4].

$$\Phi^r_{i,j-1,k} = P^r_{i,j-1,k}\left(U_{i,j-1,k} - U_{i,j,k} + E_{i,j-1,k}\right) \tag{1}$$

$$B^r_{i,j-1,k} = \Phi^r_{i,j-1,k} / S^r_{i,j-1,k} \tag{2}$$

$$E_{i,j,k} = NI/\,m \tag{3}$$

$$= \frac{M\{\theta(i,j,j)\}}{\mu_0\mu_r} r_{i,j,k} \tag{4}$$

where $F^r_{i,j-1,k}$ is magnetic flux, $B^r_{i,j-1,k}$ is magnetic flux density, $P^r_{i,j-1,k}$ is permeance, $E_{i,j-1,k}$ is magneto-motive force of permanent magnet and stator current and $r_{i,j,k}$ is the magnetization depth of permanent magnet between nodes (*i,j,k*) and (*i,j-1,k*). $U_{i,j,k}$ is unknown magnetic scalar potential and $M\{\theta(i,j,k)\}$ is magnetization of permanent magnet at node (*i,j-1,k*). *N* is turn and *m* is element number of the teeth region in the *r* direction.

Magnetic flux continuity condition in applied at node (i, j, k) as following:

$$\sum_{p=r,\theta,z} \ \sum_{q=i,j,k} \Phi^p_q = 0 \tag{5}$$

At node (*i,j,k*), the node equation is calculated by substituting (1) through (4) into (5). After calculation all nodes by applying the node equation, the system matrix equation is following:

$$[\mathbf{P}]\{\mathbf{U}\} = \{\mathbf{F}\} \tag{6}$$

Result and discussion

Two different types of 300W BLDC motors are constructed in order to compare the characteristics. Fig. 5 shows teeth, which is made from the iron powder composite, their assembling stator, and lamination core stator. The stators are commonly composed of 18 slots and the rotor has 8 poles of radial ferrite magnet.

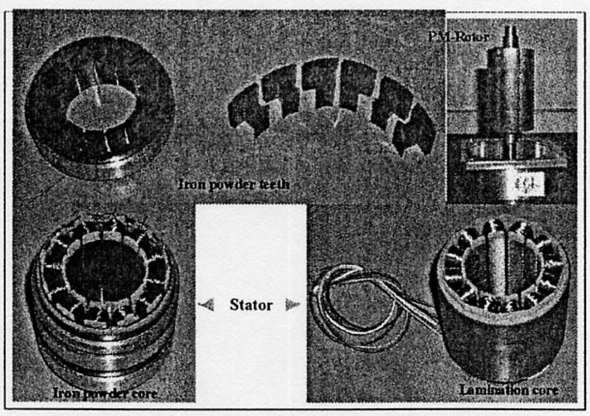
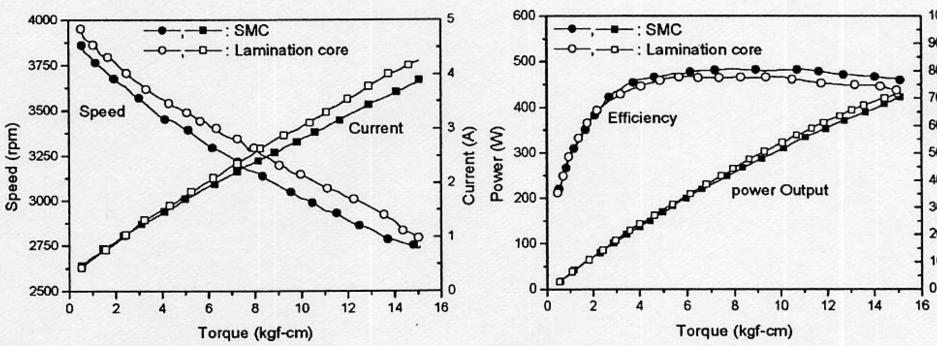


Fig. 5. Prototype of two BLDC motors.

Fig. 6 shows the experimental results of two BLDC motors. From the results, it is shown that as the torque increases, the motor with lamination core requires higher input current than the case of iron powder core. At the rated speed, the output power of the lamination core motor is 20% higher than the iron powder material motor. However, the iron powder material motor has better characteristic with the respect of efficiency than lamination core becuase of increasing the input current. A tooth segment, which has the overhang to cover the stator winding, is shown in Fig. 7. In order to dtermine the overhang lengh, 3D-EMCN is used to calculate the rated torque of the motor. Tables 2 shows the results of 3D-EMCN analysis according to overhang lengths. The various overhang lengths are investigated to satisfy the rated torque of lamination BLDC motor, which has 69 (mm) stack length. In this paper, the proper overhang length is selected as the 5.5 (mm) overhang length with 71 (mm) stack length of the motor.

Conclusion

In order to apply the iron powder materials in BLDC motors, two different type BLDC motors with the same dimensions are investigated. One is made from the iron powder and the other is produced with lamination core. From experimental results, the torque performance of the lamination core motor is 20% higher than the iron powder material motor on the whole.



(a) Curve of Speed and Current (b) Curve of efficiency and power

Fig. 6. Experimental results about the SMC Motor and Lamination core motor.

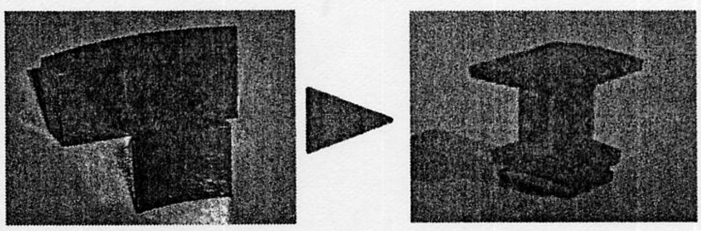


Fig. 7. Flow chart describing design of BLDC motor.

Table 2. Result of 3D Equivalent Magnetic Circuit Network (EMCN).

Stack length	Lamination core (S18)	Soft magnet composite	Overhang Length
69 (mm)	9.88 (kgf-cm)	9.11 (kgf-cm)	No overhang
69 (mm)	-	10.89 (kgf-cm)	9 (mm)
79 (mm)	-	12.36 (kgf-cm)	9 (mm)
71 (mm)	-	10.64 (kgf-cm)	5.5 (mm)

Therefore, to improve the performance of the iron powder BLDC motor over the lamination core motor, the shape of the tooth of the iron powder BLDC is introduced and it may be valuable to use its flux leakage of end winding. Additionally, the examinations of their eddy current losses and hysteresis losses according to frequency performances are required and the method of the experiment and analysis is now on the process.

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