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A New Motor Topology for High Performance Applications Using SMC Materials

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Abstract—**This paper presents a new type of axial flux motor, the Yokeless And Segmented Armature (YASA) topology. The YASA motor has no stator yoke, a high fill factor and short end windings which all increase torque density and efficiency of the machine. Thus, the topology is highly suited for high performance applications. The LIFEcar project is aimed at producing the world's first hydrogen sports car, and the first YASA motors have been developed specifically for the vehicle. The stator segments have been made using powdered iron material which enables the machine to be run up to an electrical frequency of 300Hz. Two different SMC materials are considered for the stator iron: Somaloy 3P and Somaloy 3P HR. It is shown that by using the higher resistivity material, Somaloy 3P HR, the stator eddy currents are significantly reduced, increasing the motor efficiency.**

I. Introduction

The Yokeless And Segmented Armature (YASA) topology is a new type of topology motor which has no stator yoke and a segmented armature. The axial flux YASA machine shows a step change improvement in torque density and efficiency when compared to other axial flux motors. The topology is based around a series of magnetically separated segments that form the stator of the machine. The novel motor design is made possible by using powdered iron materials [1] that enable complex magnetic parts to be manufactured easily.

The motors have been developed for the LIFEcar project whose aim is to produce the world's first hydrogen sports car. The specific goals of the project are to create a "fun to drive" vehicle without compromising on efficiency. The specification for the LIFEcar project is four 300V drives that produce a peak torque of 360Nm and a top rotational speed of 1200 rpm. A 3:1 gearbox is being used on the output of each motor, so the peak toque and speed demand of the motors is 120Nm and 3600rpm. These specifications have been chosen to enable the vehicle to have impressive acceleration and regenerative breaking capabilities.

This paper presents the design of the LIFEcar YASA machine. The SMP core material is a key part of the machine design, and the relative merits of Somaloy 3P and Somaloy 3P HR are discussed for use in the stator core.

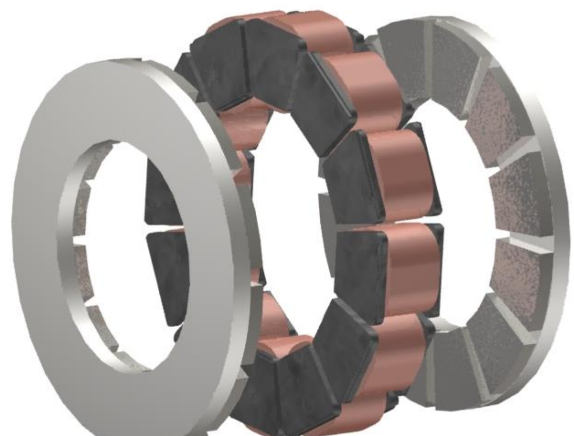


Fig. 1. The axial flux YASA Topology

II. The LIFEcar Machine

A. YASA Machine Design

The stator of the YASA motor is made by pressing Soft Magnetic Composite (SMC) materials [1], produced by Höganäs. The stator iron shown in Fig. 1 was manufactured in 3 parts: 2 shoes and central bar. The parts were bonded together and wound.

The static design of the LIFEcar motor was undertaken using firstly sizing equations, and then refined using static FEA. The FEA showed that an outer diameter of 204mm was required to give 120Nm of torque. K_r (the ratio of outer to inner diameter) has been chosen as 2/3 [2] so the inner diameter is 136mm. A list of the electrical machine parameters are shown in Table 1.

Fig. 2 shows the flux densities within the motor during no load conditions. The no load air gap flux density is just over 1T, which has been achieved by using large NdFeB magnets.

The motor bars have been designed to carry a no load flux of 1.5T. At peak load the flux density within the bars increases to 1.8T.

TABLE I
LIFECAR MACHINE PARAMETERS

Machine Parameter	Symbol	Value	Unit
Number of Poles	p	10	
Number of Stator segments	N_{seg}	12	
Number of Phases	Q	6	
Phase resistance (50)	R	54	mΩ
Inductance	L	0.6	mH
Turns per segment	ns	37	
Conductor Width	w	2.2	mm
Conductor Height	h	2.2	mm
Outer Radius	R_o	102	mm
Inner Radius	R_i	66	mm
Shoe Length	L_{shoe}	5	mm
Bar Length	L_{bar}	30	mm
Active Length	L_{active}	79	mm
Airgap length	L_g	1.5	mm
Permanent Magnet Length	L_m	10	mm
Peak Current Density	J	16	A/mm^2
Active material weight		12	Kg
Peak Efficiency	η	>95	

B. Stator Core Losses – Static Analysis

The static analysis can be used to calculate the magnetic hysteresis losses using a combination of simulation results and information about the materials from the manufacturer. The hysteresis losses in the stator are directly proportional to the speed of the motor and weakly coupled to motor torque. The loss data for Somaloy 3P and Somaloy 3P HR, Fig. 3(a), have been extrapolated using the least squares method so that the hysteresis loss can be accurately predicted for the shoes and bars in the machine under different loading conditions.

Fig. 3(b) shows the sensitivity of the SMC hysteresis losses to motor load and speed. It can also be seen in Fig. 3(b) that Somaloy 3P HR has approximately 10% higher hysteresis losses than the Somaloy 3P material. As the loading of the motor is increased, the armature current increases the peak flux in the stator iron. This results in the peak loading condition having a 40% increase in hysteresis losses compared to the no load condition.

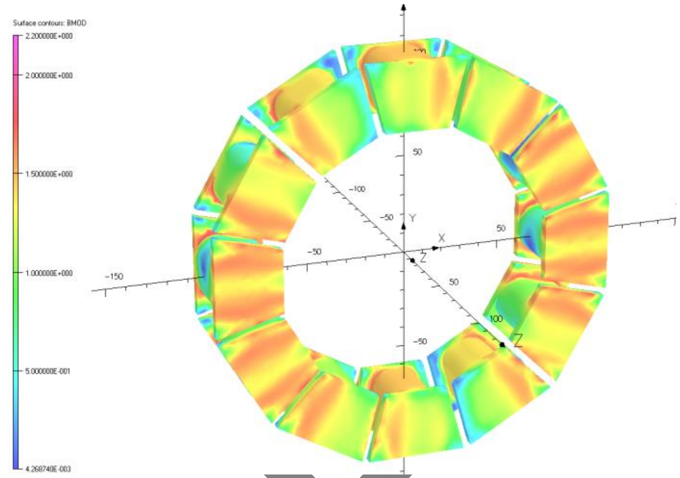
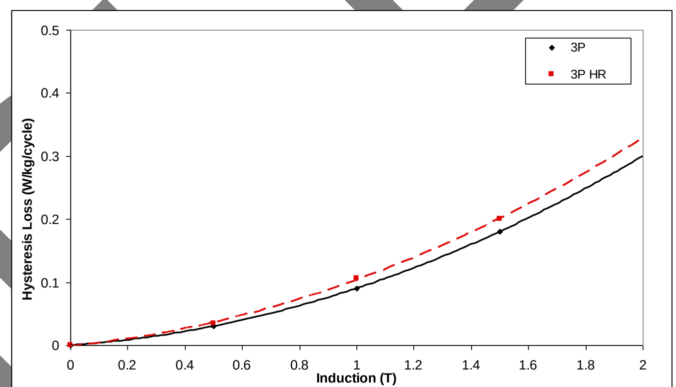
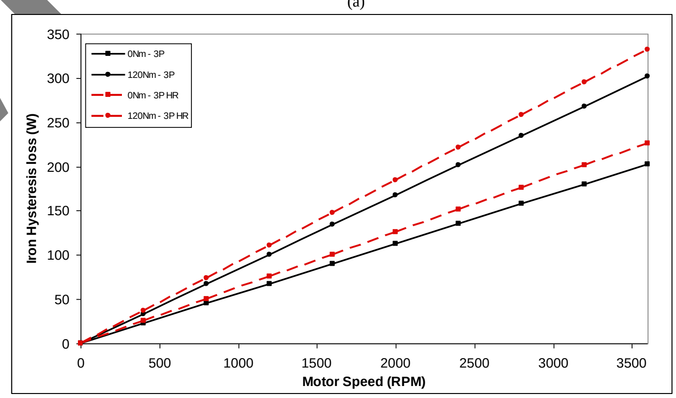


Fig. 2. Flux densities within the YASA under no load



(a)



(b)

Fig. 3. (a) Loss in Somaloy 3P and 3P HR/kg at 1 Hz as a function of flux density, (b) Hysteresis losses in the stator iron

C. Stator Eddy Currents

To calculate the eddy current losses accurately within the electrical machine a time stepping finite element method is required. The Carmen solver, part of the Opera 3D finite element package [3] has been used to achieved this. Stator eddy currents are produced by time varying magnetic fields from the rotor inducing eddy currents in stationary conductors. The most significant eddy currents in the stator are those induced in the stator iron, since it observes the largest changing flux density.

The Somaloy 3P material has a relatively high electrical resistivity of 400μΩm. However, the Somaloy 3P HR material has been optimized for high resistance and has a resistivity of 2600μΩm – a factor of 6.5 times larger. The induced eddy currents in the shoes of the machine are shown in Fig. 4. The stator iron eddy current losses for the two Somaloy materials are shown in Fig. 5. Due to the large changing flux and geometry of the part, significant eddy current losses are induced in the Somaloy 3P material – over 190W at 3600 rpm. However, using the Somaloy 3P HR material, the stator eddy current losses are reduced to less than 30W.

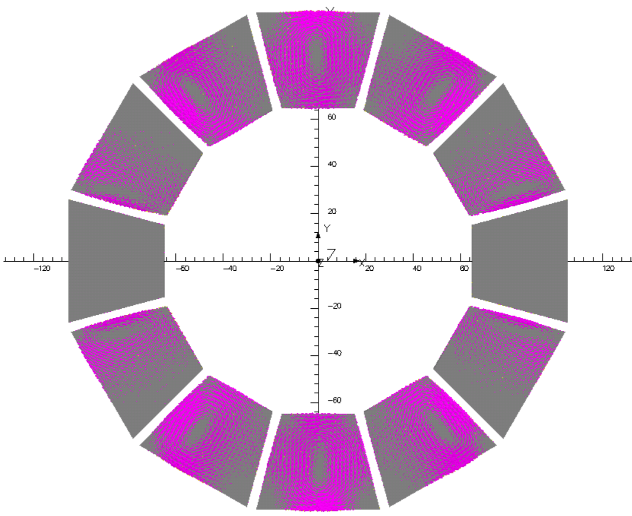


Fig. 4. Eddy current distribution in the shoes and of the stator at 3600 rpm

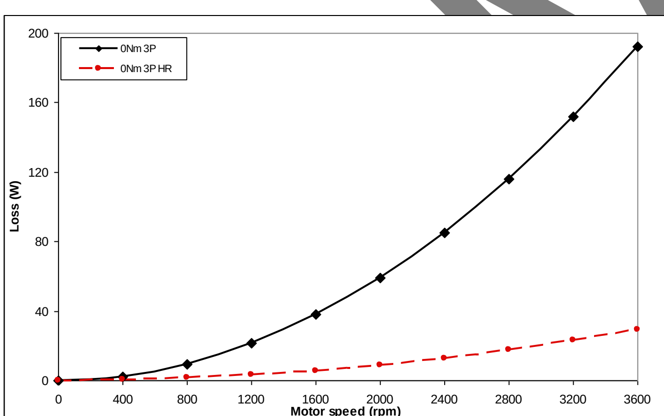


Fig. 5. Eddy current losses in the stator iron

D. *LIFEcar efficiency map*

The electromagnetic loss data presented in this section has been compiled to form an efficiency map, see Fig. 6, for both 3P and 3P HR material. Although the maps look similar, closer inspection reveals the increased efficiency of the machine when the 3P HR material is used, especially at high speed low torque. This condition is particularly important, since it represents the cruise condition of the vehicle. The 80mph cruising speed requires a motor power of 5kW per motor. This is achieved at 92% when the Somaloy 3P material is used, and 94% for the 3P HR material.

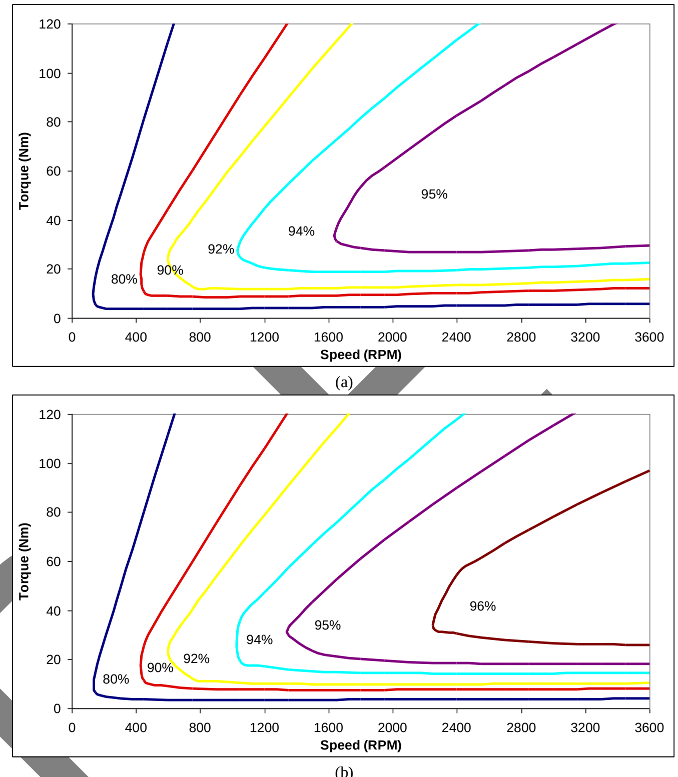


Fig. 6. Efficiency map of the YASA motor, (a) 3P and (b) 3P HR material

III. CONCLUSIONS

The YASA motor presented in this paper has been designed for the used in LIFEcar project. Two materials have been considered for the stator core material, Somaloy 3P and 3P HR. Analysis has shown that due to the high frequency and large dimensions of the stator segments significant eddy currents are induced in the stator when Somaloy 3P material is used. Thus, a significant performance improvement is made by using Somaloy 3P HR material which has been optimized for high resistivity. By using the 3P HR material, the cruise efficiency of the motor is increased from 92% to 94%, and the peak machine efficiency increased to over 96%.

ACKNOWLEDGEMENT

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REFERENCES

[1] http://www.hoganas.com accessed February 07

[2] Woolmer, T, and M. McCulloch, “Axial flux Permanent Magnet Machines: A new topology for high performance applications”, Hybrid Conference, Warwick, UK December 2006.

[3] http://www.vectorfields.com accessed February 07