Soft Magnetic Composites Used for the Iron Core of the Electrical Machines

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The electrical machines had a lot of benefits upon the developments made in the last years in the powder material industry. This statement is well proven by the coming out in the last two decades of the transverse flux machines (TFM). The iron core of most of these machines is built of soft magnetic composite (SMC), which allows three-dimensional flux paths. In this paper measurements of a SMC will be presented together with one of its possible applications, a novel transverse flux reluctance linear machine. The machine's performance will be estimated by magnetic field computations.

Keywords: soft magnetic composite, iron core, transverse flux machine, finite element field analysis.

1. Introduction

The magnetic circuits made of metal powder were first proposed for electrical machines at the end of the 19th century. But since then almost all of the electrical machines were built up of laminated sheets, due to their lower losses.

The return of powder materials used in electrical machines begun about 25 years, due to the improvements made in the field of powder metallurgy.

Soft magnetic composite materials are manufactured by powder metallurgy techniques from a pure iron powder in which the particles are insulated from each other using different dielectrics. Among the interesting attributes of these materials is the possibility to engineer their composition and processing to specifically meet application requirements. For instance, in the case of an iron-resin material system, the iron particle size may be varied as well as the amount of thermoset resin. In certain cases, a lubricant can be added, or even totally replace the resin in order to ease the pressing [1].

The soft magnetic powder composite materials from the point of the view of their applications in electrical machines have several advantages [2]. Their 3D isotropic properties permit complex three-dimensional magnetic flux paths within the machines. This allows for many new topologies for machines that could not be attempted with 2D laminations [3]. This way the designers are free to build electrical machines to suit its application, instead of restricting the application to the limitations of the motor construction possibilities. So new dimensions of performance and profitability for the electrical machines industry are opened up.

The heat transfer in electrical machines having SMC iron cores will often be superior, taking into account that also the thermal properties are 3D isotropic. The eddy current loss is much lower than that in laminated steels, especially at higher frequencies, and the hysteresis loss becomes the dominant. This property may allow electrical machines to operate at higher frequencies, resulting in reduced machine size and weight [4].

The flexibility of the powder metallurgy shaping process allows efficient production of complex shaped parts. The unique shaping opportunities open the way to smaller motors with cost advantages gained from lower winding volume, a higher fill factor and built-in assembly features.

As manufacturing material wastage is minimal (nearly 100% raw material utilisation can be achieved), reduced material costs can be achieved. Due to their good dimensional accuracy (tight tolerance) and smooth surface finish there is no need of extra final machining operations. The different core sections can be combined and fitted together with no unwanted magnetic effects and special insulation requirements. These give a high production rate, which reduces the overall production costs. The solid rather than a stack iron core give superior mechanical integrity. Also it must be mentioned that the electrical machines made of SMC cores are easily recyclable because the coil can be separated easily from the iron core.

Beside these advantages the use of SMC permits new design and production concepts. For example by applying SMC it is possible to co-compact together the core and coils (pressing coils with powder). Minimising the part numbers the manufacturing costs can be reduced. Generally it is recommended as to apply new designs rather to simply replace the laminated components [5].

The transverse flux machine has real three-dimensional magnetic flux paths, therefore they can be mostly built up by using such magnetic materials. Hence the developments in the field of SMC also catalysed the studies on transverse flux machines [6].

In the paper as an application of SMC a novel transverse flux electrical machine will be presented. The results of its magnetic field analyses performed by using finite elements method will be detailed. Finally some conclusions will be presented on the advantages of this type of transverse flux machine, respectively on the usefulness of using SMC for such applications.

2. Soft Magnetic Composites

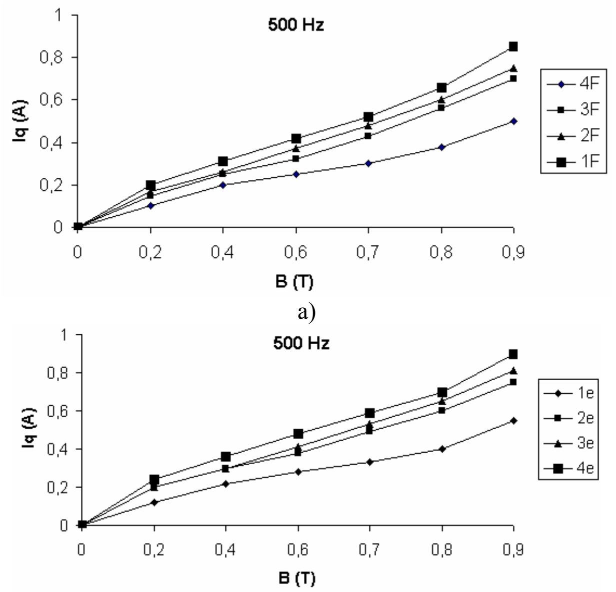
The basis for the soft magnetic composite material is the iron powder of high purity and compressibility. The powder particles are bonded with a coating of an organic material, which produces high electrical resistivity. The coated powder is then pressed into a solid material using a die and finally heat treated to anneal and cure the bond [7].

This type of material is in general magnetically isotropic due to its powdered nature and this opens up crucial design benefits. The magnetic circuits can be designed with three-dimensional (3D) flux path and radically different topologies can be exploited to obtain high motor performances, as the magnetic field restraints of lamination technology can be ignored [8].

Since the iron particles are insulated by the surface coating and adhesive, which is used for composite bonding, the eddy current loss is much lower than that in laminated steels, especially at higher frequencies. The total loss is dominated by hysteresis loss, which is higher than that of laminated steels due to the particle deformation during compaction.

In the laboratories of the Technical University of Cluj 8 SMC samples were analysed (named 1F, 2F, 3F, 4F, 1e, 2e, 3e and 4e), all of them have over 93% iron and less then 7% aluminium. The applied pressing force was between 450 and 700 kN.

The analysis was focused on gathering information on the dependence of the magnetising current and of the specific losses versus the flux density [9] . First in Fig. 1 the magnetising currents measured for the core samples in study at 500 Hz are given.



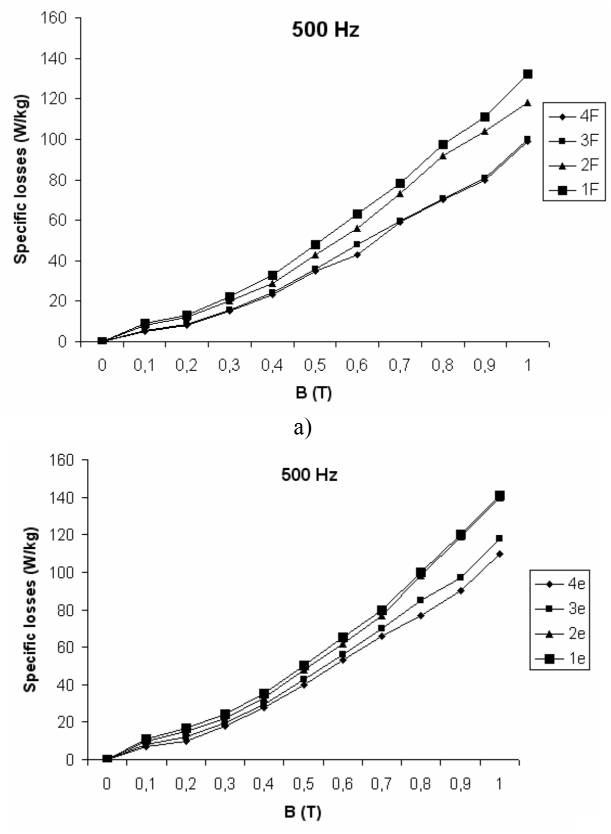
a)

b)

Fig. 1. The magnetizing current of the samples at 500 Hz

As it could be observed the best performance (the lowest magnetising current) was obtained for those samples which were obtained at the less pressing force [10].

In Fig. 2 the specific losses versus the flux density at 500 Hz are plotted.



a)

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Fig. 2. The specific losses of the samples at 500 Hz

Also in this case the best results were obtained for the same samples as in the above mentioned case.

Finally it was stated out that the sample 4F is the best fitted to be used for the core of the linear transverse flux machine to be discussed next.

3. Linear Transverse Flux Machine

The linear transverse flux machine in discussion was obtained by combining the modular structure of the double salient permanent magnet linear motor [11] with a linear variant of a transverse flux machine with permanent magnets on the stator and passive rotor [6].

The three-phase variant of the proposed linear motor is given in Fig. 3. The three modules variant was selected because of the easy implementation of the control strategy on general purpose three-phase power converters.

The working principle of the machine can be understood upon Fig. 4. When the module is passive the flux generated by the permanent magnet closes mostly inside the mover's iron core, which can be manufactured by thixoforming from the SMC previously presented [11]. When the command coil is energized, the magnetic flux produced by the winding practically enforces the flux of the permanent magnet through the air-gap, generating this way tangential and normal.

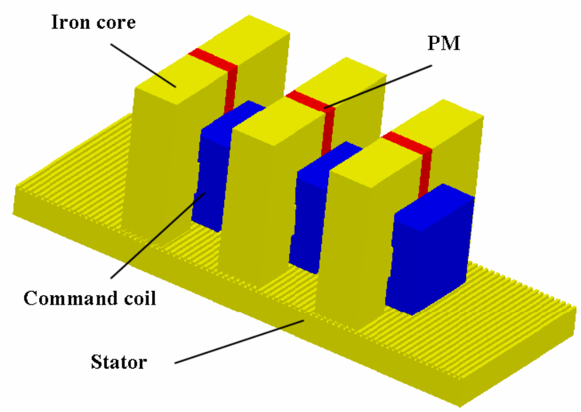

Fig. 3. The linear transverse flux machine

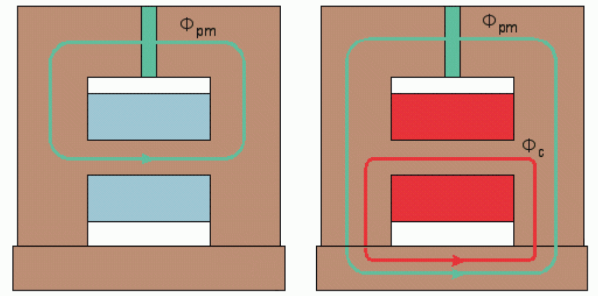

Fig. 4. The working principle of the machine

This machine is in fact a variable reluctance machine and hence its movement is possible only if the modules are shifted by a third of the teeth pitch. Energizing the command coil of one module its teeth will be aligned with the teeth of the platen. By sequential feeding of the command coils continuous linear movement of any direction can be assured [12].

The detailed design procedure of the linear transverse flux machine was presented previously [13].

Here only the main dimensions of the sample motor's modules are given. In Fig. 6 both the lateral and frontal view of a module is given.

4. 3D FEM Analysis of the Linear TFM

The designed modular linear TFM was analysed by means of field computations performed on the entire structure of the machine using a three-dimensional (3D) finite elements method based commercial program.

Two views of the linear TFM's model to be used are shown if Fig. 5.

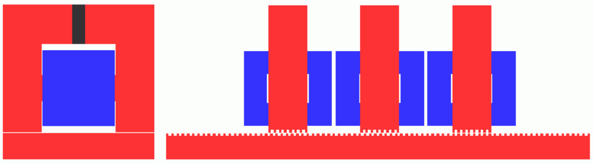

Fig. 5. The two views (the frontal and lateral one) of the model

The automatically generated 3D mesh is given in Fig. 6.

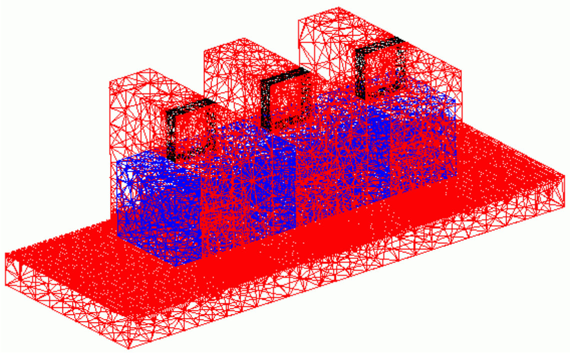

Fig. 6. The 3D mesh

From the numerous results obtained by using the FEM model here in Fig. 7 only the distribution of the flux density in the machine in the case when the command coil of the central module is only energised.

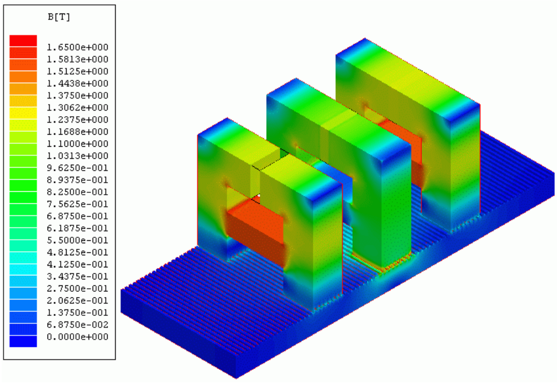

Fig. 7. The flux density distribution in the linear TFM

The results completely prove the working principle of the modular linear motors. The magnetic flux densities in the core branch on which the command coils are placed have high flux density because almost all the magnetic flux generated by permanent magnet passes thru them. The flux density in the core branch of the middle module is low, because due to the magnetic flux generated by the command coil the magnet's flux is forced to pass thru the air-gap. Thereby the flux densities are greater in the air-gap area under the middle module's poles.

Using the above presented 3D FEM model a study was performed on the effect of the core branch in the middle of the module on the tangential force developed by the motor. The obtained results are given in Fig. 9 and Fig. 9.

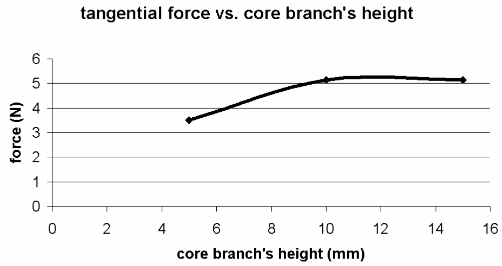

Fig. 8. The effect of the core branch's height on the generated tangential force

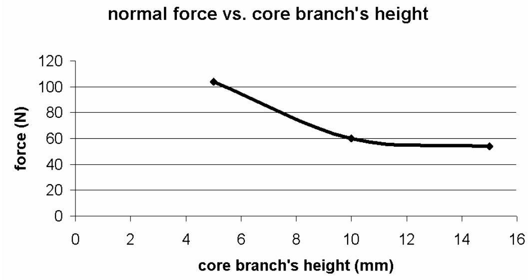

Fig. 9. The effect of the core branch's height on the generated normal force

As it can be seen in Fig. 9. by varying the height of the core branch placed under the permanent magnet of the module both the generated tangential and normal forces are modified. The best solution is to fix this core dimension to 10 mm because for this value the useful tangential force has its prescribed value of 5 N, and the unwanted attractive (normal) force between the two armatures is relatively small (only about 60 N).

5. Conclusions

The construction of the linear TFM presented in this paper is only possible by using the soft magnetic composites. Applying these advanced magnetic materials high performance electrical machines can be built up as that presented here.

The modular construction of the machine is easy to be manufactured and have relatively low production costs. This structure enables to easy adjust the motor's performances to the user's requirements without substantial changes in its basic structure. The machine is simple to control by unipolar current pulses.

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