MANUFACTURING TECHNOLOGIES OF THE LINEAR TRANSVERSE FLUX RELUCTANCE MACHINE

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Abstract ***– This paper deals with a few aspects concerning the construction of a linear transverse flux reluctance machine. The variants of linear transverse flux reluctance machines proposed until now by the authors at theoretical level were with and without permanent magnets. The constructed variant presented here is without permanent magnets. For its building two possibilities were taken into consideration. These aspects will be presented here, and conclusions regarding the best variant for the construction of the modules of such a machine will be drawn.***

Keywords: ***transverse flux machines, linear machines, manufacturing technologies***

I. INTRODUCTION

The linear transverse flux reluctance machine is a new presence in the class of linear machine [1]. Its structure was obtained as a combination between a TFM with passive rotor and a stator with permanent magnets on it and a hybrid linear stepper motor. The operating principle of the machine reveals the fact that the machine is a variable reluctance one. In order to obtain continuous movement the machine must be of modular type. The machine was designed in two basic variants: with or without permanent magnets on the mobile armature or mover. In both cases the immobile part of the machine (stator or platen) is passive. In the paper two possibilities to build the modules of this machine will be presented.

II. LINEAR TRANSVERSE FLUX RELUCTANCE MACHINES

As stated before, the machine is a variable reluctance one. Its construction is of modular type. The number of the modules is function of the tooth pitch and the desired positioning step. In order to obtain continuous movement in both ways, the number of the modules must be at least three. In Figure 1 the variant with three modules is presented. This was chosen because of the possibility to implement the control of the machine from a three-phased converter existing on the market.

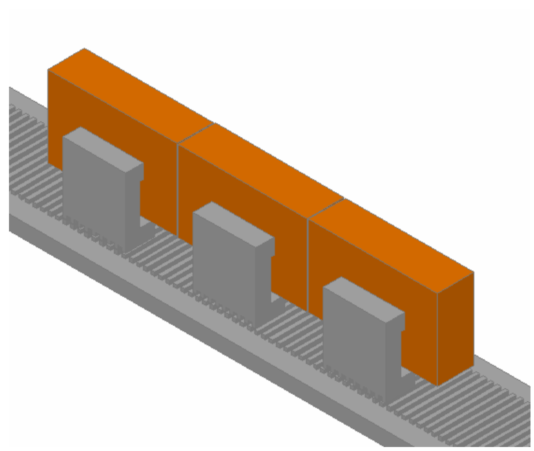

Fig. 1. The linear transverse flux reluctance machine.

To work properly the teeth of the modules have to be shifted from the stator ones by τ/N, where τ is the tooth pitch and N is the number of the modules. The step of the machine is given by the number of modules at a certain τ.

The construction of one module is very simple. It consists of a U-shapped pole on which is placed a coil. The winding used is a concentrated coil, similar to one of the transformer [2].

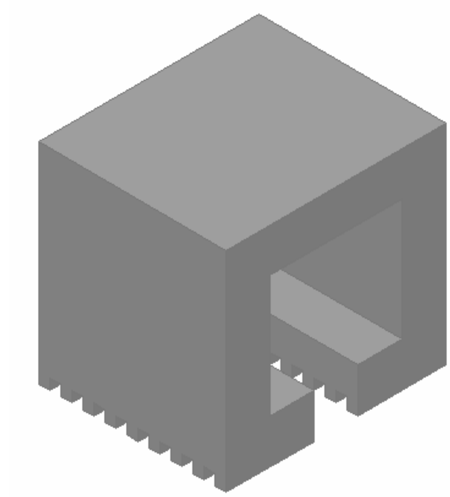

Fig. 2. The iron core of a module.

The working principle of the machine is quite simple. The tangential force is obtained only from a module. When supplying the coil of a module with the teeth unaligned with the stator ones, these will tend to align one with another and the machine will move in the desired way.

As the machine's construction is concerned, one of its most important advantages is that its iron core can be build of classical steel sheets, contrary the most variants of the TFMs having expensive Soft Magnetic Composite (SMC) cores, one of the most important shortcomings of this type of machine [3].

A design algorithm was performed specially for designing such machines. By its use several different machines had been designed.

The main dimensions of a single module of a machine's laboratory model are given in Fig. 5 [4].

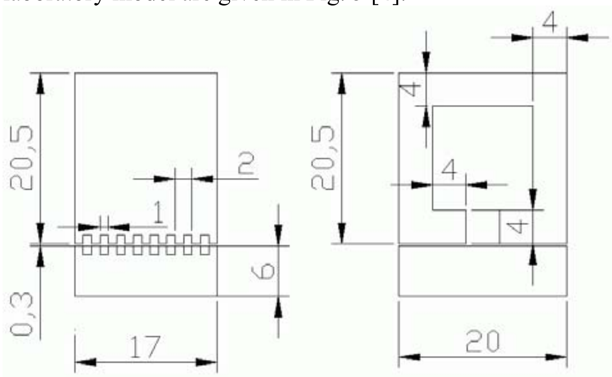

Fig. 3. Main sizes of module:
a) lateral view; b) frontal view.

III. CONSTRUCTION OF THE MACHINE

The machine has two parts: the stator, built as a toothed platen, and the modules of the mover. The easiest way to construct the stator is from solid iron.

For the modules there are two major possibilities. The first one is to use the classical steel sheets, one of the most important advantages of this machine. As it can be noted, one module has nine teeth and eight slots. In order to obtain such a module, a silicious tray with a 0.5 mm thickness was used. 18 pieces of 40 X 25 mm were needed.

In order to built a module with a length of 17 mm, a 34 steel sheets package was used. The endings consist of 2 pieces of 3 mm each. All these parts are assembled by using two M5 screws.

After compacting the whole structure, the final execution is done. By electrical erosion with a 13 X 12 copper stamp, the slot for the coil is cut from the middle of the package. After obtaining it, one can realize the alternance tooth – slot. The height of the slot is of 1 mm. The lateral parts of the package are cut next, hence resulting the next piece, with a height of 22 mm, thickness of 24 mm and the width of 37 mm. The active part, after final operations, is of 20 X 24 mm [5].

Another possibility to elaborate the magnetic iron cores of the modules is to use soft magnetic composites materials. The most representative material from this class, which was used at the most of the transverse flux machines built until now, is Somaloy 500, a product of Swedish company Hoganas. However, this is an expensive material, and the operations to follow in order to obtain it are not known yet. From this reason, various solutions were analyzed in order to obtain a new soft magnetic composites material [6].

The effects of the sinterization temperature and time are according to general norms and have as a result the improvement of the properties. In this particular case, this is obtained for ASC40+0.8% P, when the sinterization temperature is increased from 1120°C to 1250°C. The compressibility and the purity of the powder have a great influence on the magnetic properties.

Due to izotropic properties of the magnetic powders, the initial choice of the alloy should be oriented towards obtaining the minimum rezistivity accepted by the required application. Anyway, the rezistivity varies in the alloy system. As a concluzion, the phosphor increases the rezistivity of the alloy, regradless of the chosen alloy. This will alow the reduce of the eddy currents [C1].

For the construction of the modules' iron core, a powder composed of iron and phosphor was chosen. As binding material a zinc oxide was used. After homogenization the pressing was carried out, each piece in part being pressed with 150 tf (aproximately 630 MPa) on a mechanical press of 200 tf. The pressing was unidirectional with a stamp having Φ55 mm in the type mould. The pieces sinterization was done at 1250°C for two hours. After sinterization the pieces were mechanically worked out. One of the resulted iron cores was thermically threated, the other two weren't.

When rebaking the sample was heated for 400 minutes in two steps of 20 minutes each. The thermical treatment was done at 610° C, for two hours. The cooling was done for three hours in three steps of one hour each. Due to a superficial heating, the piece got a slight blue color [5].

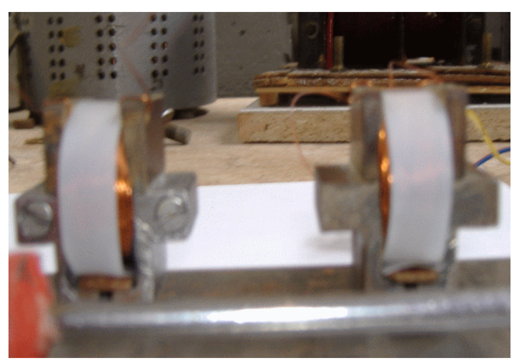

Fig 4. The difference between the two samples (those with steel sheets have M5 screws on lateral parts)

In Figure 5, a. and b., the structure of the module built from powders is presented. View of the lower part (toothed one) and uper part (where is placed the insulation of the coil) of the constructed module are captured. In Figure 6 the quotations of a module built of steel sheets are shown.

a)

b)

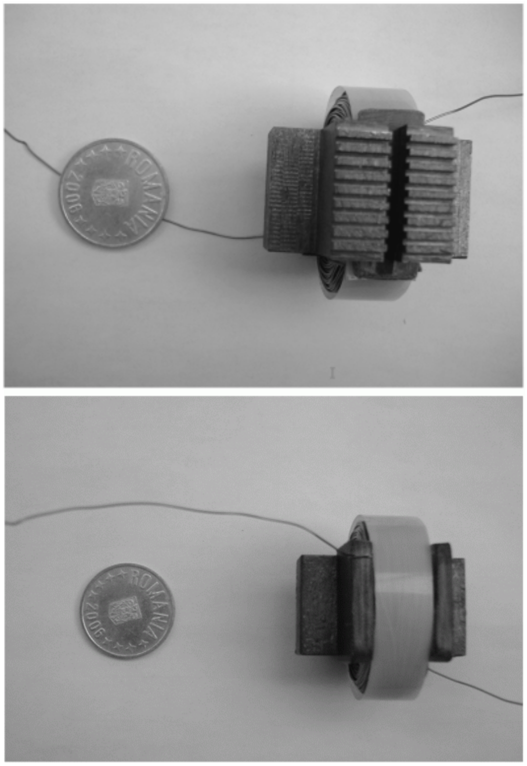

Fig. 5. a.) Lower part of the module;
b) Upper part of the module.

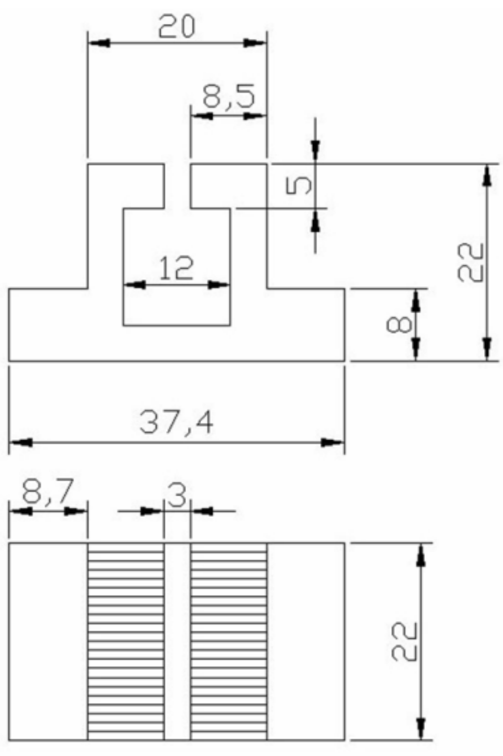

Fig. 6. Quotations of a steel sheet of a module.

Fig. 7. Iron core built of iron and aluminum.

Another variant considered for the construction of the module's iron core is the use of iron and aluminum. The ratio is 93% iron and 7%aluminum. The iron core is obtained by sinterization. The result is given in Fig. 7. As it can be noticed, the iron core isn't compact anymore, which makes it unusable for the built of the module.

Despite offering the possibility to obtain higher flux densities, when using the steel sheets some practical difficulties occure. The main problem is related by the mode the steel sheets package is compacted. As stated before, in order to obtain a module with a length of 17 mm, 34 steel sheets of 0.5 mm were used. One has to take into account that the sheets must be insulated one from another, which leads to a very small increase of tooth and slot dimension. This has very significant influence on the motor's behaviour. Besides this, the lateral parts of the module must be extended in order to use the M5 screws, as Fig. 4.

When building the iron core from powders, these shortcomings are reduced. The errors that occure at realization of the teeth are much smaller. The iron core is obtained compact, the use of screws being unnecessary.

IV. IRON CORE LOSSES

A complete analysis of the elaborated samples implies the measurement of the hysterezis and eddy currents losses when the coil of the module is supplied with a.c. voltage.

The measurements were obtained when the frequency of the volatage was of 40, 50, respectively 60 Hz. Both modules from steel sheets and powders were used. For the module made of powders two sets of measurements were taken, because one of them was baked and the other two weren't. the purpose of this thermical treatment was the increase of the magnetic properties that were diminished when doing the mechanical operations. The measurements were taken using a synchronous generator that provided different frequencies. For a better control of the voltage an autotransformer was used. The errors are within the range of 0.5%. The effective measurement was done in a similar manner to the no load operating regime of the transformer, the wounded module being placed on an iron plate.

For the precise calculus of the iron core losses, the resistance of each module's coil was measured. These have very closed values due to the ineherent practical inexactities. Hence, the coil of the module from powder has a resistance of $R = 4{,}5\ \Omega$. The coil of the module from baked powder has $R = 4{,}8\ \Omega$, and the one from module of steel sheets is $R = 4{,}14\ \Omega$.

The iron core losses are computed with the classic formula $P_{Fe} = P - RI^2$. So the variation $P_{Fe} = f(U)$ can be obtained. These variations, obtained at different frequencies, are shown in Fig. 8.

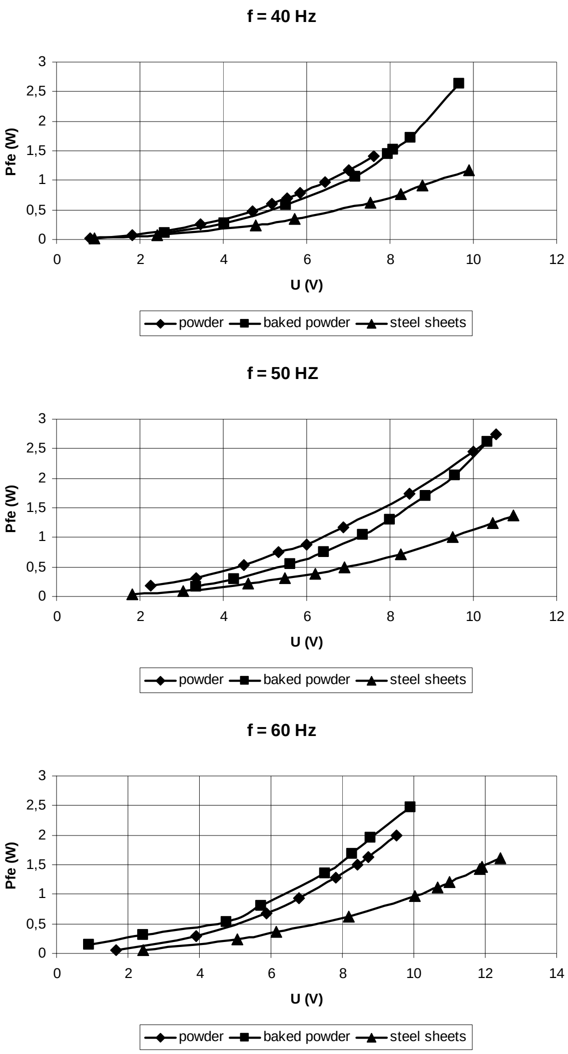

Fig. 8. Iron core losses versus voltage for the analyzed modules, at different frequencies.

V. CONCLUSIONS

In this paper the construction of a modular linear transverse flux reluctance machine is approached. Two possibilities to build the modules of this machine are analyzed. As stated in previous works, the modules of this machine can be built of classical steel sheets. The other variant analyzed here is the use of a material from SMC class.

After a short theoretic analysis presented here, the comparison between these two possibilities is carried out on some samples built of the proposed materials. The modules were constructed based on a design done in order to create a motor developing a tangential force of 1 N. The analysis focused on two aspects: the mechanical part – the construction of the module and its influence on the operating conditions, and the iron core losses. Despite having the shortcoming of lower flux densities than the steel sheets, the powder offers the advantage of a compact iron core, very important at a variable reluctance machine.

ACKNOWLEDGEMENTS

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