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THE SYNCHRONOUS ELECTRIC MACHINE WITH VARIABLE GEOMETRY DONE BY ELASTIC PERMANENT MAGNETS

BY

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Abstract. The paper refers to an electric machine (motor/generator) with an adjustable magnetic field, because its rotor has a special construction that allows the deformation of its elastic permanent magnets. The permanent magnets deform due to a clamping stroke parameter and in this way the flux density of the magnetic field as well as the width and length of the permanent magnets are variable. The variable magnetic field crosses the stator coils which are supplied by the voltages and due to a variable magnetic flux density, a higher torque will result even at lower values of the currents. As a result, a higher efficiency will be obtained due to the increase in mechanical power and the decrease in losses (e.g., Joule effect) in the stator windings. The presented electric machine is a synchronous machine with variable geometry, belonging to the category of permanent magnet machines. Specific to this machine is the fact that the rotor magnets are elastic, being made of ferritic compound rubber with neodimium magnets N45.

Keywords: rotor, elastic permanent magnets, variable magnetic field.

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1. Introduction

This article in the field of electric machines does not intend to be exhaustive but intends to place the new synchronous electric machines with variable geometry done by elastic permanent magnets in the general classification. Also, after the summary presentation of all categories of electric machines from them general classification the focus will be on the current state of the art in the field of electric machines with variable geometry. The first step in the field of electric machines is the definition of electric machines (Boldea and Tutelea, 2009) and then the general classification of these electrical machines. After that, it will be presented the position of electric machines with variable geometry done by elastic permanent magnets in this classification frame.

"Electric machines are devices that convert mechanical energy into electric energy in electric generators, and electric energy into mechanical energy in electric motors. These machines are reversible in that they can switch easily from the generating to the motoring operation modes", (Boldea *et al*., 2009). An electric machine is a device that converts, as the case may be, electrical energy into mechanical energy as in the case of the electric motor or transforms mechanical energy into electrical energy as in the case of the electric generator, (Teodoru and Gogu, 2000).

The current design of the electric machine has a specific rotor construction which can deforming the permanent magnets which are elastic made as compound structure, neodimium permanent magnets as cylinder shapes mount into ferrite silicon rubber. The variable geometry has outcome the variable magnetic flux density over the peripheric surfaces of the rotor. In comparison, for example, in Fig. 1 could be observed the induction B on generators for Geom0 (undeformed geometry) and Geom10 (totally deformed geometry).

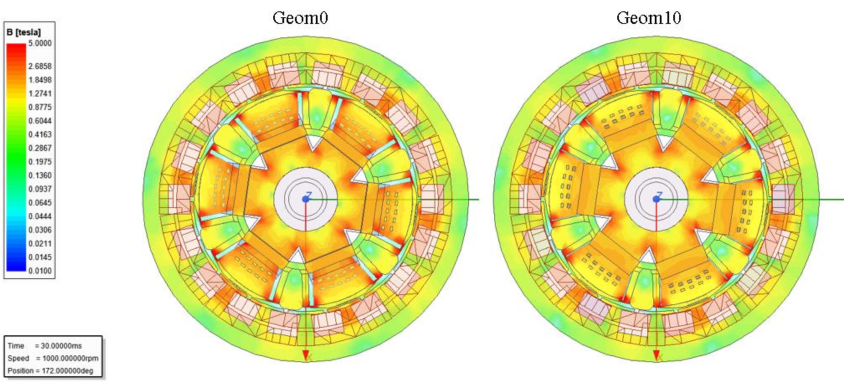


Fig. 1 – Magnetic induction B on generators at idle speed **1000 rpm.**

2. Classification of Electric Machines

There are two main groups of electric machines of direct current (DC) and of alternating current (AC) (level L1 from Fig. 2), (Electrical machine classification partially built up after information from Teodoru *et al*., 1998). The direct current ones are very well known and are not the subject of the present study. The alternating current ones are divided into two main categories: synchronous and asynchronous (induction) machines (level L2 from Fig. 2). The induction ones (the most known example is the squirrel cage type as short-circuit rotor machines) are also not the subject of the present study. For next level will be presented just the synchronous machines categories ones. So brushless DC synchronous electric machines, with Hysteresis, Step, Reluctance and also synchronous Sine Wave with Wound magnetic field are not the subject of the present study (level L3 from Fig. 2). Just for short review some electric machines from closed area with electric machine having variable geometry, the subject of present article, will be draft presented.

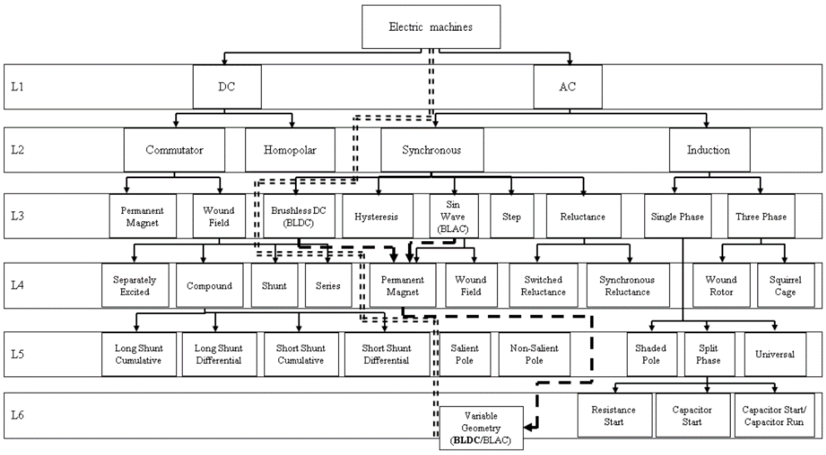


Fig. 2 – Electric machines classification.

2.1. Synchronous AC Electric Machines

a) *Brushless DC machines.* The first synchronous type machine from level L3 is brushless DC motor and can be see its construction characteristics in comparison with brushed DC motor in Fig. 3, and Fig. 4, The brushed DC motor is mechanically commutated via brushes and a commutator. The brushless motor uses electronic devices to determine the sequence for energizing the stator coils (windings), based on rotor position provided by Hall sensors or an encoder or an optical position sensor. The magnetization of the poles is on rotor radial directions (BLDC). Synchronous electric machines with variable geometry could be part of the wider category of electric machines without DC brushes.

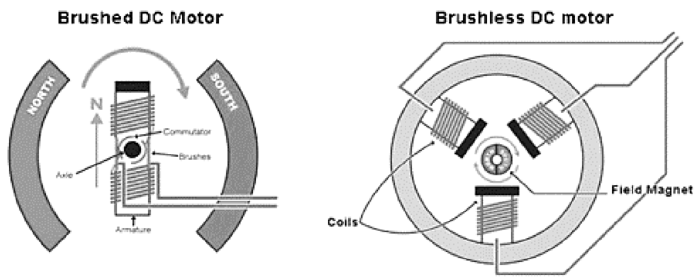


Fig. 3 – Brushed and brushless DC motor (from *** Brushless motors).

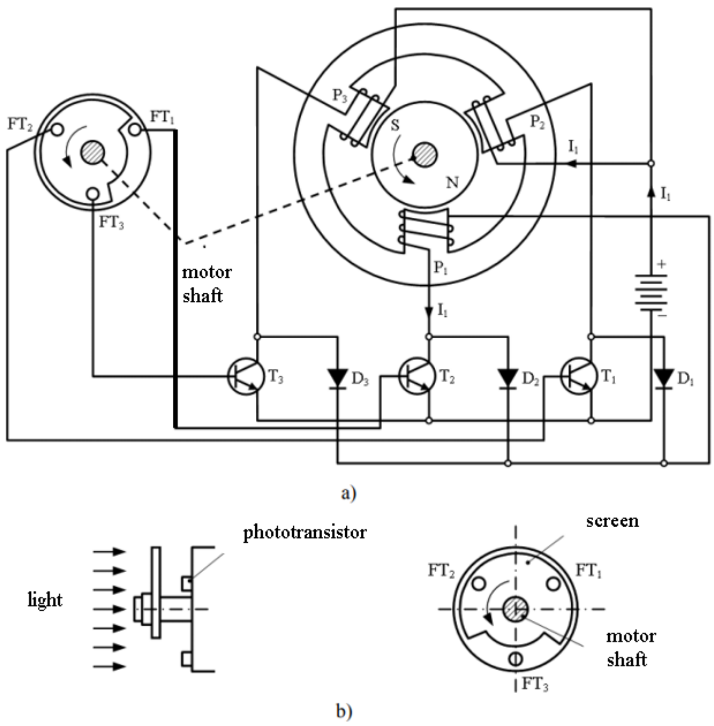


Fig. 4 – Synchronous DC brushless motor with optical position sensor (from Teodoru *et al.*, 1998).

b) *Synchronous machine with hysteresis.* The second synchronous type machine from level L3 is with hysteresis and it has the two main specificities: two stator windings and two material zones for the rotor design, Fig. 5, and due to hysteresis loop over the rotor results a residual magnetism.

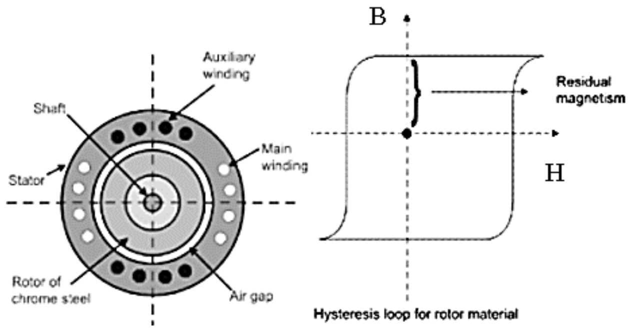


Fig. 5 – Synchronous machine with hysteresis (from *** Hysteresis motor).

c) *Step by step machine.* The third synchronous type machine from level L3 is with steps and the construction and functioning of this motor can be easily seen in Fig. 6 and Fig. 7.

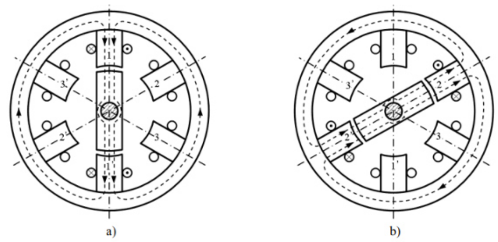


Fig. 6 – Step motor with 6 steps (from Teodoru and Gogu, 2000).

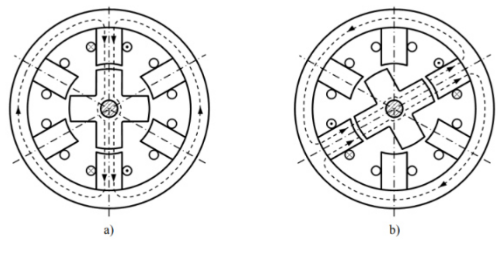


Fig. 7 – Step motor with 12 steps (from Teodoru and Gogu, 2000).

d) *Sine wave synchronous machine.* The fourth synchronous type machine from level L3 is with sine wave and the construction and functioning of this motor can be easily seen in Fig. 8. This type of machine is very good for variable geometry purpose in case of rotor with permanents magnets having parallel orientation of the magnetic poles (BLAC=PMSM).

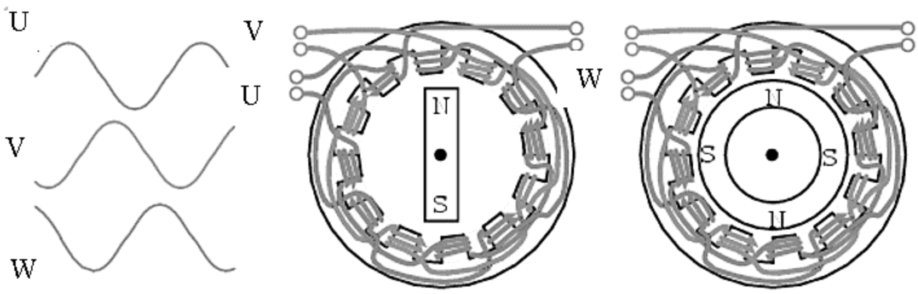


Fig. 8 – Sine wave synchronous motor (from Kuphaldt Bellingham, 2023).

e) *Synchronous reluctance machine.* The fifth synchronous type machine from level L3 is with reluctance which has specific rotor construction generating two magnetization axes: d-axis and q-axis, the construction and functioning of this motor can be easily seen in Fig. 9.

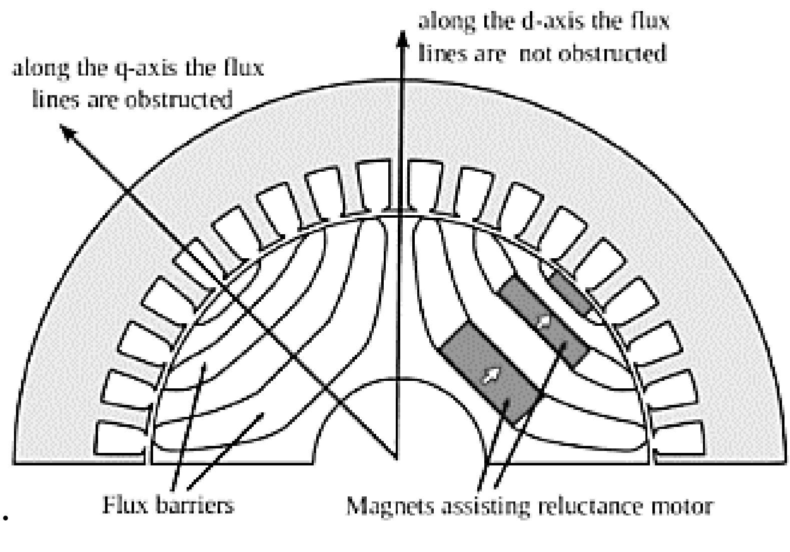


Fig. 9 – Synchronous reluctance machines (from Bianchi *et al.*, 2016).

2.2. Sine Wave Synchronous Machine with Permanent Magnets

From the synchronous AC machines (PMSM), a very important category is the one of the electric machines with permanent magnets rotor, Fig. 10. They have the windings stator, which form several poles, fed in sinusoidal current type (Pulse width modulation - PWM).

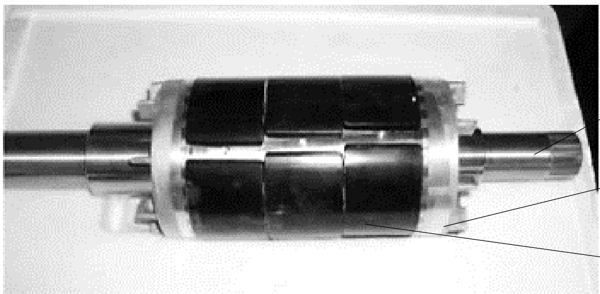


Fig. 10 – Rotor with permanent magnets (from *** VEM motors GmbH, 2020).

Sine Wave synchronous AC electric motors with permanent magnets (having parallel orientation of the magnetic poles) on rotor with fixed geometry are classic. Their study being in the sense of determining the torque/rotation characteristics depending on the voltage at the terminals of the stator windings (per poles) in the case of motor and vice versa in the generator case are known. Only, for example, it can be said that there is a nonlinearity relation between the mechanical power P_m ($P_m = M \cdot \pi \cdot \frac{n}{30}$, where: M is the torque [Nm] and n - rotation speed [rpm]) and the electrical power P_e ($P_e = U \cdot I$), where: U is the voltage [V] and I - current [A]) due to the efficiency that decreases with temperature. So, at low temperatures the efficiency is high and at high temperatures the efficiency decreases.

The change of the temperature values is due to the thermal effect of the current (Joule effect), the thermal energy (heat) produced being the source of the change in efficiency (see also the increasing of the resistivity of the coils conductors with the temperature). The temperature values depend to the produced heat which is proportional to the square of the electric current. That is why electric machines are equipped with a cooling fan (propeller) that has the function of extracting the heat produced by the Joule effect, cooling fan which consumes mechanical energy and therefore further reduces the efficiency of the electric machines. The electric power is at least linear dependent on the electric current. The resistance of the air driven by the fan is proportional to the square of the speed and therefore the loss power through the fan is also proportional to the square of the electric current. Also, as the temperature increases, the magnetic induction of the rotor's permanent magnets decreases, reaching up to 0 at the Currie temperature of the permanent magnets; this decrease in magnetic induction is still a source of decreased efficiency. So, it is very important for the electric machine to operate at low temperatures (e.g. 20°C, ideally at negative temperatures), because as shown above the losses are approximately equal to a sum of two terms (heat produced by Joule effect and mechanical power consumed by the fan) which are proportional to the square of the electric current, Fig. 11.

In the case of Sine Wave synchronous AC or brushless DC electric motors with permanent magnets rotor having variable geometry this nonlinearity relation between the mechanical power P_m and the electrical power P_e is weaker (being closer to linearity which would mean better efficiency) than in the case of machines with fixed geometry. Those with variable geometry operate at low currents, the torque and rotation speed characteristics are influenced by the modification of the magnetic geometry (of the stator or of the permanent magnets rotor, for example). So, these working with lower heat dissipation (the losses through Joule effect are smaller) and also the fan (propeller) can be much smaller or may be missing, Fig. 12.

Same considerations for brushless synchronous motor (BLDC). In comparison in between two geometric instances of the same brushless synchronous motor (BLDC) with variable geometry, the instance with smaller current at same load condition will have better efficiency, Fig. 13.

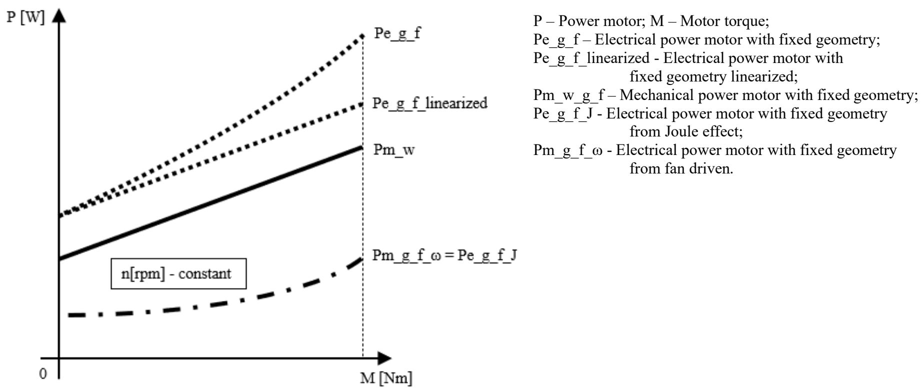


Fig. 11 – Powers of the electric motor with fixed geometry.

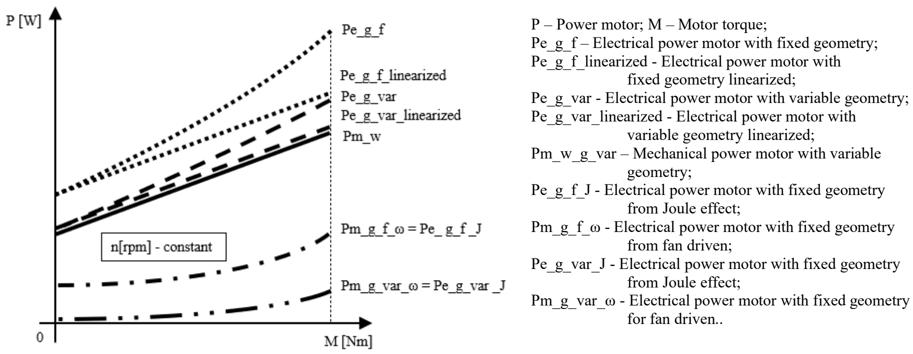


Fig. 12 – Powers comparison in between electric motors with fixed and variable geometries.

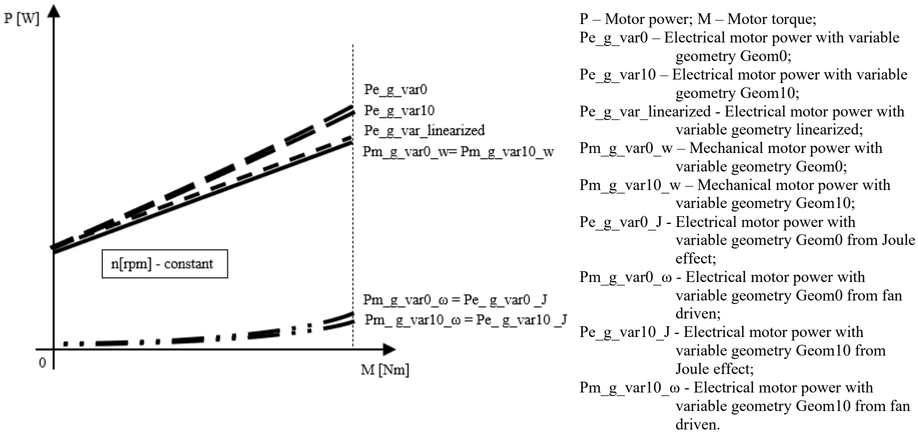


Fig. 13 – Powers comparison in between electric motors with variable geometries.

3. Applications of Electric Machines with Variable Geometry

In the field of electric machines with variable geometry, there are many patents and applications from which some of them will be presented in Table 1.

Table 1

Patents in the field of electric machines with variable geometry

Patent title	Patent number / Reference	Abstract
Contrarotating drive electric generator with variable reluctance for low speeds	RO126892A2 (EPO) / (Alexandrescu *et al.*, 2011)	The invention relates to a counter-rotating electric drive generator with variable reluctance for low speeds.
Magneto-electric generator with diminished magnetic braking	RO132794A2 (EPO) / (Arghirescu *et al.*, 2018)	The invention relates to a magneto-electric generator with diminished magnetic braking.
Synchronous machine with variable reluctance, in modular construction, for electric bicycle drive	RO131721A3 (EPO) / (Inţe and Jurca, 2018)	The invention relates to an electric machine meant for an electric bicycle drive.
Permanent magnet dc machine having meander-like stator windings to produce high torque without excessive heating	US5331244A (EPO) / (Rabe, 1994)	An electronically-switched DC machine having a permanent magnet rotor, generating a homogeneous magnetic field with linear and radially extending magnetic field lines.
Electric motor and electric compressor	US20060091752A1 (EPO) / (Adanya *et al.*, 2006)	An electric motor includes a stator and a rotor disposed around the stator and being rotatable around the stator.

Electrical machine e.g. Permanent-magnet synchronous motor for motor vehicle, has control unit that is arranged for fault detection in the magnetic field excitation and for controlling actuator in case of error	DE102012201347A1 (EPO) / (Jost and Lamers, 2013)	The electrical machine has a housing comprising a stator and a rotor between which an air gap is provided. The housing has an inner side that is provided with two axially extending grooves that are engaged with ribs provided at the outer surface of the stator. The control unit is arranged for detecting a fault in the magnetic field excitation and for controlling actuator in case of error.
Electric machine with variable geometry	DE102010049906A1 (EPO) / (Hao *et al.*, 2011)	A variable geometry electrical machine that includes a movable magnetic element that varies the flow path between a rotor and a stator of the machine depending on the machine speed to control the flow between the rotor and the stator.
Variable field motor drive	JP2009112110A (EPO) / (Yanagihara, 2009)	To provide a variable field motor drive that prevents a current drive from flowing through a motor in such a state that an effective flux is very small.
Variable field motor device and motorcycle withvariable field motor device	JP2009095078A (EPO) / (Kimura, 2009)	PROBLEM TO BE SOLVED: To provide a variable field motor device in which an axial direction length of a rotary shaft is small, and a motorcycle with the variable field motor device.

Synchronous electric machines with variable geometry could be part of the wider category of electric machines without DC brushes, but as well most common type for synchronous electric machines with variable geometry could be the Sine Wave (alternative supply electric voltages as generalisation) with permanent magnets category. In fact, DC sources successively supplies the stator coils being controlled with pulses width modulated (PWM).

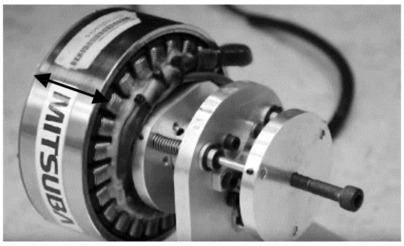
Further will be described generally the synchronous AC electric machines with Sine Wave current winding stator (alternative supply electric voltages as generalisation, with DC steps for examples) and having the rotor with permanent magnets with fixed geometry and then those with variable geometry.

The functioning of synchronous electric machines having the rotor with permanent magnets is due to the interaction between the magnetic field of the stator (rotating magnetic field) and the magnetic field of the rotor. This interaction in the case of the machine as a motor will generate a mechanical power (torque vs. speed) and in the case of the machine as a generator will generate an electrical voltage at the terminals of the stator windings.

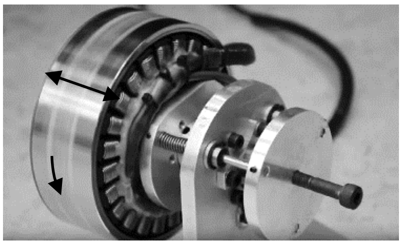
Between the rotor and the stator there is a radial air gap with a relatively small thickness (0.5 mm), which constitutes a barrier in the magnetic circuit so it is indicated that this air gap should be as small as possible, respecting the mounting tolerances of the electric machine and taking into account of thermal deformations during functioning. Therefore, the electric machine is recommended to work at low temperatures close to the mounting ones. It is also recommended that the functioning temperature be low to avoid demagnetization of the rotor.

Electric machines with fixed geometry consist of the fact that both the stator and the rotor have magnetic geometries that depend only on the electric charges (stator) and the magnetic properties of the materials used (rotor) respectively. Thus, all other electric machines that have magnetic interactions that depend on other parameters such as: deformation of stator coils, axial motion of the rotor (axial superposition of the magnetic fields is variable during functioning) deformation of permanent rotor magnets (e.g. axially or/and radially or tangentially) are called electric machines with variable geometry.

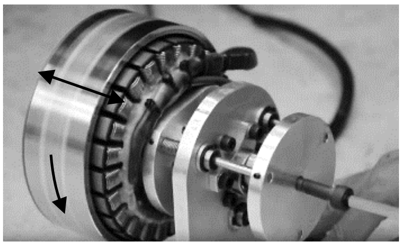
Below there are some examples of electric machine with variable geometry having just one parameter - axial stroke; current will not be considered parameter. This is very good for applications (as electric motorcycle) which need high torque as for starting and after that it is needing high speed at low torque.



a) Stand still (time 0:00 min)



b) Start (time 0:18 min)

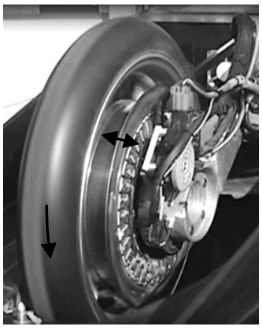


c) Acceleration (time 0:48 min)

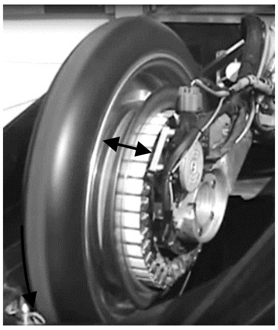
Fig. 14 – Electric machine with variable geometry (from *** Machine with variable geometry, 2020).

At the beginning, the embodiment is like in Fig. 14a with the stator not pulled out from the rotor space and in this configuration the torque is very high. After few rotations the stator can be pulled out from the rotor space and as a result the effect is acceleration of the rotor due to make the feedback influence of the currents induced by the rotor magnets into stator windings lower, Fig. 14b. At maximum speed needs the stator can be pulled out at extreme position as in Fig. 14c.

The Fig. 15 shows an example of using the electric machine with variable geometry (axial stoke) on an electric motorcycle embodiment from high torque status, Fig. 15a, to high speed status, Fig. 15b.



a) Start (time 0:00 min)



b) Acceleration (time 0:15 min)

Fig. 15 – Example of using the electric machine with variable geometry (axial stoke) (from *** Variable field magnet motor, 2020).

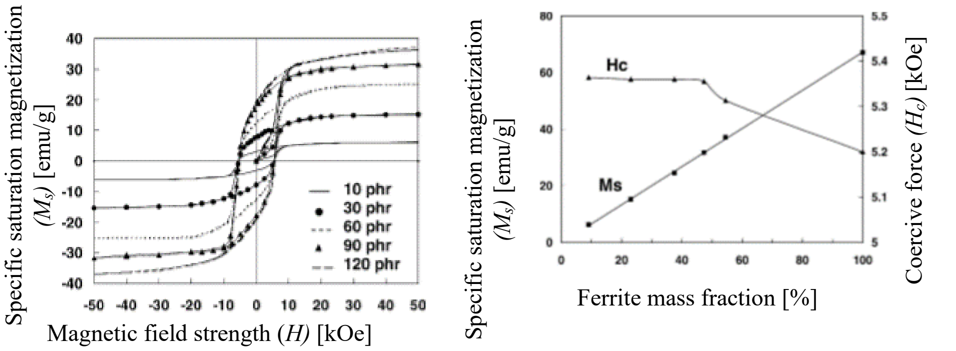
This type of electric machine (motor) is with variable geometry, varying only one parameter, namely the axial stroke of the stator vs rotor. As a practical application the company Mitsuba, (*** Mitsuba company, 2020), has built this motor which based on patents JP2009112110A (Yanagihara, 2009) and JP2009095078A (Kimura, 2009).

4. New Electric Machine with Variable Geometry done by Elastic Permanent Magnets

4.1. General Aspects Regarding the Machine

The synchronous electric machine with variable geometry presented in this paper, it's based on the patent with the title "*Rotor for an electric machine of a vehicle*", and can modify more than one parameter, (Murgoci, 2021).

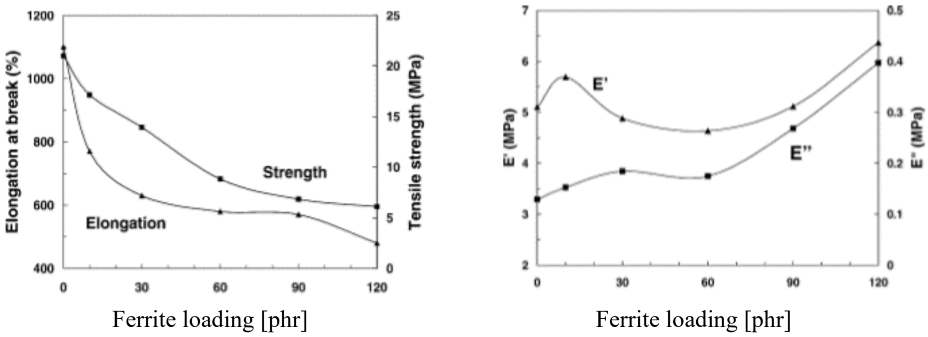
The permanent magnets of the rotor are of a special construction to be able elastically deformed. This deformation of the permanent magnets will determine the modification of at least one of the parameters: magnetic induction, the length of the conductor of the stator windings crossed by the magnetic field lines and the radius of the rotor. The permanent magnets are made from ferrite rubber, special material which is described in (Makled *et al*., 2005). The Fig. 16 presents the magnetic properties of rubber ferrite composite (RFC), namely: the hysteresis loops for RFC as a function of ferrite loading (where: phr – part per hundred rubber), Fig. 16a; the variation of specific saturation magnetization (M_s) and coercive force (H_c) as a function of the mass fraction of ferrite filler, Fig. 16b.



a) Hysteresis loops

b) Saturation magnetization (M_s) and coercive force (H_c)

Fig. 16 – Magnetic properties of rubber ferrite composite (from Makled *et al*., 2005).



a) Tensile strength and elongation at break

b) Storage (E') and loss (E'') elasticity modulus

Fig. 17 – Mechanical properties of rubber ferrite composite (from Makled *et al*., 2005),

The Fig. 17 presents the mechanical properties of rubber ferrite composite (RFC), namely: the tensile strength and elongation at break as a function of ferrite loading, Fig. 17a; the variation of storage (E') and loss (E'') elasticity modulus as a function of ferrite loading, Fig. 17b.

After their manufacture the magnets equipped a special rotor construction for electric machines. Such electric machines may be operated as a motor or as a generator, in order to fulfil respective needs. The permanent magnets as elastic pads, which can be elastically deformed in a rotor in order to obtain the modification of the magnetic induction (B), the length (L) of the conductor swept by the magnetic field lines and the radius (R) of gravity centre of permanent magnets. It was noticed that the magnetization of the rotor could be enough only because of the permanent magnets with cylinder shape and made from neodymium N45M class, as a result is described a general situation of the rotor magnetization, as due to this strategy of modelling and comparison of the behaviours of two extreme geometric instances of the BLDC motor, named Geom 0 - undeformed and Geom 10 - totally deformed, with simplified and not optimized shapes. The detailed properties of elastic compound magnets are the subject of subsequent publications due to big data.

Such a special rotor construction allows to keep the stator current in a safe region regarding the Joule effect, thereby avoiding an overheating and damage/destruction of the electric machine. Furthermore, even the mechanical torque can be increased due to a respective increase of parameters B, L, and R. Such elastic pads (permanent magnets) are manufactured by integrating ferrite powder and must be mixed with the elastic material, and then their magnetization is done using an inductor.

Compared to the Mitsuba applications, (*** Mitsuba company, 2020), and the solution from the patent with the title "*Electric machine with variable geometry*", (Hao *et al*., 2011), the synchronous electric machine with variable geometry from the patents (Murgoci, 2021; Murgoci, 2019), due to the axial stroke of a multi-profile cam, several parameters of the machine can be modified, namely: magnetic reluctance of magnets (due to shrinkage of ferritic rubber thickness depending on the stroke); magnet length and width; magnetic flux density (induction B); the number of stator windings traversed by the magnetic flux and the radius of gravity center of magnets.

4.2. Description and Functioning of the Machine

In the case of synchronous electric machines with variable geometry, the reluctance of the magnetic circuits can be changed by changing the density of the magnetic flux (magnetic induction, B). This modification can be done by changing the positions of the rotor magnets and changing their shape. In the latter case, the magnets are made of a special material that gives them elasticity (e.g. ferritic rubber) Fig. 18.

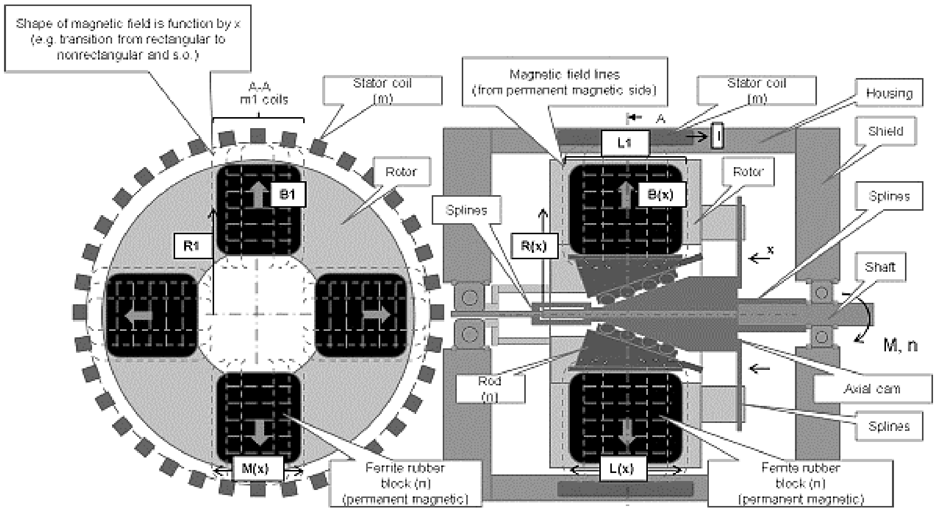


Fig. 18 – The construction of the electric machine with variable geometry (from Murgoci, 2021).

According to Lorentz law, the force $\overrightarrow{F_L}$ exerted on an electric charge q located in a magnetic field of magnetic flux density $\vec{B}$ and having velocity $\vec{v}$ perpendicular to the lines of magnetic field is given by, (Horga, 2013):

$$\overrightarrow{F_L} = q \cdot (\vec{v} \times \vec{B}). \tag{1}$$

Let it be a conductor that has a number of electric charges (electrons), $q = e$, which moves in unit time, *t*, generating an electric current *I*, due to a potential difference, *U*. By summing up all the Lorentz forces acting on charges of the conductor of length *L*, carried by a current *I* and located in a magnetic field of magnetic flux density $\vec{B}$, perpendicular to it, magnetic field produced by the magnets of the machine rotor, an electromagnetic force is obtained. This force is called the Laplace force (like the Lorentz force for a macroscopic current) or the Oersted force, $\vec{F}$, and its expression is:

$$\vec{F} = I \cdot (\vec{L} \times \vec{B}). \tag{2}$$

On a mechanical level, this force will determine a torque $\vec{M}$ given of expression:

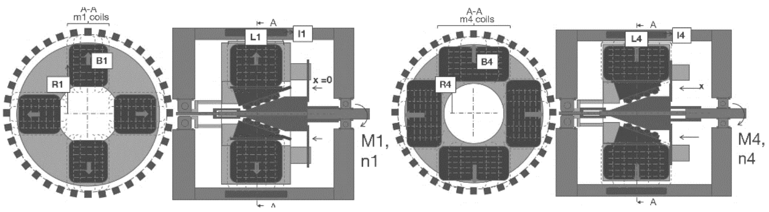
$$\vec{M} = n \cdot (\vec{R} \times \vec{F}), \tag{3}$$

where: *n* is the number of magnets and *R* is the radius of the center of application of force $\vec{F}$, (Horga, 2013).

Depending on the machine model (motor or generator), the parameters *B, L, R, n* and *I* can be variable.

In general, a variation of the torque (torque) *M* and the rotational speed of the rotor shaft of an electric machine (motor/generator) implies a change of the electromagnetic force *F* (parameters: *B, I, L*). For to increase the electromagnetic force *F*, it is necessary to increase the magnetic induction *B* and/or the electric current *I* and/or the length of the conductor *L* traversed by the magnetic field lines. A common way to increase the torque *M* is to increase the electric current, *I*. However, the increase of the current is limited due to its Joule effect, which can lead to overheating of the electric motor and its damage/destruction.

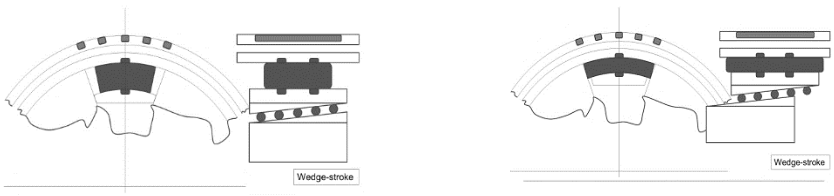
The permanent magnets of the rotor can be elastically deformed to obtain the modification of the magnetic induction *B*, the length *L* of the conductor and the radius *R*. The deformation of the magnets is carried out between a minimum limit (undeformed state) and a maximum one (totally deformed state), Fig. 19, with the help of an axial cam. By moving the axial cam linearly, in one direction or another, the deformation of the permanent magnets can be increased or decreased.



a) Undeformed state of the magnets b) Deformed state of the magnets

Fig. 19 – The construction of the electric machine with variable geometry.

Fig. 20 shows two details regarding the deformation of a permanent magnet of the rotor, one for the undeformed state, respectively the second for the deformed state obtained in step 4 of the simulation. Thus, the torque *M* can be varied over a wide range, while maintaining the stator current *I* at safe values from the point of view of the Joule effect, thus avoiding overheating and damage/destruction of the electrical machine.



a) Undeformed state b) Deformed state

Fig. 20 – Details on the deformation of a permanent magnet.

The electric machine provides the continuously variable machine function (reducer/multiplier), e.g. depending on the position of the deformation means on an x-axis (especially the longitudinal axis of the rotor shaft) and the values of the stator current. Thus, no additional gearbox is required to transmit the motion. Moreover, the electric machine can be particularly flexible, adapted for use as a motor and generator. For the numerical simulation of the electric machine, an embodiment is required that fullfill the boundary conditions for the hyperelastic structure of the magnets, realized in the Ansys Workbench on the one hand, and for the electromagnetic one realized in Ansys Maxwell (LFEFS - Low Electromagnetic Field Simulation frequency) on the other hand. Fig. 21 shows an embodiment of the electric machine with variable geometry according to (Murgoci, 2021; Murgoci, 2019) and a proposal for the shape of the ferrite rubber permanent magnet.

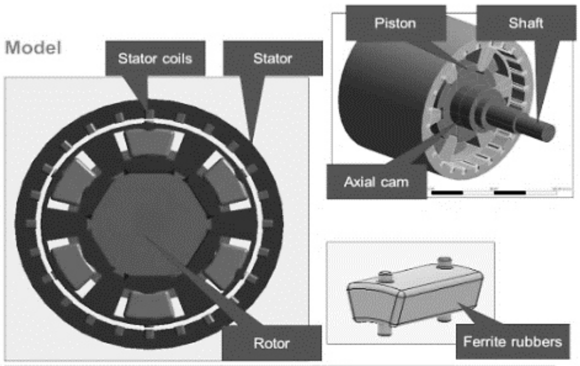


Fig. 21 – Electric machine embodiment.

For the hyperelastic simulations, some simplifications have been made to save the computational solution time. The results were saved at intermediate strokes, between the minimum stroke (x=0 mm) and the maximum stroke (x=30 mm), to export the intermediate deformed shapes of the permanent magnets. The totally deformed shape of the permanent magnets corresponds to the maximum stroke and is calculated and saved after 10 integration steps, Fig. 22.

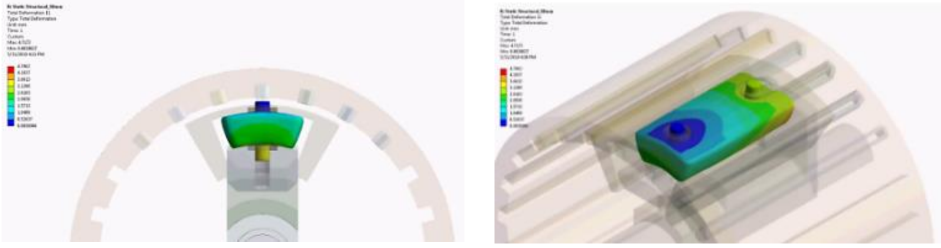


Fig. 22 – Totally deformed shape.

The shapes of the permanent magnets, obtained with Ansys Workbench, for the axial strokes of 0, 3, 6, 9, ..., 27 and 30 mm, will be exported to the Ansys Maxwell platform where the specific boundary conditions are imposed.

Figure 23 shows an extract of the simulation plan designed based on the idea of finding out the mechanical parameters, *M* - torque vs *n* - speed, in the case of the operation of the electric machine with variable geometry as a motor, respectively the electrical parameters, *U* - voltage, *I* - current, in the case of its operation as a generator.

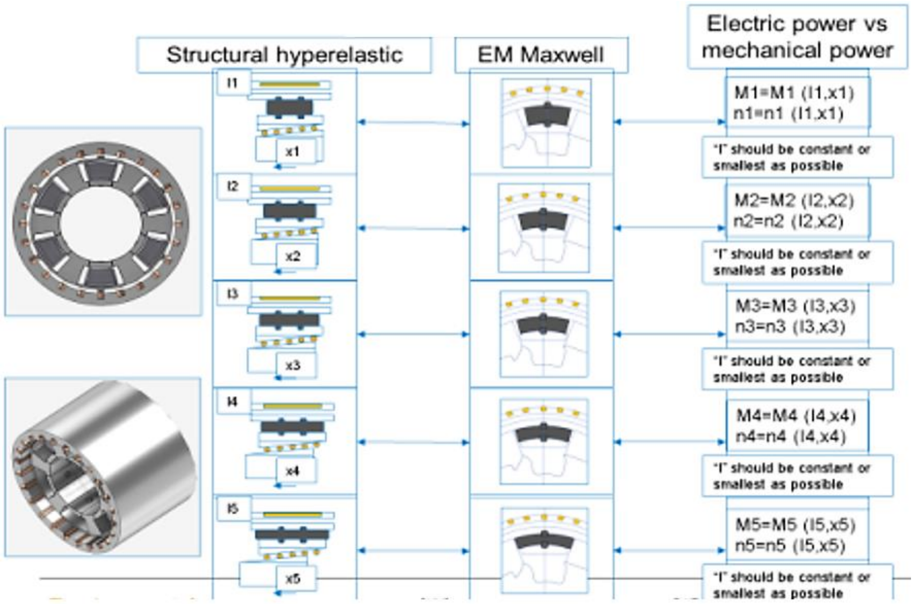
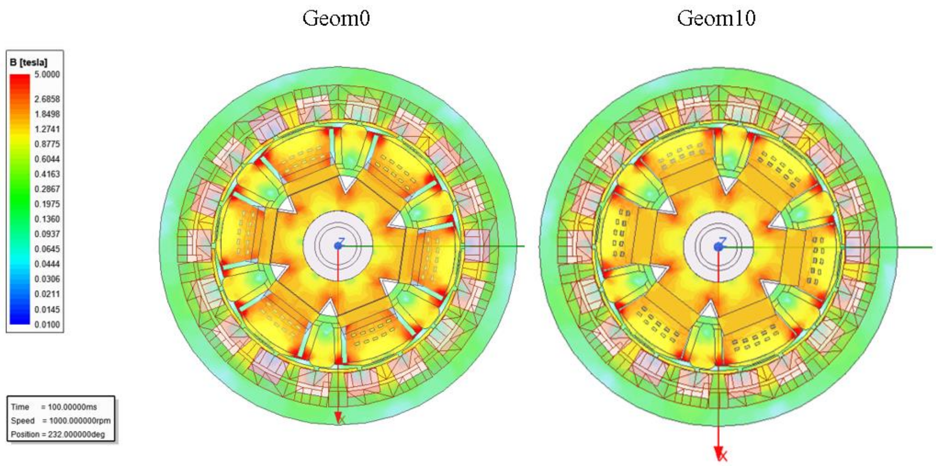


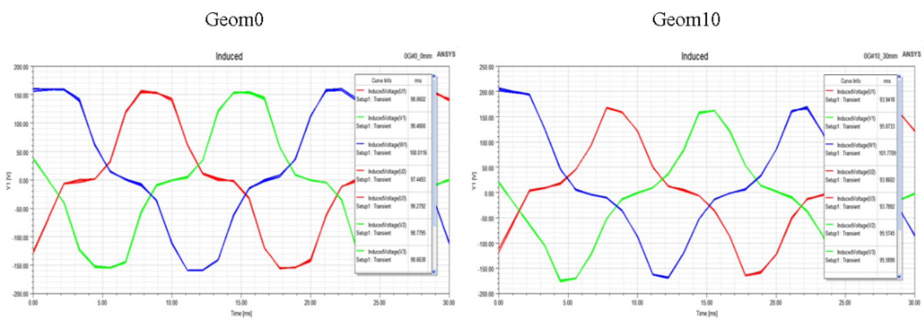
Fig. 23 – Simulation plan (extract).

For the proposed generator model will be presented simulation results such as magnetic flux density B and Back Electro Motive Force (BEMF) in Figs. 24, 25 and 26.



B is arranged on larger domains on the periphery of the rotor for Geom10

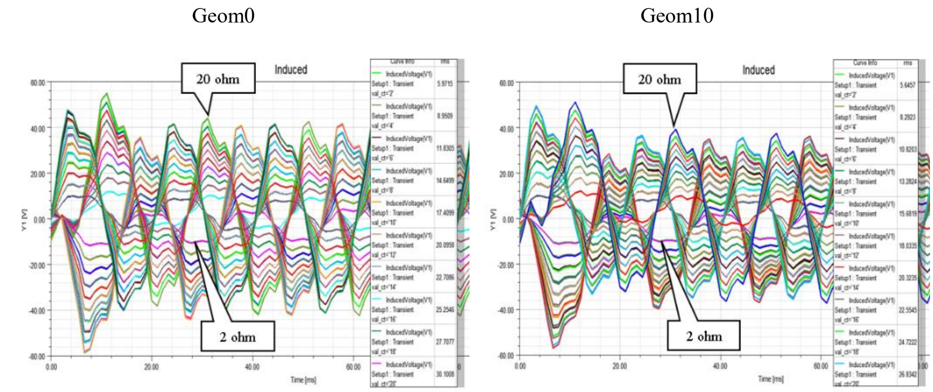
Fig. 24 – Magnetic induction B on in charged generators
at speed **1000 rpm** (on resistor **2 ohms**).



BEMF is nearly bigger for Geom0

Fig. 25 – BEMF on generators at idle speed **1000 rpm.**

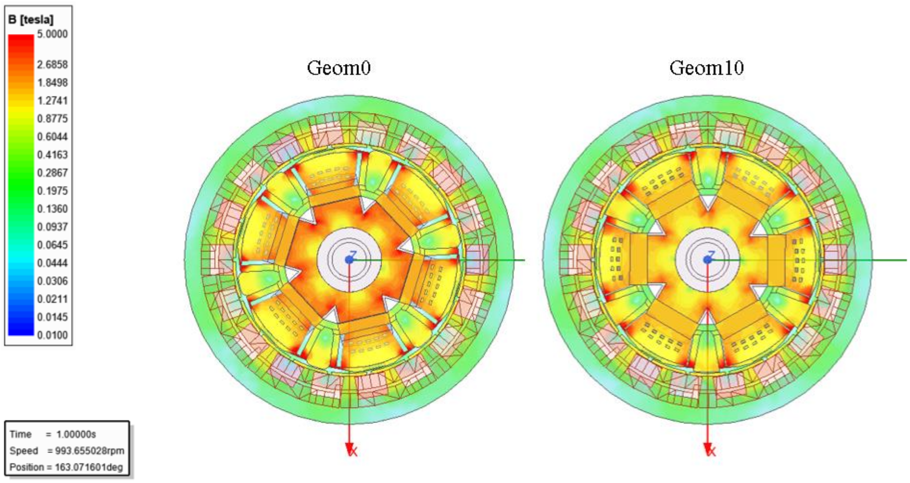
In comparison in between the generators parameters of Geom0 (undeformed) and Geom10 (totally deformed) can be observed the BEMF is a bit bigger for Geom0 at idle speed and as well the BEMF is bigger for Geom0 at same resistors.



BEMF is bigger for Geom0

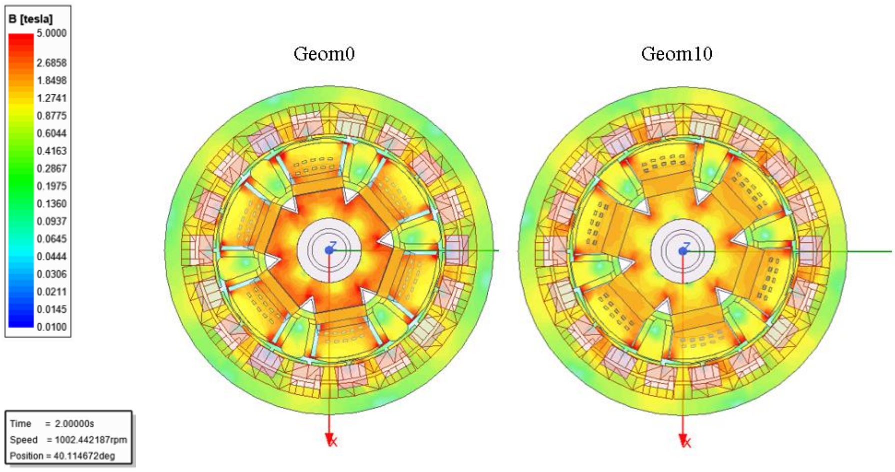
Fig. 26 – BEMF on in charged generators
at speed **1000 rpm** (on resistors **2 to 20 ohms**).

As well for the proposed motor model will be presented simulation results such as magnetic flux density B in Figs. 27, 28 and working characteristics will be presented in Table 2.



B is arranged on larger domains on the periphery of the rotor for Geom10

Fig. 27 – Magnetic induction B on motors at idle speed **1000 rpm.**



B is arranged on larger domains on the periphery of the rotor for Geom10

Fig. 28 – Magnetic induction B on in charged motors at speed $\mathbf{1000\ rpm}$ (with resistant torque $\mathbf{-3.93\ N \cdot m}$).

Table 2

Parameters on in charged motors at speed $1000\ rpm$ *(with resistant torque* $-3.93\ N \cdot m$*)*

Parameters \ Geometry		Geom0	Geom10
Power in (electrical)	$[W]$	458.7	412.4
Power out (mechanical)	$[W]$	412.2	412.1
Current supply	$[A]$	0.698	0.553
Phase voltage	$[V]$	55.3	67.6
Line voltage	$[V]$	63.9	65.0
Torque	$[N \cdot m]$	3.93	3.93
Speed	$[rpm]$	999.2	1000.2
Efficiency	$[\%]$	89.8	99.9

In comparison in between the motors parameters of Geom0 (undeformed) and Geom10 (totally deformed) can be observed the current is bigger for Geom0 at same torque (mechanical power). As well the efficiency is lower for Geom0 at same torque (mechanical power).

5. Conclusions

There is a wide range of electric machines that are grouped into DC and AC machines. AC machines are divided into two main categories: synchronous and asynchronous (induction) machines. The electric machine with variable geometry (having the rotor with deformable permanent magnets) is part of the category of AC synchronous machines or DC synchronous machines due to magnetization direction of the rotor poles. The permanent magnets of the machine's rotor are compound made of ferritic rubber and neodimium magnets, a material with special magnetic and mechanical properties, to be able to deform elastically. The synchronous electric machine with variable geometry due to the axial stroke of a multi-profile cam, several parameters of the machine can be modified, namely: magnetic reluctance of magnets (due to shrinkage of ferritic rubber thickness depending on the stroke); magnet length and width; magnetic flux density; the number of stator windings traversed by the magnetic flux and the radius of gravity center of magnets. The simulation of the construction and operation of the machine with variable geometry, made in Ansys Workbench and Ansys Maxwell, allows finding out the mechanical parameters, M - torque vs n - speed, in the case of the operation as a motor, respectively the electrical parameters, U - voltage, I - current, in the case of its operation as a generator.

The generator Geom0 has better induced voltages (BEMF) than Geom10 in idle speed case and on resistors cases.

The motor Geom10 has lower current and better efficiency than Geom0.

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MAȘINĂ ELECTRICĂ SINCRONĂ CU GEOMETRIE VARIABILĂ CU MAGNEŢI PERMANENŢI ELASTICI

(Rezumat)

Lucrarea se referă la o mașină electrică (motor/generator) având densitatea fluxului magnetic variabil, deoarece rotorul său are o construcție specială care permite deformarea magneților permanenți elastici ai acestuia. Magneții permanenți se deformează din cauza unui parametru de cursă de strângere și în acest fel este variabilă densitatea de flux a câmpului magnetic, respectiv lățimea și lungimea magneților

permanenţi. Câmpul magnetic variabil străbate bobinele statorului care sunt parcurse de curenţi şi datorită unei densităţi de flux mai mare, va rezulta un cuplu mai mare chiar şi la valori mai mici ale curenţilor. Ca urmare, se va obţine un randament mai mare datorită creşterii puterii mecanice şi scăderii pierderilor (efectul Joule) în înfăşurările statorului. Maşina electrică prezentată este o maşină sincronă cu geometrie variabilă, aparţinând categoriei de maşini cu magneţi permanenţi. Specific acestei maşini este faptul că magneţii rotorului sunt elastici, fiind confecţionaţi din matrice de cauciuc feritic cu magneţi de neodimium.