Numerical modeling of claw-poles alternator

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***Abstract*—The paper present a program of modeling of a claw-poles alternator with the program Magnet 6.11, which after the input data of machine realize the geometrical model for numerical analyzes. After analysis, the program can be changed automatically and made a new model, that can be analyzed automatically and not being necessarily construction the model with the drawing program each time its necessary.**

I. INTRODUCTION

The claw pole alternator is the most common power generation device used in cars and are mostly designed to low costs. Even though the principle of electrical machines has been used for more than a century, their design is still subject to improvements nowadays.

Production of electricity on board of classic automobile and hybrid car's is carried out with the help alternators with claw poles.

Due to increasing demand of the power requirement of the vehicle, as well as appearance green vehicle (electric) or the hybrid pursuing protecting the environment, requiring a system crossing from 14V at the drive motor 42V, adding decreasing the international fuel resources, research alternators characteristics of great importance for vehicle manufacturers and not only

Use the claw pole construction has the advantage of simplicity and high reliability, but has the disadvantage of low efficiency caused by high leakage flux.

II. PARTICULARLY CONSTRUCTIVE

The structure of the claw pole is typically homopolar and can be seen in different types of machines. Both the rotor and the stator can be built in this variant, which is very simple, by using a single winding for all obtained alternating poles exactly through the construction of claw-shaped poles.

The type of homopolar flux produced by the excitation current through the cylindrical coil of the rotor becomes, thanks to the claw poles, a heteropolar flux type in the air gap and induces electromotive voltages of almost sinusoidal variation in the stator windings.

This construction with homopolar inductor type and claw pole is simple, compact, but shows a significant dispersion, which causes a low useful flux.

Other improves the alternator power density with the use of a foil field winding to provide higher conductor packing factors and offer improved thermal transfer properties in the claw-pole alternator. These advantages are demonstrated to enable significant increases in field ampere turns and achievable alternator output power. However, realizing these advantages requires a new field excitation circuit that can deliver high field current at a low voltage, without exceeding the limited current ratings of alternator brushes. [1]

Some studies are based on the idea of increasing the power out and efficiency of the alternator, while maintaining the alternator operating point in the optimum zone and succeed to increases the output power to 200% and significant improvement of efficiency which is demonstrated at high speeds. [2]

Analytical models allow preliminary design studies, so the numerical simulations are an opportunity to validate and refine solutions based on analytical methods which has focused on the speed of calculation models.

Schulte describes two approaches for calculating the mutual inductance between rotor and stator of the synchronous alternator with claw-poles about the claw shape. Results from the analytical determination of the mutual inductance, which requires an indirect determination, with utilization in circuit-based simulations lead to currents matching measured currents very well.

Appliance of a Fourier analysis on the determined characteristic of the mutual inductance, contained harmonics are provided, to allow for analytic composition.

Due to the complex structure of the rotor, the assessment approaches are difficult. If the prototypes are available, mutual inductance can be calculated from the voltage measured at no load. Description of the mutual inductance obtained can be used to implement the circuit based on numerical simulations. [3]

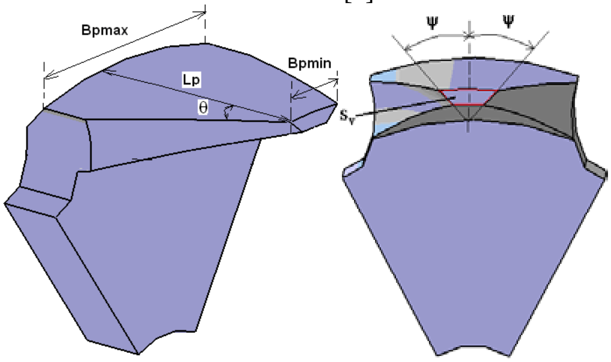

Figure 1. Angle of the claw poles

Also, the studies of *C. Stoica* have led to the observation that the dispersion fluxes specific to a pole decreases with the increase of the inclination angle ψ of the lateral surfaces of pole (Fig. 1.), and the useful flux increases to the maximum value for $\psi_{max} = 72^0$.

By studying the influence of constructive parameter ψ on the useful flux, it was observed that increasing the useful flux by optimizing the pole geometry resulted in a decrease of the excitation current. Accordingly, a decrease in the volume of active materials, iron and copper will follow, improving the power/weight ratio.

At this type of alternator the most important obstacle is determining the shape of the rotor poles. These poles have an important role in closing the magnetic field lines because they ensure the route from the rotor excitation towards the air gap and the correct dimensioning of the claw pole peak for limiting the dispersion fluxes.

Due to the high concentration of magnetic field lines through the cross section of the poles, one must consider choosing the appropriate dimensions for avoiding the rotor core saturation. [4]

Complex construction of the alternator with claw poles, the existence of magnetic fields both radial and axial, the lack of symmetry plane-parallel magnetic field study require the machine to be achieved through three-dimensional finite element numerical modeling.

Methods using numerical simulations based on finite elements are often used because they allow a better precision performance of the devices. Using these methods can overcome all the surveys and the assumptions made to establish an analytical model often long and hard to build. [7]

III. *THE SOFT MAGNET 6.11*

Magnet is made as a 3D modeling tool for solving problems of static magnetic fields and eddy-currents. The 2D modeling, magnetic may also deal with problems in which currents are induced by the motion of a system part.

Finite elements method is a numerical method based on the application of variation principles to solve equations with partial derivatives. In technique, was first developed to solve the problems of resistance material, its application to calculate electric and magnetic fields are relatively recent.

Finite element method is suitable for work with non-linear components such as electromagnets with materials ferromagnetic who manifest anisotropic phenomenal that and saturation.

Methods of numerical analysis of fields in general and in particular, the electromagnetic finite element method are currently the most used, accurate, researched and developed continuously. Applicability domains complex with scratchy, slight imposition of conditions of the border, the relatively simple mathematical problem, and equivalent required to do this method worldwide. The professional analysis developed by companies like “Vector Fields”, “Infolytica”, etc. ensure a competitive environment for the development of efficiency and applicability of the method.

The problem of solving is reduces to the solution of a set of linear equations for the unknown potentials at all the nodes. This must be repeated several times if the model contains non-linear magnetic materials. [8]

The accuracy of the finite-element solution depends on three factors: the nature of the field, the size of the elements, and the element order. In regions where the direction or magnitude of the field is changing rapidly, high accuracy requires small elements or a high element order. In addition, the methods used to find the finite-element solution are iterative, with an adjustable error criterion for terminating the process.

Starting from the model of alternator with claw-poles in the experimental study, and checking in the same time the geometric dimensions of its design, was performed three-dimensional model of the alternator to following the behavior of this. [5]

3.1. Solver

When non-linear magnetic materials are present, the permeability depends on the local value of B:

- Constant values of permeability are chosen for each element, from the initial slope of the material B-H curve.
- The resulting linear equations are solved numerically for the magnetic potential, using the semi-iterative conjugate gradient method.
- The flux density values are calculated from the magnetic potential, and these results are used to calculate new values for the element permeability.

3.2. Method of permeability calculation

For 3D problems, MagNet gives a choice of the Newton-Raphson method or successive substitution or calculating updated element permeability values. The default Newton-Raphson method normally converges more rapidly, but there can be convergence problems with some material characteristics, in which case the successive substitution method is required. Only the Newton-Raphson method is available for 2D problems.

3.3. Newton steps

At each step in the permeability calculation process, the change in the solution is monitored. The process continues either until the change is less than the Newton Tolerance or until the limit of Maximum Newton Iterations is reached. For most problems, the default values of 1% and 20 iterations should be satisfactory.

3.4. Polynomial order

The solver polynomial order setting is a global value that applies throughout the model and use order 2 is satisfactory in rotational geometry which gives a fast solution for medium accuracy of results.

For 3D models the polynomial order of elements in particular components can be specified separately but for 2D models the solver polynomial order option sets the value that will be used for the entire model.

With some models, increasing the polynomial order is as effective as using adaption to improve the solution accuracy.

3.5. Adaption

Adaption is the process of automatic refinement of the mesh to improve the solution accuracy.

For 3D models there is a choice of two adaption methods: h-type adaption, where element sizes are halved, and p-type adaption, where the element polynomial order is increased.

After each adaption step, the change in the calculated value of stored magnetic energy is monitored. Adaption continues until this change is less than a specified tolerance, or the specified number of steps has been reached. If the quantity of interest is the force or torque, rather than an energy-related quantity such as inductance, a more accurate solution may be required, and the change in the stored magnetic energy may not be a good indicator. In such cases it is often advantageous to set the tolerance to a very low (but non-zero) value, and control the mesh refinement by adjusting the maximum number of adaption steps. The optimum setting can be determined by changing the number of steps and monitoring the change in the force or torque value.

IV. The Numerical Model

With the programming language VB Script was made the interface for data input (Fig. 2.), for building the design model of claw pole alternator, in function of electrical characteristics imposed.

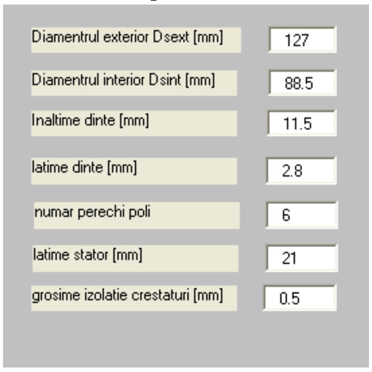

Figure 2. The inputs date

The inputs date are taken and used to construct 3D model of alternator. During the program choose the materials used for body building stator, rotor and winding them.

The program realize after model construction, the software analysis of the magnetic field with finite element and result the problems zone which need optimized.

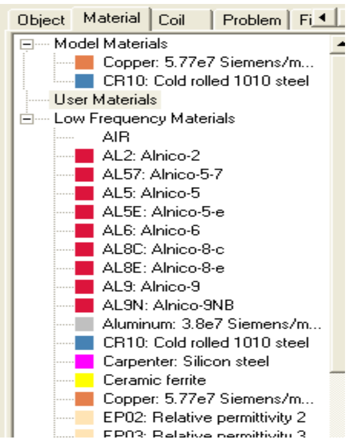

Figure 3. The library of predefined materials

We tried to implement to the program, some facilitate which made to choose for building the geometric model of alternator with claws to be done from different materials, so the stator but also the rotor.

Magnet 6.11 has a library of predefined materials (Fig. 3) what can be selected for construction of components of the geometric model, but also can be introduce the new materials base on the dependence B = f (H).

Depending on the outside and the inside diameter of the stator, the shape and dimensions of the windings is made the geometrical construction of the stator follow the winding stator construction and the definition of electric parameters of the stator. (Fig. 4.)

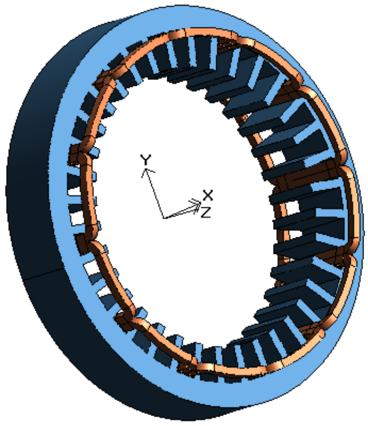

Figure 4. The geometrical construction of the stator

After achieving the stator, the rotor is built following the same principles (Fig. 5, Fig. 6)

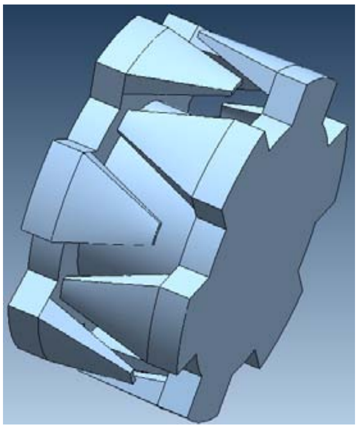

Figure 5. The geometrical construction of the rotor

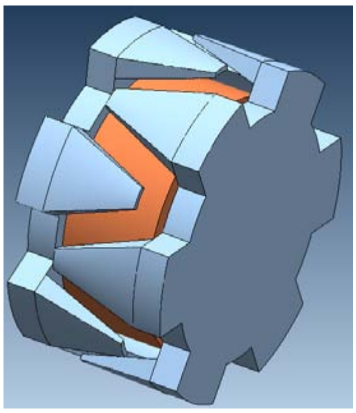

Figure 6. The geometrical construction of the excitation winding

In the program can change the size of rotor teeth which leads to default and changing the dimensions of air gap.

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CALL saveDocument("D:\doctorat\MODELE ALTERNATOR\scripturi\stator.mnte", infoMinimalModel)
Call getDocument().getView().addRotation(0, 45, 0)
Call getDocument().getView().addRotation(0, 0, 10)
Call getDocument().getView().addRotation(10, 0, 0)
Call getDocument().getView().rotateToAxis(infoPositiveZAxis)
Call getDocument().getView().rotateToAxis(infoPositiveXAxis)
CALL closeDocument()
msgbox("")
'deschidere fisier
CALL openDocument ("D:\doctorat\MODELE ALTERNATOR\scripturi\stator.mnte")
'setarea unitatilor in milimetrii
Call getDocument().beginUndoGroup("Set Default Units", true)
Call getDocument().setDefaultLengthUnit("Millimeters")
Call getDocument().endUndoGroup()
'introducere dimensiuni
dim Rrext,Rrint,Hrdinte,Lrdinte,npoli,Rgheara,Lrbaza,Lgdinte,dist,Rrbaza,Lrotor,gizol
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Figure 7. The saving model

The program allows saving the models (Fig. 7) and retrieving of this for further modifications to the building with new data, which are made by environmental Magnet 6.11 Accessing computing environment for the analysis magnet field define boundary conditions, the currents that cross both the stator and rotor windings.

Magnet computing environment allows the choice of several ways of calculating the field, find the most used Newton Raphson method, and also choose the orders of the polynomial calculation.

By interpreting the results obtained in the analysis field (Fig. 8), can automatically change the input data to obtain a new constructive model to be analyzed.[6]

We gain precious time for the model construction of the alternator with the help of the program developed, without the need to use another software for drawing.

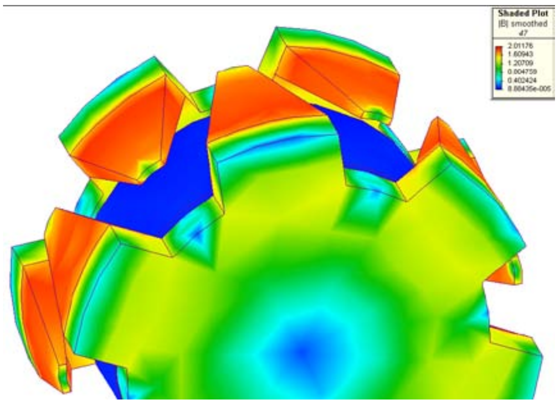

Figure 8. The magnetic induction on the claw-poles stator

V. CONCLUSIONS

The programs which realized field analysis based on the finite element method, come in help of the designer from the checks who can be made in usually time and with high precise, thus removing any errors made during in the design of electric machines, providing reached the designer intended purpose. These programs of analysis and verification ensure the safety of a proper design of the electric cars.

The dates obtained for various operating conditions imposed and verified from the experimental data will be used as reference data for future comparisons of prototypes under study work.

It aimed at establishing the optimal levels of saturation in different parts of the magnetic circuit (teeth, yokes), considering that the saturation level properly prescribed and produced has a beneficial effect under the aspect of control and minimize the effect of armature reaction on the main magnetic field.

Numerical investigations carried out aimed at optimizing the machine design by reducing the magnetic saturation of the poles' alternator into the construction of the rotor.

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