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STUDY OF ELECTROMAGNETIC FIELD IN CLAW-POLES ALTERNATOR

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Abstract: The paper presents the tridimensional analysis of electromagnetic field of an claw poles alternator, in whose construction has been used non-magnetic material, such aluminum, that form the rings in the rotor's structure. This structure aims to establish lower levels of saturation in the claw-pole of Lundell alternator. Reducing the level of saturation in the rotor, lead to reduction of the losses in hysteresis, the power will be exchangeable in the output of the machine, while achieving its growth the performances. **Keywords:** 3D analysis, claw-pole alternator, simulation, finite element method

INTRODUCTION

Due to the gradual replacement of hydraulic and mechanical organs of the auto vehicles with electrical devices, power demand in automobiles has greatly increased, where electricity plays a decisive role, the conventional vehicle generator (Lundell alternator) tends rapidly to the maximum that can charge.

The Lundell alternator is the most common power generation device used in cars. It is a woundfield three-phase synchronous generator containing an internal three-phase diode rectifier and voltage regulator. The rotor consists of a pair of stamped pole pieces (claw poles), secured around a cylindrical field winding. The field winding is driven from the voltage regulator via slip rings and carbon brushes. The output voltage of the alternator is maintained at about 14V DC, as this is the nominal charging voltage of a 12V lead-acid battery. The voltage is regulated at 14V by an internal controller that continuously samples the battery voltage and adjusts the field current accordingly. Electromagnetic behavior of the alternator with claw-poles and its interaction with the bridge rectifier, the load and the vehicle power system is generally considered as a spatial-temporal feature. Thermal model was validated by comparing calculation of temperature distribution with the measured values. [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. Theoretical expectations are compared with experimental results using a car alternator; the output power increases to 200% and significant improvement of efficiency are demonstrated at high speeds. [2]

Utilization of computational analysis allows for the substitution of expensive prototype construction at early design stages. Authentic simulations of the real machine behavior require advanced component modeling. Methods using numerical simulations based on finite elements are often used because permit 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.

Analytical models allow preliminary design studies, so the numerical simulations as an opportunity to validate and refine solutions based on analytical methods.

Henneberger S.A, Damerdash S.A., Viorel S.A. investigated the electromagnetic and thermal phenomena of Lundell alternator using the finite element method. Perreault's studies have investigated ways to extract more power from existing claw-pole alternators by using a rectifier switching system. Have also been proposed alternators driven by inverter, these can provide energy to a capacitive power factor and being able to extract about twice as much power from alternative to the low speeds.

Proposed solutions include also other types of electric machines: asynchronous machines, variable reluctance machines, synchronous machines with permanent magnet for surface and permanent magnet for interior: Boldea, Naidu, Liang, J.M. Miller s.a. The proposed alternators systems are expensive because the power electronics and the complex control. [3] Schulte describes two approaches for calculating the mutual inductance between rotor and stator of the synchronous alternator with claw-poles about the claw shape. 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. [4]

••• NUMERICAL ANALYSIS OF THE ELECTROMAGNETIC FIELD - THE CONCEPT

The numerical analysis 3D by finite element method for the electromagnetic field produced by electric drives, is currently, in terms of reliability of results obtained, one of the most powerful means for analyzing the electromagnetic field, for determining the parameters of these complex structures, indifferent of the field shape or the existence or absence of some symmetry.

FORMULATION FOR THE FINITE ELEMENTS METHOD

The software used in this paper is MagNet, 6.24.1 version, a product of Infolytica. Without many details, it will be still specified that for this software the general 3D formulation is based on the T- Ω method in which the magnetic field is represented as the sum of two parts: the gradient of a scalar potential and, in conductors, an additional vector field represented with vector-edge elements.

In a conducting medium, the equation to be solved is one in H of the following form:

$$\nabla \times [\nabla \times \overline{H}] + \frac{\overline{\sigma} \mu}{\partial t} \frac{\partial H}{\partial t} + \frac{\overline{\epsilon} \mu}{\varepsilon \mu} \frac{\partial^2 H}{\partial t^2} = 0$$
(1)

where μ is magnetic permeability tensor, σ is electric conductivity tensor, ϵ is electric permittivity tensor and H is magnetic field strength.

In a non-conducting medium, H can be written as:

$$\overline{H} = -\nabla \psi + \overline{H}_{s}$$
⁽²⁾

where \overline{H}_s is any source field that satisfies $\nabla \times \overline{H}_s = \overline{J}_s$, where \overline{J}_s is the current density in an eventual stranded coil, and ψ -scalar potential. [6]

THE NEWTON-RAPHSON METHOD

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.

Relationships formed between magnetic flux (B) and magnetic field (H) are generally nonlinear, over some materials present hysteresis, in "state" BH for a particular point in space and time depends on the previous magnetic values.

To extend the procedure for finite elements to include non-linear properties of materials are required a mathematical model to describe the properties of the material.

The software of field analysis used is based on the calculation method Newton Raphson who converges quickly, providing sufficient initial values. So, if $u^{(0)}$ is a matrix of values of the initial solution, u(1) can be write:

$$U^{(1)} = U^{(0)} + \delta U^{(0)}$$
(3)

where: $\delta u(0)$ - matrix of errors values.

$$(K(U) - Q) = F(U) = 0$$
 (4)

where: Q is independent by u, the factor F define equation (4) can be extended from multidimensional Taylor series.

The simple iteration scheme (9) Newton Raphson, as illustrated in Figure 1. b), it may not converge if the initial assumptions are not close enough solution. For this reason, is usual in practice, to get the initials startup by completing several steps of iteration before applying Newton Raphson method

In Newton Raphson is essential that curves



Fig. 1. Simple iteration scheme Newton-Raphson

made it to be smooth, this allowing to be made a better estimation of derivatives. [5].

The treatment of nonlinearities with the Newton-Raphson method and application of finite element method to solve the problems of field, for every iteration, is currently the most used method of analysis of the magnetic field of rotating electrical machines.

THE REALIZATION OF NUMERICAL MODEL OF THE ALTERNATOR WITH CLAW-POLES

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 car to be achieved through three-dimensional finite element numerical modeling.

It highlights sub domains characterized by different magnetic properties: magnetic core of the rotor (polar components as claws), axis machine made from the magnetic material, coil excitation, the stator magnetic core provided with notches in which are placed winding induced.

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. There are various studies related to various forms of cut or teeth geometry [3], we tried to make some options for changing them, to follow in the subsequent analysis of the influences on the electromagnetic field of alternative.

The program allows saving the models (Fig. 2) and retrieving of this for further modifications to the building with new data, which are made by environmental Magnet 6.11



Material type: © Default (depends on solver) © Linear © Non-linear	Method: Newton-Raphson Successive substitution (3D only)
Max. Newton iterations: 20	Newton tolerance: 1 %
Polynomial order: 1	CG tolerance: 0.01 %
Source frequency: 60	Hertz
Improve the quality of initial mesh before solving	
Close	Cancel Apply

Fig. 3. The solver options

Accessing computing environment for the analysis magnet field define boundary conditions, the currents that cross both the involution stator and the rotor.

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. (Fig. 3)

Realizing some analysis of the shape and size of the volume of air surrounding the model alternator (Fig.4), brings us attention over some influence of that, on energy stored in the model.

By interpreting the results obtained in the analysis field (Fig. 5), can automatically change the input data to obtain a new constructive model to be analyzed.

It won a precious time with automatic model building constructively us needs another soft drawing a constructive model.

The uniform level of magnetic saturation in the whole magnetic circuit is usually required, but it is seen that the magnetic flux density in the claw-poles roots is significantly higher in comparison with other magnetic circuit components and areas.

The representation of the magnetic induction along the claw-poles as so on the axis claws, but also on its edges for different excitation currents is made in Fig. 6.

The construction and optimal sizes of the claw poles are required by their role to converting the axial flow produced by the excitation winding in radial flow in air gape.

Begin from the experimental data, in the tridimensional analysis of the alternator with claw poles, we can make comparisons with different configurations of the numerical model of the alternator.



Fig. 5. The results obtained with Magnet 6.11

Thus, we can observe how the inductance of the claw poles depends by the geometry and the nature of material from the rotor is achieved.

The uniform level of magnetic saturation in the whole magnetic circuit is usually required, but it is seen that the magnetic flux density in the claw-poles roots is significantly higher in comparison with other magnetic circuit areas and components. Improvement of claw-pole design is therefore advisable. On the other side, increasing the cross-section area of the claw-pole root causes reduction of exciting winding space. The numerical analysis carried out covering two constructive variants of the rotor unit.

Fig. 4. The volume of air

surrounding the alternator model

The first variant considered involves a distribution of aluminum between the rotor claws, replacing the air gape with aluminum (Fig. 7. a.). The second consists in a ring shape build on the crown of the rotor to reduce the saturation level, but only space between the claws (Fig. 9. b.).

In Fig. 8. have represented the magnetic induction over along the claw pole for the cases: simple alternator, resulting from design and build the model studied, for the case when the air gap between the claws is replaced with

1.6 Inducția megnetică [T] 1.4 Iexcit = 1A 1.2 Iexcit = 2A 1 Iexcit = 3A 0.8 Iexcit = 3,5A 0.6 0.4 0.2 0 15 20 25 35 0 10 30

Fig. 6. The representation of the magnetic induction along the claw-poles

aluminum, and, the case when the aluminum is used as the ring shape on the crown of the rotor, but only in free space of the claw. It can be notice, an increase in saturation along the axis of claw pole in the first case, with the aluminum between the claws beside to the case of standard alternator.

1.8



Fig. 7. The repartition of aluminum in the rotor structure of the alternator





Fig. 8. The magnetic induction over along the claw-pole axis



when the aluminum is in the shape of rings on the crown of the rotor. There is a sharp reduction in magnetic saturation in the aluminum zone, but the decreased saturation is present and to the claw pole tip (up to 5%), there is initial a lower saturation.

The results obtained from experimental measurements, from the aluminum version of the crown ring rotor, show us that reducing the saturation, are going to decrease the output power of the alternator with claw-poles.

Changing the magnetic circuit of the alternator is based on the perspective to optimization the results to be included in designing a prototype of the alternator with claw-poles.

* **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 make 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.

Numerical investigations carried out aimed at optimizing the machine design by reducing the magnetic saturation of the poles' alternator which is due to the interaction of aluminum segments enter into the construction of the rotor.

The present paper deals with specific issues concerning modeling and numerical analysis of an alternator with claw-poles, with certain portions of nonmagnetic material (Al), using the finite element method. The introduction of the nonmagnetic materials in the rotor assemble as the rings shape on the rotor crowns, try to establish some lowest levels of the saturation in different parts of magnetic circuit (teeth, yokes) and to increase the useful power of the alternator.

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