Calculation and Measurement of Time Characteristics of Local Field Quantities in the Air-gap of Claw-Pole Alternators

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Abstract— **This paper deals with the calculation and measurement of local field-quantities in the air-gap of claw-pole alternators. The numerical procedures are based on three-dimensional Finite Element Methods (FEM). It is important to investigate the local field and force-density distribution on the surface of the stator in order to use these results for dynamic mechanical displacement calculations. This is the basis for acoustic prediction of the audible noise. The calculation method is presented for global values, like induced voltages, and for local time characteristics, like force-densities and flux-densities. The inductions on the stator surface are measured using thin Hall-Effect devices at different stator-tooth positions. All presented results are being compared with measurements on a simplified test-alternator and they show a good agreement.**

I. Introduction

Claw-pole alternators are used in huge numbers as generators in vehicels. Because of their special shape of claws, high saturation level and the effects of leakage flux, FE methods must be used in order to predict the electrical and mechanical behavior of the machine. The main requirements of the alternator are the improvement of output performance, the increase of efficiency and the reduction of audible noise.

To compute the audible noise, the mechanical vibrational behavior must be investigated, so it is necessary to get information about local field time quantities like flux-densities or force-densities on the stator surface. Both this calculation method and its verification by measurements are presented in this paper. The investigations are done on a test claw-pole alternator which is shown in Fig.1, but the calculation method can also be applied to any generator out of series production. The generator in Fig. 1 (p=12 poles) has a pole pitch ratio of $\alpha_i = 2/3$ and rectangular claws and stator teeth. This is different from the series alternator.

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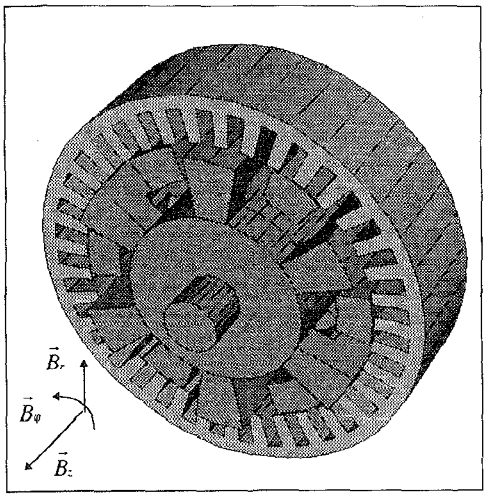

Fig. 1. Geometry of the test alternator

II. Calculation Methods

The calculation of the magnetically forced vibration is divided into three parts: At first the transient behavior of the magnetic field vectors is calculated. Subsequently the force density on the stator surface is determined and transformed into the spectral mode. Finally the components of force are used as forward signals for the displacement calculation.

For the surface force computation, it is very important to verify the exact local field distribution.

A. *Flux-density time characteristics*

As the magnetic field of the generator has three components almost everywhere, it is not possible to carry out 2D FEM. The calculation of the magnetostatic field is based on a model which consists of tetrahedras [1],[2]. The model is created using the commercial software package Ansys, field calculations are done using solvers programmed at the Institute of Electrical Maschines (IEM) and the commercial FE-programm MagNet3D [2]. The procedure of magnetic field calculation for the claw-pole alternator is described in detail in [3]. One result of the global induced voltage at no-load as function of the excitation current for the alternator (Fig. 1) is shown in Fig. 2. The correspondence of measurement and calculation with a maximum relative error of 3.53% is very

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good. The next verification of the global calculated re-

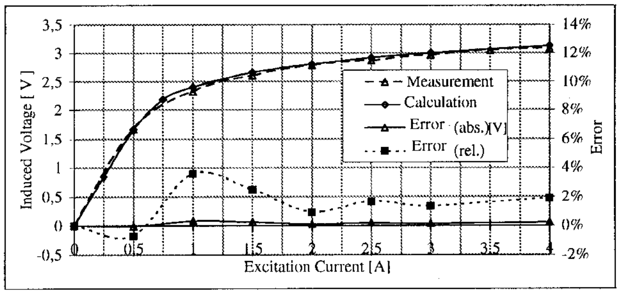

Fig. 2. Measurement and calculation of the no-load characteristic of the test-alternator, relative and absolute error

sults are the time characteristics of the induced voltage which is shown exemplarily for an excitation current of $I_f = 1.0A$ in Fig. 3. The function of induced voltage

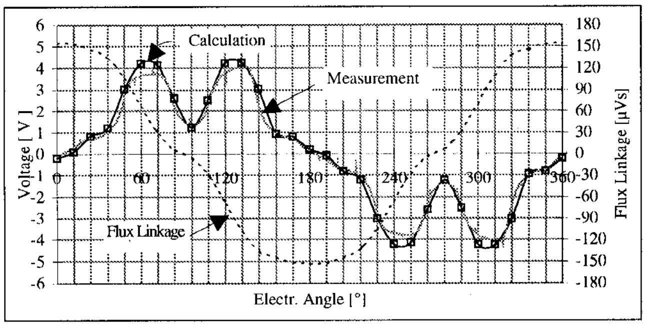

Fig. 3. Measurement and calculation (derivation of the **flux** linkage $U_{ind} = -d\psi/dt$) of the induced voltage at no-load, excitation current $I_f = 1.0A$

differs from the series generator, because of the straight claw-pole form. The correspondence of measurement and calculation is good enough to start the investigations of the local field values.

To get the time characteristics of the local flux-linkage distribution, the periodic boundary conditions are used with only one pole of the generator is being meshed. The cylindrical components of induction B_r,B_φ and B_z at two different points $P(r,\varphi,z)$ and $P'(r,\varphi+\pi/p,-z)$ are connected as follows:

$$B_r(P) = -B_r(P'),\ B_\varphi(P) = -B_\varphi(P'),\ B_z(P) = B_z(P'). \qquad (1)$$

Using these conditions and several stator-rotor positions (here 5 positions, 60^0 electrical, one tooth-pitch mechanical), it is possible to calculate 30 time values for each element within one tooth-pitch [4]. These 5 models are shown in Fig. 4 with lines of constant potential (results of one no-load calculation).

B. Force-density time characteristics

As the time-characteristics of the local field distribution are extracted, the force-densities can be calculated with

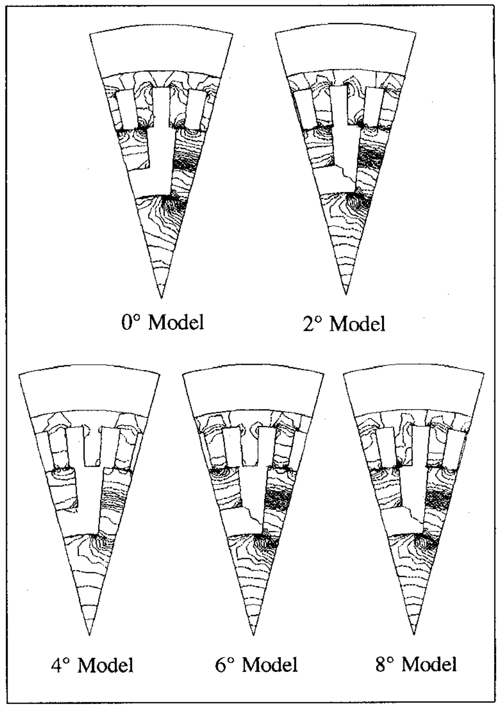

Fig. 4. Five models with different stator-rotor positions as slice at the centre of the generator

the help of the following equation [5],[6]:

$$\vec{\sigma}(P) = [B_n(H_{1n} - H_{2n}) - (w_1' - w_2')] \cdot \vec{n}_{12}. \qquad (2)$$

The periodic boundary conditions of forces in comparison to equation (1) change into the following form:

$$\sigma_r(P) = \sigma_r(P'),\ \sigma_\varphi(P) = \sigma_\varphi(P'),\ \sigma_z(P) = -\sigma_z(P'). \qquad (3)$$

Forces and force-densities are computed at the centre of triangle surfaces. This results in a much higher accuracy than using node forces because there are only components which are normal to the material surface.

It is also possible to describe the force-densities with 30 time steps, this results in a maximum calculation of 14 harmonics. Fig. 5 shows the calculated time dependent force-density results. These results are extracted at 4 different positions: The centre of the stator tooth and 3 positions which are near by the Hall-Generator positions. They are used for local flux-density measurements shown in Fig. 7. The only possibility to verify these calculated results are local flux-density measurements in the small air-gap (0.35mm) of the alternator.

III. Flux-Density Measurements

A. Method

To verify the calculated local flux-density time chracteristics in the air-gap of the alternator, Hall-Effect sensors shown in Fig. 6 are used. The sensors are cemented at different positions on the surfaces of the stator teeth

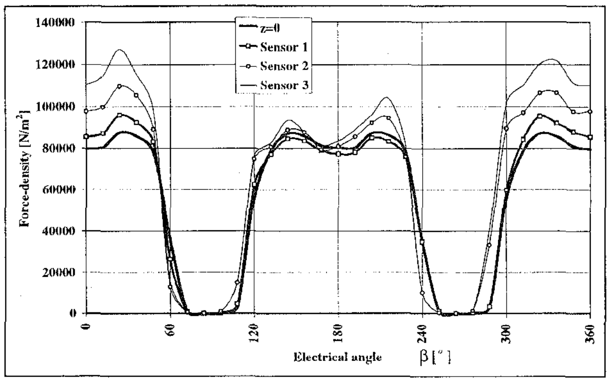

Fig. 5. Calculation of the time functions of the force-density at the different sensor positions (generator no-load)

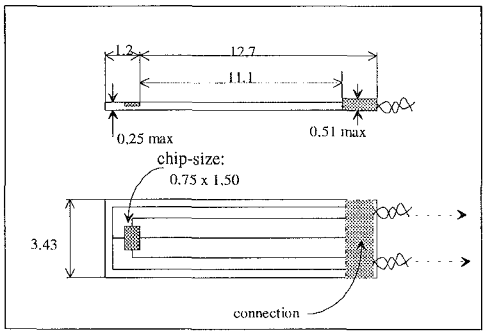

Fig. 6. Main dimensions of the Hall-Sensor (in mm)

(Fig.8). They are not located at the centre line of the stator tooth but slightly beside it, so it is possible to get more measurement positions by changing the sense of rotation.

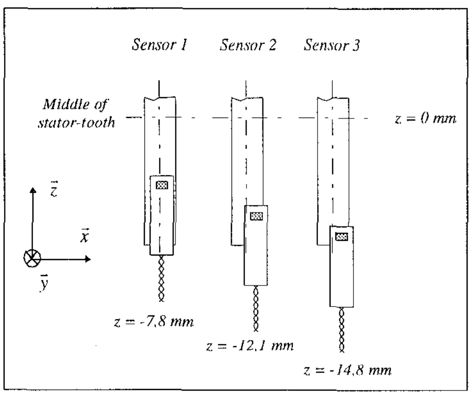

Fig. 7. Sensor positions at the stator-teeth

B. Results

In Fig. 5 the time characteristics of local force-densities at the sensor position are shown. The base of these results are flux-densities time values extracted from five FE-Models of the alternator. The time functions of inductions also contain 30 values and they are prensented in Fig. 8 (top) and compared with measurements exemplarily for

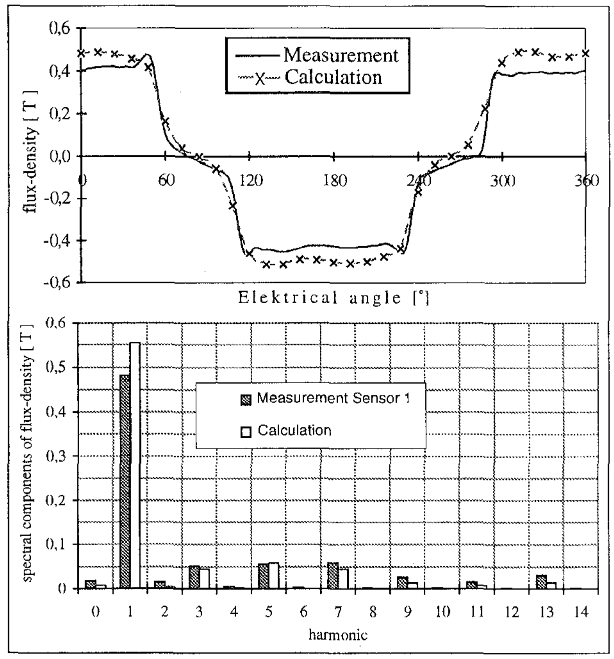

Fig. 8. Measurement and calculation of the flux-density (Sensor 1) at no-load, $n = 1000rpm$

sensor-position 1 at a speed of 1000 rpm. The difference between calculation and measurement is very small and mainly caused by two reasons: The Hall-Effect chip has a geometric extention of $0.75mm \times 1.50mm$ while the stator tooth width is about 4 mm. So it is difficult to define an exact geometric point in the FEM-Model for the sensor-position. Another reason is the influence of eddy-currents. There is no armature reaction at no-load, but the rectangular claw-pole form leads to many components of higher harmonics, which cause eddy-currents in the laminated stator package, especially for higher speeds. It can be shown, that the difference between measurement and calculation is smaller for lower speeds.

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