REDUCTION OF FORCE EXCITING INFLUENCES TO DECREASE RADIATION OF ACOUSTIC NOISE IN SYNCHRONOUS MACHINES

Stephan Schulte, Kay Hameyer

RWTH Aachen University, Institute of Electrical Machines
Schinkelstr. 4, 52056 Aachen, Germany, e-mail: stephan.schulte@iem.rwth-aachen.de

Abstract – **Salient-pole synchronous machines (SYM) as claw-pole alternators (CPA) state most common energy converters in automotive applications for decades. For the sake of cost effectiveness, relatively low efficiency as well as a comparatively high radiation of acoustic noise is accepted. Increasing efforts to enhance output power on the one hand is accompanied by growing ecologic consciousness on the other hand, requiring the improvement of the machine design. Though design modifications, such as rotor claw chamfering, leads to a reduction of noise radiation, output power is reduced at the same time.**

This paper puts focus on the analysis of different stator winding configurations and their effect on body sound. The decrease of force exciting influences responsible for the noise at reasonable output power forfeit is aimed.

I. APPROACH

Commonly used CPAs consist of a claw-pole rotor and a stator of stacked laminations, carrying a regular three-phase winding as per Figure 1.

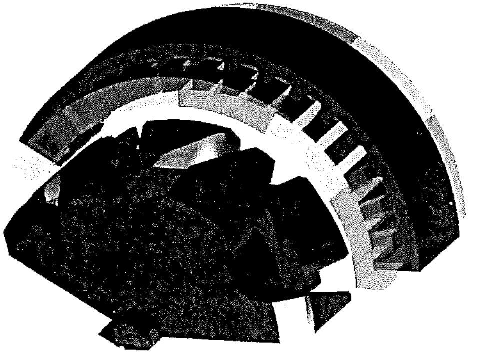

Fig. 1: Rotor and stator (with windings) of a CPA.

The correspondence of air-gap field and stator magnetomotive force (mmf) excite forces on the stator teeth, leading to deformation and furthermore to radiation of acoustic noise.

The utilization of winding systems with more than three phases reduces the currents density and therefore the mmf per phase as a matter of fact. Choosing a 6-phase winding [2] allows for the operation as two independent 3-phase systems with arbitrary connection – either systems in star or delta connection or one different than another.

If free to displace one of the 3-phase windings against the other, the phase shift of the currents of both windings systems varies due to the effect of mutual induction.

The stator contains a two layer winding, one for each winding system. Figure 2 depicts a cross section of the stator of a 6-phase CPA, indicating the displacement of winding system #1 against system #2 in principle – exemplarily shown for one stator slot. Displacement steps of one entire slot pitch appear reasonable according to Fig. 2, showing slot fillings as lumped windings. In fact, the slots contain a number of w windings. This number of windings may be distributed onto more than one slot, leading to a distributed arrangement of accordant phase currents and a slurred mmf distribution.

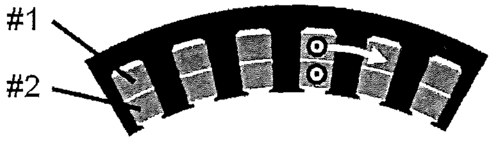

Fig. 2: Two-layer winding (with displacement).

Figure 3 shows phase currents of system #1 (index 1) and accordant currents of system #2 (index 2) for two selected displacement angles Δα (→ details and particular values not presented due to nondisclosure obligation).

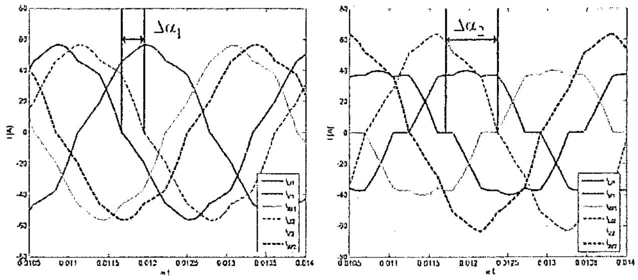

Fig. 3: Phase current mutation due to winding displacement.

The mutation of the current shape, dependent on the winding displacement, affects amplitude, phase angle and harmonic content of the currents [3], [4]. Figure 4 indicates differences in the harmonic current components of one selected phase current (belonging to system #1) for the given examples as of figure 2.

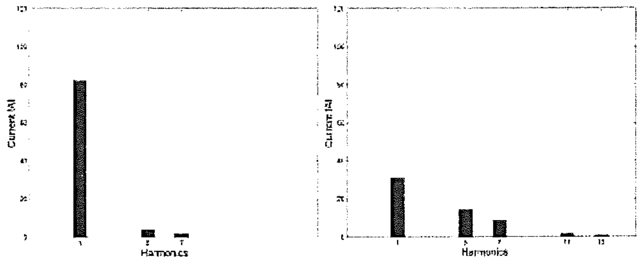

Fig. 4: Current harmonics of selected phase current of system #1.

Thus, since applicable phase currents and related flux linkages state the torque creating and force exciting components (the latter applied to stator teeth), the harmonic content of stator teeth forces can be influenced. Therefore, the mutual displacement of the two 3-phase winding systems provides a means to reduce significant force excitation leading to lower radiation of acoustic noise, as to be presented in the following.

II. COMPUTATION

A simulation model of the alternator, implemented in VHDL-AMS [5] for hardware description, is used to determine all phase currents of both winding systems accordant to the mutual displacement of their winding system. The machine model contains a set of differential equations for phase currents, flux linkages, mutual inductances, and torque as well as motion equations. This machine model is embedded into a simplified vehicle power system consisting of excitation circuit, B6 rectifier bridge and electrical load. The entire environment is called system model.

All 6 phase currents (Fig. 3) determined in the system simulation are used for the excitation of an electromagnetic Finite Element model of the alternator. The accordant flux density distribution of the alternator is simulated utilizing the transient 3D solver from iMOOSE [6]. Hence, the force density on the stator teeth is determined. Processing structure-dynamical simulations on a congruent mechanical model, based on the previously determined force exertion, stator and housing deformation ensues, stating the basis of the computation of body sound.

III. RESULTS

As of [1] the fifth and even more the sixth harmonic of the body sound appear dominantly for the radiation of acoustic noise so that focus is put on the reduction of these harmonics. Figure 5 proves a configuration to be found with a significant reduction of 13dB of the 6th harmonic of the body sound as a result of a reasonable choice of the winding displacement (left) – compared to the worst case configuration (right).

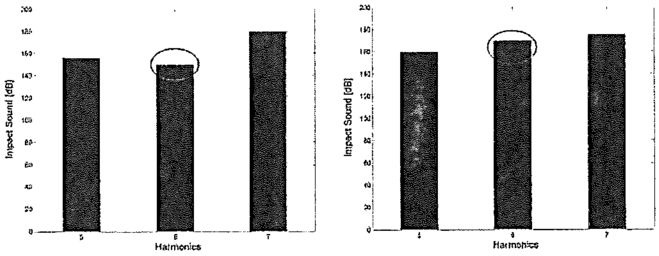

Fig.5: 5^{th}-7^{th} harmonics of body sound based on accordant winding configurations (best: left, worst: right).

The reduction of the sixth harmonic of the body sound comes along with an unwanted reduction of the output power for the chosen winding configuration.

In general the output power of an alternator in vehicle applications computes from the output current (which is the DC-link current in the B6 bridge) and the DC-link voltage (equal to the battery voltage). The DC-link current, resulting from adding all 6 currents portions of the participating stator phases is depicted in Figure 6. Different shapes of the DC-link current and therefore a varied composition of harmonics contained are studied - not providing information regarding the output power.

Therefore, a depiction of the root-mean square (RMS) values of the DC-link currents is required. See Fig. 7 for three samples, showing a selection of prominent winding configurations (best and worse case concerning output power as well as the chosen variant regarding lowest radiation of body sound 6^{th} harmonic).

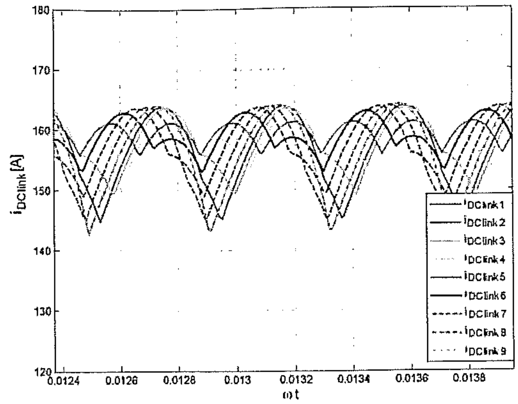

Fig.6: DC-link currents for different winding configurations.

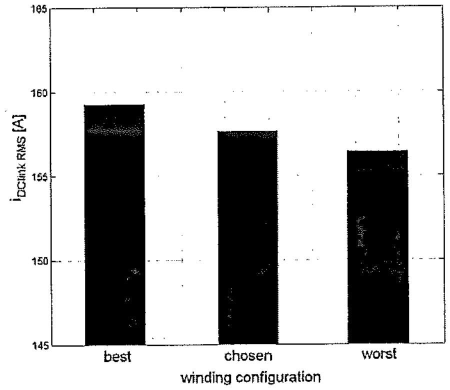

Fig.7: DC-link currents (RMS) for selected winding configurations.

IV. CONCLUSIONS

Varying the mutual displacement between two independent 3-phase systems placed in a stator of a regular claw pole alternator (forming a 6-phase system) allows for influencing amplitude and shape and therefore, the harmonic content of force exciting parameters such as current and flux linkage. A particular displacement angle is found featuring a minimum of body sound generation, still stating an acceptable forfeit of the output power coming along herein.

REFERENCES

[1] L.Xu, L.Ye; Analysis of a novel stator winding structure minimising harmonic current and torque ripple for dual sixstep converter-fed high power AC machines, *IEEE Trans. Industry Appl,* vol. 31, no. 1, 1995

[2] S. Schulte, C. Kaehler, C. Schlensok, G. Henneberger "Combined Analytical and Numereical Computation Approach for Design and Optimization of 6-phase Claw-Pole Alternators", IEE Journal on Proc.-Sci. Meas. Technol., Vol. 151, No. 6, November 2004.

[3] S. Schulte, C. Kaehler, C. Schlensok, G. Henneberger, "Stator Optimization of 6-phase Claw-Pole Alternators Using Asymmetric Winding Arrangements" COMPEL, vol. 23 no. 3, November 2004.

[4] S. Schulte, G. Henneberger, "Current-Waveform Analysis of 6-phase Claw-Pole Alternators using VHDL-AMS Implementation in Simplorer" Proceedings ICEM 2004, Cracow

[5] IEEE "*VHDL-AMS: Very high speed Hardware Description Language – Analog and Mixed Signals*", IEEE Standard 1076.1-1993

[6] D. van Riesen, C. Monzel, C. Kaehler, C. Schlensok, G. Henneberger, "iMOOSE - an open-source environment for finite-element calculations." IEEE Transactions on Magnetics, Bd. 40, Nr. 2 S. 1390-1393, March 2004