Noise Reduction using Multi-Phase Windings for Synchronous Machines

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I. INTRODUCTION

Synchronous machines with electrical excitation state most common energy converters for mobile and stationary appliances. Growing ecological consciousness leads to increasing demands for the reduction of acoustic noise radiation, notably for vehicle application. The replacement of commonly used 3-phase stator windings by multi-phase windings comes along with the reduction of current density per phase, various options for the phase interconnection and the winding arrangement in the stator slots as well.

This paper puts focus on the variation of the stator winding arrangement in order to reduce force excitation, significant for the emission of body sound.

II. APPROACH

Multi phase stator winding systems with reasonable numbers of phases due to manufacturability and accordant stator-teeth saturation (such as 5, 6 or 7) generally lead to lower current ampacity per phase compared to commonly used 3 phase windings – same output power assumed. The choice of 6 stator phases additionally provides the opportunity to mutually displace windings if split up into two independent 3-phase systems.

Fig. 1: Two-layer winding (with displacement).

Designed as two layer winding, Fig. 1 depicts the slot wise mutual displacement of winding system #1 against system #2 (exemplarily shown for one slot).

The displacement step of one entire slot pitch appears reasonable according to Fig. 2, showing slot fillings as lumped windings. In fact slots contain a number of *w* windings. This number of windings is in general distributed onto more than one slot, leading to a spread arrangement of accordant phase currents and a slurred mmf distribution. This leads to a varied appearance of the phase currents due to the effect of mutual induction, as a function of the displacement $\Delta\alpha$.

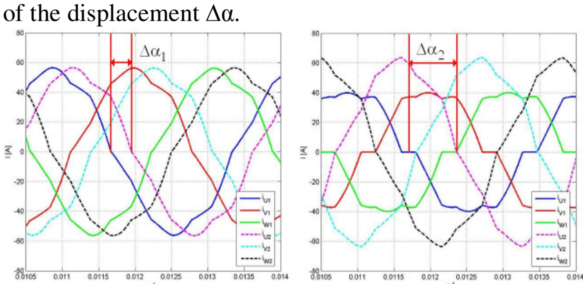

Fig. 2: Currents of systems #1 and #2 (due to $\Delta\alpha$).

The mutation of the current shape, dependent on the winding displacement affects amplitude, phase angle and harmonic content of the currents and therefore states a modified excitation for forces on the stator teeth.

III. SIMULATION

Phase currents as of Fig. 2 are determined in system simulations, consisting of a machine model and a simplified environment with B6 rectifier bridge and electrical load, for various displacement angles $\Delta\alpha$. Simulation results, used for excitation to compute the flux density distribution of an electromagnetic Finite Element model using a transient 3D solver, state the basis for the determination of the force density on the stator teeth. This force density distribution further applied to an accordant mechanical model and then processed in structure-dynamic simulations leads to the deformation of the machine, from which the emission of the body sound can be computed.

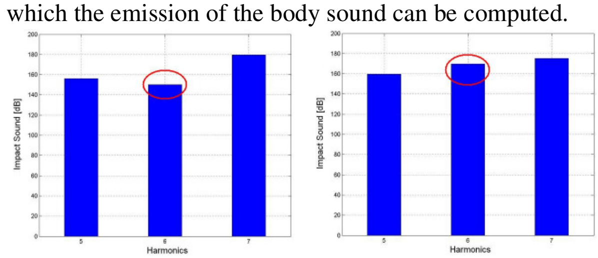

Fig. 3: Impact sound harmonics (best: left, worst: right).

As of [1] the fifth and even more the sixth harmonic of the impact body sound appear dominantly for the radiation of acoustic noise so that focus is put on the reduction of these harmonics. Figure 3 proves a configuration 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). Improvement of the acoustic behavior comes along with the attenuation of the output power, which is still acceptable [2] for the shown case as of Fig. 3 (left).

IV. CONCLUSIONS

The variation of winding arrangements based on mutual displacement of two winding systems against each other allows for the reduction of significant harmonics of the body sound at reasonable output power forfeits.

V. 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.