Summary of the doctoral dissertation

(implementation doctorate))

Title : Noise reduction of traction motors

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The aim of this dissertation was to develop design guidelines for traction PMSMs that allow for the reduction of emitted acoustic power generated by the electromagnetic circuit without deteriorating the electromechanical characteristics. The research question posed was: *Is it possible to select the design parameters of the magnetic circuit and armature winding of a permanent magnet synchronous motor, intended for traction drive applications, in such a way that the required electromechanical characteristics of the drive are achieved, while simultaneously limiting the acoustic power generated by the motor during operation to a level non-intrusive to the environment?* The theory was practically verified that, through conscious selection of the number of slots and poles, slot geometry, overall dimensions, magnet arrangement, increased stiffness of the stator/housing, and control of the supply method, it is possible to reduce the electromagnetic forces responsible for vibrations and noise levels, without compromising efficiency or the power to weight ratio of the motor.

In the theoretical part of the work, a detailed analysis of computational methods used to study vibroacoustic phenomena in traction permanent magnet synchronous motors was carried out. Classical analytical methods were evaluated, which enable fast determination of the basic frequencies of electromagnetic forces and the identification of spatial patterns responsible for the occurrence of vibrations and increased noise levels. Hybrid methods were also analyzed, combining the advantages of equivalent-circuit models, 2D numerical calculations, and simplified modal analyses, allowing for more precise prediction of electromagnetic interactions in the air gap. These methods were complemented by vibroacoustic hybrid calculations using 3D FEM, which reproduce the geometry of the machine in the most realistic way, including the housing, windings, and cooling system. However, their preparation is the most labor-intensive, and the calculations themselves require significant

computational resources and time. Based on the analysis, the Author proposed the 2D hybrid method as the optimal computational approach.

An extended hybrid computational method was developed in the dissertation, combining 2D FEM analysis with analytical approaches, numerical modeling, and laboratory testing. This method enables fast and reliable estimation of the vibroacoustic properties of traction motors already at the design stage, before costly prototypes are built. Its essence lies in determining the frequencies of spatial patterns responsible for noise and introducing corrections accounting for the influence of inverter supply and the real motor housing. This makes it possible to identify resonance frequencies and predict the acoustic power level with high accuracy, thereby optimizing motor design before physical construction. A series of laboratory tests of both prototype and series-produced motors was conducted to verify the developed models and the results of electromagnetic and vibroacoustic calculations. The tests confirmed the validity of the proposed method and allowed for the determination of correction factors for acoustic power levels resulting from inverter supply, as well as the influence of the real housing and stator core not considered in the vibroacoustic model. A practical method was also proposed for determining the inverter correction factor based on the difference in *SWL* between motoring and generating modes under the same thermal state and speed.

The developed methodology consists of integrating, within a single coherent approach:
a) selection of slot/pole combinations and the geometry of the stator and rotor with respect to reducing electromagnetic excitations,
b) modal analysis of the real housing and wound stator core with identification of resonance risks,
c) defining and applying *SWL* correction factors linking calculations with measurements, under inverter supply and with consideration of the actual motor housing.

The developed guidelines and correction factors can be applied both in prototyping and in the optimization of series production of traction drives, which has direct practical significance for the national development of electromobility. This work also opens perspectives for further research into the sources of acoustic power in multi-inverter systems, the impact of housing manufacturing technologies on natural vibration frequencies, and the tighter integration of electromagnetic, thermal, and acoustic models in CAE environments.