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Coupled thermal electromagnetic numerical modelling of an effective heat dissipation process from an electric motor

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Environmental and political tendencies prompt the industry to reduce the usage of non-renewable energy sources to mitigate anthropogenic degradation of the environment. It leads to, e.g. increase of the meaning of electrical power drives in transport and other branches of industry, at the same time replacing internal combustion engines that are characterised by a lower efficiency of energy conversion. In this case, the electric motor construction process ought to be based on the best engineering achievements grounded on the multi-physical analyses. Therefore, in the electric motor design process, the thermal analysis should play an important role. It allows to estimate the maximum temperature in the machine and to find the location of the potential overheating. The motor construction should also be protected from reaching a temperature higher than allowable that may lead to the machine failure. It is especially important for motor elements such as winding insulation. Moreover, thermal analysis allows for reduction of the machine size with maintaining the safety margin and thus also allows for the material cost reduction. On the other hand, the heat dissipation intensifications implemented on the basis of thermal analysis allows to overload the machine and reduce the temperature of the specific motor elements, e.g. windings. The amount of the copper losses is connected with windings resistance that is temperature-dependent. Therefore, the thermal motor behaviour optimisation could also lead to the reduction of the copper losses in the machine. As a result, the lower temperature of the internal motor components could also ensure maintaining the operational point beyond demagnetization of the permanent magnets in motors such as Permanent Magnet Brushless DC (PM BLDC) motor. This all mean that the thermal analysis should always be included in the electric motor design process.

Therefore, the main aim of the dissertation is the thermal analysis of the selected PM BLDC low power motor. Moreover, the heat dissipation intensifications, based on passive techniques, were proposed and then verified experimentally and numerically.

Firstly, the dissertation describes experimental activities carried out during the research. The measurement procedures are described as two independent experimental campaigns performed on the dedicated test rig. The first one focused on the measurements of the air velocity within and around the analysed motor and simultaneously on the temperature measurements. In the first experimental campaign, constant temperature anemometers were positioned in 28 positions to collect the values of the vertical velocity component of the hot air above the motor installed in the test rig. Moreover, two velocity components were recorded using Laser Doppler Anemometry technique within the rear part of the investigated motor. During the first experimental campaign, thermal measurements were also conducted using a set of 22 calibrated thermocouples. The temperature and velocity measurements allowed to investigate the natural convection phenomena occurring in the motor losses dissipation. First experimental campaign allowed to measure 11 operating points of the motor work. The second experimental campaign was focused only on the thermal measurements using a set of calibrated thermocouples and infrared thermography. In this campaign, different passive heat dissipation intensification concepts were investigated. During the second experimental campaign, 6 operating points were recorded for each variant of heat dissipation enhancement.

The experimental part of the research was used to validate the created computational fluid dynamics (CFD) models. These models were built on the basis of the motor complex geometry. During the numerical research, two thermal models were introduced to investigate thermal motor behaviour. The first one was formulated and validated in the conditions occurring in the first experimental campaign. The second thermal model was created and next validated on the base of the second experimental campaign. Moreover, it covered the proposed heat dissipation intensifications. The models were based on the standard governing equations used in CFD, while many of the model properties were implemented as the user defined functions. The motor losses were implemented in thermal models as the volumetric heat sources allocated to windings, core and bearings. Heat sources derived from Joule heating was calculated as a function of temperature. Moreover, the electromagnetic model of the motor work is also shown and its coupling procedure with the second thermal model is described. In the developed thermal model, one of the important aspects of the model properties was the anisotropic character of the windings thermal conductivity. The results of the numerical models showed a satisfactory consistency with the conducted experiment.

In this dissertation, three ways of heat dissipation improvement from the electric motor windings have been investigated. In the first step, a thin graphite layer, characterised by a high emissivity, was used to increase the radiative heat transfer from the motor test rig. Then, the concept of an external surface extension by using different radiator types was tested. The last case of the heat dissipation improvement was to introduce the thermal filler material into vacant zones of the stator. Those three concepts were tested during the second experimental campaign and using the second numerical model. Moreover, the combination of the most effective methods was also analysed.

The average winding temperatures that were measured during experiments in the reference state at the nominal rate and no heat removal enhancement reached the temperature values of 68 K above the room temperature. The numerical model results indicated the same tendency. The first variant of heat dissipation improvement was based on covering the external surfaces of the machine by high emissivity material that allowed to decrease the temperature of the windings by approx. 4 K, to the level of 64 K above the room temperature. This first variant of heat enhancement accompanied the next ones in further variants. The second variant of heat dissipation improvement was based on the application of two types of radiators on the external motor surfaces. The usage of the first radiator characterised by a smaller outer area allows for reducing the winding temperature by 9 K compared to the case without heat removal enhancement. The application of the second radiator having bigger outer area resulted in the decreasing of the winding temperature by 16 K in case of the second radiator referring both to the rise above the ambient temperature and comparing to the case before modifications. In the next variant, an application of the thermal filler (potting material) within the motor casing in the free space of the stator allowed to decrease the average temperature of the windings by 18 K referring to the ambient temperature and comparing to the case before modifications. The last thermal motor test was conducted also with the thermal filler and with the bigger radiator. This combined method allowed to reduce the temperature by approx. 30 K comparing to the original motor construction and referring it to the ambient temperature. Therefore, the combined heat transfer intensification method, tested as the last variant, was the most effective. All numerical results of the investigated heat improvements show satisfactory consistency with the conducted measurements, while a lower accuracy was observed with thermal filler application concepts.