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Multiscale Computational Models for Analysis and Advancement of Drying Process of High Voltage Resin Impregnated Paper Bushings

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Abstract

The main objective of that thesis was to develop and validate the method which could be applied for analysis and advancement of the drying process of high voltage RIP bushings. Drying of paper, which is one of the main materials used in manufacturing of high voltage bushings, is essential part of the production process. Assuring low moisture level is critical for product functionality, quality and lifetime. Different methods may be utilized for drying of paper and in this thesis the vacuum drying process is considered. In such process several drying cycles, which consist of heating period and vacuum period are used. Drying programs may differ in numbers of drying cycles and duration of the heating and vacuum periods. These parameters have direct influence on efficiency and quality of the whole process and by their proper selection drying efficiency may be controlled and optimized.

In case of any manufacturing process, of which the vacuum drying of RIP bushings is the example, the methods for its analysis are based on experiments and/or computer simulations. The method proposed in this thesis is utilizing numerical modeling at different scales. The experiments are also applied, but only for validation of the computational models.

The first numerical model, that may be called full model or material scale model, is based on CFD calculations. It consists of the well-known equations for mass and heat transfer, but also additional formulas like the one for water evaporation from the paper surface. It was build using commercial software package ANSYS® Fluent. The accuracy of result from CFD calculations was evaluated by their comparison to measurement data obtained from drying experiment in which small model of the RIP bushing was utilized. The good agreement between measured and computed temperatures as well as total water content confirmed, that model includes all relevant phenomena and may be used for process analysis.

The essential advantage of the full CFD model is analysis of changes in moisture and temperature distribution inside the bushing – in all parts and materials – during the whole drying process. On the other hand its main drawback is high computational effort resulting in long calculation time. Optimization of drying process would require calculation of many drying scenarios and for that reason direct application of the full CFD model for that purpose would be difficult.

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The second numerical model, that may be called reduced scale model of product scale model, is based on proposed drying kinetics functions. These functions predict changes in temperature and moisture distribution in drying process of bushing. However, the obtained results are limited to higher scale, which means for example average paper temperature instead of temperature distribution or total water content instead of moisture distribution. The main advantage of that model is very short calculation time, that allows analysis of many drying scenarios and process optimization.

The reduced scale model requires development of drying kinetics functions, which is done basing on the results from limited number of drying experiments with defined initial conditions and process parameters. The replacement of actual test with CFD simulations is proposed in this work due to potential difficulties in preparation and conducting of real experiments.

The proposed approach for analysis of vacuum drying process of RIP bushing by utilization of numerical models at different scales is tested and validated. The drying process of the small model of the RIP bushing is investigated and two drying scenarios with different drying efficiency are developed. Further, two drying experiments are performed in laboratory and changes in temperature distribution and total water content are measured. These results are compared with the predictions of the reduced order drying model and the obtained accuracy confirms that new approach may be utilized for at least quantitative analysis and optimization of vacuum drying process of paper coils.

The example analysis of the drying process of the small samples of the RIP bushings was done in order to demonstrate the possible options for the process improvement. It was confirmed, that the efficiency of the drying process, however it would be defined, might be controlled by the number of the drying cycles as well as the durations of the heating and vacuum periods.

Finally, the proposed methodology is validated using the full scale product and the actual drying process of RIP bushing. Again, two drying scenarios are developed and tested. Due to confidentiality of the results only selected data are presented, but they confirm the applicability and usability of the proposed method, that is based on the multiscale computational models, for the analysis of the industrial drying process of the RIP bushings.