Finite Element Analysis and Evaluation of Stator Insulation in High Voltage Synchronous Motor

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Abstract — In this paper, 2-Dimensional Finite element analysis is used to compute the electrical field in stator slot of a synchronous motor. The electrical insulation between the conductors and the edges of slot is evaluated. Secondly the slot-opening electrical field, which is not uniform, is calculated by using 3-Dimensional Finite element method. The discussion of insulation structures of slot-opening for anti-corona is conducted. A lumped circuit equivalent model is constructed for the inter-turn insulation at the impulse over voltage excitation. The inductance of the coils are achieved by using magnetic field FEA considering skin effects. The capacitances of the coils are calculated by using electric field FEA respectively. Finally the evaluation of stator insulation using Finite element method is presented.

I. INTRODUCTION

Because of the manufacturing or long-time operation, there might be some air gaps or defects in the insulation of the stator. The air gap or defects will make the local electric field distribution distortion. The position of the maximum field is concentrated in the air gap or defects, in that case, partial discharge might occur in air gap or defect, which would undermine the solid insulating material gradually. Thus, analysis of electric field distribution in synchronous motor is very necessary. In some cases, AC synchronous motor stator windings with the multi-turn coil may undergo a switching-pulse overvoltage, which would destroy the inter-turn insulation materials. Diako Azizi analyzed the impact of the destructive factors on the stator slot insulation using finite element analysis in 2009 [1]. James H described some laboratory tests and finite element simulations that examined the effect of applied surge test voltage and number of applied pulses on voltage endurance life in 2005 [2]. Transmission line model were constructed according to the geometry of the winding for inter-turn insulation analysis by H. Oraee in 1985 [3].

In this paper, the electric field distribution in electrical machine is calculated by finite element method. Firstly, the position of maximum electrical field strength in slot insulation is analyzed. Then, the uniformity of the local electric field distribution at the slot opening is evaluated by 3D finite element electric field analysis. The position where the insulation materials tend to producing corona or breakdown may be highlighted, determining electric field distribution of. And then, optimizing some design parameters of electrical machine. When analyzing the inter-turn insulation, an equivalent circuit model with lumped capacitances and inductances is applied to calculate the electrical potential distribution in the stator winding excited by switching-pulse voltage.

II. FE MODELING FOR INSULATION ANALYSIS

For the evaluation of slot insulation, the phase difference of both top and bottom coil sides in one slot may be 120 degree. In this worst operation, the electrical potential of top coil side is defined as positive peak value, and the bottom side is negative half peak value. The 2D electrical field is calculated by using FEM.

The electric field of slot opening is not uniform. The 3-dimiensional finite element analysis should be applied.

In order to achieve equivalent inductance of one turn of stator windings, the eddy current effect must be considered in both stator core and conductors in the slot. Firstly, the current flowing though stator winding is defined as zero. The permeability of stator core is recorded excited by rotor magnetic field based on the nonlinear B-H curve of the core. By this way, the operation point of the stator iron core is determined. When the coil self- and mutual inductances are calculated, the recorded permeability is reset to the core. Based on the switching-pulse voltage, the equivalent the frequency is determined as 1MHz. The different inductances due to different rotor positions will be discussed in the full paper.

III. FE ANALYSIS AND EVALUATION OF STATOR INSULATION

A. *Slot insulation*

The slot insulation structure is illustrated in Fig. 1.

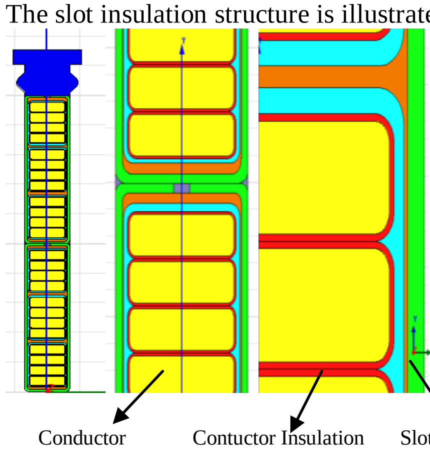

Fig. 1 Structural model of slot

The air gaps may exist in diverse positions in slot insulations. Fig. 1 shows some possible air gap positions in slot. The electric filed in slot is shown in Fig. 3.

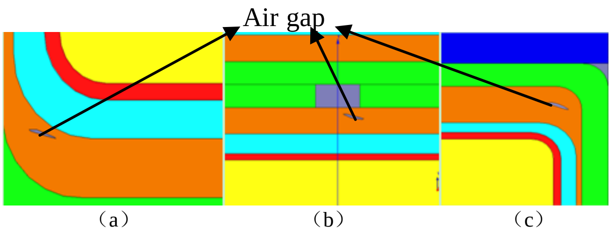

Fig. 2 FE model in which the airgap (a)near the bottom of the slot,, (b) between the top and bottom coil side and (c) near the top of slot

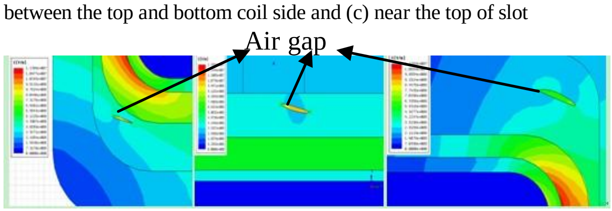

Fig. 3 Electic field strength distribution near the airgaps

It can be seen that the electric field in the air gap may be greater than those near the air gap.

B. Slot opening insulation

The FE model and FE meshes for slot opening insulation evaluation are shown in Figs. 4 and 5, respectively. The electric field distribution near the slot opening is pictured in Fig. 7. The concentration of electric field near the slot opening should be paid more attention.

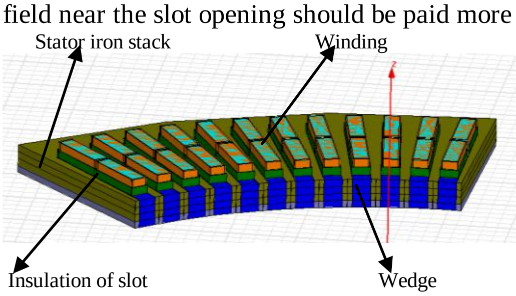

Fig. 4 3D FE model of slot opening insulation

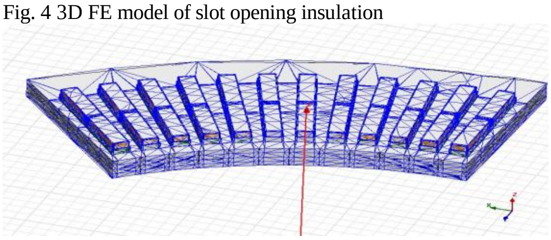

Fig. 5 FE meshes of slot opening

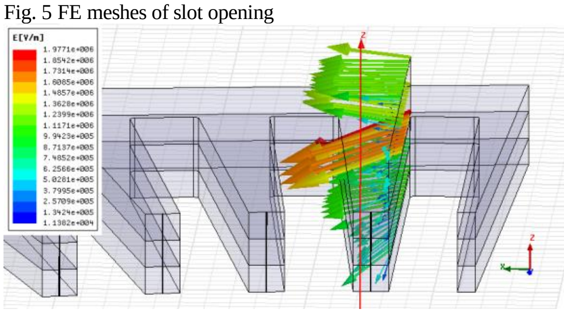

Fig.7 Vector diagram of Electrical field strength at the slot openning

C. Inter-turn Insulation

The magnetic field distribution is shown in Fig. 8. The relative permeability of stator teeth is about 1900. The inductances and capacitances of the first, second and third coils listed in Table I. The equivalent circuit model is illustrated in Fig. 9. The detailed inter-turn insulation will be discussed in the full paper.

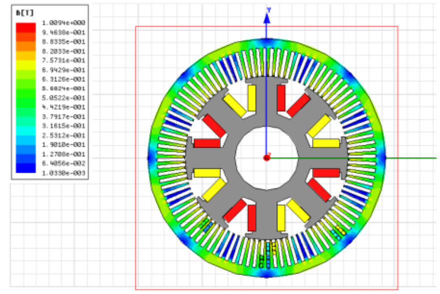

Fig.8 Magnetic field distribution of the stator core biased by rotor magnetic field only

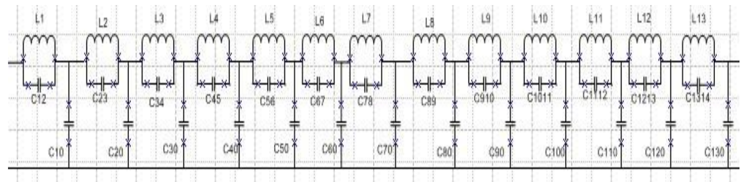

Fig. 9 A section of equivalent circuit for inter-turn insulation analysis

TABLE I

Inductance	L1	L2	L3	L12	L23	L13
Value (μ H)	302	288	290	273	222	57

IV. CONCLUSION

The finite element method is applied to analyze and evaluate the stator insulation of high voltage synchronous motor. The electrical field strength in slot insulation, near the slot opening are calculated by 2D and 3D static electrical field FEM, The corona, even breakdown, may occur in the air gap and slot opening due to the concentration of electric field. The equivalent capacitances and inductances of every turn of stator coils are respectively computed by electric field and AC magnetic field FEM under the switching-pulse voltage excitation. Detailed analysis and discussion of the insulation structures in high voltage synchronous motor will be given in the full paper.

V. REFERENCES

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