THE INFLUENCE OF COOLING DUCTS ON THE LEAKAGE INDUCTANCES OF INDUCTION MACHINES

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Abstract

In this paper the influence of the cooling ducts on the leakage inductances, and therefore on the breakdown torque, in induction machines is discussed. This effect is typically a three-dimensional one, and one has to analyse numerous geometrical variants. A simplified 3D finite element model of the induction machine is hence used, whose equivalent inductances are calculated. Due to the transversal orientation of cooling ducts, with respect to the main flow paths, the simplified model is able to deliver accurate qualitative results concerning the real machine.

1 Introduction

Large induction machines are constructed with cooling ducts in order to allow cooling air exhaust in radial direction. They are placed every 5 cm to 10 cm approximately in axial direction. Their width is usually about 8mm. Finite elements (FE) models of induction machines are often 2 dimensional ones [6] and the influence of cooling ducts is therefore not calculated but introduced as an empirical correction factor in the model.

Cooling ducts are basically uniform air gaps dividing the magnetic core into several sections. They introduce a transversal modification of the geometry, i.e. in a direction parallel to the shaft, whereas field lines flow mostly in planes orthogonal to that direction. For this reason, cooling ducts constitute a transversal geometrical effect that cannot be represented by means of a 2D FE model. A 3D model is required.

The effect of cooling ducts is also localised in the vicinity of the air gap of the machine. At other places, the field lines remain confined inside the magnetic cores and are therefore hardly affected by the presence of the cooling ducts.

Building on the above geometrical considerations, and because this analysis requires numerous computations with different input data (materials, duct widths, etc.), a simplified 3D FE model is devised to determine the influence of the cooling ducts. The number of rotor bars is modified, so that the smallest symmetry cell of the stator geometry, i.e. an angular section of the cross section with one stator slot and two half-teeth, can be extracted, Fig. 1. The simplified model allows working with a mesh sufficiently refined to capture 3D effects in the air gap and in the cooling ducts, and it can be solved within a couple of hours at most.

In the axial direction, one extract also the smallest symmetry cell, i.e. one cooling duct and two half core section of equal lengths, Fig. 1.

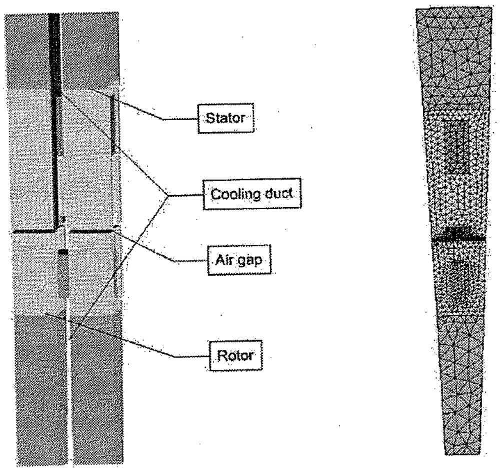

Fig. 1: Simplified FEM model including one cooling duct.

2 Calculation and results

The model described above is simulated using iMOOSE [1,6]. In order to draw some conclusions, for example about the influence on the breakdown torque, the inductances of the equivalent circuit of the simplified induction machine [3] are examined.

Different operating states are calculated. At first the locked rotor operating state is simulated by setting $I_2 = -I_1$.

Leakage inductances and the main inductance can then be evaluated [2,7] by means of the formulae (1) and (2) (See [3] for a more detailed explanation).

$$\Psi = \int \vec{A} d\vec{l} \qquad (1)$$

$$L = \frac{\Psi}{I} \qquad (2)$$

In order to estimate the main inductance of the model, the simulation is done at no-load operation. This means the rotor current I_2 is set to zero.

3 Influence of the size of the cooling ducts

The size of the cooling ducts d is now modified in order to study its influence on the magnetic behaviour of the machine. For each cooling duct width considered, the inductances have been calculated using the model described above.

Fig. 3 shows the leakage inductances and Fig. 4 the main inductance of the machine, for different sizes of the cooling ducts, holding the overall length of the model unchanged (L=58 mm).

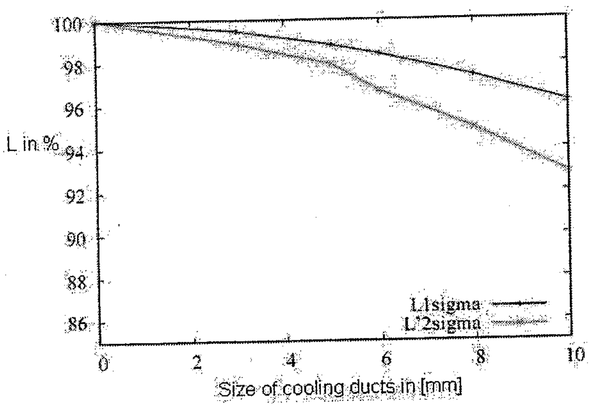

Fig. 2: Leakage inductances of the model for different sizes of the cooling duct.

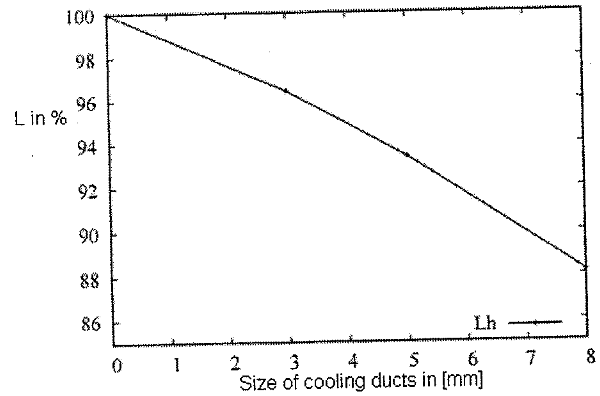

Fig. 3: Main inductance of the model for different sizes of the cooling duct.

As expected, the inductances decrease as the cooling ducts width increases. The simulations show that the main inductance is nearly proportional to $(L-d)/L$, i.e. to the steel length of the lamination stack, i.e. the main inductance is reduced to 88% of its value for d=0, as the steel length is reduced to 86% of its initial value by the introduction of 8 mm wide cooling ducts. On the other hand, leakage inductances are also decreased when the size of the cooling ducts is increased, but to a lesser extent (respectively 96% and 93% for L_1 and L_2'). They should therefore not be considered proportional to the length of the lamination stack. This demonstrates that the effect of cooling ducts should be considered carefully when calculating the leakage of an induction motor.

4 Conclusions

It is shown that the cooling ducts have a non proportional influence on the leakage inductances. Strictly speaking it is not correct to simulate induction machines with cooling ducts by means of 2D FEM simulations, as this amount to overestimate the influence of the cooling ducts on the leakage of the machine. For the application case considered in this study, this means an error of approximately 7 % up to 10 % in the calculation of the leakage inductance. In practice, the approach presented in this paper allows one to determine a correction factor to account for this difference of behaviour between the main inductance and the leakage inductances as cooling ducts of different widths are introduced. This is done by the 3D analysis of a simplified geometry. It is advocated that a correction factor obtained this way gives good account of the 3D axial effect, and that it can be applied in good approximation to a 2D model the real machine.

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