Dynamic Design of a Reluctance Synchronous Machine utilising Python Scripting in Flux®.

(continued) *F. Wright J.G., Cronje W.A., Meyer A.S. - University of the Witwatersrand, South Africa.*

the length decreases. Even though increased average torque results from the decreased airgap length, consideration needs to be given to whether a smaller airgap is obtainable considering manufacturing tolerances. The airgap is left at 0.8 mm.

Variation of l_{tw} **and** l_{rr} : Both l_{tw} and l_{rr} should be zero to maximise rotor saliency however mechanical requirements impede this. The RSM rotor would disintegrate at speed if these mechanical support widths were zero. While varying the mechanical support parameters, mean torque decreases as l_{tw} and l_{rr} increase. Torque ripple increases when l_{tw} is close to zero as a result of the rotor barriers approaching the rotor surface and thus reacting more with the stator slots. Traditionally, the length of l_{tw} and l_{rr} are chosen to be a multiple of the lamination thickness. Initial design choices of $l_{tw= 2mm}$ and $l_{tw = 2mm}$ (4x lamination thickness) are chosen.

Conclusions and Future Work

Conclusions: A RSM design is dynamically developed using PyFlux and generic Python in Flux 10.2. The linear progression approach to the design is briefly described. Geometric parameter values are chosen based on where maximum mean torque and minimum torque ripple occur.

Future Work:
● Mechanical Finite Element Analysis to investigate the mechanical strength of the rotor when rotating at nominal speed (1500 rpm) and undergoing mechanical torque changes.
● Choice of the current vector angle made dynamically during the design to ensure MTC at each simulation step.
● With no induction machine rotor (no rotor bars), the thermal operating point of the RSM changes. An investigation into whether more current can be placed
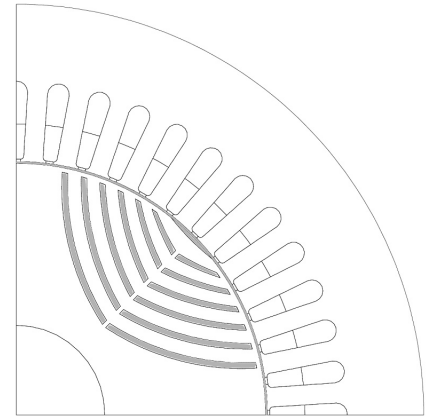
in the stator windings to generate more electromagnetic torque for the final mechanical process can be performed.
● A prototype of the final RSM should be built and tested in a laboratory environment for verification of performance.

Implementation of Lumped Parameter Thermal Model in Portunus®. *Dick Matheka - Cambridge University.*

The lumped parameter thermal model of the nested loop rotor BDFM that has been developed for use during design, and its implementation in Portunus is presented.

The BDFM (Brushless Doubly Fed Machine) is a single frame induction machine with two stator windings, which are configured to create two different pole number fields. The pole numbers of the winding fields are selected to avoid transformer coupling and the interaction between the windings is through the rotor, which couples the fields of both windings. The popular rotor option is the nested loop rotor, which is illustrated in figure 1. The nested loops of the rotor are equivalent to the bars of a cage rotor and their number is determined by the pole numbers of the stator winding fields. This machine has potential for application as a generator in off-shore

wind turbines because of the absence of brushes, which translates to reduced maintenance.

Validating the specific electric loading specified during the design of a BDFM can be complicated. This is because, the magnitudes of the stator winding currents are generally different, rotor bars have to be insulated from the laminations for performance reasons, and currents flowing in the different loops for each nested loop structure have different magnitudes. The specific electric loading is the stator current per rotor periphery and its value must be set such that the maximum operating temperatures of the machine insulation systems are not exceeded. This is difficult to do with the BDFM because the insulations for both the rotor and stator have to be taken into consideration and the rotor will likely be heated un-evenly. Therefore, knowledge of temperatures of different components of the machine is required

during the design of BDFMs. This can be obtained with the use of thermal models.

Lumped parameter thermal models use a network of resistors, capacitors, current sources and voltage sources similar to an electric circuit. The nodes of the network represent the points of average temperature for regions (or components) whose temperatures are of interest. Resistors model the
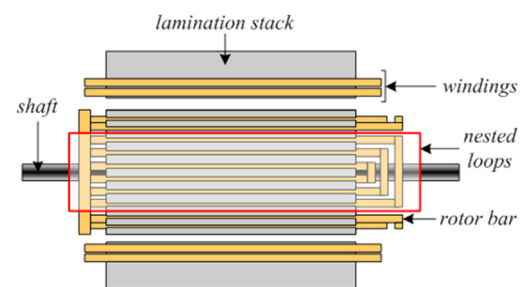

Figure 1: The structure of the nested loop rotor BDFM.

Implementation of Lumped Parameter Thermal Model in Portunus®. (continued) *Dick Matheka - Cambridge University.*

transfer of heat between the nodes by different heat transfer modes. Capacitors model the ability of materials to store heat. Current and voltage in the circuit are the flow of heat and temperature respectively. An example lumped parameter thermal model of a rectangular structure modelling the flow of heat through the structure in the direction of the longer side is shown in figure 2. These models are selected over other thermal modelling approaches for use during design because of their simplicity and computational efficiency.

Details of a lumped parameter thermal model of the nested loop BDFM that has been developed are presented in [1]. This model was implemented in Portunus, which is a multi-domain system simulation software based on the use of lumped parameter models. Models for the rotor, stator, and other machine components described in [1], are implemented as sub-circuits. The symbols of the sub-circuits are made similar to the actual machine components, making it easier and more intuitive to connect the different components to create the model for the nested loop rotor BDFM. The assembled model is illustrated in figure 3 together with a sub-circuit for one of the components.

Model parameters are computed in MS Excel from the dimensions of the machine and operating conditions. Joule losses are predicted using expected currents and finite element analysis for core losses. These values are then updated directly into the Portunus thermal model using Visual Basic for Application, with the possibility of also reading simulation results into MS Excel. This arrangement makes it possible to include the thermal model directly into MS Excel, which has the benefit of immediate validation that the thermal limit of machine insulation are not exceeded, because machine designs are often implemented in MS Excel.

Predictions of the model have been verified for DC excitation where iron losses and rotor conduction losses are zero. The verification was performed with measured end winding and rotor bar surface temperatures. Measured and predicted temperatures are shown super-imposed in figure 4 and compare well. The measured rotor bar surface temperature lies between the predicted rotor bar and airgap temperature, which is as expected because only the stator winding are generating heat. The model was then used to assess the nature of the rotor heating because the rotor bars do not carry currents of equal magnitude. This was done using the superposition principle. The steady state temperatures of the different rotor bars are compared with the different loops of each nested loop generating heat in turn. It was found that there is negligible difference between the steady state temperatures of the different rotor bars in each case.
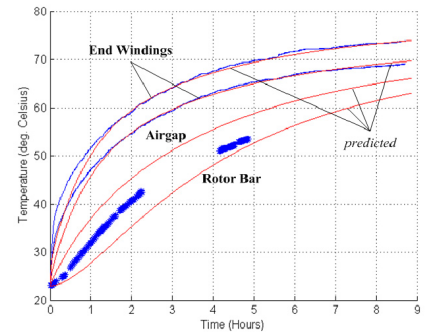

Figure 4: Measured temperatures compared with model predictions.

Therefore, it was concluded that the rotor will be heated evenly. This simplifies the process of validating that the thermal limits of insulation materials will not be exceeded for the specific electric loading, because all the bar insulations can be assumed to be at the same temperature.

[1] M.E. Mathekga, R.A. McMahon, S. Shao, D.A. Staton, "Study of Electric Loading Aspects of the BDFM Using a Lumped Parameter Thermal Model", to be presented at PEMD 2010, 19 – 21 April 2010.
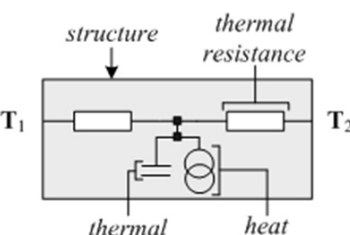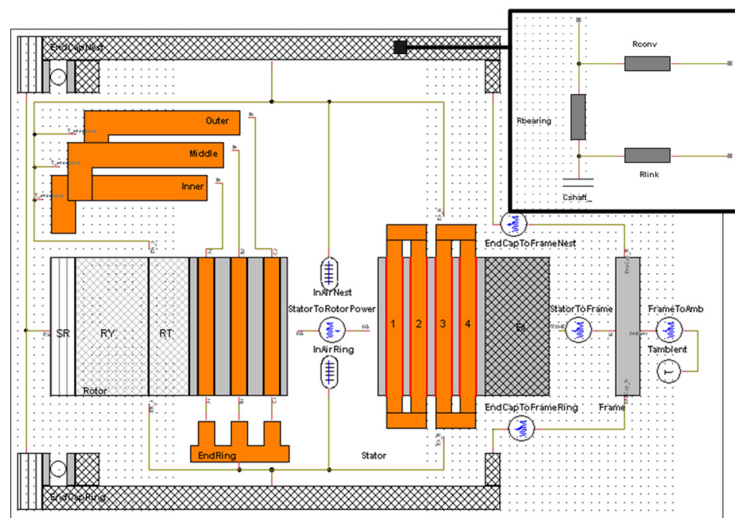
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Figure 3: Portunus model of the nested loop rotor BDFM.

Figure 2: Example lumped parameter model.