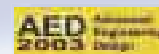


## Modelling of Eddy Currents in a Winding of a Switched Reluctance Motor.

Martin Klauz and David G Dorrell - SPEED Laboratory.

This paper received the Best Student Paper Award at AED 2003 conference



### Introduction

To some extent, the winding of a SR machine could be treated as an air-gap winding, where the eddy currents in the conductors could be significant. This is most noticeable on the leading ("motoring") side of a coil between the unaligned and aligned position, which is quite a complex magnetic circuit. For this reason a transient finite element analysis seems to be desirable to verify the affect of eddy currents.

### FLUX2D modelling

Eddy-current modelling of a SR motor has some special features and requirements. In this study two main models were created. Both represent an 8/6 SR motor; the essential difference between them is that one is for low voltage operation (4 turns per pole, 8mm squared conductors) and the other is for standard voltage operation (25 turns per pole, 2mm rounded conductors), as shown in Figs. 1 (a) and (b). A fine mesh is required around the stator conductors for precise determination of the eddy currents and in the air gap, for satisfactory estimation of performance. There are 14,067 surface elements for the low voltage model and 15,672 surface elements for the standard voltage model. The conductors assumed a constant resistivity of copper ( $\rho_{Cu}=1.72 \times 10^{-8} \Omega m$ ). The control circuit is simple and uses a single pulse control, with a constant voltage source as shown in

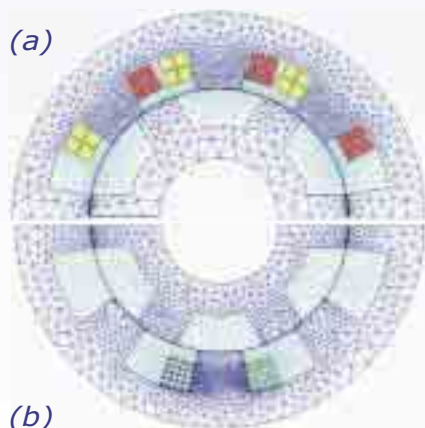
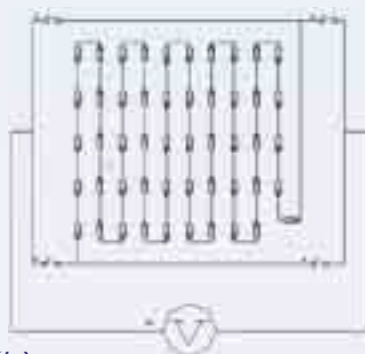


Fig. 1: (a) Mesh of low voltage and (b) standard voltage SR models.



(a)



(b)

Fig. 2: (a) Electric circuit of low voltage and (b) standard voltage SR models.

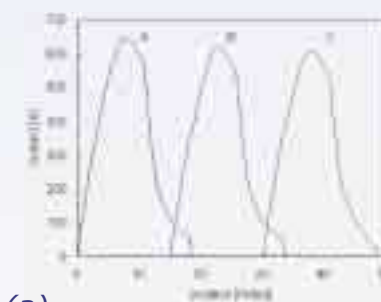
Fig. 2 (a) and (b). This circuit also provided the correct connection for the series-connected conductors; because of the large number of conductors in Fig 2 (b) only one phase was simulated.

### Simulation

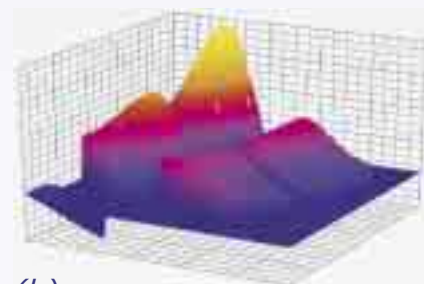
It was anticipated that the p.u. eddy current loss will be much higher in the low voltage model by virtue of its large conductors. The transient FE magnetic analysis included rotor movement. Waveforms and performance obtained from FLUX 2D and compared to SPEED PC-SRD – the results are shown in Table 1. The PC-SRD model has more phase turns but the current was adjusted to produce the same torque.

### Low voltage SR model

The phase current waveforms are shown in Fig. 3 (a). This is the mean current across a conductor. The highest distortion of current density was in the surface conductors of the coil on the rotor side and, more significantly, on the motoring side. The loss factor (= total loss / DC loss) was found to vary between 1.38 and 9.15 per period. Fig. 3 (b) shows the current density distribution across the conductors on the motoring side. The view is from top right corner on the motoring side of the coil.



(a)



(b)

Fig. 3: (a) Current waveforms and (b) 3D distribution of current density for low voltage model.

Parameter	SR Motor	Speed [rpm]	Voltage [V]	Ave. Torque [Nm]	Rms Current [A]	Ave. Current [A]	No. of Turns [-]
PC-SRD	8/6	1.800	540	46.5	22.0	9.5	86
FLUX Low voltage model	8/6	1.800	24	46.1	216.2	202.3	4
FLUX Standard voltage model	8/6	1.800	150	47.2	69.2	32.3	25

Table 1: Main parameters of the analytical and FE models.

(continued on page 14)

## Solving the More Difficult Aspects of Electric Motor Thermal Analysis. (continued)

Dave Staton, Motor Design Ltd. - Aldo Boglietti, Andrea Cavagnino, Politecnico di Torino.

manufacturing processes used and the winding model is a complex function of slot-fill, the slot liner, the impregnation, the winding process, etc.

CFD's main strength is in the visualization of fluid flow.

An example of such visualization is in the prediction of the complex air flow in the end regions of electric motors. The use of CFD is expensive in computing terms, but such data can be used to improve the accuracy of analytical models. In most cases empirical data is called upon to aid in the development of analytical models to solve thermal complexities.

A classical case of the use of empirical data is in the development of convection correlations. More recent uses of empirical data are in setting realistic values for interface thermal resistance between components, the development of bearing models, calibration of winding models and in the prediction of open fin channel air leakage.

In the Motor-CAD design package we have used both empirical data

and CFD to set realistic values for the default parameters associated with the complexities talked about. Use of default values will get the user acceptable accuracy in most cases. However, experimental calibration based on materials and construction techniques used by the motor manufacturer can improve the accuracy further. For best reuse of calibration test data it is best to setup databases and/or to define analytical curve fitting equations to predict the key thermal quantities when designing new motors. This approach is welcomed by electrical machine manufactures as they make most benefit from testing of existing motors and prototypes and improve their future design capabilities. One good thing is that in un-calibrated CFD and analytical models the user can gain great insight from trying out new design configurations and seeing by what percentage the temperatures increase or decrease - the absolute temperatures may be in error but the percentage change is usually realistic.

Analytical design packages such as Motor-CAD have been found to be of great benefit in the identification of the key thermal design parameters. Being based on analytical methods backed up by empirical and CFD data they have very fast calculations speeds. This allow the user to perform instantaneous «what if» studies with variation in parameters between upper and lower expected limits. This sensitivity analysis is used to identify the key design variables that should be concentrated on if an optimum design is to be produced and to access to what level they may be varied before a sub-standard design results.

### Acknowledgments

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## Modelling of Eddy Currents in a Winding of a Switched Reluctance Motor. (continued)

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### Standard voltage SR Model

In this case, when the radius of a conductor was significantly smaller than the skin depth, the variation of losses was not so severe and is kept below 9 per cent per period. The maximum value of the loss factor was 1.09. The torque waveform and current density

distribution are shown in Fig. 4. As can be observed, the current density is practically uniform, except for the outer conductors. This is in contrast to the thick square conductors for the low voltage model.

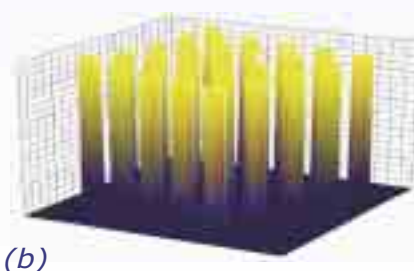
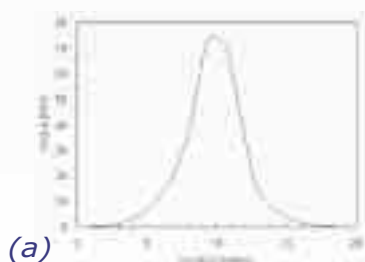


Fig. 4: (a) Torque waveform and (b) 3D distribution of current density for standard voltage model.

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### Conclusion

The eddy-current loss is high in the low voltage SR model with thick conductors. According to the finite-element results, the difference between maximum and minimum loss was almost 600% with a loss factor of about 9. Thus precise calculation of eddy currents is essential otherwise they could lead to the insulation failure and burning of the winding as well as poor performance. It was also computed that the losses due to eddy currents do not exceed about 9% of the DC loss for conductors with a radius of about one quarter of the skin-depth.