2D versus 3D electromagnetic field modelling in electromechanical energy converters

A. Demenko*, J.K. Sykulski**, R.M. Wojciechowski*
*Poznań University of Technology, ** University of Southampton
*ul Piotrowo 3A, 60-965 Poznań, Poland, ** Southampton SO17 1BJ, UK
*andrzej.demenko@put.poznan.pl, ** J.K.Sykulski@soton.ac.uk

***Abstract*—The paper provides comparative analysis between 2D and 3D numerical modelling of electromechanical devices by considering typical errors arising when 2D models are assumed to model 3D fields. It is argued that modelling simplifications need to be applied with great care as associated errors are not always predictable. In hierarchical design both types of models are desirable hence balancing accuracy and computational effort is an increasingly important issue.**

***Index Terms*— Electromechanical devices, Numerical analysis, Approximation error, Electromagnetic modelling.**

I. Introduction

Designers of electromechanical devices are frequently confronted by a dilemma of whether to use 2D or 3D models for performance prediction and analysis. Within the context of hierarchical approach both types of models are required to balance accuracy with computational effort at various stages of the design. Thus questions often arise if a faster but less accurate 2D representation is sufficient as a replacement for a more accurate but computationally expensive (less efficient) 3D model. Simplifications usually seek symmetries in the system so that only one component of current may be assumed while the associated flux density has two components. It is essential, however, to address the issues of accuracy to maintain some level of control over the adequacy of the simulation process. The paper draws on the experience of the authors in the design of electrical machines and explores different strategies by considering typical practical situations.

II. Strategies for 2D and 3D Field Computation s

In hierarchical design of electromechanical energy converters the initial stage usually involves simple analytical or semi-empirical models and extensive search spaces – often utilising the concept of an equivalent circuit – followed by more accurate 2D numerical field modelling (usually steady state or quasi static), culminating with 'fine tuning' of the performance harnessing computationally expensive 3D models (often using transient solutions). Thus with the advances in computer hardware and software numerical field simulation has established its position as the main design tool. In this paper we are only concerned with the link between 2D and 3D numerical modelling, but similar analysis could be conducted in relation to the simpler equivalent-circuit type models.

A typical approach is to use 2D models and validate them against more accurate 3D results. An interesting alternative is to use 3D simulation to establish various 'correction coefficients' which may then be incorporated into 2D models thus increasing the accuracy of the simplified model.

A typical case arises when eddy currents are considered and an adjusted resistivity, or representative length, is assumed in the 2D model, estimated from 3D calculations (or indeed from analytical models). This approach has often been applied in the analysis of cage induction motors. In the early papers describing field modelling in such machines it was often assumed that the shorting rings at both ends had negligible resistance while for the bars a slightly increased value was used [1]; this approach was reminiscent of the treatment often applied to equivalent circuit representation.

Finally, different components or sections may have different length and/or are displaced geometrically, for example as a result of the winding skew. The use of 'classical' 2D models is no longer appropriate and – should the use of full 3D simulation be a non-preferred option – equivalent 2.5D or 'quasi 3D' models must be considered.

III. Quasi 3D and 2.5D Models

In quasi 3D models the field in one direction (say in z) is approximated or neglected altogether [2], [3]. For example, as depicted in Fig. 1, the length (depth) l of the field region is taken as varying (not constant), that is $l=l(x,y)$, but the fluxes ϕ_i through the triangular facets are omitted. It is helpful in such cases to use edge elements and assume the unknowns to be the edge values of $\boldsymbol{A}$ for edges C_iC_j, denoted by $\varphi_{i,j}$ in Fig1.

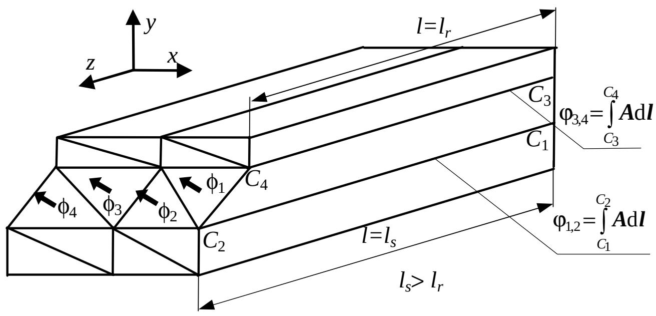

Fig.1. Part of a FE 2D model in the region of core length $l=l(x,y)$.

In machines with skewed windings or permanent magnets the 2.5D multilayer models may be useful (also known as multi-sliced 2D models). Such models are created by subdividing the relevant region into layers in which individually the field may be assumed to be 2D. The flux coupled with the winding is then found by adding components associated with each layer. Such an approach was successfully applied in [3] and [4] and demonstrated to be appropriate when modelling cage induction motors with skewed rotor.

IV. EXAMPLES

It is common practice to try to predict the errors resulting from a 2D treatment of the 3D fields before selecting the appropriate model. The following examples will show that such estimates may be unreliable.

A. *Attraction force between two magnets*

Consider two permanent magnets placed in infinite space (Fig. 2). The force obtained from the 2D and 3D models has been calculated using an analytical approach [5], [6]. The comparison is in between the force f over the area lb as a function of the length l of the magnet. Specifically, the relative error ε (taken as the difference between 3D and 2D values divided by the 2D result) is shown in terms of the ratio l/b.

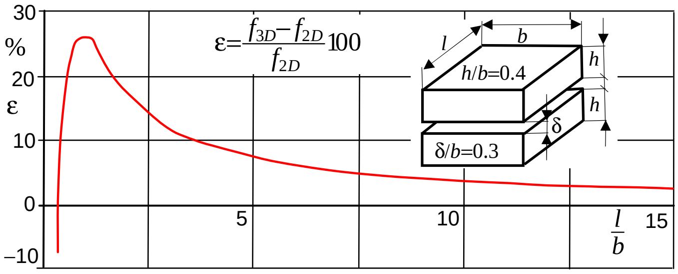

Fig. 2. The difference between 3D and 2D calculations of the attractive force density as a function of the ratio *l*/*b*.

As can be seen the 2D results are the worst when l/b =0.88, while – rather surprisingly – at l/b =0.0.35 the two models yield identical values.

B. *Permanent magnet motor*

Calculations of electromagnetic torque were performed for a permanent magnet motor (PPM) described in [7]. Two cases were considered of a laminated core and the rotor made of soft magnetic composite. The magnetic permeability of the composite material is 10 to 80 times lower – depending on the saturation level – than the permeability of the laminations. Figure 3 shows the differences between the 3D and 2D calculations of the average torque as a function of the ratio of the packet length l to the pole pitch τ, for the case when the motor is supplied with a sinusoidally varying current (I_{rms}=9.8A) at a torque angle δ=90°. The results confirm the intuitive expectation that when the permeability is lower the difference between 2D and 3D results is larger.

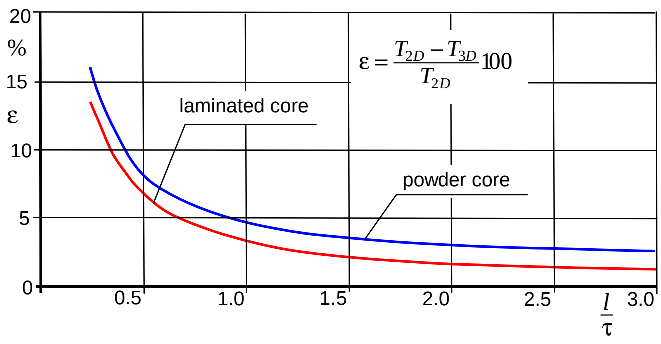

Fig. 3. The difference between 3D and 2D calculations of the torque of a permanent magnet motor for two types of the rotor.

C. *A coil above a conducting plate*

A system similar to TEAM Workshops Problem No. 7 has been considered [8]. The magnetic field and eddy current distributions were computed for different proportions of the length to the width of the coil and the plate, with sinusoidal supply at 50Hz. From these distributions the flux linkages were found and finally the amplitudes and average values of the force acting between the coil and the plate. Figure 4 shows the error distribution ε between the results obtained using the 3D and 2D models at three distances δ between the coil and the plate as a function of the ratio of the length over the width of the coil. If δ/b=0.1 then for l/c>2 the 2D modelling is quite accurate, but for δ/b=0.05 and l/c=2 the error ε =14%.

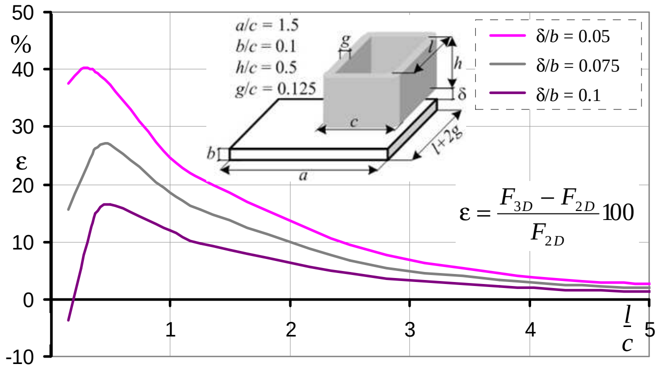

Fig. 4. The difference between 3D and 2D calculations of the average force between the coil and the conducting plate.

V. CONCLUSION

The few examples presented (and others which will be elaborated on in the full version) emphasise the difficulties in predicting the error associated with 2D modelling of 3D phenomena. Given the external dimensions, many factors such as the excitation, position of sources and material properties may influence the error. It appears worthwhile to initiate a discussion forum to exchange similar experiences.

VI. REFERENCES

[1] M. Klocke, “Zur Berechnung dynamischer Vorgänge bei von einem Drehstromsteller gespeisten Antrieben mit Asynchronmaschinen und mehreren gekoppelten Massen mittels Finite Differenzen Zeitschrittrechnung,” *Ph. D Thesis*, Universität Dortmund, 1999.

[2] M. Pietruszka, E. Napieralska-Juszczak, “Quasi 3D magnetic field computation for anisotropic sheet layer structure,” *Compel*, vol. 14 no. 4, pp.163 – 167, 1995.

[3] A. Demenko, L. Nowak, Finite element analysis of saturation effects in a squirrel cage electrical machine, *Compel*, vol. 15, no. 4, pp. 89-96, 1996.

[4] B. Gysen, K. Meessen, J. Paulides, E. Lomonova_ “3-D analytical and numerical modeling of tubular actuators with skewed permanent magnets,” *IEEE Trans. Magn.*, vol. 47, no. 9, pp. 2200 – 2212, 2011.

[5] H. Allag and J.P. Yonnet, “3-D analytical calculation of the torque and force exerted between two cuboidal magnets,” *IEEE Trans. Magn.*, vol. 45, no. 10, pp. 3969-3972, 2009.

[6] A. Demenko A., W. Łyskawinski, R. M. Wojciechowski, “Equivalent formulas for global magnetic force calculation from finite element solution,” *IEEE Trans. Magn.*, vol. 48, no.2, pp.195-198, 2012.

[7] A. Demenko, “3D Edge element analysis of permanent magnet motor dynamics,” *IEEE Trans. Magn.*, vol. 34, no. 5, pp. 3620-3623, 1998.

[8] R. M. Wojciechowski, A. Demenko, J. K. Sykulski, “Comparative analysis of ***A***-*V* and ***A***-***T***-T_0 calculations of induced currents in multiply connected regions,” *IET Sci. Meas. Technol.*, vol. 5, no. 6, 2012, pp. 312 – 318, 2012.