Electrical Machines ... a Challenge for the Year 00 ?

I. INTRODUCTION

The motivation for writing this article is unclear. Perhaps it is useful to fill up some space in the middle of the Newsletter. Maybe, if there are any computers still alive after the year 00, program developers will be looking for something to do. If so, perhaps electrical machines present some quite interesting problems to the finite element modeller.

This article describes a brief stagger around the field of electrical machines. There we examine some of the delights and a great many muddy patches. At last, through the howling sleet, we perceive a shining gate, bearing a large sign, 'NUMERICAL MOTOR'. Just as we reach for it, we wake up screaming and the illusion disappears.

II. SOME OF THE DIFFICULTIES

Electrical machines are built from materials which are often non linear and the geometry is often complex. Usually movement is involved. In addition to this, the machine may be coupled to a dynamic load and/or an electrical circuit.

Machine designers themselves are often a difficulty, they are often clever, resourceful and sometimes know the correct answers without using finite elements. The latter characteristic is particularly unsociable.

Despite the foregoing, electrical machines are of considerable commercial importance, so work is being done all over the world in order to develop convenient methods for solving the problems. Some of these techniques are reviewed here.

III. FINITE ELEMENT FORMULATIONS

Many types of elements and formulations now exist, the earliest 2D work dates back to the early 60's [1]. Most schemes are built around either classical nodal elements or edge type elements which are newer, first appearing around the late 70's [2]. In reality, it is not difficult to use both types in the same package. This area is still being explored by several groups around the world.

One of the few attractive features of electrical machines is that the displacement current can usually be ignored, this allows non-conducting regions to be modelled using magnetic scalar potentials φ. These can be coupled quite naturally to a vector variable in conductors, perhaps with or without an additional scalar variable in there as well. The well known **A**-φ, **A**, V-φ and **T** - Ω methods are in this category.

Hybrid finite element-machine equation type methods have also been successfully employed, these tend to be faster than general pure finite element methods on a more limited range of problems [3].

A. Coils... meshed or not ?

The coils of an electrical machine are very often geometrically complex, at least in the end turn regions (Fig. 1). If these are meshed, this will greatly add to the complexity of the model. It is possible to get around this problem by using reduced field variables such as, for instance, reduced φ [4] or reduced A [5]. These latter schemes are often relatively expensive if some integration of fields from coils using Biot-Savart is involved, but this type of activity can very easily be done in parallel, so there is hope for the future.

The natural source for finite elements is constant current, unfortunately, this is unusual in reality. Machines are either mains (constant voltage) driven or else, even worse, driven by some electronic circuit. This requires some modifications to the basic finite element schemes as was done in [6] for the total and reduced magnetic scalar method.

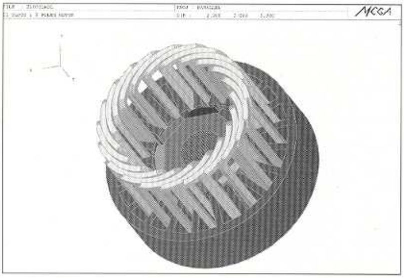

Fig. 1. A cut away view of the coils on a servomotor

IV. MOVEMENT

Electrical machines are particularly prone to this annoying habit, it is well known that they frequently spin or slide. This introduces some difficulty. The movement can be of smooth or of non-smooth objects, as defined below.

A. Movement-Smooth Conductors

If the moving media cross section normal to the direction of motion is invariant we call this a smooth conductor. In this case for constant velocity the Minkowski transformation is valid. The velocity is taken care of by modifying the **E** field by adding a **u** x **B** term, where **u** is the velocity [7][8][9]. Under these conditions only one steady state solution is required and so this is an economic method, although the resulting equations are asymmetric. Often upwinding or some other technique is required to obtain a solution [10].

B. Movement-Non Smooth Conductors

If the moving media cross section normal to the direction of motion is not invariant (as in the case of a squirrel cage induction machine for instance) no steady state solution is possible. In this situation a time transient solution is required, and the moving objects must be meshed at each time step.

This moving mesh problem has been tackled using different approaches over the years, remeshing at each position [11], using another technique to model the airgap, such as Fourier analysis, [12] or using a sliding mesh technique, such as Lagrange multipliers, [13],[14]. Hybrid finite element integral techniques are also possible [15].

The Lagrange multipliers technique can often be useful where the shapes of a rotor and stator are very different, as in the case of a vehicle alternator (Fig. 2).

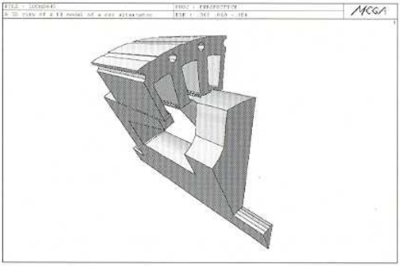

Fig. 2. Showing a Car Alternator

V. MODELLING OF SKEW

A common example of the above case of the shape of a rotor and stator being very different occurs when either object is skewed with respect to the other. Unfortunately skewing is a very useful technique for reducing unwanted torques and vibration. Machine designers seem disinclined to give it up, despite persuasion from finite element developers.

A. 3D Skew

Conventional finite element techniques are expensive for modelling skew, there has to be a radical change of shape of mesh which must often occur across a very thin air gap region. The Lagrange multiplier approach described above is very useful for this case. Where cogging torque is important, as in brushless servomotors, a 3D solution is necessary.

B. 2D Approximations for Skew

2D approximations for skew can be used, usually these are less expensive than a full 3D solution. The method consists of subdividing the machine along the axis into slices which are rotated with respect to each other according to the skew of the machine. Each slice can then be represented by 2D finite element models. Usually these models would have to be solved simultaneously and other conditions may have to be imposed, for instance in the case of an induction machine, the currents in a given rotor bar would have to be made continuous from one slice to another [16]. This should be straightforward in most finite element packages.

VI. CIRCUIT CONNECTION

This section shows an example of using external circuit connection and the sliding interface to simulate the dynamic behaviour of a switched reluctance motor. Fig. 3 shows schematically how a finite element model of the machine is connected to its control circuit. The sliding interface is defined at the centre of the air gap. In the simulation, the motor is set to rotate at a constant 1500 rpm with each phase switched on at 44° from the aligned position for 30 mechanical degrees. Fig. 4 shows the variations of phase currents and the DC-link current with rotor position.

The simulation shown here is carried out by including the circuit equations in the finite element matrix and solving simultaneously. It is also possible to calculate the machine parameters such as inductance for many different states such as position and saturation levels and form a large look up table. This look up table can then be used with a circuit simulator to calculate currents etc. As usual, both approaches have their own pros and cons.

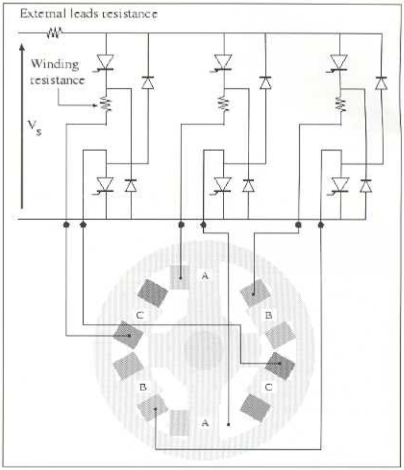

Fig. 3. A Switched reluctance motor

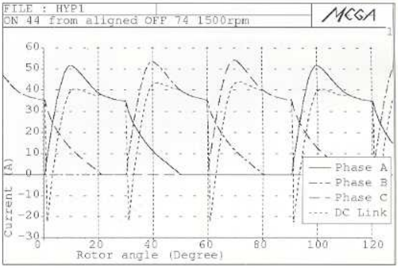

Fig. 4. Variations of phase current with rotor position

VII. UNRESOLVED PROBLEMS

Unsolved, partially solved and very nasty problems include:

- Flux steering in laminated materials.
- Iron losses, even if good numerical models were avail able for this, the input data is missing, usually only very sketchy information is available from manufacturers.
- Coupled problems, mechanical, thermal, electrical etc.

VIII. CONCLUSIONS

Some techniques for modelling electrical machines have been reviewed. Many difficult problems still remain unsolved implying that this field is worth cultivating. It is quite probable that the field of fields will still be an interesting subject even when the next 00 comes around !

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Dear Colleagues

It is my pleasure to bring to your attention the International Magnetics Conference, Intermag 2000, which will be held at the Royal York Hotel in Toronto, Canada from Sunday, April 9, through Thursday, April 13, 2000. As you may know, Intermag is the premier conference on applied magnetics and information storage technologies. We are planning an exciting and informative set of invited talks, tutorial sessions, oral and poster presentations and exhibitions which will review the latest developments in these fields.

We are soliciting contributed papers in all areas of applied magnetics, magnetic recording technologies and related topics. Interested authors are requested to submit a two-page digest to the conference prior to October 10, 1999. All digests must be submitted electronically to the Intermag website: . This site will provide detailed instructions on digest preparation and submission. In addition, you may also obtain information regarding the conference site, registration, hotel reservations, and the city of Toronto at this web site.

On behalf of the sonference Management Committee, I am looking forward to seeing you all at Toronto, Canada, during the first Intermag of the new millennium.

Doug Lavers
General Chairman