New configurations of Transverse Flux Switched Reluctance Machines

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Abstract — Conventional switched reluctance motors have been extensively researched over the last two decades. Although toroidal winding configurations have been developed for very small stepping motors, but not for switched reluctance motors because of the complication of building a laminated magnetic circuit for this type of geometry. The emergence and improvements of powdered iron and its successful use in transverse flux permanent magnet machines prompted this research, which examines the possibility of using powdered iron in transverse flux switched reluctance motors.

This research has investigated a range of possible configurations for these machines and the advantages and shortcomings of each type.

A prototype machine has been designed and tested, with both static and running measurements and has been compared to a similar size conventional machine with short-pitched windings, highlighting the relative merits of this machine configuration, which exhibits a large increase in torque per unit copper mass and a more modest increase in torque per unit total mass.

Keywords: Transverse Flux SRM, Toroidal

I. INTRODUCTION

This research has concentrated totally on developing and assessing an alternative geometry of Transverse Flux SRMs, utilizing developments in transverse flux permanent magnet machine topologies as a basis for development.

The chosen configuration of switched reluctance machine differs in the winding methods and in the magnetic circuit construction. It has one toroidal winding for each phase, with flux flowing radially in the air gap and teeth and then in an axial direction in the core backs. Because the winding is toroidal the magnetic circuit can be altered without changing the winding area. Consequently the machine can be designed with a high pole number without compromising the MMF per pole.

The concept has never been exploited fully before because of difficulties encountered in building the three dimensional magnetic circuits using anisotropic materials. The emergence of isotropic materials, such as powdered iron, opened the way for these machines as complications of assembly can be greatly alleviated with their use. These materials initially suffered from the disadvantage of having low permeability but by the mid-nineties the material improved to the point where its use became worth considering once more.

II. ALTERNATIVE CONSTRUCTIONS

A range of techniques has been used in the construction of transverse flux motors. Each technique seeks to manage the problem posed by the three dimensional field in a different way. They may be categorized as follows:

(a) The commonest technique is to recognize that the main flow of magnetic flux is in the radial and axial direction and therefore to laminate in this plane only. Each pole of both the rotor and stator can then be made from “U” shaped laminations. Whilst creation of each pole is then very simple, mechanical retention of all the poles with respect to each other is more difficult than in a conventional machine, because each pole is an entirely separate component. Machines of this type do not make optimum use of the available space in the core back regions because the core back enclosed volume is typically more than 50% air space. A transverse flux reluctance motor with “U” shaped laminations has been constructed and successfully tested by Vannier et al (1). The construction is shown in figure 1

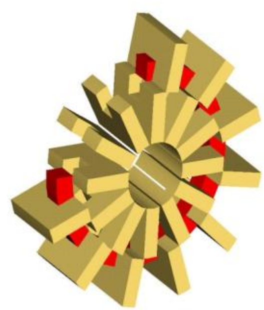

Fig.1. Transverse Flux SRM with U shaped Laminations

(b) At the air-gap the flow of flux is in the radial/circumferential direction, whilst in the core back it is predominantly axial. It is therefore possible to employ laminated poles in which the laminations are bent into a “U” shape to accommodate the flux flow. This is excellent magnetically, but fraught with mechanical problems. The bent laminations will tend to de-laminate and, as shown by axially laminated synchronous reluctance machines, no mass production method has yet been successfully developed.

(c) A third alternative is to use powdered iron which, because of the fine particle structure, provides lamination against three dimensional fields. This approach has been very successfully adopted in permanent magnet transverse flux machines, but the properties of powdered iron are less favorable for reluctance machines. The maximum relative permeability of powdered iron is only about 500, and this severely reduces the aligned unsaturated permeance. The consequences in terms of loss of machine performance are large and hence this approach is not favoured for reluctance machines.

(d) Sandwiched-Rotor Configurations

There were claims that sandwich-rotor motors produced the highest torque per unit rotor volume. This research has investigated these motors thoroughly and shown that while they produce higher torque per unit rotor volume the average torque per unit enclosed volume is much less than Transverse Flux SRM.

(e) Hybrid Powdered Iron/Laminated Assembly

These constructions attempt to exploit the best properties of both laminations and powdered iron. Where the flow of magnetic flux is two dimensional then laminations should be employed because of their superior magnetic permeability, whilst in regions of three dimensional flux flow powdered iron should be used because of its ability to prevent the flow of eddy currents. This is the design chosen for the prototype machine as it has none of the problems of the above geometries. This machines is shown in figure 2.

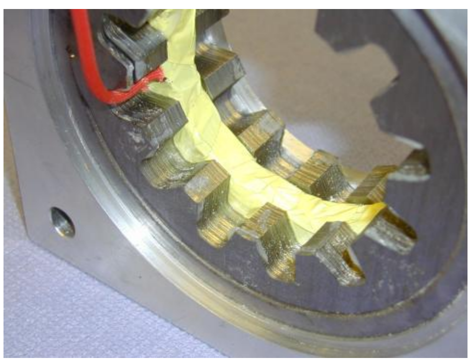

Fig. 2. A single phase of the prototype machine

III. A COMPARISON WITH CONVENTIONAL SRMS.

The machine is compared to a conventional three phase 12-8 SRM of similar dimensions. The two machines have the same outside diameter and similar axial lengths: the transverse flux SRM has three phases, each 55mm axially long, separated by a gap of 10 mm, giving a total axial length of 185 mm. The conventional SRM has a lamination stack length of 150 mm, with an end-winding projection of 30 mm, giving a total axial length of 210 mm.

Both machines are 3 phase, have similar winding turn lengths (11% less in the TFM), slot areas (15% more in the TFM) and similar magnetic circuit cross-sectional areas (5% more in the TFM). The transverse flux SRM gains substantially in three ways which act towards increasing the torque capability:

1. It has 50% more rotor teeth, so that it has only two thirds the stroke angle.
2. The entire MMF of each phase acts together to drive flux around the magnetic circuit, whilst in the 12-8 machine the magnetic flux only encloses half the MMF of a phase (2 out of four coils).
3. It only has only 67% of the copper volume, thereby both reducing the material cost and increasing the peak current density corresponding to a given total winding loss.

The transverse flux machine has 98 turns per phase and a rated r.m.s. phase current of 18.0 amps at thermal limit, giving a mean torque capability of 30 N.m. This is about 50% more torque than the conventional 12-8 SRM, operating with the same winding loss. The torque per unit copper volume is increased by 125%

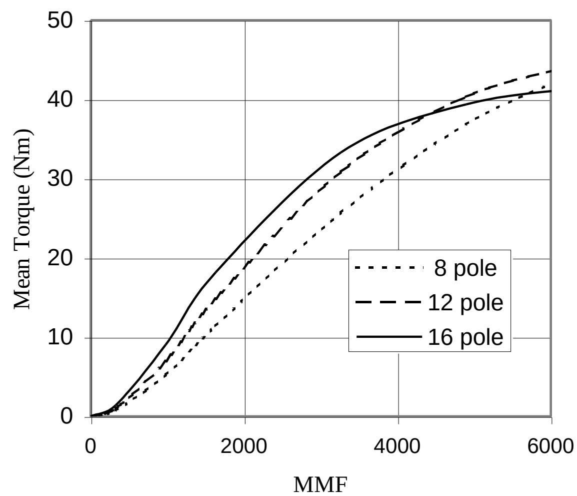

Fig. 4. Torque v MMF for different pole number

Conclusions

All possible configurations of TFSRMs have been tested and compared with each other using extensive 3D finite element analysis. A hybrid configuration was found to be the most suitable in regard to simplicity of manufacturing and performance. A Prototype machine was built and run and the measurements were compared to conventional SRMs and the results were very encouraging.

VI. REFERENCES

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