Halbach Cylinder BLDC Motor

Introduction

The effect of magnetization patterns on machine performance can be significant. Accurate results can be obtained by including the magnetization process in the simulations. This can be accomplished using the magnetization pattern prediction feature of MagNet and this has been illustrated using an example of a four pole Halbach magnetized motor. A case study including the modeling of the magnetization fixture has been presented below including motor performance results. Also presented is a qualitative comparison between the Halbach motor and an equivalent segmented radially magnetized motor.

Halbach cylinder magnetizing fixture

Pre-assembly impulse magnetization is used to create the Halbach permanent magnet cylinder. The fixture used in this example, based on similar industrially used apparatus is shown in Fig. 1. The fixture used has not been optimized with respect to exact winding/current distribution or geometrical shapes so that there is some non-uniformity (magnetization magnitude) in the resulting flux density distribution. However, the effect of these imperfections is negligible for this case study and can be ignored.

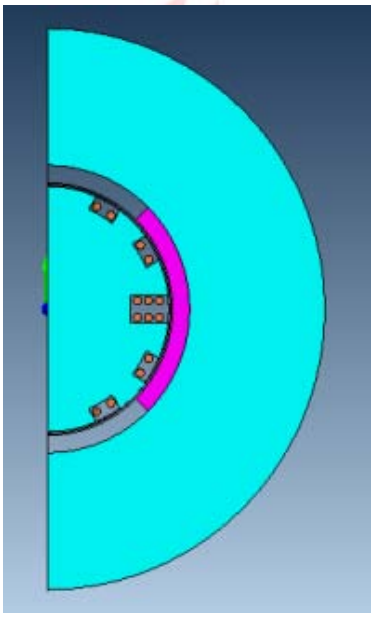

Fig. 1: The Halbach cylinder magnetizing fixture

The magnetic (B-H) and magnetization properties (magnetizing ratio) of the work piece being magnetized are shown in Figs 2 and 3, respectively. The material properties are similar to a Samarium Cobalt permanent magnet.

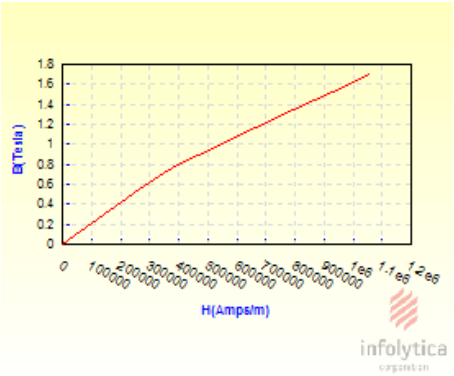

Fig. 2: The B-H curve of magnet work piece

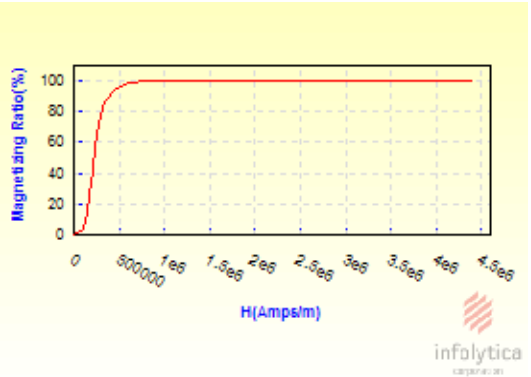

Fig. 3: The magnetizing ratio of work piece

At any point on the work piece, the orientation of the remnant magnetic field is determined by the magnetization fixture and winding currents whereas the magnitude of the remnant field is determined from material properties (Figs. 2 and 3) which is related to the recoil (B-H) loop that the given point is subjected to. After magnetization, a Halbach cylinder is assembled by importing the magnet to the motor model. The post-assembly flux density distribution at zero current of this model is shown in Fig. 4 which shows a sinusoidally magnetized Halbach cylinder.

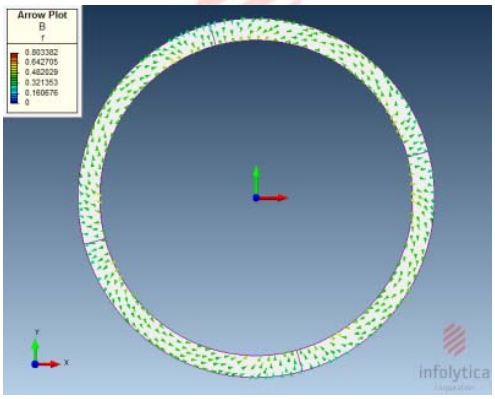

Fig. 4: Post assembly Halbach cylinder

Halbach Cylinder BLDC Motor Performance

The specifications of the motor model for this case study are given below;

Frame size	150 mm square (max.)
Frame length	No min.
Drive type	Sine wave
Voltage	150 V
Rated speed	1700 RPM

Rated torque	2 Nm. (cont.)
No of poles	4
No of Slots	12

The complete motor model (with the imported Halbach cylinder) is shown in Fig. 5.

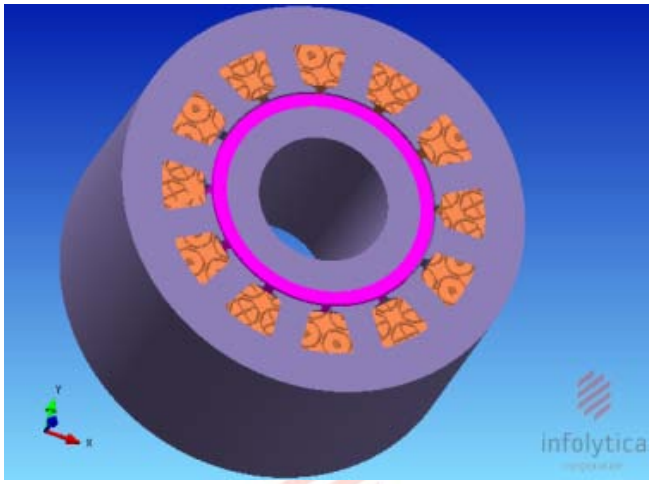

Fig. 5: The Halbach cylinder four pole BLDC Motor

The static and dynamic performance of this motor model are characterized by the steady state torque, back emf, cogging torque, efficiency and other parameters of interest to the designer. Some of these results are presented in Figs. 6-9.

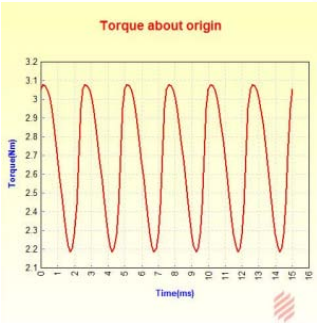

Fig. 6 Torque waveform

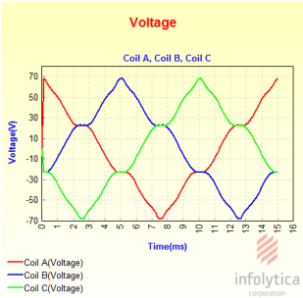

Fig. 7 Back EMF

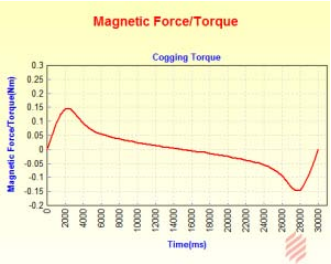

Fig. 8 Cogging torque

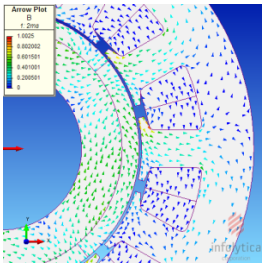

Fig. 9 Instantaneous flux density distribution

Comparison with radial, segmented permanent magnet motor

It is worth while to compare the performance of the Halbach cylinder motor to that of a surface mounted, radial, segmented PM machine. The magnetizing fixture in Fig. 1 can be modified to generate radially magnetized permanent magnets. Fig. 10 shows a section of the modified fixture that can be used to generate radially magnetized segments.

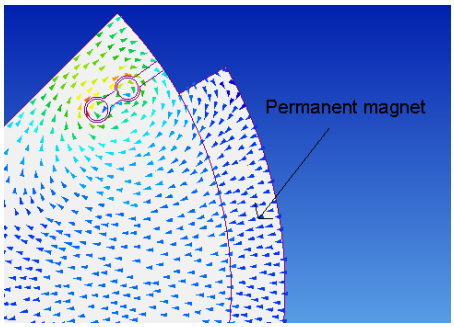

Fig 10: Section of a radial magnetization fixture

It is noted that there are some edge effects on the radially magnetized piece. It would be possible to reduce this by modifying the fixture further but that has not been done for the qualitative comparison that is presented here.

The radially magnetized piece has been imported to the same motor model described above and identical simulations were carried out. Some of these results, presented in Figs. 11-13 clearly show some of these differences.

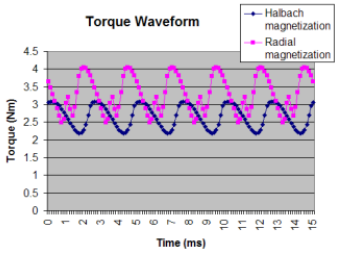

Fig. 11 Torque waveform

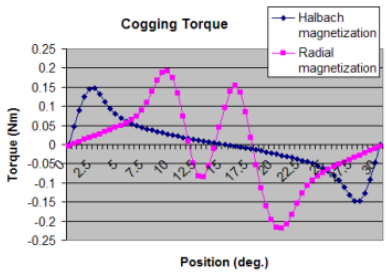

Fig. 12 Cogging torque

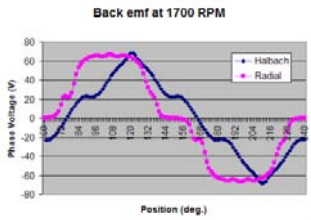

Fig. 13 Back emf

Several differences are worth noting from these results. Although the average torque for radial magnetization is a little higher in this case, the torque ripple is less in the case of the Halbach motor. This applies to the case of the cogging torque as well. The back emf is also closer to a sinusoid in the case of the Halbach motor compared to the surface mounted radially magnetized model. This is also a generally true characteristic for Halbach machines with the advantage that skewing may not be necessary for the Halbach motor compared to the radially magnetized case.

Concluding Remarks

The magnetizing pattern prediction feature of MagNet has been used to model a Halbach cylinder in this example. The cylinder was imported to a motor model and the performance of the machine has been presented here. In addition, qualitative comparison between the Halbach cylinder and an identical segmented motor model also confirmed the expected differences between the two models.