A Robust Structure Design of TFPM Synchronous Motor against Demagnetization

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Abstract: *PM machines present high efficiencies due to lack of excitation losses. Using PMs also reduces the weight and size of the machine. This yields to some increases of torque and power densities. This structure of the machine also is more simple and robust. Since the permanent magnets in a PM machine play a vital rule, even a minor variation of their magnetic properties can reduce the quality of the machine performance significantly. The demagnetization is one of the phenomena that may cause a major change in the properties of magnets. This phenomenon, depending on its intensity, will change the machine performance characteristics via altering the amplitude and waveform of the Back EMF. In this paper, a suitable design of permanent magnet motor, according to the transverse flux principle is proposed. It is nice to be mentioned that this claw pole machine is a type of TFPM with a robust structure against demagnetization. This Motor is studied in this paper as an alternative for other PM machines with similar power and other main operating characteristics especially the AFPMs that can be easily demagnetized.*

Key words: *Transverse Flux Permanent Magnet motor; robust design; Demagnetization Phenomenon; 3D Finite element;*

I. INTRODUCTION

Demagnetization phenomenon is occurred when a permanent magnet degrade in the magnetic force due to external magnetic field or temperature changes. The second quadrant of the hysteresis curve of the magnetic material referred to as the demagnetization curve. The magnets may be forced to operate in the irreversible demagnetization region which could demagnetize the magnets forever by not allowing the magnet to recover its original magnetization even after coming back to the initial condition. Therefore the PM operating point will move along the recoil curve. In this study, the recoil curve is proposed to be in parallel with the tangential line to the B-H curve at H=0 and B= B_r [1-2]. An example of the demagnetization curve of a PM is shown in Fig. 1.

After the development of NdFeB magnets, permanent magnet machines have been drawing more and more. The permanent magnet materials are used for excitation in electrical drives. The strong magnets increase efficiency of the PM machines. However, high demagnetization risk of the magnets leads to undesirable operation of the machines. Irreversible demagnetization phenomenon results in reduced total air gap flux and the back-EMF and consequently the torque capacity of the machine, so permanent magnet demagnetization reduction becomes necessary issue [1-2].

In this paper, a suitable design of permanent magnet motor, according to the transverse flux principle is proposed to provide a robust structure against demagnetization. The machine is designed such that the magnetic flux flows in paths perpendicular to the direction of rotor rotation. The demagnetization phenomenon and its leading affects are studied through a transient analysis coupled with 3D finite element analysis. The FEM analysis of new design of TFPM motor shows the ability of proposed structure against demagnetization.

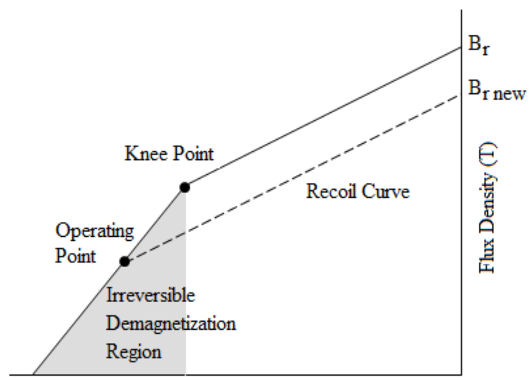

Fig. 1 Demagnetization curve

II. TRANSVERSE FLUX STRUCTURE

Permanent magnet machines are classified into AFPM, TFPM and RFPM machines, based on the traveling direction of magnetic field in the air gap. The RFPM machine produces a magnet flux in the radial direction in the air gap with longitudinal flux configuration. The magnetic flux path in AFPM machines is in the axial direction with longitudinal flux configuration. In TFPM machines the magnetic flux path is perpendicular to the direction of the rotor rotation. Among them, Permanent magnet motors with transverse flux configuration (TFPM machines) seem to be a better option for high torque applications [3]. A version of the TFPM machine structure is shown in Fig. 2 [4].

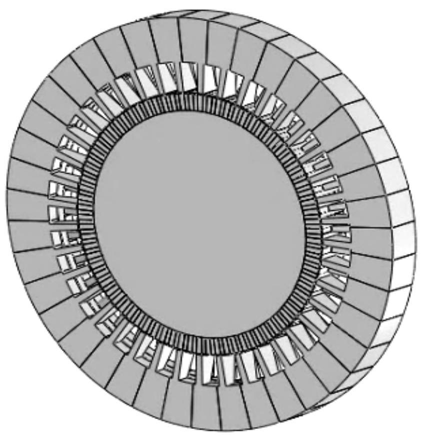

Fig. 2 The TFPM machine structure

Permanent magnets of this proposed structure are mounted on the rotor surface and directly exposed to the air gap. So it is highly possible for the magnet to become demagnetized due to the demagnetizing field produced by the armature currents. Therefore, motor structure should be improved considering demagnetization.

III. DESIGNED TFPM MOTOR

One of the important considerations during the design of a PM machine is the selection of the magnet, stator and rotor materials which influence on machine performance.

The stator and rotor material is important because it affects the machine losses and efficiency [5]. Somaloy steel is selected for this TFPM motor because of fewer losses. It has a saturation flux density of about 1.2 T.

The magnets must be selected to provide the necessary air gap magnetic field and sufficient coercive force to compensate for possible demagnetization effect. NdFeB, because of its useful properties including greater power density, high coercivity, high flux densities, is selected for use in the TFPM motor with the assumed values listed in Table 1.

Table.1. Magnet Properties

Property	Units	Value
Remanence	*T*	1
Coercivity	*kA/m*	757.250
Resistivity	*μΩ/m*	$1.44e^{-06}$

The main purpose of the design is a simple and robust structure against demagnetization combined with a high efficiency. The suggested TFPM machine is known as Claw Pole configuration. The rotor is made of flux concentrators and permanent magnets. The PMs are magnetized parallel to the direction of motion. In this structure we use flux concentrator configurations so that the leakage flux in magnets be reduced. The suitable structure considering demagnetization is found by trial and error. One pole pair of TFPM with the claw pole structure is shown in Fig 3.

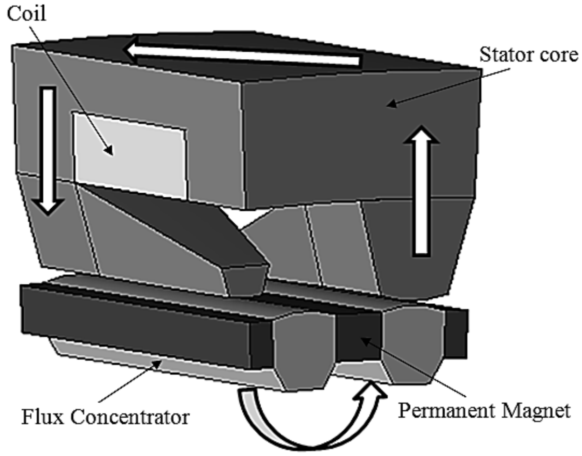

Fig. 3 Magnetic flux path

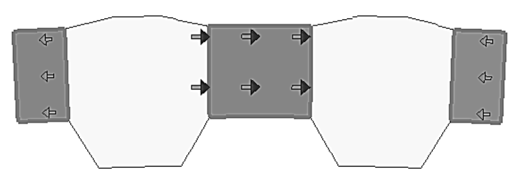

Fig. 4 Orientation of PM Magnetization

The transverse flux motor possesses a complex magnetic circuit and requires three dimensional FEA models due to its three dimensional (3D) magnetic circuits. The motor electromagnetic parameters are obtained by means of FEM analyses and the characteristics of the considered case are represented in Table2.

Table 2
Final Design Parameters

Property	Units	Value
Efficiency		*0.94*
Fhases		*6*
Power Rating	*Mw*	*1*
Speed	*RPM*	*300*
Frequency	*Hz*	*300*
Phase Voltage	*Volt*	*72.24*
Back EMF	*Volt*	*120*
Current Density	*A/mm^2*	*6*
Residual Flux Density of The PM Material	*T*	*1*
Air Gap Length	*m*	*0.001*
Flux Density in The Stator Core	*T*	*1.2*

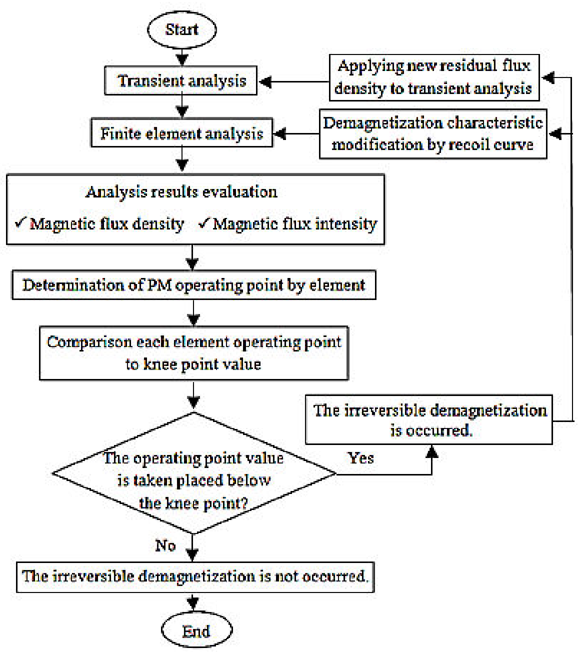

Fig.5 Demagnetization analysis process.

IV. IRREVERSIBLE DEMAGNETIZATION ANALYSIS

The machine dynamic model is used to perform a transient analysis of the designed TFPM motor including the determination of the instantaneous motor phase currents and rotor positions. To illustrate PM's demagnetization analysis, we set motor's temperature 140 degrees. Then, finite element method (FEM) is used for the magnetic field analysis. By using transient analysis, the flux density and magnetic field strength distribution over the model is obtained. When the operating point of PM is below its knee point, the new residual flux density of the PM is applied in the analysis process. By comparing results before and demagnetization analysis, irreversible demagnetization rate of PM is determined. The process of the irreversible demagnetization analysis of designed TFPM motor is presented in figure 5. The knee point the magnet used in this motor is about 0.4 T (motor's temperature is 140 degrees).

V. ANALYSIS RESULTS

In order to carry out an exact evaluation of demagnetization, it is necessary to calculate machine performance under different condition. The FEM analysis has performed under open circuit, no load, full load and worst demagnetizing condition (locked rotor), and the following results are obtained.

A. Open Circuit Condition

Fig. 6 shows the flux density distribution under open circuit condition. It can be seen that irreversible demagnetization has not occurred in the PMs.

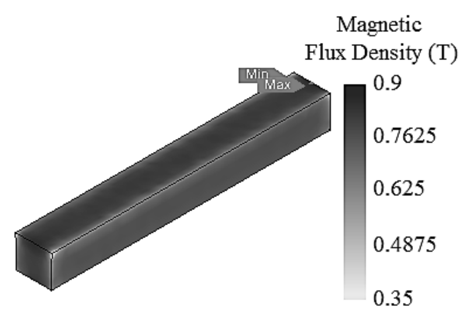

Fig.6 Flux density distribution at open circuit condition.

B. No Load Condition

Magnet flux leakage under no load condition is evaluated by magnetic field analyses using FEM, see Fig 7. The maximum value of flux leakage in magnet is about 2.8% of the total magnet flux.

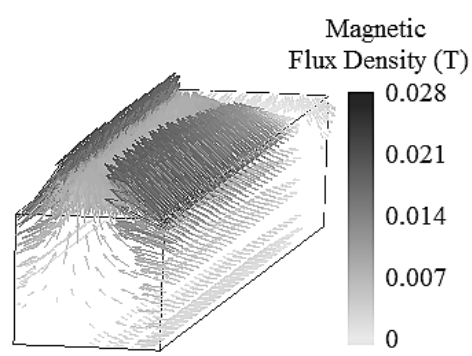

Fig.7 No load magnetic flux leakage in PMs

Consider Fig 7, the maximum concentration of the leakage flux vectors is located in the circumferential edges between the magnets and rotor flux concentrators. These amounts of leakage flux are not strong enough to cause demagnetization of the magnets.

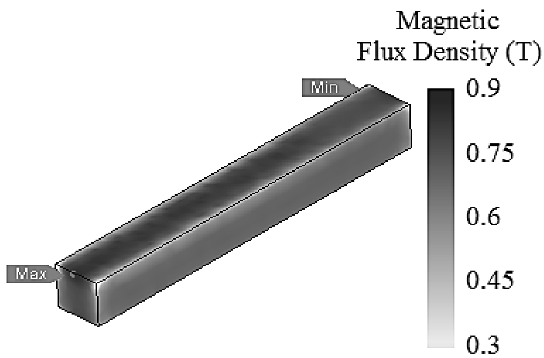

Fig.8 Flux density distribution at no load condition.

C. Full Load Condition

However the maximum value of flux leakage in magnet is about 38% of the total magnet flux but a few amounts of the armature flux lines flow at magnets.

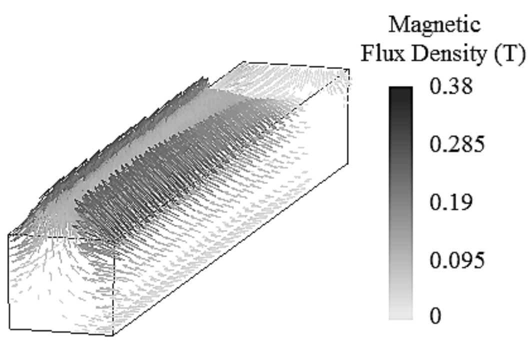

Fig.9 full load magnetic flux leakage in PMs

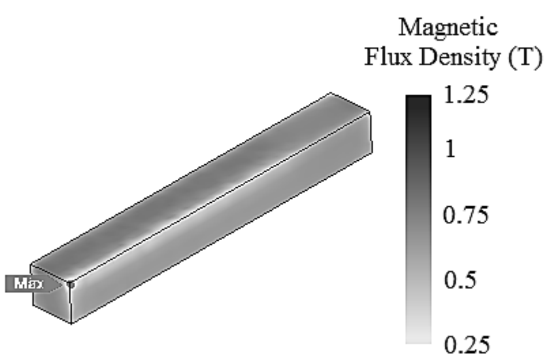

Fig.10 Flux density distribution at full load condition.

D. Locked Rotor Condition

For design comparison purposes the worst demagnetization condition in which the armature reaction flux directly opposes the magnet flux. In this proposed machine, locked rotor condition is the worst case. In this condition the large demagnetizing currents are generated by armature but very little leakage flux takes the path out through the magnets. As shown in Fig 12, although the total magnet flux is decreased, the irreversible demagnetization has not occurred in PMs.

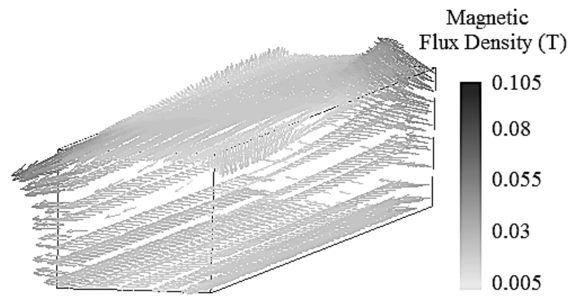

Fig.11 locked rotor magnetic flux leakage in PMs

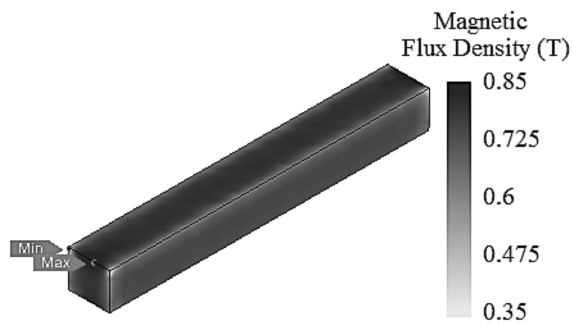

Fig.12 Flux density distribution at locked rotor condition.

As results shown, even in worst demagnetizing condition, a few amount of flux from armature windings passed through the permanent magnets and were not able to demagnetized PMs.

VI. CONCLUSION

In this paper, a suitable design of permanent magnet motor, according to the transverse flux principle was suggested to provide a robust structure against demagnetization. Then the demagnetization analysis of designed motor was studied through a transient analysis coupled with 3D finite element analysis. The analysis results have shown the ability of proposed structure against demagnetization. All of the obtained results were authenticated via FEM analysis.

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