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A Synchronous/Permanent Magnet Hybrid AC Machine

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A SYNCHRONOUS/PERMANENT MAGNET HYBRID AC MACHINE

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ABSTRACT

In this paper, a synchronous/permanent magnet hybrid(SynPM) machine is presented. It is shown that the machine has good power density and efficiency, and that the machine has true field regulation capability. The principle of operation, finite element analysis and simulation of this new machine are investigated in the paper.

Key Words: PM Machine, Synchronous Machine, Hybrid Machine.

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DIGEST

1 INTRODUCTION

In this paper, a new electric machine termed the SynPM Hybrid machine is presented. This new machine is a combination of a PM machine and a wound field synchronous machine. It has both PM poles and excitation poles on the rotor, retaining the conventional multi-phase machine stator winding. It has both the features of both PM and synchronous machines. The PM poles provide the air gap with major part of air gap flux. The excitation poles act as the flux regulator to adjust the air gap flux distribution. By proper connection the of stator windings, field weakening/strengthening operation is achieved by picking up the EMF changes caused by the change of flux density under the excitation poles. Although the slip rings and brushes are still present in this kind of electric machine, failure of the brush rigging will not cause as severe a problem as it would for the conventional wound field synchronous machine since the PM poles still produce fairly large air gap flux even with the field winding out of service.

2 PRINCIPLE OF OPERATION

The structure of the SynPM machine is shown in Fig. 1. The machine has six poles in which 4 of the rotor poles are PM poles and the remaining 2 poles are excitation poles. In general, the operation of this type of machines is quite similar to that of the permanent magnet synchronous machine except that this new structure possesses field regulation characteristics.

The armature winding of SynPM machines should be connected in the way that when field current changes, it can change the back EMF of a circuit, assuming that speed is maintained constant. The winding connection is also shown in Fig. 1, in

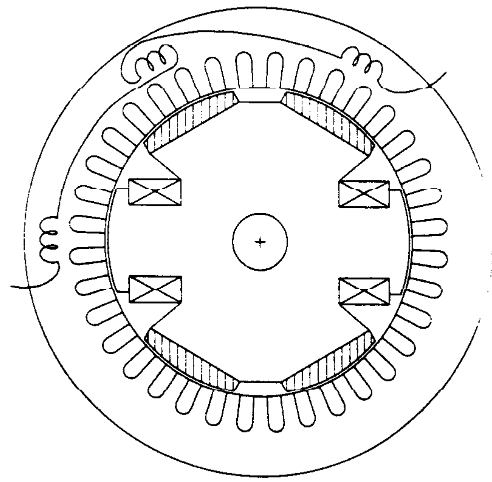


Figure 1: Structure of SynPM Machine

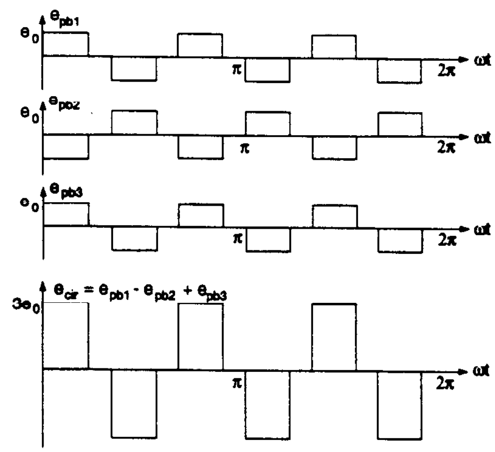


Figure 2: Back EMF of One Circuit with Full Positive Excitation

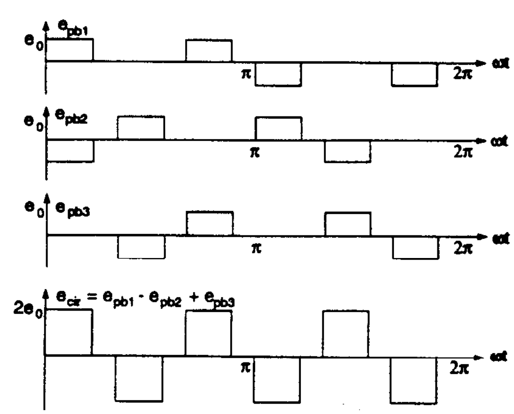


Figure 3: Back EMF of One Circuit with Zero Excitation

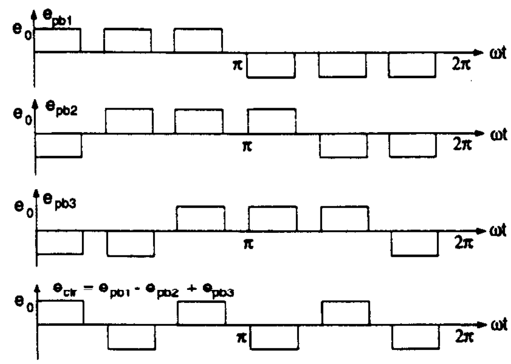


Figure 4: Back EMF of One Circuit with Full Negative Excitation

which a circuit is formed by connecting three consecutive phase belt windings of the same phase in series, so that at any moment the circuit is always under the influence of one excitation pole and 2 PM poles, resulting in an adjustable circuit back EMF. The resulting back EMFs of the circuit for the cases of positive field current, no field current and negative field current are shown in Figures 2, 3 and 4.

If the machine has a sinusoidal back EMF, then

$$e_{cir} = 2\omega\Lambda_{pm} + \omega\Lambda_{ex} = 2\omega\Lambda_{pm} + \omega L_f i_f \tag{1}$$

which shows that e_{cir} is regulated by i_f. However, it should be noted that the flux density under the PM poles remains almost unchanged.

3 COUPLED CIRCUIT SIMULATION

A magnetic circuit analysis is used to calculate the parameters for coupled circuit simulation. Figure 5 shows the calculated circuit self inductance versus rotor angular position curve. There are six positions where the inductance reaches its maximum as a result of the series connection of the member coils of the circuit.

The flux linkage of circuits produced by PM poles is another important issue in the simulation. The circuit flux linkage can also be calculated by magnetic circuit analysis and is shown in Figure 6. From the curve it is clear that from the terminals of the circuit, the number of poles is six, which is achieved by connecting the coils of same phase under all poles in series.

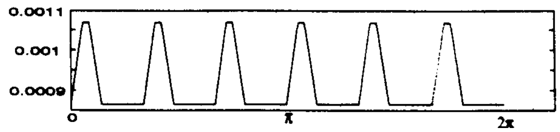


Figure 5: Calculated Circuit Inductances

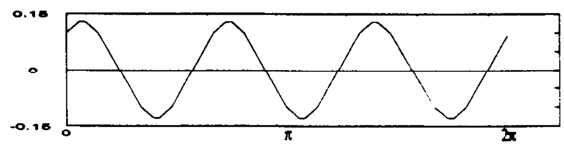
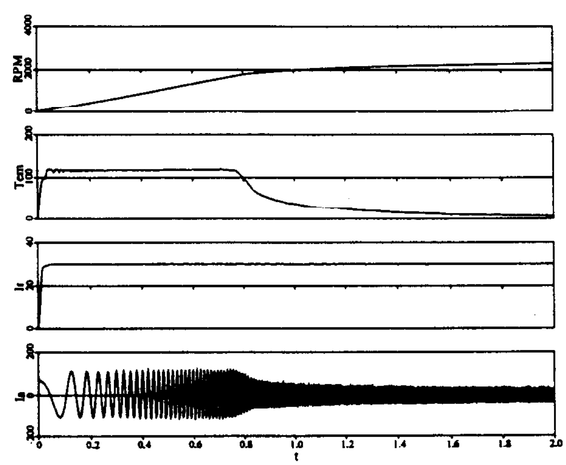
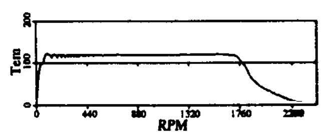


Figure 6: Calculated Flux Linkages of One Circuit



(a) Speed, Torque, Field Current and Phase A Current vs. Time



(b) Torque vs. Speed

Figure 7: Simulation of SynPM Machine Without Field Current Regulation

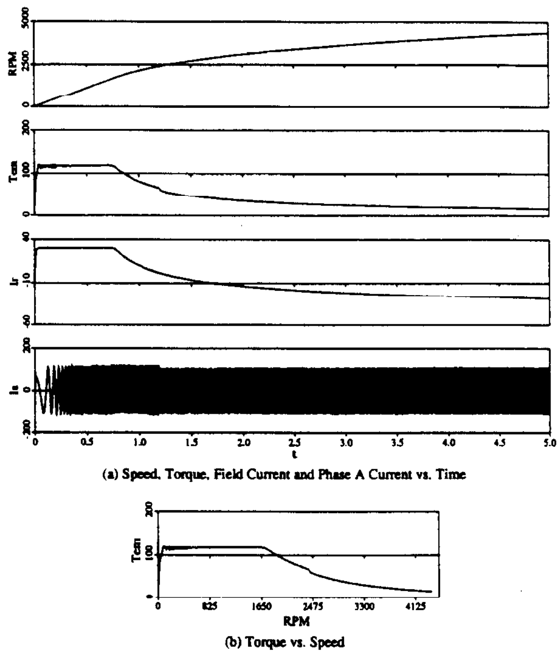


Figure 8: Simulation of SynPM Machine with Field Current Regulation

A simulation study has been made to determine the performance of the SynPM machine. The simulation results are shown in Figures 7 and 8. From these plots, it should be clear that the SynPM machine with field current regulation capability has much higher constant power speed range with considerably improved torque capability than an equivalent PM machine. In these computer traces current regulated pulse width modulation was used to control the stator and rotor current. The field weakening range has been extended from 1.3 to 2.7 per unit or greater compared to a machine without current regulation.

4 FINITE ELEMENT ANALYSIS

To verify the results of the ideal magnetic circuit analysis, an FEM analysis was also conducted. Figure 9 shows the flux lines of the SynPM machine with positive field current. Figure 10 shows another case of the SynPM machine with zero field current, and, finally, Figure 11 shows the case where the field current is negative, or the field weakening case. From these FEM resulting plots it is apparent that a change of field

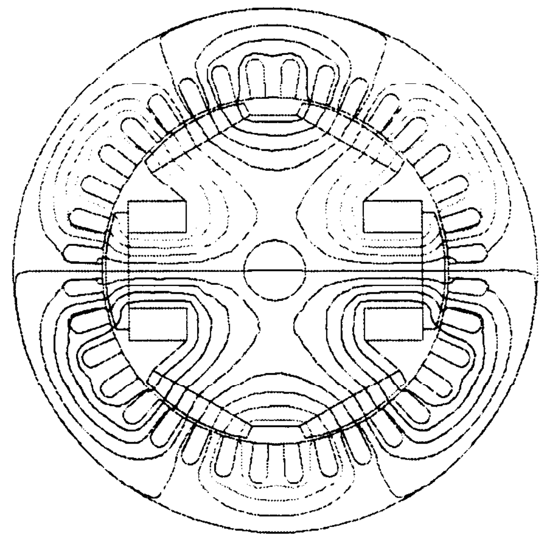


Figure 9: Flux Lines of a 6 Pole SynPM Machine with Full Positive Field Current

current does indeed change the flux pattern in the SynPM machine as predicted.

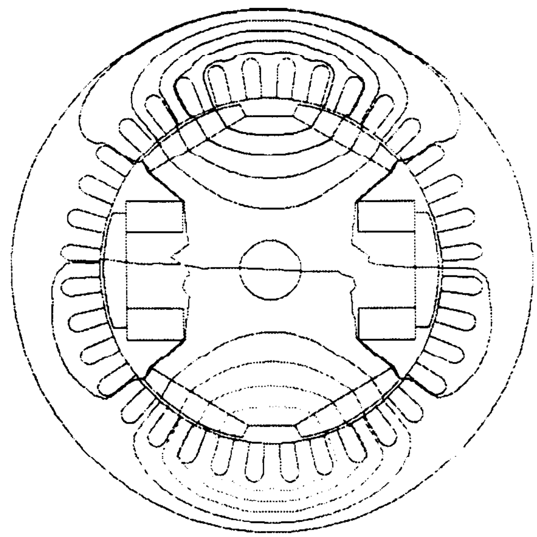


Figure 10: Flux Lines of a 6 Pole SynPM Machine with Zero Field Current

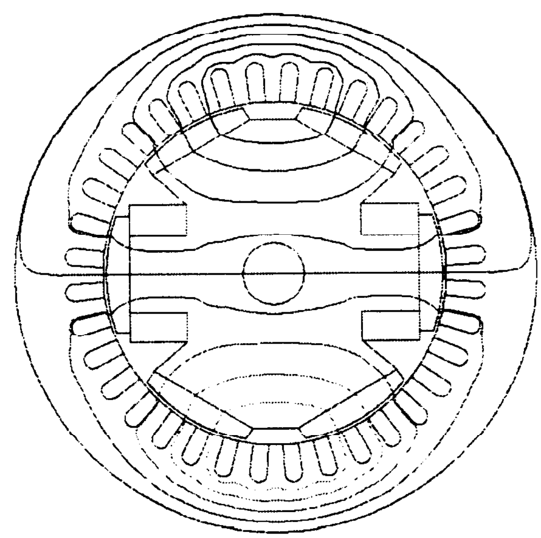


Figure 11: Flux Lines of a 6 Pole SynPM Machine with Full Negative Field Current