

ELECTRO THERMAL ANALYSIS OF PERMANENT MAGNET SYNCHRONOUS MOTOR USE IN AUTOMOTIVE INDUSTRY

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Abstract—Permanent magnet synchronous motor is being used in many low to medium power Range applications in many places of the world due to their inherent advantages. For example, permanent Magnet synchronous machines are used in automotive applications, vehicular electric drive motors, textile Industries, glass industries, and computer and robotics applications. Also to improve the efficiency of Submersible pumps, we use rotor representing a squirrel cage and permanent magnet of a synchronous motor by replacing the rotor of an induction motor. This paper proposes analytical procedure to design the rotor with buried permanent magnets placed in 'V' shape and two-pole motor. The main objective of the thesis is to design and simulate the synchronous machine in MAGNET and ANSYS software and then to calculate the output parameters of permanent magnet synchronous motor. Using analytical formulae, magnetic force, energy etc... are calculated and these are validated with the corresponding results obtained from the MAGNET and ANSYS software simulation. Also percentage error between the calculated analytical formulae results and software simulation results is analyzed.

Keywords— permanent magnet synchronous motor, stator flux linkage. Rotor flux linkage, electromagnetic torque.

I. INTRODUCTION

In order to decrease gas emission, different countries led by the United States imposed classes of efficiency for standalone induction motors through their legislation. Even though it is possible to increase the efficiency of traditional induction motors, this cannot be easily done without oversizing the motor, which is definitely contrary to the idea of an integrated motor for products such as pumps. In this case, the solution could be to find another type of motor that reaches higher efficiency levels : the Permanent Magnet Synchronous Motor is one of them. By introducing permanent magnets buried beneath the squirrel cage, a hybrid motor is obtained which combines an asynchronous start with a synchronous steady state operation. With really low copper losses at steady state (harmonic losses only), a better efficiency can be reached. Synchronous machines are among the three most common types of electric machines, the other two kind being dc commutator machines and polyphase induction machines. Synchronous machine operate at constant speed and constant frequencies under steady state conditions. In large sizes, synchronous motors are used in generating stations. In small sizes, they are used in electric clocks. It is doubly excited winding because its field winding is energized from a dc source and its armature winding is connected to an ac source. It is not self starting and it cannot be started on load. As it is not self starting due to the inertia of the rotor, damper winding is applied on the surface of the rotor or induction motor or any other external motor is used to drive the rotor of synchronous machine so that it operates as a self starting motor as induction motor and then when dc supply is applied to rotor, it operates at synchronous speed. Since it is a constant speed motor, it cannot be used to derive a variable speed load. They are used as motors in constant – speed drives and, where a variable speed drive is required , a synchronous motor is used with an appropriate frequency changer such as inverter or

cycloconverter. Synchronous machines can also be used over the wide range of power factor such as leading, unity and lagging power factor by changing the field current (excitation). Improved voltage regulation can be obtained by using synchronous motor when compared to other motors. Synchronous motor with no load operating at leading power factor just to improve power factor is called a synchronous condenser. If the motor is overloaded, it will stop. It has tendency to hunt. So damper winding is used on rotors to prevent hunting. Small induction motors are designed to operate on single phase supply. Two types of this motor are reluctance motor and hysteresis motor. These motors are used in timers, turntables and so forth. In this regard, its fractional horsepower motor is different which has large rating.

II. OBJECTIVE

The objective is to determine the electro-magnetic analysis of a two pole permanent magnet synchronous motor. Determination of electro-magnetic analysis involves computation of various parameters related to the electromagnetic analysis of synchronous machine. These parameters involve magnetic flux parallel, mesh analysis, total flux density, directional flux density, total force, directional force / torque, total field intensity, directional field intensity etc... It is also required to compute the inductance, current density and flux linkage of the conductors used in the winding of the synchronous motor. This analysis is necessary to determine the electrical characteristics of the motor so as to choose the best dimensioned synchronous motor to meet any required specific application.

PERMANENT MAGNET SYNCHRONOUS MACHINES

The vast of synchronous machine configuration in the medium and low power ranges can be classified in two groups: conventional and brushless. PM machine falls into the latter group. PM synchronous machine generally have the same operating and performance characteristics as synchronous machines in general; operating at synchronous speed, a single or polyphase source of alternating currents supplying the armature windings, a power limit above which operation at synchronous speed is unstable, a reversible power flow, damper (cage) winding for starting and stability purpose, a torque angle between armature and field phasors etc. A PM machine can have a configuration almost identical to that of the conventional synchronous machine with the absence of slip rings and a field winding. This absence of course, is responsible for the major difference between a PM machine and a conventional synchronous machine: lack of power factor or reactive power control and in association with terminal voltage regulation. The absence of brushes and slip rings is also a principal merit of PM synchronous machine. However in this regard, the PM synchronous machine is in —competition with a number of other brushless configurations. Therefore, being brushless is not necessarily a major advantage of a PM machine over the other types of synchronous machine. It is rather a low cost, simplicity of rotor construction, and reduced manufacturing assembly and cost of a PM machine that make it very competitive in market place. Only reluctance machines are simpler in construction and in assembly procedures than PM machines, but reluctance machine generally develop less torque per unit of current. Therefore on a basis of power output per unit of weight, the PM synchronous machine is superior to all other brushless synchronous machine with rare earth magnets. In terms of cost per unit of power output, it is lower than all but possibly certain reluctance machine configuration.

III. MACHINE COMPONENTS AND DESIGN

For a PM machine to be brushless, the magnet must be on the rotor. The principal components of PM synchronous machine are described in the following

A. STATOR

This is the stationary member of the machine and includes a number of elements:

STATOR LAMINATIONS

A cylindrical, radial air gap machine is similar to those of other types of laminations, in general, is similar to those of other types of synchronous and induction machine and is formed from magnetic steel stampings. Stator laminations are formed by winding continuous strips of steel. Various parts of laminations are teeth, slots which contain the armature windings and the stator yoke (the outer portion) which completes the magnetic path. Laminations depend upon frequency of the armature source voltage and cost and core- loss considerations. Laminations are bonded together in various manner to form stator stack.

ARMATURE WINDING

In most PM machines, armature is conventionally single or polyphase windings similar to those of ac machines. Windings are generally single layer. In contrast to armature windings, ac windings are —open ended. Individual coils are connected together to form phase groups, the basic element of an ac winding, and designated as number of slots per phase per pole. Phase groups are connected in series/parallel combinations to form zigzag single phase windings. AC windings are short pitched to reduce harmonic voltage generated in windings. Windings are formed from standard magnet wire. Coils, phase groups and phases are insulated from each other and required dielectric strength of the insulation will depend upon voltage rating of the machine.

AIR GAP

The air gap the region between stator and rotor is essential parameter of rotating machine. Its influence is a combination of the effects of physical air gap and stator slot openings. It also influences the mechanical and structural design of machine.

B. ROTOR

The principal elements of the rotor of PM synchronous motor are

POLE STRUCTURE

The PMs form poles equivalent to wound field poles of conventional synchronous machines. PM poles are salient and there is no equivalent to cylindrical rotor pole configuration. Many PM synchronous machine may be cylindrical or smooth rotor, but electrically the PM is equivalent to salient pole structure.

ROTOR YOKE

This magnetic portion of rotor to provide a return path for PMs and to provide structural support in some design. It is a part of pole structure.

SHAFT AND BEARING SYSTEM

This is also a part of permanent magnet synchronous motor.

HOUSING

The stator is supported by housing, which is non magnetic structural member that contains entire machine.

There are several means of housing a machine from relatively open housing to hermetically sealed housing. Housing provides other functions such as thermal conductor for conducting heat generated within machine to external sink.

ROTOR CONFIGURATION

Synchronous motor is classified according to their configuration. The optimum rotor should maximize the air gap flux density and minimize the leakage flux between magnets. Another consideration affecting rotor design is number and location of damper bars. There are four general type of rotors found in PM synchronous machines.

They are: PERIPHERAL The PM s is located on rotor periphery an PM flux is radial. INTERIOR The PM s is located in the interior of the rotor and flux is generally radial.

CLAW – POLE OR LUNDELL The PM s is generally disc shaped and magnetized axially. There is a set of equally spaced claws on each disc which alternate with each other, forming alternate north and south poles.

TRANSVERSE In this, the PM s is generally between soft – iron poles and the PM s flux is circumferential. It is also termed as hybrid configuration.

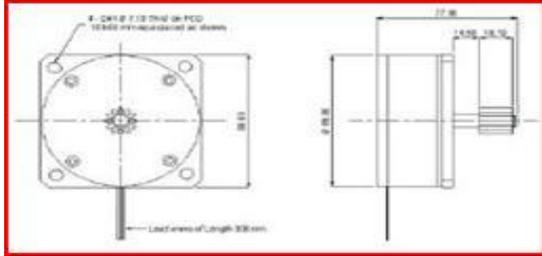


Fig.1 Project done on permanent magnet synchronous motor



Fig. 2 Dimensions of permanent magnet synchronous motor

COVERNING EQUATION

$$2A = -J$$

$$A = 4J / rdv$$

BOUNDARY CNDITION

Dirichlet's boundary condition. That is $A_z = 0$ along the boundary .

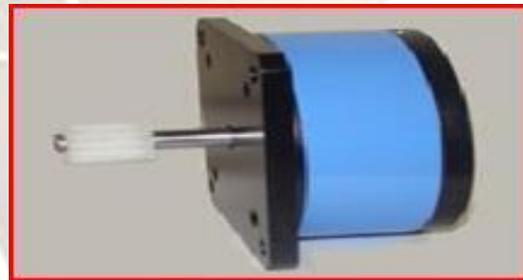


Fig. 3 Schematic diagram of permanent magnet synchronous motor

WINDING

Single layer wave winding is used here in 8 slots in stator. Here we need two phases to drive the motor. The first phase is provided by the direct dc supply and the second by phase shifting the supply using suitable capacitor divider. This makes driving circuit very simple and does not require driver that is required for dc stepper motor. Forward and reverse directions are achieved by alternating the phases. Hence motor can rotate in both directions.

WINDING DETAILS FOR FORWARD DIRECTION

SLOT IN	SLOT OUT
2	4
4	6
6	8

Table 1 Winding details for motor forward direction

SLOT IN	SLOT OUT
1	5
3	7
5	9

Table 2 Winding details for motor reverse direction

INDUCTANCE CALCULATION

INDUCTANCE MEASUREMENT	UNIT	VALUE
SPECIFICATIONS	HENRY	1.6
USING LCR METER	HENRY	1.43

Table 3. Inductance calculation

SYNCHRONOUS SPEED, NUMBER OF POLES AND TORQUE

$$NS = 120 * f / p$$

$$= 120 * 50 / p$$

i) Given NS = 60 rpm

Therefore

$$60 = 120 * 50 / p$$

$$p = 120 * 50 / 60$$

$$= 1000 \text{ Rpm}$$

Therefore

ii) Number of poles = 100

iii) Pull - in torque = Pull - out torque

Thermal Analysis of Permanent Magnet Synchronous Motor

Motor Comp/Time(MIN)	t=3	t=3	t=4	t=4	t=5	t=5	t=6
Shaft	52	54	56	59	62	65	70
Rotor Inner	51	53	55	57	60	64	69
Rotor Outer	53	55	58	60	64	67	73
Stator Teeth	54	56	59	60	65	68	74
Stator Winding	54	56	59	61	65	69	74
Stator - Outer	53	55	57	59	63	66	72

Table 4 Thermal analysis of permanent magnet synchronous motor

Given that motor has maximum withstand operating temperature is 80 degree Celsius. From the table, it is

clear

that temperature for this synchronous motor up to 60 minutes, temperature of the motor cannot exceed 80 degree Celsius. Here temperature of the motor is measured using infra – red thermo meter.

IV.MAGNET SIMULATION RESULTS

Parameters Ansys Analytical % error simulation results			
Flux linkage	* 108 Webers	-3.17 -2.02 * 108 Webers	51.93
Inductance	1.58 * 107 Henry	1.01 * 107 Henry	50.01
Torque	-2724.04 Newton metre	2024	34.58
Magnetic flux	1.58 * 107 Henry	1.01 * 107 Henry	50.01

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