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“Speed Control of Permanent Magnet Synchronous Motor Drive Using an Inverter”

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Abstract - Permanent Magnet Synchronous Motor are used in many applications that require rapid torque response and high – performance operation. New developed materials such as magnetic materials, conducting materials and insulating materials as well as several new applications have greatly contributed to the development of small and special purpose machines. Using such materials the size of the motor would considerably reduce and high performance motors can be built. Due to several new applications these motors are quite popular in a developing country such as India.

The speed of a permanent magnet synchronous motor is varied by varying the frequency of an inverter. The performance of the motor is experimentally verified and the results are found to be encouraging. It is also observed that, under varying load condition, the speed of a motor remains constant at constant frequency.

Key words- *Permanent Magnet Synchronous Motor, Inverter, clock generator counter, opt isolator. Interior Permanent Magnet Sinusoidal Machine (IPM)*

I. INTRODUCTION

A. Permanent Magnet Synchronous Motor:

In a permanent magnet synchronous motor, the dc field winding of the rotor is replaced by a permanent magnet. The advantages are elimination of field copper loss, higher power density, lower rotor inertia and more robust construction of the rotor. The demerits are loss of flexibility of field flux control and possible demagnetization effect. The permanent magnet synchronous motor has higher efficiency than an induction motor, but generally its cost is higher, which makes the life cycle cost of the drive somewhat lower permanent magnet synchronous motor particularly at low power range are widely used in industry. Recently, the interest in their application is growing, particularly up to 100 kW, only reluctance motor are simpler in construction and in assembly procedure then permanent magnet synchronous motor, but reluctance motor generally developed less torque per unit of current and per unit of weight. Therefore, on a basis of power output per unit weight and per unit volume the permanent magnet synchronous motor is superior to all other brushless synchronous motor especially with the commercial feasibility of rare earth magnets. In this motor the magnets are mounted inside the rotor. The motor is connected on load and its speed depends on the stator supply frequency. The motor forms an open loop variable speed system. Due to its constructional features, the angular displacement and speed of rotor with respect to. stator field can be precisely controlled without any feedback. This motor dose not operates at sub-synchronous speed as reluctance or hysteresis synchronous motor. Another feature of this motor is high impendence protection i.e. inductance of stator winding is high. Due to this current in motor at start, at run and at rotor lock condition is same hence no burn out of insulation.

Conventional machines either ac exited or brushed dc, are ill-suited for applications where torque density and overload capability is required. Therefore, brushless permanent magnet motors are finding more applications.

The vast array of synchronous motor configuration in the medium and low power ranges can generally be classified into two groups: Conventional & Brushless. PM motors fall into the latter group. Permanent magnet synchronous motors generally have the same operating and performance characteristics as synchronous motor in general operation at synchronous speed. A single or poly-phase source of alternating current supplying the armature windings. If the operation of the permanent magnet synchronous motor at synchronous speed is done above the power limit this gives unstable performance, reversible power flow. A permanent magnet synchronous motor can have a configuration almost identical to that of the conventional synchronous motor with the absence of slip rings and a field winding. The absence of course, is responsible for the one major difference between permanent magnet synchronous motor and a conventional synchronous motor: lack of power factor or reactive power control and its association with terminal voltage regulation.

Three Phase Permanent Magnet Synchronous Motors are

1. Sinusoidal surface magnet machine (SPM)
2. Sinusoidal interior magnet machine (IPM)
3. Trapezoidal surface magnet machine

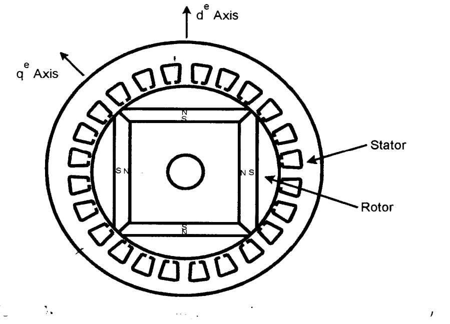

Fig.1 Cross Section of Interior Permanent Magnet Sinusoidal Machine (IPM)

B. *Sinusoidal Interior Magnet Machine (IPM)*

i) The machine is more robust, permitting a much higher speed of operation.

ii) The effective air gap in the d^e axis is larger than that in the q^e axis, which manes the machine salient pole with Ldm < lqm (unlike a standard wound field synchronous machine) and

iii) With the effective air gap being low, the armature reaction effect becomes dominant.[01]

Permanent Magnet Materials:

The properties of a permanent magnet of the selection of the proper materials are very important in the design of permanent magnet synchronous machine.

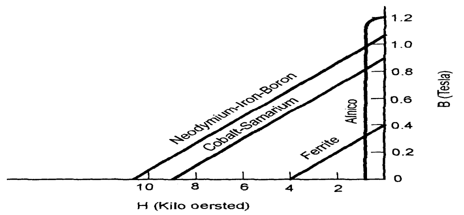

Fig. 2 Permanent Magnet characteristics

Fig. 2 shows the characteristics of several possible PM materials. A line has high service temperature good thermal stability and high flow density, but the disadvantage is low coercive force coupled with squares’ B-H characteristics, which means the permanent demagnetization high so that it is practically unsuitable for a PM machine. Barium and strontium ferrites are widely used as permanent magnets. Ferrite has the advantages of low cost and plentiful supply of low material. They are also easy to produce and their process is suited for high volume, as well as moderately high service temperature (400^0C).[06]

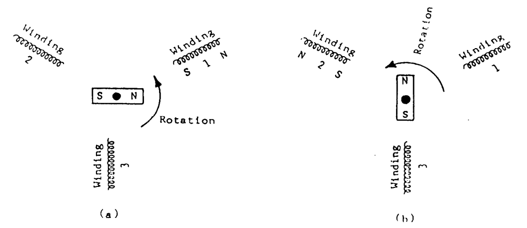

Fig3 Basic Rotation of permanent magnet synchronous motor

C. *Operating principle of permanent magnet synchronous motor:*

In these motor the rotor consist of permanent magnets and the stator consist of three phase windings. These windings are termed “Commutation” windings. By passing a current through winding a magnetic field is setup with which permanent magnet on the rotor interact. This result is the rotation of the rotor.

Fig. 3 illustrates in simplified form how rotation occurs with a current passing through a windings. Fig. a) A south pole is set up with which the permanent magnet will react and movement will begin. If, the appropriate time current is shut OFF in winding 1 and turn on in winding 2 (see in fig. b) then the rotor will continue to move. By continuation of this timing sequence, complete rotation will occurs as the rotor repeatedly tries to catch up the stator magnetic field and gets magnetically locked. In this example the operation is simplified for explanation by exciting only one winding at a time. In practical situation, to and same times three winding are energized at a time. This procedure permits the development of higher torque. As indicated, if current is properly switched from winding to winding the rotor will continue to rotate.[06]

D. *Application Characteristics of permanent magnet synchronous motor:*

The characteristics of the permanent magnet synchronous motor are determined with the aid of well known selection criteria. The criteria include the following

(a) Cost

(b) Power density

(c) Torque to inertia ratio

(d) Speed range

(e) Torque per unit current

(f) Braking

(g) Cogging and ripple torque

(h) Parameter sensitivity

(i) Losses and thermal capability

II. SIMULATION

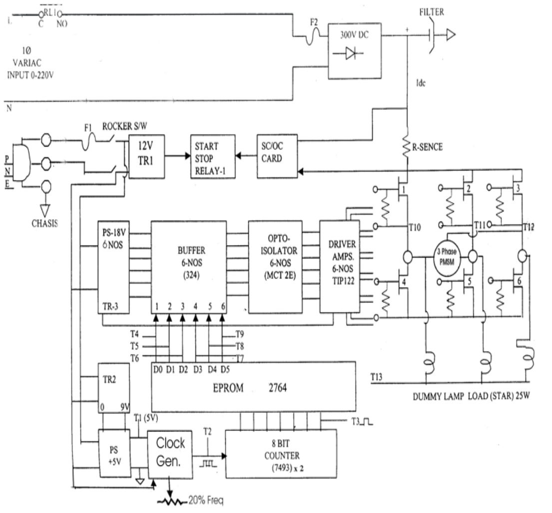

Fig. 4 Block Diagram of permanent magnet synchronous motor Drive

Three phase permanent magnet synchronous motor is used here and three phase supply voltage are obtained with the help of three phase MOSFET bridge inverters. MOSFET bridges are fed with fixed dc voltage which is obtained by rectifying ac voltage available from ac mains with the help of diode bridge rectifier. Shunt capacitor filter is used for filtering purpose. Operation of the MOSFET bridge is controlled by the control circuit. Gating pulses required to turn the MOSFET ON are obtained from the control circuit. By controlling the frequency of the gating pulses, frequency of the output from MOSFET Bridge is controlled. Control circuit consists of clock generator counter and EPROM. First data required to generate gating pulses is calculated and is stored in EPROM. This data is give to the output of the EPROM by generating the address of the memory location with the help of 4 bit binary ripple counter. Clock input required for the operation of the counter is generated using IC 555 in astable mode. Frequency of the gating signals coming out of EPROM is dependent on the frequency with which addressing is done which in turn dependent on the clock frequency. Thus by varying the clock frequency, the frequency of gating signal is varied. If frequency of gating signals is varied, then the MOSFET bridge output frequency is also varied. Thus we obtain variable frequency output.

The output of EPROM cannot be directly applied to MOSFET Bridge. So isolator and driver circuit is used, for proper isolation between low power control circuit and high power bridge circuit by using opt isolator.

Test Point Waveforms:

The waveforms at various points in the control circuit and power circuit are shown in the fig. 5.1

Various test points are taken out. The figure shows the basic waveform of timer IC 555 in astable mode. The output frequency which is 1/256 times that of timer frequency is also shown (Test point TP3).

The gate pulses for the inverter bridge are also shown which are applied sequentially after a predetermined time interval. At the end the waveforms for the line voltage and phase voltage are shown. The phase voltage waveform can be seen on dummy load (lamp load).

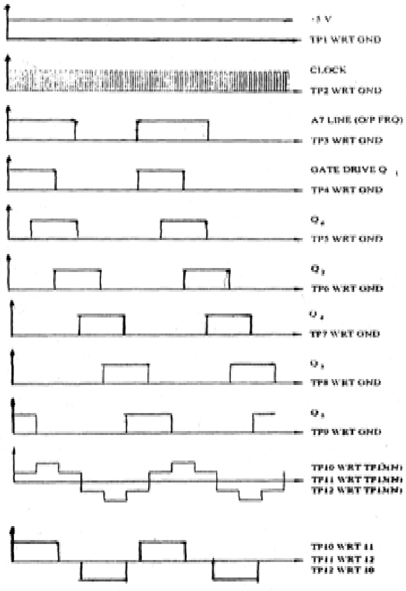

Fig.5 Waveforms at various test points

III. RESULTS

The test results for the PMSM drive are given below:

The load torque is given by the equation-

$T_L = (T_1 - T_2)$ x r x 9.81

Where, **r** = Radius of the pulley **= 3 cm = 0.03m**

T_1 = Tension in the tight side in Kg

T_2 = Tension in the slack side in Kg

T_L = T_1 x r x 9.81 in N.m.

TABLE-I

Sl. No.	Load (gm))	FRE. (Hz)	Speed (rpm)	Torque (N-M)	Power (W)
1	500	33.3	1226	0.1471	15.55
2	1000	33.3	1226	0.2943	31.12
3	1500	33.3	1226	0.4414	46.68
4	2000	33.3	1226	0.5886	62.19
5	2500	33.3	1226	0.7357	77.81
6	3000	33.3	1226	0.8829	93.38

TABLE-II

Sl. No.	Load (gm)	Fre (Hz)	Speed (rpm)	Torque (N-M)	Power (W)
1	500	40.0	1226	0.14715	18.93
2	1000	40.0	1226	0.2943	37.78
3	1500	40.0	1226	0.4414	56.66
4	2000	40.0	1226	0.5886	75.56
5	2500	40.0	1226	0.7357	94.45
6	3000	40.0	1226	0.8829	113.35

TABLE- III

Sl. No.	Load (gm)	Fre (Hz)	Speed (rpm)	Torque (N-M)	Power (W)
1	500	45.4	1380	0.14715	23.47
2	1000	45.4	1380	0.2943	42.53
3	1500	45.4	1380	0.4414	63.78
4	2000	45.4	1380	0.5886	85.06
5	2500	45.4	1380	0.7357	106.31
6	3000	45.4	1380	0.8829	127.59

TABLE-IV

Sl. No.	Load (gm)	Fre (Hz)	Speed (rpm)	Torque (N-M)	Power (W)
1	500	50.0	1520	0.14715	23.47
2	1000	50.0	1520	0.2943	46.84
3	1500	50.0	1520	0.4414	70.25
4	2000	50.0	1520	0.5886	93.68
5	2500	50.0	1520	0.7357	117.1
6	3000	50.0	1520	0.8829	140.5

TABLE-V

Sl. No.	Load (gm)	Expected speed (rpm)	Measured speed (rpm)	Voltage (volts)
1	500	999	1010	270
2	1000	999	1010	270
3	1500	999	1010	270
4	2000	999	1010	270
5	2500	999	1010	270
6	3000	999	1010	270

TABLE-VI (**VARIATION** in the speed of the motor as a function of load at constant as a function of load at constant frequency of 33.3 Hz)

Sl. No.	Load (gm)	Fre (Hz)	Speed (rpm)	Torque (N-M)	Power (W)
1	500	55.5	1682	0.14715	25.98
2	1000	55.5	1682	0.2943	51.83
3	1500	55.5	1682	0.4414	77.74
4	2000	55.5	1682	0.5886	103.67
5	2500	55.5	1682	0.7357	129.58
6	3000	55.5	1682	0.8829	155.51

TABLE VII (Variation in the speed of the motor as a function of load at constant frequency of 40 Hz)

Sl. No.	Load (gm)	Expected speed (rpm)	Measured speed (rpm)	Voltage (volts)
1	500	1200	1226	270
2	1000	1200	1226	270
3	1500	1200	1226	270
4	2000	1200	1226	270
5	2500	1200	1226	270
6	3000	1200	1226	270

TABLEVIII: (Variation in the speed of the motoras a function of load at constant frequency of 45.4 Hz.)

Sl. No	Load (gm)	Expected speed (rpm)	Measured speed (rpm)	Voltage (volts)
1	500	1362	1380	270
2	1000	1362	1380	270
3	1500	1362	1380	270
4	2000	1362	1380	270
5	2500	1362	1380	270
6	3000	1362	1380	270

TABLE IX (Variation in the speed of the motor as a function of load at constant frequency of 50 Hz.)

SL. NO.	LOAD (GM)	EXPECTED SPEED (RPM)	MEASURED SPEED (RPM)	VOLTAGE (VOLTS)
1	500	1500	1520	270
2	1000	1500	1520	270
3	1500	1500	1520	270
4	2000	1500	1520	270
5	2500	1500	1520	270
6	3000	1500	1520	270

TABLE X (Variation in the speed of the motor as a function of load at constant frequency of 55.5 Hz.)

SL. NO.	**LOAD (GM)**	**EXPECTED SPEED (RPM)**	**MEASURED SPEED (RPM)**	**VOLTAGE (VOLTS)**
1	500	1665	1682	265
2	1000	1665	1682	265
3	1500	1665	1682	265
4	2000	1665	1682	265
5	2500	1665	1682	265
6	3000	1665	1682	265

TABLE XI (Variation in the speed of the motor as a function of load at constant frequency of 59 Hz.)

SL. NO.	LOAD (GM)	EXPECTED SPEED (RPM)	MEASURED SPEED (RPM)	VOLTAGE (VOLTS)
1	500	1770	1790	265
2	1000	1770	1790	265
3	1500	1770	1790	265
4	2000	1770	1790	265
5	2500	1770	1790	265
6	3000	1770	1790	265

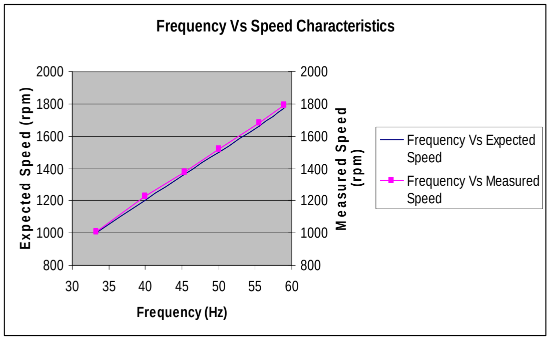

Fig. 6 Frequency Vs Speed characteristics

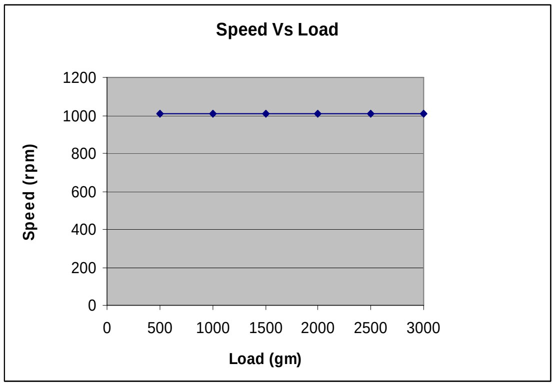

Fig. 7 (Speed Vs Load Characteristics at Constant Frequency 33.3 Hz)

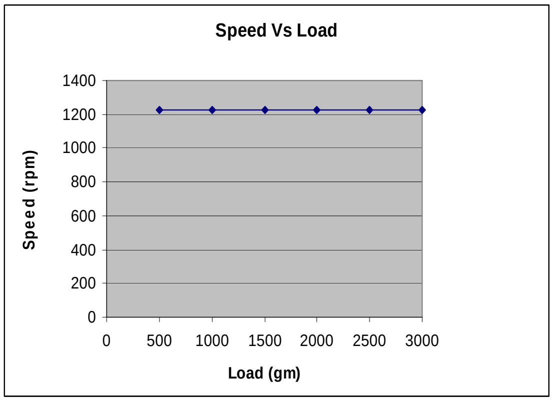

Fig. 8 (Speed Vs Load Characteristics at Constant Frequency = 40 Hz)

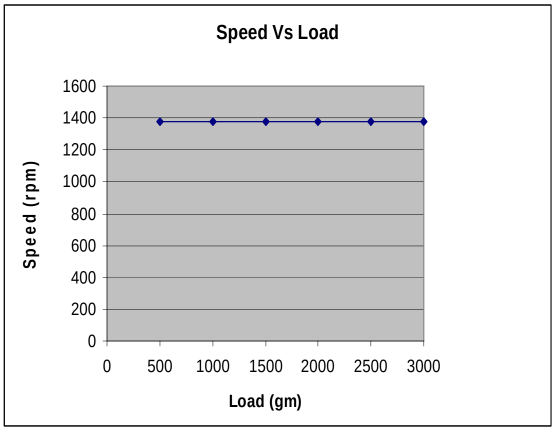

Fig. 9 (Speed Vs Load Characteristics at Constant Frequency = 45.4 Hz)

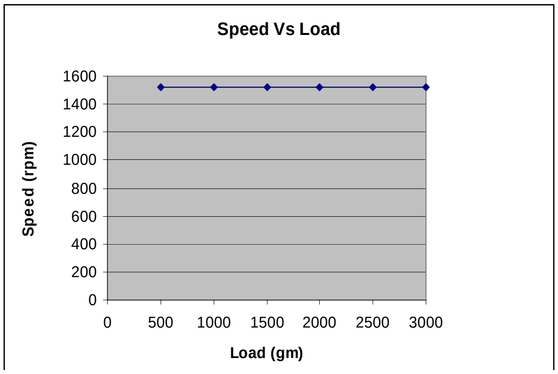

Fig10 (Speed Vs Load Characteristics at ConstantFrequency = 50 Hz)

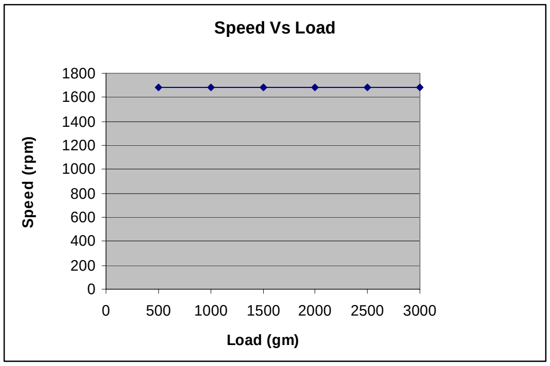

Fig. 11(Speed Vs Load Characteristics at Constant Frequency = 55.5 Hz)

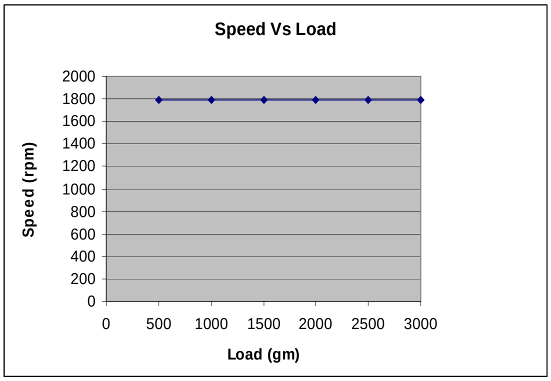

Fig. 12 (Speed Vs Load Characteristics at Constant Frequency = 59 Hz)

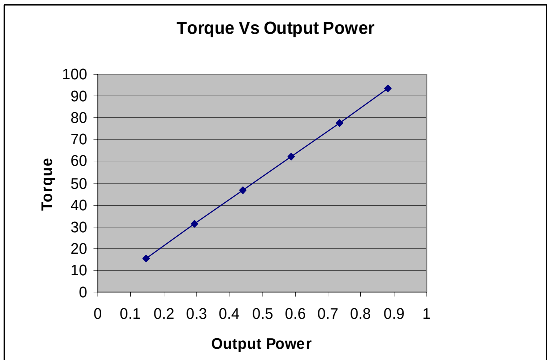

Fig13 (Torque Vs Output Power at frequency33.3 Hz)

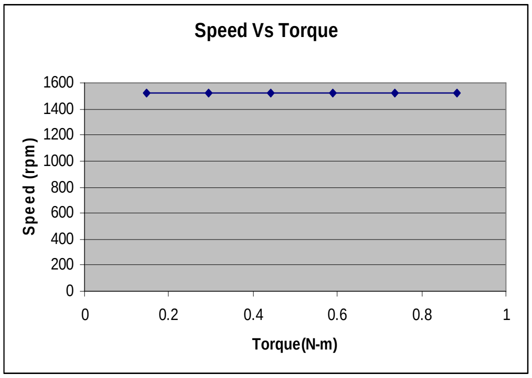

Fig. 14 (Speed Vs Torque at Constant Frequency 50 Hz)

IV. CONCLUSION:

From the above results we conclude that, by varying the inverter frequency the speed of the motor also gets varied. If the frequency increases the speed of the motor also increases and if the frequency decreases the speed of the motor also decreases.

If the frequency is kept constant at particular value, the speed of the motor also remains constant, irrespective of the load. *(If the load on the shaft of the motor increases : speed remains constant)*. It runs at synchronous speed.

V. APPLICATIONS:

The permanent magnet synchronous motor drive is generally used for variable frequency and constant speed applications. The typical applications are as follows.

- Fiber spinning mills
- Rolling mills
- Cement mills
- Ship propulsion
- Electric vehicles
- Servo & robotic drives
- MAGLEV – linear synchronous motor propulsion. Generators for aircraft engines.

VI. FUTURE SCOPE:

The implementation of DTC in permanent magnet synchronous motor is possible using currently available digital signal processor (DSP’s) and MATLAB simulations.

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