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DYNAMIC ANALYSIS OF HYSTERESIS MOTOR USING MATLAB/SIMULINK

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Abstract-**Hysteresis motors are self starting brushless synchronous motors which are being used widely due to their interesting features. Accurate modeling of the motors is crucial to successful investigating the dynamic performance of them. The hysteresis loops of the material used in the rotor and their influences on the parameters of the equivalent circuit are necessary to be taken into consideration adequately. In this paper, a comprehensive analysis of a hysteresis motor in the start up and steady state regimes are carried out based on a developed d-q model of the motor with time-varying parameters being updated during the simulation time. The equivalent circuit of the motor is presented taking into account the major impact of the input voltage. Simulation results performed in Matlab-Simulink environment prove that the existing simple models with constant parameters can not be predict the motor performance accurately in particular for variable speed applications.**

Index terms- **Hysteresis Motor, Modeling, Variable parameters, Dynamic Transient model**

1 INTRODUCTION

Hysteresis motor is widely used in small motor applications. It has simple constructional features with conventional stator windings and a solid rotor hysteresis ring. It has built-in constant torque during the run-up period, and it can pull into synchronism any load inertia that it can accelerate. Its starting current is usually less than 180% of the full-load current. Unlike conventional synchronous motors, it has no preferred synchronizing point and is practically noiseless during operation. These advantages make this motor especially suitable for wide industrial applications and they meet the requirements of new adjustable-speed drives. As a result, the hysteresis motor is manufactured with new high-energy hysteresis materials to improve its performance and rating. When the hysteresis motors are built as prototypes, their dynamic transient analyses in the design stage are quite important. In the Finite Elements (FE) method is used for analyzing, but it is rather time consuming. In this paper, a linear model with time varying parameters is proposed to predict transient behavior of the hysteresis motors accurately. The paper is organized as follows: The basic equations of the motor are presented in Section 2. In Section 3, the d-q equivalent circuits of the motor are given taking into account the exact effect of the hysteresis loops of the rotor material. In Section 4, the simulation results under various situations including the start up scenario are presented to prove the accuracy and suitability of the proposed model. Simulations of the study machine, which is a flat type motor. hysteresis motor, are carried out in Matlab-Simulink environment. Finally, Section 4 concludes the paper.

2. MACHINE MATHEMATICAL MODEL

In this model the hysteresis loop of the rotor can be replaced by 3-phase balanced windings with the same number of turns of the stator windings or two phase equivalent windings as shown in d-q frame of reference by Fig. 1. The eddy current effect on the performance of motor which depends on the slip is modeled by resistance Re, and the hysteresis loss and power are represented by Rh. As shown in Fig. 1, the parameter F is the angle between d axis and phase 'a' axis of the stator, which is called hysteresis delay angle. Also, Vrd and Vrq in are the equivalent induced voltages for the hysteresis loop of the rotor. These voltages are constant at synchronous condition, when the flux densities become fixed all through the rotor.

For modeling of the hysteresis motors, the following assumptions are made:

1.The stator winding is a sinusoidal distributed winding.

2. The magnetic flux in the air gap is axial whereas it is circumferential in the hysteresis material of the rotor.

3.Impact of the hysteresis loops, their changes (dynamic operating loop), and eddy currents all are taken into account.

4.Hysteresis loops of the rotor material are experimentally obtained by fitting the curves to the empirical data

In Fig the schematic model of a typical 3-phase hysteresis motor with 3-phase stator windings and 120 degree displacement in the abc reference frame are shown. Rotor parameters in the above mentioned equivalent circuit model can be obtained from structural parameters of a disc type hysteresis motor which are given by equations.

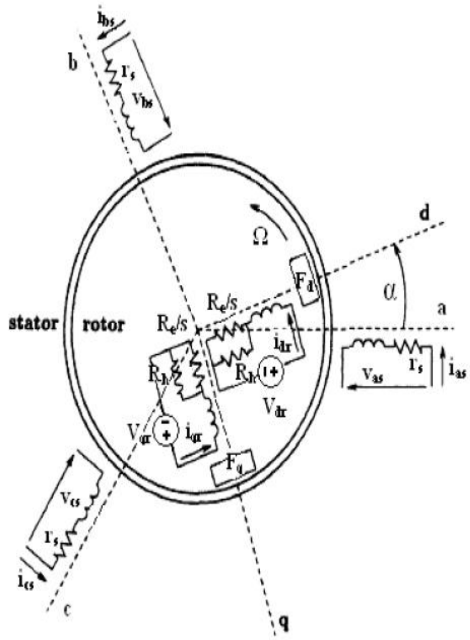

Fig. 1. Schematic model of Hysteresis Motor

$$R_h = \frac{4mf\,(K_w N_{ph})^2 t_r R_{oi} K_{sf} B_q \sin\alpha}{1000\,R_{av} H_p}$$

$$X_{rr} = \frac{R_h}{\tan\alpha} \qquad (2)$$

$$R_e = \frac{48m\rho (K_w N_{ph})^2 R_{oi}}{2\prod R_i t_r} \qquad (3)$$

$$r_r = \frac{R_h R_e}{sR_h + R_e}$$

The mathematical model is referred to the synchronous rotating reference frame

$$V = RI + \frac{1}{\omega_b} X_1 I + \frac{\omega_r}{\omega_b} X_2 I$$

where

V, R, I ,X_1 , X_2 are matrices

$$\begin{bmatrix} V_{Ds} \\ V_{Qs} \\ V_{dr} \\ V_{qr} \end{bmatrix} = \begin{bmatrix} r_s & 0 & 0 & 0 \\ 0 & r_s & 0 & 0 \\ 0 & 0 & r_r & 0 \\ 0 & 0 & 0 & r_r \end{bmatrix} \begin{bmatrix} i_{Ds} \\ i_{Qs} \\ i_{dr} \\ i_{qr} \end{bmatrix} +$$

$$\frac{1}{\omega_b} \begin{bmatrix} X_{ss} & 0 & X_{srm} & 0 \\ 0 & X_{ss} & 0 & X_{srm} \\ X_{ss} & 0 & X_{rr} & 0 \\ o & X_{srm} & 0 & X_{rr} \end{bmatrix} \begin{bmatrix} \dot{i}_{Ds} \\ \dot{i}_{Qs} \\ \dot{i}_{dr} \\ \dot{i}_{qr} \end{bmatrix} +$$

$$\frac{\omega_r}{\omega_b} \begin{bmatrix} 0 & -X_{ss} & 0 & -X_{srm} \\ X_{ss} & 0 & X_{srm} & 0 \\ 0 & 0 & 0 & 0 \\ o & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} i_{Ds} \\ i_{Qs} \\ i_{dr} \\ i_{qr} \end{bmatrix}$$

The electromagnetic torque of the hysteresis motor is given by

$$T_{em} = \frac{3}{2}\frac{P}{2}\left(i_{qs}\lambda_{ds} - i_{ds}\lambda_{qs}\right)$$

where

$$\lambda_{ds} = \frac{1}{\omega_b}(X_{ss} i_{ds} + X_{srm} i_{dr})$$

$$\lambda_{qs} = \frac{1}{\omega_b}(X_{ss} i_{qs} + X_{srm} i_{qr})$$

The equation of motion of the hysteresis motor can be finally written for a P -pole machine

$$\frac{J}{\left(P/2\right)}\dot{\omega} = T_{em} - T_L$$

3. Impact of Hysteresis Loops of Rotor

It is well known that when a hysteresis material is exposed to a sinusoidal field (H) with specified amplitude, the flux density (B) is non-sinusoidal and the corresponding B-H curve follows a hysteresis loop. By putting a small piece of the rotor material into experiment, it is possible to obtain the magnetic characteristics of the rotor substance. For this purpose, a turoidal core with rectangular cross section is designed from the rotor material with two coils on it supplied by a low frequency voltage with adjustable amplitude. While testing, voltages and currents of the coils are measured and processed by a PC computer.

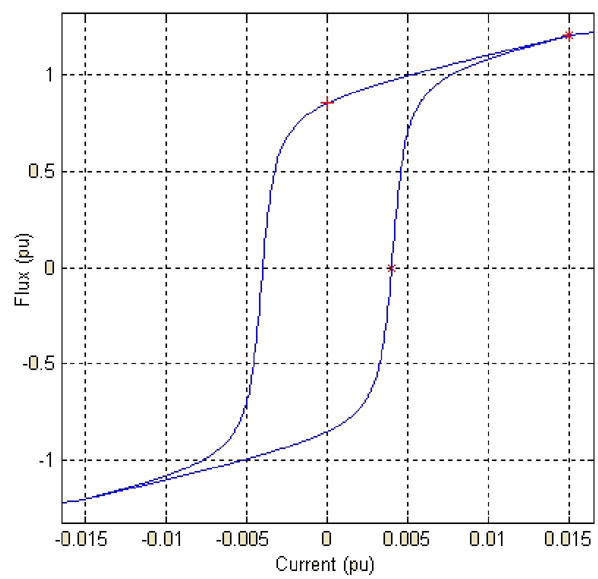

Fig. Hysteresis loops of the alloy steel of the rotor disc

4. Performance modeling equations to calculate dynamic value of X_{rr}

Air gap flux (ϕ_g), induced voltage (E_1) and resultant air gap mmf (Fg) are calculated respectively by:

$$\phi_g = 2 t_r K_{st} (R_o - R_i) B_q \times 10^{-6}$$

$$E_1 = \sqrt{2}\pi K_w N_{ph} f \phi_g$$

$$I_{eq} = \sqrt{(\frac{E_1}{R_c} + I_h \sin\alpha)^2 + (\frac{E_1}{X_{srm}} + I_h \sin\alpha)^2} \angle -\zeta$$

Where

$$\zeta = Arc\tan(\frac{\frac{1}{X_{srm}} + \frac{\cos\alpha}{Z_r}}{\frac{1}{Rc} + \frac{\sin\alpha}{Z_r}}), I_h = \frac{E_1}{Z_r}, Z_r = \sqrt{r_r^{\,2} + X_r^{\,2}}$$

$$V_{ph} = \sqrt{(E_1 \cos\zeta + Z_1 I_{eq} \cos\delta)^2 + E_1 \sin\zeta + Z_1 I_{eq} \sin\delta)^2}$$

Where

$$Z_1 = \sqrt{r_s^{\,2} + X_s^{\,2}}, \delta = Arc\tan(\frac{X_r}{r_s})$$

$$E_p = \sqrt{(X_{srm} I_{eq} \sin\zeta + (X_r + X_{srm}) I_h \sin\alpha)^2 +}$$
$$\sqrt{(X_{srm} I_{eq} \cos\zeta + (X_r + X_{srm}) I_h \cos\alpha)^2} \angle -\gamma$$

Where

$$\gamma = Arc\tan(\frac{X_{srm} I_{eq} \cos\gamma + (X_r + X_{srm}) I_h \cos\alpha}{X_{srm} I_{eq} \sin\gamma + (X_r + X_{srm}) I_h \sin\alpha})$$

5. Simulation Results of Transient Behavior of the Hysteresis Motor

It is well known that total torque of a hysteresis motor is produced via two different mechanisms, namely hysteresis torque and the eddy current torque. Hysteresis substance produces an angle between rotor mmf and the resultant air gap mmf. The difference between these fields causes a hysteresis torque, which is the dominant component of the total torque. Hysteresis power Ph in the hysteresis machines is almost constant. In the stationary state, total hysteresis power turns to heat, whereas it is the output power in the synchronous mode. The other torque is the induction torque, which is produced by eddy currents in the solid hysteresis material and its copper cover. This part is fairly considerable in accelerating the motor in the asynchronous regime.

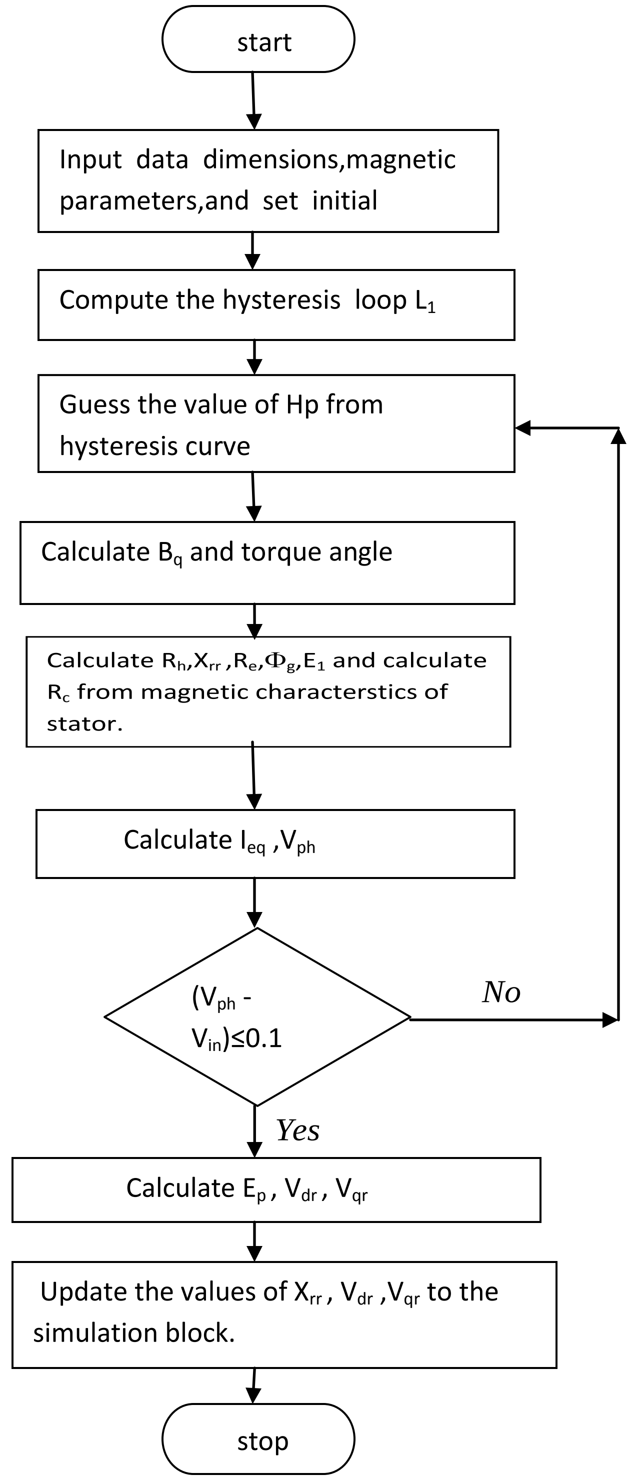

Fig. Flow diagram to compute value of rotor rectanctance X_{rr}.

In the model, expressed in d-q reference, the elements of the model are treated variable to reflect variations of the motor parameters discussed previously. Therefore the model is updated for any instant based on the information gathered from the instantaneous values of the voltage, slip, and the corresponding rotor operating loop.

Through start-up, some parameters of the motor vary. The variations of the rotor equivalent resistors Rh and Xrr due to changes in the hysteresis loops are Given.Variations of these parameters can be verified by using equations are given above.These parameters get fixed in steady state when there is no fluctuations in the flux density and the hysteresis loop either.

The hysteresis motor under study is simulated according to equations

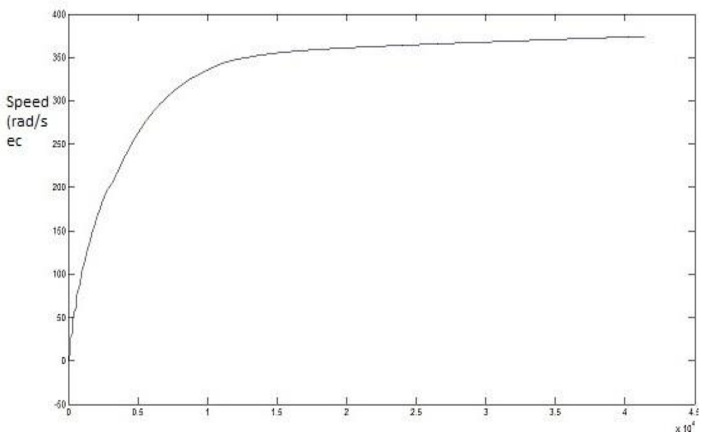

Fig. Speed in no load condition with nominal supply voltage

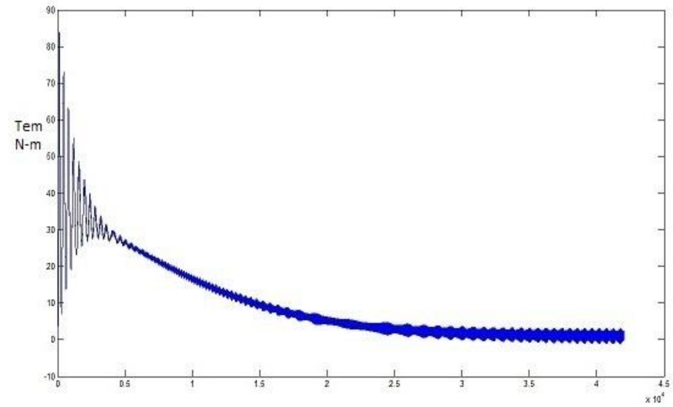

Fig. Torque in no load condition with nominal supply voltage.

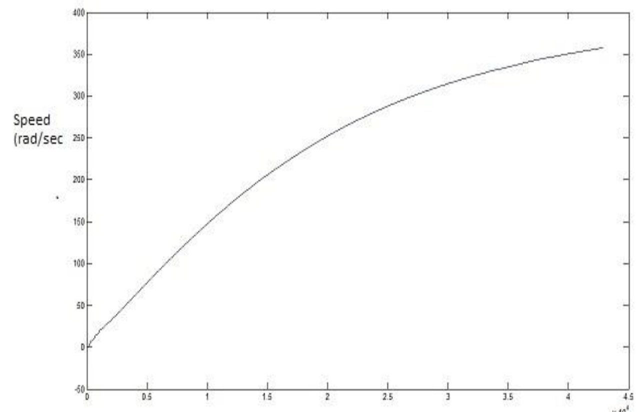

Fig. Speed in no load condition with 60% of nominal supply voltage

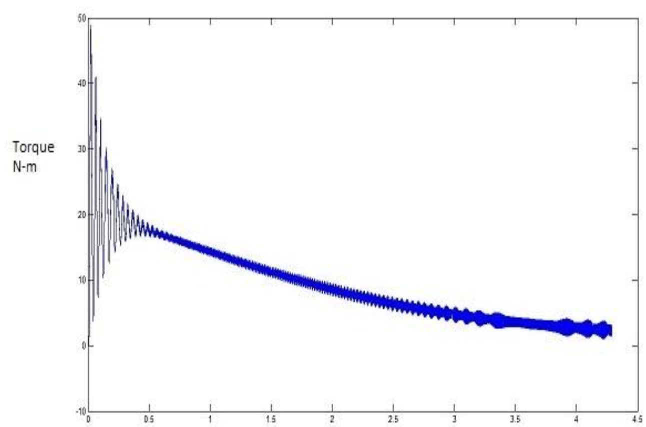

Fig. Torque in no load condition with 60% of nominal supply voltage

6.Conclusion

This paper presents an investigation of the dynamic performance of a three-phase hysteresis motor fed from a three-phase balanced power supply. A mathematical model similar to those representing conventional machines has been adopted to reflect the hysteresis motor operation.

Due to the new trend in electrical machine simulation, design and analysis, computer software Mat lab/Simulink has been used as a tool to predict the hysteresis motor stability under various operating conditions. The transient and dynamic responses of the motor to different changes such as variation in load torque and reduction in supply voltages have been provided.On the other side, high starting time, high frequency and less damped fluctuations of speed at start up with input voltage less than the nominal, and also hunting phenomenon are some of the hysteresis motors disadvantages investigated by the proposed modeling approach accurately.

Nomenclature

V_{ds},V_{qs}	Stator voltage in d-q axis
V_{dr}, V_{qr}	Rotor voltage in d-q axis
r_s,r_r	Stator and rotor resistance
X_{ss},X_{rr}	Total reactances of stator and Rotor
X_{srm}	Magnetizing reactance
i_{ds},i_{qs}	Stator currents in d-q axis
I_{dr},i_{qr}	Rotor currents in d-q axis
ω_r	Angular speed of rotor
ω_b	Basic angular speed
T_{em}	Electromagnetic torque
λ_d,λ_q	Linkage fluxes in d-q axis
T_L	Load torque
H	Rotor inertia constant
S	Slip
K_{sf}	Stacking factor of stator laminations
t_r	Thickness of rotor disk [mm]
K_w	Winding factor
N_{ph}	No. of turns per phase
m	Number of phases
R_o	Inner radius of rotor and stator [mm]
R_i	outer radius of rotor and stator [mm]
R_{oi}	R_0-R_i
R_{av}	$(R_0+R_i)/2$
ρ	Resistivity of hysteresis material

Motor Parameters

P_{out} =50 watts	f =60 Hz
r_s= 2 Ω	P=2
L_s = 0.0086 H	H=0.4
L_m = 0.0086 H	V_{L-LRms} = 400 v

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