Electrically Driven Marine Propulsion

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ABSTRACT

Problems involving in marine propulsion mechanism during wars intercepting an attacking missile are well known. Such may be the case in defense in which a torpedo attacks against a ship. This project describes a better way of controlling the navigation and propulsion system. For this Electro-hydraulic and Electrically driven models are designed. Electro-hydraulic actuator consists of several dynamic parts which are widely used in motion control applications. These dynamic parts need to be controlled to determine direction of motion. In this project, mathematical model of EHS is required in order to design a controller for the better response of the system and the performance of the system is monitored in simulation mode. In the Electric propulsion system, induction motor is used to drive the marine propeller. The control is affected by ocean surface waves, ocean currents, wind, weather and also ship motion. In this project, speed of induction motor is controlled using flux comparator.

Keywords – **Electro-Hydraulic Actuator, Induction Motor, PID Controller, Reference frames, Speed control**

1. INTRODUCTION

Marine propulsion is a mechanism used to move a ship or boat across water. Most modern ships are propelled by mechanical system consists of motors or engines are propelled by turning a propeller. A propeller is a type of a fan that transmits power by converting rotational motion into thrust pressure difference is produced between the forward and rear surfaces of the airfoil-shaped blade, air or water is accelerated behind the blade.

There are various problems involving in marine propulsion mechanism especially during wars intercepting attacking missiles against a ship. So a jammer is introduced in the warships which deny the targeting ability of the other ship. It is a part of electronic counter measures of shipboard used for providing warning, identification and bearing information about radar guided cruise missiles. It is an electronic device used in warfare to inhibit or halt the transmission of signals and to limit the effectiveness of opponent communication or detection equipment. So, basically jammers disrupt the targeting abilities of the other ships or missiles or any external disturbance. So, the objective of this project is to control the navigation and propulsion system during such severe conditions.

2. DRIVES USED IN MARINE PROPULSION SYSTEM

2.1 Electro-Hydraulic Model

Electro-hydraulic system (EHS) consists of several dynamics parts which are widely used in motion control applications. These dynamics parts need to be controlled to determine direction of motion. Electro-hydraulic actuator converts electrical signal to hydraulic power [1]. It is widely used since it has simple construction, low cost, small size-to-power and to be apply very large torques and forces with fast response time. Since electro-hydraulic actuator can provide precise movement, high power capability, fast response characteristics and good positioning capability, its applications are important in the field of robotics, suspension systems and industrial process. Actuation time, hydraulic fluid supply pressure range, acting type, over torque protection, local position indication and integral pushbuttons and controls are among the important specifications for electro-hydraulic valve actuators. A suitable controller needs to be designed in order to acquire the highest performance of the electro-hydraulic actuator. The controller design requires the best mathematical model of the system under control. Thus, a method of identifying the system needs to be chosen so that the best accuracy of the model can be obtained.

2.2 MODELLING OF ELECTRO-HYDRAULIC ACTUATOR

Consider a double acting servo valve and piston actuator [1] shown in Figure 2.1.The linearized differential equations that describe the actuator valve dynamics can be formulated as follows:

$$\dot{v}_p(t) = \frac{1}{m}\left[AP_L(t) - bv_p(t) - F_L(t)\right] \qquad (2.1)$$

$$\dot{P}_L(t) = \frac{4\beta}{V}\left[K_f x_v(t) - K_{tp}P_L(t) - Av_p(t)\right] \qquad (2.2)$$

Where,

V_p = *piston velocity*

P_L =*Hydraulic pressure*

F_L =*External load disturbance*

A =*Piston surface area*

m =*mass of the load*

β =*Effective bulk modulus*

V =*Total volume of hydraulic oil in the piston and the connecting lines*

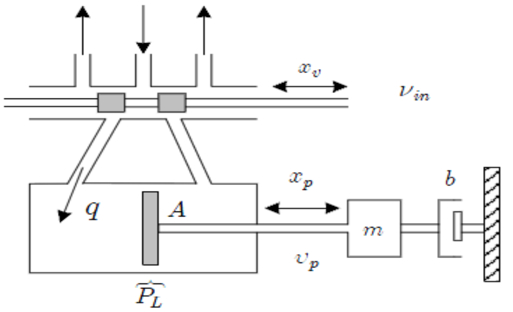

Fig2.1 Valve and Piston Schematic

For zero initial conditions [2] the Laplace transform of the equations (2.1),(2.2) produces the following input – output relations:

Transfer Function for displacement w.r.t. pressure

$$\frac{Xv(s)}{P_L(s)} = \frac{(ms+b)\,(Vs+4\beta K_{tp}) + 4BA^2}{4Bk_F\,(ms+b)} \qquad (2.3)$$

Transfer Function for displacement w.r.t. velocity

$$\frac{X_V(s)}{V_P(s)} = \frac{(ms+b)\,(V_S+4\beta K_{tp}) + 4BA^2}{4\beta Ak_F\,(ms+b)} \qquad (2.4)$$

TABLE-1

NOMINAL VALUES FOR THE HYDRAULIC ACTUATOR'S PARAMETERS

Symbol	Definition	Nominal Value
V	Volume of hydraulic oil in the piston chamber	$486/100^3\ m^3$
A	Piston surface area	$633/100^2\ m^3$
β	Effective bulk modulus	$689/10^6\ Pa$
K_{tp}	Total flow pressure coefficient	$0\ m^3/Pas$
b	viscous damping coefficient	$1000 Nm^{-1}s$
m	load mass	12*kg*
k_f	servo valve gain	$11.02\ m^2/sec$

The nominal values of the system parameters are shown in Table 1 [2] and the expected range of variations of the uncertain system parameters is shown in Table 2 [2]. Performance analysis of Electro-hydraulic actuator for controlling speed and position of propeller using PID controller is evaluated in SIMULINK using equations (2.3), (2.4).

TABLE-2

EXPECTED RANGE OF VARIATIONS OF THE UNCERTAIN PARAMETERS

Symbol	Minimum Values	Nominal Values	Maximum Values
β	550×10^6 Pa	$689\times10^6 Pa$	$895\times10^6\ Pa$
K_{tp}	$0\ m^3/Pas$	$0\ m^3/Pas$	$9.5\times10^{-11}\ m^3/Pas$
K_f	$1.02\ m^2/sec$	$1.02\ m^2/sec$	$1.75\ m^2/sec$

3. ELECTRICALLY DRIVEN MODEL

The main advantage is that induction motors do not require an electrical connection between stationary and rotating parts of the motor. Therefore, they do not need any mechanical commutator (brushes), leading to the fact that they are maintenance free motors. Induction motors also have low weight and inertia, high efficiency and a high overload capability. Therefore, they are cheaper and more robust, and less proves to any failure at high speeds.

3.1 Modeling of Induction Machine

3.1.1 Axes Transformation

During start-up and other severe transient operations induction motor draws large currents, produces voltage dips, oscillatory torques and can even generate harmonics in the power systems. In order to investigate such problems, the d, q axis model has been designed. To convert three-phase voltages Vas, Vbs, Vcs to voltages $Vqs^{e,}$ Vds^{e} in the two phase synchronously rotating frame [5], they are first converted to two-phase stationary frame $Vqs^{s,}$ Vds^{s} using equation(3.1)and then from frame to the synchronously rotating [4] using equation(3.2).

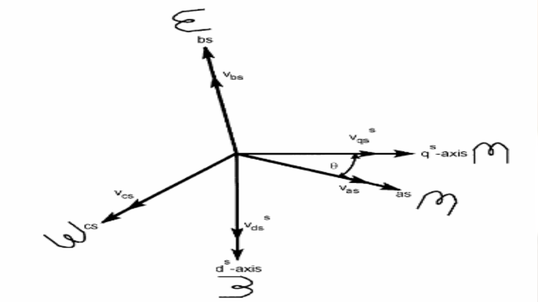

Fig 3.1 Stationary frame a-b-c to d^s-q^s axes transformation

The voltages V_{ds}^{s} and V_{qs}^{s} can be resolved into as- bs -cs components and can be represented in the matrix form as [6].

$$\begin{bmatrix} V_{qs} \\ V_{ds} \\ V_{qr} \\ V_{dr} \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta & 1 \\ \cos(\theta-120^{0}) & \sin(\theta-120^{0}) & 1 \\ \cos(\theta+120^{0}) & \sin(\theta+120^{0}) & 1 \end{bmatrix} \begin{bmatrix} V_{qs}^{s} \\ V_{ds}^{s} \\ V_{os}^{s} \end{bmatrix} \quad (3.1)$$

The corresponding inverse relation is

$$\begin{bmatrix} V_{qs} \\ V_{ds} \\ V_{qr} \\ V_{dr} \end{bmatrix} = \begin{bmatrix} \cos\theta & \cos(\theta-120^{0}) & \cos(\theta+120^{0}) \\ \sin\theta & \sin(\theta-120^{0}) & \sin(\theta+120^{0}) \\ 0.5 & 0.5 & 0.5 \end{bmatrix} \begin{bmatrix} V_{as} \\ V_{bs} \\ V_{cs} \end{bmatrix}$$

(3.2)

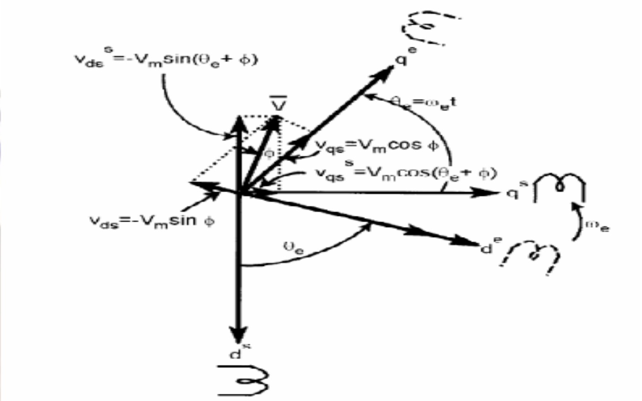

Fig 3.2 Stationary frame d^s- q^s to synchronously rotating frame d^e- q^e transformation

Fig 3.2 shows the synchronously rotating d^e-q^e, which rotate at synchronous speed ω_e with respect to the d^s-q^s axes and the angle $\theta_e = \omega_e t$. the two-phase d^s- q^s windings are transformed into the hypothetical windings mounted on the d^e-q^e axes.

3.2.2 Transient Modeling

Dynamic behaviour of the machine may be analyzed using any one of following the reference frames:

- Stationary reference frame
- Rotor reference frame
- Synchronous reference frame

A. Stationary Reference Frame

The speed of the reference frames is that of the stator ω_e=0, the electrical transient model in terms of voltage and currents can be given in matrix form [3].

$$\begin{bmatrix} V_{qs} \\ V_{ds} \\ V_{qr} \\ V_{dr} \end{bmatrix} = \begin{bmatrix} R_s+L_sp & 0 & L_mp & 0 \\ 0 & R_s+L_sp & 0 & L_mp \\ L_mp & -\omega_rL_m & R_r+L_rp & -\omega_rL_r \\ \omega_rL_m & L_mp & \omega_rL_r & R_r+L_rp \end{bmatrix} \begin{bmatrix} i_{qs} \\ i_{ds} \\ i_{qr} \\ i_{dr} \end{bmatrix}$$

Electromagnetic torque equations are given by:

Te =3/2* p/2* Lm* (iqs* idr- ids* iqr) (3.3)

B. Rotor Reference Frame

The speed of the rotor reference frames is $\omega_e = \omega_r$, where ω_r is the rotor frequency. The induction-motor model in rotor reference frames [3] is obtained by the following equations:

$$\begin{bmatrix} V_{qs} \\ V_{ds} \\ V_{qr} \\ V_{dr} \end{bmatrix} =: \begin{bmatrix} R_s + L_s p & 0 & L_m p & 0 \\ 0 & R_s + L_s p & 0 & L_m p \\ L_m p & -\omega_r L_m & R_r + L_r p & -\omega_r L_r \\ \omega_r L_m & L_m p & \omega_r L_r & R_r + L_r p \end{bmatrix} \begin{bmatrix} i_{qs} \\ i_{ds} \\ i_{qr} \\ i_{dr} \end{bmatrix}$$

Electromagnetic torque equations are given by:

Te =3/2* p/2* Lm* $(iqs^r * idr^r - ids^r * iqr^r)$ (3.4)

C. Synchronously Rotating Reference Frame Dynamic Model

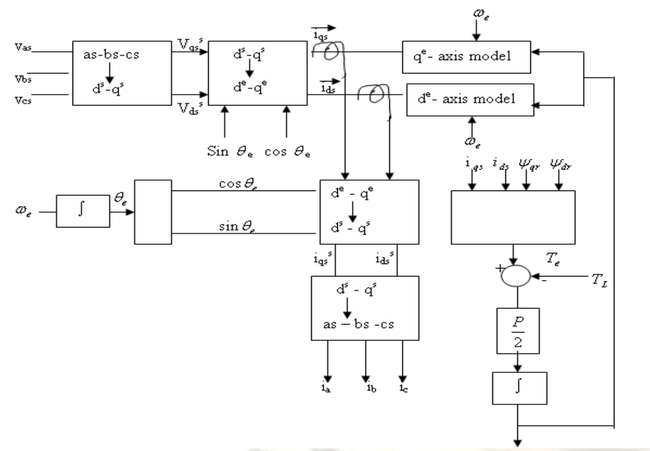

Fig-3.3 Synchronously rotating frame machine model with input voltage and output current transformations

The speed of the reference frame is $\omega_e = \omega_r$,motor model equations in synchronous reference frames [3] are given by:

$$\begin{bmatrix} V_{qs} \\ V_{ds} \\ V_{qr} \\ V_{dr} \end{bmatrix} = \begin{bmatrix} R_s + SL_s & \omega_e L_s & SL_m & \omega_e L_m \\ -\omega_e L_s & R_s + SL_s & -\omega_e L_m & SL_m \\ SL_m & (\omega_e - \omega_r) L_m & R_r + SL_r & (\omega_e - \omega_r) L_r \\ -(\omega_e - \omega_r) L_m & SL_m & -(\omega_e - \omega_r) L_r & R_r + SL_r \end{bmatrix} \begin{bmatrix} i_{qs} \\ i_{ds} \\ i_{qr} \\ i_{dr} \end{bmatrix}$$

Electromagnetic torque equations are given by:

Te =3/2* p/2* Lm* $(iqs^e * idr^e - ids^e * iqr^e)$ (3.5)

3.2 Speed Control by Flux Comparator Technique

Speed control of induction motor is done by using flux comparator [5]. The equations (3.4), (3.5), (3.6) of flux can be written using *d-q* axis components as by the following:

$$\psi_{ds} = \int (Vsd - isd*Rs)dt \qquad (3.6)$$

$$\psi_{qs} = \int (Vsq - isq*Rs)dt \qquad (3.7)$$

$$|\psi_s| = \sqrt{(\psi_{ds} + \psi_{qs})} \qquad (3.8)$$

4. SIMULATION RESULTS

4.1 Electro-hydraulic actuator

Performance analysis of Electro-hydraulic actuator for controlling speed and position of propeller using PID controller is evaluated in SIMULINK.

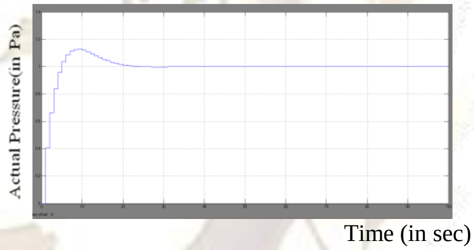

Fig4.1 Pressure Control of Electro-hydraulic Actuator Waveform

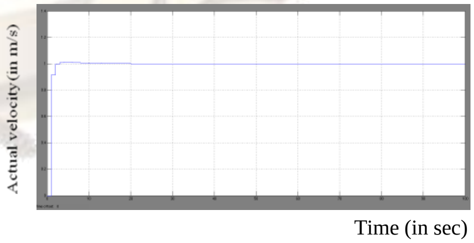

Fig4.2 Velocity Control of Electro-hydraulic Actuator Waveform

4.2 MODELLING OF INDUCTION MOTOR

The simulation results are obtained for induction motor and its parameters as given in appendix. The machine model is implemented for speed control by using flux comparator and DTC scheme using Simulink.

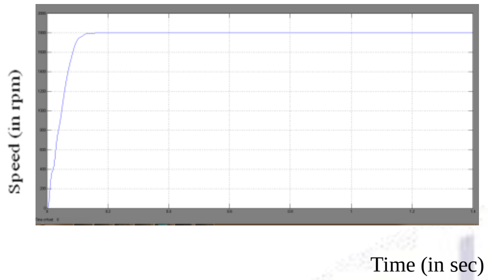

Fig4.3 Speed of Induction Motor

Fig4.4 Electromagnetic Torque Waveform

4.3 BASIC MODEL OF INDUCTION MOTOR USING FLUX COMPARATOR

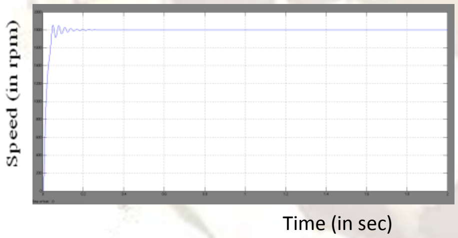

Fig 4.5 Speed control waveform using flux comparator

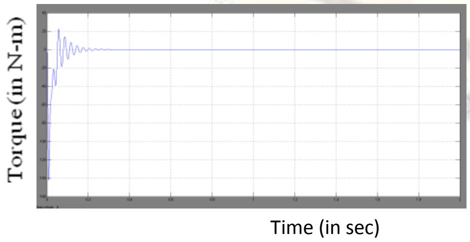

Fig 4.6 Electromagnetic torque control using flux comparator

5. CONCULSION

Performance analysis of electro-hydraulic actuator is evaluated using PID controller in SIMULINK, but the responses obtained are not satisfactory. Therefore dynamic model of induction motor has been designed and speed of the induction motor has been controlled by using flux comparator shows that the induction motor rapidly achieves the speed references, without overshoot and small steady state error and also the load disturbances is rapidly rejected.

NOMENCLATURE

d^s-q^s	Stationary reference frame d and q axis
d^e-q^e	Synchronously rotating reference frame d and q axis
V_{ds}, V_{qs}	Stator d and q axis winding voltage, [Volt]
V_{dr}, V_{qr}	Rotor d and q axis winding voltage, [Volt]
I_{ds}, I_{qs}	Stator d and q axis winding current, [Ampere]
I_{dr}, I_{qr}	Rotor d and q axis winding current, [Ampere]
ψ_s	Stator flux linkage in [Wb]
ψ_{ds}, ψ_{qs}	Stator d and q axis winding flux linkage[Wb]
ψ_{dr}, ψ_{qr}	Rotor d and q winding flux linkage, [Wb]
Lm	Magnetizing inductance, [H]
Ls, Lr	Stator and rotor per phase winding inductance, [H]
Rs, Rr	Stator and rotor per phase winding resistance, [Ω]
T_e	Electro-magnetic torque, [N-m]

J	Inertia of Motor
T_L	Load Torque
p	No. of poles

Superscripts:

r = Quantity referred to rotating frame

s = Quantity referred to synchronously rotating frame

APPENDIX

3-phase, 50 Hz, Induction Motor
Stator Resistance = Rs = 9.53[Ω]
Rotor Resistance = Rr = 5.619[Ω]
Stator Inductance = Ls=0.447H
Rotor Inductance =Lr = 0.505 H
Magnetizing Inductance = Lm =0.447H
No. of poles = p = 2
Moment of Inertia of test machine set up = J = 0.026Kgm^2

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BIOGRAPHIES

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