MODELING AND ANALYSIS OF A PROTOTYPE OF MULTIPLE LAUNCH ROCKET SYSTEM USING MATLAB SIMULINK

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Abstract- This paper presented the control modeling and analysis of the prototype of Multiple Launch Rocket System (MLRS) using Matlab Simulink. The mathematical model was determined using physical law and theoretical foundation of the turning mechanism control system and the elevating mechanism control system. Then, the model was identified in Matlab Simulink and analyzed in open-loop frequency characteristic analysis, closed-loop frequency characteristic analysis, step response characteristic analysis, and sinusoidal response analysis. The simulation results showed a good stability performance for both open-loop control and closed-loop control systems. We observed the fast response of tracking and controlling with the overshoot less than 3% and the steady-state error less than 0.2 Mil.

Index terms - Modeling, Multiple Launch Rocket System, Matlab Simulink.

I. INTRODUCTION

This paper presented the development and analysis of control modeling for elevating and turning of Multiple Launch Rocket System (MLRS). In order to design the controller for any dynamical system, a suitable dynamical model of the system is formulated and the parameters are accurately identified [1-4]. Required model parameters were obtained with various methods. Some parameters were obtained from handbooks and manufacturer specifications. Some parameters are obtained through experiments. There are other parameters obtainedthroughthecomputer simulation. Since there have no MLRS control parameters available, this paper thus proposes the modeling and analysis of the system using Matlab Simulink [6-10].The model was identified using Matlab Simulink and analyzed in open-loop frequency characteristic analysis, closed-loop frequency characteristic analysis, step response characteristic analysis, and sinusoidal response analysis. This paper was organized in the following manner: Section 2 Prototype of multiple launch rocket system; Section 3 The Modeling Theory of the Hydraulic Elevating Mechanism Control System; Section 4The modeling theory of hydraulic turning Mechanism Control System; Section 5Simulation model using Matlab Simulink; Section 6 Simulation Results and discussion; final section the conclusion.

II. PROTOTYPE OF MULTIPLE LAUNCH ROCKET SYSTEM

The plant used in this research is the prototype of multiple launch rocket system as shown in Figure.1. The multiple launch rocket system consists of seven major parts as following: (i) The chassis wheel-type cross-country vehicle with high maneuverability, use to carry all of upper part, lower part, and canisters; (ii) The packing box for storing rocket, called canisters use to bear and lock the rocket projectiles;(iii) The elevating mechanismcomposed of canister and cradle, connected to turning plate through the trunnion; (iv) The turning mechanism composed of elevating mechanism and turning plate; (v)The hydraulic system is mainly used for implement, operate, aiming, support both manual and automatic modes; (vi) The electric system is mainly used to implementpower supply and distribute electrical power via power distribution unit to deviceand all of electrical instruments; (vii) The fire control computer mainly use to control all of the launching process both automation and manual modes.

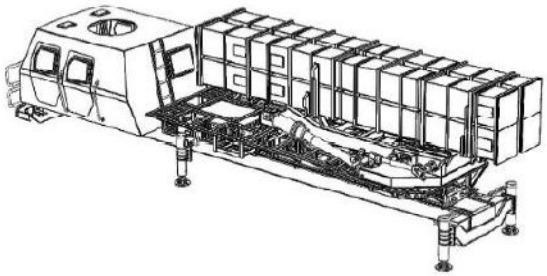


Figure 1: Prototype of Multiple Launch Rocket System

III. THE MODELING THEORY OF THE HYDRAULIC ELEVATING MECHANISM CONTROL SYSTEM

The simplified model of the hydraulic elevating mechanism is shown in Figure.2. G means the center of gravity of the elevating components. O_1, O_2, O_3 respectively stand for the upper joint point , the trunnion joint point and the bottom joint point O_3', G' respectively represents the initial position of the upper joint and the center of gravity when the elevating angle is zero.

The model of the hydraulic elevating mechanism contains the electro-hydraulic proportional valve-controlled single rod cylinder model and the dynamic

model of the load. The architecture of the studied proportional valve-controlled single rod cylinder is shown in Figure.3, which is controlled by a three-position-four-way valve.

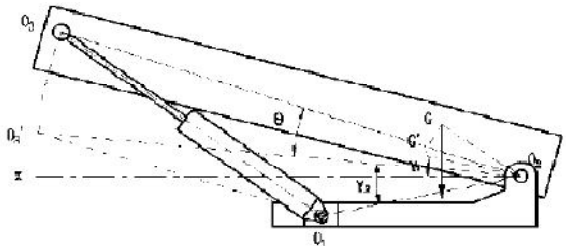


Figure 2: Model of the Hydraulic Elevating Mechanism

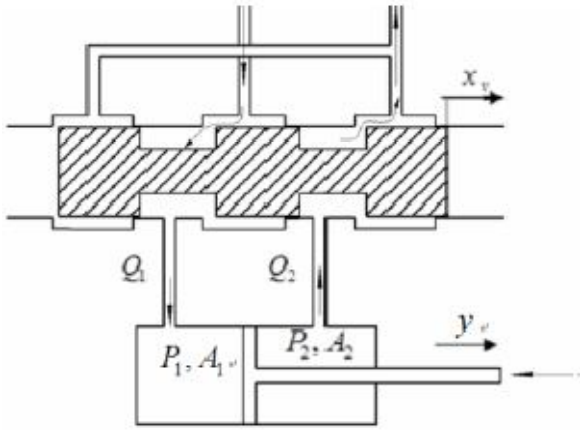


Figure 3: Architecture of the Proportional Valve-controlled Single Rod Cylinder

The valve-controlled single rod cylinder system can be described with the flow-rate pressure equation of the valve, the flow-rate continuity equation of cylinder and the force balance equation of the cylinder, while the non-symmetry between forward travel and inverse travel also need to be considered.

Let $X = [x_1; x_2; x_3; x_4; x_5; x_6]$ denotes the state vectors, where

$$x_1 = P_1; x_2 = P_2; x_3 = y; x_4 = \dot{y}; x_5 = \theta; x_6 = d\dot{\theta};$$

Then we can get the unified nonlinear mathematic model of forward travel and inverse travel of valve-controlled single rod cylinder as follows:

$$\frac{dx_1}{dt} = \frac{\beta}{V_{10} + A_1 x_3}[Q_1 + C_{ic}(x_2 - x_1) - A_1 x_4]$$

$$\frac{dx_2}{dt} = \frac{\beta}{V_{20} - A_2 x_3}[C_{ic}(x_1 - x_2) - C_{ec} x_2 - Q_2 + A_2 x_4]$$

$$\frac{dx_3}{dt} = \frac{2 L_1 L_2 \sin(x_5 + \gamma_2)}{\sqrt{L_1^2 + L_2^2 - 2 L_1 L_2 \cos(x_5 + \gamma_2)}} \frac{dx_5}{dt}$$

$$\frac{dx_4}{dt} = \frac{1}{m}(A_1 x_1 - A_2 x_2 - B x_4 - F_f - F_L)$$

$$\frac{dx_5}{dt} = x_6$$

$$\frac{dx_6}{dt} = \frac{1}{J}[F_L \frac{L_1 L_2 \sin(\gamma_2 + x_5)}{L_0 + x_3} - G L \cos(x_5 + \gamma_1)]$$

Where

$$\begin{cases} Q_1 = sign\frac{1+sign(E)}{2} P_S - sign(E) x_1 - \frac{1-sign(E)}{2} P_0]KE\sqrt{\left|\frac{1+sign(E)}{2} P_S - sign(E) x_1 - \frac{1-sign(E)}{2} P_0\right|} \\ Q_2 = sign\frac{1-sign(E)}{2} P_S + sign(E) x_2 - \frac{1+sign(E)}{2} P_0]KE\sqrt{\left|\frac{1-sign(E)}{2} P_S + sign(E) x_2 - \frac{1+sign(E)}{2} P_{02}\right|} \end{cases}$$

IV. THE MODELING THEORY OF THE HYDRAULIC TURNING MECHANISM CONTROLSYSTEM

The simplified model of the hydraulic turning mechanism is shown in Figure.4. The hydraulic turning mechanism adopts electro-hydraulic proportional valve to control angular displacement of the rotational machine is shown in Figure.5, which belongsto electro-hydraulic proportional displacement synchronous control system.

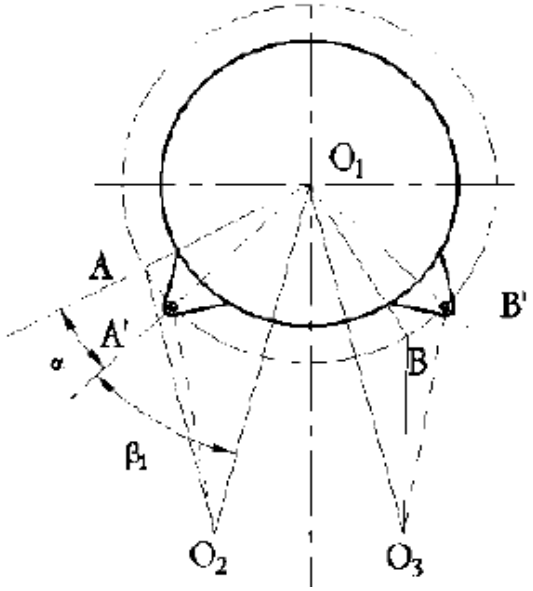


Figure 4: Dynamic Model of the Hydraulic Turning Mechanism

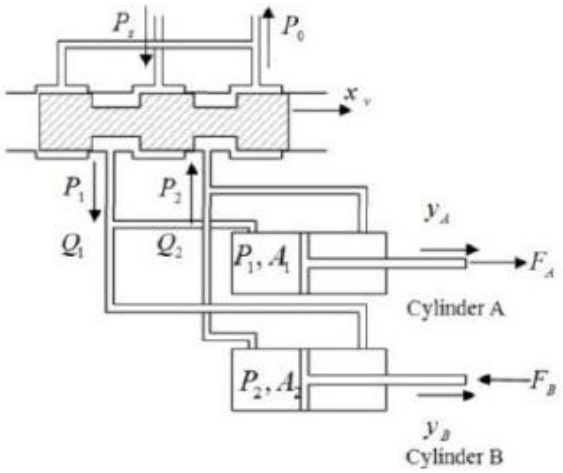


Figure 5: Architecture of Single-valve-control Two Single Rod Cylinders

Let the state variable as $X = [x_1; x_2; x_3; x_4; x_5; x_6]$, where

$$x_1 = P_1; x_2 = P_2; x_3 = y_A; x_4 = y_B; x_5 = \alpha; x_6 = \dot{\alpha}$$

A nonlinear mathematical model can be set up for the single valve synchronous control double asymmetric cylinders whose forward and backward stroke are unified as

$$\frac{dx_1}{dt}=\frac{\beta}{V_{A10}+x_3A_1+V_{B20}-x_4A_2}[Q_1-(C_{icA}+C_{icB})(x_1-x_2)-C_{ecB}x_1-f_1(x_5)x_6A_1+f_2(x_5)x_6A_2]$$

$$\frac{dx_2}{dt}=\frac{\beta}{V_{A20}-x_3A_2+V_{B10}+x_4A_1}[(C_{icA}+C_{icB})(x_1-x_2)-Q_2-C_{ecA}x_2+f_1(x_5)x_6A_2-f_2(x_5)x_6A_1]$$

$$\frac{dx_3}{dt}=f_1(x_5)x_6$$

$$\frac{dx_4}{dt}=f_2(x_5)x_6$$

$$\frac{dx_5}{dt}=x_6$$

$$\frac{dx_6}{dt}=\frac{1}{J}[(A_1x_1-A_2x_2-F_{LA}-F_{fA})\frac{RL\sin(x_5+\beta_1)}{x_3+y_{A0}}+(A_2x_1-A_1x_2-F_{LB}-F_{fB})\frac{RL\sin(\beta_1-x_5)}{x_4+y_{B0}}-M_{fa}]$$

where

$$f_1(x_5)=\frac{2RL\sin(x_5+\beta_1)}{\sqrt{R^2+L^2-2RL\cos(x_5+\beta_1)}}$$

$$f_2(x_5)=\frac{-2RL\sin(\beta_1-x_5)}{\sqrt{R^2+L^2-2RL\cos(\beta_1-x_5)}}$$

$$Q_1=sign[\frac{1+sign(x_v)}{2}P_s-sign(x_v)x_1-\frac{1-sign(x_v)}{2}P_0]C_dwx_v\sqrt{\frac{2}{\rho}\left|\frac{1+sign(x_v)}{2}P_s-sign(x_v)x_1-\frac{1-sign(x_v)}{2}P_0\right|}$$

$$Q_2=sign[\frac{1-sign(x_v)}{2}P_s+sign(x_v)x_2-\frac{1+sign(x_v)}{2}P_0]C_dwx_v\sqrt{\frac{2}{\rho}\left|\frac{1-sign(x_v)}{2}P_s+sign(x_v)x_2-\frac{1+sign(x_v)}{2}P_0\right|}$$

V. SIMULATION MODEL USING MATLAB SIMULINK

1) Simulation Model of Hydraulic Elevating Control System

Based on the computer operating system Windows 7 Ultimate x64, the mathematical model obtained from the elevating mechanism control system modeling theory and the Simulink module in software MATLAB is shown in Figure.6.

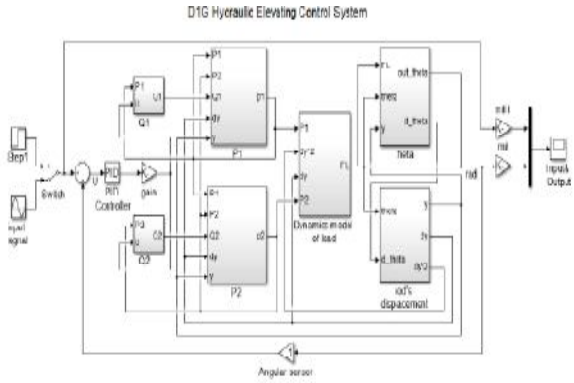


Figure 6: Simulation Model of Hydraulic Elevating Control System

2) Simulation Model of Hydraulic Turning Control System

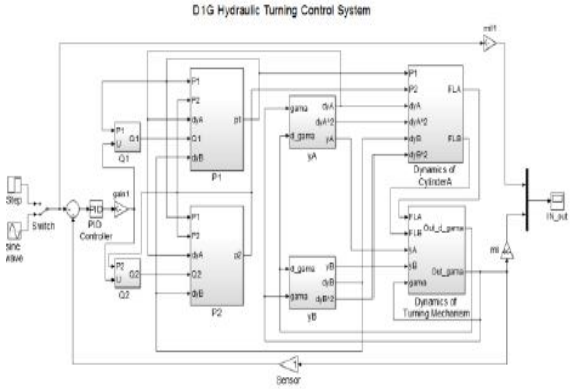


Figure 7: Simulation Model of Hydraulic Turning Control System

The mathematical model obtained from the turning mechanism control system modeling theory and the Simulink module in software MATLAB is shown in Figure.7.

VI. SIMULATION RESULTS AND DISCUSSION

1) Hydraulic Elevating Mechanism Control Performance

The open-loop frequency characteristic curve is shown in Figure.8, the control system has phase margin is 91.2deg and gain margin is 13.6dB, meeting the requirements on stability margin of engineering control system. Thus, the control system has a relatively good stability performance. The closed loop frequency characteristic curve is shown in Figure.9. We found that the control system has a relatively good stability performance. The closed loop step response curve of hydraulic Elevating Mechanism is shown in Figure.10. We found that the control system has a maximum overshoot is 2.6%; the steady-state error is less than 0.2Mil. The closed loop sinusoidal response curve of hydraulic Elevating Mechanism is shown in Figure.11. The control system has the steady-state error is less than 0.16Mil.

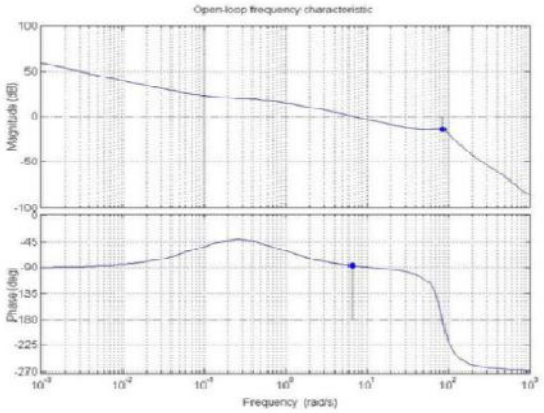


Figure 8: Open-loop Frequency Characteristic Curve of Hydraulic Elevating Mechanism

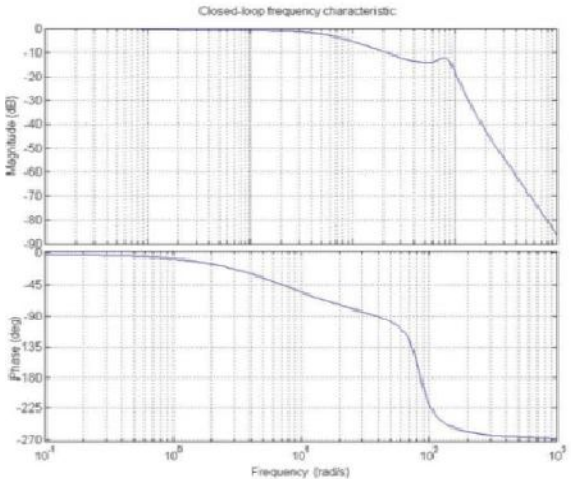


Figure 9: Closed loop Frequency Characteristic Curve of Hydraulic Elevating Mechanism

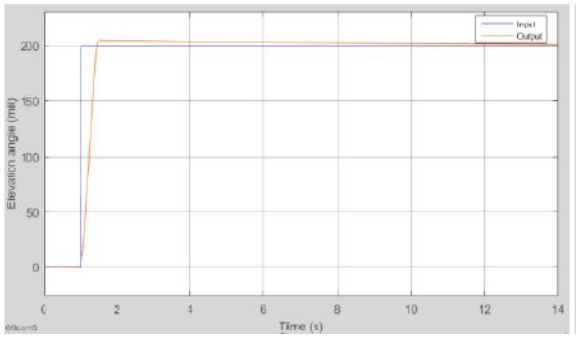


Figure 10: Closed Loop Step Response Curve of Hydraulic Elevating Mechanism

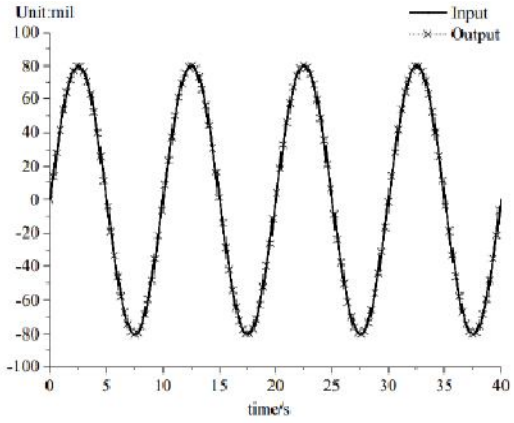


Figure 11: Closed Loop Sinusoidal Response Curve of Hydraulic Elevating Mechanism

2)Hydraulic Turning Mechanism Control Performance

The open-loop frequency characteristic curve is shown in Figure.12. The control system has phase margin is 78.2deg and gain margin is 4.7dB, meeting the requirements on stability margin of engineering control system. Thus, the control system has a relatively good stability performance.

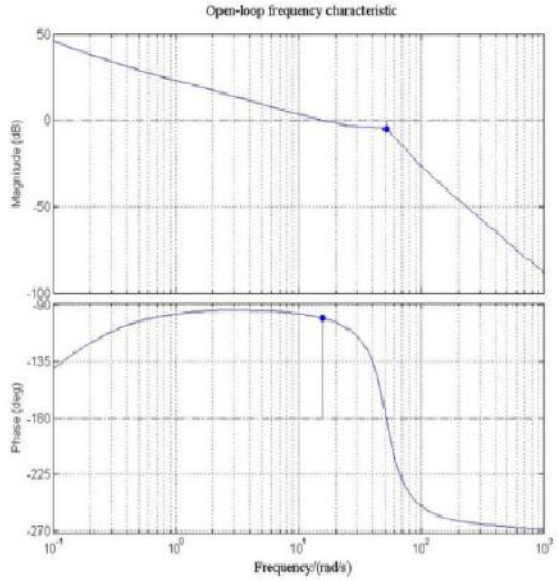


Figure 12: Open-loop Frequency Characteristic Curve of Hydraulic Turning Mechanism

The closed loop frequency characteristic curve is shown in Figure.13. The control system has a relatively good stability performance.

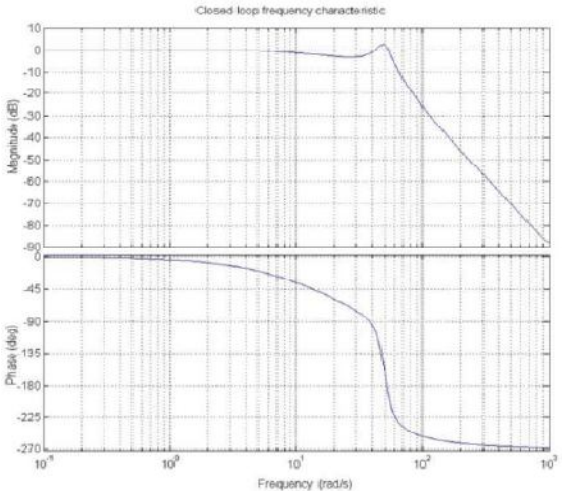


Figure 13: Closed loop Frequency Characteristic Curve of Hydraulic Turning Mechanism

The closed loop step response curve of hydraulic Turning Mechanism is shown in Figure.14. We found that the control system has a maximum overshoot is 1.7% and the steady-state error is less than 0.1Mil.

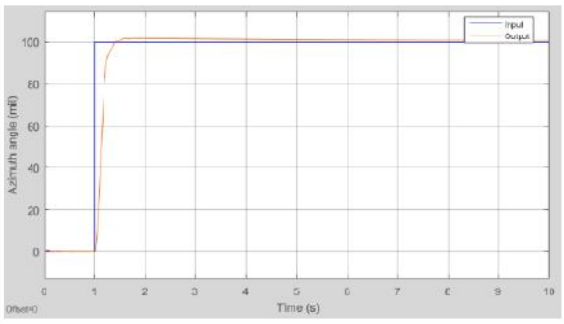


Figure 14: Closed Loop Step Response Curve of Hydraulic Turning Mechanism

The closed loop sinusoidal response curve of hydraulic Turning Mechanism is shown in Figure.15. It is found that the control system has the steady-state error is less than 0.094Mil.

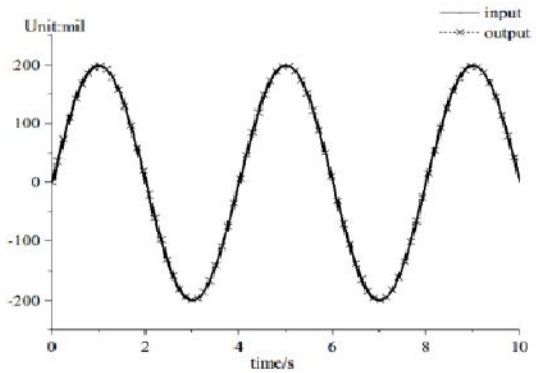


Figure 15: Closed Loop Sinusoidal Response Curve of Hydraulic Turning Mechanism

CONCLUSION

The mathematical model of Multiple Launch Rocket System (MLSR) was determinedusing physical law and theoretical foundation. Matlab Simulink was applied to analyze the open-loop and closed-loop frequency characteristic, step response, and sinusoidal response. The simulation results showed a good stability performance in all of open-loop control and closed-loop control systems. The control system presented the fast response of tacking and controlling.

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