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Design of Close loop Control for Hydraulic System

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Abstract - *This paper describes the method to implement smooth close loop control for hydraulic systems. In this paper motion control is implemented on special purpose heavy duty trailer used for articulation of cylindrical load from 0 to 90 degree with the help of electro hydraulic system and load independent pressure compensated proportional flow control valve as a typical example. Simulation runs were made to determine the parameters values for the system. Results verified with actual system are presented and discussed.*

***Key Words*: Discrete Integral control; Electro hydraulic System; Integral control**

1.INTRODUCTION

Our main focus in this paper is to show the method to implement close loop control for the example system. It has also been shown that it is desirable to estimate gain values for control algorithm by simulation or by finding the transfer function of the system otherwise for a heavy duty system implementations of direct on field tuning methods are not always feasible as well as not safe also. Mathematical model and various transfer functions of the example systems have been derived and converted to model using MATLAB which is used to generate the system behavior. Deciding criteria for combination of PID algorithms are also discussed.

2. Mathematical Model

Fig. 1 shows the example system used to articulate the load from 0 to 90 degree with the help of two stage telescopic differential effect type cylinder, load independent pressure compensated proportional flow control directional valve and other components as shown. Motion control algorithm is to be implemented to articulate the load while keeping acceleration, velocity for two stages and during the stage change of cylinder and time to reach to 90 degree within the limit. System in Fig. 1 can be derived as shown in Fig. 2 to obtain mathematical model with following considerations:

- Two stage cylinders can be treated as two independent cylinders with different area.
- Because of load independent behavior of the system inclined load can be treated as

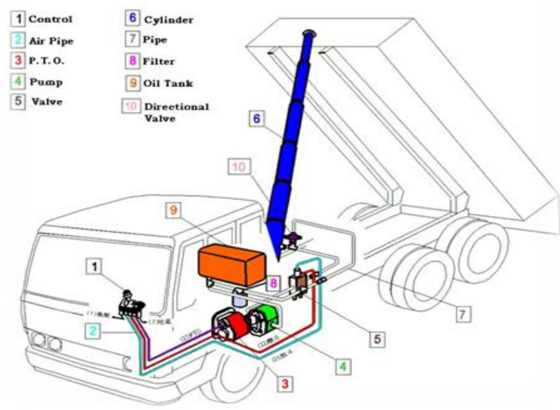

Figure 1. Hydraulic System

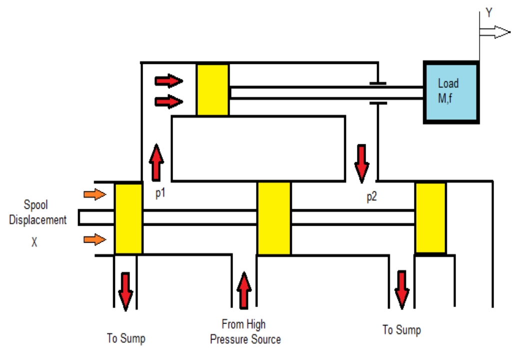

Figure 2. Derived Hydraulic System

Thus Transfer function of the system relating Cylinder velocity Y to spool displacement X is given by:

$$Y(s)/X(s) = K/(\tau * s+1) \qquad (1)$$

Where

$K = (A * K_1) / (A^2 + f * K_2)$

$\tau = (M * K_2) / (A^2 + f * K_2)$

$K_1 = \partial q/\partial x$

$K_2 = -\partial q/\partial p$

A= area of cylinder

q= Hydraulic fluid Flow to Cylinder

p= p1-p2 (pressure difference between port 1 and port 2 of valve)

f = viscous friction

Same transfer function mentioned in (1) can be used for second stage of the cylinder with different values for A and f.

3. Motion Control

In order to implement motion control for system in Fig. 1 following a criteria also have to be considered.

Natural Frequency Estimation

Because load on the system is inclined, natural frequency of the system is continuously changing along with cylinder displacement due to decrease in load resulted by shift in center of gravity.

Natural frequency (ω) of cylinder for given bulk modulus(E) of hydraulic fluid, cylinder close length (h), area of piston (A_k), area of piston rod (A_r), load (M) is given in (2) as below:

$$\omega = \sqrt{\frac{4.E.A_k}{M.h}} * \frac{1+\sqrt{\frac{A_r}{A_k}}}{2} \qquad [2]$$

For system stability minimum natural frequency should be considered to avoid resonance. For example system minimum natural frequency value occurred when system is in rest position (Value of M is maximum) which will be considered for control analysis.

4. Algorithm Selection

Selection method of P, PI or PID algorithm for implementation in example system mentioned below is influenced by criteria mentioned previously.

- Derivative control is not feasible for example system because sudden hikes in oil flow are not permissible.
- Proportional control is not feasible because it contradicts system requirement of slow and smooth start up and change over.
- Proportional Integral control with a proportional gain (Kp) value set to one and integral gain value (Ki) which is tradeoff between given time operation and acceleration and velocity limit can be used.
- Four Proportional Integral close loops in series with different set points and constraints have to be implemented to meet requirements.
- Proportional Integral loops should be initiated only after cylinder achieves minimum velocity to avoid sudden rise in cylinder chamber pressure.

5.Simulation Result

A Matlab Simulink model has been developed to study the behavior of example system with PI control.

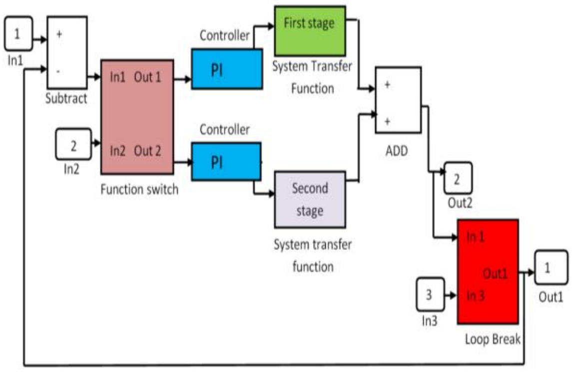

Figure 3. Motion Control Loop Model

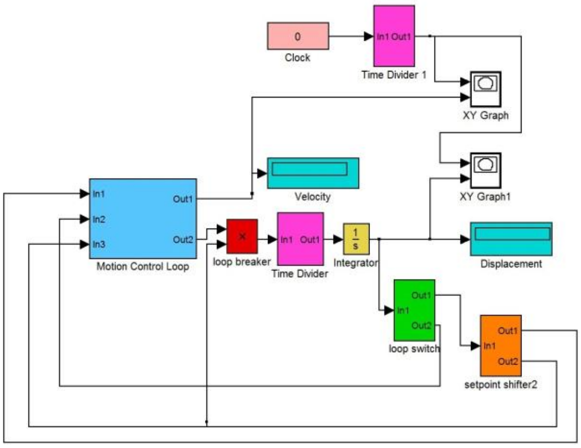

Figure 4. Outer Model

Fig. 4 is a motion control loop model which connects to various other simulation blocks as shown in Fig. 5. Motion control loop incorporates both system transfer function for first stage and second stage of cylinder in single loop. Loop breaker terminates the loop when desired angle is achieved. Function switch senses the angle or stroke length of hydraulic cylinder and switch over the system transfer function. Integral block receives the error signal and produce the output to the system based on gain Ki. Loop switch switches between four Integral loops in synchronization with Set point shifter. Set point shifter provides new set points during loop switch. Time Divider synchronizes Simulink time with clock time for data generation.

Open loop response

Example system is a first order system as given in (1). Open loop step responses for the step input are given in Fig. 6 for both stages of the cylinder. These responses based on assumption that both the chambers of cylinder are initially filled with hydraulic fluid.

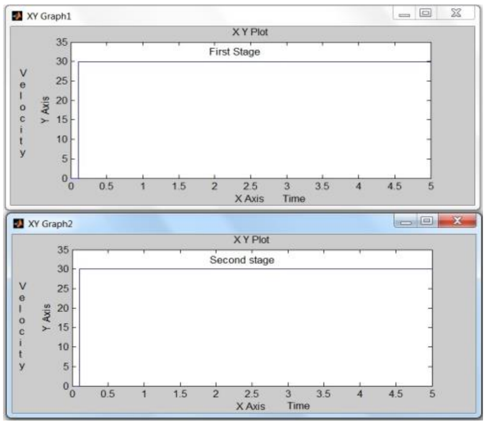

Figure 5. Open loop Response

It is clear from the step responses that system is highly responsive and it is essential to control velocity and acceleration for system safety.

Close loop Response

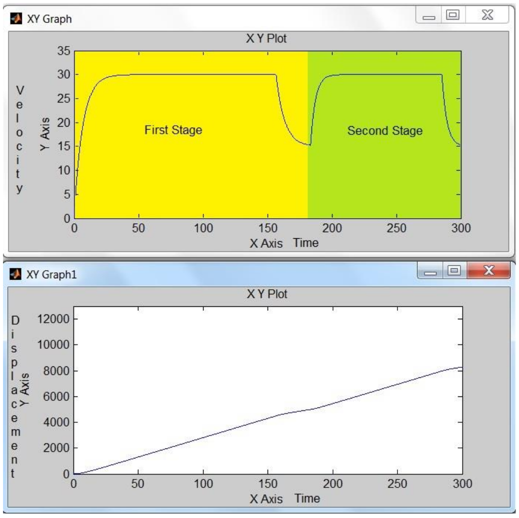

Figure 6 Close loop response for Ki=0.001

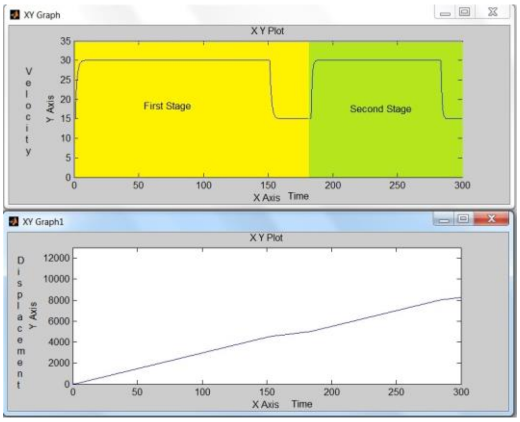

Figure 7. Close loop response for Ki=0.005

Close loop transfer function (T.F) of the example system as represented in (1) has been derived in (4) below:

$$T.F=(K*Kp*Ki) / (\tau*s^2+s+1) \quad (3)$$

Close loop responses for the example system with a different Integral gain values are depicted in Figure 6, 7 & 8.

Fig. 7 shows that for low values of integral gain, system behavior is very sluggish and system is not able to reach the final position in given time of 300 seconds.

Fig. 9 shows that for high values of integral gain acceleration and deceleration of the system cross the permissible limit.

Fig 8 shows that system's acceleration and deceleration are within the permissible limit but system takes significant time in stabilizing to the set point. In other words system becomes sluggish when reaching near the set point because of integral behavior.

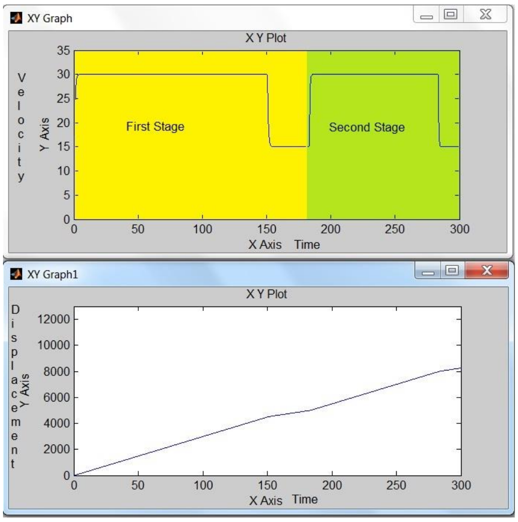

Figure 8. Close loop response for Ki=0.01

There are two ways to overcome this behavior:

1) To increase the Integral gain: Because of integral behaviour of the system, sometimes it is not feasible to increase the gain beyond certain limit otherwise it results in high acceleration or deceleration value initially while reaching to the set point.

2) Use of discrete Integral control: Discrete integral control reaches to the set point quickly compare to continuous integral control with same gain value Ki. But feasibility of implementation depends on system dynamic behaviour. Time between the two successive intervals depends on time constant of the system and order of the system.

Discrete Integral control

The main advantage of discrete integral control is that it reduces the settling time of control algorithm to reach the set point compare to the same gain value of continuous Integral algorithm. Simulink model of example system with discrete Integral control is shown in Fig. 10. It should be noticed from Fig. 10 that cylinder transfer function is continuous while integral control is discrete having interval time of T.

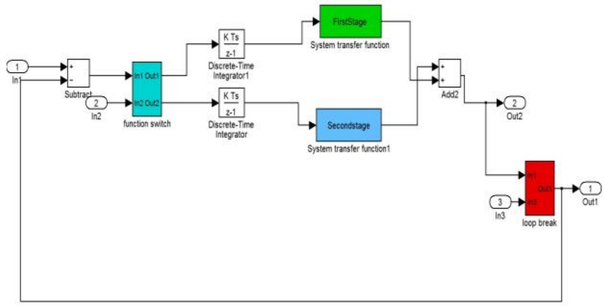

Figure 9. Discrete Integral Control Loop

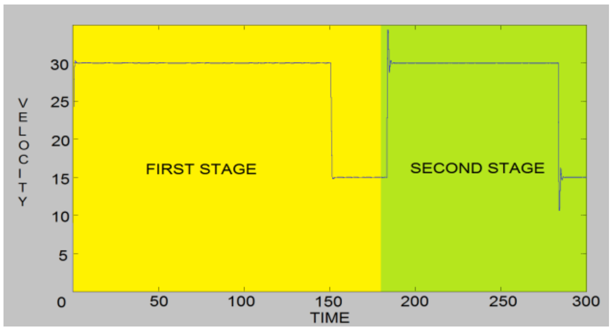

Figure 10 .Discrete Control response for Ki=0.01

So value of interval T should be chosen such that no important states of the continuous system are missed by Control algorithm otherwise system leads towards instability.

The value of T can be decided for given value of gain K as per equation (1) and Integral gain Ki by following equation:

$$T < 2/(K*Ki) \quad (4)$$

Equation (5) only shows the limit for stability region and provides guidelines to estimate the value of T. But behavior of the system for value less than T given by (5) should be observed carefully because discrete behavior of the integral control produce fluctuations around the set point compare to continuous control with same gain as shown in Fig. 11.

By comparing Fig.11 with Fig. 9 it can be understood that though system is stable, oscillations enters in system behavior for the same Integral gain Ki in case of discrete control

Fig. 12 shows the system behavior with integral gain Ki =0.005 and compares with continuous integral control behavior for the same gain value as shown in Fig. 8.

It is clear from Fig. 12 that for integral gain Ki=0.005 discrete control reaches the desired set point quickly compare to continuous integral control. Time to reach the set point is shown in yellow color zone and system behavior after reaching the set point is shown in green color zone.

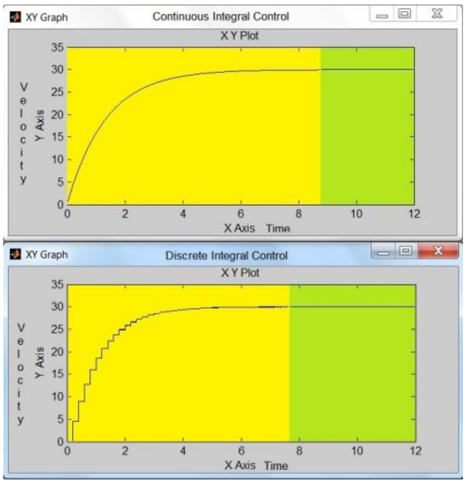

Figure 11.Discrete Control response for Ki=0.0005

It has also been seen that there are no oscillations in system after reaching the set point.

Thus for example system with given constraints discrete integral control produces satisfactory results with low settling time, no oscillations and similar acceleration/deceleration values compare to continuous integral control.

6. Conclusion

Discrete PI control is advisable for complex control such as heavy duty hydraulic system however actual implementation depends on system dynamic behavior, implications of missing the system state between the intervals and required speed of control action.

Thus Implementation of successful motion control for heavy duty electro hydraulic system is a result of careful observation and control of all system constraints and with proper optimizations of design tradeoffs.

7. Acknowledgment

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8. References

[1] Werner Gotz, and Seffen Haack, Electro hydraulic Proportional and Control Systems, 1st ed.Omegon Fachliteratur, Germany, 1999

[2] Medhat K. Bahr Khalil, “Estimated versus calculated viscous friction coefficient in spool valve modeling” IFPE Technical conference, 2008, Paper No. 14.2

[3] Curtis D. Johnson, Process Control Instrumentation Technology, 8th ed. Pearson Education Inc., 2006