Design and Response Characteristics of Electronic Control System on Hydraulic-Driven Mole Plough

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Abstract: ***Design and response characteristic of electronic control system on mole plough is the part of dissertation. Mole plough is used to construct the subsurface drainage channels on farms, to improve the absorption of water logging which caused plant deterioration. In the design, mole plough was directly mounted to hydraulic cylinder. The pressure to drive hydraulic cylinder piston was taken from tractor with capacity 55 kW using hydraulic hose.The problem that needs solving was how to observe the response characteristics of electronic control system on mole plough. This paper presented an alternative system came from the combination of mechanics, hydraulics, and electronics systemto lift and lower the mole plough based on received input sensor. The main parts of the system are hydraulic proportional controller, which is the first order control system, and convert the rotational angle of stepper motor to valve control openings in order to operate the velocity of hydraulic oil, and Electronic Control Unit (ECU) whichproduces the valve opening angle in the form of stepper motor rotation. Through the design analysis, response time in generating the valve opening system to drive the hydraulic cylinder piston was 3, 75 seconds at 89, 2° valve opening angle from the desired set point 15° valve opening, the maximum error in steady state condition was 2,1%.***

Keywords: Mole plough, electronic control system, hydraulic system, control valve, stepper motor.

1. Introduction

The construction of drainage channels is one of important land preparation activities. The crop need adequate amount of water supply for supporting plant growth. However, when the supply of water is excessive, it will damage the plants, and therefore the excess watermust be disposed [1].Mole plough is needed to construct the drainage channels. Three-point hitch tractor drags the plough and the plough movements (up or down) is controlled using hydraulic cylinder based on data input from leveling sensor. The design analysis and response characteristics of control system on hydraulic-driven mole ploughhave not been developed before. The research was aimed to observe the design of valve openings, response time, and the magnitude of errors, as well as the stability of hydraulic system during the work to pull the mole plough.

2. Research Design and Methodology

2.1 Research Design

This research was the continuation of previous research, which wastitled *Study Analysis of the Oil Flow Control Installation Pull Test Machine Hydraulic System*, a laboratory-scale research. Hydraulic system in the previous research will be used for field tests. The design testing is shown in Figure 1 [1] below.

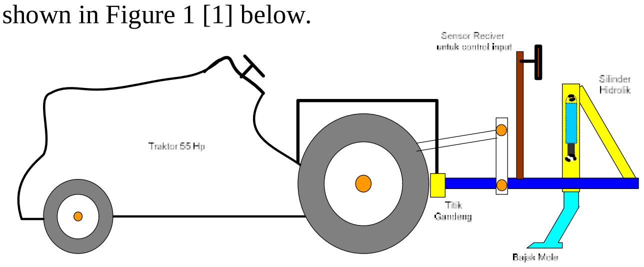

Figure 1: The installation of hydraulic cylinder on mole plough

According to Figure 1 above, a set ofmole plough is mounted to three-point hitch in tractor. The lower hitch pulls the mole plough, the upper hitch is lifted the mole plough to make slope in the range 0^o to 30^o. As the tractor moves forward and pulled the plough, the mole plough is gradually dragged through the ground, leaving in its wake a small, hollow channel as shown in Figure 2[1].

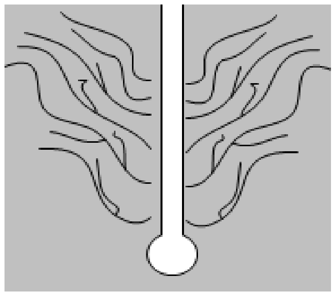

Figure 2: Drainage channel of mole plough

A hydraulic cylinder, attached to the mole plough, controls the channel depth. [2] Its movements based on leveling sensor and the input comes from electronic controller. Input data is the ground contour of the area that will be tilled by the tractor. When the tractors starts moving forward, the leveling sensors which are placed alongside the field will send signal to the sensors attached on tractor body. It will transfer input to electronic controller, and then send the input to stepper motor to open the valve control [3]. The valve opens and hydraulic cylinder will lift or lower the mole plough. The designedelectronic control system of hydraulic-driven mole plough is shown in Figure 3, [4].

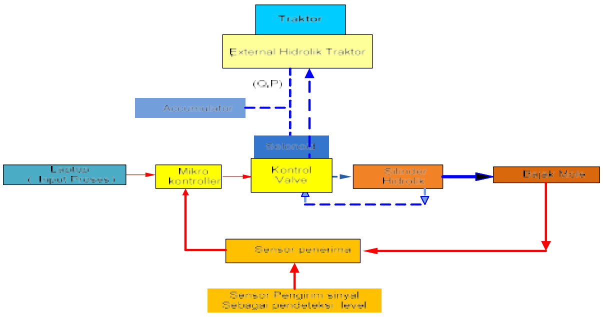

Figure 3: The designed electronic control system of hydraulic-driven mole plough.

Research design was conducted by detecting tractor movements (whether moving uphill or downhill), which really depends on the ground contour [5]. It was planned that the designed drainage channel has the surface slope starts from 0^o to 2^o. If the plough movement changes from the specified set point, the leveling detector sensor that placed alongside the field will send information to the receiver. The information will be sent to electronic controller, which will order the stepper motor to open the valve control. The valve opening starts from 0^o to 90^o. The opening of directional valve control is linear withthe flow of fluids. As the consequence, it also will be linear to the piston speed.

2.2 Methodology

Research method used in order to measure time response of speed (t) between input and output, also the stability of resulting signal form, is conducted by opening the flow control valve [6]. The designated valve control will be opened at 15^o, 30^o, 45^o, 60^o, 75^o, and 90^o, controlled byAVR Codevision. Setting of input and output pointsin this program, which has already been integrated with ATMEGA 128,is done through a computer, [7]. Once AVR Codevision program is completed, the desired setting of input and output is sent to ATMEGA 128 microcontroller via cable RG 45. The microcontroller stores data and through one of the ports (B, C, or D), data cable is connected to EMS *(*Embedded Modul Series). Then, the instruction is sent to SPS(Smart Peripheral Controller) motor controller.It is used to open and close the valve flow control so that the flow rate of working fluid (hydraulic oil) which is used to drive hydraulic cylinder piston can be set. The movement of hydraulic cylinder, both displacement and duration, can be monitored using ultrasonic sensor installed on the front of hydraulic cylinder. This sensor gives feedback to microcontroller byusing data cable which is connected to one of the ports (D, E, or F). This data, sent in the form of analog signal, can directly be processed by computer.

3. Materials and Tools

Materials and tools for the research are shown in Table 1 below.

Table 1: Material and tools

Tractor (1 set)	:	Holand 55 Hp,
Tractor hydraulic pump (1 set)	:	Capacity 100 liter/minute, 250 bar
Tractor hydraulic cylinder (1 set)	:	Capacity 100 liter/minute, 250 bar
Mole plough hydraulic cylinder (1 set)	:	Capacity 100 liter/minute, 250 bar
Solenoid (1 set)	:	30 A, 4 channels (2 in 2 out)
Flow control gate valve	:	3/8", 250 bar, proportional
1 set of pressure meter instrument	:	250 bar
Fujitsu (laptop)	:	11" screen, Hard disk 250GB,ram/rom 8 GB
Hydraulic hose and its features	:	Flexible 3/8"
Electronic control	:	AT MEGA 128
Stepper motor	:	12 V, 3A, 36 Watt, 1200 rpm

4. Analysis and Discussion

4.1 Stepper motor characteristics

Stepper motor in this research produces 15 degrees of step, which spends 25 milliseconds per cycle, and error 0,5 according to motor specification. The response of the hydraulic piston movement encounters time delay, caused by limited the starting time of motor and the opening of control valve. Therefore, there is motor delay time *(t_m)* to the change of valve opening angle *($\Delta\delta_r$)*. Stepper motor response time is*(T_m)*, [9]

$$T_m = t_m.\Delta\delta r \quad (1)$$

and the magnitude of error of working stepper motor isformulated below *(εo)*:

$$\varepsilon_o = \delta_r - \delta_m \quad (2)$$

Which $\delta_m$is the valve opening angle controlled by stepper motor.The magnitude of valve opening angle is the function of reading time:

$$\begin{aligned} \delta_m &= \delta_m,o & ,\left|\varepsilon_\phi\right| \leq 0,5 \\ &= \delta_m,o + \frac{\mathrm{t}}{\mathrm{t_m}} & ,\left|\varepsilon_\phi\right| \rangle\, 0,5 \quad (3) \\ &= \delta_m,o - \frac{\mathrm{t}}{\mathrm{t_m}} & ,\left|\varepsilon_\phi\right| \langle\, 0,5 \end{aligned}$$

4.2 Hydraulic proportional controller

The form of of hydraulic proportional controller can be seen in Figure 4 [10].

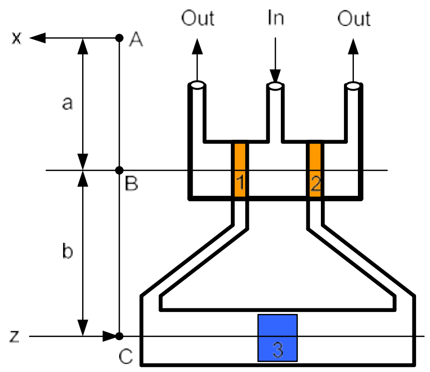

Figure 4: The form of hydraulic proportional controller

The description of response analysis of hydraulic proportional controller is as follows: when the stepper motor is turned to the right, A in link-AC will move horizontally to the left. If the input is the amount of x to the left, it will cause the opening of inlet 1, high-pressure fluids enters inlet 1, thus the hydraulic piston moves. The piston triggers the feedback AC and moves the guidance valve to the right. This action is repeateduntil the valve closes inlet 1 and 2 due to the piston movement. When the angle of valve opening is stationer, A is moved below along x, C will move along y_1 to k, the magnitude of y_1 is formulated as listed below: [10]

$$y_1(t) = \frac{b}{a+b}x(t) \quad (4)$$

Where x(t) is independentvariable input and y(t) is dependent variable output. The amplitude of B along y to the left will open the regulator valve and cause the fluid from the pump flows through inlet 1 and push the piston with the velocity dz/d to the right, and fluid will flow from inlet 2 to the tank. The greater amplitude of y, the higher speed of piston will be gained. It can be formulated as follows:

$$\frac{dz}{dt}(t) = K_1.y(t) \quad (5)$$

Feedback occurs because the piston is connected to the link (A-C) which minimizes the input y(t), resulted in the closing of valve opening regulator. The shift of y(t) caused by z(t) is formulated as follows:

$$y_2(t) = \frac{a}{a+b}z(t) \quad (6)$$

Output from y1(t) and y2(t) to y(t) is obtained using this equation,

$$y(t) = y_1(t) - y_2(t) \quad (6)$$

By simplifying the equation (4) to equation (6), we can obtain the first order differential equation that can represent the control system:

Differential Equation-1:

$$\frac{1}{K1}\frac{dz}{dt} + \frac{a}{a+b}x = \frac{b}{a+b}x \quad (7)$$

In the form of Laplace transformation is as follows:

$$\frac{1}{K_1}[s.Z(s) - z(o)] + \frac{a}{a+b}Z(s) = \frac{b}{a+b}X(s)$$

The block diagram of formula above can be seen in Figure 5. [11]

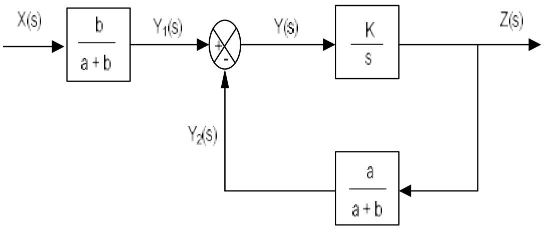

Figure 5: Hydraulic control block diagram

Based on Figure 5, the next equation can be formulated as follows: [11]

$$Z(s) = \left[\frac{\frac{b}{a+b}X(s)}{\frac{s}{K_1} + \frac{a}{a+b}}\right] + \left[\frac{\frac{1}{K_1}z(0)}{\frac{s}{K_1} + \frac{a}{a+b}}\right] \quad (8)$$

First group on the right indicates steady state condition, with initial requirement equals to zero. The second group is the complement solving affected by initial requirement, called the transient condition of system. Steady state solution is gained by assuming the input as the step function:

$$x(t) = 0 \quad at \quad t < 0$$

$$x(t) = A \quad at \quad t \geq 0 \quad (9)$$

$$maka$$

$$X(s) = A\int_0^\infty e^{-st}dt$$

$$X(s) = \frac{A}{s}$$

By simplifying the equation (8) and (9), we can get:

$$Z(s)_k = \left[\frac{\frac{b}{a+b}\frac{A}{s}}{\frac{s}{K_1} + \frac{a}{a+b}}\right] \quad (10)$$

$$Z(s)_k = \left[\frac{\frac{b}{a+b}}{s\left(\frac{s}{K_1} + \frac{a}{a+b}\right)}\right]$$

The group on the right can be divided partially into:

$$Z(s)_k = \left[\frac{\frac{Ab}{a}}{s} - \frac{\frac{Ab}{aK_1}}{\frac{s}{K_1} + \frac{a}{a+b}}\right] \quad (11)$$

Response time of steady state condition of differential equation is gained from inverse Laplace transformation*Z(s)*$_k$ as follows:

$$z(t)_k = L^{-1}\left[\frac{\frac{Ab}{a}}{s}\right] - L^{-1}\left[\frac{\frac{Ab}{a}}{s + \frac{aK_1}{a+b}}\right]$$

$$z(t)_k = \frac{Ab}{a} - \frac{b}{a}Ae^{-\left[\frac{aK_1}{a+b}t\right]} \quad (12)$$

$$z(t)_k = \frac{Ab}{a}\left[1 - e^{-\left[\frac{aK_1}{a+b}t\right]}\right]$$

The transient solution is affected by initial condition

$$Z(s)_t = \left[\frac{\frac{1}{K_1} z(0)}{\frac{s}{K_1} + \frac{a}{a+b}}\right] \quad (13)$$

$$Z(s)_t = \left[\frac{z(0)}{s + \left(K_1 \frac{a}{a+b}\right)}\right]$$

If the inverse Laplace transformation is conducted, we will get the equation:

$$z(t)_t = L^{-1}\left[\frac{z(0)}{s + \frac{a}{a+b}} K_1\right] \quad (14)$$

$$z(t)_t = z(0).e^{\left[\frac{a.K1}{a+b}t\right]}$$

From the equations above, the general equation will be:

$$z(t) = z(t)_k + z(t)t$$

$$z(t) = Z\left(1 - e^{\pi}\right) + z(0)e^{\pi} \quad (15)$$

Descriptions:

$$\tau = -\frac{aK_1}{a+b} \quad (16)$$

$$Z = \frac{Ab}{a}$$

According to the equation, if t ≥ 0, then:

$$z(t) = Z = \frac{Ab}{a} \quad (17)$$

Time needed to reach particular output value is:

$$t = \frac{\ln\left(\frac{z - Z}{z(0) - Z}\right)}{\tau} \quad (18)$$

Integral controller constant K_1greatly affects the speed of hydraulic control response, so that a more sensitive hydraulic system is desirable. According to Figure 4, the displacement of B at y = 24, 62 mm resulted in hydraulic cylinder velocity 0, 4 m/s. Thus, from equation (2) we can get integration constant 16, 25 seconds, so the time constant is -4, 98 seconds. Using the equation (3-18), system response by replacing the value of A and output position with zero will result in the equations below:

$$z(t) = 2{,}262\,A(1 - e^{-4{,}98t}) \quad (19)$$

Description:

$t = 0 \quad \Rightarrow \quad z(t) = 0$

$t = \infty \quad \Rightarrow \quad z(t) = Z = 2{,}26$

The response occurs in hydraulic cylinder is the response from hydraulic proportional controller with the input stepper motor response to control the valve opening, in different positions.

4.3 Analysis Results

Response takes place in hydraulic cylinder of mole plough is the response from hydraulic proportional control with the input stepper motor response. The analysis results and response time of stepper motor and valve opening at different angle is shown below.

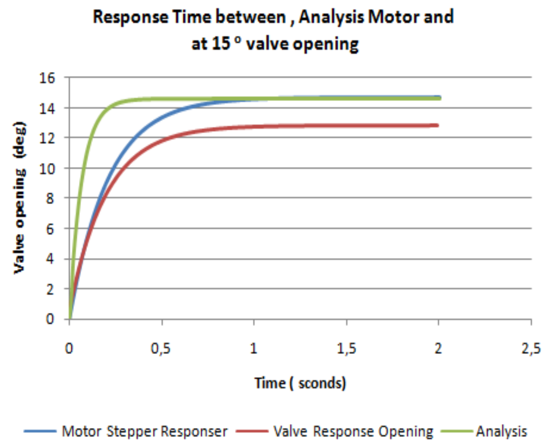

Figure 6: Response time of motor speed, at 15°valve opening

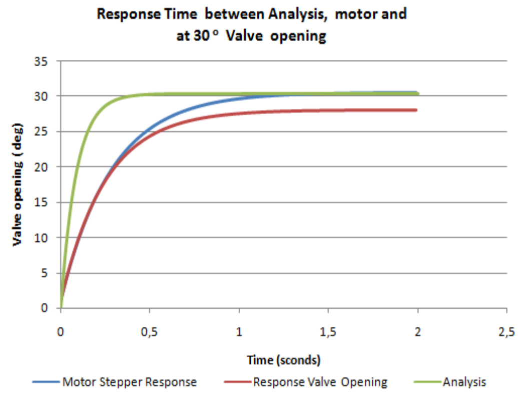

Figure 7: Response time of motor speed, at 30°valve opening

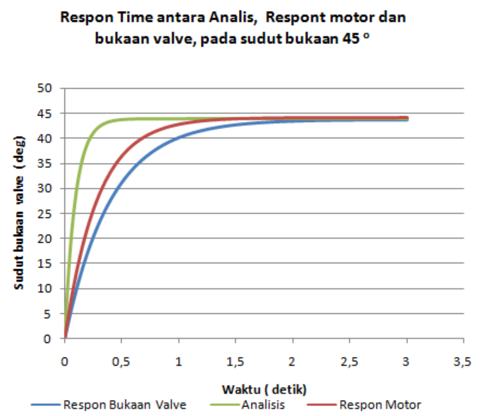

Figure 8: Response time of motor speed, at 45°valve opening

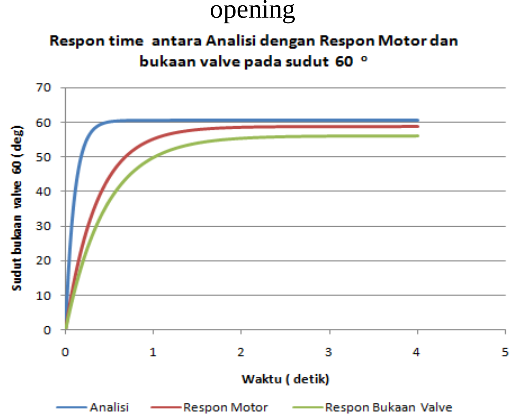

Figure 9: Response time of motor speed, at 60°valve opening

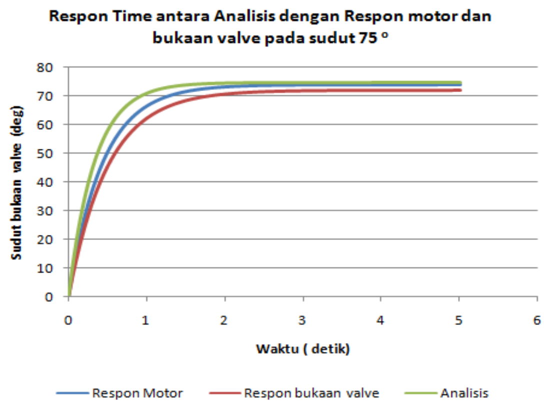

Figure 10: Response time of motor speed, at 75°valve opening

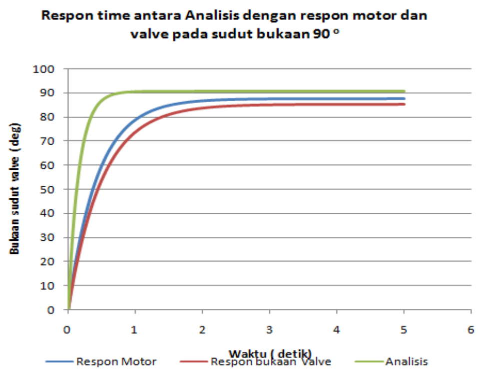

Figure 11: Response time of motor speed, at 90°valve opening

The response time (t) to reach valve opening from 15° to 90° is shown in the table below.

Measurees	Response time at valve opening (seconds)					
	15°	30°	45°	60°	75°	90°
Analysis	1,01	1,04	1,06	1,08	1,1	1,25
Stepper Motor	1,47	1,68	1,89	2,12	2,76	2,98
Valve control Hydrolic	1,62	1,96	2,09	2,35	3,14	3,75
Error (AnayisiVs Motor)	0,313	0,38	0,44	0,49	0,6	0,58
Error (AnayisiVS Valve)	0,377	0,47	0,49	0,54	0,65	0,67
Error(Motor Vs Valve)	0,093	0,14	0,16	0,18	0,19	0,21

The reach analysis, stepper motor and valve control hydrolic opening from 15° to 90° is shown in the table below.

Measurees	Set point at valve opening (deg)					
Analysis	15	30	45	60	75	90
Stepper Motor	14,60	29,40	44,20	58,70	73,90	87,60
Valve control Hydrolic	12,70	28,10	43,60	55,90	71,70	85,30
Error (AnayisiVs Motor)	0,97	0,98	0,98	0,98	0,99	0,97
Error (AnayisiVS Valve)	0,85	0,94	0,97	0,93	0,96	0,95
Error(Motor Vs Valve)	0,87	0,96	0,99	0,95	0,97	0,97

5. Conclusion

According to analysis results and equipment testing, when the stepper motor is activated and valve openings are planned in bervariable, it appears that the response time between the analysis, and stepper motor control valve opening time differences, and differences in valve opening angle. This is caused when the stepper motor is activated; there is a delay in the starting time, so the delay indicated the hydraulic control valve to open the valve. More testing so that the conclusions are: At 15 ° valve opening, response time is 1, 62 seconds, stepper motor opening 14,6°, control valve opening 12,7 ° error set point between analysis and control valve is 0,87%

a. At 30 ° valve opening, response time is 1,96 seconds, stepper motor opening 29,4° control valve opening 28,1° error set point between analysis and control is 0,96%
b. At 45 ° valve opening, response time is 2,09 seconds, stepper motor opening 44,2° control valve opening 43,6° error set point between analysis and control is 0,99%
c. At 60 ° valve opening, response time is 2,35 seconds, stepper motor opening 58,7° control valve opening 55,9 ° error set point between analysis and control is 0,95%
d. At 75 ° valve opening, response time is 2,76 seconds, stepper motor opening 73,9° control valve opening 71,7° error set point is between analysis and control 0,97%
e. At 90 ° valve opening, response time is 3,75 seconds, stepper motor opening 87,6° control valve opening 85,3° error set point between analysis and control is 0,97 %

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