

Research on the Motion Tracking Feedforward Control of Hydraulic Winch

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Abstract: The driving device of hydraulic winch is a hydraulic motor which controlled by electronic hydraulic proportional valve in general. Hydraulic winch is widely used in the field of engineering mechanism. The response speed of hydraulic winch deeply affects the control precision when the hydraulic winch needs to track a specific movement. Motion tracking feedforward control of hydraulic winch is designed for improve the control precision of hydraulic winch motion tracking. It is shown in the test of hydraulic winch motion tracking feedforward control that the non-linear of hydraulic winch decreases the control precision of motion tracking. The real time least squares parameters identification of hydraulic winch is used to amend the model parameters of hydraulic winch by using the control voltage of electronic hydraulic proportional valve and the speed of hydraulic winch. The adaptive feedforward control is designed based on the model of hydraulic winch which gets from the parameters identification. The outcome of simulation test shows that the adaptive feedforward motion tracking control which base on the real time parameters identification improves the control precision of motion tracking.

Keywords: Hydraulic winch, motion tracking, feedforward control

1. Introduction

Winch is driving equipment for lifting and descending the heavy objects. The winch usually divides into two types: electronic winch and hydraulic winch. Hydraulic winch is build by the integration of hydraulic components and mechanical apparatus. The roller of hydraulic winch finishes the lifting and descending motion by the driving of hydraulic motor and reducer. Hydraulic winch has inherent merits of hydraulic system such as heavy power density, compact construction and high security. The hydraulic winch is widely used in the field of engineering mechanism.

Electronic hydraulic proportional valve is widely used in the general engineering applications because of its low price, high capability of resist contamination and high reliability. The driving device of hydraulic winch is hydraulic motor which controlled by electronic hydraulic proportional valve in general. This paper is based on the engineering equipment of hydraulic winch tracking an appointed motion. When the maximum speed of hydraulic winch is less than the maximum speed of the tracked motion, open loop feedforward control is a useful way to get preferable control characteristics. So the motion tracking feedforward control of hydraulic winch is researched in this paper.

2. Configuration and modeling

The configuration of hydraulic winch usually includes roller, reducer, hydraulic motor, electronic hydraulic proportional valve and balanced valve. The hydraulic winch usually needs to lift heave body. A balanced valve is setting in the hydraulic loop of hydraulic winch. The balanced valve is used to prevent the hydraulic impact when the heavy body descends. The speed of hydraulic winch is controlled by electronic hydraulic proportional valve. The transfer function of electronic hydraulic proportional valve is showed as follows:

$$G_v(s) = \frac{Q(s)}{U(s)} = \frac{K}{Ts + 1} \quad (1)$$

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where $Q(s)$ is the output flux of electronic hydraulic proportional valve, $U(s)$ is the control voltage, K is the gain of proportional control and T is the response time of electronic hydraulic proportional valve.

The transfer function of hydraulic winch is made from integrating the linear flow equation of valve, the dynamic flow equation of hydraulic motor and the torque balance equation of hydraulic motor, described as follows:

$$\Delta\theta_m = \frac{\frac{Q_v}{D_m} - \frac{K_{ce}}{D_m^2} \left(1 + \frac{V_t}{4\beta_e K_{ce}} s\right) \Delta T_L}{s \left(\frac{s^2}{\omega_h^2} + \frac{2\delta_h}{\omega_h} s + 1 \right)} \quad (2)$$

where ω_h is the hydraulic inherent frequency, δ_h is the hydraulic damping ratio, T_L is the torque of hydraulic winch and D_m is the displacement of hydraulic motor.

The hydraulic winch is a system of big inertia and heavy load. The response speed of hydraulic winch effect the control precision when hydraulic winch tracking a determined motion. A feedforward control is used to improve the response speed of hydraulic winch. So the control precision of motion tracking is increased.

It is supposed that the transfer function of feedforward control is $G_c(s)$. The transfer function between the speed of hydraulic winch and control voltage of electronic hydraulic proportion valve is described as follows:

$$G_0(s) = G_v(s) \cdot \frac{1}{\frac{s^2}{\omega_h^2} + \frac{2\delta_h}{\omega_h} s + 1} \cdot \frac{d}{2 \cdot i \cdot D_m} \quad (3)$$

where d is the diameter of roller, i is the transmission ration of reducer and D_m is the displacement of hydraulic motor.

If the expectation speed of hydraulic defined as V , then V is the input of feedforward control. The transfer function of feedforward control should satisfy the following equipment:

$$G_c(s) = (Ts + 1) \cdot \left(\frac{s^2}{\omega_h^2} + \frac{2\delta_h}{\omega_h} s + 1 \right) \cdot \frac{2 \cdot i \cdot D_m}{K \cdot d} \quad (4)$$

If the frequency of tracked motion is low, then the transfer function of hydraulic winch is showed as follows:

$$G_0(s) = \frac{K}{Ts + 1} \cdot \frac{d}{2 \cdot i \cdot D_m} \quad (5)$$

So the transfer function of feedforward control described as follows:

$$G_c(s) = \frac{1}{G_0(s)} = \frac{2 \cdot i \cdot D_m}{K \cdot d} \cdot (Ts + 1) \quad (6)$$

3. Motion tracking control test

Motion tracking control test is accomplished to verify the usefulness and efficiency of motion tracking feedforward control of hydraulic winch. The mainly test equipments include hydraulic winch, industry computer, heavy load, wire rope and hydraulic station. The tracked motion is shown in the figure 1. It is shown in the figure 1 that the frequency of the tracked motion is in the range between 0.1Hz to 0.2 Hz. The speed curves of hydraulic winch feedforward control and tracking error are shown in figure 2.

The performance index of hydraulic winch motion tracking feedforward control is defined as relative error. It is described as follows:

$$\delta = \frac{\frac{1}{N} \left(\sum_{i=1}^N |S(iT_0) - W(iT_0)| \right)}{\frac{1}{N} \left(\sum_{i=1}^N |S(iT_0)| \right)} \times 100\% \quad (7)$$

where S is the speed of tracked motion, W is the speed of hydraulic winch, T_0 is sample period and N is the sample number. If the relative is low, then the efficiency of tracking efficiency is high. It is shown in the figure 2 that the relative error of motion tracking feedforward control of hydraulic winch is 20%.

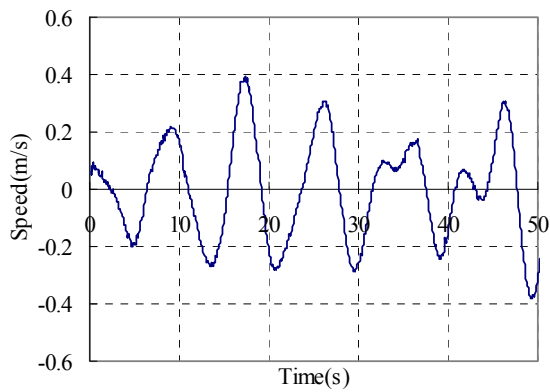


Figure 1. The tracked motion of hydraulic winch

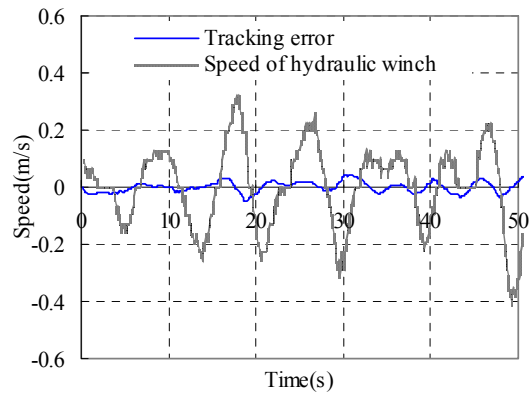


Figure 2. Speed and tracking error

4. Non-linear simulation

It is shown in the test outcome of hydraulic winch motion tracking feedforward control that the non-linear character of hydraulic winch decreases the efficiency of motion tracking. Hydraulic winch is a typical non-linear system. The non-linear character mainly comes from the flux form of electronic hydraulic proportional valve. The relation between output flux of electronic hydraulic proportional valve and core displacement of the valve is non-linear. It is affected by the load pressure of hydraulic winch. So in the frequency range of tracked motion, the model parameters of hydraulic winch are changing frequently.

The changing regulation of the model parameters is gained from the test outcome of hydraulic winch motion tracking feedforward control test. The non-linear simulation model is set up and the simulation test is finished. The outcome of simulation test is shown in figure 3.

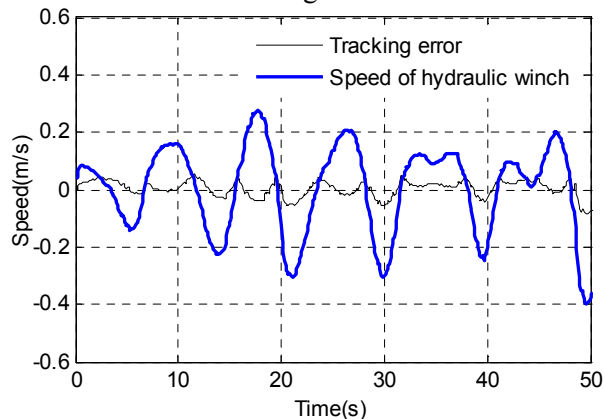


Figure 3. The curve of hydraulic winch non-linear simulation test

It is shown in the motion tracking simulation test that the relative error of hydraulic winch feedforward control is 20%. The outcome of simulation test of non-linear hydraulic winch is consistent with the outcome of motion tracking test.

5. Adaptive feedforward control

The model parameters of hydraulic winch are changed frequently because of the non-linear of hydraulic winch. The feedforward control efficiency of hydraulic winch motion tracking is decreased. The control voltage of electronic hydraulic proportional valve and the speed of hydraulic winch are used to identify the model parameters in real time by the way of least squares parameters identification. So the feedforward control is amended on-line. The feedforward control of on-line parameters modification is called adaptive feedforward control. It improves the efficiency of motion tracking control. The block diagram of hydraulic winch motion tracking adaptive feedforward control is shown in figure 4.

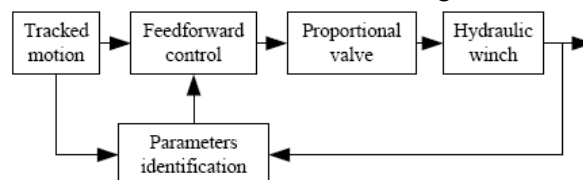


Figure 4. Block diagram of hydraulic winch motion tracking adaptive feedforward control

The outcome of simulation test of hydraulic winch motion tracking adaptive feedforward control is shown in the figure 5.

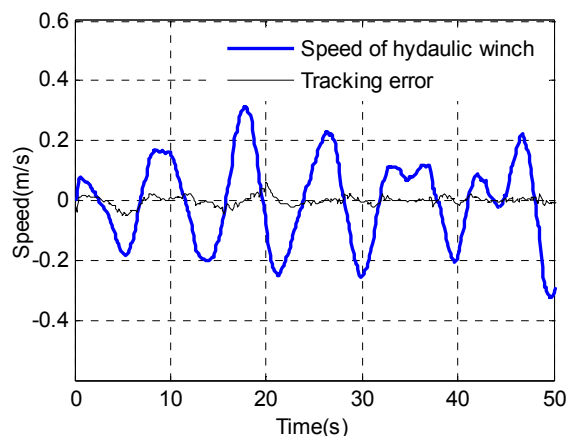


Figure 5 Curve of hydraulic winch motion tracking adaptive feedforward control

It is shown in the simulation test that the relative error of hydraulic winch motion tracking adaptive feedforward control is 7.8%. The efficiency of adaptive feedforward control is significantly higher than the efficiency of feedforward control. So the adaptive feedforward control which the parameters of feedforward control gained from parameter identification improves the efficiency of motion tracking control of hydraulic winch.

6. Conclusions

The hydraulic winch is a non-linear system which the model parameter is changing frequently. The non-linear decreases the efficiency of hydraulic winch motion tracking feedforward control. The adaptive feedforward control which based on the parameters identification of hydraulic winch is researched in this paper. The motion tracking test and simulation test show that the hydraulic winch motion tracking adaptive feedforward control which based on the hydraulic system parameters identification gains high efficiency of motion tracking.

7. References

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