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Design and Research on Constant Tension Controller in Electric Power Transmission

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Abstract. In order to improve the characteristic and control strategy in transmission lines, a tension stringing mathematical model was established which analyzed the multiple disturbance factors of tension. According to the tension control principle of hydraulic system and the influence of different factors, a control method of constant tension adapted to the system was proposed based on pressure regulating plan. By simulation, the modified tension control system enhanced the dynamic response characteristic and stability effectively, which can realize the ideal constant tension control.

Introduction

Tensioner usually apply hydraulic braking in electric power transmission, most of electro-hydraulic proportion tension control systems adopt the closed-loop feedback strategy. Hydraulic system is a nonlinear system with multiple disturbed factors and uncertain parameters, so it is difficult to set up mathematical model [2]. Precision of tension control greatly influence the follow-up work in electric power transmission. However, the majority of operators adjust the tension manually [1]. By this way not only increase the intensity of labor but also can't guarantee safe operation. With the construction level of State Grid development, the requirements of construction quality is growing, as well as the precision of tension on wire must be increased. Constant tension control system will bring great convenience to follow-up work. By adjusting tension timely and automatically can shorten the construction period, make tension kept constant and do not be affected by the pay-off speed [3].

Tension Stringing Mathematical Model

The mathematical model of tension stringing as shown in Fig. 1:

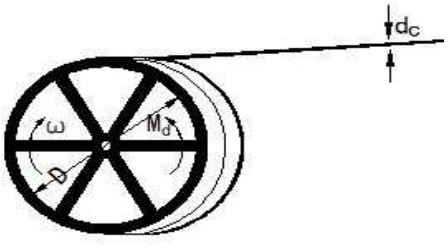

Fig. 1 Mathematical model of tension stringing

Where d_c is the diameter of wire, ω is the angular velocity of wire, D is diameter of reel.

As shown in Fig. 1, torque equilibrium equation of tension reel as follows [3]

$$\frac{d(Jw)}{dt} = \frac{FD}{2} - M_d - B\omega \tag{1}$$

Where F is wire tension, J is the rotational inertia of tension reel, B is damping coefficient, M_d is the braking torque of reel.

The length of reduced wire on reel is equal to the length of unfolded wire, as Eq. (2) shows

From Eq. (1) and Eq. (2) infer that

$$dl = \pi dD = vdt \tag{2}$$

$$\frac{d(J\omega)}{dt} = \frac{1}{16} p(D)^2 d_c v^2 + \frac{1}{16}\pi D^3 d_c p \frac{dv}{dt} \tag{3}$$

The tension is obtained according to Eq. (1), as in

$$F = \frac{1}{8} D d_c p v^2 + \frac{4B}{D^2} v + \frac{1}{8}\pi D^2 d_c p \frac{dv}{dt} + \frac{2M_d}{D} \tag{4}$$

As shown in Eq. (4), wire tension is a nonlinear and time-varying system. It is influenced by various factors, the linear velocity of wire and tension with strong coupling.

Tension Control System

Principle of Regulating Tension. Tensioners adopt hydraulic braking system, the principle of braking as shown in Fig. 2. Pressure difference on both ends of the main valve core is utilized to make High pressure relief valve move. Meanwhile, the pressure difference of the main valve core ΔP varied along with the pressure of oil inlet increasing. When ΔP is more than spring pressure, the main valve core be jacked up, oil inlet and oil outlet would be connected. So if the spring pressure increasing, there are more pressure of oil inlet is needed. The pressure of oil inlet can be adjusted by regulating the spring pressure of bolts. The adjustment of wire tension is realized with the help of hydraulic 3 controlled by high pressure relief valve 4.

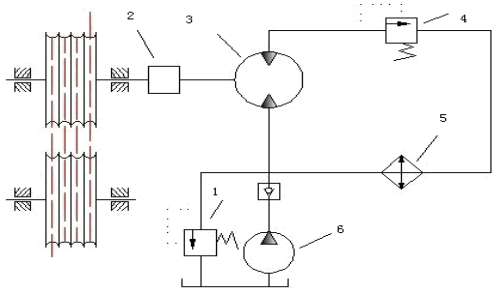

Fig. 2 Schematic of hydraulic braking for tensioner

Where 1 is low pressure relief valve, 2 is speed increaser, 3 is hydraulic motor, 4 is high pressure relief valve, 5 is radiator and 6 is auxiliary hydraulic pump.

Constant Tension Control. Constant tension control means keep tension steady during tension stringing. Add tension control loop on the inherent tension system so as to improve the accuracy of the tension. During tension stringing, actual tension which is measured by pressure senor should be compared with the set value of pressure, when detecting the deviation, MCU will produce the control signal at once. By adjusting the relief valve to control the outlet pressure of hydraulic motor, make the actual tension close to the set up value.

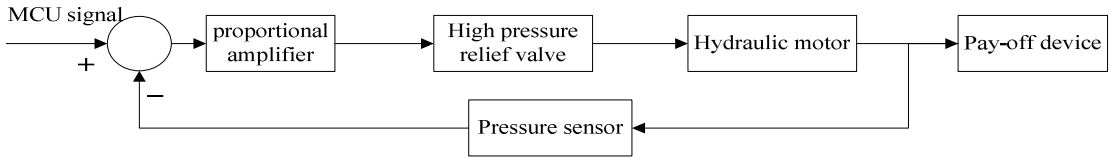

Fig. 3 Flowchart of tension control system

Transfer Function of Tension Control System. Assuming pay-off speed remains the same, the diameter of reel is looked as constant in a period of time, so the rotational inertia keeps constant. The torque equilibrium equation of tension reel and output torque equation of motor as follows:

$$M = J\frac{d^2\theta}{dt^2} + B\frac{d\theta}{dt} + FR \tag{5}$$

$$M = \frac{1}{2\pi}\eta_m q(p_s - p_r) \tag{6}$$

Where B is the viscous damping coefficient, q is the displacement of hydraulic motor, θ is the angular displacement of tension reel, F is the tension of wire, R is the radius of reel, p_s, p_r is the inlet and outlet pressure of proportional valve, η_m is the overall efficiency of hydraulic pump. The pressure difference between inlet and outlet of proportional valve has a relationship with control signal, as in [4]

$$p_s - p_r = \frac{k_i}{\frac{s^2}{\omega_i^2} + \frac{2\xi_i s}{\omega_i} + 1}(u_s - u_r)\,. \tag{7}$$

ω_i is far greater than the angular frequency of hydraulic system, in Eq. (7) the denominator is close to 1, the coefficients in formula are looked as proportional element.

$$p_s - p_r = k_i(u_s - u_r) \tag{8}$$

According to Hooke law and the relationship between angular displacement and velocity, hence

$$\frac{dF}{dt} = K(v - v_1) \tag{9}$$

$$\frac{d\theta}{dt} = \frac{1}{KR}\frac{dF}{dt} \tag{10}$$

The transfer function is described as Eq. (11)

$$\frac{F}{(u_s - u_r)} = \frac{\frac{\eta_m q}{2\pi R}k_i}{\frac{J}{KR^2}s^2 + \frac{B}{KR^2}s + 1}\,. \tag{11}$$

The main working parameters of tensioner as in

$\eta_m = 0.85$, $K = 7.9\times10^{-10}\,pa$, $B = 0.6m$, $J = 45.52kg.m^2$, $q = 6.69\times10^{-3}\,m^3/r$

$k_i = 6.55\times10^{-3}\,m^3/(S.A)$.

Therefore, we can obtain open-loop transfer function

$$G(s) = \frac{0.00001}{1.6\times10^{-9}s^2 + 0.21\times10^{-10}s + 1} \tag{12}$$

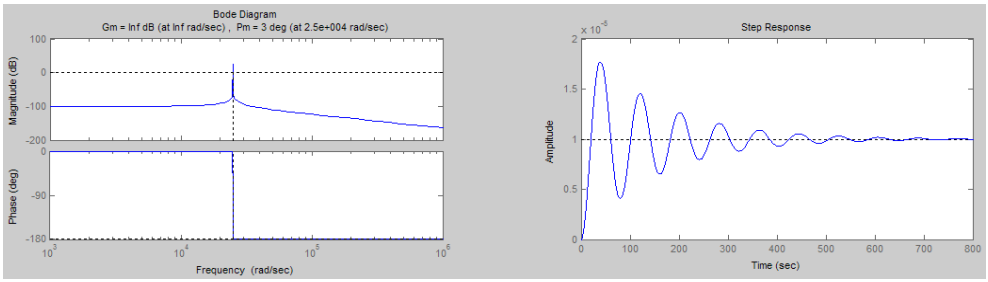

Fig. 4 Step response and bode diagram of tension control system

As shown in Fig. 4, rise time is too long, response is unstable and overshoot is more than 50%. Meanwhile, the phase margin of bode is too small. This will lead to increase the energy loss of control system.

Adjusting the Algorithm of Tension Control

In order to enhance the stability of the system, adopt the series lag corrector to meet appropriate phase margin. By using Ziegler-Nichols design PID controller to compensate the system.

Firstly, we adopt the lag corrector to perfect the system. Its essence is RC circuit, by using the high-frequency attenuation characteristic to reduce the cutoff frequency of open loop so as to upgrade the phase margin. The step response and bode diagram are shown in Fig. 5 after introducing the series lag corrector.

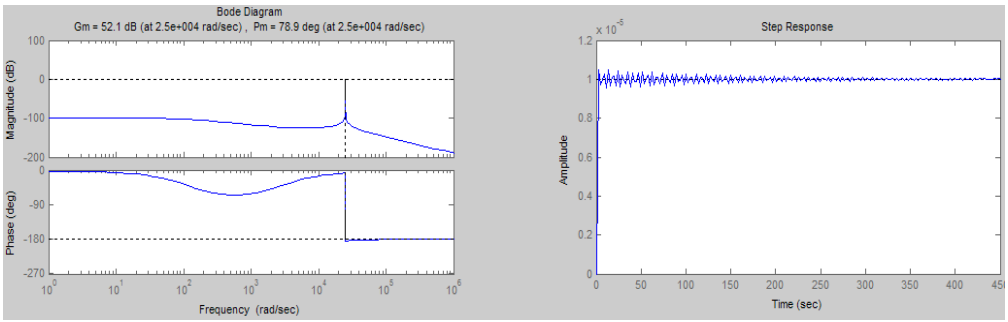

Fig. 5 Step response and bode diagram after lag correcting

PID control method is a kind of early, mature and widely used control strategy [5]. By using PID controller to adjust tension system, so as to meet constant tension. The details as follows:

First of all, according to the root locus ensure the range of K_p, we can get an accurate K_p based on the principle of overshoot minimize. Along with the growth of K_p, overshoot increasing, response time reducing. When the value of K_p ranges from 6000 to 10000, the response is better. As simulation shows when K_p=9000, the response is best. The range of T_I and T_D can be determined by Ziegler-Nichols experience formula.

After comparing different values of K_p, we choose T_I=1.54, T_D=0.34. In accordance with the above parameters to simulate, we could get Pole-Zero Map, Bode Diagram and Root Locus. Fig. 6 shows after introducing PID controller, the characteristics of tension control system are better.

Obviously, the step response of tension control system is nearly steady，overshoot keeps in 0.02%. Meanwhile, features are enhanced effectively such as the response time, response accuracy and noise immunity. From the Bode Diagram and Root Locus we can see the system characteristics have been improved greatly.

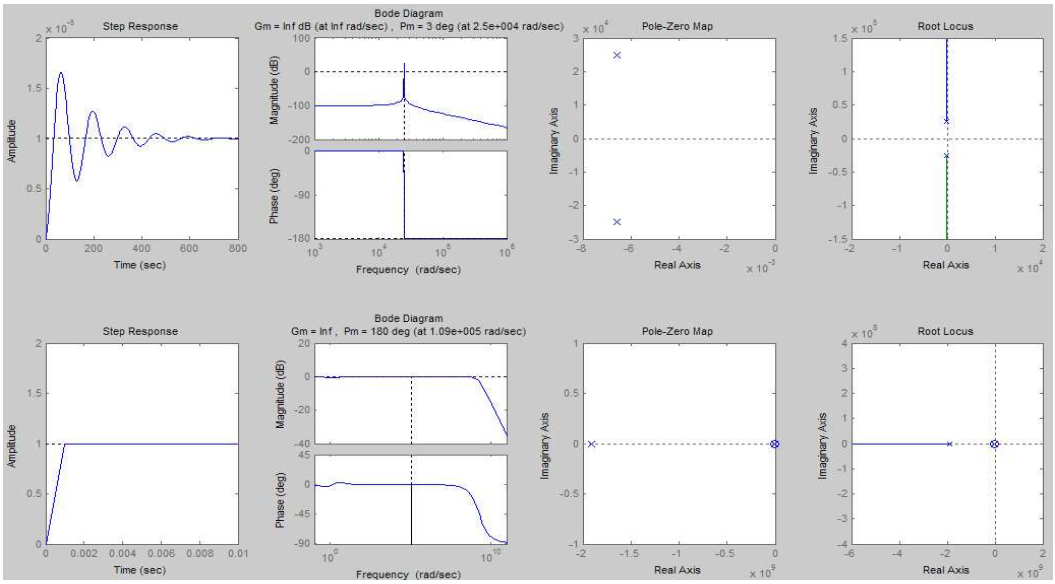

Fig. 6 Comparison of modified system and original system in some characteristics

Conclusion

Tension control system with characteristics like low stability, time-variable and long delay. It is easy to be affected by the influence of the environment. This paper utilized lag corrector to increase the phase margin of control system. The optimized PID controller is used to improve the dynamic characteristics for the tension control system. The simulation shows that tension keep constant after correction. This method ameliorates the current situation of construction, improves the work efficiency and guarantees the security operation.

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