Modeling and Simulation of Electric-hydraulic Control System for Bending Roll System

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***Abstract*—Hydraulic bending roll system has become one of key equipments to control the exit strip shape in strip rolling mills. The hydraulic bending roll system of a hot rolling mill was researched and analyzed, and its mathematics models were founded in whole based on the action principle of some representative hydraulic components. At last, the hydraulic bending roll system was simulated with MATLAB by computer. It is obvious that the simulation curves are similar to the real response curves very much.**

***Keywords*—shape control, hydraulic roller bending force control, hot strip rolling mill**

I. INTRODUCTION

Following the improvement to the industrial product, it needs the high request to the thickness precision and the shape precision. So the shape control becomes the important research subject in the steel corporation. The hydraulic bending roll system is the basic method of the shape control, which has merits of high precision, fast response speed etc. and is applied comprehensively. Improving the dynamic character of the hydraulic bending roll system has important meanings to realize the high-precision automatic shape control.

II. MATHEMATICAL MODEL OF HYDRAULIC BENDING ROLL SYSTEM

The electro-hydraulic bending roll servo system is realized by controlling the roll deflection in the rolling process[1,2]. In the rolling process, the hydraulic bending force is put down to the roll diameter, and the valid deflection of the roll is changed to change the gap figure. Then the strip extend distributes in the landscape orientation well-proportioned to control the shape. According to the different part where the bending force puts down, there are bending backup roll and the bending work roll for the 4-roll rolling mill[3,4]. To every manner, there are positive bending and the negative bending. In this article, the positive bending was analyzed, and its system structure is showed in fig. 1.

Mathematical models of the system is showed under-mentioned:

When the controller adopts the PI regulator, it's transfer function is:

$$E_0 = K_p e(t) + K_i \int e(t) \qquad (1)$$

In the equation, *Kp* and *Ki* are the proportional coefficint and the integer coefficient of the PI controller; E_0 is the output; $e(t)$ is the varialble value of the error.

The servo amplifier tranfers the voltage to the current to control the servo valve. The time constant can be ignored, so the servo amplifiercan be as the proportion loop approximately. Its mathematical model is:

$$I = K_1 E_0 \qquad (1)$$

In the equation, I is the current; K_1 is the amplifactory coefficient of the ampilifier; E_0 is the output erro voltage of the PID control loop.

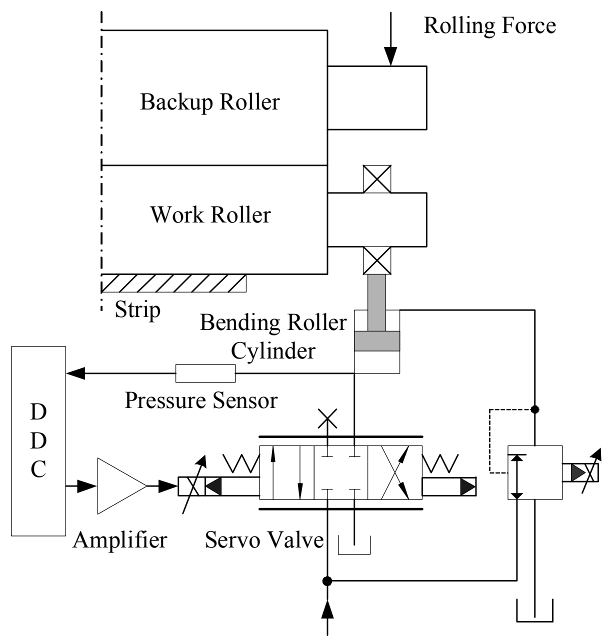

Fig. 1 Structure of Bending Roll Control System

The servo valve has the high response character, which is highly nonlinear. The relation between the displacement of the servo valve spool and the input current can be expressed:

$$\frac{x_v}{I_c} = \frac{K_{sv}}{\frac{s^2}{\omega_{sv}^2} + \frac{2\xi_{sv}}{\omega_{sv}} s + 1} \qquad (2)$$

In the equation: K_{sv} is the magnification coefficient between the valve spool and the input current; ω_{sv} is the natural frequency of the servo valve.

The flow equation of the servo valve is:

$$Q_L = \cdot C_d \omega \cdot x_v \sqrt{\frac{2}{\rho}(P_s - P_L)} \quad x_v > 0 \quad (3)$$

$$Q_L = C_d \omega \cdot x_v \sqrt{\frac{2}{\rho} P_L} \quad x_v < 0 \quad (4)$$

In the equation: C_d is the coefficient of discharge; P_s is the system pressure; Q_L is the flow through the orifice; P_L is the pressure drop across the cylinder.

The flow character of the servo valve includes the saturated nonlinear:

$$Q_L = \begin{cases} Q_L & Q_L < Q_N \\ Q_N & Q_L \geq Q_N \end{cases} \quad (5)$$

In the equation: Q_N is the rating flow of the servo valve.

The flow continuous equation of the hydraulic cylinder is:

$$Q_L = A_h \frac{dx_p}{dt} + C_{tc} P_L + \frac{(V_t + A_h \cdot x_p)}{\beta e} \cdot \frac{dP_L}{dt} \quad (6)$$

In the equation: C_{tc} is the total leaking coefficient; V_t is the total oil volume contained in the pipes; βe is the bulk modulus of the fluid.

The load equation is:

$$P_L A_h - P_b A_r = m_t \frac{d^2 x_p}{dt^2} + B_p \frac{dx_p}{dt} + kx_p \quad (7)$$

In the equation: m_t is the total equivalent mass of the the piston and the load which convert to the piston of the hydraulic cylinder; B_p is the equivalent damp of the mill; k_0 , k_1 is the spring rigidity of the load.

The pressure sensor is the SCP series of American PARKER corporation, and its transfer function can be looked on as the first order inertia loop:

$$G\ (s) = \frac{K}{1 + T\ s} \quad (8)$$

According to the mathematical model of every hydraulic part, the block diagram of the transfer function of the hydraulic bending system is showed in fig. 2. By Simulink of Matlab program and the block diagram of the transfer function, the dynamic response, between the input and the output of the bending force, can be analyzed.

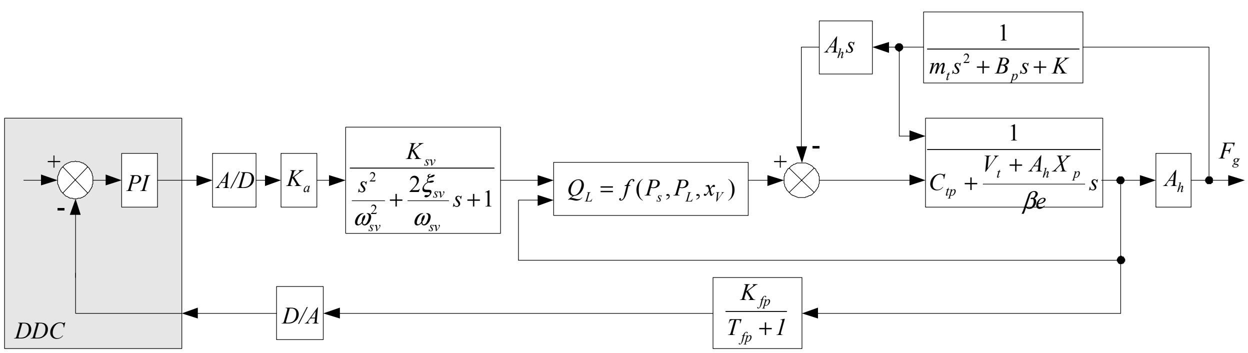

Fig. 2 Block Diagram of Transfer Function of Hydraulic Bending System

III. Dynamic Simulation Analyze

A. Parameters of Hydraulic Bending System

The positive bending work roll system of some 1580 hot tandem rolling mill is studied. One side of every stand (of the up and down work roll) has 4 bending cylinders, which are controlled by a servo valve. Parameters of every loop in the system are:

1. Electro-hydraulic servo valve

In the hydraulic bending system, it selects the electro-hydraulic servo valve of Moog Corporation. Its parameters of the dynamic character are: $\omega_{sv} = 100Hz$, $\xi_{sv} = 0.7$. The flow value of the valve is 160L/min, when the pressure reduction is 70 bar, and the current of maximum value of the valve core's hatch is $\pm$10mA. So it can be concluded:

$$\frac{Q_0}{\sqrt{\Delta P}} = \frac{160 \times 10^{-3} m^3 / 60s}{\sqrt{7 \times 10^6} Pa} = 1.01 \times 10^{-6} m^5 / s / N$$

The coefficient is:

$$K_{sv} = 2.23 \times 10^{-6} / 0.01 = 1.01 \times 10^{-4} m^5 / (s \cdot N \cdot A)$$

2. Hydraulic Bending Cylinder

The size of the hydraulic bending cylinder is $\phi 200 / \phi 150 - 160$ (work journey is 100mm). The outer diameter and the wall thickness of the pipe at the piston side are $\phi 42 \times 6$. The length is 6 m. The initial dimension of the hydraulic cylinder's contrl cavity:

$$V_t = \frac{\pi}{4} \times 0.2^2 \times 0.06 + \frac{\pi}{4} \times 0.03^2 \times 6 = 6.1 \times 10^{-3} m^3$$

3. Equivalent mass, rigidity and stickiness damp coefficient

Because of the effect of the bending force, the roll's deformation happened and made the power distribution of the system is different from the vibration system with the centralized mass. According to the theory of kinetic energy equality, the calculation of the equivalent mass and the rigidity is carried out:

$$m_t = 5.2\times10^3 kg \ , \quad k = 3.1\times10^8 N/m$$

The stickiness damp coefficient of the load can be got by the system identification:

$$B_p = 1.4\times10^5 N\cdot s/m \ 。$$

4. Parameters of PI controller

The built simulation system is linearized, and the open-looped Bode diagram is get from the system open-looped transfer function. So it can be concluded: $K_p = 6$, $K_I = 60$ 。

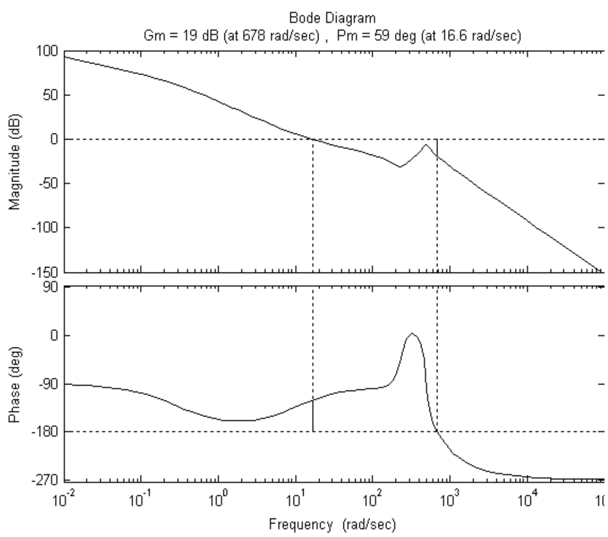

Fig. 3 Open-loop Bode Diagram of System

5. Other Parameters

Other parameters are showed in Table 1.

Table 1 **Other parameters in hydraulic bending system**

Parameter	*Value*	*Parameter*	*Value*
A_h	$0.0314\ m^2$	βe	$780MPa$
A_r	$0.0137\ m^2$	C_{tc}	$5\times10^{-12} m^3/Pa$
P_s	$25MPa$	P_b	$3MPa$
K_{fp}	$3.3\times10^{-7} V/Pa$	T_{fp}	$1\ ms$

B. Time Character of Hydraulic Bending System

The pressure of the adjusted pump is 25Mpa. The input signal is the regular from 1.5V to 2.5V. The revelant pressure is from 6.3Mpa to 7.9Mpa. Its simulation response curve and the real curve is showed in fig. 4. The sampling time is 5ms.

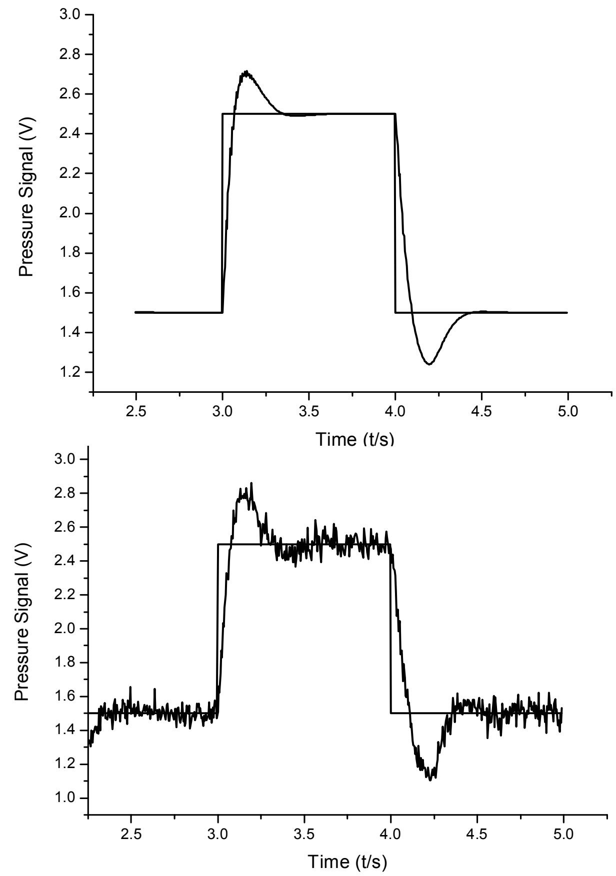

Fig. 4 Simulation response curve and Real curve of System

It can be seen that the adjusting time was 0.38 second and the overshoot was 19%, the simulation curves are similar to the real response curves very much. The model can accurately discribe characteristic of bending roll system.

C. Stickiness Damp Coefficient

Damp ratio that decided by total flow-pressure coefficient and stickiness damp coefficient is a very important parameter of hydraulic servo system. Fig. 5 shows response curve of stickiness damp coefficient decreased to half.

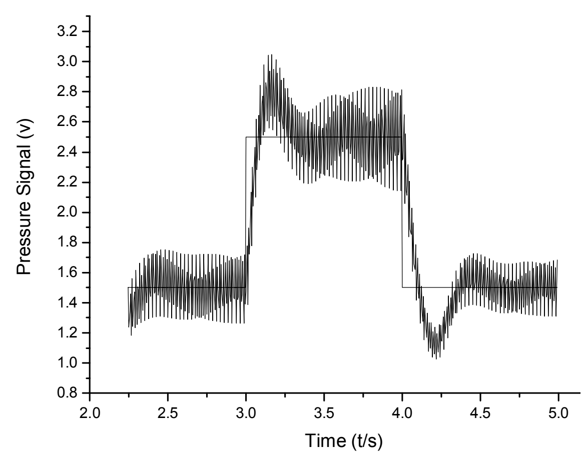

Fig. 5 Response curve after stickiness damp coefficient decreased to half

But simulation curve will be gotten nearly as same as fig4 when reduce total flow-pressure coefficient as half. So we can draw conclusion that Damp ratio is mainly provided by stickiness damp that shoud not be ignored.

IV. CONCLUSION

1) It thinks about the nonlinear, saturation, nonsymetry of the servo valve, and adopts the mechanism modeling method to get the mathematic model of the hydraulic bending sytem. The model is more similar for the real system, and the influence of every parameter to the system is more straight.

2) The damp coefficient of the hydraulic bending system should not be ignored, which is provided by the stckiness of the system. Otherwise, the damp of system is too small to get precise simulation system.

3) After building the equipment model, parameters of the system and the control strategy can be gained, before the system is debugged. It can reduce the debug period and improve debug level.

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