Vol. 6 №. 1 TRANSACTIONS OF NFsoc Mar. 1996

OPTIMIZED DESIGN OF HYDRAULIC CONTROL PATTERN OF SYNCHRONOUS SYSTEM IN LARGE SCALE DIE-FORMING HYDRAULIC PRESS[①]

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ABSTRACT The hydraulic control mode of the synchronous system in Chinese-built 300 MN die-forming hydraulic press was analysed comprehensively. To improve the deficiency of the existing system, a series investigations were put forward, such as the controlling of inclination angular-velocity, the pre-estimating of compensation, the synchronous cylinder's pressure signal protection, ratio pressure control and changing flow control etc, to increase the system's control accuracy and reliability greatly.

Key words synchronous system hydraulic control optimization

1 INTRODUCTION

As the biggest one in Asia, our 300 MN die-forming hydraulic press (DHP) which was placed in service in the 1970's has been played an inestimable role in Chinese economic development and the building up of national defence, and its synchronous balance system made a great contribution to equalize the frame's force condition and guarantee the working part's accuracy. Yet the existing compensated sychronous balance system has not been able to satisfy the production needs in control mode, response rate and control accuracy. To follow the development of science and technology and the demand for better quality of the die forging products, and to operate the equipment more reliably and accurately, it is necessary to rebuild the operation control system of the 300 MN DHP.

The hydraulic principle of compensating system (CS) is shown in Fig. 1. The master control valve employs plug-in valve of high sensitivity, level pressure is controled by overflow valve 7. The system works with different compensating flow in two working conditions: load and unload. Valve 5, 6, 11 make up the change flow link. The switch between load and unload is dominated by valve 6. Normally, the axial plunger pump runs unload through internal control cone valve 4, and works load only in the moment need compensation. All of the valve elements are integreted into a valve body.

The system's control mode has relay property. Control accuracy actually is the set dead zone value. Because the non-compensating cavity is shut by valve 7, and the movable cross beam (MCB) will deflect reversely and exceed the set control point if overcompensating, which causes the high pressure fluid in original compensating cavity dumps out in that moment without controlled and leads to the system's vibration. Under the existing control pattern and to guarantee the system's stability, it is difficult to improve the system's control accuracy and the maximum tilt protection more forward.

Under the maximum allowable eccentrici-

① Received May 30, 1995; accepted Sep. 29, 1995

ty and fast loading, the extant system's synchronous compensating moment of force, due to the shut of sychronous cylinder and the flow compensation, is lower than the growth rate of eccentric moment. So, before the pressure is stable, the resultant moment which tips the MCB will be increasing, which make the MCB's dynamic error increase; while the loading speed is low, the system will compensate multiply and the stop-position accuracy is rather low. After the pressuring, the depressurisation of the high pressure fluid compenstaed by synchronous system can not be controlled and then will produce impulsion and vibration in MCB.

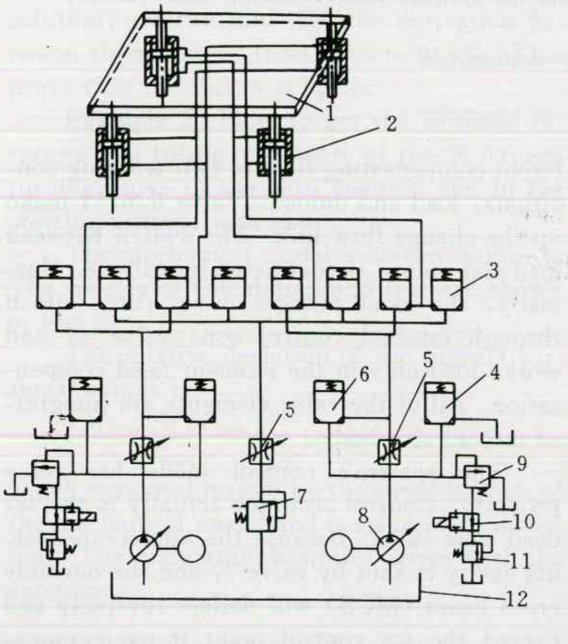

Fig. 1 Hydraulic illustrative diagram of compensating system

1—MCB; 2—synchronous cylinder; 3—master control plug-in valve group; 4—circulating valve; 5—throttlle valve; 6—load property control valve; 7—leval pressure control valve; 8—axial variable pump; 9—safety valve; 10—solenoid valve; 11—long-distance pressure regulating valve; 12—oil tank

2 DESIGN OF THE REBUILDING SCHEME

To solve the forenamed existing problems appeared in synchronous system (SS) and optimize the system's hydraulic control mode, we put forword the following steps:

(1) Check the inclination angular velocity

Check the helix angle and angular velocity at the same time, and pre-estimate the pressure and the flow compensation according to the test data and the technological parameters.

Because of the large turning inertia of MCB, when loading fast, the system response will be rather quicker through checking and controlling the inclination angular velocity, which is beneficial to decrease the dynamic error, and the flow compensation can be pre-estimated in accordance with the die forging technology.

(2) Level pressure control

Adopt the ratio control valve to replace the former level pressure control guiding slide valve and control level pressure, which can dominate the changing pressure needed in accordance with the program.

(3) Set the pressure signal protection

Under the existing control pattern, if MCB deflects reversely and surpasses the set dead area point, high pressure fluid in original compensating cavity will dump out momently without controlled and the system will lose its stability. Through checking, controlling and interlocking to protect the synchronous cylinder's pressure signal, this situation will be avoided totally, then system's reliability will be increased and it is beneficial to increase the system's control accuracy.

(4) Depressuring process control

Impulsion and vibration during the depressurisation can be decreased effectively through program controlling the depressuring process according to the given curve.

(5) Changing flow control

As the loading time is long, the existing system will compensate multiply and cause vibration before the pressure is stable. On the base of pre-estimating the compensation, adjusting and controlling the flow can eliminate this kind of system vibration effectively, ameliorate system's property and flamework's force condition, lower the system's dynamic accuracy greatly, and prolong the system's service life.

Operating system (OS) adopts industrial computer adding programmable controller. Under this kind of working form, OS is able to achieve all kinds of sequence control by program control and has various functions such as management, display and print. In addition, it becomes possible to realize the inclination angular velocity checking and depressurization curve control and is convenient to achieve various protection demanded by the system. The block diagram of control system is shown in Fig. 2.

3 SYSTEM CHARACTERISTIC ANALYSIS

300 MN DHP requires SS's longitudinal balance ability greater than its tranverse balance ability, so in this paper the system's longitudinal property was analysed only. Since the system's inertia is very large, the system property mainly refer to the maximum helix angle of MCB and the control accuracy.

3. 1 *Basic Parameters*

Under the allowable maximum eccentricity ($e_y = 0.4\,\text{m}$) and fast loading ($t_F = 3\,\text{s}$), and before the pressure is steady, existing system's parameters are calculated distinguishly as follws:

(1) Eccentric moment M (according to uniform loading process, fixed eccentricity)

$$M = \frac{dF}{dt} \cdot e_y \cdot t = 40 \times 10^6 \times t \ (\text{N} \cdot \text{m})$$

(2) Maximum inclination angular velocity

In accordance with the given condition, the results of analysis and testing show that the maximum inclination angular velocity ω of MCB approximately is:

$$\omega \approx 0.23 \times 10^{-3} (\text{rad/s})$$

(3) Compensating flow stiffness coefficient n of synchronous cylinder:

$$n = \frac{2 \cdot A \cdot L \cdot \beta_e}{V} = 5.59 \times 10^3 (\text{Pa})$$

compensating balance moment M_B:

$$M_B = - n \cdot Q \cdot t =$$

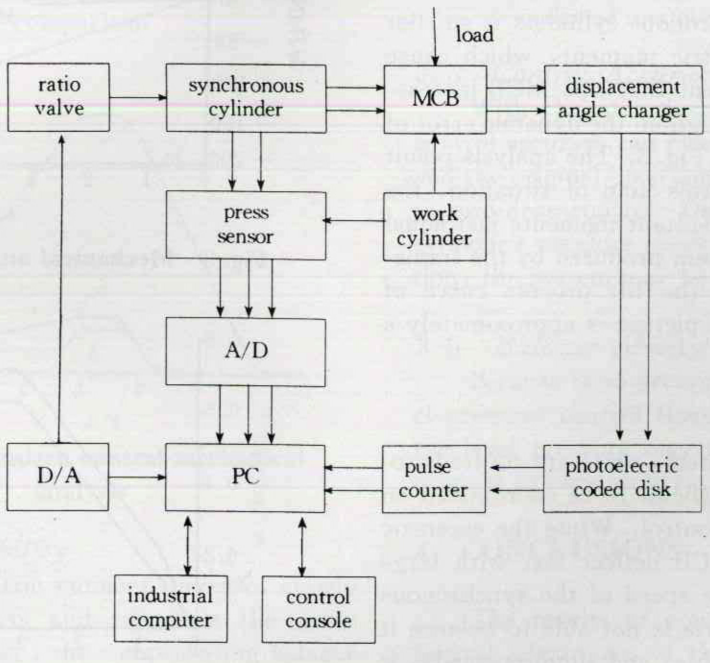

Fig. 2 Block diagram of control system

$- 22.82 \times 10^6 \times t$ (N · t)

(4) Synchronous cylinder's closed stiffness coefficient K_T (while loading):

$$K_T = \frac{4 \cdot A^2 \cdot L^2 \cdot \beta_e}{V} = 57.05 \times 10^3 (\text{N} \cdot \text{m/rad})$$

generating balance moment:

$$M_F = - K_T \cdot \varphi = - 13.2 \times 10^6 \times t \ (\text{N} \cdot \text{m})$$

In the above-listed formulas, β_e represents liquid cubical elasticity coefficient, t represent time, V represents the volume of synchronous cylinders and their correspondance connecting pipe line, L_y represents synchronous cylinder's longitudinal space, Q represents compensating flow, A represents synchronous cylinder's effective acting area, φ represents helix angle.

Without regard to the effect of frictional moment M_m and viscous damping moment M_n, we can draw from the above-listed formulas that the value of the resultant moment is:

$$\Sigma M = M + M_B + M_F = 4.06 \times 10^6 \times t \ (\text{N} \cdot \text{m})$$

It is so clear that before the pressure is steady, the growth speed of balance moment generated by synchronous cylinders is smaller than that of eccentric moment, which cause the resultant moment that tips MCB increasing all along and heighten the dynamic error of MCB, as shown in Fig. 3. The analysis result shows that under this kind of situation, the difference of the resultant moments just equal to the reverse moment produced by the framework. Therefore, the tilt process curve of MCB shown in the picture is approximately a straight line.

3.2 *Sensibility*

In original system, there are contradictory demands that difficult to be coordinated on signal check and control. While the eccentric moment causes MCB deflect fast with large scale, the response speed of the synchronous compensation system is not able to balance it as quickly as possible, and simultaneously, it is necessary to prevent the vibration possibly generated by MCB's reverse deflect under the inertia effect due to the great compensation. If MCB deflects slowly, not only will the existing system appear considerably obtuse and MCB remains rather far away from the horizontal zero-potential surface in a long time, but the final stop position accuracy will be rather low.

Through contrasting these two kinds of artificial curves (as shown in Fig. 4) between under the process of MCB's inclination angular velocity control (curve 1.) and under that of the original control (curve 2.), it is clear that system's maximum helix angle is lowered compare to the original control mode.

3.3 *Compensation Efficiency*

To reduce MCB's maximum helix angle under this situation, the level pressure control of MCB is raised and the non compensation cavity overflows in accordance with some giv-

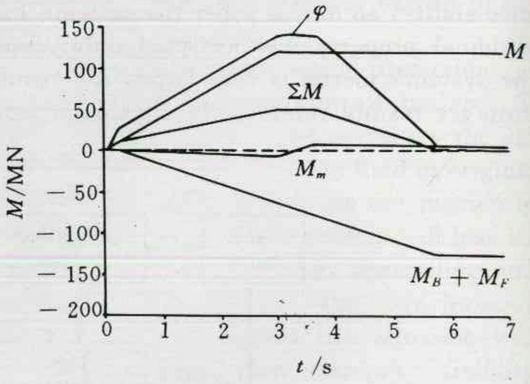

Fig. 3 Mechanical analysis of MCB

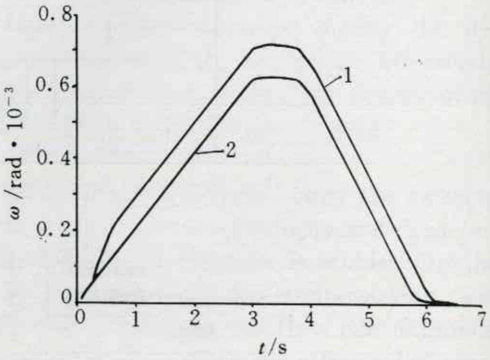

Fig. 4 System's sensitivity comparison

en control curve, then as shown in Fig. 5, the balance moment (M_y) increases rapidly which can decrease the maximum helix angle of MCB greatly. If employ 20% of system's balance ability in overflow balance, the maximum helix angle will drop 80%. This way is analogous to increasing system's flow stiffness coefficient and improves the compensation efficiency. Curve 2 and 3 in Fig. 6 represent respectively the course curves under the different overflow control mode. The changing course curves of all the moments corresponding curve 2 course, are also shown in Fig. 6.

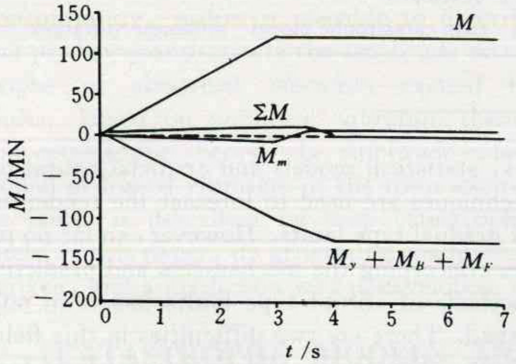

Fig. 5 System compensation efficiency comparison

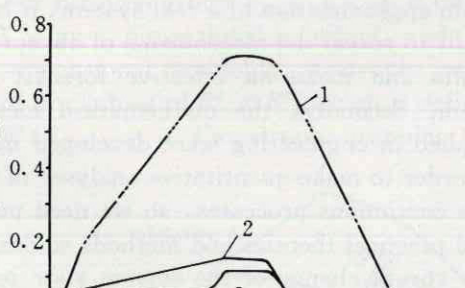

Fig. 6 Optimized control mechanical analysis

3.4 *Responsibility*

If the eccentric moment increases slowly and MCB deflects and surpasses the given dead zone value φ_0 , the compensating balance moment caused by the compensating flow of the existing system can adjust MCB back below the control value φ_0 and then stop compensating. Along with the eccentric moment's continuous increasing, MCB begins to deflect again till the compensating system start to act again.

Making use of the check of MCB's helix angle and inclination angular velocity, and combining with the die-forming technology to pre-estimate the compensation, the rebuilding plan uses the optimized compensating control parameters to adjust MCB back to the horizontal position steadily and accurately. (Shown in Fig. 7).

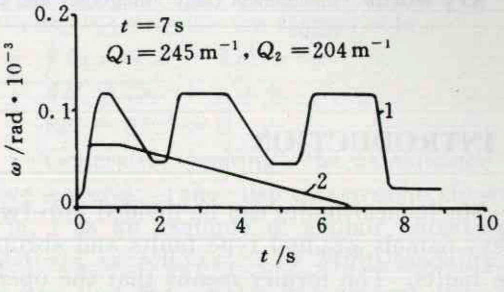

Fig. 7 System responsibility analysis

1—original response course

2—optimized control resopnse course

3.5 *Control Accuracy and Stability*

With the aid of computer control, the control accuracy can meet the check accuracy, and the original drop control can be turned into zero-drop control. Due to the synchronous cylinder's pressure check and interlock protection, the system may be stable all along.

3.6 *Balance Ability*

Because ratio pressure valve replaced level pressure control floating valve, increasing the level pressure may not decrease system's original balance ability.

4 CONCLUSIONS

The results of emulating analysis show several advantages of this rebuilding plan as follows:

(*To page 140*)