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Pilot Study of Dynamic Simulation on Hydraulic Supply System of HAGC

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ABSTRACT

The hydraulic automatic gauge control (HAGC) system is the core of the automatic gauge control system in a high speed strip mill. A ripple of the servo valve power supply may affect the performances of HAGC. From the characteristics of the servo valve power supply for a HAGC system, the static relationships of the accumulator's parameters and the power supply, which equips pressure compensated variable displacement pump, are analyzed. By the power supply system modeling and simulation, with the help of the software EASY5, the useful results have been obtained as follow: 1. the relationship of the rate of pressure ripple and the accumulator; 2. the adequate volume of an accumulator; 3. the oil pipe's parameters and the optimal position of an accumulator; 4. the diminution of the load effect in actuator.

KEY WORDS

Servo valve power supply, Accumulator, Simulation, HAGC

INTRODUCTION

An automatic gauge control (AGC) in a high speed and precise strip mill is performed by an actuator controlled by electronic hydraulic servo valve (SV). This system is a hydraulic automatic gauge control (HAGC) system. The HAGC system requires that the flowrate must meet the demand for the actuator and the pressure of the supply source should be in constant. A ripple of the SV power supply may bring varieties of the load flowrate and the coefficients in the SV and therefore affect the accuracy and response speed or may even bring the stability problem of the HAGC system. In the working process the demands for the flowrate are variable. In the situations of a roller exchanging or the wide gauge regulating the load pressure is low and the flowrate is high. But in the rolling process the load pressure is high and the frequencies of flow ripple are high although the gauge regulating is small. The power supply of HAGC is mainly in the form of a combination of a pressure compensated variable displacement pump (CP) and an accumulator. Though the high price for the combination of pump and accumulator, the CP can itself adjust the flowrate to meet the load and the combination is with a little power loss and a low temperature rise.

In a high speed strip mill, especially in a tandem cold strip mill, the dimensional tolerance, hardness and the speed of the strip are highly rippled. How can the hydraulic power supply be equipped in accord to the technical condition and how can the parameters of the power supply and the pipes be selected in reason are the issue to be discussed.

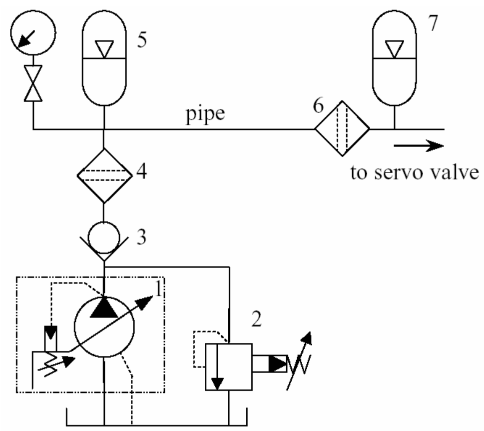


Figure 1 Power supply scheme

STRUCTURE OF THE POWER SUPPLY AND DETERMINATION OF ITS STATIC PARAMETERS

A power supply of HAGC is showed in Figure 1. The supply is basically a combination of a CP and two accumulators. The power supply contains CP 1, relief valve 2, check valve 3, filter 4, accumulator 5, filter 6 and accumulator 7. Because of the location of a mill the power supply is far away from the SV. There is a resistance in the long pipe and the accumulator 7 is equipped near the inlet of SV in order to increase the response speed and to minimize pressure ripple in the inlet of SV.

To minimize pressure ripple of the power supply two points must be taken into account. (1) Determine the static minimal nominal volumes of the two accumulators, one is in outlet of the pump and the other is in the inlet of SV. (2) Determine the reasonable volumes of accumulators, the length and diameter of the pipe and the effects of loads.

Determination of the parameter of the accumulator in the outlet of pump

A CP has a ripple of output flow and has a swivel out time in the pressure controller. The swivel out time of the CP is longer than the response time of a SV when a CP in the condition of minimal displacement and the output flow of the CP will not meet the demand of the SV. The lack in the flowrate may be made up by using an accumulator near the pump and the accumulator can also absorb the ripple of output flow. The Figure 2 shows the response time of a SV, in dotted line, and the swivel out time of a CP, in black line. By the Figure 2, the net volume of the accumulator, ΔV_1, is

$$\Delta V_1 \geq Q_s(T_p - T_s)/2 - (V_{gmax} - V_{gmin}) n \eta_v T_p \quad (1)$$

where Q_s is the nominal flow of a SV with a valve pressure differential at maximum nominal pressure, T_p the swivel out time of a CP, T_s the response time of the SV, V_{gmax} the maximum geometric displacement of the CP, V_{gmin} the minimum geometric displacement of the CP, n the shaft speed of the CP and η_v the volumetric efficiency of the CP.

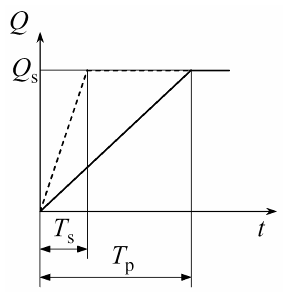


Figure 2 Flow for a SV and a pump

Determination of the parameters of the accumulator near the inlet of the SV

The parameters of the accumulator near the inlet of the SV may be determined by the rolling data of the strip mill. For a given maximum rolling speed, V_{max}, the mean length, L_p, of the fluctuation in the thick of the steel strip can be gotten by the statistic of fluctuation margin of the thick. In order to eliminate the fluctuation the moving times, n, of actuator in swivel out time, T_p, of the CP is

$$n = V_{max} T_p / L_p \quad (2)$$

so, the effective net volume of the accumulator, ΔV_2, is

$$\Delta V_2 \geq A_c X_{max} n \quad (3)$$

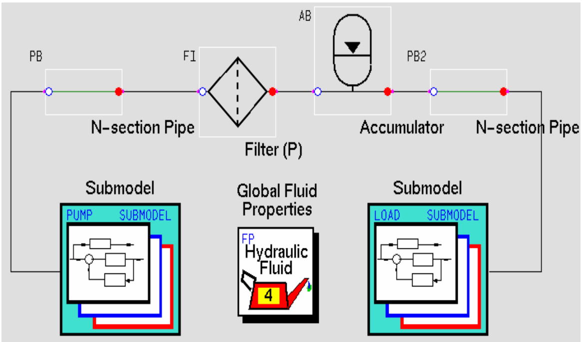
where X_{max} is the maximum displacement of actuator, i.e., the maximum fluctuation in the thick of a strip, A_c the effective piston areas of the actuator.

DYNAMIC SIMULATIONS

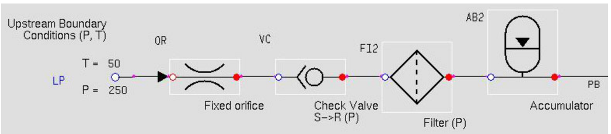
The software EASY5x, Engineering Analysis Software from The Boeing Company, is one of the software used in hydraulic system simulation. The software is superiority in the modeling of programming language, graphical modeling and selecting of algorithm. It can be used to construct a highly accurate model [1], [2].

Simulation model and parameters

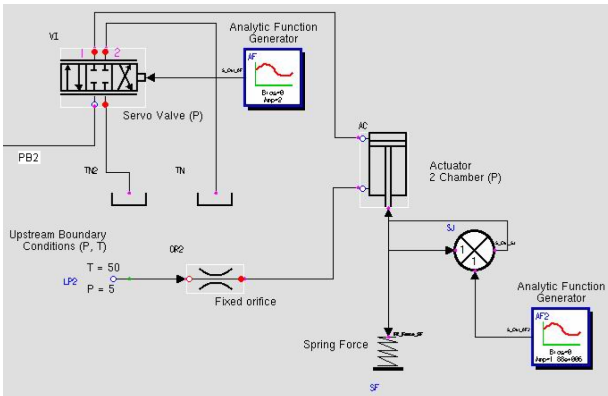
An actual power supply of a HAGC in a tandem cold strip mill is taken as the case of the simulation. First, determine the parameters of the two accumulators by using Eqs. (1) and (3). Second, setup the simulation model in accord to configuration of the power supply and the load of the actuator. The simulation now can be performed by the data in the actual system. The simulation model is showed in Figure 3.



(*a*) System model



(*b*) Upstream condition model



(*c*) Load submodel

Figure 3 Simulation model

In Figure 3, PUMP submodel contains the CP, check valve, accumulator in the outlet of pump and filter. The output of the PUMP submodel goes into the filter FI in prior the SV through long pipe PB. AB is the accumulator near the inlet of the SV. PB2 is the pipe that connects the accumulator AB and the input of the SV. The LOAD submodel includes SV, actuator and loads. All the parameters are taken from the actual system and the data are mainly listed as follow. Pressure in the outlet of the pump is 25MPa. The long pipe PB is 50m in length, 65mm in hydraulic diameter, 0.08mm in absolute roughness and 1.6×10^{10}Pa in bulk modulus. The nominal volume of the accumulator AB is 20L and its maximum precharged volume is 18.4L at 17MPa. The hydraulic diameter of the orifice in the port of the AB is 10mm and the volume of the port chamber is 0.5L. The connecting pipe PB2 is 2.1m in length, 32mm in hydraulic diameter, 0.08mm in absolute roughness and 2.8×10^{10}Pa in bulk modulus.

In the simulation the frequency of the sine input sign is 12Hz and the amplitude is 20% in rating electric current in accord with actual maximum capacity in LOAD submodel. The Gear algorithm is employed.

Analyses for the simulation result

Function of the accumulator near the inlet of the SV

Figure 4 gives curves of the pressure in the inlet of the SV. From the figures it can be seen that the pressure has a fluctuation of 4.64% without an accumulator and the pressure is only a ripple of 0.6% with an accumulator. It is evident that an accumulator can effectively decline the fluctuation of the pressure in the inlet of the SV.

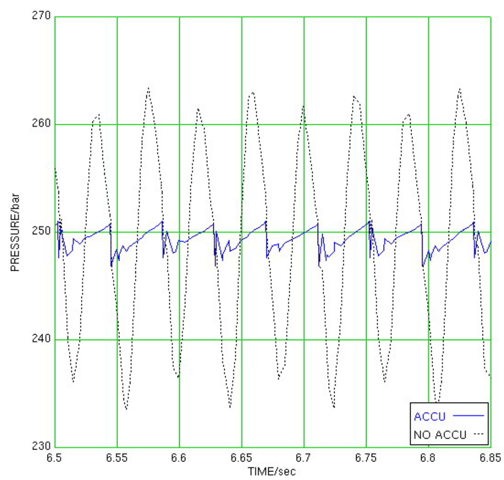


Figure 4 Pressure in the inlet of the SV with and without an accumulator

Figure 5 gives the simulation curves of pressure in the inlet of the SV with the several kinds of nominal volume of the accumulator. From the Figure 5 it can be seen that the rising time, from the precharged pressure to the working pressure, is increased and the natural frequencies are become small as the nominal volume of an accumulator is enlarged. The results show the same conclusion as the Zhan's work [4]. It can be also seen that the fluctuation of pressure in the inlet of the SV is decreased with a large volume of an accumulator. When the volume is aggrandized to 24L, the fluctuation remains nearly unchanging. This shows that the nominal volume of an accumulator has a limit in the absorbability to the pressure fluctuation.

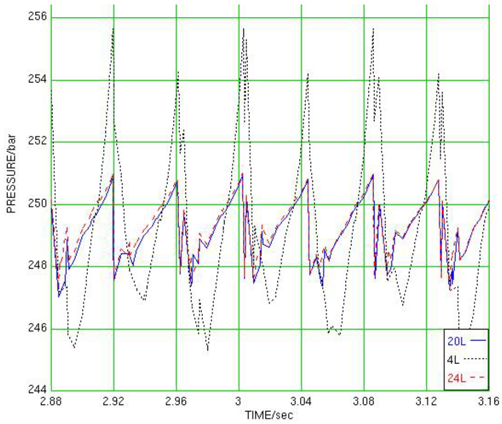


Figure 5 Pressure with several nominal volumes of the accumulator

Effects of the length and diameter of the pipe

Figure 6 shows the simulation curves of the pressure in different lengths of pipe between the port of the accumulator and the SV, i.e. PB2 in Figure 3. The fluctuation of the pressure in the inlet of the SV is reduced as the length decreasing. This indicates that a longer pipe has a larger fluctuation in the system.

Figure 7 shows the simulation curves of the pressure in different diameters of pipe between the port of the accumulator and the SV. The fluctuation of the pressure in the inlet of the SV is largely reduced as the diameter is increasing. This indicates that a too large diameter of pipe is not necessary in the system.

Contribution of the loads in actuator

Figure 8 gives curves of pressure in the inlet of the SV with the several kinds of nominal volume of the accumulator at the 5%, 10% and 15% of the maximum loads. By comparing the three charts it is evident that the loads have no effect on the pressure in the inlet of the SV as the nominal volume of the accumulator is equal to or over 20L.

CONCLUSION

By using other frequency and amplitude of input sign of the SV the simulation gives the similar results as the above simulation in another nominal volume of the accumulator. The simulation results are highly close to the actual data. From the above model and simulation it can sum up as follows. 1) The accumulator at the inlet port of the SV plays an important role in the weakening of the fluctuation of the pressure at the inlet port of the SV. 2) The nearer the port of the accumulator is to inlet port of the SV, the smaller the fluctuation of pressure is. Because there is resistance in the port of an accumulator, it is useful that the inner diameter is adequately enlarged. 3) By a proper selection of the nominal volume of an accumulator the effect on the pressure at the inlet of the SV will reduce to a least extent.

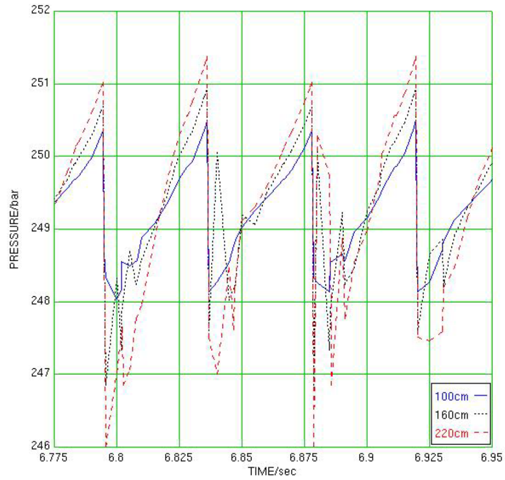


Figure 6 Pressure with different lengths of the pipe

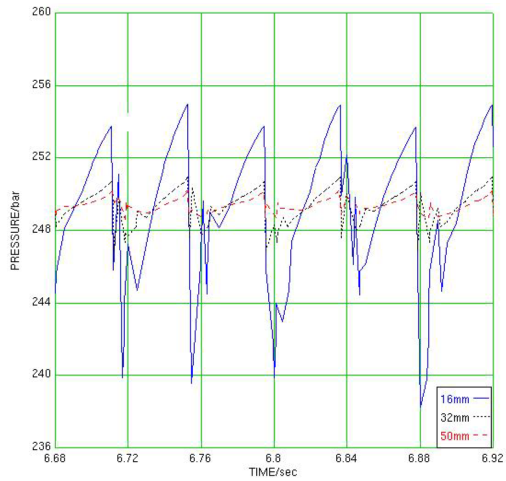


Figure 7 Pressure with different diameters of pipe

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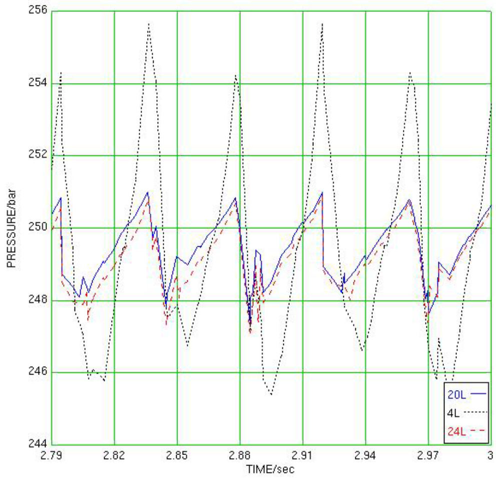
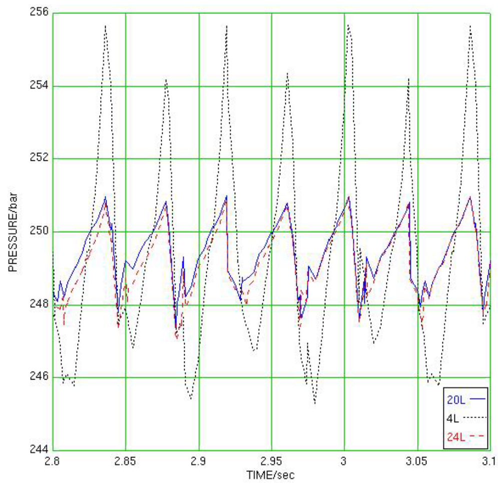
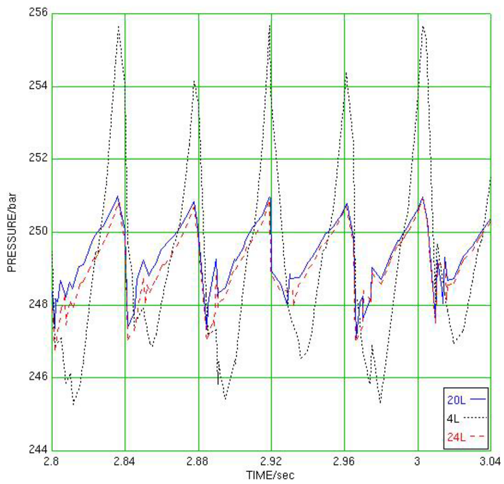


(*a*) 5%



(*b*) 10%



(*c*) 15%

Figure 8 Pressure in different loads