IOP Conf. Series: Materials Science and Engineering **382** (2018) 032027 doi:10.1088/1757-899X/382/3/032027

PID Optimization Control of the Hydraulic System for Seat Belt Anchorage Strength Testing Equipment

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Abstract: Based on the hydraulic proportional loading system for the seat belt anchorage point strength test equipment, the AMESim simulation model of the hydraulic proportional loading system is established. After analyzing the AMESim model and performing dynamic and static characteristics analysis, it is found out that the hydraulic proportional loading system can be further optimized. The PID control optimization method is employed to improve the original proportional control system, After comparing the PID parameter setting with the system before and after optimization, it is shown that the performance of the optimized hydraulic proportional loading system is effectively improved.

1. Introduction

The anchorage of car seat belt is an important component of seat belt. It is the device for transmitting seat belt assembly loads to the vehicle body. It provides sufficient strength to ensure the device could exert constraints in case of a car accident. The strength of anchorage is an important index of vehicle passive safety.

The test equipment loaded with the hydraulic system controls the loading pressure with the hydraulic proportional loading system. The paper focuses on the hydraulic proportional loading system and establishes the simulation model to analyze the dynamic and static characteristics, as a result of which the system is able to be optimized. The study shows that the method of trial-and-error is effective on adjusting the PID parameters of the hydraulic proportional loading system to optimize the original control system.

2. Introduction of Test Equipment Hydraulic Proportional Loading System

The car seat belt anchorage strength test equipment is used to simulate the force on human chest and abdomen when the car accident happens. Consequently, the test equipment needs to be loaded both on the upper and lower human body modules, while at the same time making sure the loading direction is 10±5° up the horizontal plane [1].

Through analysis and comparison, the hydraulic loading method was taken and the proportional pressure control mode was adopted to control the system loading pressure. The overall workload of the equipment during the test demanded quick response and smooth loading. At the same time, it integrates the testing standards of China, America and Europe. The overall action cycle is Pre-tensioning - Loading - Holding - Unloading - Loosening - Return – Stop.

The hydraulic loading system is mainly composed of the hydraulic cylinder, proportional relief valve, solenoid valve, vane pump, oil filter and oil pipeline etc. The hydraulic cylinder is able to react in response to the input control signal from directional control valves and proportional relief valves. A double pulley is equipped on the end of the hydraulic cylinder piston rod to realize synchronous loading of the upper and lower human body [2]. The electro-hydraulic proportional relief valve is used to control the hydraulic cylinder loading pressure. The electro-hydraulic proportional relief valve turns the input electric signal of the industrial computer into the pressure signal to control the pressure of the hydraulic cylinder.

3. Modeling and Analysis of the Hydraulic Proportional Control System

3.1. Modeling of the hydraulic proportional control system

The hydraulic proportional control system of the test equipment was analyzed by modeling and simulation analysis. AEMSim was used to establish the hydraulic proportional loading system model. AMESim enables modeling and simulation of multidisciplinary systems engineering on a unified platform with a rich library of models, easily recognizable standard ISO icons and simple and intuitive multi-port block diagrams to build complex system model[3].

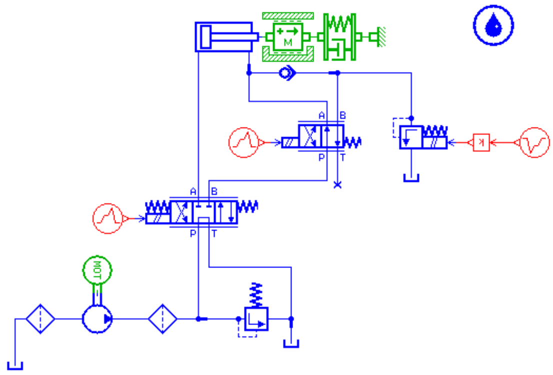

Figure 1. AMESim model of the hydraulic proportional loading system.

Figure 1 is the AMESim simulation model designed based on the hydraulic loading system. The hydraulic proportional loading system is mainly consists of proportional relief valve, hydraulic cylinder, reversing valve and other components. The proportion of the relief valve input voltage controls the signal, the two valve input signal ensures that the valve opening and closing. After setting the input signals of the reversing valves and the proportional relief valve, the AMESim model could be simulated and analyzed in the simulation model.

3.2. Analysis of AMESim simulation model

Figure 2 shows the hydraulic cylinder piston rod output tension curve and the measured experimental tension curve after the simulation by AMESim. Taking the 60-second loading process as an example, the system carries out the loosening and return operations after rise in output load from the pre-tension value to the maximum load value requested by the test. The output power of the simulation system reaches the requirements of 13500x2N load of the upper and lower human body model, showing that the system has enough dragging load capacity. It is proved that the selection of hydraulic components and the design of the loading system are correct, which meets the requirements of the test standard and proves the correctness of the AMESim simulation model established by the simulation of the tensile force curve.

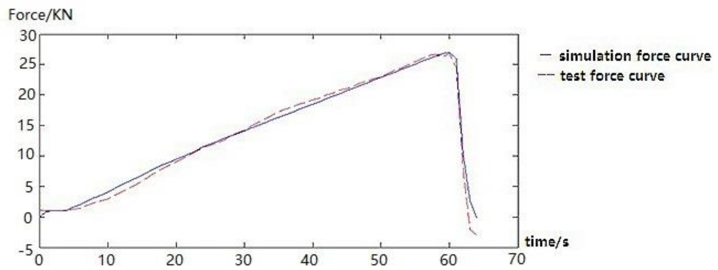

Figure 2. Test tension and simulation tension force diagram.

For a general system, the input signal for the step signal system is the most serious condition. Figure 3 is the step response of the piston rod output tension, which reflects the transient response of the loading system. It was known from figure 3 that the system rise time $t_r = 0.072s$, adjust time $t_s = 0.075s$. The transition process is fast so as to meet the rapidity requirement of system . The overshoot $\sigma\% = 4.9\%$. After the system reaches the steady state, the error between the steady state output and the given signal is 0.01MPa, which satisfies the system's accuracy requirement. It can be seen from the curve of step response that the oscillatory convergence time is about 0.16s after the amplitude of the load curve reaches the peak value, which is about ± 3%.

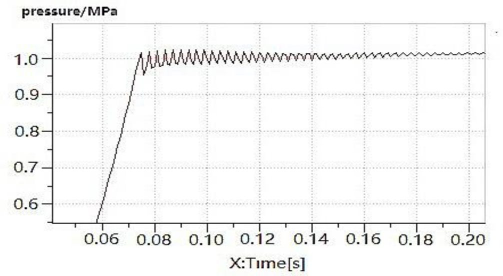

Figure 3. Hydraulic cylinder with rod chamber pressure step response.

According to the figure 3, it is found that although the system can meet the design requirements, there are shortcomings such as relatively long convergence time, relatively overshoot and relatively large oscillation amplitude. The loading system may be lack of performance in the actual loading process of large load. Therefore, it is necessary to further optimize the system to improve its performance.

4. Optimization of Hydraulic Proportional Control System

4.1 Usual control system optimization method

In general, the most direct way to obtain the ideal performance index is to adjust the control system by its parameters for a control system. However, for general second-order systems, increasing the open-loop gain is beneficial to improve the steady-state performance, but at the same time it reduces the damping coefficient of the second-order system and deteriorates the transient performance. Therefore, it is impossible to adjust the control system itself only by the parameters so that the system could obtain satisfactory performance in most conditions [4].

It is necessary to optimize the control system correction by adding correction device in order to obtain the desired performance. According to the position of the correction device in the control system, the control system can be divided into series correction, parallel (or feedback) correction, feedforward correction and compound correction.

4.2 Select of the optimization method

The commonly used optimization methods for linear control system are PID control, intelligent PID control (fuzzy, neural), LQR control methods. PID control has several decades of application and the theory is mature. Each parameter of PID control has a clear physical meaning, it can quickly adjust the parameters according to system response and requirements. It has the advantage of fast parameter setting and good system response. The hydraulic proportional control system uses PID controller to optimize the system performance.

In the control system, the optimal controller use the control strategy formed by the proportional (P), integral (I), differential (D). PID controller is a series correction and series in the system forward channel. PID controllers are not only suitable for systems with known mathematical models, but also for structures with many controlled object models or systems with uncertain or time-varying parameters.

PID correction optimization method, widely used in industry, is easy to work with and characterized by simple structure and high control precision. PID control is the proportion of the deviation signal, integral, differential control after the formation of a control law, the control output is:

$$U_t = K_p e(t) + K_i \int_0^t e(t)dt + K_d \frac{de(t)}{dt} \tag{1}$$

Wherein: K_p —Proportional coefficient; K_i —Integral coefficient; K_d —Differential coefficient. In the PID control algorithm, the three parameters play decisive roles in the performance of the controller. Generally speaking, the proportional coefficient affects the response speed of the system and control accuracy, the integral coefficient affects steady-state error of the system and the differential coefficient affects the dynamic performance.

The different proportion, integral and differential combination may achieve similar control effect since PID parameter is not very sensitive to the control effect [5]. In practical application, the main control process or the main targets of controlled objects meet the design requirements, the corresponding control parameters can be used as effective control parameters.

5. Tuning and Optimization of PID Parameters in Simulation Model

The AMESim model needs to be optimized because of its disadvantage of long convergence time and relatively large overshoot, the original simulation model. PID controller, as a common control component in industrial control, has the characteristics of simple structure, easy implementation and high control precision.

The PID controller was selected in the signal-control component library and placed in the connection position of the proportional relief valve signal input and the signal amplifier in the original hydraulic system. The tension sensor was selected in the mechanical library and connected to the tension sensor output and the input signal of the PID controller. It forms the deviation control with the total input signal, the hydraulic system composes the closed loop control simulation model, the new closed loop control simulation model shows as figure 4.

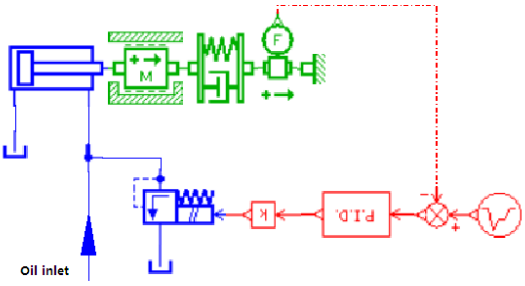

Figure 4. AMESim hydraulic PID control model.

The PID control system formed the closed-loop after adding the PID controller and the tension feedback sensor to the AMESim model. Then start the simulation trial and error after input the sensor coefficient. During the process of simulation trial and error, firstly set the proportional coefficient until the steady-state error close to the system requirements. Afterwards slightly reduce the coefficient and set the integral coefficient until more satisfactory performance. At last set the differential coefficient, reduce the overshoot of system until get satisfactory control effect.

By input the PID parameters in the parameter mode and then simulate the new control system, the simulation results could be observed. We get a relatively satisfactory result after repeated trial and error and determine the PID parameters as $K_p = 0.92$, $K_i = 0.03$, $K_d = 0.01$.

The set proportional coefficient reduces the deviation of output and input, desired the output range, and speed up the system response. The integral coefficient effectively eliminates the steady - state error existing in the proportional link, the oscillation and increases the stability of the system reduced. The differential coefficient reduced the overshoot and the system convergence time based on the PI control. The curves of the dynamic characteristics of the optimized system after simulation were produced after input these three parameter into the PID controller.

6. Analysis of the PID Optimization Result

The PID controller uses different control parameters and the control effect is obviously different. The closed-loop characteristic of the system depends on the performance of the PID controller. The adjustment and optimization of the PID controller parameters play an important role in the implementation of the control system [6].

As the simulation load is relatively large, in order to reflect the differences between the simulation tension force curve from Figure 2 and the curve without PID controller more intuitively. The step response was local amplification for comparing the performance of hydraulic proportional loading system before and after optimization. A step signal was input into the proportional relief valve to show the step response curve of the closed-loop hydraulic proportional-loading system in figure 5.

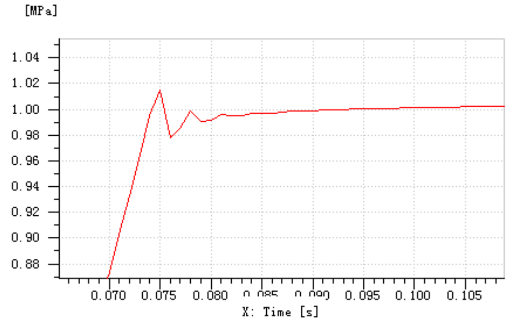

Figure 5. Step response curve after PID optimize.

Figure 5 is the step response of the closed-loop hydraulic control system with PID controller, the load pressure increases to 0.9MPa in 0.71 seconds. The rise time $t_r' = 0.071s$, adjust time $t_s' = 0.073s$, both of them has a slight improvement. The overshoot $\sigma'\% = 2\%$, compared with the non-PID control part of the hydraulic proportional load system, the overshoot is reduced by 60% and have a slight oscillation of ± 1% after reach the peak. The curve of the step response converges at 0.08s and the convergence time is reduced by half compared with the original system time. The step response curve of the hydraulic proportional loading control system is improved obviously.

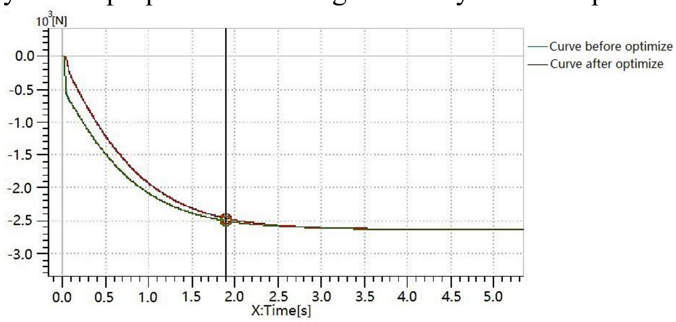

Figure 6. Step response curve after PID optimize.

The load step response curve of the hydraulic cylinder to the load drag can be obtained on the load element. After simulating the system optimized by PID controller, the step response curve of the simulated tension is obtained as shown in figure 6. From the curve comparison before and after the optimization, it is known that after the PID optimization of the system, the piston rod tension adjustment time is reduced by 0.2S when there is signal input, which is 1.9s. The loading force could reach the set value earlier than expected, which proved that the PID controller could improve the response speed of the whole system and achieve the goal of loading more quickly.

7. Conclusion

Compared with the original system, the PID optimized system improves the performance of the hydraulic loading system and has better dynamic performance. The optimized system has smaller oscillation amplitude and shorter convergence period, the rise time and adjustment time are decreased. The oscillation time decreased and the overshoot and convergence time of the system were reduced by 60% and 50% respectively.

Optimizing the system by simulation of AMESim and adding PID controller, the module can be easily added to the dynamic model, and the performance of the system can be directly observed and compared. It provides an effective analysis basis for the optimization of the test equipment.

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