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Performance Optimization of Overflow Valve Based on Genetic Algorithm

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An overflow valve is an important part of a hydraulic system which is an important machine in industrial production. Therefore, it is of practical significance to study the problem of the performance optimization of overflow valve. In this paper, a pilot-type overflow valve in the hydraulic system is the main research object used to study of its performance optimization. A genetic algorithm (GA) is utilized to establish a model of the performance optimization of the pilot-operated overflow valve. The focus of the experiment is the design of the dynamic response optimization in the pilot-operated overflow valve. Thus, the related parameters such as the optimal solution of the diameter of the orifice, the dynamic adjustment time after optimization, overshoot, etc. are obtained. A comparison of the system before and after optimization, leads to the experimental conclusion that using GA can effectively improve the performance of the dynamic response of the overflow valve and this is helpful to improve and optimize the design of the overflow valve. The experimental effect is very significant. This study provides a new route for studying the problem of the performance optimization of the overflow valve.

Keywords: genetic algorithm, overflow valve, performance optimization, dynamic response

1. INTRODUCTION

The hydraulic system consists of three parts, namely the overflow valve, the balancing valve system and the oil source variable control system. The overflow valve in the hydraulic system has the function of controlling pressure, which is an important part of the hydraulic system and can affect the working capacity of the hydraulic system. Therefore, it is an important task to study the problem of the performance optimization of the overflow valve in the hydraulic system. Zhang et al. [2] carried out modeling and simulation on the super magnetostrictive actuator hydraulic overflow valve and proposed a hydraulic overflow valve structure using a giant magnetostrictive actuator. The overflow valve had advantages of simple structure, good linearity, sufficient output force and displacement, and fast response, etc. Zhang et al. [3] studied the cavitation and noise problems of hydraulic overflow valves and designed a new type of pilot-operated hydraulic overflow valve structure based on the characteristics of traditional pressure control valves, i.e., using the micro-pressure sensor to detect the inlet pressure of the main valve and utilizing closed-loop feedback control and dynamic pressure feedback control to eliminate the steady-state error. Bo [4] proposed a fixed differential overflow valve based on power bond diagram and performed modelling and simulation on its dynamic characteristics. The experimental results of the system with good performance were verified. Zhang et al. [5] proposed a rotary motor buffer overflow valve and performed modelling analysis and experimental research on it. Zhao et al. [6] proposed a low-pressure and large-flow overflow valve and obtained the experimental conclusion that the system has superior performance. In this paper, the pilot-operated overflow valve is taken as the main research object, and genetic algorithm (GA) is applied to establish a performance optimization model of the pilot-operated overflow valve. Experimental results are obtained and the corresponding

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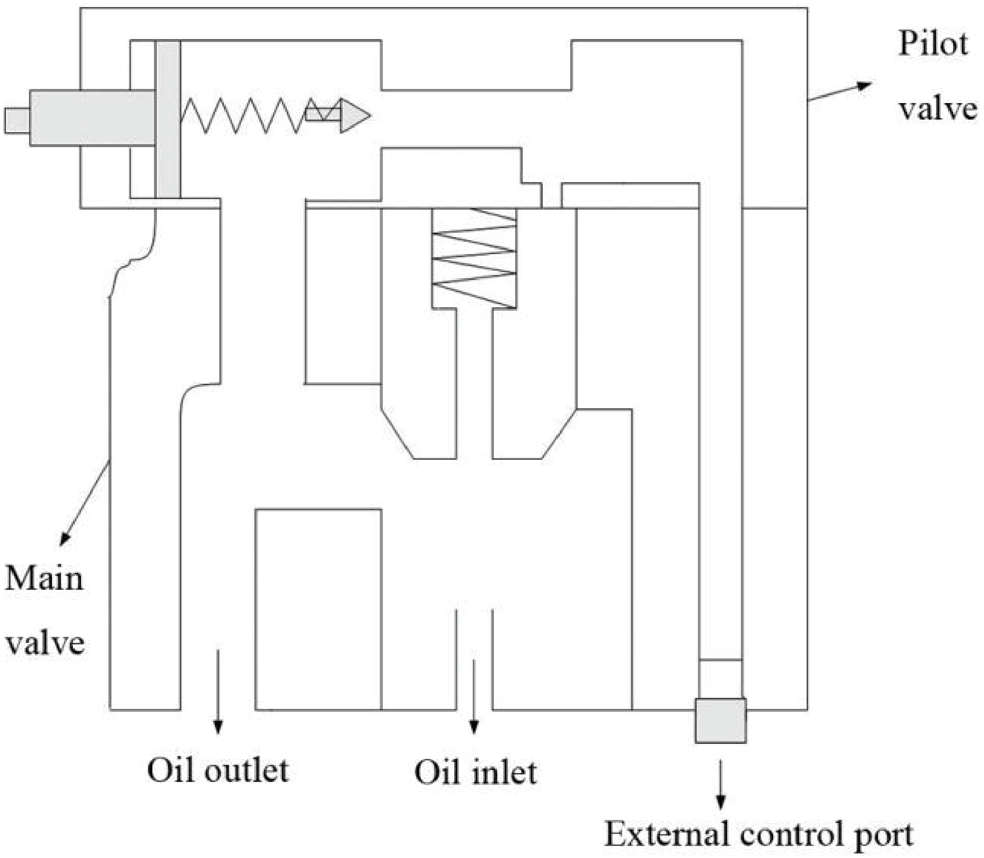

Figure 1 The basic structure of the pilot operated overflow valve.

experimental conclusions are drawn. This study provides a new model for research on the performance optimization of the overflow valve.

2. OVERFLOW VALVES

The overflow valve is a hydraulic pressure control valve [7], which is an important component device and mainly uses the overflow action to achieve the purpose of regulating the oil pressure [8]. The main principle of the overflow valve is to open the overflow valve when the oil pressure increases to a specified value to overflow a small part of the pressure oil, so as to achieve the purpose that the pressure is always maintained within a specified value. There are two main types of overflow valves, including direct-acting overflow valves and pilot-operated overflow valves [9]. In this paper, the pilot-operated overflow valve is mainly studied, and the research is carried out on its performance optimization. Figure 1 shows the basic structure of the pilot operated overflow valve.

The adjustment principle of the pilot operated overflow valve [10] is to change the pressure through adjusting the pressure regulating nut and changing the hard spring force. It mainly consists of two parts [11], including a pilot valve and a main valve, where the pilot valve is used to control the pressure of the system [12] and the main valve is used to control the flow of the system. The hydraulic pressure mainly acts on the pressure tapping surfaces of the main spool and the pilot core. The characteristics of the pilot operated overflow valve include good controllability, high operating precision, small hysteresis, good dynamic response, etc. In this study, the analysis and research of the dynamic response characteristics of the pilot-operated overflow valve are focused on. The dynamic response mainly refers to the response behavior of the control system's output from the initial state to the final state under the action of a typical input signal. Therefore, in order to find the optimal response, it needs to optimize the relevant parameters of the pilot-operated overflow valve to obtain the optimal solution of the system. Figure 2 shows the main working principle of the pilot-operated overflow valve.

3. BRIEF EXPLANATION OF GA

GA is a global optimization algorithm following Darwin's biological evolution theory and genetic mechanism [13], which is an important part of evolutionary algorithm [14]. The algorithm mainly includes the principles of natural evolution and survival of the fittest. The specific connotation of the algorithm is to retain individuals with high adaptability in the population for genetic replication operations, thus achieving the goal of making individuals in the population optimal. The basic points of GA mainly include chromosome coding, population initialization, decoding, selection, crossover, mutation, etc. GA has many advantages, including robustness, global optimality, high efficiency, strong adaptability, etc. [15], which has been widely used in various fields [16], mainly including real estate evaluation forecast, workshop scheduling

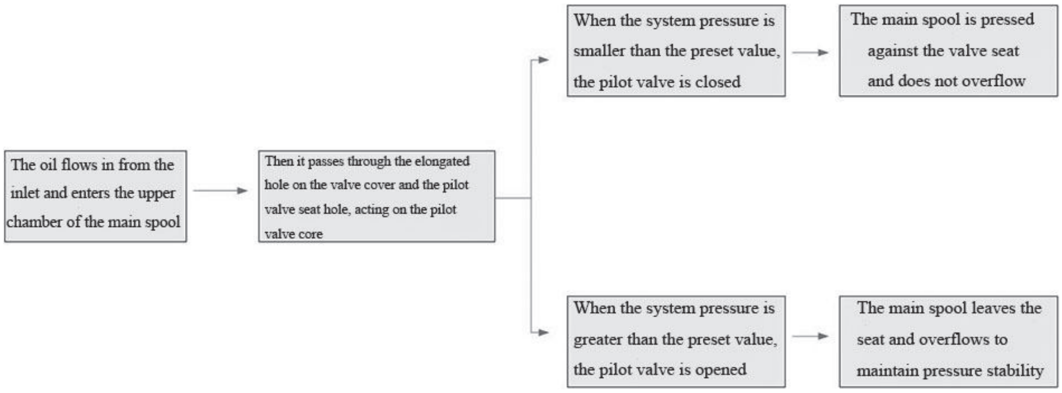

Figure 2 The working principle of the pilot operated overflow valve.

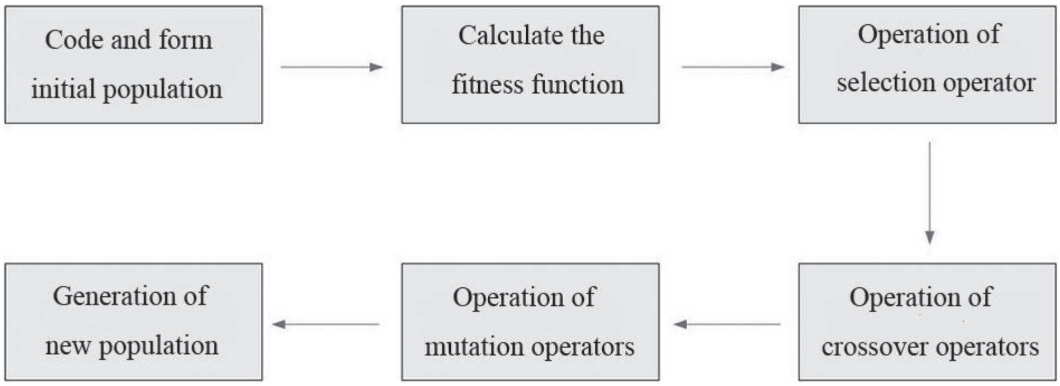

Figure 3 The specific operation process of GA.

problems, computer, Chinese word segmentation problems, etc.

The selection operation mainly refers to the process of selecting the individuals with higher fitness values from the existing initial population and finally forming the mating pool [17], and the purpose of retaining the optimal individuals and removing the individuals with lower fitness values are achieved [18]. The crossover operation mainly refers to achieving the inheritance of related features in the sub-string by genetically copying the relevant features in the parent string into the sub-string [19], and it needs to make a moderate correction in the operation. The mutation operation [20] mainly refers to changing a specific gene in the chromosome to achieve the goal of obtaining an optimal solution in the population. The schematic diagram of the specific operation process of GA is shown in Figure 3.

3.1 Performance Optimization of the Overflow Valve

In this study, GA is applied to the performance optimization of pilot-operated overflow valve for the dynamic response optimization, and a performance optimization model of pilot-operated overflow valve based on GA is established. Firstly, the binary number is used for encoding, and the population initialization operation is also performed. Then, the fitness function is set, and the calculation is performed to determine whether the output condition is met, if the output condition is met, the result will be output to obtain an optimal solution, otherwise the relevant parameters will be adjusted. Finally, the obtained optimal solution is applied to the pilot-operated overflow valve to optimize its performance, and the relevant experimental results of the dynamic response characteristics are obtained.

In this study, the binary coding method is mainly used to encode the relevant experimental parameters. It is assumed that [max, min] is the range of a parameter, t, which is expressed by a m-bit binary number, and the decimal number corresponding to the m-bit binary number is expressed by b. Then the following equation can be obtained:

$$t = \min + \frac{b}{2^m - 1}(\max - \min). \tag{1}$$

At the same time, in this study, the roulette method, the single-point crossover operator and the basic bit mutation operator are used to carry out specific operation on GA. In the roulette method, it is assumed that P_i represents the probability of the individual, E indicates the size of the group, and f_i represents the fitness value of the individual. Then the specific formula is:

$$P_i = \frac{f_i}{\sum_{i=1}^{E} f_i}. \tag{2}$$

The input signal is expressed as $P_0(t)$, $P_0^*(t)$, indicates the desired output signal, V indicates the speed at which the pressure rises, t_p indicates the time of rise, which is defined as the same as the time required to output the signal, and P_e represents steady-state pressure. Then equation (3) and (4) can be obtained:

$$V = \frac{P_e}{t_P}, \tag{3}$$

$$P_0^*(t) = \begin{cases} V * t & (t < t_P) \\ V^* t_P = P_e & (t \geq t_P) \end{cases}. \tag{4}$$

The corresponding error function is set, and the specific formula is:

$$E(t) = P_0(t) - P_0^*(t). \tag{5}$$

In $(0, t_0)$, it is required that the smaller the value achieved by $E(t)$ is, the better the result is. Then $S(t)_{\min}$, the objective function, is obtained, on which is performed weighting, and d represents the diameter of the orifice. Then the specific formula of the time weighting function can be obtained:

$$ST(t)_{\min} = \int_0^{t_0} t|E(t)|dt. \tag{6}$$

Liquid resistance networks (R_1, R_2) in the overflow valve have a significant impact on dynamic characteristics. It is assumed that R indicates the resistance value of the damping hole, and d_R indicates the diameter of the damping hole, $0.6mm \leq d_R \leq 2.0mm$. Then the following equation can be obtained:

$$d_R = \left(d_{R_1}, d_{R_2}\right). \tag{7}$$

The diameter of the damping hole is closely connected with the dynamic response of the overflow valve, the larger the diameter of the damping hole is, the smaller the pressure after stabilization is, and the longer the dynamic adjustment time is; on the contrary, the shorter the dynamic adjustment time is. At the same time, as d_{R_1} increases, the overshoot increases, but the response becomes faster, and the dynamic quality becomes better. As d_{R_2} increases, the overshoot increases, but the response becomes slower, and the dynamic quality become worse. Therefore, it needs to make appropriate parameter settings for the two parameters to optimize the dynamic response and improve the dynamic quality.

4. SIMULATION

4.1 Experimental Methods and Parameters

The main research object of this simulation experiment is the pilot-type overflow valve, which is focused on the optimization design of dynamic response, and the relevant software to be used is matrix laboratory (MATLAB) 7.0. At the same time, the relevant experimental parameters are set, which include that the size of the population is 120, the crossover probability is 0.7, the mutation probability is 0.05, and the total genetic generation is 90. The GA is used to obtain the corresponding experimental results and the relevant parameters such as the optimal solution of the diameter of the damping hole, etc. The relevant performance parameters of the pre-optimized and optimized overflow valves are compared and analyzed to obtain the corresponding experimental conclusions for reference. For the simulation experiment, the pilot-operated overflow valve equipment shown in Figure 4 is prepared.

4.2 Experimental Results

4.2.1 The Convergence Curve

The smaller the value of the objective function is, the smaller the error integral between the system pressure and the steady state pressure is, and the better the dynamic performance of the overflow valve is. Figure 5 shows the convergence curve based on GA. It can be seen from Figure 4.2 that the value of the objective function shows a downward trend as the genetic algebra increases. When the genetic generation is zero, the value of the objective function reaches the maximum value, i.e., 142. When the genetic generation is forty, the value of the objective function reaches the minimum value, i.e., 115. It can be seen that the system tends to converge at this time, and then the optimal solution of this simulation experiment is obtained. Therefore, it can be found that the optimal solution is obtained by GA after 40 generations, and the efficiency of the algorithm is good. At the same time, the optimal solution is applied to the overflow valve, which has obvious optimization effect on its performance.

4.2.2 Dynamic Response

For different steady-state pressure, the corresponding parameters are also different. In this simulation experiment, the relevant experiments are carried out respectively under the three steady state pressure conditions of 23.71 MPa, 26.53 MPa and 29.12 MPa. The dynamic characteristics of the pilot operated overflow valve are analyzed in detail, and then Table 1 can be obtained.

Table 1 shows the dynamic characteristics under different steady-state pressure. It can be seen from Table 1 that the specific values of the relevant parameters at the time of unloading and overflow such as the maximum pressure of the main valve rear cavity, the drop time of the main valve rear cavity pressure, the maximum pressure of the inlet valve cavity, etc. are obtained respectively when $P_e = 23.71MPa$, $P_e = 26.53MPa$ and $P_e = 29.12MPa$.

Through the relevant calculation solution of GA, relevant parameters of the pilot-operated overflow valve such as the optimal value of the diameter of the damping hole, etc. are obtained when $P_e = 27.63MPa$. The specific results are shown in Table 2.

Figure 6 shows the dynamic response curve of the overflow valve before and after optimization when $P_e = 27.63MPa$. It can be seen that the dynamic response characteristics of the overflow valve after optimization significantly improves. It can be found from Table 2 that the optimal solutions of the diameter of the damping hole are 0.8 mm and 1.2 mm respectively. The dynamic adjustment time after optimization is about 46 ms, and the overshoot is about 0.059%; while the dynamic adjustment time before optimization is about 93 ms, and the overshoot is about 8.2%. In general, the dynamic adjustment time and overshoot after optimization are both lower than those before optimization. The dynamic adjustment time after optimization is at least half reduced compared with the situation before optimization and quickly enters the stable state with a slight overshoot, which effectively improves the stability of the system. Therefore,

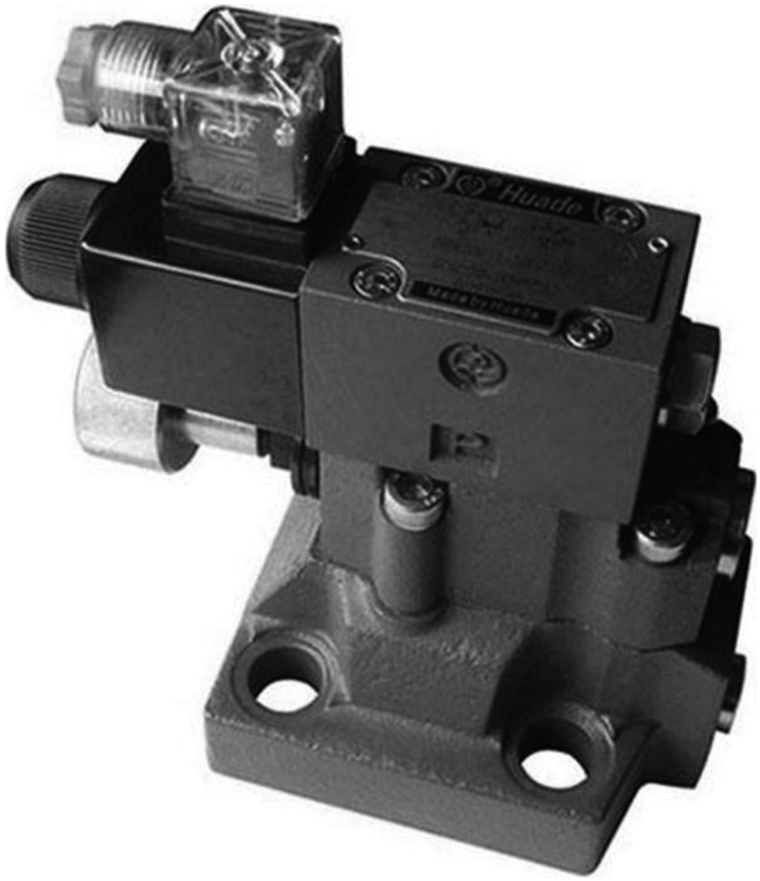

Figure 4 Pilot-operated overflow valve equipment required for the experiment.

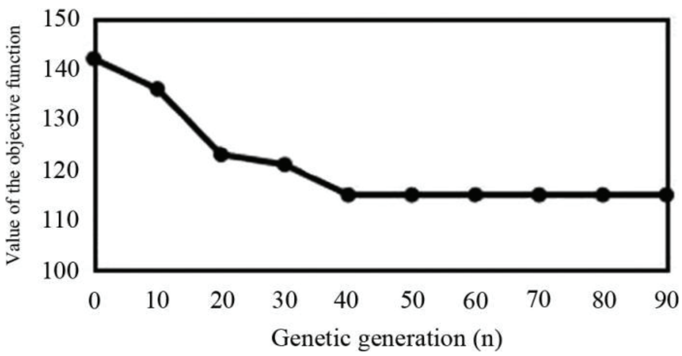

Figure 5 The convergence curve based on GA.

it can be seen that the performance of the overflow valve is improved and optimized by GA, its stability and dynamic response performance are improved, and the experimental results are significant.

5. CONCLUSION

The overflow valve is an important part of the hydraulic system, and its performance has a profound impact on the performance of the hydraulic system, which has an important impact on industrial production. Therefore, in this paper, the pilot-operated overflow valve is a focus, and the problem of the performance optimization of the overflow valve is focused on for research, and a performance optimization model of the pilot-operated overflow valve based on GA is established to carry out the corresponding simulation experiment. The experimental result that the value of the objective function shows a downward trend with the increase of genetic generation is obtained. At the same time, it is obtained that the optimal values of the diameter of the damping hole are 0.8 mm and 1.2 mm respectively, the dynamic adjustment time after optimization is about 46 ms, and the overshoot is about 0.059%. The experimental conclusions that the optimized dynamic response performance of the overflow valve significantly improves, and its stability is better are drawn. This study provides a reference for the problem of the performance optimization of the overflow valve.

Table 1 Dynamic characteristics under different steady state pressure.

Related parameters	$P_e = 23.71MPa$		$P_e = 26.53MPa$		$P_e = 29.12MPa$	
	Unloading	Overflow	Unloading	Overflow	Unloading	Overflow
Maximum pressure of the main valve rear cavity (MPa)	32.1	15.3	36.7	17.8	38.2	21.4
Drop time of the main valve rear cavity pressure (ms)	36	/	39	/	45	/
Maximum pressure of the inlet valve cavity (MPa)	37.6	17.1	41.6	26.7	45.7	35.9
Steady state pressure (MPa) of the inlet valve cavity	9	17.2	10.6	19.2	10.9	26.6
Rise time of the inlet valve cavity pressure (ms)	103	269	107	246	116	259
Drop time of the inlet valve cavity pressure (ms)	206	/	225	/	279	/

Table 2 Related parameters of the GA based optimized overflow valve.

Related parameters	d_{R_1} (mm)	d_{R_2} (mm)	Dynamic adjustment time (ms)	Overshoot (%)
Pilot operated overflow valve	0.8	1.2	46	0.059

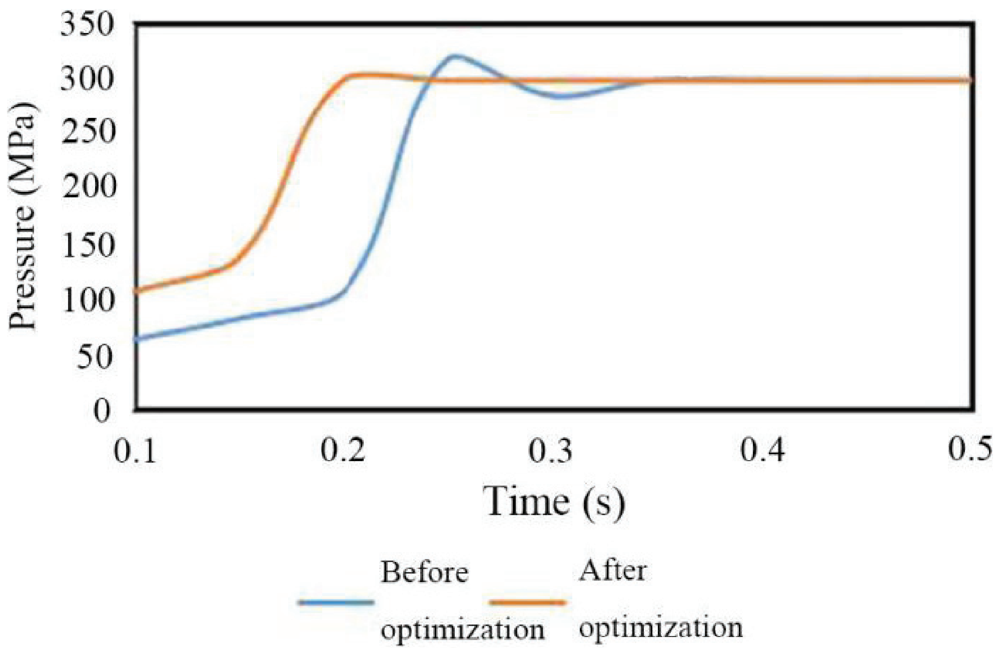

Figure 6 The dynamic response curve of the overflow valve before and after optimization.

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