# Active and Adaptive Hydraulic Shock Absorber Design and its Control Technology

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## Abstract

**As the core equipment of cushioning and shock absorption technology, the shock absorber can reduce hard collisions, thus reducing equipment wear and maintenance costs and extending the working life limit. With the development of science and technology, the traditional passive shock absorber cannot fundamentally adjust the capacity and travel, which can not protect the buffer of ultra-high load. Moreover, passive shock absorbers cannot actively adapt to the impact of uncertainty buffer, which is not only detrimental to the safety protection of equipment but also poses uncertain safety risks to users. In this context, this work first analyzed the characterization parameters of active and adaptive shock absorbers, including rated buffer capacity parameters, durability parameters, buffer stroke parameters, buffer efficiency, and attenuation coefficient. Then, the active and adaptive shock absorber buffer energy and its buffer force were analyzed, and finally, the key techniques of active and adaptive shock absorber control were presented. The research results can help to improve the buffer capacity of traditional shock absorbers and realize the design of low-cost and high-reliability alternatives.**

## Keywords

**Active Shock Absorber; Adaptive Shock Absorber; BP Neural Network.**

## 1. Introduction

The innovation and development of industrial automation technology also increase the impact and collision probability of each component. As such, how to ensure the smooth movement of the mechanism and ensure the ideal service life of the organization is worth discussing. One of the main solutions to this problem is to use shock absorber. The most obvious application advantages in various buffers are hydraulic shock absorber, which has the advantages of smooth deceleration, large buffer capacity, high efficiency and long life [1]. The hydraulic shock absorber is a typical energy-consuming buffer, corresponding to two types. One is the hydraulic shock absorber with an overflow hole in the inner wall of the cylinder block. In this hydraulic shock absorber, if the bottom touch plate of the car hits the top rubber cushion contact of the buffer piston, the contact and the auxiliary spring will complete the absorption of the first impact. The decline of the car makes the piston enter the oil cylinder with oil, and then the oil is forced to enter the external storage tank from the throttle oil hole on the oil wall. The piston continues to decline, the throttle hole shrinks, and the total area of the energy-saving hole is then reduced to increase the throttle effect of the oil. Meanwhile, there is enough oil pressure to keep the car in a deceleration motion until it stops smoothly. If the car is lifted, the spring will cause the piston to reset in time when the buffer is loaded, and the oil is returned from the external storage tank to the cylinder through the throttle hole. At this time, the buffer is automatically reset to facilitate the next use. The second buffer is one with columns and annular holes. As the car drops, the buffer plunger presses the cylinder down and the oil flows through the hollow embolization through the ring hole. When the plunger continues to move downward, the ring hole opening becomes smaller and the braking force tends to be constant, and the spring in the plunger during the car lifting process allows the plug to complete the reset operation. For modern industrial production, automation equipment is applied more frequently, and the rigid impact friction between equipment and institutions is inevitable. The application of the buffer is essential to ensure the smooth operation of the equipment and extend the service life of the equipment [2]. The buffer is to comfort the mechanical movement so that the terminal impact of the equipment can be reduced. As such the object's kinetic energy absorption and conversion can be incorporated so that the movement mechanism can be in a stable deceleration state to achieve an effective buffer. However, in recent years, equipment research and development is developing towards automation, large-scale and high-speed, and the limitations of ordinary hydraulic shock absorber application are more obvious. An active and adaptive hydraulic shock absorber is getting more and more attention, and it is expected to be used with the advantages of high buffer capacity and high efficiency.

## 2. Characterization Parameters of the Active and Adaptive Hydraulic Shock Absorber

Mechanical system differences have a decisive effect on buffer performance. The matching degree of buffer and mechanical system is the basis for the evaluation of buffer performance. The purpose of using the buffer is to improve the stability of the mechanical system operation and extend the service life of the mechanical system [1, 2]. Therefore, the degree and efficiency of the shock energy of the kinetic energy of the converted object are considered to be the basic reference of the buffer selection. The hydraulic shock absorber has related performance parameters, including the rated buffer capacity, rated buffer force, rated buffer formation, buffer efficiency, durability, etc.

### 2.1 Rated Buffer Capacity Parameter

The hydraulic shock absorber buffer capacity specifically refers to the maximum impact energy absorbed by the hydraulic shock absorber within the rated stroke buffer force acceptance range. It can also be colloquially understood as the maximum kinetic energy of a moving object, corresponding to the integral value of the buffer characteristic curve. Rated buffer capacity refers to the maximum impact energy that the buffer can withstand for a long time. The buffer shall take the rated buffer capacity as the main reference value in the buffer selection. In general, it is recommended to select a larger buffer, and the buffer should be run at no less than 75% considering the installation cost.

### 2.2 The Durability Parameter

The required capacity of the energy that the hydraulic shock absorber can buffer is called the buffer durability in service. In the TB/T1961-87 standard, the buffer durability shall be not less than 80% of the rated capacity. A buffer with a capacity of 100KJ should be replaced in time after multiple use when its capacity drops to 80KJ.

### 2.3 Buffer Stroke Parameters

Rated buffer stroke is also the main reaction parameter of the buffer performance, affecting the rated buffer capacity and buffer force. When the rated stroke increases, the rated buffer capacity increases, and the buffer force decreases [3]. That is, rated stroke is positively associated with rated buffer capacity and negatively associated with buffer force. The buffer size with a certain capacity is affected by the mechanical mechanism and the installation controls.

### 2.4 Buffering Efficiency and Attenuation Coefficient

Buffering efficiency refers to the ratio of the integral value of the buffer characteristic curve on the displacement to the product of the maximum buffer force and buffer stroke. The attenuation coefficient refers to the ratio of the energy consumed during the buffer to the energy received.

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Buffering efficiency and attenuation coefficient should be as large as possible, and both should be above 70%. The hydraulic shock absorber buffering efficiency can basically reach more than 90%. For hydraulic shock absorbers with the same capacity, higher buffering efficiency corresponds to greater attenuation coefficient, more converted impact energy, and better-buffering performance. The hydraulic shock absorber buffer force needs to maintain a stable state throughout the buffer process, allowing the object to slow down evenly to reduce the internal pressure fluctuation of the buffer and bring longer service life of the buffer [4].

## 3. Analysis of Buffer Energy and Buffer Force of Active and Adaptivehydraulic Shock Absorber

The buffer energy and its buffering force are the main parametersof thehydraulic shock absorber [1].With these parameters, the impact energy distribution composition and the cylinder displacement function are analyzed as follows.

### 3.1 Buffer Energy Analysis

With the mass (m) of the moving objectand the initial velocity (v), the impact energy distribution is composed of Equation 1 and Equation 2.

$$E_1 = \quad E_0 - \Delta E - E_2 \tag{1}$$

$$E_0 = \frac{1}{2} m_1 v_1^2 \tag{2}$$

Where, E0 representsthe initial kinetic energy of the moving object;△E represents the energy loss during the impact;E1represents the energy consumed by the oil pressure inside the the hydraulic shock absorber, i.e., the energy consumed by the buffer force during the impact process;E2 represents the energy absorbed by the reset spring.

In the process of contact between the moving object and the buffer, there may be multiple impacts. However, according to previous experience, the energy loss △E is mainly generated from the initial impact, and the impact can be used as the heart collision as shown in Equation 3.

$$\Delta E = \frac{1-e^2}{2} \times \frac{m_1 \times m_2}{m_1 + m_2} \times (v_1 - v_2)^2 \tag{3}$$

Where m1 indicates the mass of a moving object;m2 indicates the quality of hydraulic shock absorber moving parts such as collision head, isolation piston, and inner cylinder; v1 indicates the initial speed of m1 (usually 0); v2 indicates the initial speed of m2 (usually 0);e represents the recovery coefficient.

### 3.2 Buffer Force Analysis

The buffer force F shall be a function of the displacement of the inner cylinder x under Equation 4.

$$E_1 = \int_0^{S_0} F dx \qquad \text{nnnnn(4)}$$

Where S0 represents the total buffer stroke, F = m1×a1, a1 represents the acceleration of a moving object in the opposite direction to the velocity v1. The size of F is determined by the buffer rule initially set by the buffer, and the change rule of F value determines the change rule of the overflow area A of the throttle hole. Ignoring the gas spring force change and friction force, Equation 5 can be derived.

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$$E_1 = \int_0^{S_0} m_1 \times a_1 dx = m_1 \times \int_0^{S_0} a_1 dx \tag{5}$$

When the buffer energy is certain, the closer the curve is to the rectangle - the smaller the average buffer force, the better the corresponding buffer performance. To simplify the derivation process, the rectangular buffer characteristic curve is often used as the target curve, i.e., the buffer force remains constant during the buffer process.

## 4. Key Technology for Active and Adaptive Hydraulic Shock Absorber

Active and adaptive hydraulic shock absorber completes large span impact buffer through a discrete variable throttle area while achieving uncertainty buffer [5, 6]. The fluid medium is nonlinear, multiparameter, and has strong coupling, so it is difficult to obtain accurate digital damping unit flow value. While, the active and adaptive hydraulic shock absorber (see Fig. 1) can achieve the purpose of prediction and optimization control based on BP neural network and particle swarm optimization algorithm, so as to improve the accuracy of the obtained digital damping unit flow value.

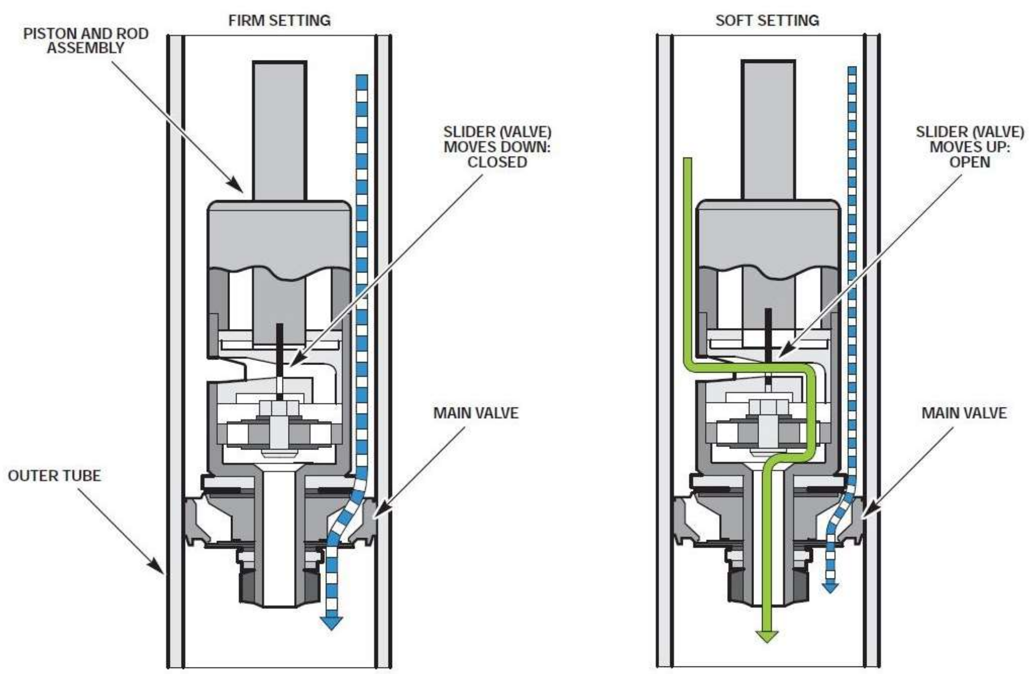


**Fig. 1** The framework of the active and adaptive hydraulic shock absorber

### 4.1 Learning Process based on BP Neural Network

BP neural network is a multi-layer network trained by an error inverse propagation algorithm, it is also one of the most widely used neural network models. BP networks can learn and store a large number of input-output mode mapping relationships, without revealing the mathematical equations describing this mapping relationship in advance. Its learning rule is to use the fastest descent method to constantly adjust the weights and thresholds of the network through backpropagation so that the sum of square errors of the network can be minimized. The BP algorithm is an algorithm designed by using such an idea. Its basic idea is that the learning process consists of two processes: forward propagation of signal and backpropagation of error. During forward propagation, the input samples are transferred from the input layer and processed layer by layer to the output layer. If the actual output of the output layer does not match the desired output, the backpropagation phase of the error will be transferred [7]. During the backpropagation, the output is transmitted through the hidden layer to the input layer, and the error is shared to all units of each layer to obtain the error signal of each layer unit, which serves as the basis for correcting the weights of each unit. The BP network is a multi-layer perceptron, so its topology is the same as that of the multilayer perceptron. Because single hidden layer (three-layer) perceptrons have been able to solve simple nonlinear problems, their applications are the most common, as shown in Fig. 2.

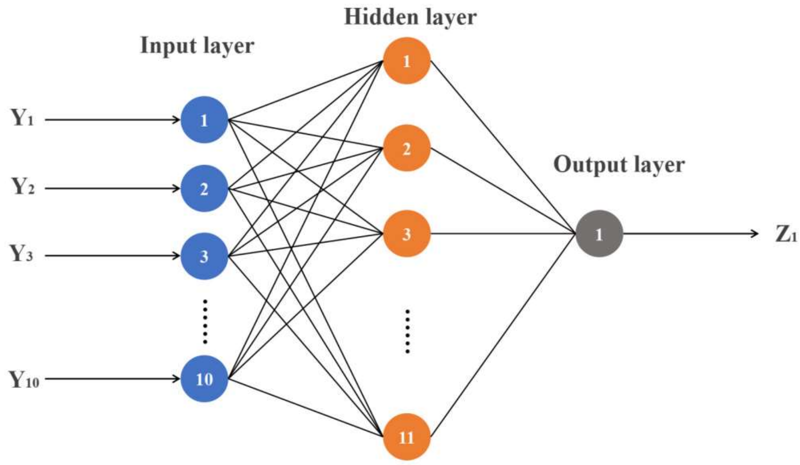


**Fig. 2** A representative three-layer BP neural network

### 4.2 Model Parameter Selection

Flow coefficient and flow state are considered as the core elements affecting the flow rate of the digital damping unit. Although there are formulas for flow, the fitting performance of the results is generally poor, and accurate flow calculation is difficult to achieve. When the active and adaptive hydraulic shock absorber is in a buffer state, the fluid in the digital damping unit can be in a high-speed flow state [8]. As such, the internal flow field can be very complex, and the parameters are in a heavily coupled state. The traditional flow coefficient calculation method focuses more on the analysis of throttle flow characteristics using Equation 6 and Equation 7. This pays less attention to the impact of other factors, making it difficult to precisely determine the flow coefficient of complex flow. Therefore, a multi-parameter coupled neural network flow calculation method is needed to establish the flow map between the fluid medium temperature and the flow characteristic data model [9]. The corresponding flow characteristic data model can be expressed by a nonlinear model with two inputs and one output.

$$Q = D_d A\sqrt{\frac{2\Delta q}{\rho}} \tag{6}$$

$$C_d = \left\{\frac{24}{sin\theta}(ln\frac{d_1}{d_2})\frac{1}{Re(\frac{2h}{d_m})} + 0.18(\frac{d_{1m}}{d_2})^2 + \frac{54}{35}(\frac{d_{1m}}{d_{21}})^2\right\} \tag{7}$$

Where Q represents the flow rate; Cd represents the flow coefficient; A represents the effective sectional area of the valve port; △q represents the valve port pressure difference; ρ represents the fluid medium density; x represents the rising height of the cone core; θ represents the half-cone angle of the cone core.

The models with different numbers of intermediate layer nodes were trained with the obtained experimental data, and statistics on their training periods and training errors were obtained, as shown in Table 1 [1, 2]. It can be seen that when the number of nodes in the hidden layer varies from 4 to 24, the error value decreases successively, and the training period is roughly similar between 6 times and 9 times.

**Table 1.** The results for the training cycle and deviation

| The number of hidden layer nodes | Training cycle | Deviation |
|---|---|---|
| 4 | 7 | $8.29\times10^{-4}$ |
| 8 | 8 | $6.82\times10^{-5}$ |
| 12 | 9 | $7.82\times10^{-7}$ |
| 16 | 6 | $1.99\times10^{-14}$ |
| 20 | 6 | $9.02\times10^{-20}$ |
| 24 | 6 | $3.22\times10^{-23}$ |

## 5. Conclusion

The application degree of industrial production automation is increasingly higher with the use of intelligent, high-speed and large-scale equipment, which will inevitably put forward higher mitigation requirements for the rigid impact between mechanical structures. In order to complete the buffer of large impact load in the narrow installation space, an effective hydraulic shock absorber is urgently needed. Traditional hydraulic buffer has been unable to meet the current use requirements, and the existing semi-active buffer control performance compared with the active buffer control performance is poor, so the active and adaptive hydraulic shock absorber is the primary choice. The active and adaptive hydraulic shock absorber is based on a hydraulic servo system or hydraulic actuator, but it faces high cost, low reliability and safety. This work analyzed the active and adaptive hydraulic shock absorber and its control technology based on the BP neural network, which helps to improve the buffer capacity of the traditional hydraulic buffer. At the same time, the active and adaptive hydraulic shock absorber design scheme realizes the active buffer function, which will have a certain reference value for realizing the design of a low-cost and high-reliability buffer.

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