Cushion system’s modeling analysis of great load tension testing machines for structural component

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Abstract. Based on the theory of conversation of energy, momentum theorem and hydrodynamics, cushion system’s model of great load tension testing machines for structural component was built, and the design method of cushion system was got. There was instructional effect on engineering application.

1. Introduction
Material testing machine is the main tool of metal materials, concrete, wood, fiber, paper and other materials development and quality management. It plays a very important role in all walks of life and occupies an important position industrial production. The development level of testing machine has affected the development level of domestic industry to some extent [1, 2].

Recently, with the rapid development of machine industry, the traditional small tonnage material testing machine has been unable to meet the present stage parts performance testing requirements of industries such as bridge, ship and marine [3]. The characteristics of parts under the actual large tonnage load were obtained by using the testing data of small tonnage samples. Practice has proved that these characteristics of parts were unreasonable and incorrect. The most effective and accurate testing method was to directly simulate the load of the actual part in the actual working state and various performance parameters of parts were obtained by cushion system's modeling analysis of great load tension testing machines for structural component.

The great load tension testing machine was a kind of material mechanical property testing machine which could load thousands of tons samples through hydraulic loading. During the test, when the specimen reached the limit of strength and the moment of fracture, the chuck would generate a considerable momentum, so in the development of this kind of testing machine, the design of the cushion system was particularly important in order to ensure the safe operation of the equipment (figure 1 is the function diagram of cushion system in material tensile testing machine).

In this paper, based on the theory of energy conservation, momentum theorem and hydrodynamics, cushion system’s was modeled and analyzed, the design method of cushion system was got. According to this method, the structure parameters of cushion cylinder were obtained, the cushion cylinder was used in the 2000 ton wide plate tensile testing machine, the correctness of the method was verified by experiments. The paper was helpful to designing cushion system of engineers. In addition, the modeling analysis method of the buffer system was widely used in the fields of national defense such as manned spacecraft, amphibious aircraft and tracked vehicle radar.
2. Mathematical model of cushion system

The real-size tensile test of large load structural parts could be divided into the following stages: Firstly, the hydraulic cylinder applied tensile load to the sample, and the sample reached the strength limit and broke. At the moment when the sample broke, the energy in the system was converted into the kinetic energy of the fixture and its accessories, which was then absorbed and transformed by the cushion system, the internal energy of the sample fracture instantaneous system was mainly the elastic deformation energy of the cylinder, fixture and its accessories. According to the engineering practice, the piston rod of hydraulic cylinder should have a complicated variable-speed movement in the cushion process. The buffer force $F$ of the buffer cylinder was simulated by means of numerical analysis with the quadratic function of $t$, and the motion equation of the cushion system could be derived from the fundamental theories of energy conservation, momentum theorem and theoretical mechanics.

\[ F(t) = k \cdot t^2 \]

The motion parameters of the buffer cylinder were calculated, and the structural schematic diagram of the buffer cylinder was shown in figure 2.

Setting the buffer cylinder back pressure $P_2 = 0$, and setting the buffer time as $t_1$, and the buffer force $F$ of the buffer cylinder was the quadratic function of $t$ (figure 3):
The motion equation of the buffer cylinder can be derived from equation (2) according to the basic theory of theoretical mechanics,

\[ v = v_0 + \int_0^{t_1} \frac{F}{m} \, dt = \frac{v_0}{t_1^3} t^3 - \frac{3v_0^2}{t_1^2} t^2 + \frac{3v_0}{t_1} t + v_0 \]  

and

\[ L = \frac{v_0}{2t_2^3} t^4 - \frac{v_0}{t_1^2} t^3 + \frac{3v_0}{2t_1} t^2 + v_0 t \]  

Where \( v_0 = \sqrt{2E_{\text{int}} / m} \) is the initial velocity of the sample split-instant fixture and its accessories, \( E_{\text{int}} \) is internal energy of sample fracture instantaneous system, \( m \) is quality of fixture and its accessories, and \( L \) is cylinder piston rod buffer distance.

3. Structure design of buffer cylinder

The design of this buffer cylinder required determining two key dimensions: one was the size of the buffer cylinder stroke, the size of the structure was mainly determined by the buffer distance; second, the ring gap \( h \) between the buffer piston and cylinder, the buffering effect of the cushion system was determined by \( h \). According to the basic theory of fluid mechanics, the flow equation of cushion system was established and the formula of the key size of buffer cylinder was deduced.

3.1. Oil pressure calculation of buffer cylinder

\[ P_1 = \frac{F}{A_1} = \frac{3mv_0}{A_1 t_1^3} t^2 - \frac{6mv_0}{A_1 t_1^2} t + \frac{3mv_0}{A_1 t_1} \]  

Where \( A = \frac{\pi}{4} \left( D^2 - d^2 \right) \) is buffer cylinder effective area, \( D \) is piston diameter, and \( d \) is piston rod diameter.
3.2. Gap $h$ of buffer cylinder

According to the fluid mechanics theory, the following equation was established,

$$
\begin{align*}
\int_0^t q dt &= \int_0^t A_v dt \\
q &= \frac{\pi dh^3}{12\mu l} P_1 - \frac{\pi dhv}{2}
\end{align*}
$$

Where $q$ is annular gap flow, $h$ is ring gap, $\mu$ is dynamic viscosity of oil, and $l$ is length of the piston.

The gap calculation formula between cylinder and piston can be obtained by substituting equation (3) and equation (5) into equation (6):

$$
h = \frac{3\sqrt{2l_t \mu A_1^2}}{\pi Dm}
$$

3.3 Results

When the buffer time $t=t_1$, the buffer distance of the buffer cylinder:

$$
L = \frac{7}{4} t_1 \sqrt{\frac{2E_{\text{eq}}}{m}}
$$

buffer clearance:

$$
h = \frac{3\sqrt{2l_t \mu A_1^2}}{\pi Dm}
$$

(Note: usually when cushion system of great load tensile testing machine was designed, the structure of multiple buffer cylinders should be used, so the buffer force $F$ and the oil pressure of the buffer cylinder $P_1$ should be modified according to the number of buffer cylinders in the design calculation process.)

4. Conclusion

With the continuous improvement of industrial level in our country, the demand for the test of great load structural parts is increasing gradually, so cushion system of the great load testing machine must become the focus of the engineers. In the paper, a kind of cushion model system was established by numerical analysis combining with basic theories of fluid mechanics and theoretical mechanics. The cushion system based on this model was applied in engineering test, and the correctness of this method was verified. It provides a reference for engineers in the design of cushion system and has practical engineering significance.

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