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# Mathematical model calculation and experimental data analysis of correction coefficient K

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**Abstract.** A gun during launch can be more stable and dependable by installing a hydraulic buffer with single way force. a hydraulic resistance mathematic model of buffer is established in this paper based on mass conservation equation and energy conservation equation, after designing the structure of buffer in accordance with design requirements. An Correction Coefficient k between theory and reality is introduced in the model, which can be measured via experiments. By contrasting dynamics simulation value of the whole gun launch with force curve of buffer and velocity curve of piston motion measured by gun launching experiments, it indicates that the buffer is effective and fits the demands if the deviation between the calculated and experimental data is less than 10% , which is helpful to provide a method for designing a hydraulic buffer with single way force.

**Key words.** Single way force, Hydraulic buffer, Mathematic model, Correction coefficient
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## 1. Introduction

As being widely applied in fields of metallurgy, engineering machinery, and special machinery, hydraulic buffer can not only absorb huge impact energy but also design buffer rule according to the requirements, to ensure its stable and reliable operation. Although many studies have been carried out on theoretical model of hydraulic duffer, force balance equation and flow conservation equation are generally adopted to establish force equations during the buffer process, however, the model is normally simplified during modeling[1-8].When buffers work in high speed and heavy load situations, results of the theoretical model are quite different from the actual ones because of the complicated characteristics of the internal liquid motion. This work is aimed at obtaining the accurate mathematical model of the buffer structure by introducing the correction coefficient K, measured by experiments, between theory

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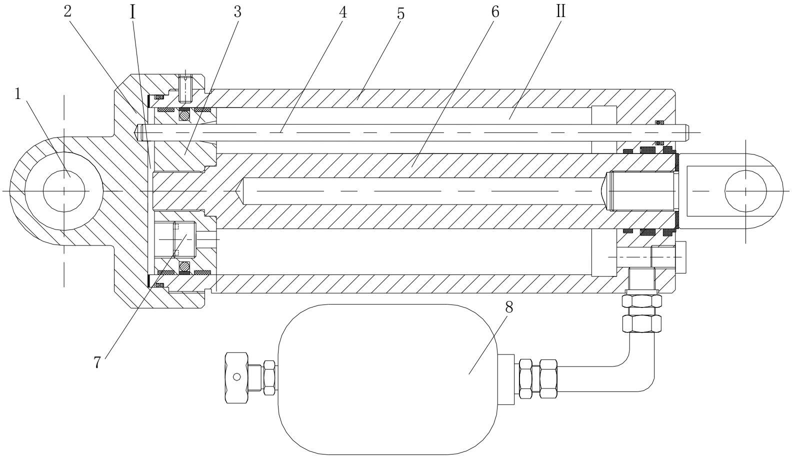
and reality into the mathematical modeling of cushioning properties.

## 2. Design requirements

On account of the recoil force in gun launch, the superstructure would upswing with high speed which needs to be constrained with force-free; After the superstructure swings to a certain position, it will fall back to the original position due to gravity, where non-impact or lower-impact is required to remain the state of gun launching. A buffer that has no hydraulic resistance when the superstructure swings upward needs to be designed, to provide hydraulic resistance when superstructure falls and make the speed of superstructure approach to zeros when it reaches the original position.

### *2.1. Structure design and working principle*

The structure of buffer conforming to the design specification is shown as Figure 1.



1-spherical plain bearing; 2-gland; 3-piston; 4-throttle lever; 5-outer cylinder;
6- piston rod; 7-check valve; 8- accumulator
I-I cavity; II-II cavity

Fig. 1. The structure diagram of hydraulic buffer

The buffer is composed of spherical plain bearing, gland, piston, throttle lever, outer cylinder, piston rod, check valve and accumulator. The piston rod is connected with the superstructure of gun by the pin shaft, and the pin shaft connects spherical plain bearing to the substructure of gun.

Its working principle is as follows: the accumulator with a certain initial pressure connects with fluid-filled cavity II. The superstructure swings up in gun launch, drives the piston rod leading the piston moving towards the right. And then, the liquid in the cavity II is squeezed to open the check valve, and the liquid flows into the cavity I through the check valve . As there are various check valve are arranged on the piston, the area of liquid flow is large when fluid flows into the cavity I, then the buffer force can be negligible, which achieves nonexistence of the force of the single motion.

After swinging to a certain angle, the superstructure begins falling, and the piston and piston rod move downward because of gravity of the superstructure, to squeeze the fluid in cavity I. At the point, the check valve is closed, the liquid in the cavity I can only flow through the annular cross section area between the throttle rod and the piston damping hole until the restoration of the superstructure, which can form the temperance force. In this way, it achieves the goal of buffering. The surplus fluid flows into the accumulator to compress air during falling process of the superstructure.

## 3. Hydraulic resistance mathematic model

### *3.1. Hypothesis of the liquid flow*

The condition of the internal fluid flow is rather complicated when the buffer is working. In order to deduce the formula of hydraulic resistance, the liquid flow in the buffer is assumed as follows:

(1)The fluid in buffer is uncompressible.

(2)The flow is one-dimensional and steady, the flow of oil through the damping hole is regarded as the laminar flow;

(3)The fluid flows in the channel within the buffer, and the inertial reference system is Earth.

On the basis of the above assumptions, the formula of hydraulic resistance can be deduced with mass conservation equation and mechanical energy conservation equation.

### *3.2. Mass conservation equation*

The size of the buffer is shown as figure 2.

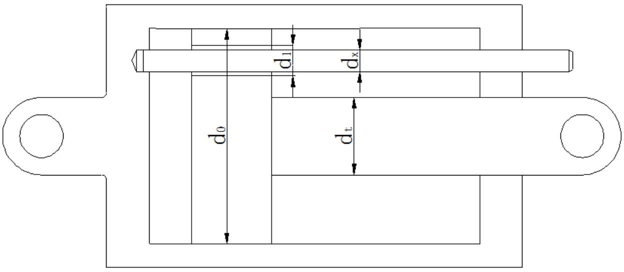


Fig. 2. The diagram of buffer size

The meanings of each variable in the formula derivation are as follows:

The meanings of each variable in the formula derivation are as follows:

$d_0$—Piston diameter;

$dt$—Piston rod diameter;

$d_1$—Damping hole diameter;

$d_x$—Throttle lever diameter;

$A0$—Piston working area, $0 = \pi 4d02$;

$A_t$—Piston rod area, $= \pi 4dt2$;

$a_x$—Groove area, $= \pi 4d12 - \pi 4dx2$;

$q_n$—Groove flow, $= axw'$;

$\rho$—Liquid density;

$p_1$—Liquid pressure in cavity I;

$p_2$—Liquid pressure in cavity II;

$w$—Absolute velocity when the fluid in cavity I flow into cavity II;

$w'$—Relative velocity when the fluid in cavity I flow into cavity II;

$w_0$—Absolute velocity of fluid in cavity I;

$V$—Movement speed of piston;

$K$—Hydraulic resistance coefficient in buffer considering the energy lose;

Hr—Specific energy loss of fluid flow;

F—Piston force, that is, the cushioning force provided by the buffer.

According to mass conservation law, when liquid flows from the cavity I into the cavity II,the relationship is as follows:

$$\rho A0dx = \rho qndt\,, \tag{1}$$

because of $\frac{dx}{dt} = V$, formula (1) could be expressed as:

$$A0V = axw'\,, \tag{2}$$

therefore,

$$w' = A0axV\,. \tag{3}$$

The absolute velocity of fluid in cavity I is:

$$w = w' - V = A0 - axaxV\,. \tag{4}$$

III. III Mechanical energy conservation equation.

According to energy conservation law,when liquid flows from the cavity I into the cavity II,the relationship is as follows:

$$p1\rho + w022 = p2\rho + w22 + Hr1\,. \tag{5}$$

because of $w_0 = 0$, Substituting equation (4) into equation (5):

$$p1 = p2 + (w22 + Hr)\,. \tag{6}$$

It is assumed that the specific energy loss Hr of a liquid flow to a section is proportional to the specific kinetic energy $\frac{w^2}{2}$ of the cross-section liquid, that is

$Hr = \varepsilon w22$

$\varepsilon$ is the loss coefficient of fluid.

And equation (6)can be expressed as:

$$p1 = p2 + \rho w22(1 + \varepsilon)\,. \tag{7}$$

The correction coefficient K is introduced, $K = 1 + \varepsilon$, K is a combination of various factors that are not considered by all the other theoretical models including the local loss and the route loss, and it is the coefficient of coincidence between theory and practice. The K values of different structures are different and can be measured by experiments.

And equation (6)can be expressed as:

$$p1 = p2 + \rho Kw22 = p2 + K\rho 2(A0 - ax)2ax2V2\,. \tag{8}$$

Hydraulic resistance F is:

$$F = p1A0 - p2A0 - At = p1 - p2A0 + p2At\,. \tag{9}$$

Substituting equation (8) into equation (9)

$$F = K\rho 2A0(A0 - ax)2ax2V2 + p2At\,. \tag{10}$$

In order to facilitate the preparation of the program in calculation, formula (10)can be expressed as:

$$F = K\rho^2 A0(A0ax - 1)2V2 + p2At\,. \tag{11}$$

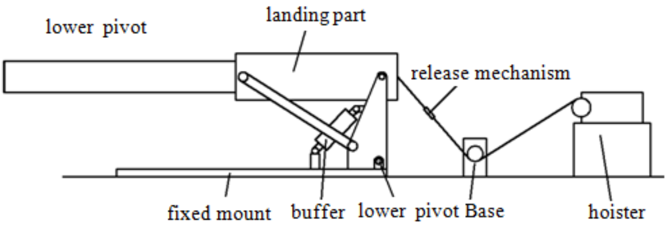
## 4. Test measurement of K

K should be measured by the experiments, because of the differences in its values between different structures. And the optimal design of the hydraulic buffer can be realized by the formula (11)that studies the motion characteristics under various working conditions with numerical calculation method. In the paper, the test of the buffer in actual condition was carried out to measure the value of K.

The bench scale test system of hydraulic duffer is composed of superstructure, fixed mount, buffer, replaceable lever, the high-pressure chamber pressure test system, piston rod displacement test system, crane, hoister and connection release mechanism of landing gear, and the landing gear is used to simulate the motion of the superstructure. The schematic diagram of the buffer bench test system is shown as Figure 3.

The displacement curve of the piston and the pressure curve of the cavity I and II were collected in experiment. The schematic diagram of buffer test system is shown in Figure 4 and the photo of testing field is shown as Figure 5.

During the test, it can make the swing of the superstructure be in accordance with the requirements of the buffer design by replacing the adjustment lever of different



1- superstructure; 2- fixed mount;3-buffer;4- release mechanism;5-Base;6- hoister

Fig. 3. The schematic diagram of the buffer bench test system

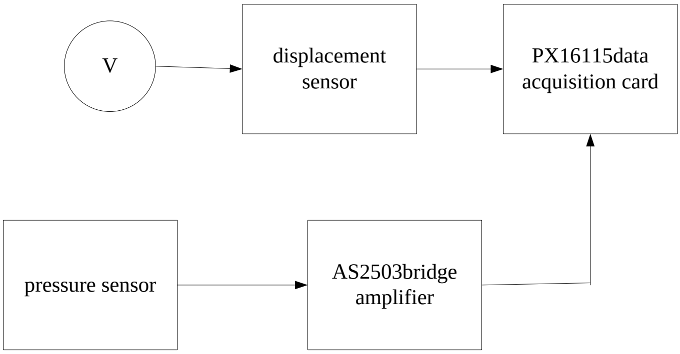


Fig. 4. The schematic diagram of the buffer test system

Fig. 5. The photo of testing field

sizes.

The hydraulic resistance coefficient is acquired according to (8):

$$K = 2 \times (p1 - p2) \times ax2\rho(A0 - ax)2V2 \tag{12}$$

The K $\sim$ t curve can be obtained according to the test data of $p_1 \sim$ curve, $p_2 \sim t$ curve and the structure parameters of buffer, as shown in Figure 6. In order to facilitate the calculation, $K$ is a constant value that is 5.0 by several tests.

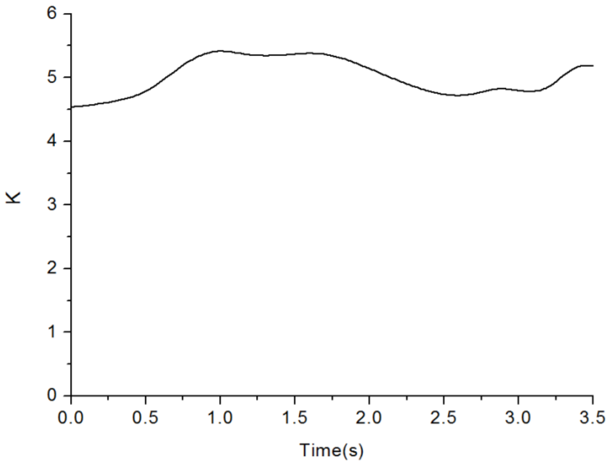


Fig. 6. The curve of $K \sim t$

## 5. Test results

According to the value of K determined by the experiments, the buffer structure is optimized by numerical calculation using equation (11), and redefine the size of buffer structure. In this paper, the whole gun dynamic model of launching process is established, using the formula (11) as the calculating formula of the buffer force. Figure 7 illustrates the curves of the calculated force and the measured force in artillery launching test, and the velocity curve of piston is shown in Figure 8.

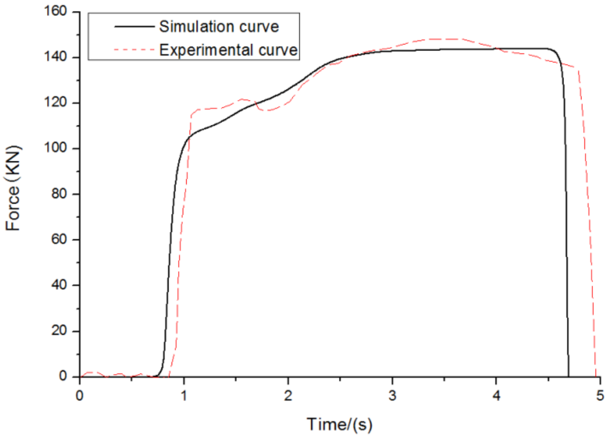


Fig. 7. The curves of the calculated force and the measured force(from upswing to ending)

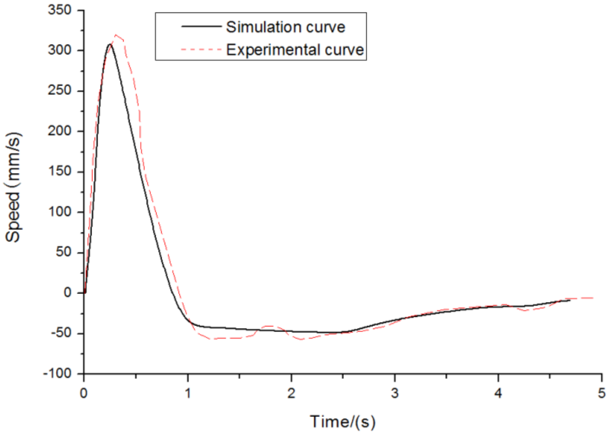


Fig. 8. The velocity curves of the piston movement obtained by simulation and experiment(from upswing to ending)

Table 1. Numerical distribution

| | Simulation value | tested value | deviation |
|---|---|---|---|
| The time of superstructure reaching to the highest point | 0.72s | 0.79s | 9.7% |
| Buffer force | 149.8KN | 140.2KN | 6.8% |
| The peak velocity of the piston | 320.6mm/s | 310.8mm/s | 3.1% |
| The time of superstructure falling to the original position | 4.95s | 4.7s | 5.3% |

Fig.7 and fig.8 indicate that the simulation and experiment curves of the buffer force and the piston velocity are consistent. There is a minimal force when the superstructure upswings which can be ignored comparing with the one when falling, making hydraulic buffer unstressed in a single direction. As can be seen from Table 1, the tested time of superstructure reaching to the highest point lags is behind the simulation time and they are 0.79s and 0.72s respectively with 9.7% deviation. And the tested peek force of buffer is 149.8 KN,while the simulation data is 140.2 KN, there is a gap of 6.8% . The tested peak velocity and the simulation data are 320.6mm/s, 310.8mm/s, respectively, and the difference is 3.1%. The tested time for falling to the original position is 4.95s, while the simulation data is 4.7s, the gap is 5.3%. The tested impact velocity of superstructure returning to the original position is 5.2mm/s, in terms of the simulation data is 9.1mm/s, and both tested and the simulation data of impact velocity down in place are below 10mm/s, which indicates that the cushioning effect is obvious.

## 6. Conclusions

(1) The results of simulation and experiment showed that the buffer with single way force was achieved with using of a check valve.

(2) It introduced the correction coefficient K between theory and reality in mathematic model of buffer force, and the value of K of buffer structure was obtained through experiment. It turned out that experimental data and simulation value of buffer force and piston velocity were coincident and deviation between two methods was less than 10%.

(3) The results of simulation and experiment showed that both experimental data and simulation value of impact velocity down in place are less than 10mm/s, and cushioning effect is obvious.

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