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# Dynamic Performance Analysis of Gas-Liquid United Hydraulic Hammer

**Zishan Xu, Guoping Yang, Hanghang Wei, Shutao Ni**

College of Automotive Engineering, Shanghai University of Engineering and Science, Shanghai, China
Email: xuzishan. cool@163. com

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## Abstract

**In order to improve the impactor performance, the dynamic performance of gas-liquid united hydraulic hammer should be optimized. Based on the analysis of the operating principle for the hydraulic impactor, one simulation model of gas-liquid united hydraulic impactor was built with AMESim software. By setting different simulation parameters, curves of displacement, velocity, acceleration and cavity pressure were obtained under different working conditions. The key component can be obtained by the analysis of activity index. The whole simulation results provide a reliable basis for component selection and parameter optimization of hydraulic impactor.**

## Keywords

**Hydraulic Impactor, Operating Principle, AMESim (Advanced Modeling Environment for Simulation Engineering Systems) Simulation, Activity Index**

## 1. Introduction

Hydraulic impactor is the key operating equipment of impact mechanism including hydraulic hammer [1], hydraulic rockdrill and so on. It can directly or indirectly drive the piston reciprocating motion by the hydraulic pressure as power source. The piston smashes the drill rod, causing damage to the strucked objects when the system is in stroke. The hydraulic impactor can be classified into 3 varieties, such as full liquid, gas-liquid and nitrogen-inflating, depending by the power source driving the piston to work. Based on the oil assignment, impcator can be divided into auto flow assignment and forced flow assignment, the forced flow assignment realize the circuit transition through electronic single controlling the flat valve, while the auto flow assignment accomplishes the flow assignment by the match of control circuit. Researches about the hydraulic impactor include structure design improvement, control method, computer simulation, performance test, manufacture process and basic theory [2]. The research results will have important implications for the design of hydraulic shock me-

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chanism and predict the performance of impact hammer by adaptive neuro-fuzzy inference system modelling [3].

## 2. Working Principle and Kinetic Model

### 2.1. Operating Principle [4]

As can be seen in **Figure 1**, when return motion begins, hydraulic pressure oil enter the front cavity of piston via fluid port, meanwhile, applying to the end of directional control valve and making valve stable showed in **Figure 1(a)**. In this figure, the high hydraulic pressure is flowed into the front cavity of piston, while the oil in the rear cavity flows to tank T via fluid 4, the piston accelerate the return and compress the nitrogen in the nitrogeon chamber to restore the energy under the drive of fluid pressure in the front cavity, energy accumulator restore oil. When return motion of the piston move to contron port 2, high pressure oil reach the upper end of the spool, meantime, the top and end of the spool connect the high pressure oil. Owning to the fact that the top of valve exceed the end of valve in the effective volume, the spool invert to the state as **Figure 1(b)** under the action of high pressure oil. In this condition, the front cavity and the rear cavity of the piston connect the high pressure oil, accumulator discharge of oil to supplement system. The piston accelerate the stroke, strike the drill rod and output the impact energy under the action of composite force. When piston reach the striking point, control port 2 and port 3 conduct, and connect the return oil port T. The top of reversing valve core leak pressure, the spool invert to the state showed as **Figure 1(a)** under the action of bottom of oil pressure. Then the system recover to the initial statement, the piston bigin to return and enter into the next shocking circuit, and so forth.

### 2.2. Kinetic Model [5]

Based on the assumption of linear model, hydraulic impactor should be firstly linearized and then be studied ideally. According to the linear theory, the system pressure is constant, hydraulic oil is incompressible, viscosity is constant, nitrogen chamber is adiabatics. According to the kinetic balance equation, fluid continuity principle and equation of state of gas, mathematical equation of hydraulic impact mechanism [6] can be described as follows:

1) Piston Dynamics

$$m_p \ddot{S}_p = \operatorname{sgn}\left(\dot{S}_P\right) m_p g - \sum_{i=1}^{4} \pi d_{pi} l_{pi} \cdot \left[ \frac{\mu}{\delta_{pi}\sqrt{1-\varepsilon_{pi}}} \dot{S}_P + (-1)^{i+1} \operatorname{sgn}\left(\dot{S}_P\right) \frac{\delta_{pi}}{2 l_{pi}} \Delta p_{pi} \right] + p_1 A_{p1} - p_2 A_{p2} + \operatorname{sgn}\left(\dot{S}_P\right) p_N A_{p3}$$

2) Dynamics Equation of Directional Control Valve

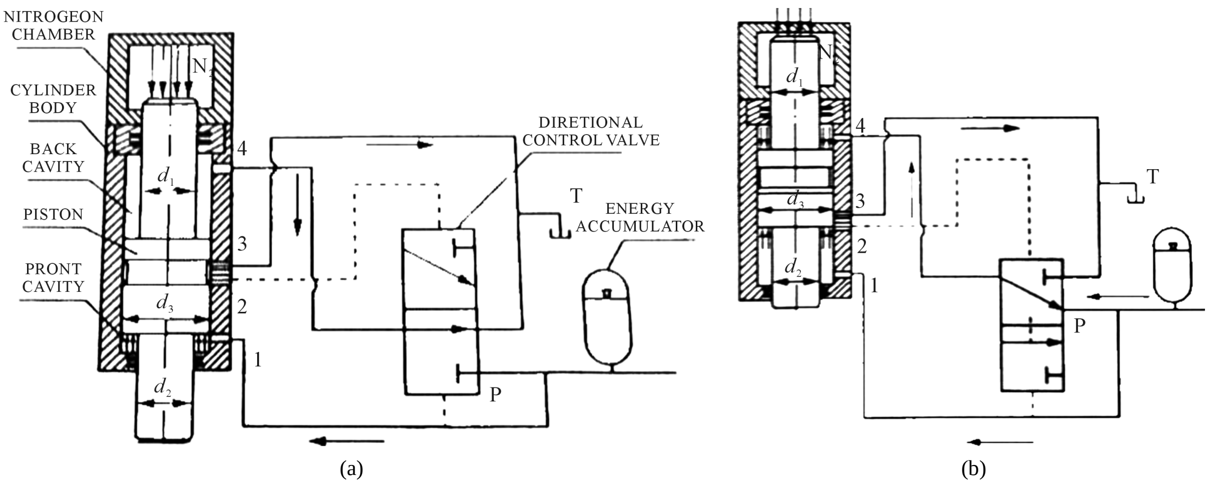



**Figure 1.** Basic diagram of impactor. (a) End of stroke, start of return; (b) end of return, start of stroke.

$$m_v \ddot{S}_v = \operatorname{sgn}\left(\dot{S}_P\right) m_v g - \sum_{i=1}^{4} \pi d_{vi} l_{vi} \cdot \left[ \frac{\mu}{\delta_{vi}\sqrt{1-\varepsilon_{vi}}} \dot{S}_P + (-1)^{i+1} \operatorname{sgn}\left(\dot{S}_P\right) \frac{\delta_{vi}}{2l_{vi}} \Delta p_{vi} \right] - p_2 A_{v2} + p_3 A_{v1}$$

3) Gas State Equation of Nitrogen in The Condition of Adiabatic State [7]

$$p_N V_N^{1.4} = p_0 V_0^{1.4}$$

where, $m_p$, $m_v$ are respectively the mass of piston and directional control valve; $S_p$, $\dot{S}_p$, $\ddot{S}_p$ are respectively displacement, velocity and acceleration of piston; $S_v$, $\dot{S}_v$, $\ddot{S}_v$ are seperately the displacement, velocity and acceleration of directional control valve; $\delta_{pi}$, $\delta_{vi}$ are seperately the tolerance clearances between piston and rigid body, and the tolerance clearance between spool and valve body; $\varepsilon_{pi}$, $\varepsilon_{vi}$ are the eccentricity ratios of piston and spool; $d_{pi}$, $d_{vi}$ are diameters of piston and spool; $\mu$ is kinetic viscosity of hydraulic oil; $l_{pi}$, $l_{vi}$ are seal lengths of piston and spool; $p_N$ is the pressure of nitrogeon chamber; $P_0$ is the initial pressure of nitrogeon cavity; $\Delta p_{pi}$, $\Delta p_{vi}$ are pressure differences of piston and spool; $p_1$, $p_2$, $p_3$ are pressures of front cavity of piston, rear cavity and differential control valve; $A_{p1}$, $A_{p2}$, $A_{p3}$ are effective volumes of front piston, rear cavity and nitrogeon chamber; $A_{v1}$, $A_{v2}$ are effective volumes of front directional control valve, rear cavity; $V_N$, $V_0$ are instant volumes when nitrogeon chamber works and initial volumes of nitrogeon chamber.

## 3. AMESim Modeling and Simulation

### 3.1. Setting Up of Simulation Model

Based on the working principle of hydyaulic impactor. According to the theory, the system pressure is constant, the model use hydraulic component design (HCD), pneumatic component design (PCD), mechanical library of AMESim software (LMS Imagine. Lab AMESim Rev 13 SL2) to build control model. As showed in **Figure 2**, A presents the part of impactor cavity.

The modeling simulation is followed by the working principle of hydraulic hammer. However, due to the restricton of model library, some parts cannot be applied with the pratical system components. So parts can be replaced and simplified with simple component. The response of the system can be studied via modifying the working parameters in different working conditions. Besides, the model can be applied in the simulation of similar system.

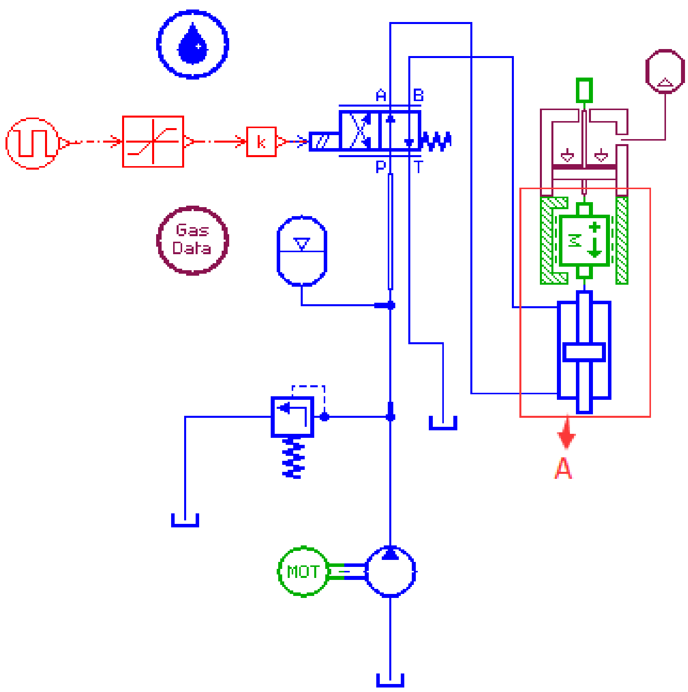
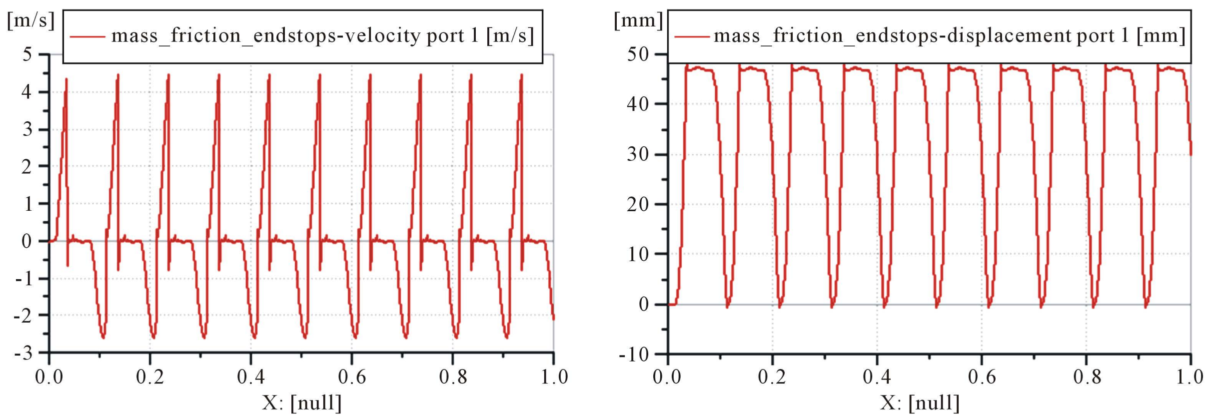



**Figure 2.** AMESim simulation model.

### 3.2. Simulation Result and Analysis [8]

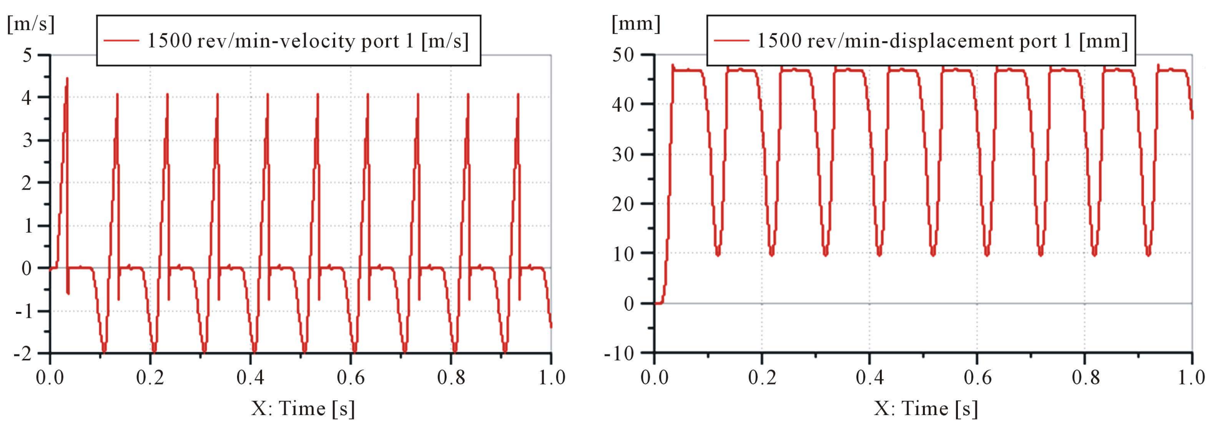
When piston mass is 42 kg, frequency is 35/3 HZ, velocity and displacement curve can be showed in **Figure 3**, **Figure 4**. As showed in velocity curve, the upper shaft of X axis indicates piston velocity in the stroke process, while the second half of the shaft indicates velocity of the return. Moreover, according to the displacement curve, a long pause can be seen in the largest travel, which means that drill rod strikes objects. Under the circumstances, the maximum velocity of hydraulic impactor is 4.34 m/s and the maximum velocity of return is 2.61 m/s when rotate speed is 2500 rev/min. The maximum displacement of hydraulic hammer is 47.97 mm. The maximum velocity of hydraulic impactor is 4. 08 m/s, maximum velocity of return is 1.99 m/s and the maximum displacement of hydraulic hammer is 47.68 m when rotary speed is 1500 rev/min. As showed in **Figure 5**, when rotoary speed change from 1500 rev/min to 2500 rev/min, the curves of velocity and displacement in the stage of stroke basically overlap, but the highest displacement and velocity of the higher rotary speed exceed the lower rotary speed in the stage of the return, and the curve approximately overlap in the equivalent phase.

As showed in **Figure 6**, the maximum impact energy [9] the system can reach is 414.22J, and maximum velocity of the system is 4.44 m/s at the same time, which prove that impact energy in the stage of stroke is decided by its velocity. Meanwhile, as shown in **Figure 7**, in the front and back cavity piston flow curve [10], numercical value is positive when fluid enter the chamber, while the value is negative when the fluid discharge of chamber. In the stage of return, the front cavity was fed, the back cavity ingress of oil; While in the stage of stroke, the process is on the contrary. From the curve, we can see that flow and piston velocity is proportional to the effective acting volume. As to the front and back piston, its velocity is same, but the acting volume of back cavity is larger than front cavity. Moreover, outlet oil flow in the back cavity is larger than the front cavity [11].



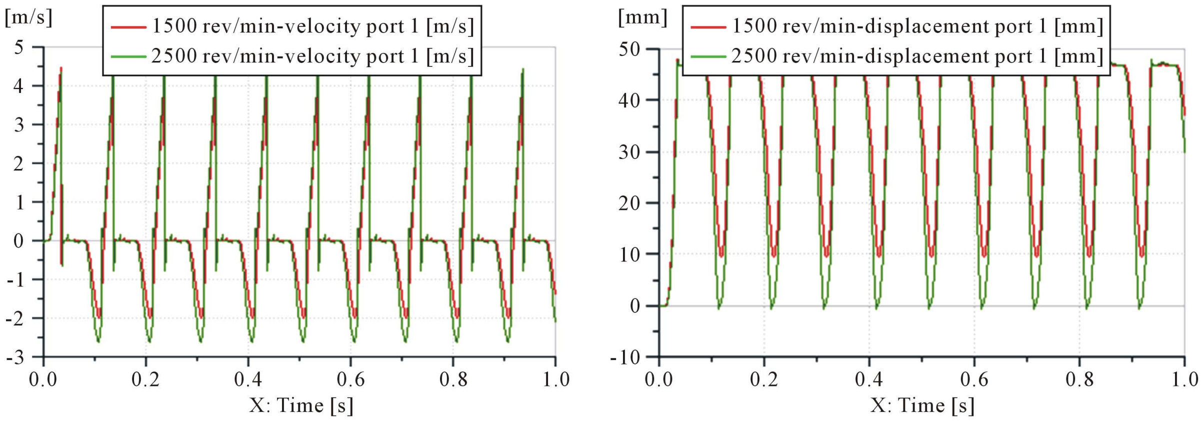

velocity curve displacement curve

**Figure 3.** Velocity and displacement curve when rotary speed is 2500 rev/min.




velocity curve displacement curve

**Figure 4.** Velocity and displacement curve when rotary speed is 1500 rev/min.




velocity comparison displacement comparison

**Figure 5.** Comparison of velocity and displacement when rotary speeds are 1500 rev/min and 2500 rev/min.

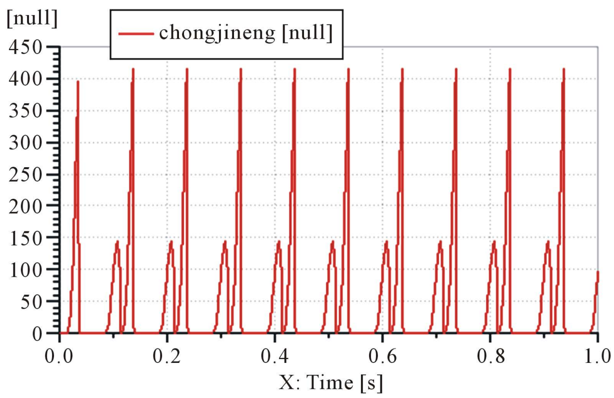



**Figure 6.** Impact energy curve.

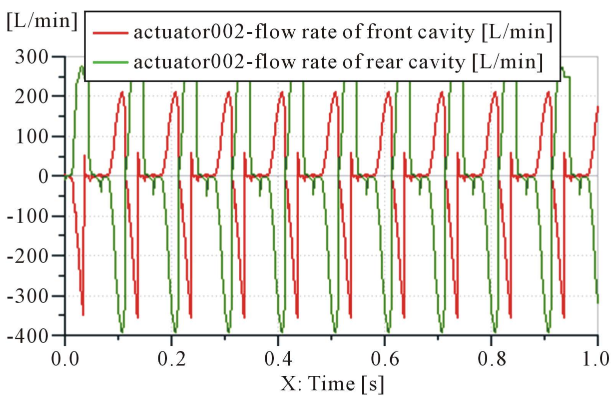



**Figure 7.** The front and back piston flow curve.

Obviously, input flow of the back cavity is 270 L/min, the output flow of the front cavity is 250 L/min, their flow difference is provided by oil supply system.

### 3.3. Activity Index Analysis of Simulation Model

1) Mathematical definition of activity index

a) Activity: integration of power that is the component of number *i* from the submodel, expression is described as follow:

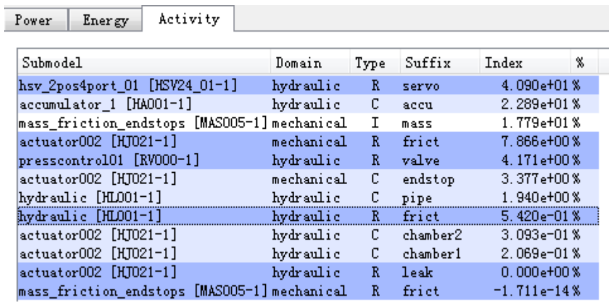
$$\text{activity} = A_i(\tau)\int_0^\tau |P(t)|\mathrm{d}t$$

where, the unit of activity is *J* which describe the energy of assigned component. Because what we consider is the absolute value of power, so it is different from the definition of energy.

b) Activity index: the ratio between activity of submodel and total activity.

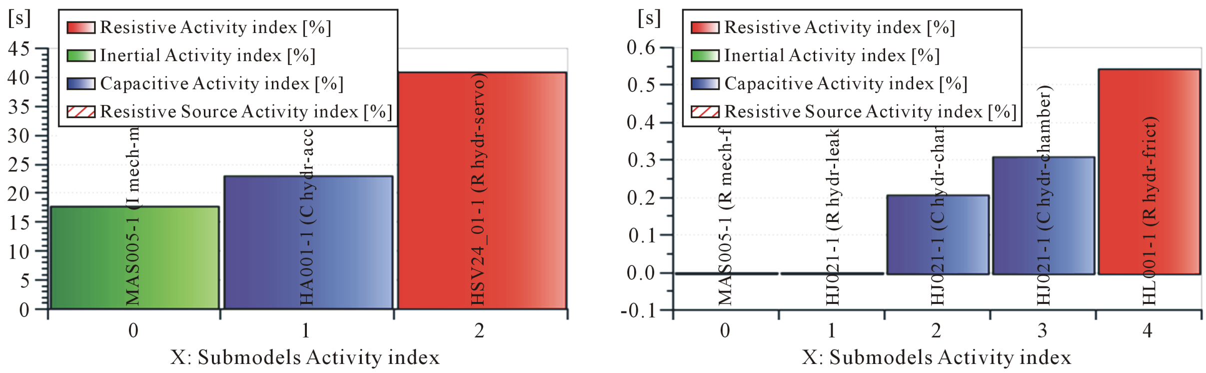
2) Analysis of model activity index

The analysis results is showed in **Figure 8**. From the result, the activity index of piston mass is the highest, so change of mass is the greatest impact in dynamic performance system. Therefore, simulation can be realized by changing the mass. The following **Table 1** is relationship between different mass and corresponding impact energy of system. Using Matlab software to fit the above data, as curve between impact energy and piston mass showed in **Figure 9**, the system can gain the largest impact energy when piston mass is about 71 kg.


Power | Energy | Activity

| Submodel | Domain | Type | Suffix | Index | % |
|---|---|---|---|---|---|
| hsv_2pos4port_01 [HSV24_01-1] | hydraulic | R | servo | 4.090e+01 | % |
| accumulator_1 [HA001-1] | hydraulic | C | accu | 2.289e+01 | % |
| mass_friction_endstops [MAS005-1] | mechanical | I | mass | 1.779e+01 | % |
| actuator002 [HJ021-1] | mechanical | R | frict | 7.866e+00 | % |
| presscontrol01 [RV000-1] | hydraulic | R | valve | 4.171e+00 | % |
| actuator002 [HJ021-1] | mechanical | C | endstop | 3.377e+00 | % |
| hydraulic [HL001-1] | hydraulic | C | pipe | 1.940e+00 | % |
| hydraulic [HL001-1] | hydraulic | R | frict | 5.420e-01 | % |
| actuator002 [HJ021-1] | hydraulic | C | chamber2 | 3.093e-01 | % |
| actuator002 [HJ021-1] | hydraulic | C | chamber1 | 2.069e-01 | % |
| actuator002 [HJ021-1] | hydraulic | R | leak | 0.000e+00 | % |
| mass_friction_endstops [MAS005-1] | mechanical | R | frict | -1.711e-14 | % |

Activity index list




The activest 3 active variate　　The laziest 5 activity variate

**Figure 8.** Analysis results of activity index.

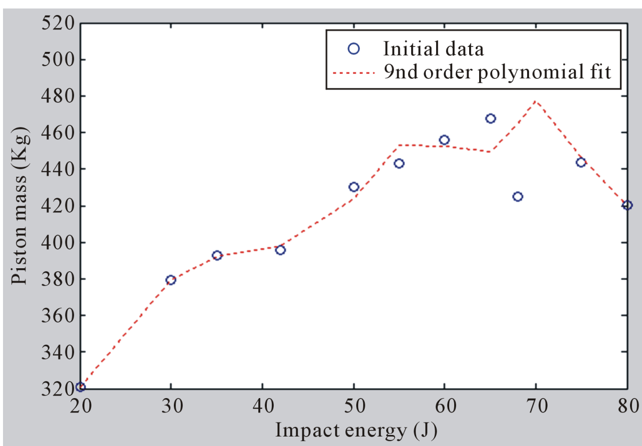



**Figure 9.** Curve between impact energy and mass piston.

**Table 1.** The relationship between piston and impact energy.

| Piston mass | 20 | 30 | 35 | 42 | 50 | 55 | 60 | 65 | 68 | 70 | 75 | 80 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Impact energy | 320.8 | 379.3 | 392.9 | 395.5 | 430.5 | 443 | 455.7 | 467.7 | 424.7 | 503.7 | 443.9 | 420.2 |

## 4. Conclusion

The paper explains the application of AMESim software in the modeling of gas-liquid united hydraulic hammer. Based on the working principle of hydraulic impactor, mathematical model can be built. The data, necessary for constructing models, were obtained from theoretical calculation. The output of the model is a variety of curves considered as main performance indicator. The activity index research provide a theory for simplying model and find out the research priorities, which we can find the fast way to improve the impact energy of the impactor. The reasonable hydraulic impactor model provides a good platform for the impacor character research, and research with respect to compensation flow of impactor, impact rebound, oil return, the holes and so on will be discussed in another paper.

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