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Original Paper

Impact performance for high frequency hydraulic rock drill drifter with sleeve valve

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Abstract

A high frequency hydraulic rock drill drifter with sleeve valve is developed to use on arm of excavator. In order to ensure optimal working parameters of impact system for the new hydraulic rock drill drifter controlled by sleeve valve, the performance test system is built using the arm and the hydraulic source of excavator. The evaluation indexes are gained through measurement of working pressure, supply oil flow and stress wave. The relations of working parameters to impact system performance are analyzed. The result demonstrates that the maximum impact energy of the drill drifter is 98.34J with impact frequency of 71HZ. Optimal pressure of YZ45 rock drill is 12.8 MPa-13.6MPa, in which the energy efficiency reaches above 58.6%, and feature moment of energy distribution is more than 0.650.

Keywords: rock drill drift, sleeve valve, energy efficiency, impact energy, feature moment of energy distribution

1. Introduction

Hydraulic rock drill drifter is a tunnel construction and mining device widely used in projects of mining, railway and highway construction. It supplies basic condition to speed up project construction, and reduce labor intensity [1-2]. At present, the use of hydraulic rock drill drifter need special propeller under limit of structure and inverse impact force in drilling process, which makes self-propelled drill frame have large work range with high cost, or low cost with small work range[3-4]. Excavator is widely used earthwork excavating equipment with a large range adjusted arm. Development of the hydraulic rock drill drifter used on excavator can extend the working range of the drill and increase the additional value without cost increase. However, under restrain of the arm in excavator, the hydraulic rock drill drifter used in excavator must be with compact structure, small volume and light weight. The hydraulic rock drill drifter has two types according to structure of flow distributing valve [5]. Spool valve is used by one type, and sleeve valve used by the other. Piston and sleeve valve installed on the same axis in hydraulic rock drill drifter controlled by sleeve valve, which makes volume of the drifter smaller, weight lighter and structure more compact [6]. In the paper, a high frequency hydraulic rock drill drifter with type YZ45 will be designed, which uses sleeve vale to control flow distribution.

The impact system is the core part of hydraulic rock drill drifter. Its performance determines the effect of rock drilling. The working process of impact system obeys movement law of fluid and mechanic, however, the movement law is quite complex under the coupling of structure and hydraulic mechanical coupling [7]. Song [8] designed a testing system to test drilling efficiency of a drill bit and investigated the effect of bit design factors on the performance of drilling. Kwon [9] built a percussion testing system to evaluation of drilling efficiency. The evaluation system mentioned above only considered one index. However, the performance index of impact system for hydraulic rock drill drifter contains of stress waveform, impact energy, impact frequency and so on, and a synthetically evaluation system is lacked. The actual performance and the evaluation index whether the drill performance reaches the expected index are the basis to ensure working condition. At the same time, the influence law of working parameters and performance parameters obtained through prototype testing is the theoretical basis for the structural parameter optimization and working parameters choosing.

In order to ensure optimal working parameters of impact system for the new hydraulic rock drill drifter controlled by sleeve valve, the performance test system is built using the arm and the hydraulic source of excavator. The evaluation indexes of impact power, energy efficiency, and feature moment of stress wave distribution are acquired through measurement of working pressure,

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supply oil flow and stress wave. Then, the optimal working parameters of impact system are obtained by analysis relation of working pressure and supply oil to impact performance, which gives a lead to use the new type drill more efficiency.

2. Working principle and structure characteristics for high frequency hydraulic rock drill drifter with sleeve valve

2.1 Working principle of impact system for high frequency hydraulic rock drill drifter with sleeve valve

The hydraulic impact system is the core part of hydraulic rock drill drifter with sleeve valve, in which the energy transforms happened. It is composed by the impact piston, accumulators, sleeve valve, and cylinder block. The schematic of the hydraulic impact system for high frequency hydraulic rock drill drifter with sleeve valve is shown as Fig.1 [10].

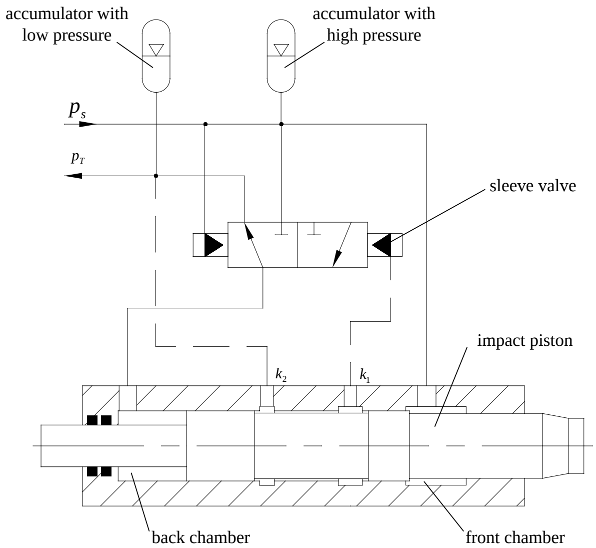

Fig.1 Schematic of hydraulic impact system for high frequency hydraulic rock drill drifter

High pressure oil p_s from hydraulic pump flows into cylinder body and sleeve valve. The sleeve valve is reciprocated by hydraulic oil, which shares cylinder body with impact piston. The porting of fluid into and out of cylinder chambers is accomplished by flow distribution of the sleeve valve. The sleeve valve can be treated as two position-three way directional valve controlled by hydraulic. In status of impact end shown as Fig.1, high pressure p_s flow into the front chamber directly through the hole in the cylinder body, and the impact piston moves left with acceleration called as return travel. When the front side for the front shoulder of impact piston passes control orifice k_1, high pressure p_s flow into the right control chamber of sleeve valve trough font chamber of impact piston, and the sleeve valve moves left. The sleeve valve is working on the right position.

At this moment, the front and back chambers are filled high pressure oil with the back connection. Thus, the impact piston moves left with moving velocity decreased until the velocity decreases to zero. The kinetic energy of the impact piston is absorbed by accumulator with high pressure. Then, the impact piston moves right with acceleration called as impact travel under force difference between the front chamber and back chamber, and the flow of back chamber increases. When the flow needed exceeds the flow that the pump can supply, the return oil of front chamber and the storage oil of accumulator with high pressure flow to back chamber in order to meet the needs of impact acceleration. When the back side for the front shoulder of impact piston passes control orifice k_1, the right control chamber of sleeve valve connects with tank through ports k_1, $k_2$and p_T. The sleeve valve moves right quickly under hydraulic force of the left control chamber, and the impact progress completes. The impact piston continuous strikes drill tail reciprocally that realizes by the in turn open of ports k_1 and k_2.

The accumulators set on circuit of supply oil and return oil are used to decline the impact of hydraulic, and improve the life of hydraulic house. Another important role of accumulator with high pressure is to supply oil with high pressure, which reduces the rated flow and power consumption of a hydraulic pump.

2.2 Structure characteristics of impact system for high frequency hydraulic rock drill drifter with sleeve valve

The structure of high frequency hydraulic rock drill drifter with type YG45 is shown as Fig.2. It is composed by the impact piston, cylinder, valve sleeve valve, sealing ring, accumulator with high pressure, sleeve valve, rotary motor and so on. The impact system has the following characteristics in structure:

1) Supporting seat is set on front and back of the cylinder body hole, respectively, and impact piston is supported and guided by supporting seats. Therefore, direct friction between the piston and cylinder hole is avoid, which prolong the service life of the cylinder body. The inner leakage of oil changes a little with invariable efficiency, and machining error of supporting seat and the hole in the cylinder body can be compensated.

2) The seal is installed between impact piston and supporting sleeve in order to prevent gas and water with pressure into oil. The seal on the front of impact piston and cylinder is clearance seal. Leak oil flows to tank through the leak hole of cylinder body. The leakage of impact piston and supporting sleeve is reduced by setting several seals.

3) In order to reduce leakage of high pressure chamber and low pressure chamber for sleeve valve, Step seal is set on all outer surfaces of sleeve valve with different cylinders, and Glyd seal is set on all holes of the sleeve valve. Two circles of holes are opened on the middle circumference of the sleeve valve to increase the flow area and reduce oil resistance. Sleeve valve is a thin-walled tubular part with weight of 140g, which increases sensitivity of spool movement, reduce the impact force and prolong

the service life of the sleeve valve.

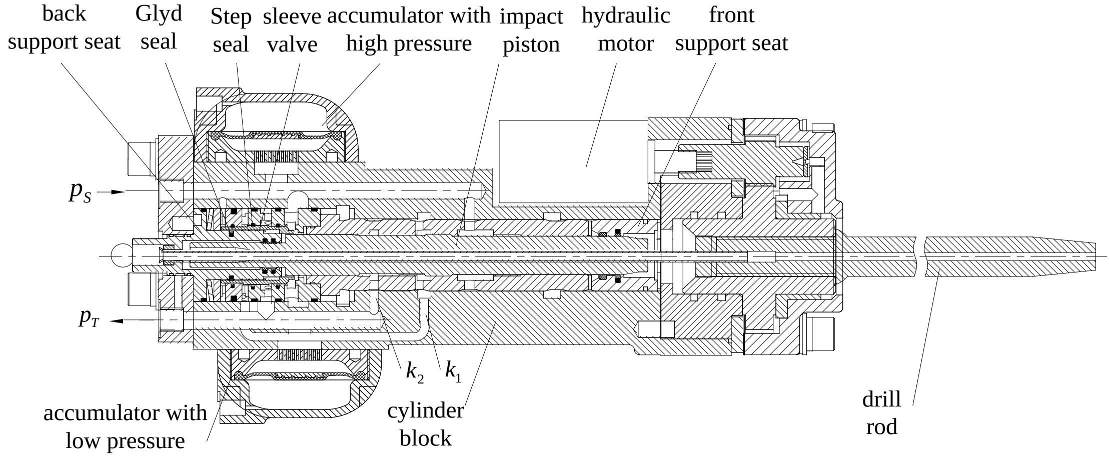

Fig.2 Structure of high frequency hydraulic rock drill drifter

3. Impact performance of high frequency hydraulic rock drill drifter

Drilling efficiency of high frequency rock drill drifter with sleeve vale is mainly decided by the performance of impact system. Impact power, energy efficiency and feature moment of energy distribution are import performance measurement parameters. Improving the drill impact output power will inevitably increase the drilling efficiency [11]. The energy efficiency of impact system is the scale of energy utilization and conversion. Feature moment of energy distribution describes the bias degree of energy to the wave tail, and its value is more conducive to the transfer of energy to the rock.

3.1 Impact power

The product of impact energy and frequency is impact power. It reflects the capacity of rock drill drifter, which is given by

$$W = E_p f \tag{1}$$

$$E_p = \frac{1}{2} m v^2 \tag{2}$$

Where, W is impact power, E_p is impact energy, f is impact frequency, m is weight of impact piston and v is maximum impact velocity.

3.2 Energy efficiency of impact system

The energy efficiency of impact system expresses efficiency of energy utilization and conversion. The energy efficiency of impact system is the ratio of impact power and input power of system, which is given as

$$\eta = \frac{W}{E_e} = \frac{\frac{1}{2} m v^2 f}{pq} = \frac{f m v^2}{2pq} \tag{3}$$

Where, E_e is the effective supply hydraulic power to impact system of rock drill drifter, p is the effective pressure for impact system of rock drill drifter, and q is working flow of impact system.

3.3 Feature moment of energy distribution

Stress wave moment of energy distribution can describe the bias degree of energy to the wave tail, which is expressed as

$$T_E = \int_0^{t_p} \sigma^2 t dt = \sigma_{i\max}^2 \int_0^{t_p} \phi^2(t) t dt \tag{4}$$

On the basis of stress wave moment of energy distribution for rectangular wave moment, we can get

$$\overline{T_E} = \sigma_{i\max}^2 \int_0^{\frac{2L}{c}} \frac{1}{4} t dt = \frac{1}{8} \sigma_{i\max}^2 \left(\frac{2L}{c}\right)^2 = \frac{\sigma_{i\max}^2}{2\alpha^2} \tag{5}$$

Feature moment of energy distribution can be given by

$$\widehat{T_E} = \frac{T_E}{\overline{T_E}} = 2\alpha^2 \int_0^{t_p} \phi^2(t) t dt \tag{6}$$

Where, $\alpha = \frac{c}{L} = \frac{I_m}{m}$, I_m is fluctuation of inertia, t_p is the time at the end of stress wave, σ_{imax} is the maximum stress of piston impact, and $\phi(t)$ is the function of incident stress wave.

$$\phi(t)=\frac{\sigma(t)}{\frac{E}{c}v}=\frac{\sigma(t)}{\frac{E}{c}\sqrt{\frac{2E_p}{m}}} \tag{7}$$

Where, $\sigma(t)$ is the measure stress wave, E is the elastic module of drill rod, and c is the compression wave velocity in the drill rod.

$$\widehat{T_E}=2\alpha^2\int_0^{t_p}\phi^2(t)tdt=\frac{I_m^2c^2}{mEE_p}\int_0^{t_p}\sigma^2(t)tdt \tag{8}$$

Choosing time interval as $h=\frac{t_p}{2n}$, and dividing integral subarea as 2n, the integral transformation of equation (8) can be transformed by Simpson formula as

$$\widehat{S}=\int_0^{t_p}\sigma^2(t)tdt\approx\frac{h}{3}[\sigma^2(t_0)t_0+\sigma^2(t_{2n})t_{2n}+4(\sum_{k=1}^{n}\sigma^2(t_{2k-1})t_{2k-1})+4(\sum_{k=1}^{n-1}\sigma^2(t_{2k})t_{2k})] \tag{9}$$

$$\widehat{T_E}=\frac{I_m^2c^2}{mEE_p}\widehat{S} \tag{10}$$

4. Experimental system

Actual performance of the new type rock drill drifter is the basis to ensure its scope of application and verify whether the drill performance reaches expected index. At the same time, influence law of working parameters and performance parameters acquired through the prototype test is theory basis of working parameters selection and structure parameters optimization. The test mainly includes stress wave in drill rod, pressure, flow rate, impact frequency. Among them, the principle of pressure and flow rate test including font and back chamber of the cylinder body for the drill is shown as Fig.3 according to the references [12-13]. The impact energy test system for hydraulic rock drill drifter is composed by strain bridge, pressure sensor, flow sensor, WS data collector, Synergy multi-channel waveform recorder, and so on[14], which uses the arm and hydraulic oil source to build test platform shown as Fig.4. The impact power, energy efficiency and feature moment of energy distribution can be evaluated accordingly through working parameters of hydraulic pressure system and parameters of impact performance, which are obtained in the test system.

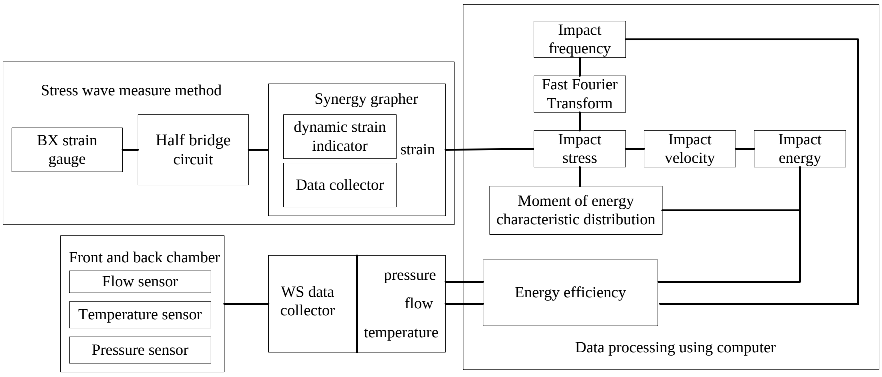

Fig.3 Principle of impact performance test for high frequency hydraulic rock drill drifter

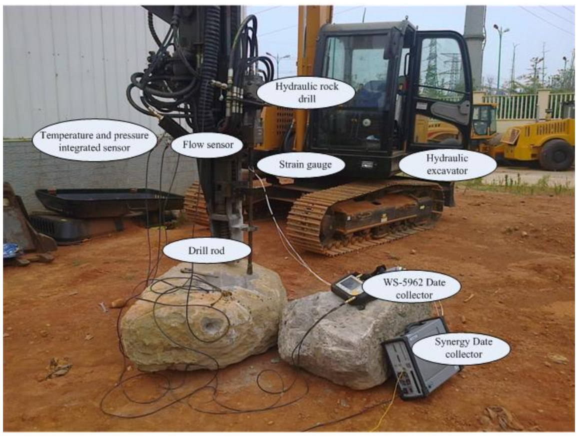

Fig.4 Test system of high frequency hydraulic rock drill drifter

As Fig.3 shown, the impact energy of impact system for the rock drill is achieved using stress wave measuring method [15-

17]. The resistance strain gauge adopts BX120-2AA foil strain gauge with size of 2mm x 1mm. In order to eliminate the signal interference of nonaxial strain and stress wave superposition, strain gauge is installed on the cylinder which has distance of 240mm to rod top, shown as Fig.4. Two strains in series gauges connect testing system using half bridge circuit with single arm work, shown as Fig5. R2 and R4 are the resistance of BX120-2AA foil strain gauge. R1 and R3 are constant resistant with 120Ω, which are set in Synergy multi-channel waveform recorder.

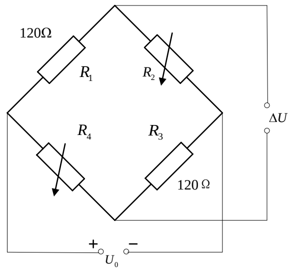

Fig.5 Half bridge circuit

As Fig.5 shown, assuming excitation voltage of half bridge is U_0, and the resistant of each arm for half bridge is R_1, R_2 , R_3 and R_4, respectively, the output voltage ΔU can be expressed as

$$\Delta U = [\frac{R_2}{R_1 + R + \Delta R} - \frac{R_3}{R_3 + R + \Delta R}] \tag{11}$$

Where, $\Delta R=4G\varepsilon R$ is the resistance variation of R_2 or R_4, R is the nominal resistance of the stain gauge, G is the strain sensitivity coefficient, and ε is the strain of the stain gauge.

The strain produced by piston impacting drill rod is obtained by Synergy multi-channel waveform recorder. The pressure and flow rate in the font and back chamber of the cylinder body is obtained by WS data collector. The signals of strain, pressure and flow rate acquired often have noise pollution, which can affect the effect and precision of the subsequent analysis. Wavelet transform can reduce noise in the signal and improve resolution ratio in the domain of frequency and time without signal distortion. Hence, wavelet transform toolbox in MATLAB is used to deal with noise signal. Combining Eq.1, Eq.3, and Eq.6, the effects of working parameters to evaluation parameters can be acquired accurately.

5. Analysis of test results

5.1 Energy efficiency of impact system

The hydraulic rock drill drifter is ensured to work in the largest system pressure and flow rate. The largest system pressure is 14Mpa, and the largest flow rate is 60L/min. The test cycle of Synergy multi-channel waveform recorder in the experiment is 50ms with data collecting frequency 1MHZ. Strain acquisition starts when the drill works stably. Strain changing curve on gauge in the experiment is shown as Fig.6. Pressure changing curves in the front and back chamber of cylinder body are shown as Fig.7 and Fig.8, respectively. The stress amplitude to frequency curve through analysis of Fast Fourier Transformation (FFT) is shown as Fig.9.

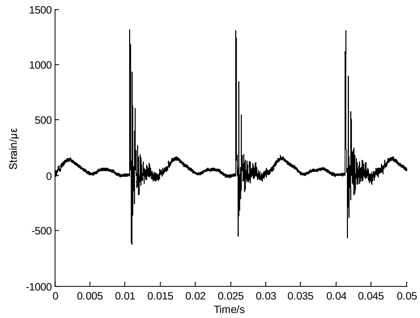

Fig.6 Strain changing curve on gauge

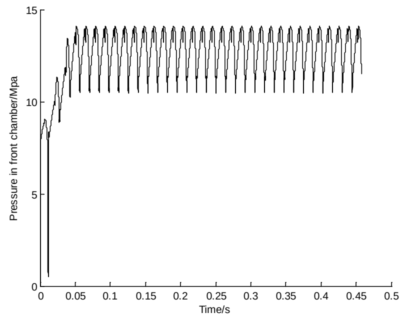

Fig.7 Pressure changing curve in front chamber

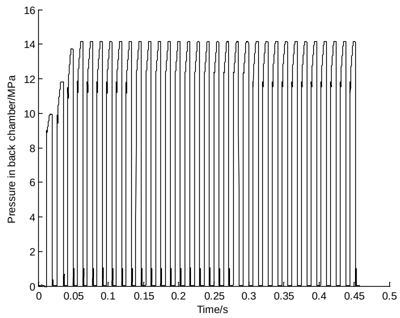

Fig.8 Pressure changing curve in back chamber

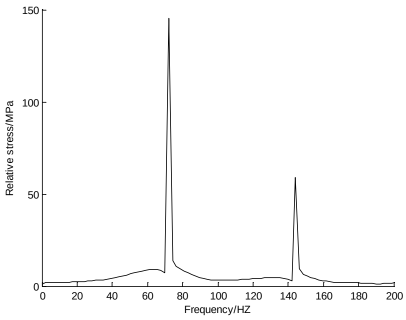

Fig.9 FFT changing curve of stress

As Fig.6 shown, the maximum strain is 1310$\mu\varepsilon$, and the maximum impact velocity is 12.9m/s through stress wave theory calculation. Fig.7 shows pressure changing in front chamber of the cylinder body. The peak pressure in front chamber increases at first and reaches stabilization at 0.11s. The stable peak pressure in the front chamber is 14.69Mpa, and pressure in the front chamber fluctuates in 10.52Mpa-14.69Mpa. The peak pressure appears in the moment of impact piston movement changing. Fig.8 shows pressure changing in back chamber of the cylinder body. The pressure in the back chamber fluctuates in 0.07Mpa-14.19Mpa in cycle after the drill works in stabilization. When back chamber of the cylinder body connects with tank, the pressure declines to the lowest value and impact piston moves left in return travel. The sleeve valve reverses after impact piston passing return signal hole, and the pressure in back chamber increased to 14.19Mpa. At this moment, the impact piston moves right with acceleration called as impact travel under force difference between the front chamber and back chamber.Fig.9 shows that the impact frequency of impact system is 74.8HZ. Hence, the maximum impact energy of the new type rock drill is 109.7J.

5.2 Relation of supply oil and working pressure in high frequency rock drill drifter

According to working parameters to get function index of the hydraulic rock drill drifter, lots of pressure and flow rate tests are done. A relation of working flow to pressure is as Fig.10 shown.

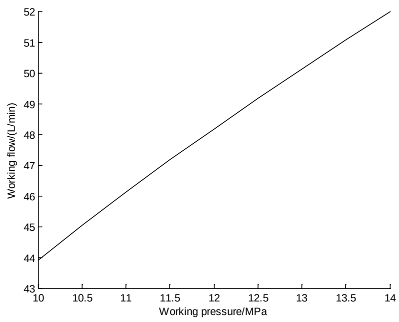

Fig.10 Relation of working flow and pressure

According to experimental data, setting working pressure ranges in 10MPa- 14MPa, the relation between the working pressure and supply flow can be described as Eq.12 by adopting cubic polynomial fitting.

$$Q = 0.0083333p^3 - 0.35714p^2 + 6.9631p + 1.6457 \quad p \in [10MPa, 14MPa] \tag{12}$$

Fig.10 shows that, the working flow increase to the incensement of working pressure in order to ensure the quick moving of impact piston. The increase of working flow can also increase working pressure of the impact system to a certain extent. In the experiments, the working pressure is adjusted trough regulating variable pump displacement of excavator. Therefore, working pressure of the impact system depends on the supply of working flow, and has nothing to do with the nature of the impact object. The slope of working flow and pressure has a trend to get smaller. When the working pressure reaches a certain value, the value of slope of the curve becomes zero. Hence, increasing working flow has little effect to increase of working pressure after the working pressure reaches a certain value. Repeated experiments found that the relation of working flow to pressure describes the value of working flow to get working pressure when the structure and technology parameters keep the same.

5.3 Relation of impact performance and working pressure

According to collect datum in experiment, the relations of energy efficiency and feature moment of energy distribution to work pressure are shown in Fig.11 and Fig.12 by Eq.3 and Eq.6, respectively.

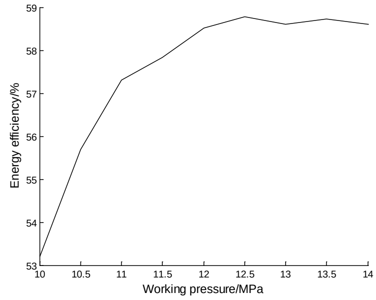

Fig.11 Relation of energy efficiency and working pressure

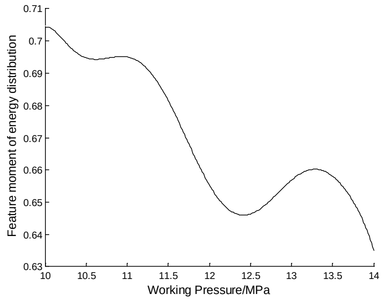

Fig.12 Relation of feature moment of energy distribution to working pressure

Fig.11 shows that energy efficiency has an optimal value. When working pressure is 12.45MPa, the energy efficiency reaches the largest value 58.82%. When working pressure ranges in 12.1MPa -14.0MPa, each energy efficiency is greater than 58.6%. The energy efficiency of impact system can not be improved after it reaches a certain value. That is explained by the fact that the increasing rate of product of working pressure and flow exceeds the product of impact energy and frequency.

Fig.12 shows that feature moment of energy distribution vary randomly. However, the overall trend is the case that feature moment of energy distribution decreases with the increase of working pressure. The feature moment of energy distribution can get a large value more than 0.650 in local with working pressure ranges in 12.8MPa-13.6MPa.The feature moment of energy distribution is the ratio of stress wave moment of energy distribution to energy distribution for ideal rectangular wave moment, and it describes the bias degree of energy to the wave tail. When the feature moment of energy moment of energy distribution increases, the bias degree of energy to the wave tail becomes larger. The energy required for rock breaking is supplied by drill rod directly. The increased stress wave moment of drill rod is conducive to rock breaking. That is, the bias degree of energy to the wave tail is larger in 12.8MPa-13.6MPa, which is conducive to the transfer of energy to the rock. The maximum impact velocity increases with the increase of working pressure [2-4]. Hence, feature moment of energy distribution gets the inverse relationship with maximum impact velocity.

In summary, the optimal working pressure of the high frequency hydraulic rock drill drifter with type of YZ45 lies in 12.8 MPa-13.6MPa. At this time, energy efficiency reaches above 58.6%, and feature moment of energy distribution is more than 0.650.

6. Conclusions

A high frequency hydraulic rock drill drifter with type YZ45 is developed to use on arm of excavator. The test system of impact system performance is built. The impact performance of the hydraulic rock drill is evaluated through evaluation indexes. The following conclusions are obtained:

(1) The maximum impact energy of the YZ45 hydraulic rock drill drifter is 98.34J with impact frequency of 71HZ.

(2) Adequate flow is the necessary condition to ensure the system working pressure of the rock drill. Working pressure of the impact system depends on the supply of working flow, and has nothing to do with the nature of impact object. The relation of working flow to pressure is the same, when the structure and technology parameters keep the same.

(3) Energy efficiency has an optimal value. When working pressure is 12.45MPa, the energy efficiency reaches the largest value 58.82%. The overall trend for feature moment of energy distribution is declining with the increase of working pressure. The feature moment of energy distribution has an optimal value in local.

(4) According to evaluation indexes of energy efficiency and feature moment of energy distribution, the optimal pressure of YZ45 rock drill is 12.8 MPa-13.6MPa, in which the energy efficiency reaches above 58.6%, and feature moment of energy distribution is more than 0.65.

Acknowledgments

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Equipment (No.201305) and Hunan Provincial Natural Science Foundation of China (No. 14JJ6029 and No.2015JJ5030).

Nomenclature

σ_{imax}	maximum stress of piston impact
$\phi(t)$	function of incident stress wave
$\sigma(t)$	measure stress wave
η	energy efficiency of impact system
c	compression wave velocity in the drill rod
E	elastic module of drill rod
E_e	effective supply hydraulic power to impact system of rock drill drifter
E_p	impact energy
f	impact frequency
h	time interval
I_m	fluctuation of inertia
m	weight of impact piston
p	effective pressure for impact system of rock drill drifter
q	working flow of impact system
t_p	time at the end of stress wave
T_E	stress wave moment of energy distribution
$\overline{T_E}$	stress wave moment of energy distribution for rectangular wave moment
$\widehat{T_E}$	feature moment of energy distribution
W	impact power
v	impact velocity

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