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Characteristic analysis of a rock drill impact energy measuring device using pressure sensing principle

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ABSTRACT
A new structure of the measuring device to estimate the impact energy of a percussive drill was proposed and characterized. In the newly proposed measuring device, the maximum value of the pressure wave generated by 50 J of impact is less than 10 MPa, which is about one fifth of the maximum value of the stress wave generated in the drill rod. In contrast, the time of pressure wave generation is more than four times longer than that of stress wave, which is advantageous for measurements. It is shown that the error in the new proposed measurement device is less than 5% when the oil temperature is 10-70 °C, air content is less than 2% and oil leakage is 10%. From the results of the study, it can be seen that the proposed method can significantly reduce the damage of the sensor as well as the high measurement accuracy. This measurement device can be used in the performance testing process in the drilling machine plants as it performs measurements without altering the structure of the drill.
KEYWORDS;- *Percussive drill, Impact energy, Numerical analysis, Pressure wave*

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I. INTRODUCTION

The percussive drill is a drilling equipment widely used in coal mines, mines and construction sites, which receives energy from compressors or hydraulic systems and transmits the percussion energy through the drill steel and bit to crush the rock [1]. Since the impact performance of a drill is the main parameter determining the drilling efficiency, the study of the impact performance of a drill has a crucial influence on its productivity [2]. As the impact energy of a rock drill is an important characteristic to evaluate its performance, many researchers have proposed various methods of measuring impact energy to accurately evaluate this value. Shu-yi Yang [18] verified the accuracy of the piston, valve displacement and velocity curves obtained by AMESim simulations using stress wave test data. The comparison shows that the error between the simulated and experimental values for the impact energy is 9.74%. The method of measuring the impact energy by means of stress wave sensors, discussed in previous studies [9,18], is the most widely used technique of measuring the impact energy. In the method of measuring the impact energy proposed by these authors, the main measurement element is the resistive wire displacement sensor, which measures the small changes in the appearance of the material. For the deformation of the solid material surface, the corresponding mechanical energy is obtained by a calculation such as a micro-integral. This method has been widely used in various fields due to its high computational accuracy and stability. However, the accuracy of the signal obtained in the resistive wire displacement sensor can be greatly degraded due to the influence of the operating environment and temperature. The drill is highly shocked and vibrated during the drilling. Therefore, when the measurement is carried out with a resistive wire displacement sensor, errors are easily generated due to the temperature variations and complicated deformation of the drill rod. Especially when measuring the impact energy of a large-capacity rock drill, there is a disadvantage that the sensor is damaged early. Also, if the drill steel is hit and rotates simultaneously, the connection of the signal line is difficult. In addition, several researchers have determined the impact energy by obtaining the impact velocity by measuring the working pressure of the front and rear chambers of the piston. Kun Bo [10] proposed a performance analysis method of a self-propelled circular drill, optimized the structural parameters, and determined the impact energy by obtaining the impact velocity by measuring the working pressure of the front and rear chambers. In this study, the error between the simulated and experimental values was 9.6%. Yelin Li [11,12,13] studied the dynamic characteristics of hydraulic rock drill impact system, and the performance evaluation experiment was carried out by obtaining the pressure in the front and rear chambers, and the errors of the simulation and experiment were not presented.

Next, several studies [8, 9,10,11] have reported the method of determining the impact energy by measuring the acceleration of the piston in a rock drill. The above measurement methods require a change in the structure of the rock drill, which makes it difficult to apply to performance tests carried out at the rock drill plant. In addition, several researchers [1,4, 5] have introduced methods to evaluate the impact performance of rock drills by directly drilling rocks. In order to evaluate the impact performance of the rock drill by this method, a standardized rock sample must be prepared in advance. Therefore, it is difficult to apply the performance test of the rock drill in the batch production process. In this paper, we propose a new method for measuring the impact energy by means of the pressure sensing principle. This method is used to estimate the impact energy by converting the stress wave of the drill bit into a pressure wave of a closed oil tank. This measurement device can be used widely in industrial practice because of its simple structure, high reliability, and the estimation of impact energy without modifying the structure of the rock drill.

II. METHODS

Description of the impact energy measurement device using the pressure sensing principle

Figure 1 shows the structure of the impact energy measurement device using the pressure sensing principle.

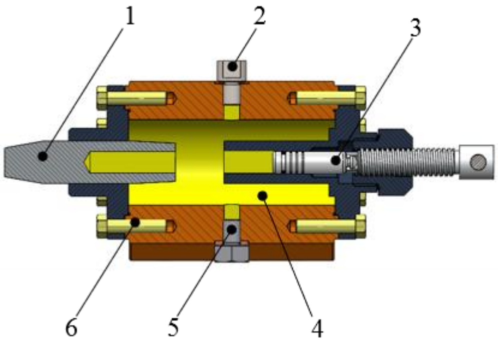

Figure 1: Structure of the impact energy measurement device using the pressure sensing principle. 1-plunger; 2-oil plug; 3-regulator; 4-oil tank; 5-oil drainage hole; 6-bolt.

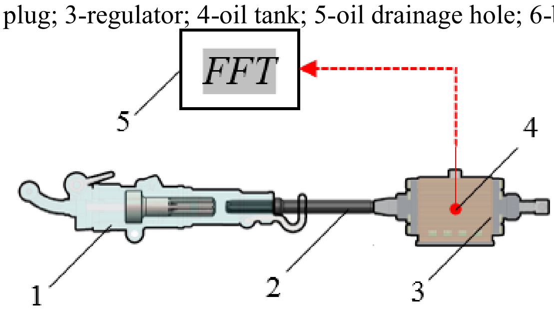

Figure 2. principle of rock drill impact energy measurement. 1-drill; 2-drill; 3-measuring device; 4-pressure sensor; 5-FFT analyzer.

As shown in Fig. 1, the unit consists of a sealed oil tank, an impact-sensitive plunger, and an oil injection and adjustment unit. The oil tank is filled with about 2 l of mineral oil and is secured to the base through a bolt-mounting hole in the lower part. The impact-sensitive plunger is mounted on the same axis as the impactor and the drill rod, and the gap between the plunger and the cylinder in the moving part is about 5-10 um, so the oil leaking to the outside is very small. The oil injection and adjustment unit is intended to remove bubbles generated during oil injection by adjusting the piston position with a screw adjustment unit with a manual handle and to provide the correct position of the impact sensor plunger during work. The stress waves generated by the impact of the rock drill are transmitted through the drill rod and the impact sensor plunger into the oil in the oil tank and are presented in the form of pressure wave. Since these hydraulic phenomena inside the oil tank are different depending on the impact velocity of the rock drill, a precise determination of the relationship between the impact energy and the pressure rise can be made to determine the impact energy of the rock drill. However, when such an impact energy measuring device is used in an industrial environment, the external environment, i.e. summer, winter, day and night temperature differences are high and the oil volume changes with the leakage of oil from the outside of the working room and the air content of the oil changes. Therefore, the measurement accuracy can be improved by accurately characterizing the variation of the measured signal with these working conditions.

simulation method

For the simulation model for the signal characteristics analysis of the rock drill impact energy measuring device by the pressure sensing principle, the following assumptions are adopted. First, the viscosity of the oil filled inside the tank is assumed to be constant. Generally, if the fluid pressure is less than 20 MPa, there is little change in the viscosity of the working fluid [2]. Therefore, it is assumed that the viscosity of the hydraulic oil is not affected by pressure. Second, the effect of friction on the impact sensor plunger is not taken into account. In general, the friction coefficient affects the measurement results of the impact energy. However, in hydraulic devices, this effect is relatively small compared to dry contact. The friction coefficient on the moving surface of the hydraulic device is very small, so that it does not have a significant influence on the results of the study, and the friction force is neglected in the simulation. Third, the elements including the impact-sensitive plunger and the oil tank of the measuring device are considered as ideal rigid bodies. Fourth, the effect of impurities in the oil is not taken into account. The AMESim model for the signal characteristic analysis of the impact energy measurement device is shown in Fig. 3. Figure 3 shows the simulation model of the proposed device.

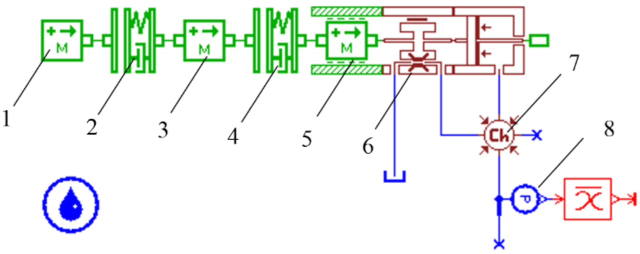

Figure 3. AMESim simulation model of the proposed device

1- Impacter model; 2-Impact contact model of the impactor and the drill rod; 3-drill rod model; 4-drill rod and impact sensor plunger impact contact model; 5-impact sensor plunger model; 6-plunger leakage model; 7-work chamber model; 8-pressure sensor

The masses of the impactor, the drill rod and the plunger can be set in the impacter model (1), the drill rod model (3), and the plunger model (5). The impact contact model of the impactor and the drill rod (2) and the impact contact model between the drill rod and plunger (4) set the reduced impact stiffness and damping coefficient, which are determined by the material and shape of the impactor, the drill rod and the plunger. The plunger leakage model(6) sets the gap and seal length between the plunger and the cylinder. In the simulation, the plunger diameter is 50 mm, the seal length is 50 mm, and the gap size is 10um. The parameters and set points of the model are given as follows:

The impacter mass of the drill is set to 2.03 kg, the weight of the drill rod to 4.35 kg, the diameter of the plunger to 50 mm, the seal length to 50 mm, the mass of drill rod to 2 kg, and the working volume of the oil to 2 l. The simulation time is set to 5 ms, the computational step is set to 0.01 ms, and the simulation is carried out. In the simulation, the signal variation characteristics of oil filling in the tank, air content and oil volume can be considered in the above structure of the impact energy measurement device.

III. RESULT VIEW

First, we compared the stress waves generated in the drill bit when the impacter hits the drill rod at a speed of 7 m/s, i.e. 50 J of impact energy, and the pressure waves of oil generated inside the measuring device.

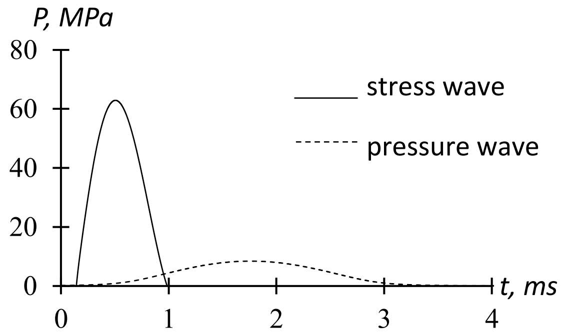

Figure 4: Stress and pressure waves generated by 50 J impact

As shown in Fig. 4, the maximum value of the stress wave generated in the drill rod by 50 J of impact is more than 60 MPa, while the maximum value of the pressure wave generated in the newly proposed measuring device is less than 10 MPa. In contrast, the time of pressure wave generation (about 4ms) is four times longer than that of stress wave (about 1ms).Fig. 5 shows the pressure wave variation diagram with oil temperature. As shown in Fig. 5, it can be seen that the pressure is slightly different under constant impact energy when the temperature of the oil is changed. It is due to the fact that the bulk modulus of oil is temperature dependent. As shown in the figure, it can be seen that the pressure change at temperatures of 10-70 °C is relatively small, with a pressure change less than 2%, except for the oil temperature of -10 °C. Next, the variation of the air content of the oil is considered in the simulation, considering the range of 1-14% and the corresponding pressure wave.

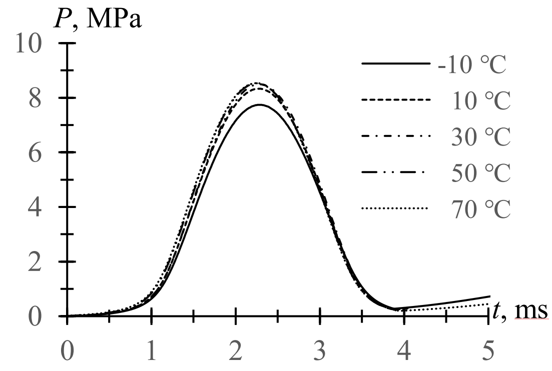

Figure 5: the pressure wave variation diagram with oil temperature.

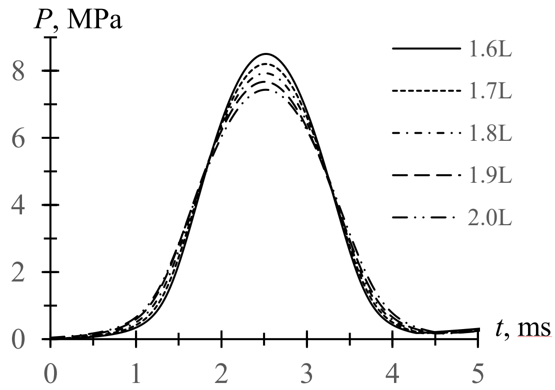

Fig. 6. Variation of pressure wave with air content of oil.

As shown in Fig. 6, it can be seen that the pressure decreases relatively with increasing air content of oil at constant impact energy. Especially, when the air content of oil is more than 4%, the pressure change rate reaches more than 5%. Therefore, minimizing the change in the air content of the oil in the measurements is an important technical requirement to reduce the measurement error. Next, the range of volume change due to the external leakage of oil in the tank was considered to be 1.6-2 l, and the range of pressure signal change with the working volume change was determined.

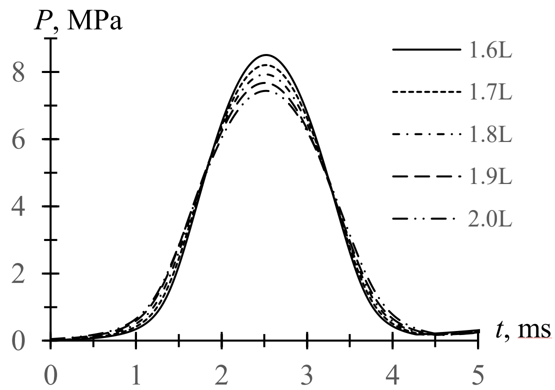

Figure 7: Variation of pressure with volume of the working chamber.

As shown in Fig. 7, it can be seen that the maximum value of the pressure signal generated by the impact increases by about 5% when the volume of the working chamber decreases from 2.0 L to 1.6 L.

As shown in Fig. 3, the stress waves generated in the drill rod that were struck from the drill are at a maximum value of 60 MPa and the impact time is less than 1ms. In contrast, the normally propagating stress wave is converted to the pressure wave of oil in the impact energy measuring device, with a maximum value of less than 10 MPa and an operating time of 4ms. In other words, it is found that the maximum value decreases and the operating time increases as the stress wave is converted into pressure wave. This change is a favorable condition for measurement, so the sensor lifetime increases with the pressure wave measurement method compared to the direct measurement of the stress wave, which can also reduce the measurement error. On the other hand, this measurement device is difficult to use at low temperatures because the measurement error increases by 5% under temperatures below -10℃ (Fig. 5). However, the testing of the rock drill in the rock drill plant is mostly conducted indoors, so that large measurement errors due to temperature drop will hardly occur. Also, the temperature of the oil during the operation can be easily measured, thus easily compensating for the error. Another disadvantage of this measurement device is that when the air content of oil is changed by more than 4%, the error in the measurement is more than 5%, which is relatively large. However, the oil filled in this measurement device is contained in a sealed working space, so that there is little change in the air content of the working oil. The air content of the oil can also be adjusted to a minimum in practice. Therefore, the measurement error due to the variation of air content in this measurement device can be neglected. As shown in Fig. 6, if the tank volume decreases from 2 l to less than 1.8 l, the pressure change rate increases by more than 5%, so it is necessary to supplement the oil in time to estimate the impact energy with less than 5% accuracy. According to the simulation, the amount of oil lost by a single stroke by the impactor is about 1.2 x 10-8 l, so the impact number of the auger is 34 Hz, so that after a period of 1 s, about 4.08 x 10-7 l of oil is lost, after a period of 136 h, the addition of oil can provide a measurement accuracy of less than 5%. It can also be used to provide higher accuracy when designing auxiliary devices that automatically refill oil. Unfortunately, we did not study the automatic oil supplement in this study. However, our results are believed to be of some help in determining the impact performance of a percussive rock drill.

IV. CONCLUSION

The proposed impact energy measurement device can be measured without modifying the structure of the impact drill to evaluate the impact performance, and therefore it is considered to be very suitable for performance evaluation of the drill under field conditions. The measurement accuracy is influenced by the temperature of the working oil, the air content and the volume change of the working chamber, and its influence on the indoor conditions is negligible.

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