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Reasonable Location of Measurement Points in Measuring Device for Impact Energy Estimation in Performance Test of Rock Drill

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***Abstract*: A new structure of the impact energy measuring device, which can be used for performance testing of a percussive rock drill, was proposed and its performance was analyzed by means of finite element analysis. In the simulation, when the drill hits 50 J, the stress wave generated in the drill rod is about 64 MPa. Then the stress wave transmitted through the drill rod is converted into a pressure wave of oil inside the cylinder, whose maximum value is 15-28 MPa, which varies with position. Therefore, a reasonable location of the measurement points can increase the measurement accuracy while extending the service life of the sensor. From the results of the study, it can be seen that the new proposed device can be used effectively in the field of impact energy measurement of rock drill due to its simple structure and high reliability. Especially, it is possible to estimate its impact energy without altering the structure of the rock drill so that it can be used in the performance testing process in rock drill plants.**

***Keywords*: characteristic test, impact energy, pressure wave, stress wave.**

1. Introduction

The percussion drill receives energy from compressors or hydraulic pumps and transfers the impact energy through the drill rod and bit to crush the rock [1]. The impact energy, which is the main performance index of a percussive drill, was estimated by many researchers as an indirect method because of the difficulty of direct measurements. Kun Bo [2] performed a simulation of the motion of the impact and rotation mechanism of an air drill and verified the accuracy of the results by measuring the acceleration of the piston in the experiments. Un Hyok Yang [3] proposed a new method to experimentally determine the friction force of an air rock drill and to take its value into account in the simulation model. This method allows the estimation of the impact energy with an accuracy of about 2% when the performance of the pneumatic rock drill is evaluated. Zeng Bin [4] evaluated the performance of the rock drill by measuring the working pressure of the front and rear chambers in a hydraulic rock drill, and the error between the simulated and experimental values was 9.6%.

Y. Li [5] proposed a method to measure the impact velocity of an impactor in a hydraulic rock drill and, based on it, estimate the impact energy and impact power, and the measurement error was not presented. Sui Yang [6] confirmed the impact energy values by the stress wave method and the error between the simulated and experimental values was less than 9.8%. In paper [7], a method for determining the impact energy is proposed by measuring the deformation at the collision surface at the moment of collision of the piston and drill rod of a hydraulic rock drill. In paper [8], the stress wave method for determining the impact energy using strain sensors is claimed to be limited in range because of the short service life of the sensor and the difficulty of installation in the case of the drill rod rotating. S.B. Kivade [9] and D. Rempel [10] evaluated the performance of rock drills by drilling directly rock.

The measurement methods introduced above are difficult to apply to the performance tests of mass-produced drills, as they require the modification of the structure of the percussion drill or the preparation of standardized rock samples. In view of these practical requirements, we propose a new measurement device structure for impact energy and analyze its performance and availability in a simulation way. This device is simple in construction, convenient in use, and reliable, and will be widely used in industrial practice.

2. Structure of Hydraulic Impact Energy Measuring Device

Fig. 1 shows the structure of the hydraulic impact energy measurement station installed on the rock drill test bench.

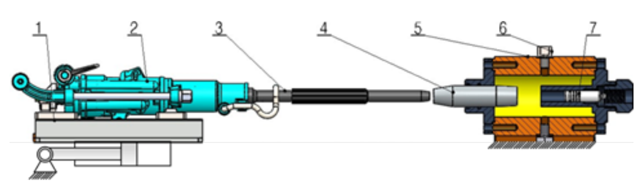

Fig. 1. Framework of the impact energy measurement unit of the pneumatic rock drill test bench
(1-rock drill rack, 2-pneumatic rock drill, 3-test rod, 4-plunger, 5-cylinder, 6-sensor, 7-oil injection piston)

As shown in Fig. 1, the impact energy measurement device consists of a rock drill, a test drill rod, a plunger and cylinder and a pressure sensor. The drill, a drill rod and a plunger are mounted on one axis and a sealing ring is installed between the plunger and the cylinder to reduce the oil leakage. As shown in

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Fig. 1, the impact energy measurement device consists of a rock drill, a test drill rod, a plunger and cylinder and a pressure sensor. The drill, a drill rod and a plunger are mounted on one axis and a sealing ring is installed between the plunger and the cylinder to reduce the oil leakage. The cylinder consists of a pressure sensor, an oil injection piston, and an oil discharge port, which removes air from the cylinder by means of a screw regulator of the oil injection piston. The cylinder contained about 2 L of oil and was firmly fixed to the base.

When compressed air is supplied to the pneumatic hammer, the piston moves forward and hits the test drill rod to generate a stress wave. This stress wave is transmitted to the fluid in the cylinder through the drill rod and plunger, generating a pressure wave, which is measured by a pressure sensor. According to the values measured in the pressure sensor, the computer displays the corresponding impact energy.

The structural features of the above-mentioned impact energy measuring device are: first, the simple structure, ease of operation, and second, the advantages of the measurement without altering the structure of the auger.

3. Simulation Method of Hydraulic Impact Energy Measuring Device

The geometric model for the analysis of the impact energy measurement device is shown in Fig. 2 below.

As shown in Fig. 2, the geometric model consists of a piston, a drill rod, a plunger, and an oil tank in order to visualize the propagation of stress waves and pressure waves in the impact system in detail. The geometry of the impactor is the same as the prototype "YT24", with a mass of 2 kg, a weight of 4.35 kg, a plunger diameter of 50 mm and a mass of 2 kg.

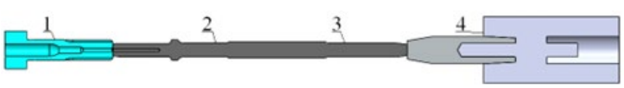

Fig. 2. Cross-section of the rock drill testbed
(1-piston, 2- test rod, 3- plunger, 4- oil)

In simulation, the following assumptions are adopted: First, the effect of the frictional force acting between the cylinder and the plunger is not taken into account. Since the coefficient of friction in the hydraulic device is very small compared to the impact force, the results of the study are considered to have no significant influence, and the friction force is neglected in the simulation. Second, when pressure waves occur, the deformation of the cylinder filled with working oil is not taken into account.

Under the above assumptions, a geometric model was established in the DM of Ansys workbench. To simultaneously observe the stress wave propagation process of a system composed of rigid bodies such as a piston, a drill rod and a plunger, and the pressure wave propagation in a liquid tank, the simulations are carried out by combining Transient Structure and Fluent in System Coupling. The contact condition shall be set to the sliding frictionless contact between the impactor, test drill rod and plunger. As shown in Fig. 3, the contact meshing between the piston, the drill rod, the drill rod and the plunger is carried out and the whole system is meshed by a multi-meshing method. The total number of elements is 89350 and the number of nodes is 10726.

The dynamic mesh for the oil model filled inside the cylinder is shown in Fig. 4, with 9741 nodes in the mesh and 42,834 elements. The maximum skewness is 0.765, which meets the dynamic solution stability condition of fluid analysis.

Fig. 3. Results of the mesh of rigid bodies

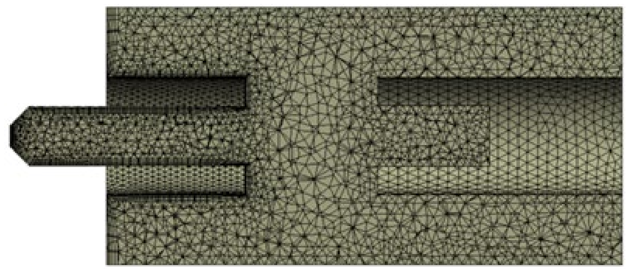

Fig. 4. The dynamic mesh for the oil model filled inside the cylinder

The outer surfaces of the liquid tank are set as wall boundary conditions, the plunger and contact surfaces are set as contact boundary conditions, and the pressure of the liquid tank is set as atmospheric pressure. Since the work of the impactor is an unsteady process, the unsteady analysis module is set, and the liquid tank material is set to Hydraulic Oil in the fluid analysis material library. The turbulence model uses the Realized k-ε model and the standard wall function. The dynamic meshing function is used to set the fluid boundary conditions for contact with the plunger and the liquid tank contacts. Set the initial velocity of the impactor as the initial condition. The initial velocity of the impactor is determined by the impact energy of the rock drill and the mass of the impactor. After applying the fluid contact boundary condition to the plunger contact as the boundary condition, the loading step time was chosen to be 0.6ms.

4. Simulation Results

First, stress waves and pressure waves occurring inside the measuring device were simulated when the impactor hit 50 J. Figure 5 shows the time-dependent propagation of stress and pressure waves. The two points (P1, P2) marked on the plunger and cylinder of the figure are the measurement points.

Since the result of the analysis at t = 0.1 ms is the state before the impact, no stress waves or pressure waves are generated in the measuring device. The plunger and fluid are in contact, and the fluid pressure has the same value as the initial condition. The impactor collides with the drill rod at t = 0.16 ms to generate a stress wave, which propagates positively and reaches the contact surface with the plunger at t = 0.26 ms. After collision, most of the stress waves propagate to the plunger and some are reflected back to the drill. At t = 0.28 ms, the stress wave propagating into the plunger reaches the contact with the oil inside the oil tank and then propagates in the fluid to produce a pressure wave, whose maximum value is 14 MPa.

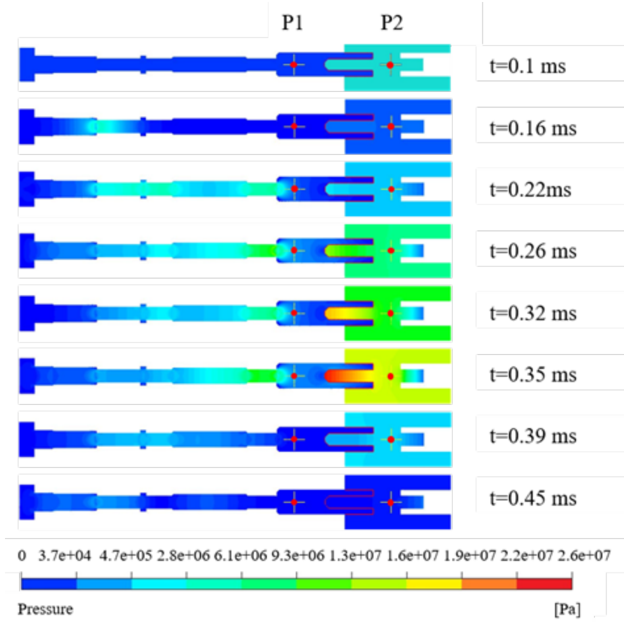

Fig. 5. Propagation of stress and pressure waves

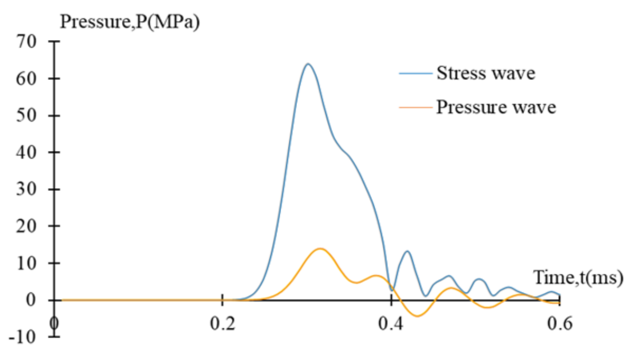

Fig. 6. Stress wave and pressure wave generated by the impact

Fig. 6 shows the time-dependent stress and pressure gradients at two measuring points P1 and P2 in the plunger and cylinder. As shown in the graph in Fig. 6, the stress wave generated by the impact reaches a maximum value (64 MPa) at the moment 0.22 ms to t = 0.3 ms in the plunger. Most of these stresses propagate from the plunger into the fluid, and some are reflected, leaving residual stresses in the plunger and gradually decaying. As can be seen from the graph, the graph plot after t = 0.4 ms shows the behavior of some reflected residual stresses as the stress waves collide with the fluid in the cylinder. With respect to the pressure change over time, the fluid in the cylinder reaches its maximum value (14 MPa) at the moment of 0.32 ms with the pressure wave generated at t = 0.25 ms and gradually decays inside the tank. In other words, the maximum value of the stress wave generated by a 50 J stroke is 64 MPa, and the corresponding pressure wave is significantly small at 14 MPa.

Next, six points inside the cylinder were selected for analysis in order to observe the pressure change with position in the fluid space inside the cylinder. Fig. 7 shows the measured position points in the cross-section inside the cylinder.

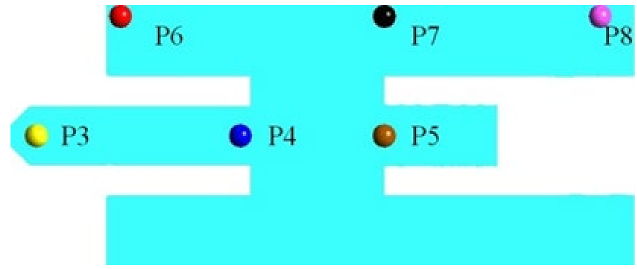

Fig. 7. Location of measurements in the cylinder cross-section

Point 3 was selected for direct contact with the plunger and points 6, 7 and 8 were arranged relatively apart from the contact area with the plunger. Four points were set centrally on the central axis in the cylinder, and five points were set at the point farthest from three points. The measurement results are shown in Fig. 8 below.

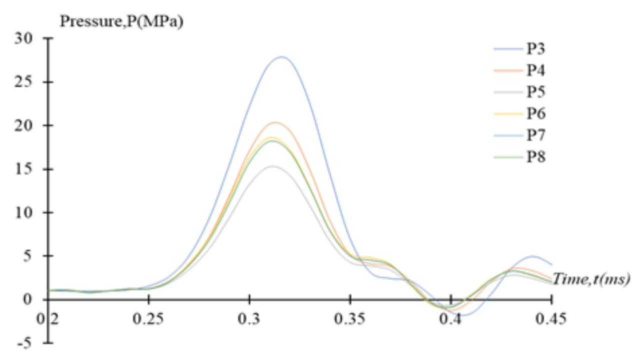

Fig. 8. Pressure variation with measurement position inside the cylinder

From Fig. 8, it can be seen that the maximum pressure value at each measurement points occurs at the moment t = 0.29 to 0.31ms. In addition, the measured value decreases away from the contact area with the plunger, with significant differences at points 3, 4, and 5 located on the central axis of the cylinder. It can be seen that the measurements at points 6, 7, and 8 located along the outermost rim, although decreasing away from the center line of the cylinder, have a relatively small range of variation.

Comparing the maximum measurements at the two most different measurement points, 3 and 5, we have a 1.79-fold difference of 27.4 MPa for point 1 and 15.3 MPa for point 4.

From the simulation results, it can be seen that the measurement values are different depending on the location of the sensor in the cylinder, so the location of the measurement points affects the measurement accuracy and the lifetime of the sensor.

As shown in the graph given in Fig. 9, the measurements between points 3 and 5 are the largest and the smallest at position 5, so it is reasonable in terms of sensor protection. The pressure measurement is about 1/5 of the stress wave generated by the impactor.

However, it should be emphasized that the precise measurement location at the manufacturing stage should be realized because the pressure measurements are different depending on the location of the sensor.

On the contrary, it can be seen that the pressure measurements at measuring points 7 and 8 are large, but the range of variation with position is small. Therefore, according to the designer's objective, a reasonable measurement points may be chosen differently.

5. Discussion

As shown in the above simulation results, the maximum value of the stress wave generated by the impact from the impactor is 64 MPa. It can be seen that the maximum value of the pressure wave propagating in the cylinder is considerably small at 14 MPa. The difference between the maximum stress and the maximum pressure is due to the different elastic moduli of the rigid body and fluid.

Therefore, compared to the stress wave measurement method, the pressure wave measurement method is advantageous for measurement because the impact force on the sensor is relatively small, and the service life of the sensor can be significantly increased.

The maximum value of the second waveform in the stress diagram in Fig. 6 is 6.5 MPa, which is about 9.9% as the residual stress transmitted to the cylinder. This residual stress gradually decreases, yielding in the rigid body. The time taken to completely disappear is 1.1 ms, which is very short compared to the impact period (about 20-50 ms) of the rock drill. Therefore, the residual stress remaining in the rigid body during the propagation of the stress wave is completely dissipated before the next collision and thus does not affect the measurements.

Likewise, the pressure diagram in Fig. 5 is different in size and similar, but it disappears completely before the next stroke. Therefore, it is considered that the pressure wave measurement method is capable of obtaining a maximum value by computer from the measured signals obtained, so that the relationship between the impact energy and the pressure wave can be fully determined. In addition, the proposed measurement device is simple in structure and can determine the impact energy without altering the structure of the rock drill, which is expected to be effectively used by factories specializing in the production of rock drills under field conditions.

Unfortunately, in our study, we did not investigate the effects of temperature and oil leakage on determining the relationship between the impact energy and the pressure value of the rock drill. However, since the characterization is carried out at room temperature and the leakage phase can be technically controlled, this effect is expected to be overcome.

In summary, we believe that our new proposed striking energy measuring device can be helpful in measuring the impact energy of striking machines such as rock drills under field conditions because of its simple structure, convenient operation and high reliability in field conditions.

6. Conclusion

In this study, a new structure of impact energy measurement device, which allows the measurement of impact energy without altering the structure of the rock drill, is proposed. The newly proposed measuring device is more reliable and more convenient to operate compared to the method of determining the impact energy by means of stress wave measurement. A finite element analysis method is presented to analyze the performance of the impact energy measurement device. The stress wave transmitted through the drill rod is converted into a pressure wave of oil filled inside the cylinder, whose maximum value is 15-28 MPa, which varies with position. Therefore, a reasonable location of the measurement points can increase the measurement accuracy while extending the service life of the sensor.

In the future, we will further investigate the effect of temperature on the impact energy measurement device so as to further reduce the error.

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