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Dynamic performance of self-controlling hydro-pick cutting rock

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ABSTRACT

A new self-controlling hydro-pick, which can control water flow automatically, was designed based on hydrodynamic theory. Firstly, the balance of forces acting on the pick was shown to present the operating principle of it, specifically, the force exerted by the water pressure acting over an annual area of the pick. A rock-breaking test bed was developed to study the frictional resistance, dynamic response, flow and rock-breaking characteristics of the self-controlling hydro-pick. The results indicate that, the external and internal diameter of the annual area on the pick should be 40.6 mm and 40 mm, respectively to ensure normal shutdown of the self-controlling hydro-pick at a jet pressure 40 MPa. The opening times (time taken to open the valve) increased with jet pressure and decreased with the cutting depth. For a jet pressure and cutting depth of 40 MPa and 12 mm, respectively, the opening time was 0.035 s. The water flow of the self-controlling hydro-pick was less than that of the common hydro-pick when the diameter of the damping hole was 0.5 mm. The percentage water flow reduction increased with the jet pressure and cutting depth. When the jet pressure and cutting depth are 40 MPa and 12 mm, respectively, the percentage cutting force reduction was 22.6%, the depth of the cutting slot increased by 24.2%, and the volume of rock breakage increased by 29.3%.

1. Introduction

Conical picks are essential cutting tools that are widely used in engineering machinery. The pick that directly impacts rocks is in a harsh cutting environment.[1–3] During the excavation of hard rock, conical picks are subjected to high cutting forces, extensive wear and high temperatures, which result in a short life and low cutting efficiency.[4,5] Many studies have been conducted, and the results show that the cutting efficiency can be improved by changing the pick structure, although this does not solve the fundamental problems of extensive wear and high temperature.[6–11] In contrast, it has been shown that using a water jet in rock breaking could effectively assist the cutting tools and reduce the cutting force, wear, temperature and dust.[12–17]

Thus, the performance of water jet was studied firstly in numerical and experimental.[18–24] It has been pointed out that there are two main types of rock fragmentation via a water-jet, the cutting effect and extrusion effect. For cutting effect, the rock is initially cut by the water jet, which results in a certain depth of slotting and the formation of a free surface on the rock surface, followed by fragmentation via machine tools. This approach can improve the rock fragmentation efficiency and reduce the cutting force of the machine tools. When the water jet acted via an extrusion effect, cracks are generated under the action of cutting via machine tools, which extend and propagate via the water jet, leading to rock further breaking.

Then, water jet technology has been widely used to assist tools for rock breaking, such as PDC cutters[25–28] and drilling tools.[29] As expected, it has been also applied in rock breaking by a conical pick. The mechanism of rock breaking via a pick assisted by a high-pressure water jet was studied and found to be divided into three processes:[12] (1) the hydraulic erosion process, when the water jet erodes the rock breaking zone; (2) the hydraulic fracturing process, when the expansion of micro cracks is accelerated by a water jet; and (3) the pore pressure process, when a pressurized water jet produces expansion, thus accelerating crack initiation and propagation.

At present, the arrangements of the water jet and pick are JCP (a water jet through the centre of the pick), JFP (a water jet placed in front of the pick), JSP (a water jet placed at the side of the pick) and JRP (a water jet placed behind the pick), as shown in Fig. 1(a)–(d).[30–32] The JCP mode is proved the best, followed by the modes of JRP and JFP, and the worst mode is JSP. The decrease in the rates of the pick force of the JCP, JRP, JFP, and JSP mode are up to 30.96%, 28.96%, 28.17%, and 25.42%, respectively, in experiments.

For the JRP, the nozzle is easy to interfere with rock in the cutting process, thus a new typed JRP was designed, shown in

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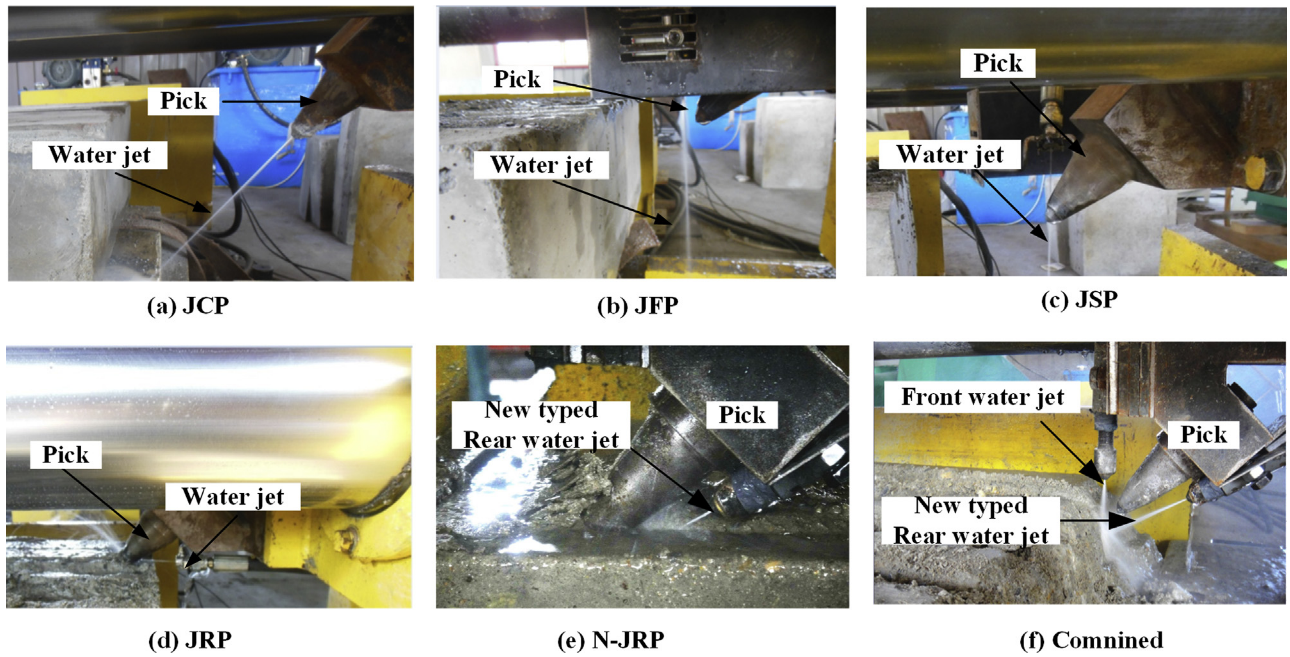

Fig. 1. Arrangements of water jet and pick.

Fig. 1(e).[33] Experiments on JFP, N-JRP and the combination of those two water jet configuration modes were conducted. The combined mode is shown in Fig. 1(f). The results showed that, the N-JRP is less effective than the JFP on decreasing cutting force. The variance of JFP is smaller compared with the N-JRP. The combination of those two water jet configuration modes is effective for rock breaking. It can both decrease the cutting force and low down the fluctuation. However, the effect of the combined water jet configuration is not that of the direct adding of JFP and N-JRP. Thus, the combined water jet should not be applied due to much water and energy waste.

The fruitful achievements of the previous studies provide a reference for this paper, but there still exists room for improvement. On the one hand, during the cutting progress, picks work in severe conditions. To avoid damage to nozzles by broken rocks, nozzles are installed far away from picks, resulting in long stand-off distances and high energy losses. Moreover, due to installation errors, the impact points of the pick and water jet may not be the same, and thus, water wedging cannot be fully effective. Thus, water jet should flow through the centre of the pick. On the other

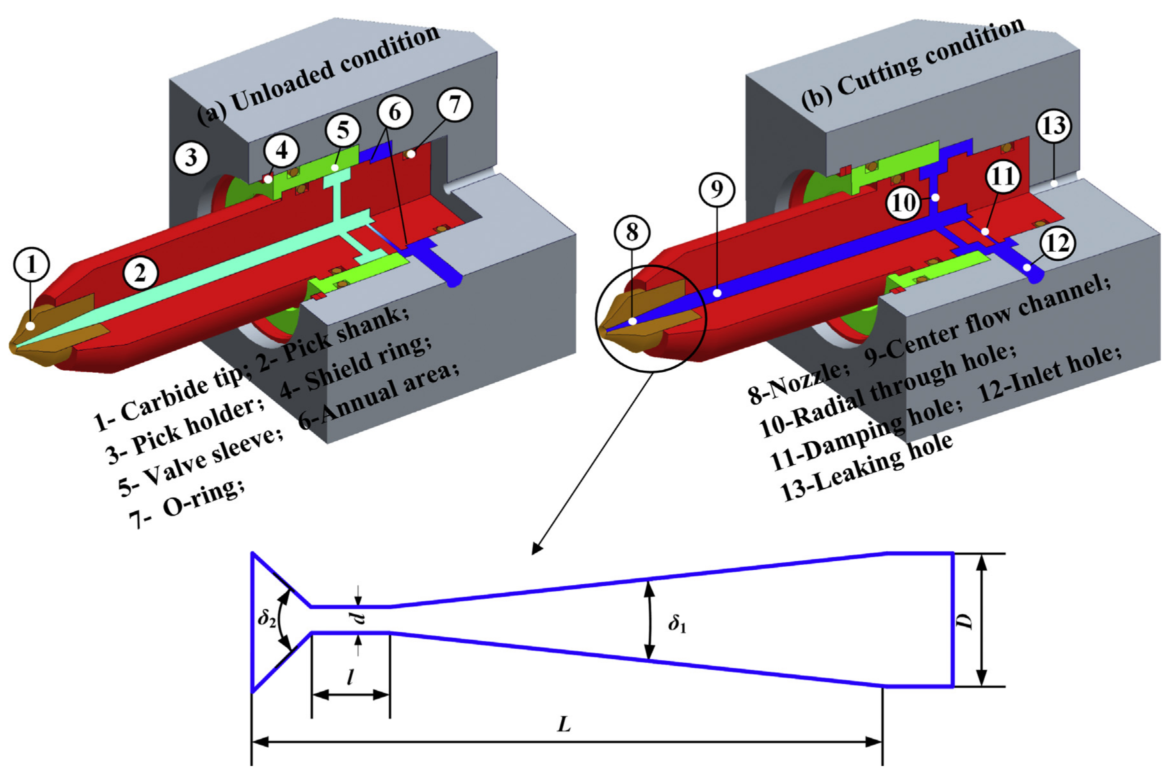

Fig. 2. Structure of the self-controlling hydro-pick and carbide tip.