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Rock fragmentation mechanisms and an experimental study of drilling tools during high-frequency harmonic vibration

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Abstract: Resonance drilling is a new technology, still at the laboratory stage. It has great potential to improve rock fragmentation efficiency. We analyzed the amplitude-frequency characteristics of steady-state mechanical vibration excited by harmonic vibration in rocks and an apparatus was built to achieve high frequency vibration of rock. The influence of rock drillability, rotary speed, excitation frequency, and other parameters on the rate of penetration (ROP) in resonance drilling was analyzed. The results show that the rock drillability decreased with an increase in excitation frequency. When drilling with a large size drill bit, the ROP increased with excitation frequency. The ROP reached a maximum value at the resonant frequency of the rock. The ROP of the bit increased linearly with rotary speed when no vibration was applied on the rock and increased approximately exponentially when harmonic vibration was applied. In addition, the resonant frequency of the rock was changing during the process of rock fragmentation, so in order to achieve the desired resonance of the rock, it is necessary to determine an appropriate harmonic vibration excitation frequency.

Key words: Resonance drilling, high frequency excitation, amplitude-frequency characteristics, natural frequency, drillability

1 Introduction

Resonance is a common phenomenon in nature (Broer, 2012). Due to its negative effects, drilling parameters are generally adjusted to reduce the occurrence of resonance phenomena (Cobern et al, 2007; Gonzalez et al, 2007; Gao and Gu, 2008; Eltrissi, 2009). Resonance drilling is a technology to achieve high fragmentation efficiency of rock. Adjusting the impact frequency of drill tools to the natural vibration frequency of the rock formation causes rock resonance to occur, which results in a high rate of penetration. Resonance drilling is a special rotary drilling technique operating at a particular impact frequency interval. High-frequency vibration drilling has been applied in metals, plastics, glass and other field broadly (Ishikawa et al, 1998; Zhang and Wang, 1998; Egashira et al, 2002; Tichkiewitch et al, 2002; Wang et al, 2004). At present, resonance drilling is still in the laboratory research stage. However, the use of resonance in breaking rocks has been applied in engineering and many achievements have been obtained (Ksaibati et al, 1999; Li, 1999; Zhang, 2005).

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Some researchers have undertaken a series of investigations into resonance drilling (Flanders et al, 2000; Wu et al, 2000; Gonzalez et al, 2007; Wiercigroch, 2010; Zou et al, 2010). Aberdeen University carried out laboratory experiments on rock fragmentation using resonance drilling and found that the cutting rate was 10 times higher than using conventional drilling. Yang et al (2007) investigated rock fragmentation mechanisms and the effect of crack propagation on rock fragmentation in the process of resonance. However, few previous studies have considered the coupled effect of rotary shear and impact vibration on rock fragmentation. Based on the principle of mechanical vibration, a calculation model of steady state vibration response was established. By carrying out experiments, the effect of mechanical and vibration parameters on rock fragmentation during resonance drilling was analyzed. The results provide theoretical guidance for the further application of resonance drilling.

2 Vibration response of rock in high-frequency harmonic vibration

A high-frequency rotary resonant device can keep shearing rocks as effectively as longitudinal vibration of the drill bit. It can improve the rock breaking efficiency by combing advantages of rotary and percussive drilling (high-