An experimental investigation of vibration characteristics in the diamond wire sawing of granite

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ABSTRACT

Compared with circular and gang sawing, diamond wire sawing is a flexible machining mode due to its special structure characteristic. The diamond wire with the elastic steel core bends and vibrates in sawing process. In this paper, the vibration characteristics are analyzed in the granite sawing with the diamond wire. The vibration signals in the sawing process are simultaneously measured at six different measurement points along the cutting zone. The influences of sawing parameters on the vibration characteristics are explored. The results show that the vibration amplitude is a U-shaped distribution in the sawing arc. The vibration amplitude decreases with the increase of wire speeds, feed rates and the tension forces. The vibration fundamental frequency is certainly proportional to the number of wheel speed times the number of beads per meter, which has no related to the feed rates and tension forces in the saw process. The wire vibration indicates the impact of bead acted on the workpiece.

KEYWORDS

Diamond wire; Granite; Sawing; Vibration amplitude; Vibration frequency

INTRODUCTION

Diamond wire sawing technology has been introduced to the stone processing industry since 1970s. It has been regarded as one key technology lighting up the future of diamond tools in the stone processing due to their environmental benefits, higher extraction rates, greater yield and ultimately cost competitiveness [1]. Nowadays, diamond wire sawing has been developed for many applications in the field of natural stone [2], construction materials [3] and metal materials [4], especially for very thick materials or components that are difficult to access.

The diamond wire is made up of a steel wire where small beads bonded with diamond grits are mounted at a regular distance with spacing material placed between the beads, as shown in Fig. 1. The steel wire acts as a spine to join all the beads. The beads provide the actual cutting action in machining process. The spacing materials acted to fix and insulate the beads are steel spring, molded plastic, rubber or the combination of the mentioned spacing materials, e.g. springs and rubber. The diamond wire bends and vibrates in cutting process due to the elasticity of twist steel, as shown in Fig. 1. The vibration of wire sawing is more obviously than in the case of the circular and gang sawing. Understanding the vibration behavior of the system is very pivotal in the prediction of dynamic behaviors and machining mechanism of the wire cutting process.

Linear and nonlinear vibration behaviors of a translating media, such as string, sheet, beam, have been studied. The vibration of moving media which is directly related to the wire saw process is shown in the references, especially in the wafer slicing with thin wire [5-7]. The vibration of wire is modeled as the transverse vibration of an axially moving string under tension. Some papers are presented the eigenfunctions and natural modes of transverse vibration.

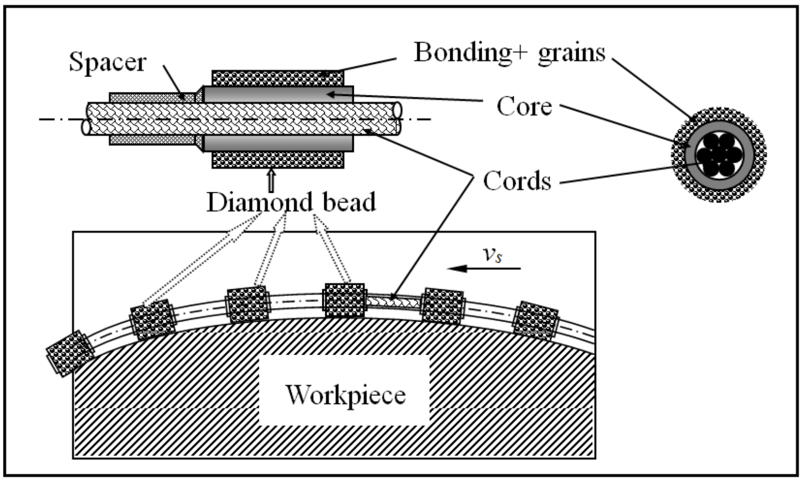
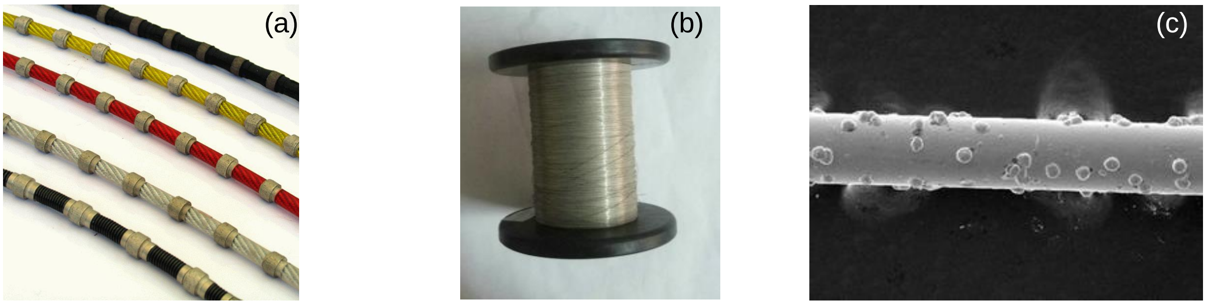


Fig. 1: Illustration of the diamond wire sawing

The structure of the wire used in the wafer slicing and the stone sawing is very different, as shown in Fig. 2. The wire used in the wafer slicing is homogeneous structure. However, the wire in the stone sawing is heterogeneous structure, as shown in Fig. 2(a). In this paper, the vibration characteristics of granite sawing with diamond wire were experimentally studied with a special device. The effect of machining parameter on the wire vibration was discussed.



(a) Wire for the stone sawing (b) Wire for the wafer slicing (c) Enlarged photo of (b)
Fig. 2: Wire used in the stone sawing and the wafer slicing

1 EXPERIMENTAL DETAIL

1.1 Sawing procedure

Wire sawing experiments were carried out on a developed CNC diamond wire machine which was smaller than commercial machines as illustrated in Fig. 3. The power of the spindle drive motor was 5.5 kW. The diamond wire was 5.5 m long, with a maximum wire speed of 45 m/s. The wire had 38 abrasive beads per meter length. The cylindrical sintered diamond beads were 7 mm in diameter and 6.5 mm in length, which contained diamond abrasives of mesh size of 40/50 (in US standard) and had a diamond concentration of 10 volume percentage. The gap between two adjacent beads was approximately 20 mm, giving a diamond bead ratio (λ, is the bead length over one meter of wire length) of 0.247. Prior to sawing, diamond beads were dressed by gently rubbing a refractory brick installed on the machine for 20 minutes until the diamond grits were fully exposed. The infeed of the diamond wire were carried out through two bevels gears driven by an electrical feed drive.

The workpiece material is typical natural granite (G603) which is the medium hard granite. The composition and mechanical properties of the workpiece are listed in Table 1. The rectangular specimens for testing were 600 mm long, 300 mm wide and 300 mm thick. A traditional grinding coolant nozzle was used to provide coolant and city water was used as the cutting fluids with the flow rate 0.25 l/s. The flow rate and the position of nozzle were kept constant.

Table 1: Compositions and mechanical properties of the workpiece

Workpiece name	Shore's hardness	Compression strength [MPa]	Percentage of main minerals [%]			Texture
			Quartz	Feldspar	Others	
G603	106	104.4	69.66	19.29	11.01	Fine and Compact

1.2 Sawing vibration measurement

The vibration of wire was measured with a high-precision laser displacement sensor (LK-G150), as shown in Fig. 3. Six different measurement points along the cutting zone were simultaneously measured to obtain the vibration signals in the cutting process due to the long cutting arc of wire sawing. The distances for the six measurement points were 50mm, 150mm, 250mm, 350mm, 450mm, 550mm, from the wire entrance into workpiece (as shown in Fig. 3). In order to avoid the effect of the vibration of sawing machine, the sensors were locked in special fixtures which are fixed in a bracket. The bracket was mounted on the ground and insulated from sawing machine. The vibration signals from sensors were fed to a Model View signal acquisition system at a sampling frequency of 10 kHz and recorded by a PC. The machining parameters used in the vibration test are listed in Table 2.

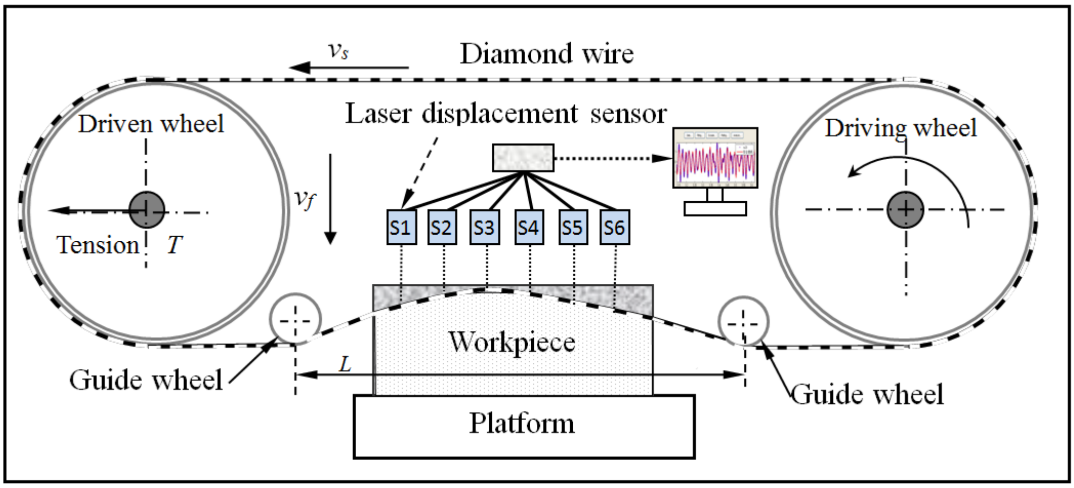


Fig. 3 Illustration of the wire vibration measurement

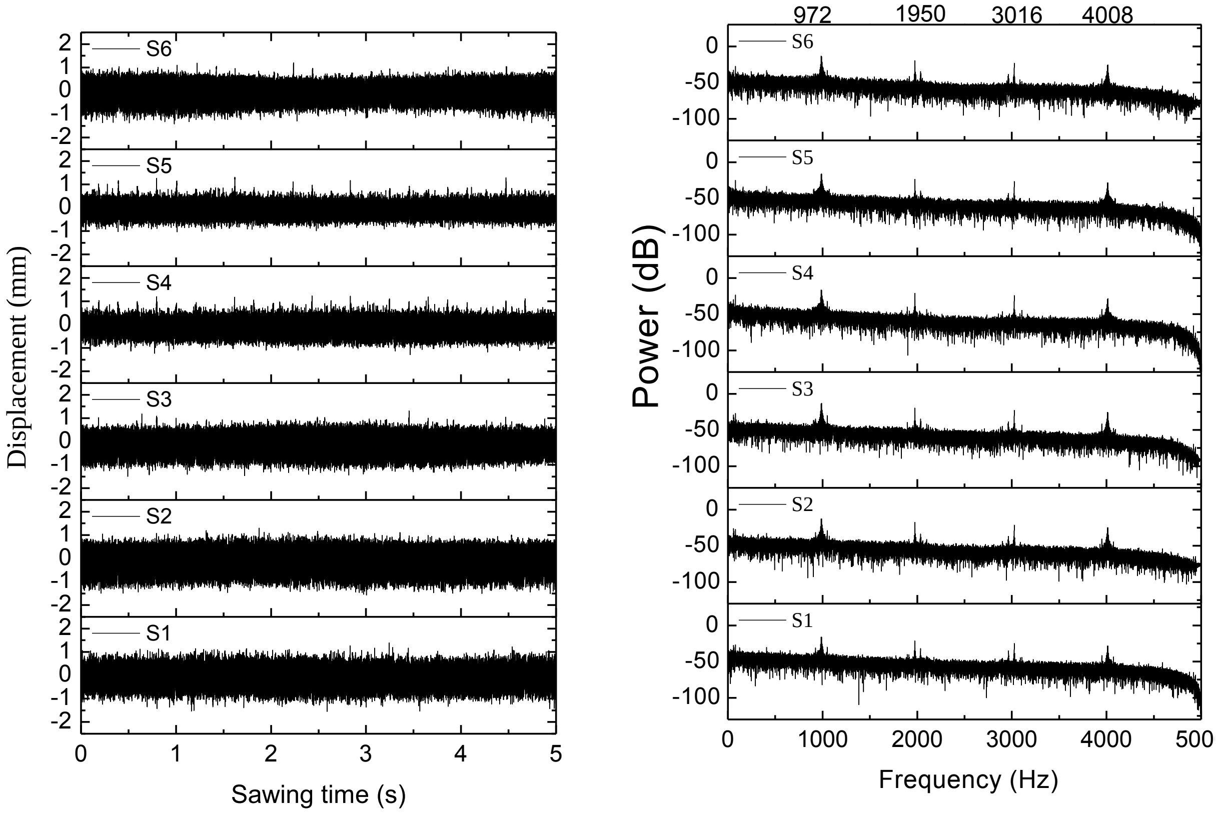
Table 2: The machining parameter used in vibration test

Wheel speed v_s [m/s]	18.32, 21.85, 25.38
Feed rate v_f [mm/min]	5, 8, 12
Tensile force T [N]	1380, 1500, 1650
Distance of the guide wheels L [mm]	650, 700, 750

2. RESULTS AND DISCUSSION

2.1 General aspects

Typical curves of sawing vibration obtained at different measurement displacements are shown in Fig. 4a. In general, the vibration signal is characterized by the vibration frequency and vibration amplitude. Fast Fourier Transform (FFT) is widely used in the frequency analysis of the vibration signal. The FFT curves of the vibration at different measurement displacements are shown in Fig. 4b. Although there are some differences in the vibration signal at each measurement displacement, the FFT curves are more similar. It is shown that the vibration fundamental frequency in this machining parameter is about 972 Hz. The values of the other dominant frequencies are similar equal to the multiplication of the fundamental frequency. Only fundamental frequency is recorded in the subsequent analysis. RMS (root mean square) is a statistical measure of the magnitude of a varying quantity. The vibration amplitude of wire sawing is described with RMS value defined as the square root of the arithmetic mean of the squares of the original amplitude values.



(a)Typical vibrations at different measurement points (b)FFT curves of vibration signal

Fig.4 Typical vibration signals and FFT curves obtained at different measurement points, where a wire speed of 25 m/s, a feed rate of 12 mm/min, a tension force of 1500N and a distance of 700 mm were used.

2.2 Effect of the parameters on the vibration amplitude

Figure 5-8 show plots of vibration amplitude versus machining parameters. It is found that the RMS values of the wire vibration amplitudes are about 0.4-1.6 mm. The vibration amplitudes on the different measurement displacements are obviously different. The vibration amplitude values at both ends of cutting region are bigger than that in the middle. There is U-shaped distribution of the vibration amplitude in the sawing arc. It is interesting that the RMS values are not symmetrical in the sawing arc. The position of the lowest RMS values is about 350 mm. This case may due to the cutting force distribution in the sawing region, which will be investigated in the future. The amplitude values are decreasing with the increasing wire speed, feed rate and tension force. The decreasing distance of the guide wheels could effectively decrease the vibration amplitude.

The vibration amplitude describes the impact degree of bead acted on the workpiece, which is relate to the contact condition of bead and workpiece. With the increasing feed rate and the tension force, the wire bending degree is decrease; therefore the vibration amplitude is correspondingly decreased. The increasing wheel speed increases the bead number into the cutting arc in per unit time. The material removal rate of each bead decreases and subsequently results in the decrease of impact of each bead. The vibration amplitude is also decreased.

In the other hand, the higher wire speed and shorter guide wheels distance improve the dynamic stiffness of wire, which also decrease the vibration amplitude.

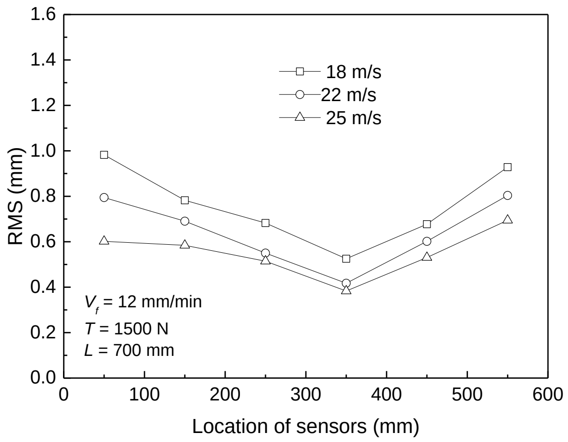


Fig. 5 Effect of the wire speed on wire amplitude

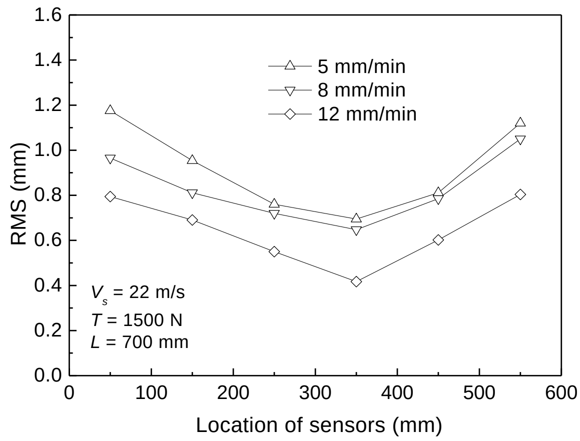


Fig. 6 Effect of the feed rate on wire amplitude

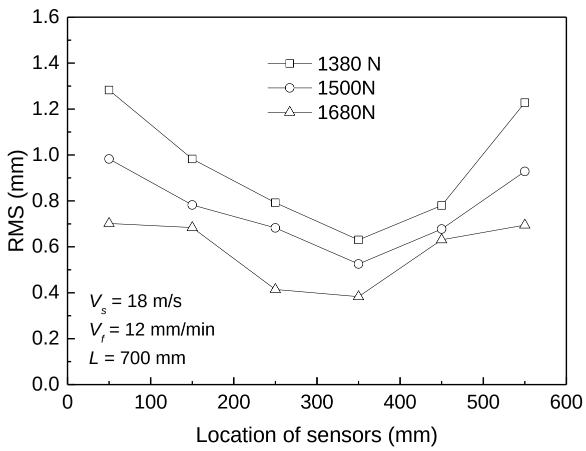


Fig. 7 Effect of the tension force on wire amplitude

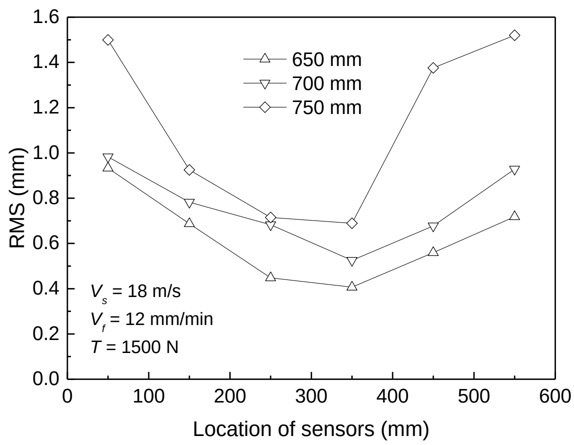


Fig. 8 Effect of the guide wheels distance on wire amplitude

2.3 Effect of the parameters on the vibration frequencies

Figure 9-11 show plots of vibration fundamental frequencies versus machining parameters. It is seen that the fundamental frequencies increase with the increasing wire speed as shown in Fig.9. Feed rate, tension force and the distance of guide wheels have no influence on the fundamental frequencies as shown in Fig.9-11. Therefore, the relationship between the wire speed and the fundamental vibration frequencies was reploted in Fig. 12. There exists a good linear correlation (R^2=0.997) between the vibration frequency and wheel speed, as shown in Fig. 12. The indicated slopes of N = 42.8 which is similar to the number of beads per meter.

From the experimental results, it is found that the fundamental frequency in wire sawing has no relevance to the feed rate, tension force and guide wheels distance. It is certainly proportional to the number of wire speed times the number of beads per meter. For understanding the implication of the wire vibration, it is useful to consider the structure of wire and the cutting kinematics at the interface between the abrasive tool and the workpiece in Fig.1. The product of the number of wheel speed and the number of beads per meter can be indicated the number of beads entering the cutting interface per time. From the diamond wire structure as shown in Fig. 1, it is found that there is the gap between the diamond bead and spacer. The gap causes the wire bounce up and down when the beads enter the cutting interface. Therefore, the wire vibration is the results of diamond beads entering the cutting region which is very different from the vibration of thin wire used in the photoelectric material cutting [7].

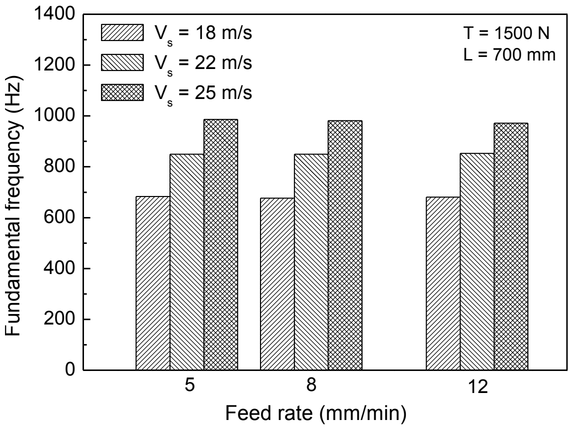


Fig.9 Effect of feed rate and wire speed on the vibration frquences

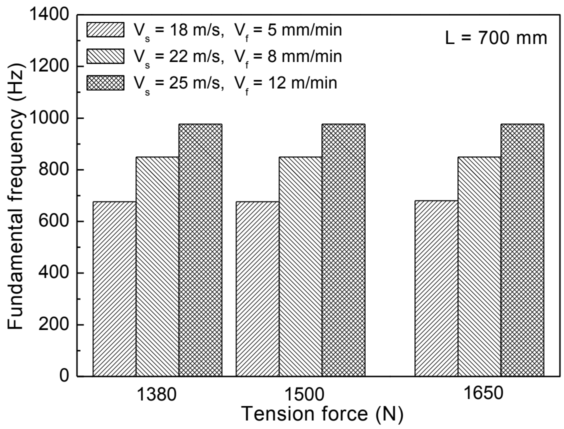


Fig. 10 Effect of tension forec on the vibration frequencies

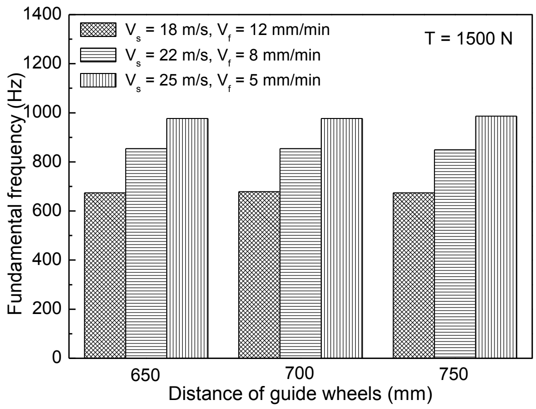


Fig. 11 Effect of guide wheels distance on the vibration frequencies

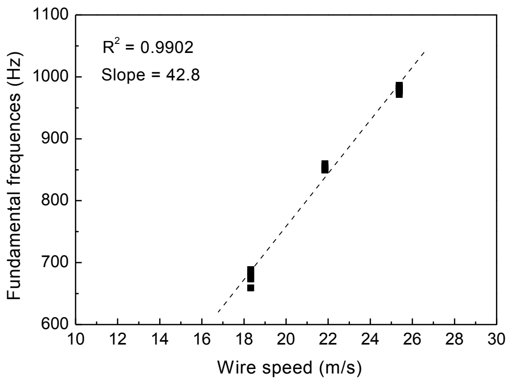


Fig. 12 Ralationship between the wire speed and the fundamental vibration frequencies

3. CONCLUSIONS

The vibration in the sawing arc for the granite sawing with a diamond wire was successfully measured at six difference points of the sawing arc with laser displacement sensors. The RMS values of the wire vibration amplitudes are about 0.4-1.6 mm. The vibration amplitude decreases with the increase of wire speeds, feed rates and the tension forces. The fundamental frequencies of the wire sawing is similar to the product of wire speed and number of beads per meter. However, fundamental frequency has little been influenced by the feed rate, tension force and the distance of the guide wheels.

ACKNOWLEDGMENT

Hui Huang, Guoqing Huang, Hua Guo, Xipeng Xu would like to acknowledge the financial support from National Key Technology Support Program of China (2012BAF13B04) and Natural Science Foundation of China(51175193).

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