Analysis of Impact Characteristics of Diamond-Beaded Rope and Its Influence on Cutting Efficiency and Life

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Abstract. The impact of wire saw cutting is one of the important factors affecting the cutting of diamond wire saw. It affects not only the efficiency of wire saw cutting, but also the service life of beaded rope. The actual working conditions of the impact of diamond wire saw cutting are analyzed in this paper. The wire saw impact model was built using ANSYS WORKBENCH and the dynamics simulation study was carried out. The stress distribution of the bead rope and maximum stress at different linear velocities are obtained. The results show that as the linear velocity increases, the additional stress on the bead increases. Through experiments, it is concluded that the wear of the bead will increase as the linear velocity increases. The cutting efficiency of the wire saw increases with the increase of the linear velocity in the early stage, but when the speed exceeds a certain speed, the cutting efficiency will decrease rapidly. Studies have shown that the impact of beading will be beneficial to cutting to a certain extent, but when it exceeds a certain limit, the bead wear will increase, which will seriously affect the cutting efficiency and service life.

1. Introduction
Underwater diamond wire saw cutting is a means of underwater mechanical cold processing[1]. Compared with other marine equipment, the diamond wire saw cutting method has strong adaptability to the marine environment, and has the advantages of large diameter of processing pipeline, and can cut metal materials, non-metal materials and composite materials[2]. Due to the non-continuous cutting characteristics of the wire sawing machine, the beaded rope will continuously impact the pipe wall during the working of the wire sawing machine[3]. The slight impact is beneficial to the cutting of the submarine pipeline, but the impact is too large, which will seriously affect the beading rope life and cutting efficiency[4]. There are currently few studies on this phenomenon.

2. Establishment of beaded rope impact model
2.1 Beading condition analysis
When the wire saw machine performs the cutting experiment, taking the round pipe as an example, the impact of the diamond bead and the cutting object is shown in Figure 1.

The figure 1 indicates several probability positions of a single diamond bead at the initial impact with the wall of the tube.
Figure 1. Beaded random position.

Combined with the model established in Figure 1, a single diamond bead is continuously struck against the pipe wall throughout the cutting process, and the impact position and timing are random, mainly acting on the radial motion of the beaded rope. The impact causes the diamond abrasive grains embedded on the substrate to fall off and break, reducing the working efficiency and service life of the wire saw. In the model, it can be considered that the main impact phenomenon is periodic and has the greatest influence on the diamond wire saw [5-6].

2.2 Bead impact model

The individual beads have a small mass, which is negligible here to simplify the model and other forces when hitting the transient state. In the event of an impact, it is assumed that the bead and the bead string are aligned at a sufficiently small length. The length of this beaded rope is assumed to be \( l \), and the impact model is established as shown in Figure 2.

Figure 2. Model of string bead wires impacting.

In the initial state, the bead rope moves at a speed \( v \) in the axial direction. When the left side of the bead hits the wall in an instant, the speed of movement cannot be abrupt, and an acceleration is generated. At this time, the force analysis of the bead is performed, and the projection to the bead axis direction can establish the equation (1):

\[
F_1 = (F + f) - F_h
\]

Where \( F_1 \) is the traction of the beaded rope on the left side of the bead; \( f \) is the friction of the tube wall against the outer surface layer of the beaded rope, and its value is small relative to the other two, which is ignored here; \( F_h \) is the mutual impact force between the bead and the tube wall. Then the stress on the bead rope can be written as (2) before the impact occurs.

\[
\sigma = \frac{F_1}{A} = \frac{F + f}{A} = \frac{F}{A}
\]

Where \( A \) is the cross-sectional area along the radial direction of the diamond bead.
At the moment of impact, a single bead can be decomposed into two parts of stress by transient stress $\sigma'$: one is the stress $\sigma$ generated by the traction force $F_1$; the other is the impact stress $\sigma_h$ caused by the impact force $F_h$:

$$\sigma' = \sigma + \sigma_h = \sigma + \frac{F_h}{A}$$

(3)

3. Explicit dynamics finite element simulation of beaded rope impact

3.1 Explicit dynamics simulation model for bead rope impact

Through the analysis of the single diamond bead motion process, combined with the diamond wire sawing machine to cut the 8′′ single-layer tube operation process, this chapter uses the explicit dynamics module in Ansys Workbench to simulate the impact effect caused by the beaded rope cutting 8′′ single-layer tube. The finite element simulation model is shown in Figure 3.

![Finite element simulation model](image)

Figure 3. Finite element simulation model.

3.2 Analysis of explicit dynamics finite element simulation results of bead rope impact

It can be seen from figure 4 that when the bead rope is in contact with the pipe wall, the stress at the contact point of the bead is the largest, and the stress on the bead rope near the impact position is the largest. The stress amplitude spread in the opposite direction of the movement direction of the wire saw, the further away from the impact position, the smaller the stress amplitude is. Due to inertia, the impact mainly affects the next bead, which has little effect on the subsequent bead rope.

![Stress cloud chart](image)

Figure 4. Stress cloud chart.

It can be seen from figure 5 that when the beaded rope moves at a given speed, its initial stress is small; but when the beaded rope collides with the pipe wall, the additional stress will reach a maximum. And the maximum value of the stress increases as the wire speed of the wire saw increases. After the impact, the stress on the bead rope decays rapidly and reaches a stable value.
As can be seen from figure 5, since the finite element model initially has a certain distance between the bead and the tube wall, when the bead rope speed is 18m/s and 19m/s, the bead and the tube wall are in contact with the tube wall at 0.000125s. At higher than 19 m/s, the bead is in contact with the tube wall at 0.0001 s. The maximum stress on the beaded rope is the smallest at 18m/s, reaching 83.396MPa, the maximum at 24m/s, and the maximum can reach 124.01MPa. Since the yield strength of the bead matrix is 350 MP, considering its fatigue characteristics, its fatigue strength should be 30% to 35% of its yield strength [7], so the impact stress should be less than 116 MA. As can be seen from the figure 6, the linear speed of the beaded rope should be no more than 23 m/s.

Figure 6. Maximum stress at different linear velocities.

4. Experimental study on the effect of beaded rope impact on cutting

4.1 Experimental equipment and method

The experimental platform is mainly used for underwater pipeline cutting experiments. The outer diameter of the beaded rope used in the experiment is 10.5mm, the diameter of the flywheels on both sides is 0.32m, the center distance is 1.4m, and the tension is 2000N.

To comprehensively study the impact of impact on the wear of different parts of the diamond saw rope, the single bead is divided into three parts: front, middle and back, as shown in figure 7.

Figure 7. Diamond bead segmentation diagram.
To objectively analyze the wear of the bead, 20 beads were selected as the research object at the same distance. The machine was stopped at intervals of 3 minutes. The diameter of the bead was measured twice in the direction perpendicular to the bead circumference. The average value is recorded as the measured bead diameter value.

4.2 Impact of impact on bead life

Figure 8 shows the SEM photograph of the bead at the end of the cutting. From figure 8, it can be seen that the diameter of the front and rear of the bead is significantly smaller than the middle of the bead. Most of the diamond abrasive grains have fallen off, and the carcass has obvious scratches. The cylindrical shape becomes a waist drum.

Figure 8. Bead SEM morphology at the end of cutting.

Figure 9, Figure 10, Figure 11 shows the variation of the diameter of different parts of the diamond saw rope at different cutting speeds (feed speed 0.25m/h, rope tension 1500N).
Figure 11. Diamond bead back diameter.

It can be concluded from the figure that the diameters of the front, middle and back parts of the bead are different at different cutting speeds. When the cutting speed is 18m/s, the diameters of the beads in front, middle and back are reduced by 1.59mm, 0.92mm and 1.77mm respectively. When the cutting speed is 21m/s, the diameters of the beads in front, middle and back are reduced respectively 1.99mm, 1.05mm and 1.89mm; the diameter of the bead in front, middle and back was reduced by 2.10mm, 1.26mm and 1.93mm respectively at the cutting speed of 24m/s. It can be seen that as the cutting speed increases, the wear of the beads increases. The cutting speed has a significant effect on diamond bead wear.

4.3 Impact of impact on cutting efficiency

Figure 12 shows the curve of the cut-away area of the steel pipe with the cutting speed (pressure 50N, feed rate 0.25m/h) in the same time.

Figure 12. Cutting amount at different cutting speeds.

It can be seen from Figure 12 that under the condition that the cutting speed is changed, the cutting area of the steel pipe will change. When the cutting speed is less than 22m/s, the cut-out area of the steel pipe increases with the increase of the cutting speed, but when the cutting speed is greater than 22m/s, the increase of the cutting speed reduces the cut-out area of the steel pipe.

5. Conclusion

In this paper, the finite element model of diamond bead rope impact is established. Under the condition that the tension of the bead rope and the constraint are the same, the other parameters are set. Only the influence of the speed of the bead rope on the impact is analyzed. The bead rope cutting life and cutting efficiency experiment were completed, and the experimental results were compared and analyzed. The conclusions are as follows:

(1) The impact of the wire rope on the impact is less than the impact of the diamond bead. The impact of the impact on the operation of the diamond wire saw is mainly due to the influence of diamond beads.

(2) The impact on the beaded rope increases as the speed of the beaded rope increases.

(3) The wear of the bead will increase as the impact increases.
Within a certain impact range, the impact will promote the cutting of the wire saw machine, but as the impact increases, the increase of diamond particle damage will also reduce the cutting efficiency and seriously affect the service life of the bead rope.

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