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Analysis on Vibration Characteristics of the Stringed Bead Wire of an Underwater Diamond Wire Saw

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Abstract. Vibration is one of the most important factors when the diamond stringed bead wire cuts pipeline, which not only affects the quality and efficiency of cutting operations but also affects the life of the stringed bead wire. The finite element model of the stringed bead wire is established by ANSYS Workbench in the paper. The all kinds of vibration of the stringed bead wire is analyzed by the dynamic simulation of diamond bead vibration, and The natural frequency and vibration amplitude of each order are obtained. The results show that the third - order model of stringed bead wire has large amplitude. The influence of the central distance of the drive wheel and the guide wheel and the diameter of the stringed bead wire on the vibration of the bead rope is studied, which obtain the third-order vibration amplitude of the stringed bead wire with the change of the two parameters and determine the best value of the amplitude of the bead rope in the saw cutting. The experimental results show that the effective cutting time of the stringed bead wire is the longer when the vibration amplitude is the optimum value,which means that service life of stringed bead wire is the longer.

1. Introduction

The diamond wire saw has a wide range of applications not only in mining, stone plate processing, special-shaped processing, road or building demolition, but also can be applied to ocean engineering operations such as cutting of submarine pipelines and demolition of pipeline support on offshore oil platforms [1]. The stringed bead wire, the main cutting part of diamond wire saw, is a kind of flexible processing tool with unique processing characteristics [2]. However, the vibration of the stringed bead wire will always accompany the entire cutting process of diamond wire saw. Slight vibrations are good for machining [3]. Severe vibration will cause the bead rope to break during operation and the excessive exfoliation of the diamond grains, which will seriously affect the cutting efficiency and service life of diamond wire saw [4]. Therefore, the issue of vibration of this type of flexible element attracted the attention of researchers. Wickert [5] studied the elastic moving string by using the modal analysis method of structural dynamic characteristics, and analyzed the steady state of any simple harmonic excitation on the string. Foda [6] used the Green function to study the suppression of the vibration of the fixed-axis moving string at both ends of the hole, and obtained a method to suppress the vibration of the axially moving string. Prof. Chen Liqun conducted in-depth theoretical research on the vibration of the axially moving string, and simplified this type of flexible element into an axially moving string [7]. However, there are few theoretical studies related to the stringed bead wire vibration. What are the relationships between the vibration amplitude of the stringed bead wire and various parameters, and how to adjust the parameters to achieve the purpose of vibration reduction. These issues are worthy of in-depth research.

2. Experimental conditions and finite element model

2.1. Experimental platform and conditions

The vibration frequency measurement of the stringed diamond bead wire is carried out on a prototype machine of the diamond wire saw. The experiment used the stringed bead wire produced by the Italian Maritime company to cut reinforced concrete and steel materials. The experimental platform is shown in figure 1. This experimental platform is mainly used for underwater pipe cutting experiments. The outer diameter of the bead used in the experiment is 10.0mm. The diameter of the flywheels on both sides is 0.32m. The center distance of the two flywheels is 1.4m. The stringed bead wire tension is 2000N. The cutting speed of the diamond wire saw is 23m/s.

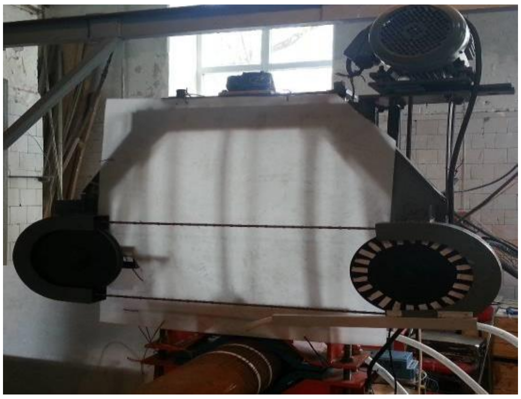

Figure 1. The stringed bead wire experiment bench

The natural frequency of free vibration allows the design of the mechanical structure to avoid resonance or to vibrate at a specific frequency, which is an important parameter in dynamic load structure design. The stringed bead wire vibration system mechanical model is shown in figure 2.

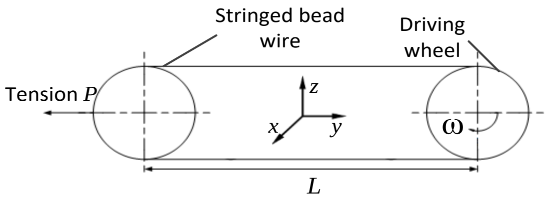

Figure 2. The stringed bead wire vibration system mechanical model

2.2. The establishment of the stringed bead wire finite element model

The study of longitudinal vibration of axially moving strings originated from the work of Skutch in 1897. When the axial displacement of the string is small, the linear vibration model can be used. In the previous study, the natural frequency of the stringed bead wire free vibration was obtained by analytical method, and the natural frequency is 771.5Hz. However, in practice, the structure of the stringed bead wire is complex and there are many influencing factors. Therefore, it is very important to establish the finite element vibration model of the stringed bead wire and to realize the free vibration simulation of the stringed bead wire [8].

The natural frequency finite element model of the bead string was established, which is shown in figure 3. In the model, the performance parameters of 45# steel are selected for the driving wheel, the driven wheel and the bead. Its elastic modulus is E=2.09e11Pa and its Poisson's ratio is μ=0.3. The wire rope belongs to the flexible body and its parameters are as follows: its elastic modulus is

E=0.981e11Pa and its Poisson's ratio is μ=0.26. In the contact setting, the annular section between the beading rope and the flywheels on both sides is in contact with the binding, so that the wire rope and the wheel are always in contact with each other within the angle of the wrapping angle. Then, meshing is performed. The meshing takes into account that the driving wheel, the driven wheel, and the beading rope are all in the rotating state. Therefore, the sweeping mesh is used for division. The set constraint is that the left drive wheel xyz is fixed in all three directions, the right driven wheel is fixed in the x and z directions, and there is a forced displacement along the y direction. The forced displacement of the driven wheel at the right end is obtained from the following formula (1):

$$\Delta l = \frac{TL}{EA} = \frac{2000 \times 3.81}{2.06 \times 10^{11} \times \pi \times \left(5 \times 10^{-3}\right)^2} = 0.471 \times 10^{-3} m \tag{1}$$

In this formula, T is the tension force of the stringed bead wire, L is the length of the stringed bead wire, E is the elastic modulus of the stringed bead wire, A is the cross-sectional area of the stringed bead wire.

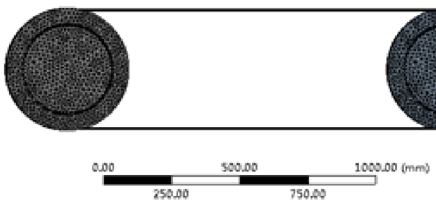

Figure 3. The stringed bead wire free vibration finite element model

3. Finite element result analysis

When Δl=0.471mm, the results are shown in figure 4, figure 5 and figure 6 respectively.

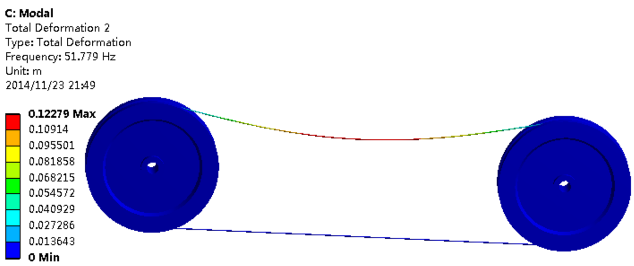

Figure 4. First-order model of the stringed bead wire modal analysis

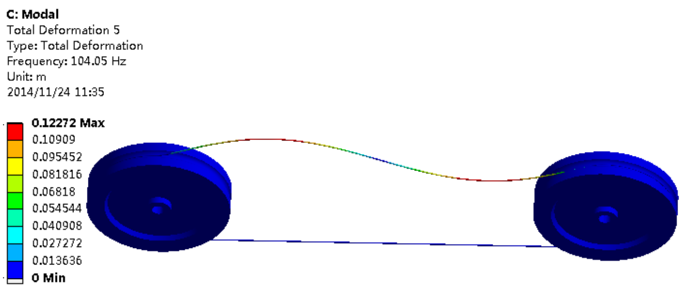

Figure 5. Second-order model of the stringed bead wire modal analysis

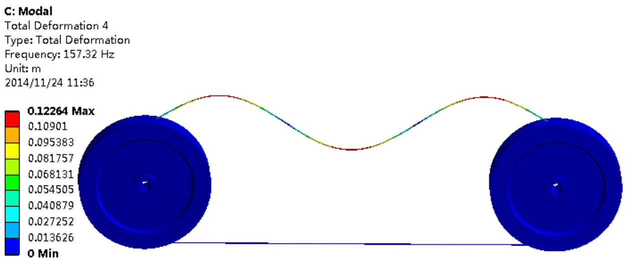

Figure 6. Third-order model of the stringed bead wire modal analysis

From figures 4, figures 5 and figures 6, it can be seen that the frequencies of the first, second and third order models of the stringed bead wire are 51.779 Hz, 104.05 Hz and 157.32 Hz respectively. It can be seen from figure 6 that the vibration amplitude of the third-order model during the stringed bead wire movement is relatively large. In view of this situation, this paper changes the two parameters of center distance L between the two rounds and bead diameter D, and focuses on the analysis of the variation law of the third order vibration amplitude of the beaded string with the corresponding parameters.

4. Influence of the parameters on vibratory amplitude of stringed bead wire

4.1. Influence of center distance on vibrational amplitude of stringed bead wire

In actual production, the distance L between the driving wheel and the driven wheel of the diamond wire saw varies with the cutting work size. In the simulation analysis, the nominal diameter of the wire rope is d=5.8mm, the outside diameter of the beads is 10mm, the number of beads per meter is 38, and the tension of the stringed bead wire is 2000N. figure 7 shows the amplitude values obtained when the parameters of L are set to 1.2 m, 1.3 m, 1.4 m, 1.5 m, and 1.6 m respectively. It is the third-order vibration amplitude of the stringed bead wire that changes with the center distance L.

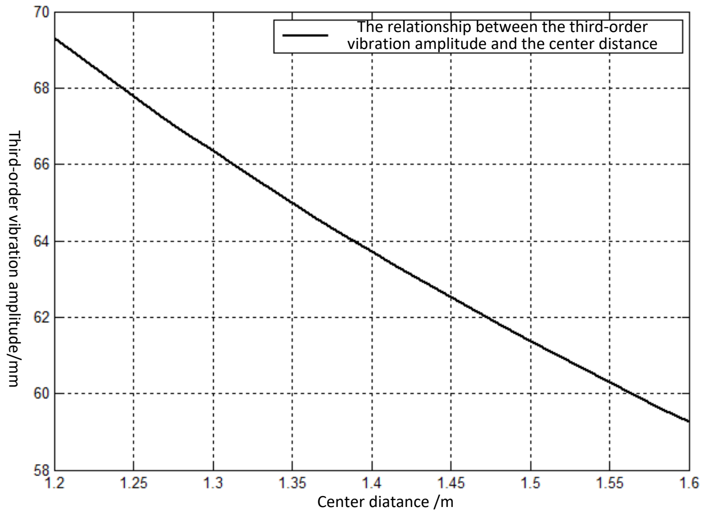

Figure 7. Change law of third-order vibration amplitude with central distance

From figure 7, we can see that when the center distance L is in the range of 1.2~1.6m, the vibration amplitude of the stringed bead wire third-order model decreases as the center distance increases, and the overall change trend is approximately a linear decrease. The main reason is that as the center distance increases, the length of the stringed bead wire becomes longer, so the vibration amplitude is reduced due to the energy consumption during the vibration process.

4.2. *Influence of bead diameter on vibration amplitude of stringed bead wire*

The bead diameter will decrease as the bead wears during beading. The nominal diameter of wire rope, the length of the stringed bead wire and the bead number per meter are set as in the previous paragraph. Bead diameter is taken as 9.0mm, 9.5mm, 10.0mm, 10.5mm and 11.0mm respectively. In this condition, simulation analysis is performed. The vibration amplitude of the stringed bead wire modal analysis is shown in figure 8.

From figure 8, the diameter of the bead is in the range of 9~11mm, and the other parameters remain unchanged. With the increase of the bead diameter, the vibration amplitude of the stringed bead wire third-order model also decreases, and the overall change trend is approximately linear.

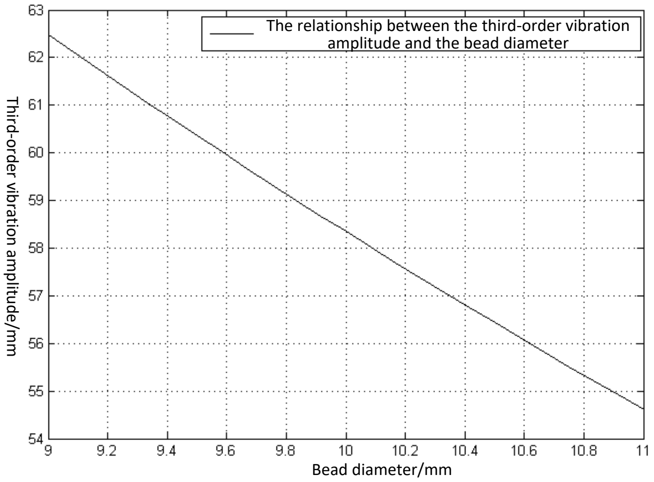

Figure 8. Change law of third-order vibration amplitude with bead diameter

4.3. *Influence of two-parameter coupling on vibrational amplitude of stringed bead wire*

From figure 9, the corresponding relationship between the third-order vibration amplitude of the stringed bead wire and the two parameters (the bead diameter and the center distance) is approximated as a curved surface, which is not a single linear proportional relationship.

As shown in figure 9, the sensitivity curves of the two parameters corresponding to the curved surface are displayed, where DS_1 is the bead diameter and DS_2 is the center distance.

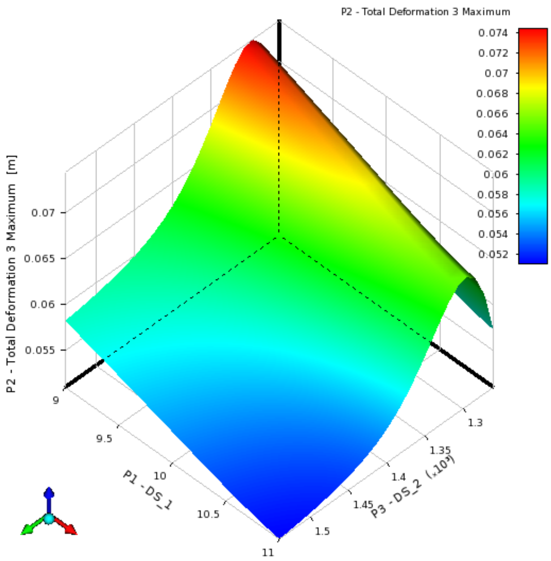

Figure 9. Correspondence between output and input parameters

From figure 10, when the sensitivity is less than 0.5, the curve DS_2 is above the curve DS_1, which indicates that the variation of the center distance has a greater influence on the vibration amplitude of the stringed bead wire. On the contrary, when the sensitivity exceeds 0.5, the curve DS_1 is above the curve DS_2, which indicates that the diameter of bead has a greater influence on the vibration amplitude of the stringed bead wire. When the sensitivity is 0.5, the two effects are equivalent, and the stringed bead wire vibration amplitude is about 0.0585m.

5. Influence of the parameters on vibratory amplitude of stringed bead wire

In this paper, based on the existing experimental platform, the experimental study, the influence of the center distance and the bead diameter on the stringed bead wire cutting life, was carried out. During the experiment, the center distance was changed by adjusting the tensioning device. The center distance is adjusted to 1.2m, 1.25m, 1.3m, 1.35m, 1.4m, 1.45m. According to the diameter size of the commonly used stringed diamond bead wire, the experimental stringed bead wire diameter is 9.0mm, 10.0mm, 10.5mm, 11.0mm respectively. The stringed bead wire cutting life is evaluated based on the effective cutting time per unit length, which is the ratio of the effective cutting time of the wire saw to the length of the beaded rope. When the cutting speed of the diamond wire saw is 23m/s and the feed speed is 2.5mm/min, the data is measured. And the change law curve is drawn.

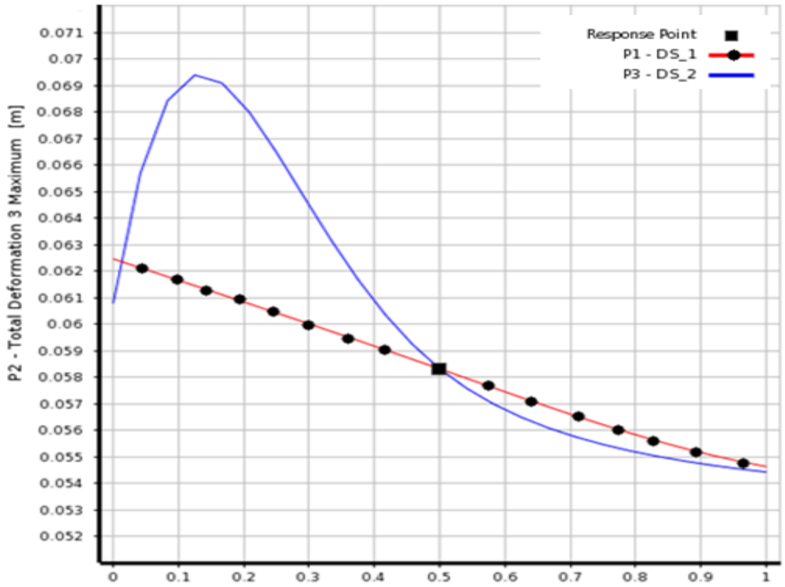

Figure 10. Parameters curve sensitivity correspondence

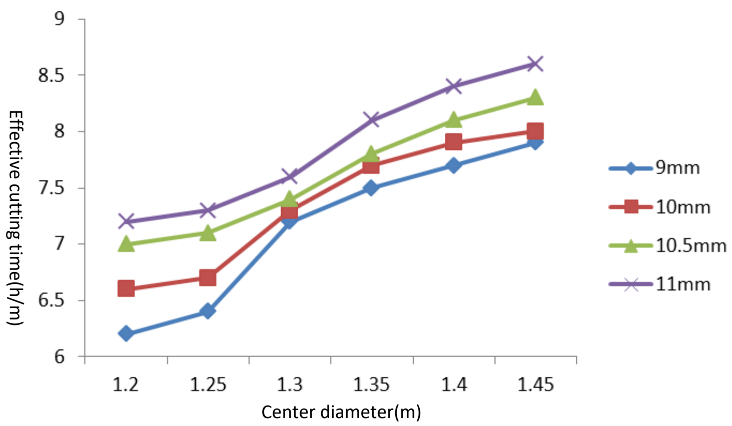

Figure 11. Cutting life test curve

The curve of the cutting life test change law is shown in figure 11. As can be seen from figure 11, when the center distance is constant, the effective cutting time of the stringed bead wire becomes longer as the bead diameter increases. And when the bead diameter is constant, the effective cutting time of the stringed bead wire increases with the center distance increasing. From the simulation results, it can be seen that as the center distance and bead diameter increase, the vibration amplitude of the stringed bead wire decreases. In summary, the stringed bead wire vibration amplitude of the diamond wire saw has an impact on the cutting life of the stringed bead wire. When the vibration amplitude affected by the center distance and bead diameter becomes small, the stringed bead wire has longer cutting times, which means the cutting life of the stringed bead wire becomes longer. The stringed bead wire cutting life test was completed and the experimental results were compared and analyzed. Draw conclusions as follows:

6. Conclusion

In this paper, the free vibration finite element model of the stringed diamond bead wire is established. When other parameters are fixed, the influence of center distance and bead diameter on vibration amplitude was analysed.

(1) Within a certain range of the center distance, if the center distance between the driving wheel and the driven wheel of the diamond wire saw machine increases, and the vibration amplitude of the stringed bead wire will decrease accordingly.

(2) If the bead diameter of the stringed diamond bead wire increases, the vibration amplitude will be reduced.

(3) If the bead diameter of the stringed diamond bead wire increases, the vibration amplitude will be reduced, the center distance has a great influence on its vibration amplitude during the initial vibration stage. Subsequently, the bead diameter gradually becomes the dominant influence factor of the vibration amplitude change.

(4) According to the sawing experiment of the diamond wire saw, the center distance and the bead diameter of the diamond wire saw will affect the cutting life of the diamond wire saw. Two parameters jointly affect the third-order vibration amplitude of the stringed bead wire. And the smaller the vibration amplitude, the longer the effective cutting time of the stringed bead wire.

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