Structure Design of Detachable Knotter mouth and Its Fatigue Performance Analysis

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Abstract. Knotter mouth is the key part of the knotting on the knotter. Under the action of variable amplitude cyclic load, such as extrusion, shear, torsion and so on, the surface wear of knotter pliers and the fracture of clamp hooks are easy to occur. It takes a long time to disassemble and assemble the knotter mouth, which seriously affects the field operation efficiency of the square baler. In view of the present situation that the knotter mouth of D-type knotter is easy to fail and difficult to replace, on the premise of not affecting the normal knotting function of the knotter, the detachable knotter mouth is designed and completed by reasonably designing the thread structure and rotation direction of the knotter mouth. The disassembly and assembly time is significantly reduced, which is beneficial to the continuous operation of the square baler. ANSYS simulation analysis shows that, compared with the original knotter mouth, the maximum equivalent stress and maximum equivalent strain of the detachable knotter mouth are increased by less than 3%, and the maximum impact fatigue life of the detachable knotter mouth is 60 000 times. The fatigue life of the knotter mouth is much lower than that of the original knotter mouth, but it can still meet the rated life requirements of 40,000 knotting times of the knotter. The research content makes full use of the safety margin of the knotter mouth structure, which has reference value for facilitating the maintenance and replacement of the knotter mouth and improving the operation efficiency of the whole machine.

Keywords: the mouth of knotter, detachable, structural design, fatigue performance

1. Introduction
The assembly of the D-type knotter on the square baler is shown in figure 1. The process of removing the knotter is troublesome As shown in figure 2, the gear and the rod of knotter mouth are connected by a pin. It is observed that the pin type is a coil type elastic pin, and the outer diameter of the pin is measured to be 5 mm, which is slightly larger than the diameter of the pin hole, so, the link is tight. Cooperate. Therefore, if the disassembly is to be carried out directly, it is likely to make the frame damaged, as shown in figure 3.
The knotter mouth is the part of the D-type knotter on the square baler, which is responsible for knotting the rope. [1] The top-end is subjected to the variable amplitude cyclic load of the rope, such as pressing, shearing and torsion, and the rope is caught by the joint action of other mechanisms. A series of complicated movements, such as buckles, are the wearing parts on the knotter, so it has a very important influence on the overall performance and service life of the D-type knotter. [2]
Figure 4 shows the damaged knotter mouth that is removed from the D-type knotter. It can be seen from the figure that there are two forms of damage to the knotter mouth: 1. The surface of the knotter mouth is seriously worn; 2. The joint of the roller on the bite bar is broken. No matter what happens in the knotter, the D-type knotter will not continue to work and must be replaced to continue working. [3]

Based on the above, this paper has a detachable design for the knotter mouth, which is easy to damage and not easy to replace. The fatigue performance is analyzed and compared with the fatigue performance of the original knotter mouth.

2. knotter mouth detachable design

This article does not affect the normal knotting function of the D-type knotter. A detachable improvement was made. The improvement content is shown in Figure 5: the knotter mouth bar and the knotter mouth are originally divided into two, and the two are threaded links. According to the power input direction of the D-type knotter and the rotation direction of the knotter mouth, the end of the knotter bar is designed as an external thread structure, and the end of the knotter mouth is designed as an internal threaded structure. [4] When the knotter mouth is broken, like the break of the bite bar and the invalidation of the knotter mouth, the incomplete gear on the rod does not need to be disassembled. The knotter mouth can be disassembled and replaced directly on the square baler. The specific data of the thread design is shown in Table 1. The relevant parameters of low carbon alloy steel are shown in Table 2. [5]

| Table 1. The parameters of thread design |
|-----------------------------------------|
| Maximum torque | Knotter rod diameter | Knotter mouth material | Thread Type |
| 45 N·m         | 15 mm                | Low carbon alloy steel  | Single thread |

| Table 2. The parameters of low-carbon alloy steel |
|-----------------------------------------------|
| Yield stress | Elastic modulus | Poisson's ratio |
| 620.4Mpa    | 210Gpa          | 0.28            |

Since the thread is subjected to the preload force and the preload force is controlled, the safety factor \( n = 1.2 \) is selected. The strength is calculated according to the tight bolt connection that only bears the preload. [6]

\[
T \approx 0.2F_0d \quad (1)
\]

The tensile stress of the dangerous section is:
The torsional shear stress of the dangerous section is:
\[ \tau = \frac{\tan \lambda + \tan \phi}{1 - \tan \lambda \tan \phi} \frac{2d_i^2}{\pi d_1^2} \frac{F_0}{d_1^2} \]

According to the fourth strength theory, the calculated stress is:
\[ \sigma = \sqrt{\sigma^2 + 3\tau^2} \approx 1.3\sigma \]

That is, the threaded connection subjected to the pre-tightening force is subjected to the composite stress of the torsion caused by the frictional moment between the thread pair, and the strength can be calculated according to the pure tension, but the tensile force is increased by 30% because of the effects of torsional moments.

Therefore, the strength condition of the dangerous section is:
\[ \sigma = \frac{1.3F_0}{4d_1^2} \leq [\sigma] \]

At the same time, it is necessary to consider the strength of the thin-walled round shaft which is caused by the thread of the knotter mouth. If the thread diameter is too large, the threaded hole of the knotter mouth may be damaged due to insufficient thin-wall strength. The maximum diameter allowed is calculated by twisting the circular axis. [7]

The maximum shear stress for the torsion of a circular shaft is:
\[ \tau_{\text{max}} = \frac{TR}{I_p} \]
\[ W_p = \frac{I_p}{R} \]

The torsion section factor is:
\[ W_p = \frac{2I_p}{D} = \frac{\pi D^3}{16} \left(1 - \alpha^4\right) \]

Of which, \( \alpha = \frac{d}{D} \), which represents the ratio of the inner and outer diameters of the hollow circular section. [8]

It can be seen from the figure 5, that the detachable knotter mouth is assembled, and there is no change in the shape and the original knotting mouth, and other sizes and materials are consistent with the original. Because when the D-type knotter works, the driving toothed disc drives the incomplete gear on the knotter mouth to rotate clockwise (from the knotter mouth rod to the direction of the knotter mouth), the binding rope will apply a torque in the opposite direction to the knotter mouth, so if the pre-tightening force is not applied, the mouth will be tightened more tightly during the roping process. [9]
Once the rotational displacement is generated, the timing of the knotter mouth and the disengaging rod will change. As shown in figure 6, it is the relative position of the disengaging bar and the knotter mouth when the tripping action is about to be performed. The preload force can be determined by referring to the maximum torque applied by the rope to the knotter mouth, \( t \) is 45 N·m. When disassembling the broken knotter mouth, only need to fix the incomplete gear, and then use the vise to clamp the end of the knotter mouth to counterclockwise (from the knotter mouth to the direction of the knotter mouth rod) to rotate.

3. Strength check and fatigue verification

The thread structure of the detachable knotter mouth weakens the strength of the knotter mouth, so it is checked for strength, and it can be verified by simulation calculation of fatigue life. Design life of D-type knotter: knotted 40,000 bundles. [10]

3.1. Finite element analysis

The main material of the knotter mouth is low carbon alloy steel. After multiple heat treatment processes and surface degree chromium treatment, the yield stress and other parameters are shown in Table 2. Define materials for more than one parameter in the workbench's engineering material library.

Through the analysis of the force of the knotter mouth, it is mainly affected by two kinds of loads: the torque of the tied rope to the knotter mouth and the collision of the disengaging bar against the knotter mouth. [11] This part of the collision cannot be avoided. In order to obtain the magnitude of the load during the collision, the entire D-type knotter model was introduced into the ADAMS for motion simulation, and the force curve of the contact portion at two cycles was acquired. The result is shown in figure 7 below:

![Figure 7. The force curve of the contact part of the knotter mouth and the disengaging bar](image)

It can be seen from figure 7 that the maximum contact force between the knotter mouth and the disengaging bar is close to 1000N. The maximum force found in the literature is 1320N. In summary, the original knotter mouth and the detachable knotter mouth are respectively applied with loads of 1000N and 1350N in the position that shown in figure 8 below. After the static solution is obtained, ncode is started to calculate the stress fatigue life that is alternating load under constant amplitude.

3.2. Simulation results of transverse load on the knotter mouth
When performing stress simulation on the detachable knotter mouth, the threaded connection of the knotter mouth bar to the knotter mouth is set as the binding contact. The simulation results take the 1000N lateral load of the knotter mouth as an example, and the maximum equivalent stress and equivalent strain of the original knotter mouth are obtained as shown in figure 9. The maximum equivalent stress and equivalent strain of the detachable knotter mouth are as follows figure 10 shows.

It can be seen from the above two figures that the maximum equivalent stress of the two is much smaller than the material yield stress of 620 MPa. Under the same boundary conditions and equal load, the maximum equivalent stress and the equivalent strain of the detachable knotter mouth is 2.16% and 2.18% larger than the original knotter mouth. It can be seen that the threaded connection still has an effect on the strength of the knitter mouth, but it is completely within an acceptable range. [12]

Therefore, when calculating the fatigue life in ncode, the load map should be set as shown in figure 11 below: Right-click the stress fatigue analysis engine block Perform load map editing, setting the maximum factor and the minimum factor to 1 and -1 respectively, which means that the load loading form is the amplitude round-trip loading. In this loading form, the fatigue life of the two knotters is shown in figure 12. The left side of the picture is the original knotter mouth, and the right side of the picture is the detachable knotter mouth.

In order to ensure the reliability of the simulation results, for the maximum collision load of 1320N on the
knotter mouth found in the literature, the simulation calculation is carried out with the same condition under the load of 1350N amplitude, and the result of the cloud diagram shown in figure 13 is obtained:

![Figure 12. Fatigue life comparison diagram of knotter mouth](image)

![Figure 13. The cloud chart of the simulation results of the 1350N load](image)

Figure 13 (top) is the result of the original knotter mouth, and figure 13 (bottom) is the result of the detachable knotter mouth. The above results are summarized to obtain the results shown in Table 3 below:

### Table 3. The simulation results of fatigue life of knot mouth

|                  | Original knotter mouth | Detachable knotter mouth |
|------------------|------------------------|--------------------------|
| 1000N            | Maximum equivalent stress(Mpa) | 171 | 174 |
|                  | Maximum equivalent strain(mm) | 0.82 | 0.84 |
|                  | Minimum fatigue life(times) | $3.5 \times 10^5$ | $1.6 \times 10^5$ |
| 1350N            | Maximum equivalent stress(Mpa) | 230 | 235 |
|                  | Maximum equivalent strain(mm) | 1.11 | 1.14 |
|                  | Minimum fatigue life(times) | $1.8 \times 10^5$ | $6.0 \times 10^4$ |
It can be seen from the above results that under the load of 1350N, the fatigue life of the knotter mouth has also reached 60,000 times, which still exceeds the design life of the D-type knotter. Therefore, the detachable design of the knotter mouth fully satisfies the requirements of the D-type knotter in terms of stress damage. [13]

3.3. Mulation results of torque load on the knotter mouth

The maximum torque of the tied rope to the knotter mouth is 45 N·m, which is rotated around the knotter mouth rod and applied to the knotter mouth to obtain a stress cloud diagram as shown in figure 14 below:

The left side of figure 14 is the stress cloud diagram of the original knotter mouth, and the right is the stress cloud diagram of the detachable knotter mouth. It can be seen from the figure that the maximum equivalent stress of the detachable knotter mouth is about 25Mpa larger than the original knotter mouth, but the maximum equivalent stress of both is less than 200Mpa than the yield stress of the material, so it is safe. [14]

In order to obtain the critical value of the torque damage, after multiple simulations, the result shown in figure 15. That is, when the maximum equivalent stress value is close to the yield stress value of the material, the maximum torque that the original knotter mouth can withstand the bundle rope is 76N.m, the detachable knotter mouth is 70N.m, which is nearly double the torque value that the rope is generally applied to the knotter mouth, so it is proved that the detachable design of the knotter mouth is also satisfactory in terms of resistance to torque damage. [15]

4. Conclusions

The traditional knotter mouth is prone to damage such as surface wear and nipper rod breakage, but due to the small disassembly space, the disassembly and assembly is not easy, which makes the replacement of the knotter mouth extremely complicated; if it is directly disassembled, it is extremely easy to damage the frame. Caused irreversible damage and further expanded losses. Therefore, a detachable design of the knotter mouth is more advantageous for quick replacement when the knotter mouth is damaged, and does not affect other components, and improves the overall knotting efficiency.

The ANSYS is used to compare the detachable knotter mouth with the original knotter mouth. The results show that after the detachable design of the knotter mouth, although it has been affected in terms of strength and fatigue life, it still has good reliability under the condition that the strength and fatigue life meet the requirements of use.

Considering the interaction and cooperation between the knotter mouth and the incomplete bevel gear, it should be noticed that the relative position between the knotter mouth and the rod of the knotter mouth during processing and assembly. The detachable knotter mouth is identical in size with the original knotter mouth, and does not require re-matching design of other components, thereby solving the problem of difficulty in disassembly and replacement after the knotter mouth is damaged.

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