Force and Strength Analysis of the Reel with Jaw of Torsion-bar Spring

Ke Ma, Weiqi Liu, Jiawei Wang, Le Gu
College of Mechanical & Electrical Engineering, Hohai University, Changzhou, 213022, China
make@hhu.edu.cn

Abstract. Structure characteristics and working principle of the reel with jaw of torsion-bar spring are introduced. The reel can not only eliminate the leakage risks of hydraulic jaw, but also reduce the investment cost of enterprises and improve the surface quality of the products. The static analysis of mandrel, sector plate and oblique wedge were conducted, and the main data of stress distribution and deformation were obtained, which provide a reliable theoretical basis for the design and optimization of the reel. The research results show that the external support has a great effect on the stress and deformation of the mandrel. With the increase of the weight of steel stress increases, the drum deformation increases, but the analysis of the position of maximum stress, can be obtained to drum stress and deformation is the main reason of excessive bending moment caused by heavy steel rolls. The bending moment and deformation can be reduced significantly at the end of the steel coil, which can effectively improve the service life of the drum.

1. Introduction
Cold coiler is one of the most important equipment in the production line of the cold rolled strip which can wind the long strip into a coil thereby not only increases the rolling speed, but also provides favorable conditions for subsequent production, transportation and storage. Nowadays, the steel industry is facing serious difficulties in both Europe and China, and even the world. Under this situation, the development emphasis of cold-rolling mill train should transfer from expansion the quantity to high quality, low cost, low energy consumption and greening [1-3].

Reel is the core equipment of the cold coiler, which directly affects the production of cold-rolling manufacturing line and the quality of the cold rolled strip [4-5]. In this study, a kind of reel with four wedges and configuring jaw with torsion-bar spring was used to overcome the problems of an enterprise production which include the oil leakage of the reel, non-circularity of the reel for the expansion of the path and the great wave of the tension of coiling etc. Further, Solidworks software is used for establishing the 3D model of the reel. Finally, the finite element model is established in the Solidworks Simulation module, and the static stress analysis is carried out, in addition, the strength, the deformation and the displacement of the reel are checked. On the basis of practice production, it is proved that the reel has the evident advantages which contain the simple structure, low investment cost, low pollution and high quality of the strip surface.

2. Structure characteristics and working principle of the reel
Fig 1 shows the structure of the reel which consists of mandrel, oblique wedges, sector plates, external support, expanding-collapsing cylinder (with a rotary joint) etc. Because the thickness of strip greater
than 3mm, so it is necessary to set the jaw in the sector plate. After the strip is inserted into the jaw and clamped by pre-tightening force of torsion bar, the tie rod pushes the internal wedge to the right along the axial direction through the cross-head, which is driven by the high pressure of expanding-collapsing cylinder. The internal and external oblique wedge is matched with the inclined plane, and the axial movement of the internal oblique wedge is transformed into the radial movement of the external oblique wedge. Sector plates rise slightly with the support of the external oblique wedges. The external wedge strip can fill the gaps between the sector plate, and a complete circle is formed on the surface of the inclined wedges and the sector plates for expansion of coiler. After the completion of the coiling, internal oblique wedge move toward the left along the axial direction while external oblique wedges contracted along the radial direction driven by the high pressure of expanding-collapsing cylinder. Sector plates are slowly contracted under the tension of the butterfly spring.

![Figure 1](image1.png)

**Figure 1.** Structure of the reel

As shown in Fig 2, the torsion-bar spring type jaw is composed of tooth plate, jaw plate, hexagonal socket, torsion bar etc. It has the characteristics of simple structure, stable and reliable operation. Torsion bar spring is a torsion bar made of spring steel. When the torsion bar is manufactured, the torsion bar is made to produce a permanent torsional deformation, which has a certain pre-pressure. In order to ensure the rigidity of the structure, two torsion bars are arranged in series in the axial direction of the mandrel. In order to increase the clamping force of the jaw, surface of tooth plate is designed into a zigzag. A circular hole is processed on the oblique wedge, and hexagonal socket is arranged in the circular hole with the torsion bar. Then the torsion bar is rotated to a certain angle. When the strip is inserted in the jaw, pre-tightening force produced by torsion deformation of torsion bar can clamp the strip.

![Figure 2](image2.png)

**Figure 2.** The structure of torsion-bar jaw

3. Finite element analysis of reel

3.1. Simulation parameter setting

As the existence of jaw may weaken the structure of mandrel, sector plates and oblique wedges, analyzing and checking the strength of reel is of great significance. Compared with the traditional mechanics of materials, the stress distribution and deformation calculated by the finite element analysis of the reel are much closer to the actual working conditions[6]. The fatigue analysis method of
the main mandrel of the winding drum based on the finite element analysis is briefly introduced by Li Jisong\(^7\). But the mandrel in his paper is a kind of cantilever beam structure, and ignore the spool pin hole, jaw and other architecture, leads to the analysis results and the actual situation is not entirely the same. So it is very necessary to carry out finite element analysis for the reel with jaw of torsion-bar spring. The material of mandrel of the reel, sector plates and oblique wedges are all 42CrMo steel. The mechanical parameters are shown in Table 1\(^8\). When dividing cells, the unit grid with high quality is selected. According to the characteristics of the type and size of the reel, Solid-works stimulation can generate the corresponding curvature of the cell and automatically adjust the size and density of the cell.

| Parameters       | Value | Parameters       | Value |
|------------------|-------|------------------|-------|
| Tensile strength (MPa) | $\geq 1080$ | Impact energy(J) | $\geq 63$ |
| Yield strength (MPa)      | $\geq 930$  | Impact toughness(J/cm2) | $\geq 78$ |
| Elongation (%)            | $\geq 12$    | Hardness         | $\leq 217$HB |
| Reduction of area(%)      | $\geq 45$    | Elastic Modulus(GPa) | 210    |

3.2. **Finite element analysis of mandrel**

Constraint definition of mandrel: define gravity acceleration of 9.8N/m\(^2\); define weight of steel coil of 45t; taking the external support into account, define the boss of mandrel for radial constraint; define the pressure of guide rail of $P_1$, $P_1=3526776$N which is vertical to the plane of guide rail; define the pressure of piston rod to the mandrel of $S$, $S=466397.5$N; define the bearing that near the gear for radial constraints and the bearing that near the motor for both radial and axial constraints. Finite element model of mandrel is shown in Fig 3.

The results of finite element model for the mandrel are shown in Fig 4, Fig 5 and Fig 6. The maximum equivalent stress occurs at the end face of the mandrel, value of which is 456.96MPa. This phenomenon is caused by pin holes near the end of the mandrel which weaken the rigidity of the mandrel. The maximum equivalent displacement occurs at the center of the guide rail, whose value is...
0.1503mm and does not affect the normal operation of the reel. The reel is equivalent to the beam, the middle of which is suspended in the theory of mechanics. When the mandrel is subjected to a radial load, a larger area of stress occurs in the middle part of the beam. Therefore, the displacement of the larger area is just in line with the theory of mechanics. If the maximum equivalent stress is used to check the strength of the mandrel, the mandrel meets the requirements of the use, and the safety coefficient of the mandrel is 2.04.

3.3. Impact of the steel coil weight on the mandrel

The steel coil weight is a very important parameter and its impact on the mandrel is very necessary to be studied. It is difficult and unnecessary to establish the finite element model directly because the geometric structure of the reel is very complex which is composed of many parts. In the finite element analysis, we can grasp the main structure and ignore the secondary structure according to the main purpose of the analysis and study, and the model can be simplified without affecting the accuracy. The following assumptions were made in the model: first, the supports are rigid body without deformation; second, the reel and the steel coil are considered as a whole and the gaps and chamfers are ignored; third, the bearings were seen as a part of the support. In order to find out the influence of the external support and the weight on the stress distribution and deformation of the drum, the finite element model is established, which is shown in Fig 7 and Fig 8.

![Figure 7. Finite element model of reel without external support.](image1)

![Figure 8. Finite element model of reel with external support.](image2)

The finite element analysis of the stress distribution is shown in Fig 9 and Fig 10. It can be seen from Fig 9, the maximum stress occurs at the portion of the shaft connected with the reel without considering external support. While, if the external support is to be considered, the maximum stress will occur at the portion of the shaft outside of the reel. Under different loads, the stress and deformation of the weight t=35 tons, 40 tons, 45 tons and 50 tons are calculated, and the maximum stress and deformation curves are shown in Fig 11 and Fig 12 respectively. From the results of static analysis, with the increase of the weight of steel stress increases, the drum deformation increases, but the analysis of the position of maximum stress, can be obtained to drum stress and deformation is the main reason of excessive bending moment caused by heavy steel rolls. The bending moment and deformation can be reduced significantly at the end of the steel coil, which can effectively improve the service life of the drum.
The reel in the design has the evident advantages which contain the simple structure, low investment cost, low pollution and high quality of the strip surface. In the product design stage, the use of effective software simulation to optimize the design to improve product life is both scientific and economical methods. The finite element analysis is carried out to obtain the distribution of stress, displacement and strain, and the stress concentration position is found. According to the results of the use of enterprise site, the reel with jaw of torsion-bar spring runs normally and meets the requirements of the structure.

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