Influence of friction coefficient on mechanical properties of braided wire rope in winding traction state

Weihua Cui, Weilin Gu, Xiaoyang Li and Hui Wang*

School of Mechanical Engineering, University of Jinan, Jinan, Shandong, 250022, China

*Corresponding author’s e-mail: me_wangh@ujn.edu.cn

Abstract. In the construction of cable erections, when passing through the reel of the tractor, the braided wire rope used for traction in the state of winding traction is subjected to the composite action of tensile, bending, extrusion, friction and other forces, of which the stress condition is the most complicated, and the wear is the most likely to occur. The Friction coefficient is an important factor which directly affects the mechanical and wear properties of wire ropes. Therefore, according to the cable traction condition, the influence of friction coefficient on the rope tension attenuation during the winding traction process is analyzed. Because the wear of wires between braided wire rope strands is the most serious, this paper focuses on the influence of the friction coefficient between the rope strands on the mechanical properties of wire ropes. Regarding YS9-8×19 braided wire rope as the research object, a solid model of "rope-wheel" winding traction system is established. Based on the actual conditions, the finite element simulation model of winding traction system is established by setting load and constraint conditions. The influence of friction coefficients on the stress and deformation of braided wire rope strands is researched, by setting different friction coefficients between rope strands and analyzing the simulation results, in order to provide theoretical instructions of braided wire ropes used for traction.

1. Introduction
Braided wire rope is widely used in tension line construction of power transmission and transformation engineering as a guide rope and traction rope because of its good anti-torsion performance, good flexibility and high strength. Because its reliability is crucial to construction safety, it is known as the "lifeline" of line construction[1].

The cable erection construction of the power transmission and transformation project is shown in figure 1. Under the action of the traction machine, the cable passing through the tension pay-off machine is hauled and placed between the towers to form a power transmission and transformation line by the traction rope. The main power of the wire construction comes from the tractor, in which the reel is used to wind the traction rope by friction to realize traction, as shown in figure 1. Meanwhile, in the winding traction process, the traction rope is subjected to the composite action of tensile, bending, extrusion, friction and other forces, of which the stress condition is the most complicated, and the initial section where the wire rope is entangled is subjected to the greatest tensile force, which has become the most dangerous position. Therefore, the mechanical properties of the braided steel wire rope in the winding traction state directly affect its service life.
According to data retrieval, domestic and foreign scholars have conducted in-depth studies on the factors affecting the mechanical properties and the life of twisted steel wire ropes. References [2-6] respectively study the life-effect factors of twisted steel wire ropes used in friction hoists, elevators, electric shovels, cranes and other lifting conditions. For braided steel wire ropes, our research group has conducted the research on the mechanical properties under straight and curved conditions, as well as friction and wear under winding traction conditions [7-8]. Based on relevant research results, the main factors affecting the mechanical properties and the life of steel wire ropes are obtained, as follows:

- Manufacturing factors: rope material, twisting force, etc..
- Structural factors: wire rope type, lay direction, lay distance, etc..
- Using factors: Reel size, D/d ratio, impact load, elastic vibration, friction coefficient, etc..

Moreover, the above studies have found that various damages in the use of wire ropes are the main factors that reduce the life of the wire ropes, and wear is one of the main forms of mechanical damages. The coefficient of friction has a direct effect on wear. In order to reduce wear, the friction coefficient should be smaller. However, the friction coefficient also has a great influence on the mechanical properties of the wire rope. Therefore, while considering the influence of friction coefficient on wear, it is necessary to consider its influence on the mechanical properties of steel wire ropes. That is, its impact should be considered comprehensively.

In order to guide the use of the braided steel wire rope and extend its life, this paper analyzes the force of the steel wire rope under the winding traction condition to determine the degree of influence of the friction coefficient on the mechanical properties under this condition. And with the aid of finite element simulation, the effect of friction coefficient on mechanical properties of the braided steel wire rope under winding traction state is studied, which provides supports for the comprehensive analysis of the influence of the friction coefficient on the service performance of braided steel wire rope.

2. Analysis of force and wear of braided steel wire rope under winding traction conditions

The schematic diagram of the tension on the wire rope when it is "winding in-winding out" two traction drums is shown in figure 2. The tension that the wire rope receives when it is wound into the left reel is denoted as $F_1$, and the tension that the wire rope receives when it is wound out of the right reel is denoted as $F_2$, of which the directions are shown in figure 2. Literature [12] calculated the tension attenuation of the wire rope under this working condition, and the relationship between $F_1$ and $F_2$ was obtained, that is, the tension change function when the wire rope passes through the traction device, as follows:
Where $e$ is the base of the natural logarithm; $f$ is the friction coefficient between the wire rope and the rope groove of the traction drum; $n$ is the number of grooves of the traction drum; $\gamma$ is the angle between the wire rope and the horizontal line when the wire rope is rolled into the first rope groove of the left traction drum; $\theta$ is the angle between the wire rope and the horizontal line when the wire rope is wound out of the $n^{th}$ rope groove of the right traction drum.

According to equation (1) that the coefficient of friction has the greatest impact on the force change of the wire rope. The greater the friction coefficient, the faster the wire rope tension decays. Therefore, the performance can be improved, while the wire rope is worn more severe.

The wear of the scrapped braided steel wire rope used in the cable rack facility was analyzed by the literature [8], in which the severe wear positions were divided into the rope-wheel contact position and the inter-strand contact position. It was found that the wear of wires at the inter-strand contact position was more severe, the wear scar area is larger, and the number of the wear positions is more.

Therefore, this paper mainly studies the influence of the friction coefficient between strands on the mechanical properties of braided steel wire ropes.

$$F_2 = \frac{F_1}{e^{[2\pi f \gamma]}^{-\gamma \theta}}$$

(1)

Figure 2. Schematic diagram of wire rope passing through the traction drum.

3. Model construction of winding traction system

3.1. Establish a physical model of the winding traction system

Combining figure 1 and figure 2, during the cable traction process, the braided steel wire rope is wound only half a turn in each traction drum rope groove. The bottom diameters of the rope groove of the two drums are the same, and the speed is the same. Therefore, taking any half circle of one of the reels as the research object, the model of the "rope-wheel" winding traction system is established. The YS9-8×19 braided steel wire rope and the traction drum rope groove with the bottom diameter of 506mm are selected, and through appropriate simplification, the geometric model of the "rope-wheel" winding traction system is established, as shown in figure 3.

3.2. Establish a finite element model of the winding traction system

3.2.1. Basic parameter settings. The material property parameters are set as follows: the elastic modulus of the braided steel wire rope is $E=196.9$GPa, the Poisson's ratio $\mu=0.3$, the elastic modulus of the traction drum material is $E=185$GPa, the Poisson's ratio $\mu=0.3$, and the simulation stiffness
coefficient is 0.01. Using ANSYS Workbench Mesh command, the "rope-wheel" traction winding system is meshed based on hexahedral elements.

3.2.2. Restraint and load settings. According to the actual working conditions of the braided steel wire rope passing through the traction drum, the load and restraint are set. The contact between the rope strands is set as frictional contact, and the contact between the steel wire rope and the rope groove is set as non-separated contact. One end of the wire rope is set as a fixed constraint, and the other end is subject to a displacement constraint. The x-direction displacement is set to 0, and the y and z directions are free to move. At the same time, a concentrated surface load along the axial direction is applied on the end face. Because the steel wire rope rotates with the traction drum, the traction drum is stationary relative to the steel wire rope, and the rope groove of the traction drum is set as a fixed constraint, as shown in figure 3.

4. The effect of friction coefficient on the mechanical properties of braided steel wire ropes
According to the rated load range of YS9-8×19 braided wire rope in cable erection, the finite element simulation of the "rope-wheel" winding traction system is carried out with 4KN as the tensile load. The coefficient of friction between strands of braided steel wire rope is generally between 0.05 and 0.15. The friction coefficients of 0.05, 0.06, 0.08, 0.10, 0.12, 0.15 are selected, and the finite element simulations under the same load and boundary are performed. The stress and strain cloud diagrams with friction coefficients of 0.08 and 0.15 are shown in figure 4 and figure 5. The above simulation analysis results are sorted into table 1.
Figure 4. Equivalent stress cloud diagrams of the same load with different friction coefficients. (a) 0.08, (b) 0.15.

Figure 5. Total deformation of the same load with different friction coefficients. (a) 0.08, (b) 0.15.

Table 1. Equivalent stress and total deformation of the braided wire ropes with different friction coefficients.

| Coefficient of friction | 0.05  | 0.06  | 0.08  | 0.10  | 0.12  | 0.15  |
|-------------------------|-------|-------|-------|-------|-------|-------|
| Equivalent stress(MPa)  | 1888.2| 1762.3| 1823.1| 1690.6| 1665.4| 1640.9|
| Total deformation(mm)   | 8.3617| 8.3595| 8.2546| 8.2815| 8.2491| 8.2144|

It can be seen from table 1 that as the coefficients of friction increasing, the equivalent stress of the rope strands and the total deformation of the braided wire rope under the winding and bending state show a decreasing trend.

Since the friction force between the strands increases with the increase of the friction coefficient, the friction force can offset the tensile force in the axial direction of the strands. As a result, so the axial tension of the rope strands is reduced, and the equivalent stress and strain of the rope strands are reduced accordingly.

5. Conclusion
As the coefficient of friction between the strands increasing, the equivalent stress of the strands of the braided steel wire rope in the winding traction state shows an overall decreasing trend, and the amount
of deformation gradually decreases. Therefore, when the braided steel wire rope is used as a guide rope or traction rope for tension stringing, the friction coefficient can be within the allowable range of 0.05-0.15. By changing the lubrication condition between the wire rope strands and increasing the friction coefficient between the strands, the force status of the wire rope can be improved. However, as the friction coefficient increasing, the wear of the wire rope will be more serious. Therefore, the comprehensive influence of friction coefficient on the mechanics of braided wire ropes and friction and wear properties of braided wire ropes will be further studied, and a reasonable range of friction coefficients when braided wire ropes are used as cable traction ropes will be determined to extend their service lives.

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