Test and Analysis of A Skidding Winch Drum with Combined Shaped Groove

Chuanyu WU¹, Chengjun ZHOU¹, Xinnian ZHOU¹, Zhengxiong ZHANG*¹,
Rongfeng SHEN¹, Huoming ZHANG²

¹Fujian Agricultural and Forestry University, Fuzhou 350002, China
²Zhangping Wuyi state-owned forestry Farm, Zhangping 364400, China

Abstract — A new combined cross-section shaped groove friction roll is designed to overcome the problems that traditional friction roll has with small traction and large wear. Mechanical analysis of connection change of V-shaped groove friction roll’s traction and equivalent friction coefficient and the test of combined shaped groove model are conducted to optimize the combined type of roll’s section and its parameters. Experiments show that the smaller circular arc’s included angle of the combined shaped groove is, the bigger equivalent friction coefficient is. Equivalent friction coefficient is 0.93 when circular arc’s included angle of the combined shaped groove equals to 45°, improving almost 9 times than conventional flat friction. However, wear extent increases only 0.05%. Regression analysis is conducted to obtain the relation between different circular arc’s included angle of combined shaped groove and equivalent friction coefficient. Our results in this paper provide a vital reference for the optimal design of combined cross-section friction roll and lightening design of the winch.

Keywords - winch; friction roll; combination shaped groove; optimal design

I. INTRODUCTION

Friction roll, a main form of skidding winch drum, drags rope through friction force which is generated by the friction between the rope and the circular groove’s surface of the friction roll. According to different structure, friction roll is classified as the single circular groove friction roll and the multiple circular groove friction roll, which can be used in closed cableway [1-4]. Compared to winding roll, the biggest advantage of the friction roll is that traction process is not restricted by the length of rope and rope allowance. The friction roll is much smaller than the winding roll when the skidding distance is larger than 500m (long distance skidding). Therefore, it’s an efficient way to replace the winding roll by the friction roll for the lightening design of the skidding winch drum [5].

Restricted by structure, conventional friction roll can only provide a small traction. In the case of winch JS3-2, the traction of a friction roll is around 2/3 of that of the winding roll [6]. Ropes wear roll continuously, increasing the abrasion between the rope and the roll. The situation becomes worse for traditional drums with smooth single circular shaped groove, as twined by 2.5 laps or 3.5 laps of ropes, in which not only there is a friction between each lap, but also a friction between the rope and the groove (caused by horizontal displacement), which worsens the abrasion between the roll and the rope. Although multiple circular groove roll overcomes the deficiency of the single circular groove roll and improves friction condition, the increase of the number of the circular grooves, would lead to the increase of the weight of the roll. This is not good for lightening design of the winch [7]. As a result, how to improve the friction traction of the friction roll without increasing the weight of the roll is a key point for the winch’s lightening design.

There are 3 different methods to improve the friction traction of roll: improving the tensile force on the loose side, increasing the twining wrap angle of ropes and increasing the frictional coefficient. Since the increase of the frictional coefficient could significantly enhance the friction traction and has no effect on the roll’s size, it is the best option to improve the friction roll’s traction. There are also two ways to increase friction coefficient: the first is to choose a material having high frictional coefficient, the second is to improve the structural design and the equivalent frictional coefficient [8].

The main purpose of this research is to improve the friction roll’s equivalent frictional coefficient by improving the friction roll’s structural design (form), which increases the friction traction and reduces wear. The research could provide a scientific reference for the optimal design of the forestry skidding winch.

II. ANALYSIS OF THE TRACTION OF THE V-SHAPED GROOVE FRICTION ROLL

Frictional force between the rope and the bottom of the groove is small in traditional V-shaped groove friction roll. As shown in Fig.1, the friction roll can be designed as a narrow V-shaped groove roll so that the rope contacts both sides of the groove firmly, which increases the equivalent friction coefficient [9]. The equivalent friction coefficient is obtained by:

\[
\mu_e = \frac{\mu}{\sin\theta + \mu\cos\theta}
\]
Where
\( \theta \) - the wedge angle of the groove, (°),
\( \mu \) - the friction coefficient,
\( \nu \) - the equivalent friction coefficient.

As shown in Fig.2, friction coefficient \( \mu \) is defined as 1.2. When \( \theta \) decreases from 180° to 10°, the equivalent friction coefficient increases exponentially. When \( \theta \) equals to 10°, \( \nu \) is 0.58. Compared to the level case when \( \theta \) equals to 180°, \( \nu \) is increased by 4.8 times significantly. This is mainly because of the wedge effect of the V-shaped groove, elevating the equivalent friction coefficient by improving the positive pressure. However, the rise of the positive pressure enhances the wear extent of contact pair and therefore this is not the best solution.

Fig 1 Cross-section of the V-shaped friction drum

Fig 2 Relationship between equivalent friction coefficient (\( \nu \)) and angle of the V-shaped groove (\( \theta \)) and angle of the V-shaped groove (\( \theta \))

III. COMBINED CROSS-SECTION SHAPED GROOVE DESIGN

The contact pair of the rope and the roll in the traditional friction roll is the line contact. In addition, single the circular groove friction roll creates the horizontal displacement and the friction between ropes. As shown in Fig.1, the contact between the rope and the roll is a line contact in the narrow V-shaped friction roll. They have high pair friction. As the positive friction force rises, the wear condition is not improved [10].

Increasing the contact area of the friction pair reduces wear efficiently. As shown in Fig.3 (a), the circular groove in this paper is designed as an arc-shaped section corresponding to the shape of the rope. In this condition, the contact between the rope and the roll is a surface contact, reducing the wear effectively. This design, however, contributes nothing in improving the friction traction. If the circular groove is designed as a combined cross-section type of the bilateral circular arc-shaped and groove at the bottom, shown in 3(b), equivalent friction coefficient is increased by wedge effect. In addition, the line contact is replaced by a surface contact, leading to a better result.

The detail design parameters of the combined cross-section type requests that the wedging angle of the V-shaped open on the top of the cross-section is at least two times of the friction pair’s self-lock angle. In addition, the V-shaped open being tangent to the circular arc of the cross-section ensures a well separation between the rope and the groove. The size of the circular arc and the contact area is determined by that of the bottom opening of the combined cross-section which directly influences the wear extent and the friction force of the friction pair.

Fig 3 the groove section
As shown in Fig. 3(b), the rope is defined as a steel body for simplified calculation. Stress ($Q$) is evenly distributed along x axis, the value of the positive stress $N$ is given by:

$$
N = \int_{\theta_0}^{\theta_1} \frac{Q}{(\cos\theta_0 - \cos\theta_1)} \times \frac{1}{\sin(\theta)} \, d\theta
$$

After calculation we have:

$$
N = \frac{Q}{2(\cos(\theta_0) - \cos(\theta_1))} \left( \ln\left(\tan\left(\frac{\theta_1}{2}\right)\right) - \ln\left(\tan\left(\frac{\theta_0}{2}\right)\right) \right)
$$

Therefore, the friction force is given by:

$$
F = 2\mu N = \left( \frac{\ln\left(\tan\left(\frac{\theta_1}{2}\right)\right) - \ln\left(\tan\left(\frac{\theta_0}{2}\right)\right)}{(\cos(\theta_0) - \cos(\theta_1))} \right) Q = \mu v Q
$$

As a result, $\mu_v$ can be expressed as:

$$
\mu_v = \mu \left( \frac{\ln(\tan(\frac{\theta_1}{2})) - \ln(\tan(\frac{\theta_0}{2}))}{(\cos(\theta_0) - \cos(\theta_1))} \right) K
$$

In the above equations, $F$ is the friction force, $(N)$, $\theta_0$ is the initial angle of the circular arc, larger than the friction angle; $\theta_1$ is the circular arc’s included angle; $K$ is the correction factor. The reason that the correction factor $K$ is introduced in Eq. (5) is because the ropes are defined as the steel body in the model but they are twisted together in reality.

IV. TEST AND ANALYSIS OF THE COMBINED CROSS-SECTION GROOVE

To calculate the equivalent friction coefficient of the combined cross-section groove, the value of $K$ should be given. For this purpose, tests of the combined cross-section groove model are conducted. The equipment is a computer-controlled friction wear testing machine (model: MMS-2A), manufactured by Jinan Jingcheng Testing Technology Limited. With principle of the experiment shown in Fig. 4(a), the ropes (radius 5mm) are fixed in the jig which is mounted on the axis of the friction wear testing machine and the groove model is fixed on the bottom axis. A stress of 100N is applied on the jig to rotate the groove model at a speed of 200r/min. Experiment data is transferred to the data processing module by the sensor module. Fig. 4(b) is the cylindrical model, (c) is the combined shaped groove model and (d) is the section amplification drawing. The circular arc radius of combined shaped groove is 2.5mm and the bottom width is $B$. Experimental scheme consists of one group of the cylindrical model and 5 groups of groove models with different width $B$. The result of the experiment is shown in Table 1.

The experiment data in Table 1 can be substituted into Eq. (5) to calculate the relative correction factor. If the average value of the correction factor $K$ equals to 1.8, Eq. (5) can be rewritten as:

$$
\mu_v = 1.8\mu = \left( \frac{\ln(\tan(\frac{\theta_1}{2})) - \ln(\tan(\frac{\theta_0}{2}))}{(\cos(\theta_0) - \cos(\theta_1))} \right) K
$$

Correlation test is conducted based on Eq. (6), $|R|=0.85$ shows the correlation is high. When $F$ equals to 7.8, $F(0.01)>F>F(0.05)$, which means Eq. (6) is significant. So Eq. (6) can be referenced on relativity design.

V. WEAR TESTS AND ANALYSIS OF THE COMBINED SHAPED GROOVE FRICTION ROLL

Substitute $\theta_0(12^\circ)$ and $\theta_1(15^\circ \sim 90^\circ)$ into Eq. (6) separately, we can obtain the equivalent friction coefficient $\mu_v$. In accordance with the circular arc’s radius, the initial and the included angles of the circular arcs in the experiment model, and the length of the contact circular arc can be obtained. The equivalent friction coefficient and the length of the contact circular arc vary according to Fig. 5. We can see from Fig. 5 that the smaller $\theta_1$, the bigger the equivalent friction coefficient. When $\theta_1=45^\circ$, $\mu_v$ equals to 0.93, which is 9 times of the friction factor of the friction
pair, having an obvious effect. Meanwhile, the contact pair of the sections transfers from the point contact to the line contact with a 2.88mm’s arc length, which enhances the ability of wear resistance a lot.

groove and cylindrical is almost equally, only with a difference of 0.03%. When bottom width of combined shaped groove is 3.5mm, wear extent is a little bigger than flat bottom groove, but the difference is only 0.05%. Nevertheless, the equivalent friction coefficient improves 8.2 times. It’s the best choice to set the bottom width of combined shaped groove to be 3.5mm (θ1=45°).

<table>
<thead>
<tr>
<th>θ1 (°)</th>
<th>Equivalent friction coefficient</th>
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<tbody>
<tr>
<td>0.17</td>
<td>0.19</td>
</tr>
<tr>
<td>0.37</td>
<td>0.40</td>
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<tr>
<td>0.38</td>
<td>0.37</td>
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VI. CONCLUSION

Mechanical analysis of connection change of friction roll’s traction and equivalent friction coefficient and the test of combined shaped groove model show that contact pair’s positive pressure of combined shaped groove friction roll increases with included angle of circular arcs decreases. Equivalent friction coefficient is 0.93 when θ1 equals to 45°, improving for 9.3 times than conventional flat friction. And contact area of contact pair is higher than conventional friction roll, resulting in a small friction increment (0.05%). On the contrast, wear extent increases significantly with continuous decreasing of θ1 when θ1 is lower than 45°. Above all, θ1 should not be set below 45°. In addition, equivalent friction coefficient equation is deducted through theoretical analysis on the basis of experiment, fitting experiment results well. This research provides a reference for the optimal design of combined cross-section friction roll and it is significant in lightening design of the winch.

ACKNOWLEDGMENT

This work was supported by The National Natural Science Foundation of China (General Program,30972359), Fujian Provinical Forestry Department projects (Fujian Forestry [2014] 2), Zhangping fifty one State Forestry Center cooperation project funds (KH1400850), Fujian Agriculture and Forestry University class universities funded projects(113-612014018).

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