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Determination of parameters of cable drums of capstanshunting winches

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Abstract. The article considers the problem of determining the rational geometric parameters of friction cable drums of capstan shunting winches. The basic technical means for performing shunting works within the cargo yards of railway stations and industrial enterprises are given. Today, shunting locomotives are the most common means of shunting works at railway stations and cargo yards of industrial enterprises. However, using them is not economically feasible for small amounts of shunting. Both sheave-type and capstan shunting winches are often used to move individual cars or groups of cars along the freight front. In the capstan shunting winches, a frictional drum of infinite coiling length is used, which rotates around a horizontal axis. It is established that the known sources give only the theoretical principles of the operation of drums of infinite coiling length and do not contain any practical recommendations for the design and operation of capstan shunting winches. The article provides a theoretical study of the forces of friction that occur between the drum and the cable, as well as between the cable lines when drums with different profiles of working surfaces are used. It was found that in shunting winches, the coefficient of friction of the rope along the drum can increase by 2.5 times, as a result of which it is necessary to increase the curvature of the profile of the drum. Also, friction forces between adjacent branches of a cable wound on a winch drum are considered. On the basis of the conducted study, recommendations on the type and geometrical parameters of cable drums of capstan shunting winches are proposed, which are aimed at extending the service life of traction cables of these mechanisms.

1. Introduction

Conducting cargo handling work with railway cars implies that these cars have to move within the cargo yards of stations or other industrial enterprises, i.e. performance of shunting work. Railway locomotives are most commonly used to perform this work (Figure 1) [1].





Figure 1.Shunting locomotiveChME-3.

However, shunting with locomotives is not always economically feasible. For example, if one or more cars have to be moved along the cargo front or within a specific enterprise for a relatively short distance. For this purpose both hybrid road-rail vehicles –locomobiles(Figure 3) [2, 3] and shunting winches [4] can be used.



Figure 2.Locomobile by Spetskran LLC (Ukraine).

In Ukraine, locomobiles have not yet been commonly used. Shunting winches are much more often used by enterprises for shunting. Their main advantages include a simple design, as well as moderate capital and operating costs, and high reliability.

2. Analysis of designs of shunting winches

The principle of operation of shunting winches is based on the use of a steel cable connected to the car as a traction body. The traction cable is reeled on the winch drum, which is rotated by an electric motor through a reducer.

Two types of shunting winches are currently used. The first type includes sheave-type winches (Figure 3) [5-9], in which the traction cable is completely reeled on the drum. Usually, such winches are irreversible, which means that only one-way movement of cars is possible. The reversible sheave-type winches are also known, however, they have a complex design, complicated to install, and operation of such winches is much more expensive than of irreversible ones.



Figure 3.Shunting sheave-type winch.

Shunting winches of the second type include capstan winches (Figure 4) [5, 10, 11]. These winches use a friction drum of infinite coiling length that rotates around a horizontal axis. The cable is not fastened to the drum, but is seized by the force of friction that occurs between the surface of the drum and a few coils of the cable (normally 3-4 coils).



Figure 4.Capstan shunting winch.

Such winches are usually reversible. They can be used on long load fronts, and the drum size is much smaller than that of sheave-type winches. These advantages, as well as the lower cost of the winches as compared with sheave-type winches, have contributed to the common use of capstan winches as shunting machinery not only at railway enterprises, but also at industrial sites, such as grain warehouses, seaports, river ports, quarries, etc.

3. Analysis of recent research and publications.

The principle of operation of friction drum winches has been known for a long time and is described in many literary sources, for example in [5-7]. Three to four coils of traction cable are reeled on the drum. As the drum rotates, one cable line is reeled on it and the other one is unreel.

For normal operation of the friction drum winch, the reeling cable line should constantly shift to the center of the drum. For this purpose, the drum profile has variable diameter with a minimum value in the center of drum (Figure 5).

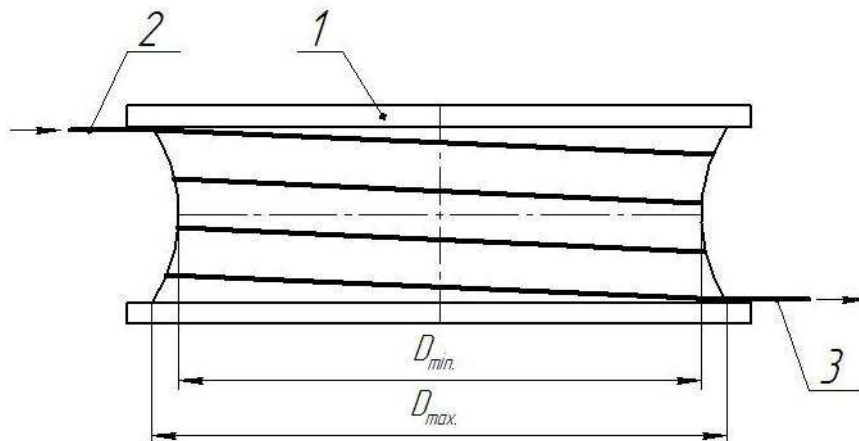


Figure 5. Profile of the friction drum and the cable winding diagram:
1 – drum; 2 – reelingline; 3 – unreeling line.

The angle of inclination of the drum profile is determined from the diagram of forces acting on the cable when it is reeled on a variable profile drum (Figure 6) [5].

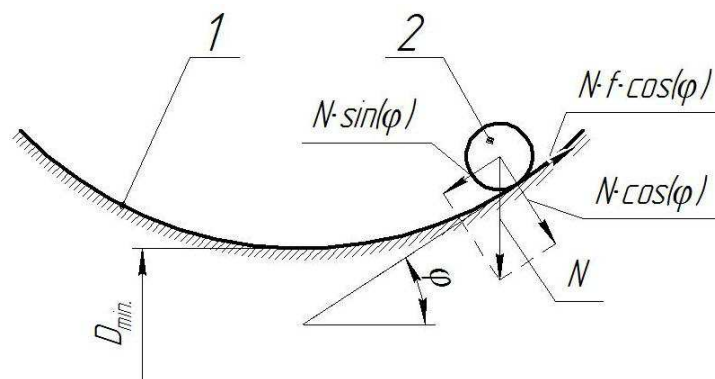


Figure 6. Diagram of forces acting on the cable reeled on a variable profile drum:
1 – drum; 2 – cable.

The condition of shift towards the center of the drum will be as follows [5]

$$N \cdot \sin \varphi - N \cdot f \cdot \cos \varphi > 0, \tag{1}$$

where N is traction force in the cable, N ;

φ is angle of inclination of the drum surface to the horizontal, degrees;

f is friction coefficient of the cable on the drum.

It follows that for the cable to shift to the center of the drum, the angle of inclination of the surface of the drum should exceed the angle of friction of the cable on the drum

$$\varphi > \arctg f. \tag{2}$$

4. Purpose of the study

The above method, however, does not fully cover the processes taking place in the cable-drum system.

First, the traction cable of the shunting winch is located mostly outdoor and has constant contact with the ground. Therefore, the friction coefficient of the cable on the drum is unstable.

Secondly, the above method does not take into account that 3 to 4 coils of the cable are wound on the drum, rub against each other during the operation and negatively affect the service life of the cable.

Third, the above method does not provide any guidance on the shape of the drum profile.

In view of the above, the purpose of the study can be stated as follows: developing recommendations on geometrical parameters of profile of the cable drums of capstan shunting winches.

5. Results of the study

5.1 Study of the friction coefficient of the cable on the drum

According to published sources [5-7], the values of the friction coefficient of the cable on the drum μ are within the range from 0.12 to 0.16. The cable of the shunting winch, however, is usually located outdoor and trails on the ground during the operation (Figure 7).

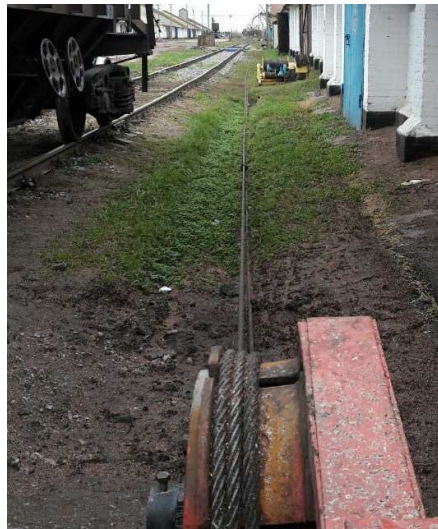


Figure 7. Trailing of the traction cable of the shunting winch on the ground.

As a result, soil particles stick to the grease used to lubricate the cable. Consequently, the conditions of friction of the cable on the drum will approach the dry friction conditions, which may result in the value of the friction coefficient of the cable on the drum μ increasing 2.5 times [12]. Thus, μ will be 0.3 to 0.4. Therefore, taking into account formula (2), the angle of inclination of the working surface of the friction drum in capstan shunting winches should be increased from 6.84-9.1° to 16.7-21.8°. Greater angles of inclination of the working surface of the drum will increase the projection of traction force on this surface $N \cdot \sin \varphi$, which will increase the friction force between the coils of the traction cable, which will adversely affect the service life of this cable.

5.2 Study of friction arising when the cable is reeled on the drum

Three to four coils of cable are reeled on friction drums of capstan winches [5-7]. Due to the curvature of the surface of the drum, these coils cling to each other which results in the friction force of the cable not only on the drum, but also between the individual coils of the cable.

Let us consider the position of four coils of the cable on a conical drum (Figure 8). As the drum rotates at a circumferential speed ω , each coil of the cable will also rotate at the same circumferential speed ω . According to the laws of theoretical mechanics [13], the linear velocity of a point rotating around the center at a distance R can be determined by formula

$$V = \omega \cdot R = \omega \cdot \frac{D}{2}, \quad (3)$$

where D is the rotating diameter.

According to Figure 8, diameters of coils of the cable differ:

$$D_{L1} > D_{L2} > D_{L3} > D_{L4}, \quad (4)$$

where $D_{L1}, D_{L2}, D_{L3}, D_{L4}$ are diameters of the drum under the respective coil of the cable.

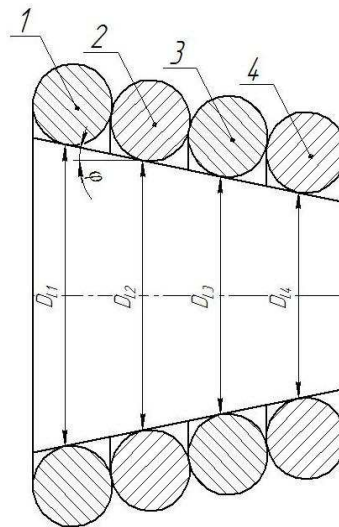


Figure 8. Location of coils of the cable on the conical drum:
1-4 – coils of cable.

Then, the linear windup speeds of the cable will have the ratio

$$V_{L1} > V_{L2} > V_{L3} > V_{L4}, \tag{5}$$

where $V_{L1}, V_{L2}, V_{L3}, V_{L4}$ are linear windup speeds of respective coils of the cable.

Therefore, during the rotation of the capstan winch drum, friction forces will occur in each cable line not only between the cable and the drum with friction coefficient μ , but also between the cable lines with the friction coefficient f .

As an example, let us consider line 2 of the cable (Figure 8). At the bottom, it rests on the drum and on the sides is sandwiched between lines 1 and 3, which is very similar to the position of the cable on the V-shaped groove [14]. In this case, the friction coefficient between the coils of the cable f is determined by formula

$$f = \frac{\mu_L}{\sin \frac{\delta}{2}}, \tag{6}$$

where μ_L is the actual friction coefficient between the cable lines;

δ is angle of the profile of the cable.

The angle of the profile of the cable lines reeled on the conical drum is unchanged, its value will be $\delta = 90^\circ$ (Figure 9). If its value is substituted into the formula (6), then:

$$f = 1.41 \cdot \mu_L, \tag{7}$$

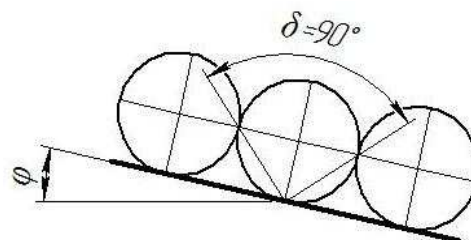


Figure 9. Design diagram for determining the angle of the profile of rope lines reeled on the conical drum.

I.e., on the conical drum, the friction coefficient between the cable lines is 1.41 times larger than the actual μ_L , and does not depend on the angle of the drum profile φ_0 .

If the drum profile has a certain curvature of radius R (Figure 10), the angle of the profile of the cable lines will decrease in proportion to the decrease of the curve radius R ($R \neq 0$, $\delta < 90^\circ$). This, according to formula (6) will lead to an increase of the friction coefficient between the coils of the cable f vs. its value on the conical drum. In this case, it can be assumed that the cable lines will be exposed to higher friction forces, which will negatively affect the service life of the cable. For this reason, using conical drums in capstan shunting winches can be recommended.

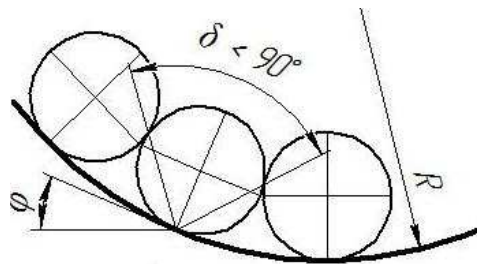


Figure 10. Design diagram for determining the angle of the profile of cable lines reeled on the drum of a given curvature.

6. Conclusion

According to the results of the above studies, the rational values of the angle of inclination of the working surface of the friction drums of the capstan winches are within the range of 16.7° to 21.8° . Greater angles of inclination of the working surface of the drum will lead to augmentation of the friction forces between the coils of the traction cable of the winch, which will have negatively effect on the service life of this cable.

Also, from the point of view of the service life of the cable, it is recommended to use friction drums with conical working surfaces in capstan shunting winches.

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