

Design and Simulation Analysis of the Transmission Scheme for the Mine Double Speed Winch

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Abstract. Mine winches are widely used in coal mine production, but the traditional operation mode still exists and the transmission efficiency is low. In order to improve the transmission efficiency of mine winches, this paper designs a transmission scheme for the mine double speed winch. Briefly, the transmission scheme is introduced and the degree of freedom of the winch mechanism is discussed to guarantee the rationality of the movement. The kinematics mathematical model of the winch is established. Theoretical derivation and simulation analysis show that the winch mechanism has superior performance at a high or low speed. The combination of fast speed and slow speed can effectively improve the transmission efficiency of the mine winch, which provide a design thought.

Keywords: mine winch, transmission efficiency, double speed, kinematics mathematical model.

1. Introduction

As a commonly used auxiliary transportation equipment, winches are widely used in the mine, ocean, architecture and other engineering fields [1-5]. China is one of the largest coal producers in the world and coal plays an important role in the energy structure of China [6]. In the field of coal, mine auxiliary transportation, the winch is responsible for important tasks such as the material transportation, personnel dispatching, equipment traction, etc. Mine winches have become an indispensable transportation equipment in the coal mine production [7]. Therefore, how to design an efficient winch transmission scheme and improve the transportation efficiency has become a hot topic.

Although the winch has been widely used in the coal mine production, the traditional operation mode still exists. Figure 1(a) shows the JYB type mine winch. To make the winch operation and stop, the operator handles the operation handle to control the brake and the clutch. This kind of operation is time-consuming and laborious, and there is a big personal safety hazard [8]. It is the JSDB type double speed winch in Figure 1(b). It realizes the meshing of different gears by shifting the sliding gear to receive the fast speed and slow speed of the winch. However, this type of transmission scheme has a risk of being out of gear, and the gear meshing accuracy is precise [9]. With the development of technology, the winch technology is also continuously improved. As shown in Figure 1(c) and Figure 1(d), Rv type hydraulic winch and SQ type variable speed winch are used in the engineering field, which has improved the winch transmission efficiency. However, their price limits the application [10]. Throughout the



development process of the winch, the winch is developing towards the miniaturization, standardization and intelligence [11-14].

In order to improve the transmission efficiency of the winch considering the economics, this paper designs a transmission scheme for the mine double speed winch. By analyzing the degree of freedom of the mechanism, it is proved that the transmission scheme has a clear movement. In addition, kinematics mathematical model of the winch is established, and the theoretical parameters of the roller speed are derived during the fast running and slow running of the winch. Theoretical and simulation analysis shows that the transmission scheme is reasonable in design and superior in performance.

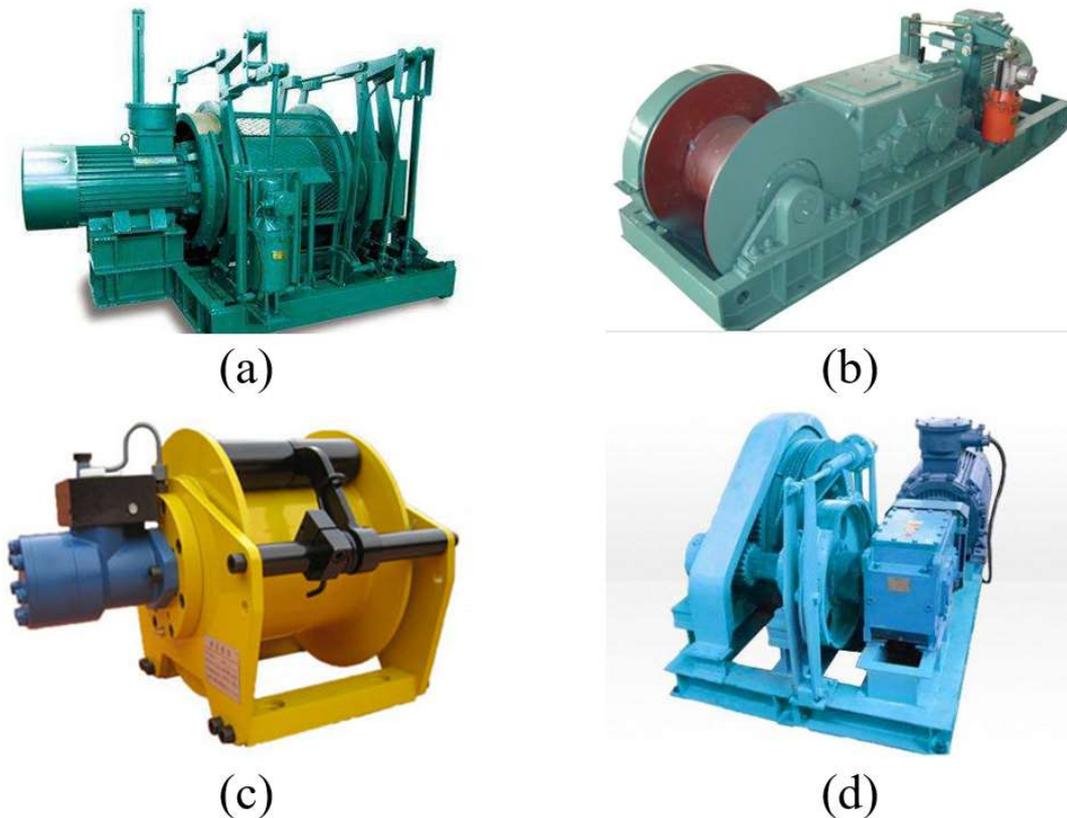


Fig. 1 Four typical winches

2. Design of the winch transmission scheme

With continuous improvement, the transmission scheme is shown in Figure 2. The transmission principle is as follows. When the speed regulating brake A opens and the speed regulating B closes, the motor drives the first stage sun gear. Because the second-stage planet carrier is fixed, the winch runs fast through two stages planetary gear transmission. In addition, the speed regulating brake A closes and the speed regulating brake B opens, and then the motor drives the first-stage sun gear. The third-stage ring gear is fixed to the rack so the winch runs slowly through three stages planetary gear transmission. The transmission scheme has disadvantages. Two stages planetary gear trains are placed in the roller and the winch has a small volume, which can effectively utilize the space.

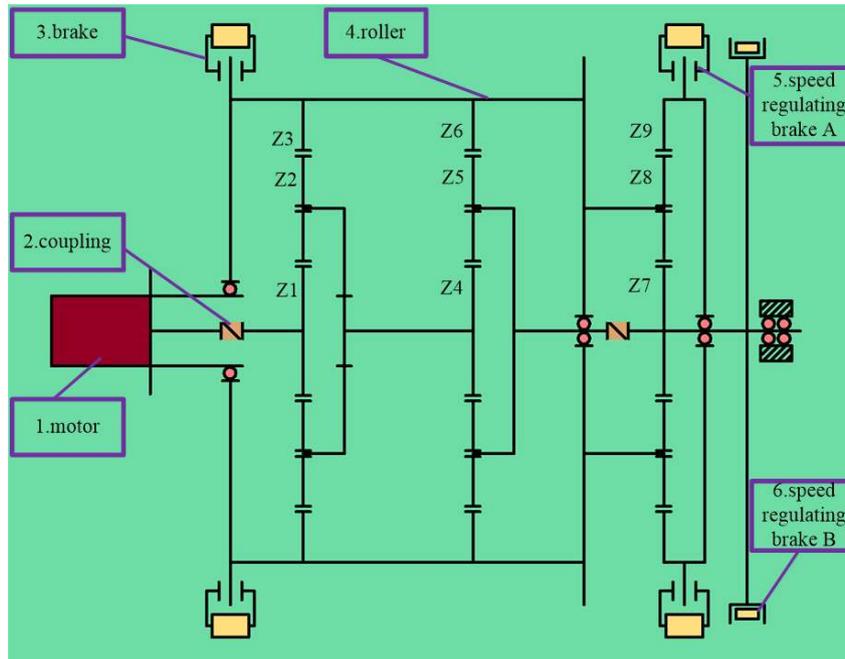


Fig. 2 The final transmission scheme for the double speed winch

In order to ensure the rationality of the design, it is necessary to analyze the degree of freedom of the winch mechanism. Figure 3(a) is the schematic diagram of the winch mechanism at a high speed and Figure 3(b) is the schematic diagram of the winch mechanism at a low speed.

The formula for calculating the degree of the freedom of the winch mechanism is as follows:

$$F = 3n - 2P_L - P_H \tag{1}$$

Where n is the number of active components, P_L is the number of low pairs, P_H is the number of high pairs.

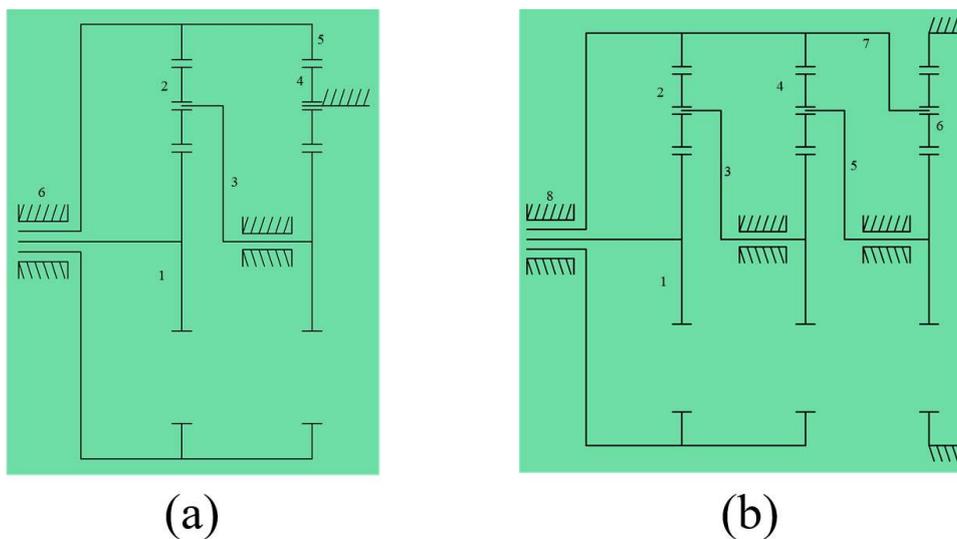


Fig. 3 Transmission mechanism diagram; (a) the schematic diagram of winch mechanism at a high speed; (b) the schematic diagram of winch mechanism at a low speed

The winch is at a high speed as shown in figure 3(a). The winch has six components. Among them, there are five active components with five low pairs and six high pairs. According to the formula 1, the degree of freedom of the winch mechanism is one.

The winch is at a low speed as shown in figure 3(b). The winch has eight components. Among them, there are seven active components with seven low pairs and four high pairs. According to the formula 1, the degree of freedom of the winch mechanism is one.

By analyzing the degree of freedom of the winch mechanism at a high or low speed, the degree of freedom of the mechanism is equal to the number of its original parts and it is equal to 1, which proves that the winch mechanism has certain motion conditions. Therefore, the designed winch transmission scheme is reasonable.

3. Establishment of the kinematics mathematical model of the winch

Table 1 shows the main parameters of gears. The following is the derivation of the kinematics mathematical model of winch.

Table 1. The winch gear parameters

Stage	Sun gear	Planetary gear	Ring gear	Center distance/mm	Modulus
1	$Z_1=14$	$Z_2=31$	$Z_3=76$	159	7
2	$Z_4=27$	$Z_5=27$	$Z_6=81$	216	8
3	$Z_7=16$	$Z_8=23$	$Z_9=62$	235	12

3.1. Rotational speed of the roller at a high speed

When the speed regulating brake A opens and the speed regulating brake B closes, the winch performs two stages planetary transmission. As a result, the winch works at a high speed.

The transmission ration of the first-stage planetary gear train can be obtained by

$$i_{13}^2 = \frac{n_1 - n_2}{n_3 - n_2} = -\frac{z_3}{z_1} \quad (2)$$

$$n_2 = n_4 \quad (3)$$

Where n_1 is the rational speed of the first-stage sun gear, n_2 is the rational speed of the first-stage planet carrier, n_3 is the rational speed of the first-stage ring gear, n_4 is the rational speed of the second-stage sun gear.

For the second-stage planetary gear train, the second-stage planetary carrier is fixed and the second-stage planetary gear is an idler. Thus, its transmission ratio is expressed as

$$i_{46} = \frac{n_4}{n_6} = -\frac{z_6}{z_4} \quad (4)$$

$$n_3 = n_6 \quad (5)$$

Where n_6 is the rational speed of the second-stage ring gear.

Combined the formula 3, the formula 4 can be written as

$$n_2 = n_4 = -\frac{z_6}{z_4} n_6 \quad (6)$$

Substituting the formula 6 into the formula 2, it can be obtained by

$$\frac{n_1 + n_6 z_6 / z_4}{n_6 + n_6 z_6 / z_4} = -\frac{z_3}{z_1} \quad (7)$$

The formula 7 is converted to

$$i_{16} = \frac{n_1}{n_6} = -\left(\frac{z_3}{z_1} + \frac{z_6 / z_4}{1 + z_6 / z_4}\right)\left(1 + \frac{z_6}{z_4}\right) = -24.71 \quad (8)$$

Since the selected motor speed is 740r/min, the rational speed of the winch roller at a high speed is expressed as

$$n_6 = \frac{n_1}{i_{16}} = \frac{740}{-24.71} = -29.95 \text{ r/min}$$

3.2. Rotational speed of the roller at a low speed

When the speed regulating brake A closes and the speed regulating brake B opens, the winch operates through three stages planetary transmission. Thus, the winch works at a low speed.

The transmission ration of the first-stage planetary gear train can be obtained by

$$i_{13}^2 = \frac{n_1 - n_2}{n_3 - n_2} = -\frac{z_3}{z_1} \quad (9)$$

$$n_2 = n_4 \quad (10)$$

For the second-stage planetary gear train, the transmission ratio is expressed as

$$i_{46}^5 = \frac{n_4 - n_5}{n_6 - n_5} = -\frac{z_6}{z_4} \quad (11)$$

$$n_5 = n_7 \quad (12)$$

$$n_3 = n_6 = n_8 \quad (13)$$

Where n_5 is the rational speed of the second-stage planet carrier, n_7 is the rational speed of the third-stage sun gear, n_8 is the rational speed of the third-stage planet carrier.

For the third-stage planetary gear train, the transmission ratio is obtained by

$$i_{79}^8 = \frac{n_7 - n_8}{n_9 - n_8} = -\frac{z_9}{z_7} \quad (14)$$

Where n_9 is the rational speed of the third-stage ring gear.

Since the third-stage ring gear is fixed, the formula 14 can be written as

$$\frac{n_7 - n_8}{0 - n_8} = -\frac{z_9}{z_7} \quad (15)$$

$$n_7 = \left(1 + \frac{z_9}{z_7}\right)n_8 \quad (16)$$

Substituting the formula 16 into the formula 11, it can be written as

$$\frac{n_4 - \left(1 + \frac{z_9}{z_7}\right)n_8}{n_8 - \left(1 + \frac{z_9}{z_7}\right)n_8} = -\frac{z_6}{z_4} \quad (17)$$

According to the formula 17, it can be obtained by

$$n_4 = \left[\left(1 + \frac{z_6}{z_4}\right) \frac{z_9}{z_7} + 1 \right] n_8 \quad (18)$$

Substituting the formula 18 into the formula 9, it can be expressed as

$$\frac{n_1 - \left[\left(\frac{z_6}{z_4} + 1\right) \frac{z_9}{z_7} + 1\right]n_8}{n_8 - \left[\left(\frac{z_6}{z_4} + 1\right) \frac{z_9}{z_7} + 1\right]n_8} = -\frac{z_3}{z_1} \quad (19)$$

According to the formula 19, it can be obtained by

$$i_{18} = \frac{n_1}{n_8} = \left(\frac{z_3}{z_1} + 1\right) \left(\frac{z_6}{z_4} + 1\right) \frac{z_9}{z_7} + 1 = 100.64 \quad (20)$$

Therefore, the rational speed of the winch roller at a low speed is obtained by

$$n_8 = \frac{n_1}{i_{18}} = \frac{740}{100.64} = 7.3529 \text{ r/min}$$

4. Kinematics simulation analysis by the ADAMS software

A three-dimensional(3D) simplified model of the double speed winch is established, as shown in Figure 4. The 3D model is introduced into the ADAMS software for kinematics simulation analysis. The winch is simulated at a high speed. The second-stage planet carrier is fixed to the ground and the first-stage sun gear is applied with a rational speed of 740 r/min. The simulation time is set to 5 seconds. Consequently, the angular velocity of the roller at a high speed is obtained in Figure 5. Figure 6 is a partial enlarged view of the angular velocity of the roller.

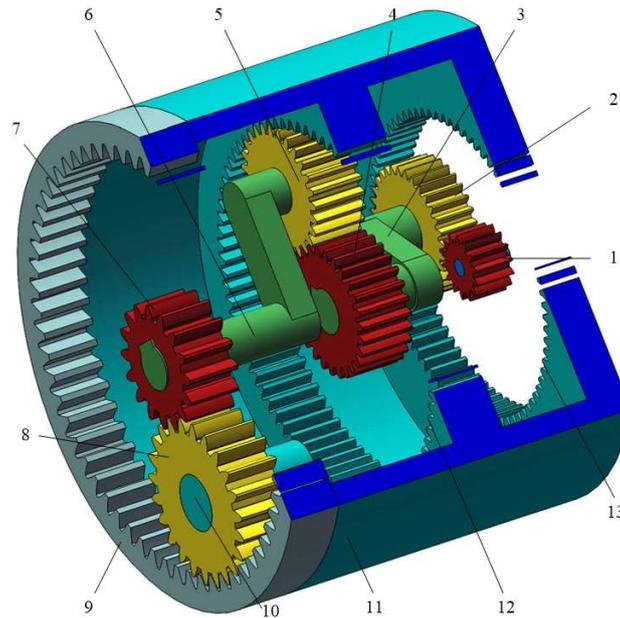


Fig. 4 The three-dimensional model of the double speed winch. 1-the first-stage sun gear; 2-the first-stage planetary gear; 3-the first-stage planet carrier; 4-the second-stage sun gear; 5-the second-stage planetary gear; 6-the second-stage planet carrier; 7-the third-stage sun gear; 8-the third-stage planetary gear; 9-the third-stage ring gear; 10-the third-stage planet carrier; 11-the winch roller; 12-the second-stage ring gear; 13-the first-stage ring gear.

From Figure 5, the angular velocity of the roller at a high speed is about -179.65 degrees/sec so the simulated rotational speed of the winch roller is -29.94 r/min. Compared with the theoretical value, the error is within 0.03%. The simulation analysis verifies that the winch transmission scheme is feasible at a high speed.

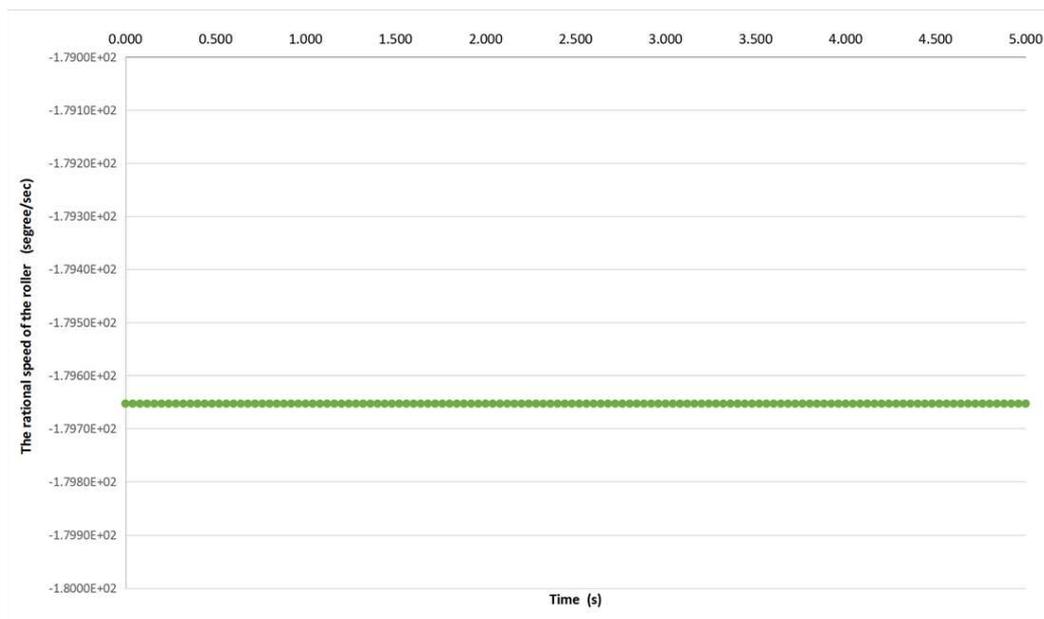


Fig. 5 The angular velocity of winch roller at a high speed

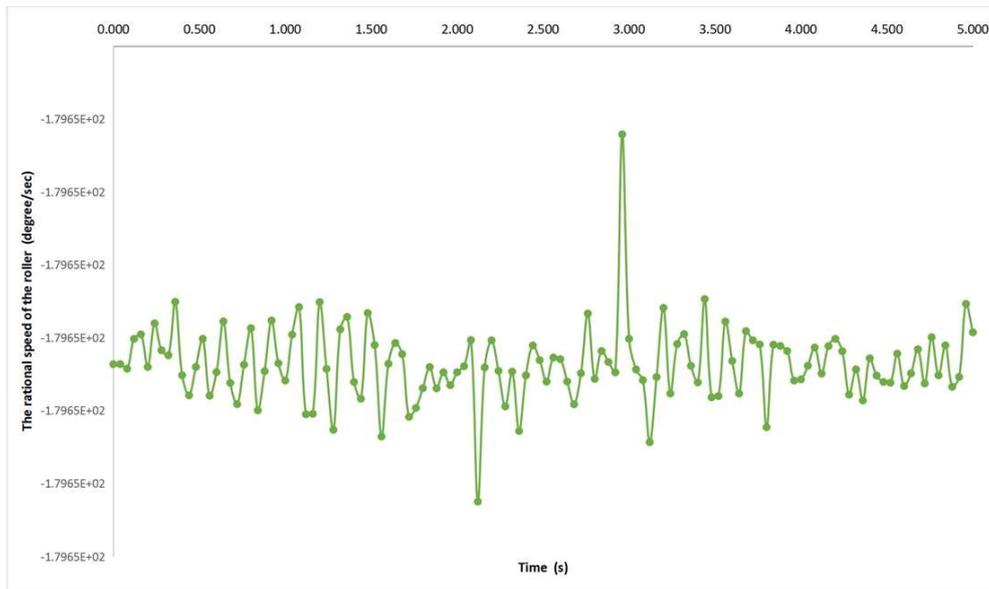


Fig. 6 Partial enlarged view of the angular velocity for the winch roller at a high speed.

The winch is simulated at a low speed. The third-stage ring gear is fixed to the ground and the first-stage sun gear is applied with a rotational speed of 740 r/min. The simulation time is set to 5 seconds. As a result, the angular velocity of the roller at a low speed is obtained in Figure 7. and a partial enlarged view of the angular velocity of the roller is shown in Figure 8.

As can be seen in the figure 7, the angular velocity of the roller at a low speed is about 44.12 degrees/sec. Thus, the simulated rotational speed of the winch roller is 7.3533 r/min. The maximum error is less than 0.005% in comparison with the theoretical value of the roller. Therefore, the winch transmission scheme is feasible at a high speed. Comparing Fig. 6 with Fig. 8, it is found that the fluctuation of the slow angular velocity is relatively small and the fluctuation at a high speed is relatively large. This simulation result is also in line with the actual operating work conditions of the winch.

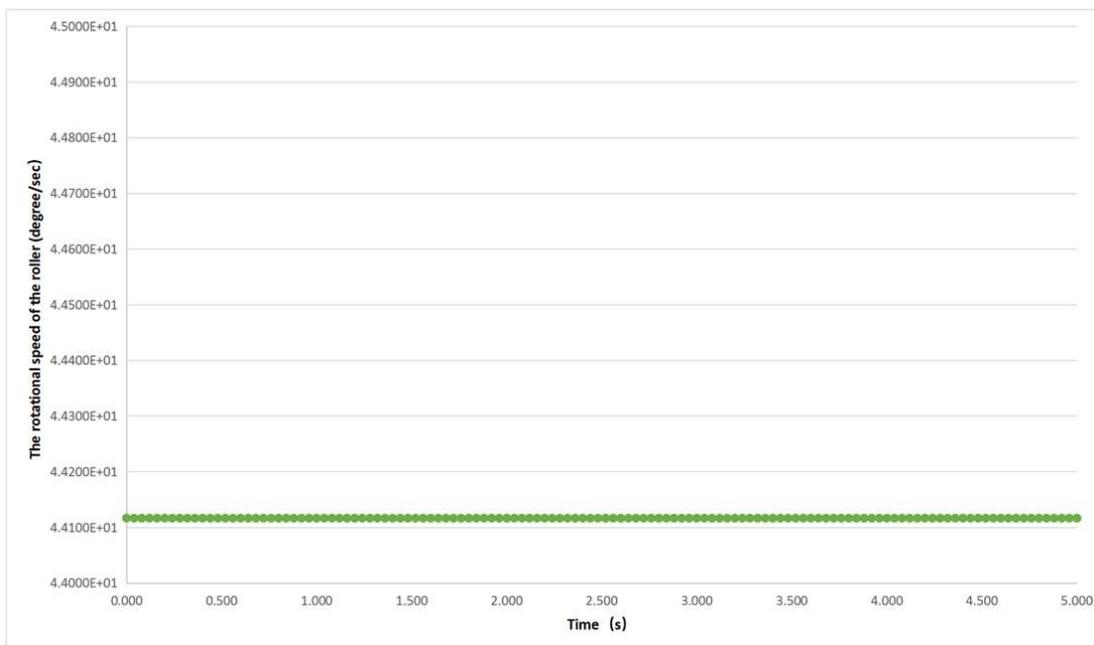


Fig. 7 The angular velocity of winch roller at a low speed

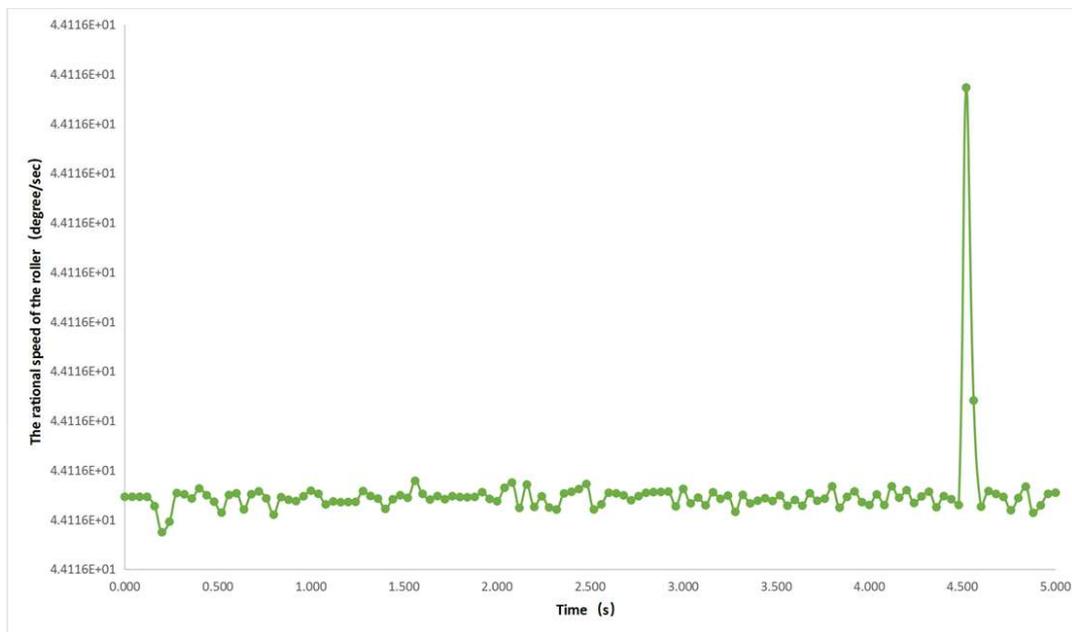


Fig. 8 Partial enlarged view of the angular velocity for the winch roller at a low speed

5. Summary

A transmission scheme for mine double speed winch is designed in the paper, which combines the fast speed and slow speed to improve the transmission efficiency. The kinematics mathematical model of the winch is established to derive that the rational speed of the winch roller is -29.95 r/min at a high speed and it is 7.3592 r/min at a low speed. The rational speed of the winch roller at a high speed is -29.94 r/min simulated by the ADAMS software and its simulation rational speed at a low speed is 7.3533 r/min. The error is minimal comparing the simulated values with the theoretical values. Theoretical derivation and simulation analysis show that this transmission scheme is reasonable in design. The transmission scheme is efficient.

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