Development and Experimental Research of Variable Frequency Speed Regulating Automatic Tensioning Device

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Abstract: A new variable frequency speed regulating automatic tensioning device has been developed. The tensioning device is applied to the long distance and large capacity telescopic belt conveyor. It realizes the tensioning automatic adjustment of the conveyor under different working conditions such as starting, running and stopping. After studying the dynamic characteristics of the variable frequency tension device, a tension control strategy and a closed loop control method for long distance telescopic belt conveyor are put forward. The test shows that the determination of the tensioning speed of the variable frequency speed regulating automatic tensioning device is related to the starting speed of the conveyor and the peak tension is effectively reduced by using the tension winch and the buffer device to adjust the tension in the shutdown stage.

Keywords: telescopic belt conveyor, variable frequency speed regulation, tensioning device, buffer device, experimental study.

1. Introduction
In the process of starting the long distance telescopic belt conveyor, the elastic deformation of the tape is concentrated at the separation point of the head driving drum. It requires the tightening device to be quickly tensioned, and the length of the stretch is received in the storage bin. During constant speed operation, the elongation and shortening of the belt caused by load increase and decrease are far less than the start-up process, and the speed of the tightening device is small. The shutdown process is more complex than the starting process and the uniform speed process. In the case of normal shutdown, the deceleration time is much less than the acceleration time. The same elastic deformation is released. It requires looser belt speed to be larger than the tighter belt speed. It can be seen that the speed of the tighter belt in the
tension device is different from the looser belt in the different operation stages of the long distance telescopic belt conveyor, and the Variable Frequency Speed Regulating Automatic Tensioning Device can be used to solve this problem.

A. Harrison studied the lag phenomenon of the tension device during the loading and unloading process of the conveyor, and put forward the transfer function of the tension system [1]. After studying the tension device of winch, G.G.Shortt of South Africa puts forward the formula for calculating tension and rope number, which is applied to short distance conveyor and manual control [2]. After analyzing the static characteristic and tensioning operation of the belt conveyor, Piotr kulinowski of Poland puts forward a new formula for calculating the elastic modulus of adhesive tape, and uses this formula to calculate the length of the tensioning of the belt, considering the influence of the initial tension and the sag of the long distance conveyer. This paper describes the operation of conveyor with the static characteristics of tension system, and points out the advantages and disadvantages of various design tensioning methods [3]. Piotr kulinowski treats the tension system as a sub model of the discrete model of the conveyor, which reflects the rheological characteristics of the belt. With this dynamic model, a new type of servo tensioning device is designed and a series of simulation studies are made. The results are tested on the 1000m fixed belt conveyor, and the correctness of the simulation results is verified. It is concluded that the servo tensioning is superior to other ways [4].

2. Structure and Working Principle of Variable Frequency Speed Regulating Automatic Tensioning Device

According to the changing characteristics of tension force of long distance telescopic belt conveyor and the demand for tensioning speed, the variable frequency speed regulating automatic tensioning device is mainly composed of two parts: variable frequency speed regulating automatic tensioning winch and buffer device.

2.1 The Structure and Composition of the Device

The variable frequency speed regulating automatic tensioning winch.

The variable frequency speed regulating automatic tensioning winch is mainly composed of tension winch, brake hydraulic pump station and electric control part and so on. As shown in Fig. 1.
The variable frequency speed regulating automatic tensioning device

Table 1 the main parameters of the tensioning winch

<table>
<thead>
<tr>
<th></th>
<th>Value</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Motor power</td>
<td>75KW</td>
<td></td>
</tr>
<tr>
<td>Drive ratio of reducer</td>
<td>74.8</td>
<td></td>
</tr>
<tr>
<td>Wire rope traction speed</td>
<td>0.65m/s</td>
<td></td>
</tr>
<tr>
<td>Maximum traction of wire rope</td>
<td>95.1KN</td>
<td></td>
</tr>
<tr>
<td>Brake maximum dynamic braking torque</td>
<td>410-500Nm</td>
<td>740Nm</td>
</tr>
<tr>
<td>Minimum opening pressure of brake</td>
<td>3.5MPa</td>
<td></td>
</tr>
</tbody>
</table>

The buffer device

The buffer device is composed of emulsified hydraulic pumping station, check valve, pressure gauge, safety valve, stop valve, hydraulic cylinder and accumulator. The working principle is shown in Fig. 2. The design of the buffer device mainly determines the working pressure, the opening pressure of the safety valve, the buffer stroke and so on. During the normal operation of the telescopic belt conveyor, the tension adjustment of the belt is entirely completed by the automatic tension winch, and the buffer device does not participate in the regulation of the tension.

Fig. 2 working principle of buffer device
### Table 2 the main parameters of the buffer

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motor rated power</td>
<td>4KW</td>
</tr>
<tr>
<td>Working pressure</td>
<td>14MPa</td>
</tr>
<tr>
<td>Opening pressure of safety valve</td>
<td>22MPa</td>
</tr>
<tr>
<td>Safety valve flow</td>
<td>250L/min</td>
</tr>
<tr>
<td>Accumulator volume</td>
<td>252L</td>
</tr>
<tr>
<td>hydraulic cylinder stroke</td>
<td>2.3m</td>
</tr>
</tbody>
</table>

### 2.2 Working Principle

Working principle: after sending out the working order of the conveyor, the tension sensor of the variable frequency speed regulating automatic tensioning device detects the tension of the separation point of the head driving drum, and the tension signal is transmitted to the PLC. PLC compares the detection value with the set value to get the difference between the two. According to the difference, PLC controls the size and direction of the output frequency of the frequency converter. The frequency converter provides the power for the winch motor in different directions and frequencies. Winch motor drive forward or backward at different speeds, so as to realize the belt tightening and loosening. If the tension detection value is greater than the upper limit of the set value, the tension winch loosens tape and reduce the tension until it is equal to the set value; if the tension detection value is less than the lower limit of the set value, the tension winch tightens the belt and increase the tension; the greater the difference between the two, the greater the speed of the belt tightening and loosening of the winch. The closer the tension difference is to zero, the winch speed will also go to zero.

### 3. Analysis and Study on Dynamic Characteristics of Automatic Tensioning Device

#### 3.1 Transfer Function of a Tension Feedback Control System

The feedback system of the automatic tension device is composed of frequency converter, explosion-proof motor, tension sensor, reducer, drum, pulley block, wire rope and so on. Automatic control block diagram of tension is shown in Fig. 3.

![Fig. 3 Automatic control block diagram of tension](image)

If all links are connected in series, the block diagram of the open loop transmission system of the feedback system is shown in Fig. 4.

The above systems can be connected in series, and the overall transfer function of the feedback system:
Web(S)- Transfer function of frequency converter, We(S)- Transfer function of the winch motor, We(S)- Transfer function of reducer, Wag(S)- Transfer function of the winch roller, Why(S)- Transfer function of pulley block.

Fig. 4 The transfer function block diagram of feedback system

3.2 Transfer Function of Buffer Device

The hydraulic cylinder of the buffer device is connected with the traveling car through the wire rope, and the piston rod is pulled out when the tension force of the rubber belt is greater than the hydraulic pull force; when the tension force of the belt is smaller than that of the hydraulic pull, the piston rod is retracted under the action of the liquid pressure. Therefore, the hydraulic cylinder is the actuating element of the tensioning device under tension force, and the force balance equation on the piston rod is:

\[ f = m \frac{dv}{dt} + Bv + f_L \]  

(1)

Formula: FL -tension force, m -piston rod movement part quality, f -hydraulic drive force, B -liquid resistance coefficient.

Because inertia force and frictional resistance are all related to speed, inertia friction is represented by five.

\[ f_{in} = m \frac{dv}{dt} + Bv, \text{ that is, } f_{in} = f - f_L \]  

(2)

For tensioning buffer, tension FL is input for system, displacement of his output. The change process of the output h with the input FL is as follows: the internal tension of the belt in the operation of the telescopic belt conveyer changes under the operation of the disturbance, and changes the displacement h of the piston rod of the cylinder. The change of h will cause the change off of hydraulic drive force and form a closed loop system with connection.

The type (2) for the Laplace transform, can get the transfer function:

\[ W_m(S) = \frac{H(S)}{F_m(S)} = \frac{1}{s(ms + B)} \]  

(4)

Formula: We(S) - Transfer function of buffer device.

By analyzing the tensioning winch and buffering device of the automatic tensioning device, it can be concluded that the block diagram of the system is input with the change of tension FL, and the displacement of the wire rope is h as output, as shown in Fig. 5.
Fig. 5 The transfer function block diagram of tension device system.

From the diagram, we can see that the transfer function $W_e(S)$ of winch system is the feedback link of tensioning device. In order to work properly, the tensioning device needs to respond to the real time conditions. It is necessary to adjust the tension automatically after the change of $FL$, so as to ensure that the system tends to balance.

The performance of the tensioner depends on the performance of the feedback system and the performance of the feedback system, which is determined by the characteristics of the frequency converter, the motor, the roller and the friction resistance.

The open loop transfer function is as follows:

$$W_k(S) = W_m(S) * W_e(S) = \frac{W_h(S) * W_g(S) * W_j(S) * W_d(S) * W_b(S)}{s(ms + B)} \quad (5)$$

The closed loop transfer function is as follows:

$$\phi_s = \frac{H(S)}{F_L(S)} = \frac{W_m(S)}{1 + W_k(S)} \quad (6)$$

The transfer functions of the whole tensioning device system can be obtained by introducing various parameters into (5) and (6).

4. Experimental Research of Variable Frequency Speed Regulating Automatic Tensioning Device

Test results of the starting process of conveyor.

Fig. 6 300s start test results
Fig. 7 300s start vehicle displacement test results
Test result of conveyor shutdown process.

Fig. 8 Controlled 90s shutdown test results

Fig. 9 Test results of controlled 90s shutdown vehicle displacements

Fig. 10 Test results of full load free stop

Fig. 11 Test results of full load free stop displacement
Through the test of free load free stop and full load free shutdown process, it is shown that the peak tension is effectively reduced by using the tension winch and the buffer
device to adjust the tension in the shutdown stage.

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**References**


