Research on Optimization of Full Frequency Conversion Intelligent Speed Regulation Algorithm for Bulk Cargo Terminal

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Abstract. In view of the operating conditions of the bulk cargo terminal, a bulk cargo terminal frequency conversion speed regulation control scheme and an intelligent full frequency conversion speed regulation algorithm are put forward, the study completes the intelligent speed regulation function of the belt conveyor according to the source material flow. This research solves the problems of low equipment efficiency and high unit energy consumption caused by uneven distribution of material flow and long-term no-load operation of belt conveyors under various operating conditions. Research on the optimization of intelligent speed regulation algorithms provides strong technical support for the construction of green ports and the completion of energy-saving and emission-reduction targets for the water transportation industry.

1. Introduction
Due to the complex loading and unloading process, numerous loading and unloading equipment and large installed capacity, the bulk cargo terminal has huge energy consumption, which accounts for a large proportion of energy consumption in the water transportation industry. Therefore, promoting the energy-saving design of bulk cargo terminals and reducing energy consumption are problems that need to be solved urgently at present.

2. Frequency conversion speed regulation energy saving technology
Motor drive systems are divided into constant speed and speed regulation drive systems. Speed control drives are divided into DC speed control and AC speed control. In recent years, the fastest growing of AC speed regulation is the frequency conversion speed regulation technology. The use of variable frequency speed regulation can achieve stepless speed regulation and maintain good dynamic characteristics. At the same time, the use of frequency conversion starting of AC motors can significantly improve its starting performance, greatly reduce starting current and increase starting torque. Compared with DC motors, AC motors are cheaper, have fewer operating failures, are simple to maintain, and are not restricted in use occasions. The single-unit capacity can be much larger than DC motors. The speed control performance of AC motors is comparable to DC speed control system technology, and has replaced DC speed control systems in most areas. The earliest purpose of applying variable frequency speed regulation technology is mainly for speed control. With the rapid development of power electronics and control technology, variable frequency speed regulation can obtain high-precision speed and torque control, and achieve the adjustment accuracy of DC speed...
regulation systems\textsuperscript{[3-4]}. Squirrel-cage induction motors have simpler structure, lighter weight, lower price, no commutator, and reliable operation than DC speed control systems. The control circuit is simpler and easier to maintain than DC speed control systems. For the load with extremely large capacity and extremely high speed, because the commutation ability of the DC motor commutator limits its capacity and speed, the AC motor is not restricted. Therefore, the transmission with extra large capacity and high requirements on the control of the transmission device should adopt AC frequency conversion speed regulation.

The variable frequency drive has efficient start-stop and speed regulation functions, which can ensure the smooth progress of the process. The variable frequency drive can achieve greater torque output at lower speeds and achieve smooth starting of heavy loads. The inverter has multiple protection functions such as overcurrent, short circuit, overvoltage, undervoltage, phase loss, overheating, etc. In view of the inverter's good energy-saving effect, it has been widely used in large-scale port machinery, but its application in belt conveyor systems is still In the initial stage\textsuperscript{[5-6]}, it is extremely important to develop a full-frequency intelligent speed regulation technology to enable the belt conveyor to intelligently adjust the operating speed, fully tap the energy-saving potential of the frequency converter, and increase the input-output ratio of the frequency converter.

3. Research on Optimization of Full Frequency Conversion Speed Regulation Technology for Bulk Cargo Terminal

This technology is aimed at operating conditions above the bulk cargo terminal. This research proposes a frequency conversion speed control scheme, and develops an intelligent full frequency conversion material conveying speed regulation algorithm for the bulk cargo terminal, so that the belt conveyor can intelligently adjust the speed according to the source material flow. The full frequency conversion material conveying speed regulation algorithm solves the problems of low equipment efficiency and high unit energy consumption caused by uneven material flow distribution and long-term no-load operation of belt conveyors.

3.1. Research on Energy Saving Theory of Frequency Conversion Speed Regulation

3.1.1. The principle of frequency conversion

Modern AC variable-speed transmission refers to the frequency-conversion and variable-speed transmission of AC motors using electronic power converters. There are many speed regulation methods for AC asynchronous motors, among which the frequency conversion speed regulation is the best. The synchronous speed of the asynchronous motor, that is, the speed of the rotating magnetic field:

\[ n_1 = \frac{60f_1}{p} \]  

(1)

In the formula, \( f_1 \) is the power supply frequency, and \( p \) is the number of pole pairs of the motor. The asynchronous motor shaft speed:

\[ n = n_1(1 - s) = \frac{60f_1}{p} (1 - s) \]  

(2)

In the formula, \( s \) is the slip rate of the asynchronous motor, \( s = \frac{n_1 - n}{n_1} \).

Frequency conversion speed regulation means that when the number of pole pairs of the motor is constant, the synchronous speed \( n_1 \) is changed by changing the power supply frequency \( f_1 \) of the motor, thereby changing its speed \( n \) to realize speed regulation operation. In order to keep the excitation current and power factor constant during variable frequency speed regulation, it is desirable that the magnetic flux \( \Phi_m \) also remains constant. Therefore, it is generally required that \( \Phi_m \) remain unchanged during frequency control. It can be seen from the electromotive force equation of the stator circuit that, while ignoring the stator leakage impedance, we have:
\[ U_{\Phi} \approx E_1 = 4.44f_1N_1k_{N1}\Phi_s \]  
(3)

In the formula: \( E_1 \) is the effective value of the electromotive force induced by the air gap magnetic flux in each phase of the stator, \( f_1 \) is the stator frequency, \( N_1 \) is the effective number of turns per phase of the stator, \( k_{N1} \) is the fundamental winding coefficient, \( \Phi_m \) is the magnetic flux per pole. In order to keep \( \Phi_m \) unchanged at \( f_1 \), it can be seen from the above formula that \( U_{\Phi}/f_1 \) must be a constant value, that is, \( U_{\Phi} \) must change in proportion to \( f_1 \).

When constant torque loads such as belt conveyors are used for constant torque speed regulation, if the frequency conversion device guarantees the proportional change of \( U_{\Phi} \) and \( f_1 \), it can ensure that the motor has the same overload capacity during the frequency change.

The maximum torque of the motor is:

\[ T_{max} = \frac{m_1}{\pi} \left( \frac{U_{\Phi}}{f_1} \right)^2 \]  
(4)

In the formula, \( \Omega_1 = 2\pi f_1/p \), \( X_1 + X_2' = 2\pi f_1(L_1 + L_2') \), with the above formula and considering that when \( f_1 \) is relatively high, \( X_1 + X_2' >> R_1 \) and \( R_1 \) are omitted, we get:

\[ T_{max} = C \left( \frac{U_{\Phi}}{f_1} \right)^2 \]  
(5)

In the formula, \( C = m_1p/[8\pi^2 (L_1 + L_2')] \). Since \( T_{max} = K_T T_N \) is substituted into the above formula:

\[ T_N = C \frac{U_{\Phi}^2}{K_T f_1^2} \]  
(6)

Therefore, if the frequency changes to \( f_1 \), the stator phase voltage, rated torque and overload multiples corresponding to \( U_{\Phi}' \), \( T_N' \), \( K_T' \), then the ratio of the rated torque before and after the frequency change is:

\[ \frac{T_{N1}'}{T_N} \approx \left( \frac{U_{\Phi}'}{U_{\Phi}} \right)^2 \left( \frac{f_1}{f_1} \right)^2 \left( \frac{K_T}{K_T} \right) \]  
(7)

For constant torque speed regulation, \( T_N = T_N' \). It can be seen that when constant torque frequency conversion speed regulation, if \( U_{\Phi}/f_1 \) can be kept equal to a fixed value, the constant voltage frequency ratio method can ensure that the overload capacity of the motor during the speed regulation process is basically unchanged, and the magnetic flux \( \Phi \) is basically unchanged.

### 3.1.2. Research on Transmission Power of Belt Conveyor

Transmission power calculation:

\[ P_A = F_U v \]  
(8)

In the formula: \( P_A \)—the required power of the drive roller shaft, KW, \( F_U \)—circumferential driving force, kN, \( v \)—belt speed, m/s. Incorporating formula (9) into formula (8) to obtain:

\[ P_A = \left\{ C_f f_1 g[q_{v0} + q_{va} + (2 q_{v0} + q_{v}\cos\delta)] + q_{vs} H_g + F_{s1} + F_{s2} \right\} v \]  
(9)

Putting formula (8) into formula (9), we get:

\[ P_A = \left\{ C_f f_1 g[q_{v0} + q_{va} + (2 q_{v0} + q_{v}\cos\delta)] + q_{vs} H_g + F_{s1} + F_{s2} \right\} v + \frac{C_f g q_{v} \cos\delta}{3.6} + \frac{q_{v} H_{g}}{3.6} \]  
(10)

The power \( P_M \) required to drive the motor shaft, that is, the positive power required by the belt conveyor:

\[ P_M = k_1 P_A \]  
(11)

In the formula, \( k_1 = 0.78~0.95 \). Since \( q_{v0} \), \( q_{va} \), \( q_{v} \) and \( C, f, L, g, \delta, H, F_s1, F_s2 \) are constant after the belt conveyor is built, \( k_1 = \left\{ C_f f_1 g[q_{v0} + q_{va} + 2 q_{v0} \cos\delta] + F_{s1} + F_{s2} \right\} \), \( b_1 = \frac{C_f f_1 g \cos\delta + H_g}{3.6} \).

\[ P_A = k_1 v + Q b_1 \]  
(12)

Then

\[ P_M = k_1 \frac{Q b_1}{k_1} \]  
(13)

Let \( k_1 = \frac{k_1}{\eta_1} \), \( b_1 = \frac{b_1}{\eta_1} \) we can get
\[ P_M = kv + Q_b \quad (14) \]

It can be seen from the formula that when the transportation volume \( Q \) is constant, \( P_M \) is proportional to the speed of the belt conveyor \( v \). Under the premise of meeting the conveying capacity of the belt conveyor and the material does not overflow, the greater the belt speed, the greater the belt conveyor speed. The greater the positive power, the smaller the belt speed, the smaller the power required by the conveyor, and the more energy-saving.

The bulk cargo terminal loading and unloading process mainly includes stacking operations and stacking operations. When entering and exiting the stack, the materials of the belt conveyor are mainly provided by the ship unloader and the stacker and reclaimer. The belt conveyor is used as the load object and passively ship unloaders and bucket turbines receive materials. Therefore, regardless of the size of the belt speed \( v \), the total transport volume \( Q \) is constant. In summary, under the premise of meeting the carrying capacity of the belt conveyor, the bulk cargo terminal adopts frequency conversion speed regulation when the incoming material flow of the belt conveyor is reduced, reducing the operating speed can effectively save energy consumption.

### 3.2. Intelligent speed regulation algorithm

When the material flow rate of the belt conveyor is low or there is no material, reducing the operating speed can effectively save energy. Combining actual operation conditions and loading and unloading technology, this research proposes a full frequency conversion control algorithm, which intelligently reduces the operating speed and energy consumption when the material flow of the belt conveyor is small, when the material flow of the belt conveyor is large, it can dynamically increase the operating speed to prevent material overflow from the belt conveyor and cause sprinkling or stacking when the material flow is too large and the belt conveyor speed is low. The intelligent speed regulation algorithm is universal, and all full frequency conversion bulk cargo conveying systems can realize intelligent speed regulation based on this algorithm.

When the job is busy, the operator's operation tasks are heavy. If the process speed setting mode is adopted, it is impossible to set the process speed in time according to the on-site operation situation. When the running speed of the belt conveyor is low but the material flow rate increases, if the speed is not increased in time, it may cause the material to spill or block the material. If the belt conveyor is running at a high speed but the material flow is reduced, if the speed is not reduced in time, energy consumption will be wasted. Applying the intelligent speed regulation algorithm, PLC controls the operating speed of the belt conveyor according to the algorithm, so that the belt conveyor intelligently adjusts its own speed according to the flow rate of the upstream equipment, ensuring the uniformity of the belt conveyor material and improving the use of the belt conveyor efficiency, reduce energy consumption. The flow chart of intelligent speed regulation mode setting is shown in Figure 1:
Figure 1. Flowchart of Smart Speed Control Mode Setting

The principle of the intelligent variable frequency speed regulation algorithm is that the first belt conveyor in the incoming material direction intelligently adjusts the running speed according to the size of the material flow. After the first belt speed is adjusted, it will delay intelligently adjust the running speed of the lower belt in the direction of the material flow to make the lower belt speed synchronized with the upper belt speed. When the process is set to intelligent speed control, first select the process to belong to the "heavy load" or "light load" mode. When there are many materials on the belt conveyor used in the process, the "heavy load" mode should be selected. The system will set the frequency of all frequency conversion equipment in the process to 45Hz to prevent the belt conveyor from being too low when the belt conveyor is started under heavy load, causing the belt conveyor to fail to start. When the belt conveyor used in the process is under no load or light load, it should be selected as the "light load" mode, and the system will set the frequency of all variable frequency equipment in the process to 20Hz.

3.3. Intelligent speed regulation algorithm test
The intelligent speed regulation algorithm of this research is tested at Fangcheng port 20-22 berths. During unloading, because the unloader can move at any time and is affected by the position of the unloader, the intelligent speed regulation mode has two belts for speed regulation, two belts for Fixed 45Hz operation. The lower-level belt performs intelligent speed regulation according to the belt scale process. When loading a ship or a vehicle, the under-machine belt performs intelligent speed regulation according to the flow of the upper belt scale of the bucket wheel. The maximum conveying capacity of the 20-22 berth belt conveyor in Fangcheng port is 4500t/h. During the actual operation of the belt conveyor, the material distribution is extremely uneven and the flow is unstable, and the instantaneous flow changes quickly. Therefore, in the actual speed adjustment process, the speed of the belt conveyor is divided into 3 gears, and each gear corresponds to a different flow. As shown in Table 1. The belt on the bucket wheel machine is equipped with a belt scale to measure the flow and accumulation of the bucket wheel machine. The lower belt of the bucket wheel machine uses this flow rate as the basis for speed adjustment, and the downstream belt adjusts its own speed in turn after the upstream belt speed adjustment is completed.
Table 1. Correspondence between flow rate and speed

| Gear | Flow (t) | Frequency (Hz) | Speed (m/s) |
|------|----------|----------------|-------------|
| 1    | >=3000   | 45             | 3.6         |
| 2    | 1000-3000| 30             | 2.4         |
| 3    | <=1000   | 20             | 1.6         |

After testing, when the belt conveyor material is constant, reducing the operating speed can effectively reduce the energy consumption. When running at no load, reduce the running speed and the energy saving effect is the greatest. As the material flow rate increases and drops to the same speed, the energy saving rate gradually decreases.

4. Conclusions
This study combines modern control theory and intelligent control methods to carry out research, and proposes an intelligent full frequency conversion speed regulation algorithm. Intelligent full frequency conversion speed regulation technology has obvious effects in port energy saving and emission reduction. This technology has made certain contributions to the port to reduce production costs, complete energy conservation and emission reduction tasks, and realize green ports. The application of full frequency conversion in the port industry is still in the exploratory stage. With the diversification and intelligence of material detection methods, its core control algorithm will become more and more perfect. After adopting full frequency conversion drive, various new control techniques will continue to emerge. In the future, the intelligent full frequency conversion speed regulation algorithm can be continuously optimized for specific working conditions and application scenarios to provide continuous technical support for energy conservation and emission reduction in the port industry.

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