Research on Energy-saving Process Control Method of Bulk Cargo Terminal Based on Frequency Control Technology

Dongqi Lu¹, Hankun Shi¹*, Xuelin Wang¹

¹China Waterborne Transport Research Institute, Beijing, 100088, China
*shihankun@wti.ac.cn
*Corresponding author’s e-mail: 17801034960@163.com

Abstract. The bulk cargo terminal conveying system has the problems of low equipment efficiency and high energy consumption during operating conditions such as no-load starting, ship loader shifting, and ship unloader clearing. In this paper, combined with the full frequency conversion control technology, the research on the frequency conversion control mode of the bulk cargo terminal and the energy saving effect test are carried out, and the optimized control method for the energy saving process is proposed. Under various common working conditions, the bulk cargo terminal can control the belt conveyor to run at low or zero speed according to the actual situation on the spot, so as to minimize energy consumption.

1. Introduction
The improvement of the port's comprehensive transportation capacity provides strong support for the development of the national economy and foreign trade, but it also brings about huge energy consumption problems. At present, frequency conversion speed regulation has been widely used in the world's advanced industrial countries [1]. Since entering China in the 1990s, it has now been used in all walks of life [2]. So far, variable frequency speed regulation technology has also been used in some port terminals, and its application range has become wider and wider, and some economic benefits have been achieved [3]. 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 [4-5], which accounts for a considerable proportion of energy consumption in the water transportation industry. Therefore, vigorously promoting energy-saving design of bulk cargo terminals, optimizing loading and unloading processes, tapping energy-saving potential, and reducing energy consumption are problems that need to be solved urgently.

2. Research on Frequency Conversion Speed Regulation Technology of Wharf
The process control in the terminal control system can adopt a fixed frequency control method, that is, all equipment in the process runs at the same conveying speed. After the belt conveyor adopts the frequency conversion speed control system, it not only solves the problems of soft start, soft stop, multi-motor power balance, and improved power factor, but also has energy-saving effects [6-7]. When the conveying volume of the belt conveyor with variable frequency drive changes, an operator will appropriately adjust and control the output frequency of the inverter in the monitoring system in real time, so that the belt conveyor will run at a speed matching its conveying volume, which not only makes full use of the belt conveyor carrying capacity, and reduce unnecessary power loss of the drive motor, so as to achieve the purpose of saving energy.
In the actual operation of the terminal, the central control operator is usually the center of the entire terminal control and communication. Not only does it need to perform production operations, but also monitor the status of operations and non-operating equipment, cooperate with on-site maintenance operations, handle various conditions on the site, and coordinate operation and maintenance, records, summarizes and transmits various information, etc., and the central control operator is very busy. It is difficult to adjust the operating speed of the process at any time. In order to avoid accidents caused by the slow process of the process, a higher operating speed is usually selected during the operation. From the beginning of the operation to the end of the operation, no matter what kind of flow and what kind of operation status, it is usually not the operating speed will be changed, and the best effect of energy saving and consumption reduction using frequency conversion speed regulation has not been achieved. The full frequency conversion intelligent speed control algorithm is embodied in the intelligent speed control operation mode in the automatic operation mode in the supporting project. In the intelligent speed control mode, the conveying equipment in the process aims at equalizing the material flow and increasing the material filling rate, based on the source flow of the material, taking the material conveying position as the node, and automatically frequency conversion speed control. Realizing the speed control of the conveying equipment with adaptive load changes, and optimizing the control of the material conveying process to achieve the purpose of energy saving.

3. Frequency Conversion Control Mode Research and Energy Saving Effect Test

3.1. Selection and switching of full frequency conversion control mode

This study was tested in Fangcheng port. The belt conveyors in this study are all frequency conversion drives. The output frequency of each inverter can be changed through the upper monitoring system. The upper monitoring system controls the output frequency of the inverter in two ways: single frequency Setting mode and process speed setting mode.

The stand-alone frequency setting method is shown in Figure 1. Enter the new frequency in the frequency setting box and click the "frequency modification" button to complete the setting. After the setting is successful, the belt conveyor will run at the new frequency.

![Figure 1. Single machine frequency setting diagram](image)

Process speed setting mode: Process speed control mode is divided into two types: process fixed speed operation and intelligent speed control mode. The process constant speed operation mode is to artificially set the operating speed of the frequency conversion equipment in the process. After the setting is completed, all the frequency conversion equipment in the process will run at a constant speed at the set frequency. If you need to change the operating speed of the equipment in the process, you need to reset the operating frequency of the process. The intelligent speed regulation mode is that the belt conveyor intelligently adjusts the operating speed with the size of the source material flow. When the incoming material flow of the belt source increases, the belt conveyor will increase the
speed to match the flow rate. Operation: When the incoming material flow from the source of the belt decreases, the belt conveyor runs at a speed that matches the flow.

When the process speed control mode is set to intelligent speed control, you should also select whether the process starts with light load or heavy load. If it is started at light load, the system will automatically set the initial operating speed of the frequency conversion equipment in the process at a lower speed, if it is started at a heavy load, the system will automatically set the initial operating speed of the frequency conversion equipment in the process at a higher speed. In the process of process operation, the two modes of process speed control can be switched to each other. After the switching is completed, the frequency conversion equipment in the process will run according to the new mode and speed. There is no need to stop during the switching process, and the running frequency is excessively stable and will not have any impact on the system. The speed control modes are all completed by Figure 2.

![Figure 2. Speed control mode setting diagram](image)

3.2. Energy saving effect verification

When the belt conveyor is running under no load, because there is no material, the belt conveyor mainly overcomes the friction of the rollers, conveyor belts, etc., and basically does not change, and is a constant torque load. At this time, the inverter output torque remains unchanged. For constant torque load:

\[ PL = \frac{T_L}{9550} \]  

(1)

The input power of the motor is proportional to the first power of the speed. After adopting frequency conversion speed regulation, the saved power can be calculated by the following formula:

\[ P_1 - P_2 = \frac{T_L n_1}{9550} - \frac{T_L (n_1 - n_2)}{9550} \]  

(2)

The power saving rate \( k \) is calculated by the following formula.

\[ k = \frac{P_1 - P_2}{P_1} \frac{n_1 - n_2}{n_1} \]  

(3)

When the belt conveyor is running at no load, the motor running speed is changed, and the motor current is basically unchanged. Because the inverter has a constant voltage-frequency ratio output (that is, \( U/f = \text{fixed value} \)), the voltage and frequency change proportionally, and the asynchronous motor power calculation formula \( P = UI\cos\Phi \) calculates the motor power consumption and energy saving rate. When the belt conveyor material is constant, reducing the operating speed can effectively reduce the energy consumption, when the belt conveyor is running at no load, the operating speed is reduced, 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. Research on Energy-saving Process Control Method

4.1. Flow start control method along material flow

With the massive promotion of energy-saving technologies, the original control schemes are becoming less and less suitable for the requirements of energy-saving production, and the traditional process
startup sequence itself has energy loss. Regardless of whether there are materials on the belt conveyor, as long as the belt conveyor is running, energy consumption exists. When the belt conveyor is running under no load, energy consumption is wasted, which directly leads to an increase in the unit energy consumption of the belt conveyor. Therefore, energy-saving belt conveyors must first reduce the no-load rate of belt conveyors.

The traditional start-up scheme considers that there will be no accumulation during the material conveying process, and the conveying equipment is mostly started in the opposite direction of the material flow. In the process, the equipment starts in the reverse direction of the material flow, and the time to wait for all equipment to start is the no-load operation time. The equipment farthest from the source of the material has the longest no-load operation time and has serious losses. Take the ship unloading-storage yard process as an example, according to the equipment used in the material flow direction, ship unloader-A101-A201-MA201-A301-A401-A501-A601-5# bucket wheel stacker. If the process starts in the reverse direction, the A601 starts first, then A501, A401, A301, MA201, A201 start, and finally A101 starts. After the process is started, the ship unloader is notified to start unloading. During the start-up process, the first belt conveyor started is always in an idling state, and then the belt conveyor started is also no-load operation, but the no-load time is slightly shorter, until all the belt conveyors are running, the ship unloader starts to give Material, energy consumption and waste are serious. Set the start-up time of a single belt conveyor to 20s, and the accumulated idle waiting time and energy consumption (calculated at 50 Hz) for each belt conveyor in starting are shown in Table 1.

Table 1. No-load cumulative timetable of 5# process belt conveyor

| Belt conveyor number | Start set time (s) | Length (m) | Belt speed (m/s) | Material running time (s) | Measured energy consumption (KW) | No-load cumulative time (s) | Cumulative energy consumption (KWh) |
|----------------------|-------------------|------------|-----------------|--------------------------|---------------------------------|---------------------------|-------------------------------------|
| A101                 | 20                | 800        | 4               | 200                      | 336                             | 120                       | 11.2                                |
| A201                 | 20                | 150        | 4               | 37.5                     | 171                             | 300                       | 14.3                                |
| MA201                | 20                | 20         | 4               | 5                        | 47                              | 418                       | 5.5                                 |
| A301                 | 20                | 100        | 4               | 25                       | 110                             | 483                       | 14.8                                |
| A401                 | 20                | 100        | 4               | 25                       | 112                             | 548                       | 17.0                                |
| A501                 | 20                | 100        | 4               | 25                       | 109                             | 593                       | 18.0                                |
| A601                 | 0                 | 100        | 4               | 25                       | 108                             | 618                       | 18.5                                |
| **Total**            |                   | **3080**   |                 |                          | **99.2**                       |                           |                                     |

After calculation and actual testing, the cumulative total time for the belt conveyor to wait for no-load operation during only one startup process is 3080s, and the total no-load energy consumption of the motor is 99.2KWh. If it accumulates day by day, the no-load energy consumption is quite huge, and this part of the energy consumption is wasted. If the new energy-saving technology is adopted to shorten the no-load waiting time during process startup, a lot of electric energy will be saved.

Start-up along the material flow refers to a starting method in which the equipment in the process starts in the same direction as the material flow. Also take the 5# process as an example. When the process starts, the A101 belt conveyor is first started. After A101 runs normally, the ship unloader is notified to start unloading. When the material reaches the end of A101, the A201 belt conveyor starts, and starts A301, A401, A501, and A601 in turn according to this rule until the process equipment is started. In this starting mode, the main machine starts feeding after the belt conveyor at the source of the material runs, and the downstream belt does not start before the material reaches the end of the belt, which reduces the no-load running time, improves the conveying efficiency, and reduces energy consumption.
4.2. Energy-saving process control method for ship unloader clearance
When the ship unloader is clearing the warehouse, because the material in the warehouse is already small, it is necessary to hoist the rake and other mechanical equipment to pile up the remaining materials for the ship unloader to grab. Therefore, the clearance process is relatively slow, and the distribution of the grabbed materials is extremely uneven, and the belt conveyor is in a light or no-load state for a long time during the clearance process. Therefore, the process can be set to run at low speed or even at zero speed during this process, which will effectively reduce energy consumption.

4.3. Energy-saving process control method for moving warehouse of ship loader
When loading bulk materials on the ship, in order to ensure the balance of the hull, the loading equipment performs multiple changes to the cabin when loading the materials. This is the so-called shifting. In the actual process of loading bulk materials, moving the cabin will consume a lot of time, and will also lead to a long no-load operation of the entire process. After adopting the full frequency conversion speed control technology, during the process of moving the cabin, the equipment used in the process is set to run at a low speed, and the original speed is restored when it restarts to load materials to achieve the purpose of saving energy and reducing energy consumption.

4.4. Process switching process control method
There is also a very practical operation in the process operation that is process switching. Specifically, before a process is about to be completed, the central control room (CCR) operator can reset a new process or stop the process according to the conditions of the job site. If there is a switching relationship between the reset process and the original running process, the process switching operation can be selected. Start the new setting process related equipment, stop the equipment not included in the new process in the original process, and complete the process switching. The equipment selected into the new process in the original process will continue to operate without stopping. This will reduce the time to stop the original process and start the new process, and improve work efficiency. At the same time, it will save the power consumption of traditional process equipment restarting. The flow algorithm for process switching is shown in Figure 3:

![Figure 3. Process switching process](image)

5. Conclusions
Compared with the traditional bulk cargo terminal, the introduction of frequency conversion speed regulation technology can solve the energy consumption problem of the conveying system to a large extent. Especially in the environment of equipment no-load operation, the energy-saving process control method based on frequency conversion speed regulation technology can save the energy efficiently. In the future, further optimizing the control methods for different frequency conversion algorithms and specific process environments on site, and maximizing the energy-saving effects of frequency converters, is the key to improving operational efficiency and intelligent level of bulk terminals.
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