Research on the method of measuring effective energy for quayside container crane based on weighted average method

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Abstract. With the rapid development of the world economy, more and more quayside container cranes are put into use in ports. The quayside container crane has the characteristics of large quantity, large power consumption and great energy saving potential. In order to save energy of quayside container crane, the key is to accurately measure the effective energy, the supply energy and the energy utilization efficiency. The weight of the loaded goods carried by the quayside container crane varies greatly in actual work. The test load in the traditional method is specified as 60% of the rated lifting weight, which is different from the actual situation of the crane. Based on the load state level, this paper puts forward the new concept of weighted average effective energy and optimizes the calculation formula. The new test method provides a basis for the accurate test of the effective energy and the energy utilization efficiency in the future.

1. Introduction
With the rapid development of the world economy, more and more quayside container cranes are put into use in ports. The quayside container crane has the characteristics of large quantity, large power consumption and great energy saving potential [1]. The law of the People's Republic of China on energy conservation stipulates that special equipment with high energy consumption shall be examined and supervised for energy conservation. In order to save energy of quayside container crane, the key is to accurately measure the effective energy, the supply energy and the energy utilization efficiency [2].

2. Problems in current test method
The test method is set up according to Chinese Standard The method of checking and measuring energy utilization efficiency for port electric-crane (JT/T 314-2009), which clearly defines the effective energy, the supply energy and the energy utilization efficiency: the effective energy refers to the energy consumed in a crane during an operation period as required; the supply energy refers to the energy consumed theoretically when a crane finishes an object (e.g., goods loaded and unloaded) displacement activity as required; and the energy utilization efficiency refers to the ratio of the effective energy and the supply energy in a crane during an operation period under specified conditions [3].

Although the test results according to JT / T 314-2009 can reflect the effective energy, the supply energy and the energy utilization efficiency, there are also defects. The test load in the standard is specified as 60% of the rated lifting weight, which is different from the actual situation. The weight of the loaded goods carried by the quayside container crane varies in actual work [4]. For example, the crane with light load state level is often used to lift light loads. The crane with extra heavy load state
level is often used to lift rated loads. Therefore, it is unscientific to take only 60% of the rated lifting weight as the test load, and the test results can not accurately reflect the actual situation.

3. Optimization of the test method

In the design of quayside container crane, the load state level is determined according to the use conditions and working requirements [5]. The load state level refers to the ratio of lifting times corresponding to various typical lifting loads to the total lifting times during the expected life of crane. There are four load state levels: light load state level, medium load state level, heavy load state level and extra heavy load state level. If the test load is determined according to the load state level of the crane, the test results will be very close to the actual situation. Therefore, this paper puts forward the new concept of weighted average effective energy and optimizes the calculation formula.

The weighted average effective energy refers to the sum of the product of the effective energy of various typical lifting loads and the weighted coefficient in a test cycle. The weighted coefficient refers to the ratio of the lifting times corresponding to various typical lifting loads to the total lifting times [6]. The new test method is to take all kinds of typical lifting loads as test loads for many times, and equivalent them to a test period.

If the typical lifting loads and the corresponding weighted coefficient during the expected life of the crane are known, the typical lifting loads can be tested and calculated as the test load. If the typical lifting loads and the corresponding weighted coefficient of the crane are not known, the typical lifting loads and the corresponding weighted coefficient can be determined according to the load state level as shown in Table 1.

| The typical lifting loads | The weighted coefficient |
|---------------------------|--------------------------|
|                           | Light load state level    |
|                           | Medium load state level   |
|                           | Heavy load state level    |
|                           | Extra heavy load state level |
| 30% 50% 60% 80% 100%      |

Table 1. Relationship between the typical lifting load and the weighted coefficient

4. New test method based on weighted average method

4.1. Test requirements

When measuring the weighted average effective energy for quayside container crane, the following requirements shall be met:

- The wind speed should be less than 3m/s.
- The crane shall be on the flat ground and the inclination shall not be greater than 2.5%.
- The deviation between the load mass and the specified value shall not be greater than 5%.
- Before the test, the encoder shall be cleared and calibrated to ensure the accuracy of the test position.
- All measuring instruments shall comply with relevant regulations and be within the qualified verification period.

4.2. Test steps

Repeat the test at least three times for each working condition of each mechanism. Take the arithmetic mean of the three measurements as the test result. The specific steps are as follows:

- Step a): The lifting mechanism is lifted and lowered at the rated speed without load. The lifting height shall not be less than 50% of the rated lifting height and shall not be less than the height listed in Table 1.
- Step b): The trolley moves a distance at rated speed without load. The distance shall not be less than 50% of the rated distance and shall not be less than the distance listed in Table 2.
• Step c): The lifting mechanism is lifted at the rated speed with the typical lifting load \( G_1 \), and the lifting height is the same as that in step a).

• Step d): When the load is lifted to the height as that in step a), the trolley moves the same distance as that in step b) at the rated speed with the load.

• Step e): The test load is taken as typical lifting load \( G_2 \), \( G_3 \) until \( G_{\text{max}} \) instead of \( G_1 \), repeat step c) and step d).

### Table 2. Lifting height of load and moving distance of trolley in test

| Max lifting height of the crane \( H_{\text{max}} \) (m) | The lifting height in test \( H \) (m) | Max moving distance of trolley \( S_{\text{max}} \) (m) | The moving distance of trolley in test \( S \) (m) |
|----------------|----------------|----------------|----------------|
| \( H_{\text{max}} \geq 25 \) | 15 | \( S_{\text{max}} > 20 \) | 15 |
| \( 15 < H_{\text{max}} < 25 \) | 10 | \( 10 < S_{\text{max}} < 20 \) | 5 |

#### 4.3. Calculation of weighted average effective energy

The calculation formula of weighted average effective energy in a test cycle is as follows:

\[
Q_t = \frac{\sum k_i [9800(G_i + G_0)H_i + 500(G_i + G_0)v_i^2] + 9800G_0H_0 + 500G_0v_0^2 + 9800(G_0 + G')\mu S_0 + 500(G_0 + G')v_0^2}{\sum k_i [9800(G_i + G_0)H_i + 500(G_i + G_0)v_i^2] + 9800G_0H_0 + 500G_0v_0^2 + 9800(G_0 + G')\mu S_0 + 500(G_0 + G')v_0^2} \quad (1)
\]

In the calculation formula, \( Q_t \) is the weighted average effective energy during a test period, and the unit is J; \( k_i \) is the weighted coefficient; \( G_0 \) refers to the weight of the lifting tools, and the unit is \( T \); \( G_i \) refers to the weight of the loaded goods, and the unit is \( T \); \( G' \) refers to the weight of the trolley, and the unit is \( T \); \( H_0 \) refers to the height of lifting tools when container is not lifted, and the unit is \( m \); \( H_i \) is the height of the container when it is loaded, and the unit is \( m \); \( v_0 \) refers to the speed of the lifting tools when the container is not lifted, and the unit is \( m/s \); \( v_i \) refers to the speed of the trolley when the container is not lifted, and the unit is \( m/s \); \( \mu \) refers to the friction coefficient between steel wheels and steel rails, which is 0.015.

#### 5. Conclusion

At present, the method of measuring effective energy for quay-side container crane has defects. Based on the load state level, this paper puts forward the new concept of weighted average effective energy and optimizes the calculation formula. The new test method provides a basis for the accurate test of the effective energy and the energy utilization efficiency of the quay-side container crane in the future.

#### Acknowledgments

This research was supported by The National Key Research and Development Program of China (2018YFC0809005).

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