Study on Stress Distribution Law and Stress Performance Characteristics of Multiple Data Mining for Harbour Portal Crane Detection

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Abstract. Taking the actual test of harbour portal crane as the sample, the evident high-stress measure points have been selected through the potential high-stress measure points, and the high-risk structure have been identified. Then stress distribution law and stress performance characteristics of the high-risk structure have been studied. The basis for the safety production of the port have been provided.

1. Introduction
The harbour portal crane for cargo handling and loading is widely used at the harbour [1]. Four bar combinatorial boom portal crane is the most common category [2] (hereinafter called the ‘portal crane”). It is divided into disc-supported slewing ring and pillar-supported slewing ring types [3], as shown in Figure 1. As the frequently used machine, the portal crane works in extremely bad working environment and serves long time [4].

In order to ensure production safety and maintain portal crane in a planned way, it is necessary for us to know the stress distribution law and the stress performance characteristics of portal crane in the

Figure 1. Four bar combinatorial boom portal cranes.
process of production operation. In this paper, the actual test date of a total of 50 portal cranes from different regions and ports are selected as the sample.

2. Potential high-stress measure points, evident high-stress measure points and high-risk structure

Combined with the finite element analysis and the practical experience in production process [5, 6], we select 16 representative measuring points on each portal crane in the sample, as shown in Table 1. According to the transportation industry standard JT/T 1262-2019 Technical specifications requirements for testing of jib cranes, the portal crane is tested by static load and dynamic load [7].

Table 1. Measuring Points on Each Portal Crane.

|   | Description                                      |   | Description                                      |
|---|--------------------------------------------------|---|--------------------------------------------------|
| A | front bar of trunk beam                         | G2| root of propeller strut right rear post inside the machine room |
| B | back bar of trunk beam                          | G3| root of propeller strut left front post inside the machine room |
| C | head of main boom                               | G4| root of propeller strut right front post inside the machine room |
| D | middle of main boom                             | H | top of cylinder/rotary column                    |
| E | root of drawbar                                 | I1| root of cylinder/rotary column                   |
| F1| root of propeller strut left rear post above the machine room | I2| root of cylinder/rotary column(45-degree)       |
| F2| root of propeller strut right rear post above the machine room | K1| underneath of end-plate of balance beam on left sea-side driving mechanism |
| G1| root of propeller strut left rear post inside the machine room | K2| underneath of end-plate of balance beam on right land-side driving mechanism |

(Note: we determine the direction of slewing part through cabin orientation, and we face the sea-side to determine the direction of fixed part)

In static load test and dynamic load test results of each portal crane, five measure points with the maximum stress value are selected as potential high-stress measure points. Further, the frequency of potential high-stress measure points in the sample is counted, as shown in Figure 2.

Figure 2. Frequency accumulation of potential high-stress measure points in static/ dynamic load test.

In static/ dynamic load test, potential high-stress measure points with frequency more than 30% of the total number of sample are defined as evident high-stress measure points. It can be seen from the figure that there are 8 evident high-stress measure points in static/ dynamic load test, and these 8 measure points are exactly identical. According to the location of their distributions, these 8 evident high-stress measure points can be classified into the following three categories:
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a) Located on trunk beam (measure point A and measure point B);
b) Located on propeller strut (measure point F1, measure point F2, measure point G1 and measure point G2);
c) Located on cylinder/rotary column (measure point H and measure point I2).

Therefore, these three types of structure have a high probability of accidents in the operation, which are high-risk structure. It can be seen from the figure that the frequency accumulation of measure point A and B located on trunk beam in dynamic load test is significantly higher than that in static load test. The law of measure point H and I2 located on cylinder/rotary column is the same, while that measure point F1, F2, G1 and G2 located on propeller strut is the opposite. Thus, high vibration in dynamic load test have a greater impact on trunk beam and cylinder/rotary column, while the impact on propeller strut is relatively small. Then, we analyze three types high-risk structure one by one.

3. High-risk structure trunk beam

3.1. Stress distribution law of trunk beam

The evident high-stress measure points of trunk beam include measure point A and measure point B. In static/dynamic load test of portal cranes in the sample, the stress values of measure point A and B are selected as potential high-stress measure points, and the linear trend lines are generated through the distribution of the stress values, as shown in Figure 3. It can be seen from the figure that in the two tests, individual stress values are significantly higher than the linear trend lines. Considering that this situation is caused by disrepair and improper maintenance of individual sample.

In addition, the stress values of static load test are concentrated in the range of 50-80Mpa, and the stress values of dynamic load test are concentrated in the range of 55-90Mpa. The overall linear trend is relatively gently.

![Figure 3. Stress distribution of evident high-stress measure points located on trunk beam.](image)

3.2. Stress performance characteristics of trunk beam

Through calculation, the mathematical expectations and the standard deviations of evident high-stress measure points located on trunk beam are shown in Table 2.

| Table 2. Stress performance characteristics of trunk beam. |
|-----------------------------------------------------------|
| measure point A | E₁(A) = 71.76MPa | σ₁(A) = 34.92MPa | E₂(A) = 75.72MPa | σ₂(A) = 37.62MPa |
| measure point B | E₁(B) = 68.27MPa | σ₁(B) = 25.80MPa | E₂(B) = 77.04MPa | σ₂(B) = 24.67MPa |
The comparison of the data in the table shows that the mathematical expectations of measure point A is relatively close to measure point B, while the standard deviation of measure point A is significantly higher than measure point B in static/dynamic load test. Measure point A is located on front bar of trunk beam, and measure point B is located on back bar of trunk beam. This shows that the stress of front bar is close to that of back bar, but the stress fluctuation of front bar is stronger than that of back bar.

4. High-risk structure propeller strut

4.1. Stress distribution law of propeller strut

The evident high-stress measure points of propeller strut include measure point F1, measure point F2, measure point G1 and measure point G2. In static/dynamic load test of portal cranes in the sample, the stress values of measure point F1, F2, G1 and G2 are selected as potential high-stress measure points, and the linear trend lines are generated through the distribution of the stress values, as shown in Figure 4. It can be seen from the figure that in the two tests, individual stress values are significantly higher than the linear trend lines. Considering that this situation is caused by disrepair and improper maintenance of individual sample.

In addition, the stress values of measure point F1 and F2 are concentrated in the range of 50-95MPa in static load test and 65-105MPa in dynamic load test. The stress values of measure point G1 and G2 are concentrated in the range of 55-90MPa in static load test and 65-100MPa in dynamic load test. The stress distribution of the posts above the machine room is more scattered, the span is larger and the linear trend is steeper than that of the posts inside the machine room.

![Stress distribution of evident high-stress measure points located on propeller strut.](image)

**Figure 4.** Stress distribution of evident high-stress measure points located on propeller strut.

4.2. Stress performance characteristics of propeller strut

Through calculation, the mathematical expectations and the standard deviations of evident high-stress measure points located on propeller strut are shown in Table 3.

| Measure point | Mathematical expectation (static load test) | Standard deviation of mathematical expectation (static load test) | Mathematical expectation (dynamic load test) | Standard deviation of mathematical expectation (dynamic load test) |
|---------------|-------------------------------------------|---------------------------------------------------------------|---------------------------------------------|---------------------------------------------------------------|
| F1            | $E_1(F_1) = 76.73$MPa                     | $\sigma_1(F_1) = 14.89$MPa                                  | $E_2(F_1) = 87.35$MPa                      | $\sigma_2(F_1) = 19.77$MPa                                   |
| F2            | $E_1(F_2) = 66.65$MPa                     | $\sigma_1(F_2) = 19.96$MPa                                  | $E_2(F_2) = 76.21$MPa                      | $\sigma_2(F_2) = 22.19$MPa                                   |
| G1            | $E_1(G_1) = 70.44$MPa                     | $\sigma_1(G_1) = 19.66$MPa                                  | $E_2(G_1) = 80.97$MPa                      | $\sigma_2(G_1) = 20.93$MPa                                   |
| G2            | $E_1(G_2) = 72.89$MPa                     | $\sigma_1(G_2) = 14.40$MPa                                  | $E_2(G_2) = 80.03$MPa                      | $\sigma_2(G_2) = 17.02$MPa                                   |
The comparison of the data in the table shows that the mathematical expectation of measure point F1 is largest, while measure point F2 is smallest in static/dynamic load test. The standard deviation of measure point F2 is largest, while measure point G2 is smallest in static/dynamic load test. In general, the mathematical expectations and the standard deviations between evident high-stress measure points located on propeller strut are relatively close, which show that the overall stress is comparatively stable.

5. High-risk structure cylinder/rotary column

5.1. Stress distribution law of cylinder/rotary column

The evident high-stress measure points of cylinder/rotary column include measure point H and measure point I2. In static/dynamic load test of portal cranes in the sample, the stress values of measure point H and I2 are selected as potential high-stress measure points, and the linear trend lines are generated through the distribution of the stress values, as shown in Figure 5.

It can be seen from the figure that the stress value of measure point H is concentrated in the range of 50-105Mpa in static load test and 60-110Mpa in dynamic load test. The stress value of measure point I2 is concentrated in the range of 50-85Mpa in static load test and 55-95Mpa in dynamic load test. The stress distribution of the top of cylinder/rotary column is more scattered, the span is larger and the linear trend is steeper than that of the root.

![Stress distribution of evident high-stress measure points located on cylinder/rotary column.](image)

5.2. Stress performance characteristics of cylinder/rotary column

Through calculation, the mathematical expectations and the standard deviations of evident high-stress measure points located on cylinder/rotary column are shown in Table 4.

|                     | mathematical expectation (static load test) | standard deviation (static load test) | mathematical expectation (dynamic load test) | standard deviation (dynamic load test) |
|---------------------|--------------------------------------------|--------------------------------------|---------------------------------------------|----------------------------------------|
| measure point H     | $E_1(H) = 77.80\text{MPa}$                | $\sigma_1(H) = 32.82\text{MPa}$      | $E_2(H) = 86.55\text{MPa}$                  | $\sigma_2(H) = 32.00\text{MPa}$        |
| measure point I2    | $E_1(I_2) = 70.64\text{MPa}$               | $\sigma_1(I_2) = 15.06\text{MPa}$    | $E_2(I_2) = 75.80\text{MPa}$                | $\sigma_2(I_2) = 21.97\text{MPa}$      |

The comparison of the data in the table shows that the mathematical expectation and the standard deviation of measure point H are both significantly higher than that of measure point I2 in static/dynamic load test. Measure point H is located on the top of cylinder/rotary column, and measure point I2 is located on the root.
I2 is located on the root of cylinder/rotary column. This indicates that the stress on the top of cylinder/rotary column is greater than the root, and the stress fluctuation on the top is also stronger than the root.

6. Overall stress performance characteristics of three types of high-risk structure

Through calculation, the mathematical expectations and the standard deviations of three types of high-risk structure are shown in Table 5.

Table 5. Overall stress performance characteristics of high-risk structure.

|                         | mathematical expectation (static load test) | standard deviation (static load test) | mathematical expectation (dynamic load test) | standard deviation (dynamic load test) |
|-------------------------|--------------------------------------------|---------------------------------------|---------------------------------------------|----------------------------------------|
| trunk beam              | $E_1$ (tru) = 69.67Mpa                     | $\sigma_1$ (tru) = 29.84MPa           | $E_2$ (tru) = 76.46Mpa                      | $\sigma_2$ (tru) = 30.99MPa            |
| propeller strut         | $E_1$ (pro) = 70.96Mpa                     | $\sigma_1$ (pro) = 18.20MPa           | $E_2$ (pro) = 80.79Mpa                      | $\sigma_2$ (pro) = 20.53MPa            |
| cylinder/rotary column  | $E_1$ (cyl) = 73.87Mpa                     | $\sigma_1$ (cyl) = 24.96Mpa           | $E_2$ (cyl) = 80.49Mpa                      | $\sigma_2$ (cyl) = 27.34Mpa            |

The comparison of the data in the table shows that trunk beam has the lowest mathematical expectation and the highest standard deviation, which indicates that the overall fluctuation of trunk beam is large. Propeller strut has the lowest standard deviation, which indicates that the overall stress is relatively stable. Fixed cylinder/rotary column has the maximum or near maximum mathematical expectation, which indicates that the overall stress is generally large.

7. Conclusion

The potential high-stress measure points of portal crane are concentrated in trunk beam, propeller strut and fixed cylinder/rotary column, which are high-risk structure.

Among three types of high-risk structure, the overall fluctuation of trunk beam is greatest and the overall stress of fixed cylinder/rotary column is generally large, while propeller strut is relatively stable.

In high-risk structure trunk beam, the stress difference between front bar and back bar is not big, but the stress fluctuation of front bar is stronger than that of back bar. In high-risk structure propeller strut, the stress and the stress fluctuation of each part are close to each other. In high-risk structure fixed cylinder/rotary column, the stress and the stress fluctuation on the top are greater than the root.

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