Research on Lifting Characteristics of Flat-Head Jib Tower Crane Based on Hydraulic Luffing Force

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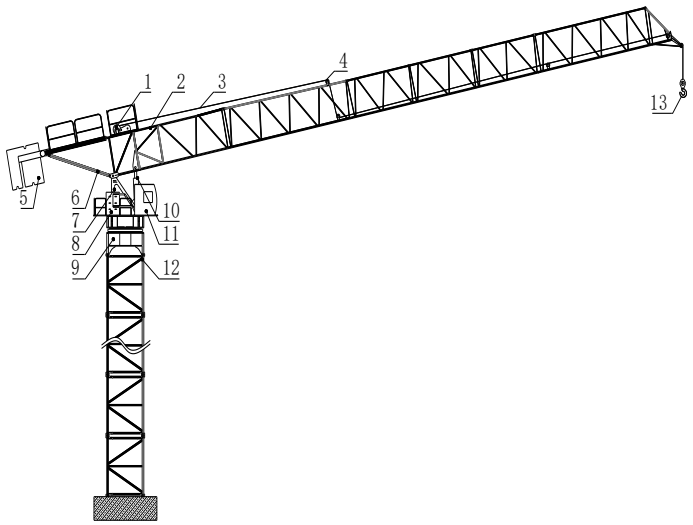
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Abstract. This paper investigates a design and computational method for its lifting characteristics using the flathead jib tower crane as a research object. We use a mechanical model based on classical mechanical theory and derive the expression for the characteristic lifting equation. The influence of different hinge points of the hydraulic cylinder on the boom and other hinge points of the hydraulic cylinder on the slewing frame on the lifting characteristics is discussed by using MATLAB with examples, providing a theoretical benchmark for calculating the bearing characteristics of the flat head jib tower crane.

Keywords: Flat boom tower crane; Lifting characteristics; Hinge point position of hydraulic cylinder; Matlab.

1. Introduction



1 Lifting mechanism 2 Jib 3 Lifting rope 4 Pulley 5 Counterweight 6 Balance arm 7 Slewing frame 8 Electric cabinet 9 Swing assembly 10 Hydraulic cylinder 11 Cab 12 Tower body 13 Lifting hook

Fig 1. Schematic diagram of crane.

A flathead jib tower crane is a form of the tower crane. The primary difference from other jib tower cranes is the structural integration of the jib boom and the balance arm, and hydraulic actuators actuate the jib and the balance bob to realize the boom and balance together with the pitch and luffing, as illustrated in Fig. 1. The counterweights are arranged at the tail of the balance arm, and the lift mechanism is fixed at the junction of the balance arm and the boom close to the axis of the pylon. Both the lift mechanism and the counterweight will oscillate with the balancing arm. The boom tower crane has a simple structure and is practical for disassembly and assembly.

Based on the operational characteristics of this type of flathead jib tower crane, the purpose of this paper is to investigate the theory and method for establishing its lifting characteristics and to discuss the influence of hydraulic cylinder installation position on the lifting characteristics in order to provide a theoretical basis for determining its operational parameters.

2. Analysis of crane lifting characteristics

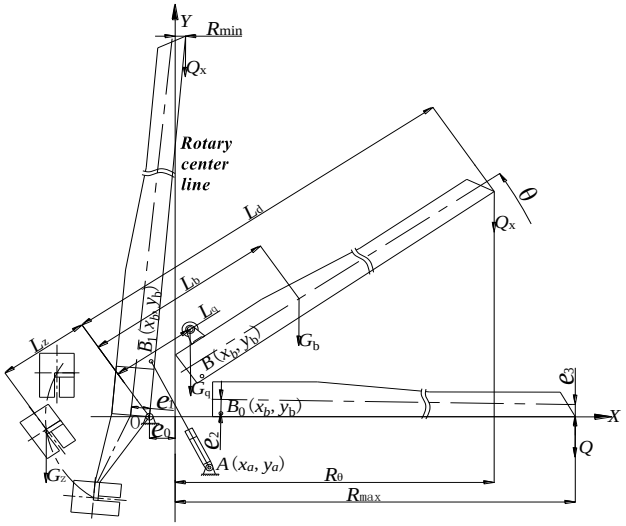


Fig 2. Schematic diagram of mechanical model.

The lift torque calibrates the work capacity of the flathead jib tower crane. Lift torque refers to the product of the tower crane operating range and the corresponding nominal lift coefficient. The lift characteristic curve can express the actual lift capability of the crane at any distance. Calibration of the tower crane's lift characteristics is directly linked to the control of the lifting torque. In the case of the flathead boom, the lifting characteristics of the tower crane can be controlled by controlling the axial force of the hydraulic driving cylinder or by controlling the lift rope tension and the lift arm angle. Currently, control of lift string tension and lift arm angle is commonly used. The objective of this paper is to investigate the method of controlling the lift characteristics by controlling the axial force of the hydraulic cylinder. In addition, the influence of its hydraulic cylinder layout on lift characteristics is analyzed.

2.1. Mechanical model

In contrast to other boom tower cranes, the boom of the boom tower crane with a flat head is horizontal at maximum amplitude. The maximum lift load determined can determine the lift characteristics at the boom tip as an initial parameter. The principle of calculating lift characteristics with hydraulic actuator thrust as a constant value is that the boom is horizontal to the maximum amplitude of the primary boom of the crane and that the crane is in the plane of luffing. With the change of the boom pitch angle, the lifting load of the hydraulic cylinder to the boom at all amplitude is always kept equal to the thrust of the hydraulic cylinder to the boom at the maximum amplitude of the primary boom.

Fig. 2 shows that the working range of the crane changes as the boom angle is changed, and its computational formula can be expressed as:

$$R_\theta = L_d \cos\theta - e_1 \sin\theta + e_3 \sin\theta - e_0 \tag{1}$$

Where

L_d——Distance from lifting the center of gravity to the root hinge point of the boom.

θ——Boom bearing angle corresponding to different magnitudes during actuation.

e_0——Horizontal distance from the root hinge point of the boom to the centerline of rotation.

e_1——Horizontal distance from the hinge point at the boom root to the boom axis.

e_2——Horizontal distance from the hydraulic cylinder to the boom support point B and the boom axis.

e_3——Distance from boom head pulley center to boom frame axis.

Fig. 2 shows that the nominal lift capacity of the primary boom of the flat head jib crane in the horizontal maximum amplitude condition is Q, and the hydraulic actuator moment at the boom can be expressed as:

$$M_1 = F_1 L_t = Q\left(R_{\max} + e_0\right) + G_b L_b + G_q L_q - G_z L_z \tag{2}$$

Where

G_q——the weight of the lifting mechanism.

G_z——counterweight weight.

G_b——boom weight.

F_t——piston rod thrust of hydraulic cylinder.

L_b——the distance from the boom center of gravity to the root hinge point.

L_q——the distance between the center of gravity of the lift mechanism and the root hinge point.

L_z——the distance from the center of gravity of the counterweight to the root hinge point.

L_t——in the horizontal condition, the force arm from the hinge point O at the root of the boom to the hydraulic actuator.

R_{max}——the maximum operating range of the crane.

As can be seen in Fig. 2.The essential boom of the flathead jib crane is at an angle θ the moment of the hydraulic actuator with respect to the boom is expressed as:

$$M_i = F_i L_t^i = Q_x\left(R_\theta + e_0\right) + G_b L_b^i + G_q L_q^i - G_z L_z^i \tag{3}$$

Where

$$L_b^i = L_b \cos\theta - e_1 \sin\theta \tag{4}$$

$$L_q^i = L_q \cos\theta - e_1 \sin\theta \tag{5}$$

$$L_z^i = L_z \cos\theta + e_1 \sin\theta \tag{6}$$

Where

L^i_b——the angle of the boom θ the distance from the center of gravity of the boom to the root hinge point.

L^i_q——the angle of the boom, θ the distance from the center of gravity of the lift mechanism to the root hinge point.

L^i_z——the angle of the boom, θ the distance from the center of gravity of the counterweight to the hinge point at the root.

L^i_t——the angle of the boom θ the hydraulic actuator force arm.

2.2. Analysis of hydraulic cylinder traces

The operational performance of the crane will be affected by whether the hydraulic cylinder pivot and hinge point settings are reasonable. The flathead jib tower crane has a simplified luffing mechanism in the form of a flat triangle below.

Fig. 3 shows that O is the root hinge point of the link between the boom and the swingarm. A is the mounting hinge point of the hydraulic cylinder, B is the fulcrum of the hydraulic cylinder to the boom, OB_0=OB=OB_1, where △ OAB_0 corresponds to the position of each hinge point of the hydraulic cylinder without stroke in the horizontal state of the boom, and its coordinates are O (e_o, 0) A (x_a, y_a) B_0 (x_{b0}, y_{b0}), △ OAB is the deflection at angle θ The position of each hinge point corresponds to △ OAB_1 corresponding to the position of each hinge point at the maximum deflection camber of the deflection. The coordinate at this point is B_1 (x_{b1}, y_{b1}).

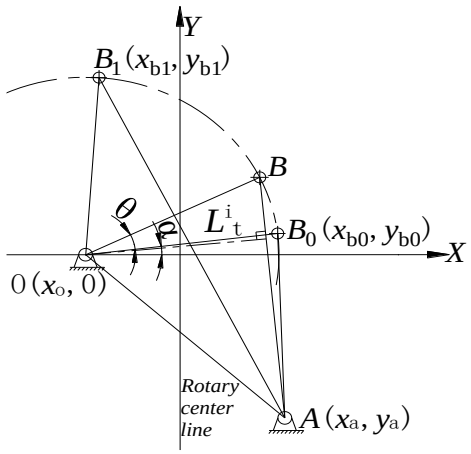


Fig 3. Schematic diagram of hydraulic cylinder track analysis

The shortest stroke AB_0 of a hydraulic cylinder can be expressed as:

$$AB_0 = \sqrt{(x_a - x_{b0})^2 + (y_a - y_{b0})^2} \tag{7}$$

The maximum stroke AB_1 of the hydraulic cylinder can be expressed as:

$$AB_1 = \sqrt{(x_a - x_{b1})^2 + (y_a - y_{b1})^2} \tag{8}$$

The telescopic ratio of the hydraulic cylinder shall meet the following formula when the crane boom reaches the maximum angle from the horizontal state:

$$\lambda \le \lambda_{\max} \tag{9}$$

Where

$$\lambda = \frac{AB_0}{AB_1} = \frac{\sqrt{(x_a - x_{b0})^2 + (y_a - y_{b0})^2}}{\sqrt{(x_a - x_{b1})^2 + (y_a - y_{b1})^2}} \tag{10}$$

Where

$\lambda_{\max}$——Maximum telescopic ratio of hydraulic cylinder.

B_0, B, and B_1 are regarded as moving points on the circle with O as the center and OB as the radius, and the coordinates of B are at the angle of boom θ the moving point can be expressed as:

$$\begin{cases} x_B = \omega\cos(\theta + \alpha) - x_0 \\ y_B = \omega\sin(\theta + \alpha) \end{cases} \tag{11}$$

Where

$$\omega = \sqrt{(x_{b0} - x_0)^2 + y_{b0}{}^2} \tag{12}$$

Where

α——The included angle between the connecting line between the root hinge point O and the hydraulic cylinder to the hinge point B_0 of the boom and the horizontal plane when the boom is horizontal.

The linear equation of AB can be expressed as:

$$\frac{(y - y_B)}{(y_{a-} y_B)} = \frac{(x - x_B)}{(x_{a-} x_B)} \tag{13}$$

The arm of force L^i_t at any time can be expressed as:

$$L_t^i = \frac{\left|(y_a - y_B)x_0 + (x_a y_B - x_B y_a)\right|}{\sqrt{(y_a - y_B)^2 + x_B{}^2}} \tag{14}$$

According to the principle that the thrust of the maximum lifting hydraulic cylinder on the boom in the horizontal state is equal to the thrust of the hydraulic lifting cylinder on the boom in different amplitude:

$$F_1 = F_i \tag{15}$$

The thrust of the hydraulic cylinder at full load in the horizontal state of the boom can be expressed as:

$$F_1 = \frac{Q(R_{\max} + e_0) + G_b L_b + G_q L_q - G_z L_z}{L_t} \tag{16}$$

The boom is lifted at different amplitudes and corresponds to different lifting weights. At this time, the thrust of the hydraulic cylinder on the boom can be expressed as:

$$F_i = \frac{Q_x (R_\theta + e_0) + G_b L^i_b + G_q L^i_q - G_z L^i_z}{L^i_t} \tag{17}$$

Simplify the formula (10) to the corresponding lifting weight under different ranges:

$$Q_x = \frac{L^i_t \left[Q(R_{\max} + e_0) + G_b L_b + G_q L_q - G_z L_z \right] - L_t \left(G_b L^i_b + G_q L^i_q - G_z L^i_z \right)}{L_t (R_\theta + e_0)} \tag{18}$$

The lifting characteristic curve equation can be expressed as:

$$Q = \begin{cases} Q_{\max} & R_\theta < R_1 \\ \dfrac{L^i_t \left[Q(R_{\max} + e_0) + G_b L_b + G_q L_q - G_z L_z \right] - L_t \left(G_b L^i_b + G_q L^i_q - G_z L^i_z \right)}{L_t (R_\theta + e_0)} & R_\theta \geqslant R_1 \end{cases} \tag{19}$$

Where

R_1——the maximum amplitude that Q_{max} can reach.

Substitute Q_{max} into equation (14) to solve the relationship between lifting weight and working range:

$$R_1 = \frac{L^i_t \left[Q(R_{\max} + e_0) + G_b L_b + G_q L_q - G_z L_z \right] + L_t \left(G_z L^i_z - G_b L^i_b - G_q L^i_q \right)}{Q_{\max} L_t} - e_0 \tag{20}$$

3. Case analysis

Taking a 133.6B flathead jib crane as an example, the lifting characteristics of the flathead jib tower crane at different fulcrum positions B of the boom and different hinge positions A of the hydraulic cylinder are analyzed by using MATLAB software. The critical parameters of these are given in Table I. The nominal lift coefficient is Q=2.5t when the boom is horizontal and Q_{max}=6.2t when the boom is raised with the maximum amount of load.

Table I. Main structural parameters of the crane.

Item	code	numerical	unit
The total length of the boom	L_b	52.6	m
The total length of the boom	G_b	12725	Kg
Weight of lifting mechanism	G_q	1320	Kg
Counterweight weight	G_z	5200	Kg
Boom elevation range	θ	0-85	°
Distance from the root hinge point to the rotary center	e_0	0.75	m
Distance from root hinge point to boom axis	e_1	1.2	m
Distance from hydraulic cylinder fulcrum to boom axis	e_2	0.5	m
Distance from boom head pulley to boom frame axis	e_3	1.7	m

3.1. The influence of the hydraulic actuator on different B-boom hinge point positions

Fig. 4 shows the value of the hinge point coordinate A of the hydraulic actuator (x_a, y_a) is fixed in order to discuss the different coordinates of the hydraulic cylinder up to the hinge point of the boom B. the hydraulic cylinder motion trace can be considered as when lifting the boom. For example, when the axis of the hydraulic cylinder connected to the upper hinge point B of the boom and the upper hinge point A of the sled frame is vertical or tilted relative to the center of rotation as the boom is lifted, the axis of the hydraulic cylinder gradually oscillates towards the center of rotation, Another case is that when the axis of the hydraulic cylinder connected to the upper hinge point B of the boom and the upper hinge point A of the slewing frame inclines to the outside of the slewing center, during the boom lift motion, the hydraulic cylinder axis gradually returns to the vertical state and deflects toward the center of the slewing. In this paper, we discusses the points of fulcrum B in different coordinates. The model uses the hydraulic cylinder transverse thrust value calculation principle described in II and the crane parameter data determined in Table. Through formula (1), formula (9), and formula (14), with the aid of MATLAB software, the lift characteristic response diagram of the hydraulic cylinder as a function of the change in the boom hinge point B is plotted subject to the constraint that the hinge point A on the swing frame is fixed.

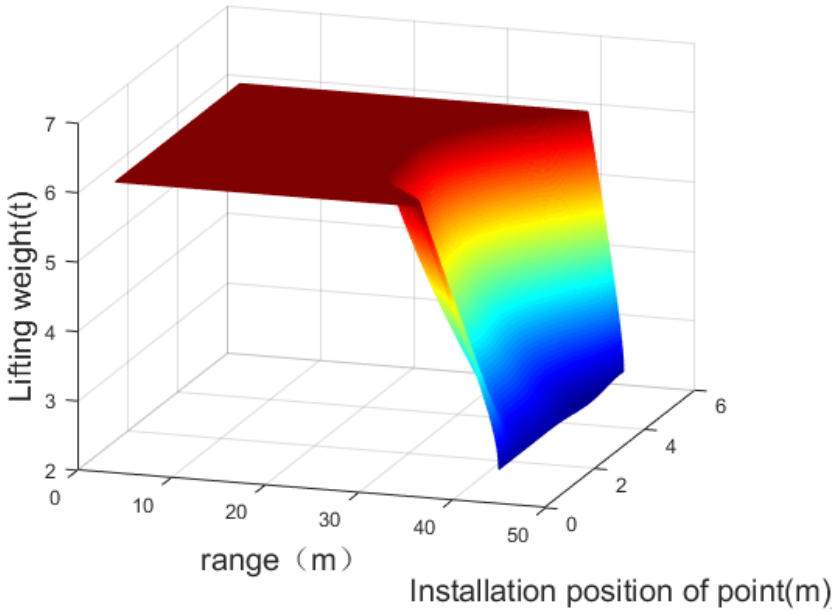


Fig 4. Influence diagram of lifting characteristics at different positions of hinge point B

It can be seen from the image display that the fluctuation of the curved lifting feature surface is irregular. As the hydraulic actuator moves away from the pivot point of the boom stand, there is also a delay in the inflection point of the curved lifting characteristic surface, which means that the lift performance is different under different support points. If the position of the boom support point is found to be at [0 1.5], there is a gradual delay in the inflection point of the lift feature, meaning that the lift capacity is gradually weakened below the same amplitude, Where the position of the boom support point lies at [2 6], since the bottom of the curved surface is inconsistent with the true fluctuation, such a point location should be abandoned during design.

3.2. The influence of the hydraulic actuator on the position of different hinge point A on the rotating frame

Fig. 5 shows that when considering the influence of different support positions on the lift characteristics, in addition, it is necessary to consider the influence of different hydraulic cylinder hinge point positions on the lift characteristics when the B (x_b, y_b) value of the pivot point is fixed. The position of the hinge point can be selected on the top turntable or rotating frame. When the hinge point is on the upper turntable, adjust the horizontal coordinate according to the upper turntable's

design structure. The hinge point on the rotary frame has a functional relationship according to the design structure coordinates of the rotary frame. Taking into account that the stability hinge point of the entire machine is installed close to the slewing frame boom, and stability is more reliable than that fitted to the top turntable, in order to discuss the actual impact on lift characteristics, the different positions of the hinge points within the upper span of the slewing frame are used in MATLAB.

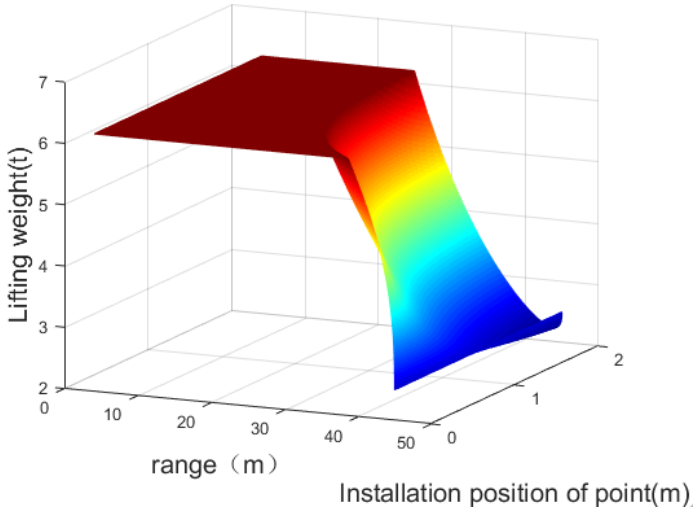


Fig 5. Impact plot of the lift characteristics at the different hinge point positions A

Based on the characteristic hydraulic cylinder lift curve at different hinge locations on the rotating frame shown in Fig. 5, progress is made gradually towards the inflection point of the lift feature shown in the figure, that is, the lifting performance of the hinge point on the rotating frame is progressively weakened as it is moved away from the center of rotation. If the position of the hydraulic cylinder hinge point is at [1 2], then the wedge appears at the apex of the curve. This point position would have to be abandoned during the design.

3.3. Influence of different installation positions

Fig. 6 shows that when point A and point B are considered separately, further discussion of the influence of point A and point B on lift characteristics, the hinge point A (x_a, y_a) on the sled frame of the hydraulic cylinder and the pivot point B (x_b, y_b) from the hydraulic cylinder to the support point of the boom, is required.

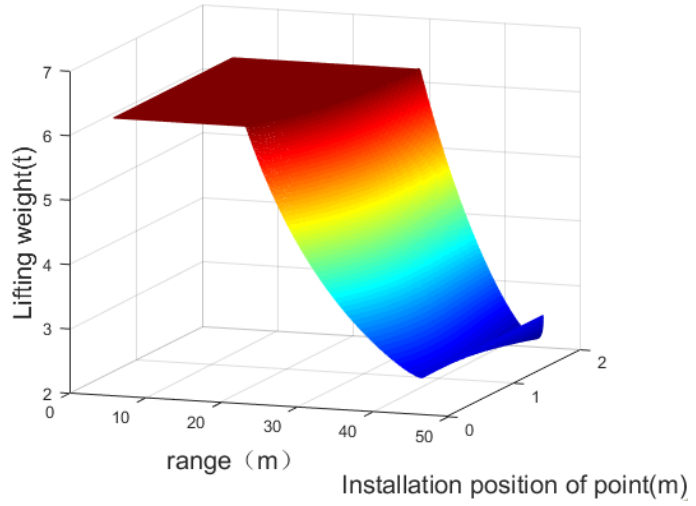


Fig 6. Impact plot of lift characteristics at various installation positions

It can be seen from Fig. 6 that different installation positions of hydraulic cylinders have an impact on the characteristic lifting curve. As can be seen in the figure, when the setup position is far from the center of rotation, there is a gradual delay in the inflection point of the lift feature, and the lift

performance is gradually improved. By the time [1 2] is reached, the tail of the image is gradually warping because the hinge point A on the rotating frame exceeds the pose range, and irregular changes are seen in the image, which should be discarded during the design. From the center of rotation, the characteristic lift curve that meets the usage requirements can be found in the range of installation position [0 1], as shown in the Fig. 7 below.

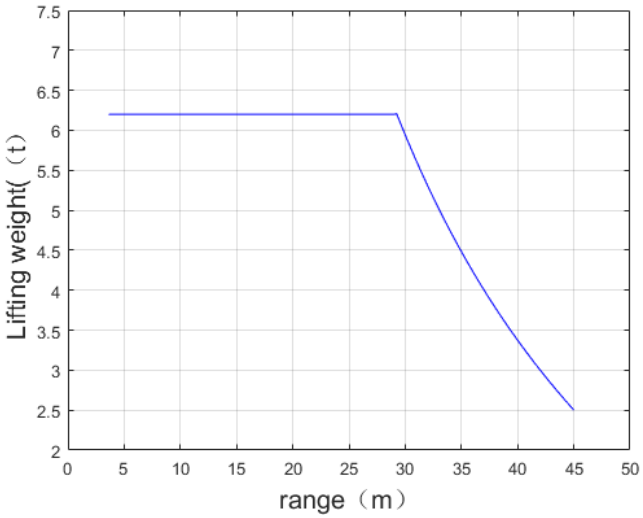


Fig 7. Lifting characteristic curve.

4. Conclusion

The purpose of this paper is to investigate the theoretical calculation method for establishing the lifting characteristics of the flathead jib tower crane, which deduces the method of calculating the lift characteristics of the flathead jib tower crane along with the value of the hydraulic cylinder transverse thrust, and discusses the influence of the unique and complex conditions on the lift characteristics, and derives the following conclusions. Based on the working characteristics of the flathead jib tower crane, once the computational method for lifting features is established, the computational expression is given; The lifting characteristic equation is verified with a crane example, and the characteristic lifting curve conforms to the conventional law after the specific data are substituted; The actual influence of different hydraulic cylinder hinge points on the boom is discussed in the following sections, different hydraulic cylinder hinge points on the slewing frame and different double-hinge point installation positions on the lift characteristics. It then concludes that facility positions consistent with the actual situation should be chosen in the design.

References

[1] Bin Li. Lifting characteristic analysis of tower crane [J]. Journal of Shenyang Institute of Architecture and Engineering, 1991 (03): 242-247

[2] GB/T 13752-2017, Code for Design of Tower Cranes [S]

[3] Yuqiu Long, Shihua Bao. Structural Mechanics [M]. Higher Education Press, 201111

[4] Yaguang Zhang. Research on some key technologies of flathead jib roof crane [D] Liaoning: *Shenyang* Jianzhu *University*. 2019