Research on New Lifting Technology of Gantry Crane

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Abstract. In order to improve the safety, efficiency and economy of hoisting operation for gantry crane, the overall lifting scheme of hydraulic lifting device of double upright door frame cluster with multiple anchors is optimized in the process of hoisting operation. According to the ‘carrying method’ ascension process principle, the innovative design for the hinge structure of gantry crane is conducted. The allowable stress method and limit state design method are applied to make the design and checking calculation of the bearing capacity of crossbeam structure caused by installed load, hinge structure and strength of weld and pin to make sure the safety of hoisting hinge structure. The proposed lifting scheme is more secure, efficient and economic and it has extensive application value.

Lifting Technique and Development Trend

From the perspective of lifting capacity of hosting equipments, the hoisting technology can be divided into fission hoisting and integral lifting. Many engineering equipments are generally segmented before hoisting along the axis direction due to their larger length and greater weight. Although the fission hoisting method solves the problem of hoisting and size, the lifting process and difficulty will be increased. The air splicing group after segmental hoisting will prolong the hoisting time and bring much hidden trouble to workers working at height.

Compared with the fission hoisting, the integral lifting technology is relatively simple and has the smaller impact on the lifting equipment structure. It improves the work efficiency, safety coefficient because of avoiding the connecting in air, which has become an important development trend of the current lifting technique.

Hydraulic synchronizing lifting technique is a more mature technology developed based on the requirement of integral lifting. Hydraulic synchronizing lifting equipments have the obvious advantages in the integral hoisting process of oversize equipment due to the larger lifting weight, operation stable, safe and reliable.

Through the optimization of the overall lifting scheme of hydraulic lifting device of double upright door frame cluster with multiple anchors in the process of hoisting operation, aiming at the innovative design for the hinge structure of gantry crane according to the ‘carrying method’ ascension process principle, this paper proposes a more secure, efficient and economic lifting scheme.

New Overall Hoisting Process Principle

‘Carrying Method’ Hinge Structure Innovation

In the process of gantry crane hosting the steel girder, the outriggers on both sides of gantry crane follow up with the girder to the appropriate location, thus realizing a hosting of gantry
crane as the whole structure. The ‘carrying method’ is that the outriggers on both sides of gantry crane follow up with the girder to the appropriate location under construction, as shown in Fig.1.

According to the ‘carrying method’ ascension process principle, the synchronizing lifting of overall steel structure of gantry crane is implemented by the hinge structure. New integral hoisting is that hinge structure, used for the connection of girder and leg, leg and beam, is conducted the innovation design, which makes the leg, segmented horizontal beam and car frame follow along with the girder to the appropriate location in the process of hosting the steel girder and ensures a lifting of gantry crane as the whole, as shown in Fig.2.

The hinge structure is usually used to make the connection of the girder and leg under integral hoisting. The connection of the leg and lower beam is replaced with the slipped car. After the hosting of the girder and leg, the beam and car are pulled into the leg installed position instead of the slipped car, which extends the hoisting time to a certain extent. New integral hoisting realizes the innovative design of the hinge structure for girder and leg, leg and lower beam and implements an overall hosting, thus improving the lifting efficiency. The hinge structure of girder and leg is shown in Fig.3 and the hinge structure of leg and lower beam is presented in Fig.4.

**Technological Principle of the Gantry Crane’S Outrigger Sliding**

Usually the technological principle of the gantry crane’s outrigger sliding is to stick the Teflon plate which friction coefficient is only 0.01 on the bottom of the outrigger to reduce its friction and the transverse stress in the whole process of lifting. It can ensure the safety of the
lifting process. The method in this paper that using the gantry crane’s cart orbit to make the outrigger sliding does not need Teflon plate, which can save the cost, reduce the pollution and ensure the safety of the lifting process.

New Type of Gantry Crane’s Hoisting Technological Process

Traditional hoisting technological process

**Girders’ first lifting.** According to the design requirements, assemble the girders of gantry crane on the ground; use the crane to lift the trolley to the calculated equilibrium position on girders’ orbit. Then seal the trolley up and make sure the entrainment is fastened to girders’ orbit.

Step loading is applied in girders’ first lifting until the girders leave the assembly jig. Then observe and check stress and strain state of the towers and cable rope. Keep the girders 200 mm from the ground for 24 h. Observe and check the vertical state of towers detailedly and check the situation that whether the stress points, each girder, each component, the opening parts, the tower foundation and the anchor foundation is abnormal. If all goes well, do the girders’ lifting and check the synchronization status of each lifting point to make sure the safety of the structure and construction during the hoisting process.

When all the testing results are normal, lift the girders gradually to a certain distance from the ground, then stop, lock the cylinder, and prepare to do the installation of the rigid leg and A-line joint of flexible leg.

**Girders’ second lifting.** Girders’ second lifting to a certain distance is to be carried out after finished the installation of rigid leg and flexible leg of gantry crane. Then complete the hinge of girder and segmented rigid leg, jack up the rear of segmented rigid leg, complete the hinge of the slipped car and the rear of segmented rigid leg. Then assemble the car frame, connect car frame to lower beam of rigid leg and flexible leg after finished the welding of lower beam as the whole. Finally do the hinge of one side of the flexible leg and lower beam, the other side and the slipped car.

**Overall hoisting of gantry crane.** Lift the gantry crane as the whole to a certain distance through the design decision with rigid leg and flexible leg follow up with the girders to the appropriate location to meet the design rules. Then do the installation of legs and the car frame, finish the welding and fastening. When all has been done, observe the installation quality and deformation condition. If all the testing results are normal, the acceptance can be done.

New hoisting technological process

Because of the same structural type of leg and hinge structure of the gantry crane with double rigid legs, this paper only to introduce the new lifting scheme for gantry crane with double rigid legs. For the gantry crane with one rigid leg and one flexible leg, only to change the hinge structure of flexible leg and this hinge structure can also used to the lifting scheme design for super large gantry crane. The new type of gantry crane’s hoisting technological process as shown in Fig.5.
**Girders’ once lifting.** When all the testing results are normal after finished the girders’ first lifting, lift the girders gradually to a certain distance from the ground, then stop, lock the cylinder, and prepare to do the installation of the girder and the connection of leg, assemble the segmented rigid legs of two sides of gantry crane as the whole, use the crane to move them to the upholders, do the hinge of the girders and rigid legs. Assemble each car frame, connect car frame to segmented lower beam, then put the lateral segmented lower beam onto the slipped car. Pull the slipped car on the cart orbit to move to the rigid leg, do the hinge of the leg and lower beam. When all goes well, remove the upholders slowly.

**Overall hoisting of gantry crane.** Lift the gantry crane as the whole to a certain distance through the design decision with rigid legs follow up with the girders to the appropriate location to meet the design rules. The segmented lower beams then meet each other naturally, and then connect them with two hinge pins. Finally do the connection of girder and leg, leg and lower beam with high strength bolt. Make the connection fastening. When all has been done, observe the installation quality and deformation condition. If all the testing results are normal, the acceptance can be done.

**Mechanical Calculation for Gantry Crane’s Overall Hoisting System**

As for the structural design of gantry crane, the mechanical calculation for overall hoisting system should also do checking calculation of bearing capacity of crossbeam structure caused by installed load, the strength calculation of the hinge pin on hinge structure and the weld strength calculation except that mechanical analysis of anchor point and foundation, the beam structure calculation of lifting towers and the auxiliary scaffold structure calculation. The allowable stress method and limit state design method are applied to make sure the safety of hoisting hinge structure. The most adverse condition among hoisting process is that rigid legs follow up with the girders to the appropriate location to meet the design rules.
Checking Calculation of the Bearing Capacity Caused by Installed Load

The calculation model is shown in Fig.6. The maximum installed load is given by

\[ F_d = 2P_{Gz} + 2P_{Gd} + 4P_{Gt} + 2P_s \]

The value of bending moment of girder’s middle section is given by

\[ M_s = \frac{1}{2} F_q S \left( l_1^2 - l_1 + l_2 \right) - \frac{1}{2} l_1 (F_q l_1 + P_{Gd}) + \frac{1}{2} F_q Z (S + l_1 + l_2) + \frac{1}{2} P_{Gd} Z + P_{Gt} Z + \frac{1}{8} P_{Gd} S + \frac{1}{4} P_{Gt} Z \]

Where \( Z \) distance between lifting point of the tower and cart orbit, \( F_q \) uniform load of girder, \( P_{Gz} \) mass of trolley load, \( P_{Gd} \) mass of girder load, \( P_{Gt} \) mass of outrigger load, \( P_{Gd} \) mass of beam load, \( P_{Gd} \) mass of lower beam load, \( l_1 \) length of left cantilever, \( l_2 \) length of right cantilever, \( S \) span of gantry crane.

Strength checking calculation of the girder’s middle section caused by installed load should be done according to the load combinations C11. The value of dangerous point stress on girder’s middle section used the allowable stress method is given by

\[ \sigma = \frac{M_s}{I_x} \leq [\sigma] = \frac{R}{\gamma_f \gamma_n} \tag{1} \]

The value of dangerous point stress on girder’s middle section used the limit state method is given by

\[ \sigma = \frac{\gamma_{pC21} \times M_s}{I_x} \leq \lim \sigma = \frac{R}{\gamma_m} \tag{2} \]

Where \( R \) yield strength of material, \( \gamma_f = 1.22 \) coefficient for calculating allowable stress, \( \gamma_n = 1.05 \sim 1.10 \) coefficient for high-risk application, \( \gamma_m = 1.10 \) resistance coefficient, \( \gamma_{pC21} = 1.28 \) partial safety factor.

Strength Calculation of the Hinge Pin

The hinge structure for girder and outrigger is shear connection. The strength calculation of the hinge pin used allowable stress method is given by
The value of diameter of the hinge pin is given by

\[ d \geq 2 \sqrt{\frac{P_j}{2\pi \tau_j}}, \]

In which \( P_j = P_{Gi} / 2 + P_{Gdi} / 4 \)

Where \( P_j \) shear stress of hinge pin, \( [P_j] \) maximum shear stress of hinge pin, \([\tau_j]\) allowable shear stress of hinge pin.

The strength calculation of the hinge pin used limit state method is given by

\[ F_{v,Sp} \leq F_{v,Rd} = \frac{A\sigma_{Sp}}{\sqrt{3m_{Sp}\gamma_{Sp}}} = \frac{\pi d^2 \sigma_{Sp}}{4\sqrt{3m_{Sp}\gamma_{Sp}}} \]

The value of diameter of the hinge pin is given by

\[ d \geq 2 \sqrt{\frac{\sqrt{3m_{Sp}\gamma_{Sp}} F_{v,Sp}}{\pi\sigma_{Sp}}} \]

In which \( F_{v,Sp} = P_{Gi} / 2 + P_{Gdi} / 4 \)

Where \( F_{v,Sp} \) design of shear stress of hinge pin, \( F_{v,Rd} \) limit design of shear stress of hinge pin, \( m = 4 / 3 \) shape coefficient, \( \gamma_{Sp} = 1.0 \) specific resistance coefficient of shear stress, \( \sigma_{Sp} \) minimum yield stress of hinge pin.

**Weld Strength Calculation**

The hinge structure for girder and outrigger is fillet weld connection, which under the common role of bending moment and shear force. The maximum shear stress of weld used allowable stress method is given by

\[ \tau_h = \sqrt{\tau_F^2 + \tau_M^2} = \sqrt{\left(\frac{F}{A_f}\right)^2 + \left(\frac{M}{W_f}\right)^2} \leq [\tau_h] \]

In which \( F = P_{Gi} / 4 + P_{Gdi} / 8 \), \( A_f = 2 \times 0.7h_f l_f \), \( M = FL \)

Where \( F \) maximum shear stress of weld, \( A_f \) area of the calculation weld section, \( h_f \) thickness of the weld, \( l_f \) length of the weld, \( M \) maximum bending moment of weld, \( L \) vertical distance between the maximum shear stress and the weld.

Design of weld stress used limit state method is given by

\[ \tau_{w,Sp} \leq f_{w,Rd} \]
In which

\[ \tau_{w,\text{ld}} = \frac{F_t}{h_j \times I_j}, \quad F_t = \frac{1}{4} P_{Gt} + \frac{1}{8} P_{Gtl}, \quad f_{w,\text{ld}} = \frac{\alpha_w \times f_{y_k}}{\gamma_m} \]

Where \( f_{w,\text{ld}} \) limit design of weld stress, \( f_{y_k} \) minimum yield stress of adapting piece, \( \alpha_w = 0.6 \) coefficient for limit weld stress.

Hinge strength calculation of weld and pin for leg and lower beam is the same with girder and leg, so here omit the calculation process.

Conclusions

(1) A new overall hoisting scheme has been proposed, which is more secure, efficient and economic. After the girders’ once lifting, the hinge connection of leg, lower beam and car frame realizing a hosting of gantry crane as the whole structure. This scheme depends on the innovative design for the hinge structure of gantry crane’s girder and leg, leg and lower beam, and the optimization of the traditional lifting scheme, which need to lift the girder twice. The eventual installation of gantry crane just needs to do the hinge connection of the segmented lower beam, the bolted connection of girder and leg, leg and lower beam, and needn’t to do the welding operation. This scheme reduces the aerial work and makes the most installation be done on the ground, which greatly improve the lifting efficiency and safety degree, and reduce the costs of lifting.

(2) The allowable stress method and limit state design method are applied to make the design and checking calculation of the bearing capacity of crossbeam structure caused by installed load, hinge structure and strength of weld and pin to make sure the safety of hoisting hinge structure and the feasibility of the installation scheme. This scheme can also used to super large gantry crane and has a certain reference value to research on the lifting technology of super large gantry crane.

References


