Finite Element Analysis of the Integral Hoisting of 49m Flange Connection Flare

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Abstract. Installation of flange connection structure in flare stack commonly adopt parts assembly or segmental hoisting. In this paper, due to the harsh conditions of construction, an innovation of flange connection type flare stack’s one-time integral hoisting technology and method is proposed. This paper use CATIA finite element analysis simulate force of flare stack under two extreme conditions during the integral hoisting: horizontal and vertical conditions. The strength and stability of the hoisting stack are checked and calculated. Then we find out the dangerous point and propose the reinforcement solutions for weak structure, providing the basis for hoisting process design.

1. Preface
In construction of petroleum chemical station, the flare are usually required to be installed, due to the large volume of the component assembly, equipment height, installation position limitation and space limitation, which cause difficulties for installation[1]. Conventional flare stack using aerial parts assembly or segment hoisting method to install. Laoqianling Station flare system maintenance station needs to construct a new 49.00m flange connection type flare system. The flange connection structure of flare stack generally adopts a sectional hoisting, but during construction the Daqing area is in the winter. The temperature is lower than -25°C, it is windy and snowy. There is high risk in climbing construction and high labor intensity. By combination of ideas from each sides, we determine the reasonable reinforcements and the integral hoisting of the stack, this paper conduct check calculation and analysis for the whole flare stack hoisting process.

2. Flare stack structure parameters[2]
The flare stack is equilateral triangle in cross-section. Corner section is 9m×9m, the top section of the stack is 3×3m, and total height is 45.8m. The lower end of the flare cylinder is Φ630×14 steel pipe, height is 7.31m. Upper end is Φ508×12 steel pipe, its height is 39.19m, and the height of flare cylinder is 49m. There flare tip is on the top platform of the stack, the height of flare head is 3.5m. Total height of flare cylinder and head is 50m. Total lifting weight of flare cylinder, stack and accessories is 29.5 tons, and height is 45.8 meters. Flare head weighs 1 ton, its height is 3.5 meters. Flare base weighs 2.8 tons, its height is 7.3 m. Reinforced attachment weighs 2 tons. Total weight of flare stack Q=29.5+2.8+1+2=35.3 tons. Height from top of the flare stack foundation to the ground is 0.3m.
3. Model establishment and mechanical properties query of the flare stack

3.1. Model building[3]
In CATIA 3D design and computer aided analysis integration platform, we establish a 3D model of flare stack (Figure 1), applying CATIA’s tetrahedral adaptive nonlinear meshing technique to divide the grid of the overall model. And we refine the mesh division at position where stress deformation increase in the stack to improve the accuracy of calculations.

![Figure 1. 3D model of flare stack](image)

3.2. Flare weight, center of gravity and moment of inertia check results
After the calculation model was established, we check the mechanical properties of the three-dimensional model of the flare stack in the CATIA software. Then we evaluate, analyze and calculate the total weight, coordinates of gravity center location and volume mass. Parameter data are shown in Figure 2. Total weight of flare stack is 27.4 tons, the overall height is 50m. The centre of gravity of the integral is 20.496m from the end by calculation.

| Graphic | Product | Mechanical | Drafting |
|---------|---------|------------|----------|
| Characteristics | Inertia center |
| Volume: 3.487138m3 | x: -12.923183mm |
| Mass: 27408.908037kg | y: 50.1873mm |
| Surface: 684.69786m2 | z: 20495.563778mm |

![Figure 2. Mechanical properties of flare stack model](image)

4. Flare stack reinforcement
(1) Reinforcement of the bottom of the flare stack
Bottom of the Flare stack adopt Ф159x6 seamless steel tube stack with welding, and the C12.6 U-steel and flare stack cylinder body is connected to the reinforcement (Figure 3).
(2) Sliding tail reinforcement
As shown in Figure 4, tailing lug is 9.3 meters from the stack bottom plane. We use a Ф159x6 seamless steel pipe connecting lug and oblique beam to reinforce support.
(3) The reinforcement of the flare tube
The barrel adopts C12.6, C10.0 U-steel connected with the beam reinforcement (Figure 5), there are 4 sets of interlayer reinforcement in total.
5. CATIA finite element analysis and check of flare stack
In lifting process, we analyze the force situations of flare stack in the two extreme positions. The strength and stability of the flare stack will be checked. First, when the flare stack is in horizontal state, truck crane and crawler crane wire rope jointly bear the weight of the flare stack. This is in accordance with the law that center of gravity is inversely proportional to the distance from the flare stack. At this time, load of the lifting lug and steel wire rope is not high. But under the force of gravity, the moment in the middle of the flare stack is too large. The second is when the flare stack is in upright position, total weight of the flare stack is hold by the upper portion of the main lug, so lug bear the full weight of the main flare stack. At this time, the stress of lifting lug and hanging ear near the flare stack is higher. This need to be checked. The specific strength and stability check analysis are as follows:

5.1. Strength, stability check of the flare stack in horizontal state
When flare stack frame is hoisted in the horizontal state, main and auxiliary hanging ear wire rope are vertically upward and the upper end of the steel wire rope, are set by fixed constraint. Calculation of the Von Mises stress is shown in Figure 6. The stress level of the structure as a whole is very low, which is in the order of 10~40 MPa. This ia far less than the material yield strength value, which is 240Mpa. So stress of overall structure in horizontal position is low and the strength satisfy the safety requirements.

When the structure is in the horizontal state, the stack structure is under the effect of gravity. This will induce a downward displacement. If the displacement is too large, structure in the lifting process may produce unstable damage. We can check whether the horizontal lifting point is arranged reasonably through the horizontal displacement.

Figure 7 shows the displacement of flare stack frame in horizontal position, maximum displacement of the middle part is 27.8mm, distance between two hanging point is 36.5m, maximum deflection $F(m) = L/300 = 0.1217m > 0.0278m$, stability satisfy safety requirements.
5.2. Strength, stability check of flare stack in vertical state

When whole flare stack is lifted in a vertical state, we calculate the Von Mises stress cloud of overall flare stack shown in Figure 8. The stress of overall structure is low, in the order of 10~50MPa, far below the yield strength of the material value, which is 240 MPa. The strength satisfy the safety range, because the structure is only subjected to gravity load. There is no other external load.

Calculation of overall displacement in flare stack shows (as shown in Figure 9), in the vertical position, flare stack structure does not bear the external force. It only bear the gravity. We calculate the displacement size, and the maximum displacement of the structure is 15.9mm, which is located in the bottom of the flare stack. Results are conform to the requirements of the maximum deformation and satisfy the safety conditions.

5.3. Partial dangerous point inspection and treatment measures

The partial structure flare stack will be checked one by one (as shown in Figure 10) in horizontal state. The stress monitoring of main column flange bolts shows that, at horizontal state the 2,3,4-level flange bolt stress in the upper part of the main column is large, which is between 190-260 MPa. The stress of third flange bolts is over 400MPa. The reason is that the third flange locates near the junction of the oblique column and main straight column, so the bolt has high stress there. Therefore, at site we must reinforce flange in these positions. The maximum stress of main, vice hanging lugs is around 100 MPa, and it is less than the yield strength of the material. So the design of the lifting lug is safe and can satisfy the safety requirements when the lifting lug is in horizontal position.
At upright state, we conduct dangerous points detection for partial flare stack structure, without outer force the whole stack can be freely deformed, it is suffered less stress. Due to the weight of a fully loaded stack on the main lifting lugs flange bolts, the structure is exposed to the maximum equivalent stress which is located at the upper part of the main flare stack lug flange bolts (in Figure 12). The maximum stress of the overall stack is the tensile stress suffered by main lug bolt flange (value is 293MPa), so we need to use a bolt with higher intensity level (level 8.8 M20×100) to connect the main bolt lugs.

6. On-site lifting implementation

Refer to the CATIA finite element checking calculation and results analysis, and according to the reinforcement guidance program, on-site engineering completion of the flare stack, main lug, side lug and column flange reinforcement work are shown in Figure 13, 14, 15. On 2016 January 14, after 1 hour of lifting operation, the integral hoisting work of flare stack frame is achieved successfully (as shown in Figure 16).

7. Conclusions

By applying the accurate, reliable, mature computer aided engineering (CAE) calculation, for 49.00m flange connection type flare stack hoisting process, flange bolt stress, overall structure deformation and lug partial stress are possibly too larger. Focus on these, we conduct 100% solid modeling, then we check and analyze overall strength and stability of flare stack under extreme horizontal and vertical condition, which satisfy the safety requirements. By reasonable setting of the main and side hanging ear, column flange reinforcement measures and the selection of high strength grade of the main lifting lug flange bolt, we ensure intensity and stability of the flare stack in integral hoisting better satisfy the safety requirements, and ensure flare stack integral hoisting could be completed successfully. The integral hoisting process of flare stack flange connection structure solve many difficulties of aerial
parts assembly and segmental hoisting operation in winter construction, and lay a solid foundation for promotion of this hoisting method.

References
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