Large Capacity Constant Spring Support Hanger Design Optimization

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Abstract: *This article discussed how to improve constant force performance of the large capacity constant spring support hangers. Large deviations have been found between product testing results and theoretical calculations after years of research and testing. The deviations mainly are caused by internal frictions inside the constant spring support hangers. By reducing or properly using internal frictions, consistent results between testing and theoretical calculation have been achieved. Based on product performance testing results recently, constant force performance of hangers has been improved greatly by adopting new methodology.*

Key words: constant hanger; friction; spring

1 Introduction

The thermal expansion due to temperature variation is always a big consideration in plant piping design. The displacements caused by thermal expansion could range from several millimeters to several hundred millimeters from installed/shut down (cold) condition to operating (hot) condition. The typical piping systems of steam, water, smoke, and air in power or petrochemical plants need to be supported properly to reduce extra loads caused by thermal expansions on piping systems and main equipment such as boilers or burners. A common frequently used device is constant spring support hangers when the constant support forces or moments are required.

There are force balance or moment balance methods for constant hanger designing. The moment balance method has been more frequently used for general design. In addition, coaxial or non-coaxial types are classified based on the collinear features of anchor and load locations. A typical non-coaxial hanger is a connecting rod structure with either three or four rods. Four-rod hangers from ITT series of the United States and three-rod hangers per China machinery industry standard JB/T8130. 1 series are widely used in the industry.

Although theoretically three-rod configuration [1] is much better than four-rod construction on the constant force performance, this advantage can be hardly achieved through massive production due to instability of force reactions caused by improper spring design and production. There is a single point contact between a tension rod (pull rod) and spring without any auxiliary support points or guides. The centerline of spring and tension rod forms an angle, which makes the spring force direction deviate from its centerline to form an angle. At this point spring easily bending will occur and further cause the spring force to change with its values and directions. Usually designers pay more attention to structure configuration than spring design [2]. However, a proper spring design is essentially a key element in this case to achieve the spring's manufacturability, functionality, and stability. Material selection of the spring is also vital to avoid unexpected deformation of the spring due to creep within a certain temperature range. The good design practice of hanger should be design structure configuration first then the spring with considerations of certain special non-standard criterions such as size and weight requirements. An unsuccessful spring design in massive production will result in unstable constant force performance of the hangers.

On other hand, there is a slotted guide in the four-rod hanger construction to avoid all cons derived from the single point contact of three-rod hanger configuration. Their constant force performance is more stable comparing to that of three-rod hangers. However, during

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the production testing [3] of large capacity [1,4] (capacity = load x displacement) constant hangers, the results of constant force performance are apparently out of expectations. After numerous experiments and research, it is found that the huge differences between testing results and theoretical calculations are caused by the internal frictions between mating surfaces of those connections.

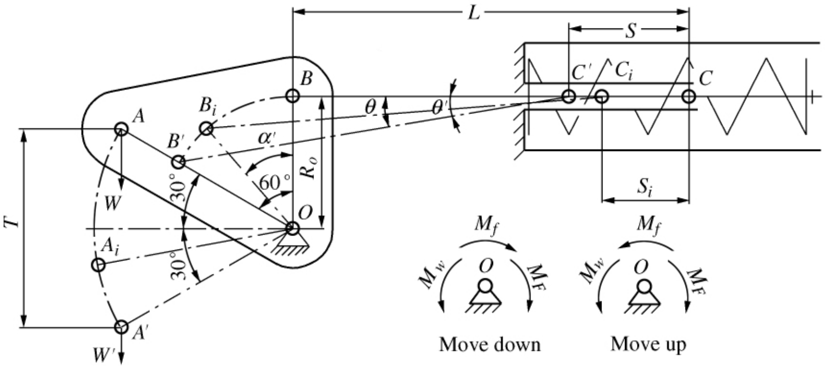

Figure 1 Four-rod structure

1) Structure of constant hanger

Equilibrium of the constant hanger: External load W, generates torque M_w based on center of rotation O through the pull rod BC; the spring force generates torque M_F based on the center of rotation O. When $M_w = M_F$, and torque is in the opposite direction, so as to achieve the effect of an external load constant.

As shown in Figure 1, the external load is W; displacement is T; OAA' is an equilateral triangle, OAB is a rotating frame; the initial position of OA and horizontal included angle is 30°; pull rod BC is at the horizontal position and pull rod BC and OB is vertical, the rotating frame OAB rotate 60° to the end position of the total distance, namely OAB rotation to $OA'B'$ position. Suppose rotating frame OAB from the initial position to rotate at any angle α', move to the OA_iB_i position and the pull rod move from BC position to B_iC_i position, B_iC_i and the initial position BC included angle is θ'. The amount of spring compression is S_i, suppose $OB = R_o$, $BC = L$, when the initial state, the spring force is F_1, spring rate is F':

The rotation angle relation:

$$\theta' = \arcsin\left(\frac{R_o(1-\cos\alpha')}{L}\right)$$

The initial spring force:

$$F_1 = \frac{W \cdot T \cdot \cos 30°}{R_o}$$

Arbitrary position of the spring force:

$$F_i = F_1 + S_i \cdot F'$$

The amount of spring compression:

$$S_i = L + R_o \cdot \sin\alpha' - L \cdot \cos\theta'$$

Arbitrary position, clockwise tension at point B_i where the spring force is transferred to the rod OB_i, and perpendicular to the OB_i:

$$F_i \cdot \frac{\cos(\alpha' - \theta')}{\cos\theta'}$$

In the arbitrary position, external load W makes spindle O generate torque equal to the torque that the force of the spring by the pull rod transfers to the spindle O, then balance equation:

$$W \cdot T \cdot \cos(30-\alpha') = F_i \cdot R_o \cdot \frac{\cos(\alpha'-\theta')}{\cos\theta'}$$

Simplify:

$$W = \frac{R_o}{T} \cdot \frac{F_i \cdot \cos(\alpha'-\theta')}{\cos\theta' \cdot \cos(30-\alpha')} = \frac{R_o}{T} \cdot \frac{F_i}{A(\alpha')}$$

Type $A(\alpha')$ —angle function:

$$A(\alpha') = \frac{\cos\theta' \cdot \cos(30-\alpha')}{\cos(\alpha'-\theta')}$$

In order to make the balance equation identity in an arbitrary position and meet the identical condition:

$$\frac{F_i}{A(\alpha')} = \text{constant}$$

The derivation can be calculated: $L/R_o = 2.997$, can meet the identical condition; in engineering design, general simplified value $L/R_o = 3$, draw function curves $F_i(\alpha')$ of spring force and the rotation angle of function curves $A(\alpha')$ by different scale, as shown in Figure 2, two curves approximately parallel, which meet the identical condition.

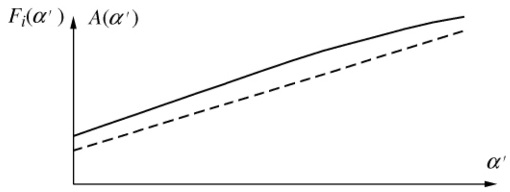

Figure 2 Curve relation between spring force $F_i(\alpha')$ and angle function $A(\alpha')$

Constant hanger main technical index of "constant force performance" by detecting the load deviation [4] is defined:

$$\Delta = \frac{W_{\max} - W_{\min}}{W_{\max} - W_{\min}} \times 100\% \leq 6\%$$

In the equation: $W_{\max}$ is the maximum load of the whole rotary process; $W_{\min}$ is the minimum load of the whole rotary process.

In the constant hanger load deviation tests, the actual external load is not completely constant, but fluctuates in load value W. When the actual load fluctuation is larger, load deviation will be more than 6%; this kind of phenomenon in a large capacity of a non-standard constant hanger is more obvious, and basically not effective adjustment method. Load fluctuation is the fundamental cause of constant hanger exists within the large friction. The structure of the constant force principle of derivation without considering the influence of friction on constant hanger performance, in fact, in actual production, the friction force on the load deviation test results have great impact, the friction is larger, constant hanger performance will not be ideal.

2) Structural analysis

In the constant hanger internal structure, internal friction (below referred to as the friction) is mainly manifested in the various connection of parts O, B, C, and the value of the friction force is directly influenced by the spring force F_2 (the spring force that the pull rod from the initial position BC move to $B'C'$), and it has relation to the roughness of the parts surface. This frictional force also will make the rotation center O produce torque M_f. When the constant hanger displaces downward (the process from A move to A'), this friction will make the rotational center O produce clockwise torque M_f. When the constant hanger displaces upward (the process from A' moves to A), this friction will make the rotation center O produce anticlockwise torque M_f. In the actual process of operation, the friction torque generated by the friction force made the constant hanger external load change. Especially it changed the direction of displacement, because the constant hanger torque internally generated by the friction force changed direction. For load deviation of a large capacity constant hanger, the friction torque has tremendously affected the load deviation. It is also the main reason that load deviation of the large capacity constant hanger is not easy to guarantee load deviation requirements. Because the friction can not be eliminated, reducing of friction force can improve load deviation.

When the displacement move from A to A', pull rod moves from BC to $B'C'$. Pull rod increases gradually from horizontal angle 0 to $\theta°$, spring froms the initial installation force F_1, then compresses deformation of S, finally reaches the spring force F_2. During the course of movement, the spring force increases gradually, the friction of the point O, B, C also increases. The internal friction of the structure formed mainly by the frictions at these three locations should show a trend of first increasing and then decreasing in the whole movement Figure 3a). In theory without considering friction, the external load should approximately be a constant line Figure 3b). After considering internal friction of the structure, theoretical load graphics should approximately be as shown in Figure 3c). But in actual test, distribution of load force is similar to the law. If the constant hanger operates throughout the whole process, reducing the friction torque M_f structurally inducing, an optimized theory load force curve will be obtained Figure 3d). Comparing Figure 3c) and Figure 3d), it can be seen that comparing to the unoptimized one the optimized load force has outstanding characteristics of reduced load fluctuation, so that the load deviation can be improved.

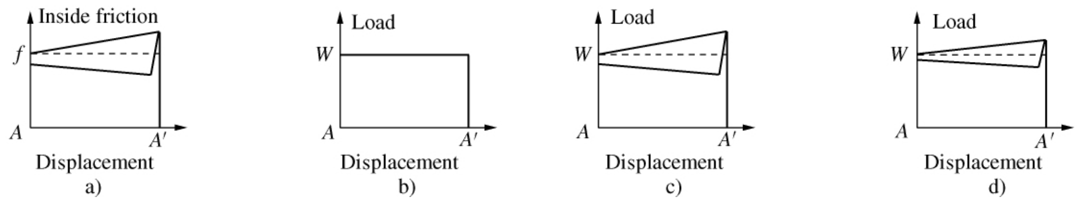

Figure 3 Relation between friction and load force

In the process of structural design, more attention should be paid to reduce internal friction formed in the structure; it might be appropriate to reduce the friction torque generated in the moving process. The internal friction force of a constant hanger depends on the amount of the spring force. In the design, you should try not to make the spring force designed too large. By structural design to reduce the spring force, in addition to using proper tools to assemble, as can improve the assembly precision and has good symmetry, so that the final assemblyment of the actual equipment is closer to the plane mechanics structure of the design principle. Reducing deviation between practical mechanics and theoretical mechanics, and improving parts′ surface roughness in the revolving pairs can reduce the friction factor, and negative friction torque in the actual service and make actual "mechanics balance" more closer to the theoretical design, because in the theoretical design friction torque is not considered. In the design, in order to reduce the friction factor and bearings or copper sleeves other parts are applied.

3) Optimization of design and application

In actual production, large capacity constant hanger load deviation easily exceeds load deviation requirements, because of its large load, and the designed spring force is also large, resulting in large internal frictions. Actual load in the testing result can fluctuate greatly, and it is very difficult to adjust to make load deviation test in an ideal range. Table 1 is a load deviation test report of a non-standard high-capacity constant hanger which is designed according to the principle of normal designing method; load of constant hanger is 232 kN (capacity larger than 60 000 kN·mm).

Table 1 Constant hanger test report before optimization (load 232 kN)

Test point	0	2	4	6	8	10
Load	223 100	242 200	241 700	241 200	236 000	232 000
Test point	10	8	6	4	2	0
Load	232 000	200 620	203 190	204 820	205 770	205 520
Max load	242 200	Min load	200 620	Deviation	9.4%	9.4%

From the load deviation test report, it can be seen that the load fluctuation occured in the test point 10 to the test point 8 of the process where the location do the displacement direction is changed too. The changing of loads is 31 380 N and load deviation is greater than 6%. In tests, the load deviation of this constant hanger had no obvious changes after repeated adjusting. Table 2 is a load deviation test report of a non-standard high-capacity constant hanger which is designed with consideration friction designing method; loading of constant hanger is 232 kN (capacity larger than 60 000 kN·mm).

Table 2 Constant hanger test report after optimization (load 232 kN)

Test point	0	2	4	6	8	10
Load	232 000	240 900	238 600	238 060	239 120	241 020
Test point	10	8	6	4	2	0
Load	241 020	217 440	216 270	216 400	216 690	216 350
Max load	241 020	Min load	216 270	Deviation	5.4%	5.4%

From the load deviation test report it can be seen that the load fluctuation is reduced. In the test point 10 to the test point 8 of the change load is 23 580 N. With load deviation less than 6%. The load deviation test proves that constant force performance of the constant hanger by optimization design is significantly better than the constant hanger which is not optimized.

Table 3 and Table 4 are two load deviation test reports of before and after optimization design. The load of non-standard constant hanger was 156 kN (larger than 45 000 kN · mm).

Table 3 Constant hanger test report before optimization (load 156 kN)

Test point	0	2	4	6	8	10
Load	155 800	162 500	164 000	163 220	163 400	164 320
Test point	10	8	6	4	2	0
Load	164 320	140 620	140 800	141 770	142 890	142 810
Max load	164 300	Min load	140 620	Deviation	7.8%	7.8%

Table 4 Constant hanger test report after optimization (load 156 kN)

Test point	0	2	4	6	8	10
Load	156 000	166 000	165 330	164 400	164 100	166 110
Test point	10	8	6	4	2	0
Load	166 110	151 130	151 090	151 140	151 830	151 810
Max load	166 110	Min load	151 090	Deviation	4.7%	4.7%

Through the test results it can be seen, load change of the optimized constant hanger is smaller and constant force performance is better.

3 Conclusions

The experiment proves that the friction in the large capacity constant hanger greatly affects the constant force performance of the constant hanger. In the design, it should be considered the design method of reduced friction force. Design by reducing the friction of main connection position, or by using friction method will improve the constant force performance; optimized design in the structure can also get an obvious effect. In the constant hangers do all parts, the spring is the most important one, a good spring is prerequisite to ensure that spring constant hanger performance is good.

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Brief Biographies

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