Performance evaluation of constant hanger for in-service pipelines in power plant

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Abstract. Aiming at the in-service pipeline of thermal power plant, considering the impact of pipeline operation factors, the finite element method is used to calculate the static load and modal analysis of the pipeline system, under the method of selecting the constant hanger according to the risk size, the constant hanger with abnormal state is found accurately, realize the evaluation of the whole state of the constant hanger of the pipeline system. The results show that after a long period of operation or vibration, the output load of the constant hanger near the maximum thermal displacement point and the maximum response point of the low order natural frequency will decrease due to the relaxation of the spring, resulting in the deviation of the performance index of the constant hanger, which can still meets the standard requirements after correction by the performance test. It is feasible to evaluate the overall state of the pipeline constant hanger by selecting partial constant hanger, which has some reference value for the safety evaluation of the Steam Pipe branch hanger in power plant.

1. Introduction
Thermal displacement of steam pipe outside furnace in thermal power plant is very large. Constant hanger is widely used in high temperature pipelines, collecting boxes and other pressure equipment in thermal power plants for its characteristics of keeping load output basically unchanged in the case of large thermal displacement and avoiding excessive bending stress in pipeline system. Several literatures have pointed out that the abnormal state of the constant hanger is one of the key reasons to induce the fault of the pressure pipeline in thermal power plant[1-3]. Therefore, the performance of the constant hanger and whether the bearing is reasonable will directly affect the life and safe operation of the piping system.

Constant force support hangers may have factors that affect their performance during the design, manufacture, installation and use phases. Lee, Chen, Liu[4-6] discussed the influence of different design methods on the performance of constant hanger from the design principle. Wei[7]studied the influence of various influencing factors on the performance of constant hanger in the manufacturing stage. Chen, Tang[8-9] studied the key points of performance evaluation in installation stage. However, the performance of in service constant hanger was not involved in these studies. Liu[10]studied some indexes such as load deviation degree of in-service pipeline support hanger, but this method does not consider the influence of operation factors, and the selected constant hanger has great contingency, so it cannot accurately find the constant hanger in service that is easy to fail. At present, the influence of operating factors on the support hanger has not been considered, nor has the full performance evaluation of the constant hanger of the whole pipeline system been studied.
Therefore, under the premise of considering the operating factors of pipeline, this paper uses the finite element method to carry on the static load calculation and modal analysis of the pipeline system, selects the constant hanger according to the risk degree to carry on the performance test, realizes the evaluation of the whole pipe system in the service constant hanger state.

2. Principle of constant hanger

The displacement range of constant hanger is 50 to 400mm, and its loading limits is about 123 to 364120N[11]. Main parts of constant hanger including fixed frame, rotation module, cylindrical spiral spring component, load connection component, spindle and load adjust equipment, as is described in Figure 1.

![Figure 1. Structural diagram of ITT constant hanger.](image1)

The constant hanger is designed according to the principle of moment balance[12]. Through delicate geometric design, it can create a permanent load output by making the external load moment and the spring moment always in balance in the working process[13](refer to Figure 2). The equipment is in cold state and no heat displacement after the constant hanger been installed, and the hanger bears the distribute load of the equipment, so it follows the following formula:

\[ G \times L_1 = F_{t1} \times S_1 \]  \hspace{1cm} (1)

Where G means external load, \( L_1 \) represents force arm of cold state external load, \( F_{t1} \) means cold state spring force and \( S_1 \) means cold state spring force arm.

Operating equipment brings heat displacement that makes constant hanger to move in the same direction, the external load remains unchanged and its arm turns to \( L_2 \), the spring force and its force arm changes synchronously until reaches a new balance.

\[ G \times L_2 = F_{t2} \times S_2 \]  \hspace{1cm} (2)

Where \( L_2 \) represents force arm of thermal state external load, \( F_{t2} \) means thermal state spring force and \( S_2 \) means thermal state spring force arm.

From the perspective of the whole pipe system, the constant hanger can coordinate its movement and achieve torque balance when the pipe displacement is generated from cold state to hot state, keeping the theoretical output load basically unchanged. While under actual conditions, the output load is not absolutely constant due to structural processing and assembly errors, friction during rotary operation and uncertainties in the field operation[14]. Therefore, the ability of constant hanger to keep constant is the main index to evaluate its performance.
3. Selection of constant hanger

The steam pipeline design pressure of a power plant is 17.74 MPa, and the design temperature 541 °C, there're 20 support hangers in the whole section, including 7 constant hangers (refer to Figure 3). It has been running for 90000 hours after launched in July 2005. By means of pipe maintenance, the performance test of some constant hangers carried to in order to investigate the overall condition of hangers.

![Figure 3. Sketch of pipeline and support hanger.](image)

For the given pipeline, representative constant hangers should be selected as the object of performance test for the test of all constant hangers on the whole pipe line is large and uneconomic, then expanding the test range according to the test result. The frequency of running and start-stop are the same for the same pipeline under different working conditions, only the heat displacement and the vibration intensity are variables, which can be obtained by static load calculation and modal analysis.

The main steam pipe is modelled by finite element method, and the static load of the pipe is calculated by means of inputendpoint displacement, load of each lifting point, structural parameters and operating conditions of the pipe. Since the primary stress has no self-limitation and can directly cause the damage of pipelines, the distribution of primary stress in pipelines is emphasized. After static load calculation of the model, the primary stress distribution and the thermal displacement of the constant hanger is shown in Figure 4 and Figure 5 respectively. As a whole, the static primary stress of the pipeline is at a reasonable level, and its larger stress position (the red area in Figure 4) is at the elbow position next to the NO.12 constant hanger at a elevation of 23m.

The pipe can be simplified as linear elastic structure appropriately in the modelling process. Lifting points should be arranged by the actual situation, and the rigid components such as three-way and valve are added to the corresponding nodes as concentrated mass in the modal analysis process. Analysis results show that the first-order natural frequency of the pipeline is 0.17Hz, the maximum response point of its vibration mode is at the elbow of 23m elevation (refer to Figure 6). It shows that the pipe's natural frequency is low and extremely susceptible to vibration at the bend of 23m horizontal section.

According to the results of static load calculation and modal analysis, No.12 constant hanger is at the largest thermal displacement point and the maximum response point of the first-order vibration mode of the pipeline, resulting in its performance extremely easy to change. In addition, No.12 hanger is located in the largest primary stress area of the whole pipe, which has a great impact
on the pipe stress. Therefore, No.12 hanger with the highest risk is selected as the representative test object.

**Figure 4.** Primary stress distribution of main steampipe.  

**Figure 5.** Thermal displacement comparison of constant support hanger.

**Figure 6.** First order mode of main steampipe.

4. **Full performance test of support hanger**

4.1. **Appearance inspection**

The selected constant hanger is checked in both hot and cold states, it is installed reasonably, and has a sound appearance and no obvious corrosion, the spring can be normally extended, displacement indicator is in the effective range and the pendulum angle is not more than 4 degrees under various working conditions. In the cold state, the hanger was removed with its rotating pin fixed and no
damage on the overall structure after the removal. The performance parameters of the constant spring hanger, which has a structural form of horizontal double lifting plate connection is shown in Table 1.

Table 1. Basic parameters of constant hanger.

| Std  | Spec     | Rod size (mm) | Load (N) | Thermal displacement direction | Design thermal displacement (mm) | Actual thermal displacement (mm) |
|------|----------|---------------|----------|---------------------------------|---------------------------------|---------------------------------|
| ITT  | 58H-49C  | M42           | 19964    | down                            | 131                             | 165                             |

4.2. Installation and debugging before test

The hanger performance test machine is consisted of test bench, connecting tooling, force sensor (accuracy level not less than 0.2), displacement sensor (accuracy not less than 0.5%), and the corresponding control centre and soft processing equipment.

Installing the constant hanger straight into the hydraulic test machine with connecting tool, inverted mounting installation method is adopted so as to eliminate the influence of the self-weight of the hanger (as shown in Figure 7). Checking the connection rod and the vertical Angle not exceed 4°.

![Figure 7. Hydraulic test bench.](image)

Operating the test machine to make the constant hanger run in the total range, checking whether the moving parts are flexible without clamping and no interference with the non-moving parts, confirming whether the state of force sensor and displacement sensor is normal or not. Adjusting the testing machine to make the hanger not loaded and zero the force sensor in the central control system after the trial operation is confirmed to be trouble-free.

4.3. Method and procedure for performance test of constant hanger

(1) Initial load deviation test: Start the test machine to load slowly, when the displacement indicator is in cold position and the locking pin can be loaded and unloaded freely, read the load value, which is the constant hanger set load, then calculating the initial load deviation according to the following formula:

\[
\lambda = \frac{|w_g - w_s|}{w_g} \times 100\%
\]  

Where \( \lambda \) is the initial load deviation, \( w_g \) is support hanger working load, \( w_s \) is support hanger set load.

(2) Constant degree and running load deviation test: Continue to load slowly, tested the reciprocating round trip, recorded the load-displacement curve, and calculated the constant degree and the running load deviation respectively according to the following formula:
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\[ \Delta = \frac{(w_{\text{max}} - w_{\text{min}})}{(w_{\text{max}} + w_{\text{min}})} \times 100\% \]  

(4)

Where \( \Delta \) is constant degree, \( w_{\text{max}} \) and \( w_{\text{min}} \) is the maximum and minimum load value in the whole course of rotation separately. Calculation method of the running load deviation follows:

\[ \max \left\{ \left( \frac{w_{\text{max}} - w_g}{w_g} \right), \left( \frac{w_{\text{min}} - w_g}{w_g} \right) \right\} \]  

(5)

3) Displacement: According to the load-displacement curve, the difference between the maximum and the minimum displacement in the whole return journey is the displacement amount.

4) Double working load test: Loading slowly and inserting the locking pin when the constant hanger is in the initial state, and then slowly loading to 2 times the working load, check the integrity of the hanger and whether the load output is stable.

5) Load adjustment test: Repeat step (2) to perform a constant metrication and load difference test on the basis of reducing or increasing the working load of not less than 10%.

4.4. Test results and evaluation

Using above steps to test the performance of the selected constant hanger, simulating the loading and unloading process when the equipment produces forward or reverse displacement. Stretching boom (simulated loading process), constant force support hanger moves along the upper displacement curve, the curve extends smoothly, and the output load seldom changes. Relax the lifting rod when reaching the set displacement (simulated unloading process), the load mutated and then run back along the lower displacement curve with the curve extends smoothly and the output load changes little, when the load returns to the starting point, the travel ends (Load-displacement curve is shown in Figure 8). The output load of the constant hanger is between the upper and lower displacement curves, however the load output at the same stroke point (the spring compresses the same amount) in the loading and unloading process is inconsistent (the difference value is the load difference between the upper and lower displacement curves at the same displacement), which is mainly caused by the difference in friction during loading and unloading [15].

![Figure 8. Load-displacement curve.](image-url)

The test data is shown in Table 2, and the performance test results of constant hanger were evaluated according to the qualified index recommended in DL/T1113-2009, where the initial load deviation and the running load deviation are not qualified whereas the constant degree and displacement are qualified. It does not have the necessary conditions for double working load and load adjustment test due to the nonconforming items, detail evaluation data are shown in Table 3.

Analyse the performance parameters, if constant metrication and displacement are acceptable, means the suspension torque structure is well-adjusted and has enough movable quantity, the initial and running load deviation deviate from the index indicates that the preloading force has changed [16].

Start testing machine load slowly, when the displacement indicator in the cold position and the locking pin can loading and unloading freely, adjusting the hanger load adjustment bolt, and then
adjust the load to working load. Conducted the performance test again and the load-displacement
curve is shown in Figure 9, the results are shown in Table 4, the index evaluation is shown in Table 5.
The results show that the performance index of some abnormal constant hangers can still meet the
standard requirements after adjusting the precompression load of springs.

![Figure 9. Load-displacement curve after adjustment.](image)

**Table 2. Performance test result of constant hanger.**

| Performance index | Unplug | Min | Max | Min | Max | Disp disp amount |
|-------------------|--------|-----|-----|-----|-----|-----------------|
| Test data         | 18550 N | 16960 N | 18620 N | 13.94mm | 179.41mm | 165.49mm |

**Table 3. Evaluation of constant hanger performance test.**

| Performance index | Recommended Index in DL/T1113 | Test result | Evaluation |
|-------------------|-------------------------------|-------------|------------|
| Initial load deviation | ≤2% | 4.20% | Unqualified |
| Constant metrication | ≤6% | 4.67% | Qualified |
| Running load deviation | ≤6% | 12.44% | Unqualified |
| Disp amount | ≥135mm | 165.49mm | Qualified |
| Double working load | — | — | — |
| Load adjustment | — | — | — |

**Table 4. Performance test results after adjustment.**

| Performance index | Unplug | Min | Max | Min | Max | Disp disp amount |
|-------------------|--------|-----|-----|-----|-----|-----------------|
| Test data         | 19710 N | 18240 N | 20060 N | 16.84mm | 181.98mm | 165.13mm |

**Table 5. Evaluation of constant hanger performance test after adjustment.**

| Performance index | Recommended Index in DL/T1113 | Test result | Evaluation |
|-------------------|-------------------------------|-------------|------------|
| Initial load deviation | ≤2% | 1.76% | Qualified |
| Constant metrication | ≤6% | 4.75% | Qualified |
| Running load deviation | ≤6% | 5.83% | Qualified |
| Disp amount | ≥135mm | 165.13mm | Qualified |
| Double working load | — | — | — |
| Load adjustment | — | — | — |
4.5. Overall evaluation results of pipeline constant hanger

The inspection scope was expanded because of the unqualified index of No.12 constant hanger, and the No.11 and 13th constant Hanger were selected for they located near the maximum response point of the first order mode of the pipeline and has a large thermal displacement. It shows that the initial and running load deviation of these constant hangers are not qualified in the original state and qualified after adjustment. Expand the inspection again, conducted performance test on No.7, 10, 19 and 20th constant hanger for their lower risk as well as small thermal displacement, and far away from the maximum response point of the first-order vibration mode of pipeline, results indicated that all indexes meet the standard requirements.

Analysis of the causes of the above situation, if the spring is naturally slackened after 90,000 hours of operation with the pipeline, the output load is reduced, and this batch hanger will all have abnormal indexes. While only 23m elbow close to No.11, 12, and 13th hanger indices abnormal, which most likely due to the first-order natural frequency of pipeline is low, and three hangers are near the maximum response point that easily produce vibration under the excitation of fluid or the outside vibration source. Moreover, the thermal displacement of the pipeline is the largest, which accelerates the relaxation of the spring under the repeated stretching and compression of the large stroke and finally resulting in abnormality.

5. Conclusions

(1) Aiming at the in-service pipeline of thermal power plant, considering the impact of pipeline operation factors, the finite element method is used to calculate the static load and modal analysis of the pipeline system, under the method of selecting the constant hanger according to the risk size, the constant hanger with abnormal state is found accurately, realized the evaluation of the whole state of the constant hanger of the pipeline system.

(2) After running for a long time or under the influence of pipeline vibration, the constant force hanger near the maximum thermal displacement point and the maximum response point of low order natural frequency will reduce the output load due to spring relaxation, resulting in the deviation of constant force hanger performance index, which can be corrected by performance test.

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