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Analysis and Improvement Practice for Stream Control Valve Stem Fracture of Back Pressure Steam Turbine

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Abstract

During the running of the steam turbine for XyMax recycle hydrogen compressor in an aromatics union plant, the stem of stream control valve had fractured several times. According to the characteristic of structure, assembly, force and the process data, it was thought that when the stream come into chamber from side end, the beam end-face will be struck directly by steam inevitably, the valve disc will be subjected to irregular torque force under the action of steam flow, resulting in vibration frequency difference between the valve beam and the valve disc. When there are some defects in the stem, such as threaded rod was not strength enough, or had some stress concentration, or had low anti-fatigue performance, etc., the rod is highly likely to be fractured. Passed optimizing the force distribution and disturbance gave by steam, reforming the rod structure, and upgrading the material comprehensive performance and anti-cavitation ability, after this final improvement, the problem never happened again.

Keywords

Steam Turbine; Valve Stem; Valve Disc; Fracture; Fatigue; Stress Concentration.

1. Introduction

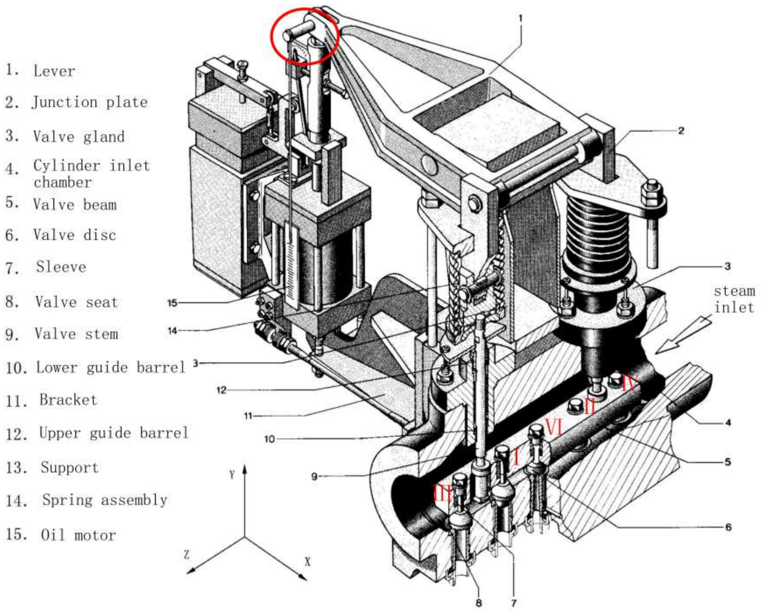

Figure 1. Mechanism of Turbine Speed Control Valve

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As critical equipment, centrifugal compressors are widely used in the petrochemical industry, The stability of the equipment affects directly the safety and long-term operation of a plant[1]. The isomerization circulating hydrogen compressor(ICHC) is the critical equipment in an aromatics complex union, The capacity of the specific PX plant is 1.0 Mt/a, the ICHC was driven by 3.7MPa steam turbine, with 1.2 MPa back pressure, steam consumption is 35 t/h (rated) , trip speed is 12062 rpm. The speed control valve is a single side feed steam, double guide barrels , the speed control valve is composed of valve stem, valve beam, valve disc bolt, valve disc and valve seat, there are five groups in total, arrangement in parallel, opening and closing in sequential. Under normal working, the I, II, III valves are fully opened, and the IV and V valves are on adjusting. the specific structure showed in Figure 1.

2. Fault Description and Fast Solution

2.1 First Failure: Stem of V-Valve Disc Break

In the 14th month after the first commissioning, there was a power flash interrupt happened, the interrupt held 100 ms, this GPF (General Power Fault) event caused the pressure of the 3.5 MPa steam network dropping from 3.7 MPa to 2.8 MPa within 15 minutes, and continued for about half an hour before the pressure gradually rose to 3.5 MPa. This GPA caused some other critical equipment tripped, but the XyMax recycle hydrogen compressor did not interlock shutdown.

While the pressure of steam system was recovering, the opening of the steam control valve of the steam turbine was gradually to reduced automatically, but on the way of steam system recovered to normal, it was found that the speed of the compressor turbine could only be held above 8300 rpm, could not came down below 8300 rpm, whether manual model or automatic model. Finally, unwillingly, it was stopped by activating the fast-shutdown valve. After checked the control instruments, oil motor, hydraulic cylinder, secondary oil pressure, regulating valve level rod, etc., no abnormality problem was found, so it was preliminary judged that a valve disc of the steam valve assembly had fallen off. After disassembly, we found that the V-valve stem was broken, and the breaking location was at the end of the screw thread, and the hexagon head of the stem nut had been damaged with round friction , as shown in Figure 2. In order to reduce the impact of process, the damaged V-valve stem replaced and the II valve disc (slight damaged) were repaired and assembled again, and then, the compressor was restarted without problem. At meantime the original supplier was notified and they transported a set of V-valve stem and disc by air as urgent spare parts to be stored.

Figure 2. V-Valve Stem Fracture and II-Valve Disc Scar

According to the analysis, the speed of 8300 rpm was in the control region of the V-valve, while the valve controller output was on closing stroke, the V-valve disc could not moved to the seat because it was stuck, of course it had deducted the noneffective stroke, show Figure 3, so the steam flow and the speed had no decrease.

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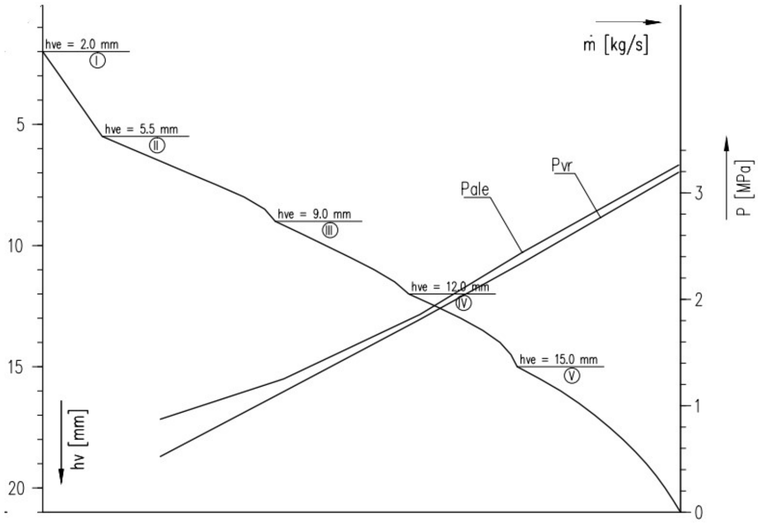

Figure 3. Action Sequence and noneffective stroke height of Steam control Valve

2.2 The Second Failure: Transmission Mechanism Frame Separate Away from Rod of Hydraulic Piston

Fifth months later, the compressor stopped without any prior alarm messages. It was found that the the speed-regulating connecting rod and the hydraulic cylinder piston was separated off, and the failure caused the control valve closed by spring force. See Figure 4. Further inspection revealed that there were no dowel hole be made and therefore no anti-slip cotter pins were installed. After the problem was confirmed, the connecting rod mechanism was reconnected, and the points which were easy to slip were welded together, to prevent the hydraulic piston rod to have rotating movement.

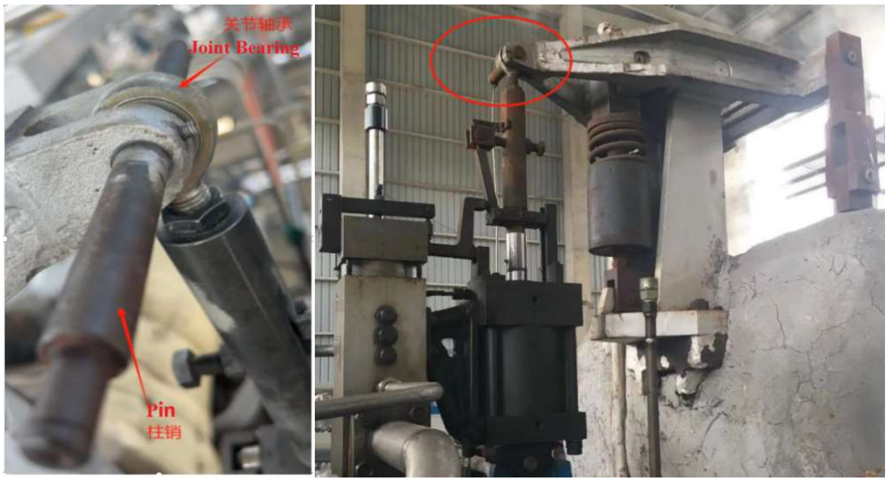

Figure 4. Connecting Rod of Hydraulic Piston to Transmission Mechanism

When on executing the compressor start-up SOP (Standard Operating Procedure) , it was found that the speed began to fluctuate greatly at low speed (warm-up stage), which was shown as a regular sinusoidal wave with a fluctuation range of about ±300 rpm, and the wave could not made a convergence. Took several times to optimize the PID parameter, nothing changed better. Further checked the secondary oil pressure was consistent with the on-site indicator which fixed on the rod, but the piston rod oscillation amplitude was very large, ranging from 0.7 to 1.0 mm, far exceeding the designed control range of amplitude from 0.2 to 0.3 mm. The analyst suggested that the problem might be the rotating plate of the throttle slide valve. The rotating plate sketch show in Figure 5. In the case of compressor on running, the rotating plate was disassembled from the throttle breathing cap, and it was found that the rotating plate could not rotated smooth. Further check found that one

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of the three tangential oil injection holes was blocked by some slag inclusion. When pressure oil enters the central chamber of the slide valve from the oil inlet hole, and then squirts out from the three radial and tangential oil injection holes of the rotating plate. Under the action of tangential force, the slide valve continuously rotates, the torque depends on the amount of oil injection, and the speed of the slide valve can be adjusted by means of the regulating valve. The recommended working speed of the slide valve is 300 ~ 800 r/min. After cleaning the rotating plate of the slide valve, the rotating speed oscillation disappears and PID can be controlled normally.

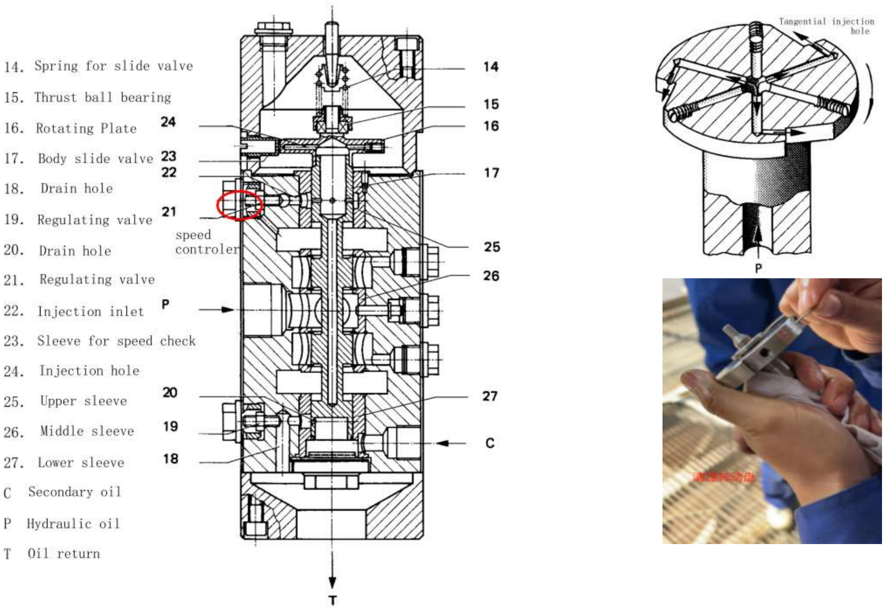

Figure 5. Sketch of Rotating Plate

2.3 The Third Failure - V-Valve Stem Fracture Again

After the compressor ran again for 1 month, the plant was stopped to take a planed turnaround. During the shutdown procedure, the compressor was found that the turbine speed could not to reduce when it was reduced to 4000 rpm, even the hydraulic cylinder of the speed control valve was gradually fully extended. According to the phenomenon, the mechanism connection, the control system, the spool tremor, the rotation rotation and the spring compression were checked, but no abnormality was found, so it was judged that a certain valve disc fell off again. When disassembled, it was found that the V-valve stem fractured again, see detail Figure 6. Since the online valve beam was re-repaired during the first failure, so the valve beam assembly was replaced by warehouse-spare. After replacement, the compressor started again, the failure disappeared and turbine ran smoothly.

Figure 6. Fracture photo of V-Valve Stem

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2.4 The Fourth Failure - The IV-Valve Stem Fracture

When the compressor ran for 3 months, the pressure of steam network had failure again because of GPF, the residual pressure of steam could not keep the compressor speed, so the compressor tripped on low-low flow interlock. While the steam system recovered, the compressor was restarted again, but it was found that the quick-closing valve opened and the speed-regulating valve closed, but the steam turbine speed rushed to 4000 rpm directly, the speed-regulating valve could not control the low-speed warm-up procedure. So it was judged again that a certain disc had fallen off. After disassembled, it was found that the IV-valve stem fractured, , See Figure 7. and the V-valve was checked OK by PT(Penetrant Testing), In order to recover the process as fast as possible, the repaired valve-assembly last time was replaced again, and the compressor parameters were normal after starting.

Figure 7. Fracture Diagram of IV-Valve Stem

3. Fault Cause Analysis And Troubleshooting

Reviewed above failure, it always repaired to shorten the compressor stopping time, but never to try to find the root cause, so the fault happened again and again. Therefore a summary analysis was made afterwards, as follows:

3.1 Turbine Shafting System Analysis

From the start-up vibration spectrum after each failure, the specific spectrum amplitude and total amplitude of discrete frequency were good, so it could be concluded that the influences of balance, alignment, loosening and friction problems can be ignored, see Figure 8 (the spectrum are almost same of each start-up).

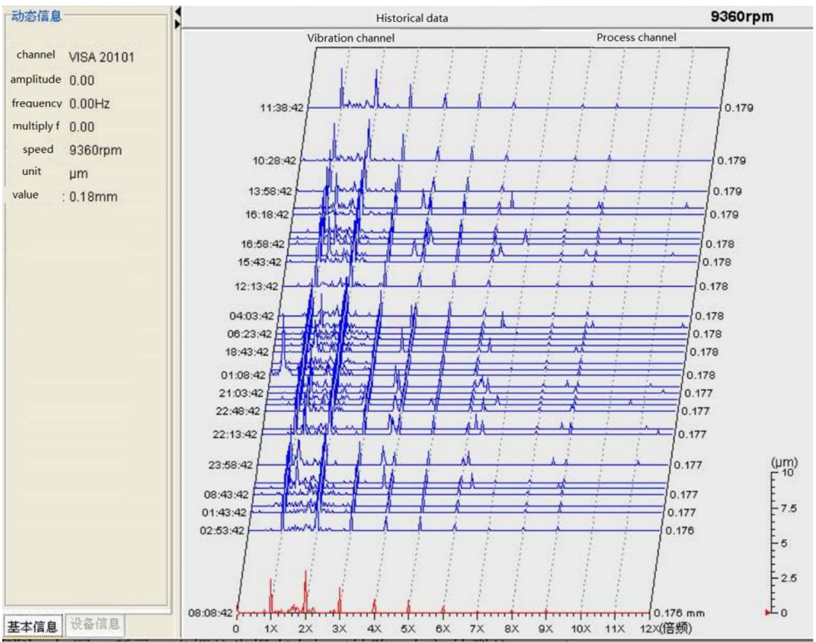

Figure 8. Waterfall Spectrum of Turbine Bearing

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3.2 Structural Analysis of Valve-Assembly

From the perspective of structure, the valve disc and the valve stem are connected through screw threads, the end of stem screw thread is the abrupt point of geometric shape, which will inevitably become a weakest point. When the valve-beam-assembly is subjected to external forces, the stress concentration of the screw thread starting point is apparent [2][3], see Figure 9. When there are machining defects in the tooth root of the screw, such as initial Crack Opening Displacement (COD), turning defects, excessive roughness, and too small transition angle of variable section of the screw will cause stress concentration. When the excitation force by steam is large, the gap between the rod sleeve and the valve stem will cause the valve stem to swing from side to side sharply, the cracks caused by vibration will occur at the stress concentration point. With the initiation and expansion of cracks [4], fatigue brittle fracture will eventually be happened[5]. This is the structural reason that the steam control valve stem always fatigue fractured in the same position which reported in many thesis [6][7][8][9][10][11][4].

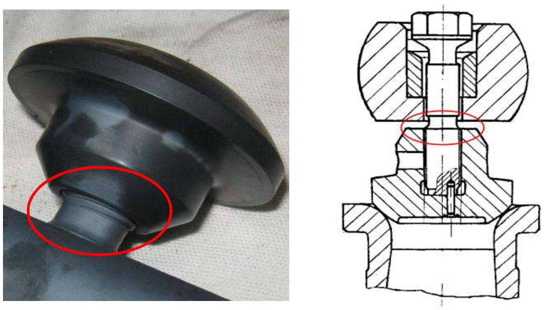

Figure 9. Structure of Valve Disc Components

3.3 Force Analysis

As shown in Figure 1 and Figure 10, when water steam enters the turbine chamber from the side end, the end face of the valve beam will be struck inevitably in horizontal direction. If the following six influencing factors exist:

a. the flow channel is not completely symmetrical or smooth;

b. Uneven steam feed on both sides;

c. The alignment of disc and seat is not good;

d. Insufficient clench force of the packing of the valve rod;

e. Steam carries liquid water;

f. The valve stem is bent.

The valve disc will be subjected to irregular torque force under the action of steam flow, resulting in a vibration frequency difference between the valve beam and the valve disc, and the stress will inevitably concentrate on the weak point of the component, which is the screw thread end. slowly, the tiny cracks will expand. When the cracks expand to a certain extent, the cracks will connected together, and finally lead to fracture [12].

Figure 10. Valve Beam End Face and Steam Impact Zone

From the failure of twice V-valve and once IV- valve fractured, the struck scars of the valve disc were obvious, and the abrasion trail were not showy, so these revealed that there was no rotation movement before stem fractured, or the rotation movement was not enough strong, but the hexagon edges of the stem had rubbed off, so it inferred that the stem had a period of time rotating movement after it fractured, and it was to be showed the steam produced a fluid disturbance in the steam room.

For the compressor, the working speed was always controlled by IV-valve and V-valve, see Figure 3, when the rotational speed approached to the IV- valve upper-boundary or V-valve lower-boundary, the V-valve will open or close frequently, if the alignment of valve disc and valve seat was not good, the steam will have a pulse force to make the stem and disc to have vibration and displacement in horizontal and vertical direction, finally lead to stress fatigue fracture of stem, which was the main reason for the many fracture of stem of IV-valve and V-valve reported in many thesis.

3.4 Working Condition Analysis

Before the first failure of V-valve stem fractured, the steam pressure decreased from 3.7 Mpa to 2.8 Mpa in 15 minutes, normally the steam superheated level will only increase in this process, but in the after half an hour, the steam temperature had been stabilized at 245°C@2.8 Mpa, higher than the saturation temperature of 230°C@2.8 Mpa, therefore, the possibility of steam carrying liquid can be excluded.

The analysis showed that the smaller the turbine type, the worse the anti-wave ability, the higher the installation accuracy and the precision of the components, the greater the influence of the steam turbine on the thermal expansion of the pipeline, so the fault rate would increase. The smaller the turbine, the greater the deviation of steam flow in the chamber from the ideal condition and the greater the disturbance. When the quality of steam system fluctuates, the disturbance of steam valve group is more obvious. When the working speed is working above or below the switching point between the two IV-valve and V-valve, the valve disc will strike the seat frequently, the valve stem will be instability, and the fatigue probability will increase faster. Therefore, according to the performance curve, it can be concluded that that choosing the right turbine model and the good match of the working speed, avoid working speed near the switch point, can significantly reduce the probability of fatigue fracture of the stem.

3.5 Matching Inspection

During inspection, it was confirmed that the grip force of the rod packing was suitable and no eccentric friction, the surface of the barrel was smooth, its roundness run-out was good, and the pre-tightening force of the spring was consistent, so the problem of lacking holding force of the packing and the bending of the rod can be excluded; Further measurement showed that the valve disc and valve seat are aligned well, and the inside of the steam chamber was smooth and clean. However, due to the structural characteristics of the steam chamber, it was difficult to measure whether the valve beam and the steam inlet are aligned, so about this, no qualitative judgment could be made.

4. Improvement Practice and Implementation

In order to ensure that the problem can be found in each startup and shutdown, it was recommended that at least two more precise static tests should be done, before each startup to check the linear curve and DEH (Digital Electro-Hydraulic Control System) performance of the control valve, record the corresponding relationship between output/secondary-oil pressure and valve position, and verify the accuracy, hysteresis and repeatability of steam control valve action [13][14][15].

From the above analysis, it can be seen that the main reason for the fracture was that there were certain design defects in the structure of the valve beam assembly, that is, insufficient stem strength, stress concentration in the structure and weak anti-fatigue performance of the valve stem. In order to solve the problem radically, finally, several suggestions for improvement were proposed:

a. The valve disc and stem should be manufactured integrally, optimize the stem structure, strengthen the connection strength, and avoid the stress concentration caused by the necking-down of the stem;

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b. Increase the cone ratio of the windward surface of the end of the valve beam to enhance the guiding effect on the stem, optimize the positive impact force and flow field disturbance distribution of the steam on the valve beam assembly;

c. Material of valve beam assembly use tempered stainless steel to improve the mechanical performance and fatigue resistance;

d. Take a detailed Non-Destructive Testing of weak parts, especially corner point, eliminate steep corners to reduce COD eigenvalue.

With the next one month, the improved valve beam assembly was manufactured according to the requirements, see Figure 11. After replaced, the compressor was started-up and continued to run for four months, until the plant had a planned shutdown for turnaround. During the turnaround period, the components of the valve beam assembly were checked, and there were no abnormal friction, no abnormal cracks, etc.. Since then(3 years), similar problems had no occurred again.

Figure 11. Improved Valve Beam Assembly

5. Conclusion

Through fault analysis and optimization, the effect of the valve beam assembly has been significantly improved. Although the problems of the stem have been effectively solved, the new valve beam assembly still had margin to advanced. From a structural of view, steam flow will also have an impact on the hexagonal head of the valve stem bolt, causing a disturbance to the valve beam assembly. If the end nut sink into the valve beam entirely, that the steam flow will reduce disturbance to the beam assembly, alleviate the rotating movement of the valve disc and stem, and avoid erosion and circumferential friction.

As the valve stem fracture problem has been reported in many thesis, it can be seen that this problem is not an single case, so it was suggested that turbine manufacturers should do a specific research, change the designing philosophy, give a root proposal. And in the view of the friction of the contact part between beam and the stem is also a common problem, so the beam assembly should be checked during each maintenance time, and it is quite necessary to take a well detection and elimination of defects.

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