Prohibition of Boiler Feed Water Pump Failure in Power Plant

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Abstract: This paper deals with failure investigation of boiler feed pump's shaft of a steam power plant. Boiler feedwater pump is a specific type of pump used to pump, feedwater into a steam boiler and is one of most important part of steam power plants. Feed pumps failure may cause failure of other parts of steam power station, therefore keep them safe, which is an important problem. There are 12 feed pumps in Bandar Abbas power plant. They are old and due to failure of feed pumps because of trying to avoid repetition problem, working condition of 3 dimensional pump's shaft is modeled with Abaqus software via finite element method analysis. Causes of pump failure and stresses exerted on it are investigated and finally appropriate suggestions such as smooth starting and inverter are proposed.

Keywords: Boiler Feed Water Pump, Fatigue Failure, Finite Element

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1   INTRODUCTION

Today, most of the electricity which is produced throughout the world is from steam power plants and power is produced in a steam power plant by supplying heat energy to the feedwater, changing it into steam under pressure, and then transforming part of this energy into mechanical energy in a heat engine to do useful work [1]. The feedwater therefore acts merely as a conveyor of energy. The basic elements of a steam power plant are the heat engine, the boiler, and a means of getting water in the boiler. Modern power plants use steam turbines as heat engines. This basic cycle is improved by connecting a condenser to the steam turbine exhaust and by heating the feedwater with steam extracted from an intermediate stage of the main turbine. The combination of the condensing and feedwater heating cycle requires a minimum of three pumps: the extraction pump, which transfers the condensate from the condenser hot well into the direct-contact heater, the boiler-feed pump, and a circulating pump, which forces cold water through the condenser tubes to condense the exhaust steam.

Therefore, pumps are very important components of power station, and boiler feedwater pumps are a significant part of any boiler operation because they control the amount of water fed to the boiler [2]. Boiler feedwater pump failure is a major cause of power plant unavailability [3], hence their working condition and maintenance are of prime importance. This paper includes the results of numerical analysis and theoretical calculations, with the aim of investigating the cause of shaft failure used in feedwater pump of Bandar Abbas power station. A three dimensional model was developed in Abaqus software for stresses analysis. Causes of pump failure and stresses forced on it are investigated and finally some suggestions like use of soft starting and inverter are presented. Use of soft starting and inverter enable an increase in an energy saving while guaranteeing the safe condition for starting of pump and changing of its velocity.

2   BANDAR ABBAS POWER PLANT

Bandar Abbas thermal power plant was established in 1975 in land with 560000 m^2 area and has four 320 MW unites equipped as follows:

1. Four boilers: capacity 1056 ton per hour, temperature 540°C, pressure 178 atmosphere, fuel gas or mazut.
2. Four generators: 320 MW, voltage 20 KV, frequency 50 hertz.
3. Four turbines: high, intermediate and low pressure, 3000 rpm.

Schematic view of Bandar Abbas power station cycle is depicted in Fig. 1. A number of auxiliary services not illustrated in Fig. 1 are normally used, such as service water pumps, cooling pumps, oil circulating pumps, and the like.
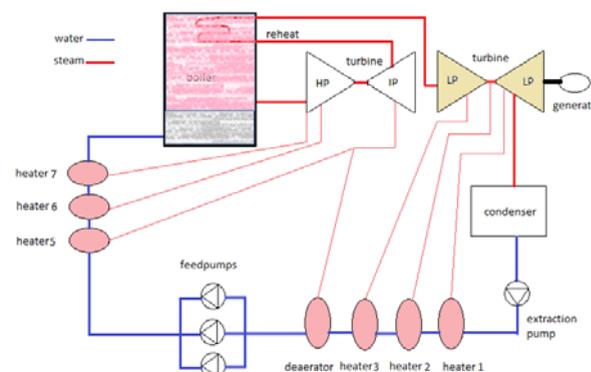

Fig. 1   Schematic view of Bandar Abbas power plant cycle

3   BOILER FEED WATER PUMP

Boiler feedwater pumps which act as the delivery system to the boiler, provide water under pressure to the boiler. They act by taking suction from a deaerating feedwater heater and pumping the feedwater into the boilers through high pressure feedwater heaters. To provide sufficient net positive suction head (NPSH) for the boiler feedwater pump, a booster pump is installed before feedwater pump.

In order to control feedwater volume an electric motor running at a constant speed, is coupled with a variable speed hydraulic coupling drive. The hydraulic coupling has two rotating case, provided with circulation oil includes system for coupling. When scoop is opened, the oil flow is maximum, rotational speed of primary rotor case and secondary rotor case are equal, and pump rotates at high speed. With closing of scoop, the amounts of oil flow between two case of hydraulic change and rotational speed of feedwater pump is controlled. Arrangement of them is shown in figure 2.
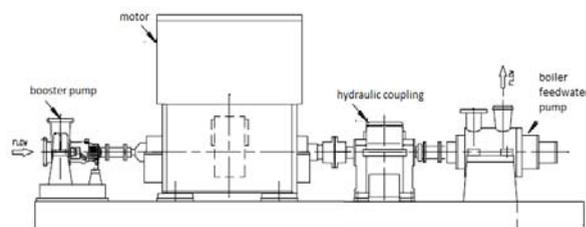

Fig. 2   Set of boiler feedwater pump

Each feedwater pump has segmental ring and could radials split. Each 320 MW unite includes three sets of feedwater pumps, one of them is always in standby. However, if any working pump receives alarm, it automatically shuts down with alert alarm and the standby pump starts. This also allows pump deactivation to perform normal maintenance, such as replacing the bearing seals, packing or repairing the electric motor driving the pump. Operation of feedwater pumps at reduced flow may lead to very undesirable results such as maximum stresses. Therefore a recirculation valve sets in output of feed pump. If water flow drops below 165 ton/hour, the recirculation valve is opened to recycle water between deaerator and pump and when flow increases above 320 ton/hour, it is closed.

4   CIRCUMSTANCES LEADING TO FAILURE

In summer of 2010 a feedwater pump failed during the starting stage. The pump was shut down immediately and subsequent inspections revealed that pump shaft has failed (during failure, contact of pump shaft with other parts of coupling, i.e. between pump and hydraulic coupling). The pumped was disassembled and transferred to workshop for detecting the reasons of failure.

5   VISUAL EXAMINATION OF GENERAL PHYSICAL FEATURE AND CONJECTURES

The failed shaft location is shown in Fig. 3. The damaged areas were located in the left side of shaft near the hydraulic coupling. Unfortunately, because of shaft contact with other parts of coupling during failure, the primary surface of failure was destroyed and physical features of failure surface were not observable.

Fig. 3   Shaft failure location of feedwater pump

In general, pump shafts should never break. They are normally designed such that the stresses are below the endurance limit, resulting in infinite life. However, the endurance limit may drop even below 50% due to induced stresses and corrosive effects of fluid. Some causes of induced stress which has lead to ultimate strength failure are considered to be:

1.   Presence of a foreign object inside the pump housing
2.   Excessive corrosive effect of fluid
3.   Operation at low flow rates which causes excessive pressure on the shaft
4.   Running with high vibration / transients / excessive starts

After the pump was disasembled, all the components were inuesfigated, and no foreign object was abserved inside the pump. Therefor, working conditions of pump was simulated in order to further study the cause of shaft failure.

6   ANALYSIS PROCEDURE AND RESULTS

Finite Element method was used to analysis the fracture cause of feedwater pump shaft. First, shaft was modeled three dimensionally and different working conditions were imposed on the shaft. Next, due to long life of feedwater pump, sever working condition of pump, and corrosive water surrounding the shaft, fatigue analysis was proposed.

6.1. Modeling

The working condition of pump was simulated using Abaqus software which was finite element method for analysis. The shaft was three dimensionally modeled and meshed using triangular elements. Next, the working condition data such as boundary condition, material property, rotational speed and fluid pressure was introduced to Abaqus. Shaft material property is presented in table 1.

**Table 1**   Material properties of feedwater pump shaft

ρ (Kg/m^3)	v	E(Gpa)	Average of tensile strength
7850	0.3	210	1275

In accordance with feedwater pump chart, rotational speed of pump changes between 1400 rpm to 6912 rpm where an increase in rotational speed leads to increase in water pressure. The simulation was executed at two different speed of 4000 rpm and 5000 rpm, the results are shown in table 2, and Figure 4, which confirms that high speeds leads to high stresses.

Moreover, according to the feedwater pump chart, the worst working condition of pump happens at high rotational speed with minimum water flow where the pressure receives to 240 bars. This operating condition is applied to the shaft model which results in the maximum stress of 72.67 MPa as shown in Figure 5.

Table 2   Maximum stresses according to simulation analysis

Rotational Speed (RPM)	Pressure (bar)	Maximum Stress (MPa)
4000	110	30.29
5000	150	41.31
6912	240	72.67
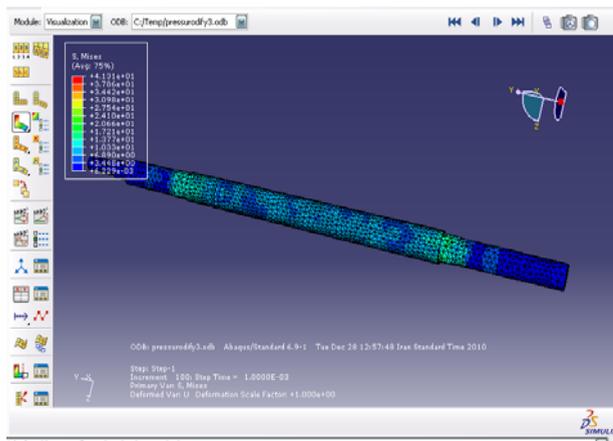
Fig. 4   Stress analysis at 5000 rpm and 150 bar pressure
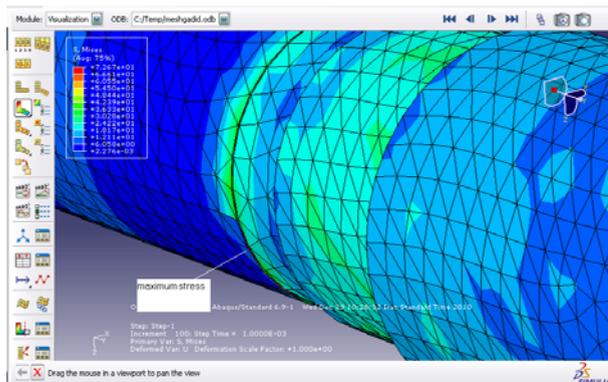
Fig. 5   Stresses analysis at worst working condition

6.2. Fatigue

In dynamic working conditions, machine parts may fail even at stresses below the ultimate strength or yielding strength of material. The characteristic of this sort of part failure is that the stresses are repeated many times, which is so called fatigue failure.

Fatigue failure starts with a micro crack, where the crack is so small that is not visible with normal eyes.

Crack is extended from a point of discontinuity (such as change in cross-section, or a hole) on the part. When the crack is created, the effect of stress concentration is increased; hence the original micro crack is extended. While the cross-sectional area under stress is decreased, stress gets increased until the failure happens at the remaining cross section.

In general, all materials have an endurance limit, where any applied stresses below this limit, wouldn't cause the fatigue failure to happen, regardless of the number of revolution. The endurance limit relation is shown in equation (1) [4].

$$s'_e = \begin{Bmatrix} 0.504\,s_{ut}\,,s_{ut}\ \le 1400\,Mpa \\ 700\,Mpa\,,s_{ut}\ \ge 1400\,Mpa \end{Bmatrix} \qquad (1)$$

However, during actual working conditions, some factors may affect endurance limit which should be taken into consideration, as shown in equation (2). So, endurance limit of our purpose (feed pump shaft) is amended by some coefficients.

$$s_e = K_a K_b K_c K_d K_e s'_e \qquad (2)$$

For the feedwater pump's shaft the minimum ultimate strength is 1275 Mpa, therefore:

$$s'_e = 0.504(1275) = 642 \text{ Mpa} \qquad (3)$$

The related coefficient factors used for fatigue failure calculations of the feedwater pump are shown in table 3.

Table 3   Coefficients values [4]

	coefficient	description	value
K_a	Surface Polish		0.678
K_b	Size	For shaft with diameter size bigger than 51 mm	0.65
K_c	Load	For bending	1
K_d	Temperature	Shaft material is strength against temperature change	0.95
K_e	Other effects	Corrosion, Stress concentration, etc.	0.24

So the endurance limit for feedwater pump's shaft is defined as below.

$$s_e = (0.678)(0.65)(0.24)(0.95)(642) = 64.5\,Mpa \qquad (4)$$

Therefore, stresses more than 64.5 MPa could lead to fatigue fracture.

7   DISCUSSION

The results of simulation and fatigue analysis indicate that some factors may reduce the pump's shaft endurance limit. The water required for boiler feed purposes of steam generation should have a high quality standard, but in Bandar Abbas power plant there is considerable leakage of chlorine in water supply due to tube changing of condenser. Moreover, because of exhaustion life of power plant component, the amount of oxygen in water supply is more than standard. Oxygen and chlorine have corrosive effects on pump's shaft performance in long term.

The set of feedwater pump is relatively old. Therefore pump shut down and start for deactivation, to perform maintenance (such as replacing the bearing seals and packing) are excessive. Additionally, use of hydraulic coupling for changing of speed, also causes some vibration.

Therefore, under the above working condition and according to fatigue analysis, stresses more than 64.5 MPa can restrict shaft endurance limit. The Finite Element analysis of pump has shown that maximum stress in worst working condition of pump is 72.67 MPa, which is more than its endurance limit. So, inspection of pump outlet is done to investigate whether the pump is exposed to the maximum stresses or not?

Based on this inspection it was indicated that the recirculation valve which is located at the pump outlet, was broken. In fact, the recirculation valve prevents pump to be exposed to the low flow rate. Therefore, right at the beginning, pump would experience the worst working condition! Hence, in feed pump 3 due to the failure of the recirculation valve, maximum stresses would be exerted to the pump and due to the fact that the pump was aged and the fact that shaft was continuously being surrounded by corrosive water, the endurance limit of the pump would be less than the maximum exerted stresses, hence leading to the shaft failure.

8   CONCLUSION AND RECOMMENDATION

Following working condition simulation of feedwater pump, it was revealed that recirculation valve is broken and leading the pump to the worst working condition. Therefore different factors such as high stresses exerted on the shaft, presence of corrosive elements like chlorine and oxygen in fluid, vibration and fatigue nature of application, are among the critical causes of the pump failure. However, due to the fact that feedwater pump is one of most important elements of the power plant, hence in order to improve its performance, some recommendations are described as following:

1. As for long life of feedwater pump, regular inspection of recirculation valve is necessary in order to prevent the pump being exposed to the worst working condition.
2. Non-destructive testing for investigating the presence of micro-cracks during pump overhaul.
3. Frequent number of shutting down and starting of the pump, necessitates a smooth and soft starting procedure. Surge current at startup of pump leads to high stresses on the pump shaft. Soft starter would limit the motor current to the right amount required and causes a smooth increase of starting current, therefore prevents imposing shock to the pump, and also prevents the development of mechanical stresses at starting of pump. The soft starter would also reduce turbulent of fluid at starting of pump and prevents cavitation phenomena. Soft starter also prevents water hammer at the time of pump shut down [5].
4. The rotational speed of feedwater pump must alternate based on the working conditions such as loading condition and boiler pressure. Change of rotational speed is a function of hydraulic coupling, and due to the fact that all mechanical devices such as hydraulic coupling cause vibration on pump, hence the use of electrical devices like inverter is strongly recommended. By applying inverter which enables direct change of rotational speed of electromotor, thus hydraulic coupling could be avoided. Moreover, some special dedicated inverters are not only able to control rotational speed of parallel pumps but to ensure the desired water pressure of the boiler as well [6]. Therefore, use of soft starter for starting electromotor, and inverter for changing rotational speed, would lead to boost in energy saving, while assuring the safe starting condition of pump and changing its speed.

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