Failure Analysis of High-Pressure Turbine Control Valve and Its Remedial Measures in 210MW Leningrad Metal Works Turbine

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Abstract -- Turbine are defined as the hydraulic machines which convert fluid energy (i.e., gases and liquids) into mechanical energy. This mechanical energy is used in running an electric generator which is directly coupled to the shaft of the turbine. Thus, the mechanical energy is converted into electrical energy. Steam is the gaseous from of liquids (normally water). This steam is at high pressure is used to produce power plants. The steam so used will have high pressure and temperature, which may affect the other components (control valve, turbine blade etc.,) of the turbine, in turn affects the power generation. Our project aims at analyzing and control the defects caused in the control valves. Control valves are valves used to conditions such as flow, pressure, temperature, and liquid level by fully or partially opening or closing in response to signals received from controllers. Failure in control valve arises mostly due to heavy load, throttling movement of the steam, breaking in the stem and cone joint, bearing wear and washer wear. We have planned to rectify the above defects by analyzing the control valve no.2 in Tuticorin thermal power station- tuticorin.

I. INTRODUCTION

Boiler

Boiler has two components namely, boiler drum and furnace. The coal from the mill is sent into the boiler by primary air fan through fine holes at four corners of the furnace to create a fire ball. The temperature of main steam inside the boiler should be around 540 degree Celsius to obtain the full power generation of 210 MW. In the boiler drum, steam separator is used to filter the fine steam to saturated steam. Forced draught fan, induced draught fan, Reheater and Air preheater are some of the components work along with the boiler for full power generation. [I], [IV]

Water Handling System

The water required for the power generation is 5 million gallons per day is supplied by TWAD board. TWAD receives water from Manjalneerkayal of the Thamirabharaniriver. Three grades of water is used in power station. Demineralized (DM) water is used for the boiler and stator cooling. The second one is filter water used for the auxiliary cooling system. Third is the service water used for the various purposes like seal water, coal wetting, dust suppression etc. [I], [IV]

Cooling Water System:

Sea water is drawn by means of gravity to the pump house by two channels. Sea water is pumped through concrete pressure channels to the condenser and the hot water will pass through another set of concrete tunnels and flow into the sea through the sea well and outfall arrangement. Each CW pump is provided with a travelling water screen at inlet to prevent entry of foreign matters. Chlorine dozing at inlet to the pumps is carried out regularly and the concentration is monitored at outlet. To prevent the corrosion of the condenser tubes ferrous sulphate dozing is given at the inlet of the condenser. [I],

Turbine:

Steam is supplied to the turbine through the two automatic stop valves placed at the front end of the H.P cylinder. From the stop valves, steam flows to four regulating valves. The exhaust from the H.P cylinder is taken to the reheater for reheating up to 5400 degree Celsius. The reheated steam flow to the intermediate pressure turbine through two interceptor valves. From the exhaust of the I.P turbine, steam is let into the L.P turbine through two cross pipes. The steam flow is divided into two streams flowing in opposite direction and let into condensers. The steam is condensed into two separate condensers, cooled by sea water. A main oil pump is coupled to the turbine shaft and located at the front supplies oil for the lubrication and cooling as the turbine is running at 3000 rpm. [I], [IV]

Generator:

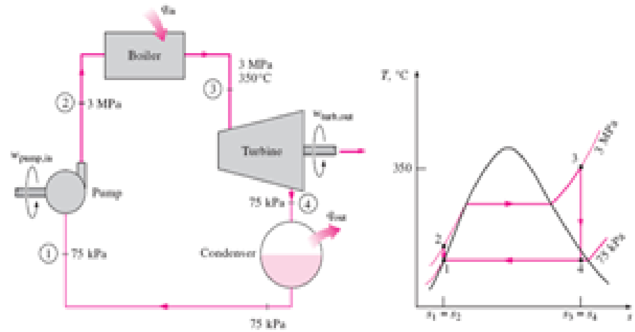
The generator stator has a three-phase double layer, short pitched and bar windings having two parallel paths. Each bar consists of solid as well as hollow conductors. The hollow conductors are cooled by DM water on the circulation and the stator winding and the rotor winding are cooled by the hydrogen gas with the purity more than 97%. The rotor shaft is supported by pedestal type bearings. The slip rings, supplying D.C excitation supply to the rotor winding through the semi flexible copper leads and current bolt placed radially in the shaft. [I]

210 Mw Lmw Turbine Layout:

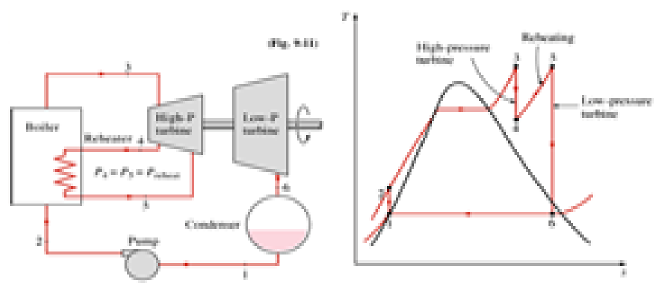
The PS5010: 210MW Power Plant consists of a comprehensive Model of a fossil fired (coal, oil, gas) power plant. The power plant can be operated in the full dynamic range, including startup from cold condition, load maneuvering, and shutdown. The fully integrated simulator includes an Instructor Console, and operator Stations. The Operator display software can be selected from a list of DCS emulations. The description of the power plant and the training features are as below. [II]

II. MODIFIED RANKINE CYCLE

The efficiency of the simple rankine cycle can be improved by increasing the pressure temperature of the steam enter into the turbine and keeping the steam as dry as possible at the end of turbine. In reheat cycle the steam is extracted from a suitable point in the turbine and it is reheating with the help of flue gas in the boiler furnace. In reheat Rankine cycle the expansion is being carried out in two stages. The steam is initially expanded in high pressure turbine (H.P) to some pressure and then it is reheated with the help of flue gases in the boiler. Then, the steam is expanded in low pressure (L.P) turbine to the condenser presser The main purpose of modified rankine cycle is to increase the dryness fraction of the steam and increase the efficiency by 5% but the dryness fraction of steam coming out from the turbine should not follow 0.92. [I], [IV]



SIMPLE RANKINE CYCLE



MODIFIED RANKINE CYCLE

Process 1-2: Reversible adiabatic or isentropic pumping process in the feed pump

Process 2-3: Constant pressure or isobaric heat supplied in the boiler

Process 3-4: Isentropic expansion in high pressure turbine

Process 4-5: Steam is reheated at constant pressure

Process 5-6: Isentropic expansion in low pressure turbine

Process 6-1: Constant pressure or isobaric heat rejection in condenser

III. GOVERNING SYSTEM

Governing:

This chapter deals with the theoretical or basics of governing & protection mechanism of steam turbine in general but, to give salient feature and design aspects of governing & protection mechanism of 210 MW (MLMW make). Turbine manufacturing by M/s

BHEL, Haridwar. The subject can be conveniently divided into three sections, Normal Governing mechanism, Protection mechanism, Pre-emergency devices[IV]

Need for Governing:

Governing mechanism is intended to carry out the following functions:

To bring the turbine speed smoothly from barring gear to synchronizing speed, under the control of operator action.

Stable speed control in isolated operation of the set. The desired degree of load distribution between sets running in parallel. The governing system of 210 MW turbine is based on constant oil pressure principle. That is to say during stable operation of the unit, the sensitive oil pressure which positions the pilot valves is always same at any load. Only during the transient conditions of load/speed variations the sensitive oil pressure varies and returns to the original value as soon as the condition stabilizes. The turbine is provided with nozzle governing for controlling the steam flow through the turbine. There are four CVs on HPT and four CVs on IPT which open in a pre-arranged sequence. This brings down the throttling losses in the CVs, during partial load operation. A specific feature of 210 MW turbine is that a single servo motor operates all the control valve of HPT and IPT through a set of levers, racks, pinions and camshafts. The cams are so shaped to give the required sequence operation of CVs. [II]

Governing Methods:

To control load, the turbine can be either nozzle controlled, or throttle controlled. In both the cases operating at pressure or variable pressure or a combination of two. (i.e. in constant pressure mode over a certain load range and variable pressure mode over remaining load range). In nozzle-controlled turbines, steam flow is controlled by sequential opening or closing of the control valve (at least 4 for effective sequential opening) allowing steam to flow to associated nozzle groups. In throttle-controlled turbines, steam to flow is controlled by pressure of steam by the control valves (either 2 or 4) to the extent required by load.

In a constant pressure mode, the pressure upstream of control valve is kept constant at all the loads, while in variable (sliding) pressure mode the control valves remain fully open and pressure upstream of control valves varies proportionally with the load over a definite load range. As the turbine generator sets operating in frequency control must be continuously throttled by a limited amount so as to obtain necessary instant reserve output because steam generator cannot supply necessary pressure changes so quickly.

Three combinations:

- Variable pressure with throttle control,
- Constant pressure with nozzle control and
- Constant pressure with throttle control, are commonly used.

Elements in Governing Mechanism:

The following elements are involved in the normal governing mechanism,

- Speed governor
- Follow-up pilot valve
- Speeder gear
- Speed/load control pilot valve
- Summation pilot valve
- Intermediate pilot valve
- Servomotor pilot valve
- Servomotor
- Feedback pilot valve
- Control valves

Role of Control Valves In Governing System:

There are 4 Nos. CVs for HPT and 4 Nos.CVs for IPT. All the control valves are operated by a single servomotor as explained earlier. As throttle governing is adopted for 210 MW turbine, the CVs open in a pre-arranged sequence. This is achieved by suitably shaping the individual’s cams, which operate the corresponding CVs. [IV]

Integrated Operation of Normal Governing Elements:

When there is a drop in the frequency or the speeder gear is operated the following sequence of operation occurs. The Governor sleeve moves towards left as the tension spring pulls the governor flyweight nearer. This makes the follow-up pilot valve also to move towards left and the summation pilot valve reduces the draining oil from the primary sensitive oil line and differentiator oil line. The speeder gear move the load/speed control valve PV towards right. The lever moves the summation PV to left, as in the above case, since the point where the follow-up PV is connected to the lever acts fulcrum. This also causes the same effects as above, i.e. reduces the draining of oil. Reduction in the drain causes the primary sensitive oil pressure to increase. The intermediate PV moves up which reduces the admission of oil into primary sensitive oil line. [I]Hence, intermediate PV settles down at a new higher position where the reduction in the drain. The new position of intermediate PV in turn reduces the drain in the secondary sensitive oil line which makes the pressure to increases. The increased pressure makes the servomotor PV to move up causing draining of oil from the top and admission of more oil to the bottom of servomotor piston. The servomotor moves up opening the control valves causing increased steam flow through the turbine. The machine picks up more load.When the servomotor piston moves up, the feedback lever makes the feedback PV to move down restricting the supply of oil into secondary oil line. Hence the CVs continue to open till such time the reduction in the supply of secondary sensitive oil is matched with the reduction in the drain at intermediate PV so that the pressure is restored to 10.3 atm. And the servomotor PV occupies the on-part position. Thus it can be seen that a definite movement of the speeder gear in ‘load increase’ direction or fall in frequency by a definite amount cause the CVs to open by a specific amount. Speaker gear movement ‘load increase’ direction or increase in frequency causes the reserve effect and the CVs close by a definite amount. [II]

Governing System Operation:

Bring speeder gear hand wheel to ‘Zero’ position of its scale. Check the servomotor for ESV’s, IV’s and control valves are in completely closed position. Set the load limiter to ‘Zero’ position of its scale. Bring in service the A.C Lube oil pump for charging the Lube oil line and governing oil line as per usual procedure. Switch ‘ON’ the Starting Oil Pump (SOP) with its discharge valve in closed condition and raise the oil pressure of Governing system to 20 atg. By slowly opening the discharge valve on delivery line of SOP and then open it fully. Switch ‘OFF’ the A.C LOP and check that injectors maintain lube oil pressure at 3 atg before oil coolers. Check that MSV’s and its by-pass valves at Turbine end are closed completely and tightly. Turn the Speeder Gear hand wheel in anti-clockwise direction and check that following events occur. Turn the hand wheel of load limiter in clock wise direction until it close the control valve completely. [I]Main oil pump (MOP) would take over automatically. Switch ‘OFF’ SOP and put it as standby with its discharge valve in opened condition. Run of turbine from cold state The Turbine start-up procedure recommends full are admission of steam in case of cold start up. This can be achieved by turning the Speeder Gear in anti-clockwise direction until the servomotor of the control valves move up to the reading 290mm on the scale. The steam is admitted by slowly opening the by-pass valves of MSV’s. As the speed would pick-up, the governing system would tend to close the servomotor. This should be counter acted by actuating the speeder gear in anti-clockwise direction. [II]

Governing Characteristics When Turbine Is At No Load:

Bring the turbine to 3000 rpm by admitting steam through the by-pass valves of main steam valves and keeping control valve of turbine open.Set the load limited at ‘ZERO’ position. Turn the speeder gear in clockwise direction to such an extent that turbine speed begins to fall. Slowly close the by-pass valve of MSV’s. This would result in reduction of steam pressure before turbine. The governing system would now open the control valves, to maintain the speed within the static regulation limits. Keep on closing the by-pass valves until the control valves have opened fully.

For various positions of speeder gear take reading on the position of control valves servomotor, travel of the follow pilot valve and the speed of the set accurately. Draw the speed s control valves servomotor position characteristics and compare the same with the characteristics supplied with the turbine. Repeat the test by opening the by-pass valves of MSV. [I]

IV. WHEN TURBINE IS ON LOAD

This can be done only when the turbine has been connected to the grid and has taken the full load at rated parameters. The procedure for conducting the test is as follow:

Reduce the load in steps of 20MW and maintain the rated parameters before MSV and after reheater. Maintain vacuum at rated value corresponding to load and cooling water temperature. For each new condition of the load, the take the reading of the servo motor. Plot characteristics between load and position of control valve servo motor. Using the speed vs servomotor characteristics obtained during no load test, plot the characteristics between speed and load change. [III]

V. CONTROL VALVES

The inlet valves are located just before the turbine inlet, see Figure 1.3. The main purpose for the inlet valves is to regulate the steam flow through the turbine and adjust the power output from the power plant. The valves also have another important feature; if the power plant in case of an emergency needs to be shut down the valves can cut off the entire steam flow in fractions of a second. The control valves have two important tasks. The first and most obvious purpose with the valves is to adjust the steam flow. The second purpose is to enable steam cut off in case of an emergency. [V]

Valve Design

The valve used today at Siemens, shown in Figure is a poppet valve mounted directly to the turbine inlet. High pressure steam enters the valve from the left and exits downwards into the turbine. The amount of steam flowing through the turbine is depending on how much the cone is raised from the seat and the diameter of the throat. The cone is lifted (making the valve open) with a hydraulic servo that is attached to the cone with the stem. Around the stem there is a graphite packing preventing the steam from leaking out from the valve towards the servo. The graphite packing is compressed by the pressure applied from the gland. Finally, there is a strong set of cup springs used for closing the valve for regulating purpose as well as emergency shut off. The cover holds all the components in place within the case. [V]

Valve Movements:

The steam pressure induces large forces to the cone in both axial and radial direction. These forces vary in size and direction depending on the position of the cone and on the pressure drop over the valve. When the valve is fully closed, the resulting steam pressure force is acting in the closing direction since p1 is much larger than p2. When the valve is about to open, the steam pressure forces are still behaving the same but now there is also large flow forces acting in the closing direction. In this position, the largest force in the stem's axial direction appears and therefore determines the demand for the servo power. When the valve is fully open, p1 and p2 are about the same and the resulting steam pressure force is acting at the cone in the opening direction. The flow forces may be neglected in this position. [V]

Safety Requirements:

In order to obtain required safety two valves must be mounted in series, the first is an ESV (Emergency Stop Valve) with the only purpose to be able to cut off the steam flow in case of an emergency. The ESV is usually fully open and therefore designed for minimum pressure loss. The second valve is a CV (Control Valve) used for regulating the steam flow and also this one is able to cut off the steam flow quickly. Both emergencies stop devices are so called fail-safe which means that they will close also without any help from surrounding systems, such as electric and hydraulic systems. [VI]

Control Valves in Steam Turbine:

There are eight control valves are used in steam turbine. They are, Four valves are used for High pressure turbine. Four valves are used for Intermediate pressure turbine. [III]

High Pressure Turbine Valves:

In High pressure turbine had a four valves and there locations are, Two valves are located on the top of the turbine (VALVE NO 1&2)Two valves are located on the right and left side of the turbine (VALVE NO 3&4)

Failures of Control Valves and Its Remedial Measures Failures of Control Valve 2

Initial control valve design had been the cause of concern as some of failure of strainer and valve stem of this control valve due to high lifting (40mm) of control valve. To overcome the above problems in HP Control Valve (CV) no.2, a new design of the control valve (skirt type) was developed Features of new control valve no.2 (skirt type) [VI]

Control valve no2 design envisages a stronger and reliable control valve which has totally dispensed the use of strainer in it. The direct impact of the steam on valve and its stem has been obviated by providing skirt all around the valve.The basic level of the stresses measured on this valve during operation were found to be much less as compared to old design In order to further reduce the stress level, following features have been incorporated in this new type of the control valve:

- Increased valve stem diameter.
- Increased thread size.
- Increased fillet radius.
- Use of better material design.

Reduction in clearance between valve nut and the liner.

The grooves have been transferred to liner from the stem.

Work involved for modification Supply of complete control valve assembly of new design, as per drawing from the plant, against order from the customer. The fitting and the machining work of the new valve cover with chest. [III]Co-axiality checking and planning of the steam chest cover with stem chest. Proper checking and assembly of valve in position It is suggest that commercial order for the supply of HP control valve no.2 be placed so that it is made available at site. Its installation can be planned in any suitable shut down.

Stem Failure in Control Valves:

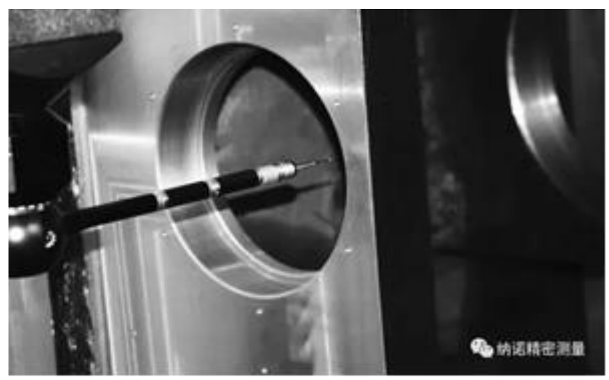
In general stem failure occurs in control valve no 1,2,3& 4. The Following reason for stem failure as listed below

Absence of Co-Axiality Testing Co-Axiality

Coaxiality is the tolerance for how closely the axis of one cylinder is to another. Examples are a shaft having two diameters, or perhaps two bores located on opposite sides of a housing. In either case, the center of one element is expected to be along the same axis as the second element.

Co-Axiality Testing

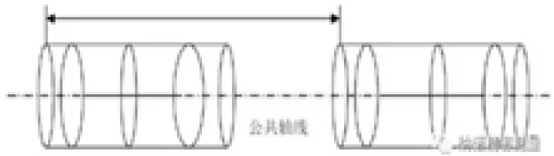
Coaxiality is a common kind of tolerance in mechanical product testing. It is indicated that the axis and axis of the part, hole and hole, the axis and the hole, it can also be understood as: control the deviation degree of the actual axis and the reference axis. In measurement, coaxiality is often encountered in the measurement, the commonly used measuring equipment mainly is 3D coordinate measuring machine (CMM), CMM is recognized as precision testing equipment with better form error. [V]



The method of measuring the Coaxiality by using coordinate measuring machine are the common axis-line method, the straightness method and the distance method, the common axis method is the most widely used method.

1. Common axis-line method

Measuring multiple circular cross section on the measured element and reference elements, then insert the round circle constructing a 3D line, as a common axis, the diameter of each circle can be inconsistent, and then calculate the benchmark measured cylindrical columns and the common axis of coaxiality, take the maximum as the coaxiality of the parts. This common axis is similar to a simulated mandrel, so the measurement of the common axis-line method is the closest to the actual assembly process of the parts. [VII]



2. Straightness method

The circle of multiple cross sections is measured on the elements and reference elements, and then selects these elements to construct a 3D straight line. The coaxiality is approximately twice as the degree of straightness. The collected circles are best whole-circle measured, and if they are measured in a sector, the error calculated by measurement software can be large.

3. Distance method

The coaxiality is twice as the maximum distance between the measured element and the base element axis. When the maximum distance between the measured element and the reference element is calculated, multiply it by 2. The distance method is calculated by projecting maximum distance onto a plane at, so this plane is better perpendicular to the axis used as the benchmark. The condition is more suitable for measuring concentricity. [VII]

Process In Co-Axiality testing

The initial step is establishing a measurable datum axis. Following this, a series of cross-sections must be measured. The next step is to obtain the exact plot of the surface and determine the cross section's median points. To see whether or not they fall into the cylindrical tolerances zone, the points must be plotted. A computer measurement device such as a CMM is the only way that this can be done. And it takes a lot of time. By now, surely, you realize the complex nature of concentricity. It is for this reason that it is reserved for parts which, in order to function properly, need a high degree of precision. One example would be transmission gears. To ensure that all the axes line up correctly, and to avoid oscillations and wear, they always need to be coaxial. [VII]

Remedial Measures:

To avoid the failure of stem during operation proper co-axiality testing should be carry out with proper equipment and geometry dimensions. [VIII]

Low Load Operation:

Generation of power is not constant for any time because we can't save produced power from the power plant due to this power can be generated as per the requirement. Maximum power generation is only at the peak time (hours) at that time consumption of current is very high so maximum power can be generated but other times power generation may vary as per the requirement. Power generation is minimum, TTPS generates the power 160-180 MW instead of 210MW.While the generation of power will be reduced from 210MW to 160MW due to LDC request, the steam flow has been reduced, due to this the HP turbine control valve no 4 is goes to closed condition and the control valves no 3 in partial open condition (i.e 5mm to 7mm instead of 27mm of full open). [VII]

a) Control valve 1 remains open at its full lift (i.e 24 mm of lift).

b) Control valve 2 remains open at its full lift (i.e 40 mm of lift).

c) Control valve 3 remains partial open(5mm to 7mm).

In this minimum opening of control valve no 3, any minor fluctuation of steam flow or load the valve have been continuous close and open is occur on this position. Due to this condition move stress will act on the valve and steam, in this condition the valve steam may be failure at thread portion or bottom of the steam. The 210 MW LMW design TG set will be run with full load condition. Then only the failure of control valves can be avoided. [VIII]

Load Hunting:

Due to the load hunting, control valves 3 & 4 undergo some problem due the fluctuation of loads in the turbine. It causes the action of stress in the control valves 3 &4 due to this stresses control valves failure occur Most of the cases braking of control valve failure occur due the load hunting braking of control valve at the top or bottom of the stem. [VIII]

Remedial Measures:

1. 1.The turbine operating parameters were maintained at the design valve.
2. 2.The load hunting was occurred due to the steam flow variation (or) pressure variation of flow variation at the turbine. [VIII]

Failure of Steam Chest Liner:

In absence of co axiality testing in control valves linear movement of stem of control valve may vary from its center of axis due to this, stem surface are friction with the inner side of the chest liner. It causes the change of geometry of the liner inner surface and change the clearance dimension between the stem and liner.

Removal of Damaged Liner Already Fitted In The Valve Cover

1. Remove caulking by grinding.
2. Heat by gas torch the body of the valve cover (at the zone of shrink fitting)/outside. The liner should be pressed down with the help of hydraulic press or by any other suitable method.

Fitting of New Liner

a. New liner bore size is to be measured and it should be 45+.05mm.
b. After removal of the old liner, bore of the cover to be cleaned properly to remove burr and scales etc.,
c. Size of the bore of valve cover is to be measured with the help of bore dial gauge at sections for ϕ 88, ϕ90, ϕ110,
d. Spare liner is supplied with 2mm allowance on its fitting diameter ϕ 88, ϕ90, ϕ110,
e. 5) The spare liner is to be machined at fitting diameters for achieving diametrical interference of .02 to .05mm at the valve cover and ϕ90, ϕ88
f. 6) Machining of ϕ 110is to be done to achieve a diametrical clearance of .2 to .6 mm. A chamfer of 5*1mm is to be provided in the liner at the beginning of stepsϕ88,ϕ90 and a chamfer at 2*45degree at the beginning of step ϕ110 for easy inserting in the cover.
g. 7) Clamping device as shown in the enclosed sketch is to be made at site. This device is to be fitted in the liner for its lifting and inserting into the valve cover.
h. 8) Valve cover is to be heated by gas torch and liner (fitted with clamp) is to be cooled in solid ice or liquid nitrogen. In case liquid N2 or O2 is used for shrinking the liner, heating of the cover is not required. By measurement of diameters during shrinking process, diametrical clearance of at least .2 mm may be ensured.
i. 9) Note down the depth of collar of ϕ 110 in the cover and liner. Comparison of the same after shrink fitting of liner will indicate if the liner has been inserted fully.
j. 10) Insert the liner into the valve cover and ensure its proper fitting in the cover by hammering. [VIII]

Remedial Measures

a. Replacement of old liner by new one and proper checking of stem can be used to avoid failure of valve chest liner.
b. Proper co axialiity checking also used to avoid the failure of valve chest liner which is fitted on the steam turbine control valve.
c. Maintain diametrical clearance between stem and liner inside the control valve. [VIII]

Failure of Bolt In Control Valve Head:

Proper clearance should be provided with bolt and bush which is provided on the head of the control valve. The clearance between the bush and bolt is 0.05mm only if Clarence should be increased or decreased it will lead to breaking of stem or bold head.

Remedial Measures

Clearance between the control valve bolt should be maintained at 0.05mm only.

Control Valve Seat Damaged

In the absence of co-axiality checking bottom of the control valve is damaged. When the axis of the control valve chest and bottom of the valve are to in the same axis. If the axis are not in the same line of axis stem cannot be seated in its position hence the erosion of material from the bottom portion of control valve gets damaged. [VIII]

Remedial Measure

Proper inspection and testing of co-axiality is to avoid the damage of control valve.

VI. CONCLUSION

The conclusion of our analysis of control valve failures in LMW Turbine is that to suggest the remedial measures for the failures in the control valves of the turbine. The overall layout of the thermal power station and its working are studied from this project. Thus the control valve failures are reduced by the above explained remedial measures. By implementing the new technologies and ideas the losses are completely averted.

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