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ADMISSION OF BYPASS STEAM INTO A WATER COOLED CONDENSER AND AIR COOLED CONDENSER. SIMILARITIES, DIFFERENCES AND AREAS OF CONCERN

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ABSTRACT

In power plant locations with adequate supply of cooling water the steam from the steam turbine is condensed in a water cooled condenser. In most instances circulating water from the cooling tower is used to condense the turbine exhaust steam. In other instances once through cooling is deployed wherein water from a lake, river or sea is used to condense the turbine exhaust steam. In water challenged locations or locations where wet cooling cannot be deployed due to permitting or regulatory issues, the steam from the steam turbine is condensed in an air cooled condenser (ACC) wherein ambient air is used to cool and condense the turbine exhaust steam. In a combined cycle plant, during normal operation, the water or air cooled condenser condenses the turbine exhaust steam. During bypass operation, when the steam turbine is out of service, the high-pressure steam from the HRSG is attemperated in a pressure reducing/desuperheating (PRD) valve and then admitted into the water cooled or air cooled condenser. The bypass steam flow is substantially higher than the design turbine exhaust steam flow and the duration of bypass operation can vary from a few hours to several weeks.

The requirements for admission of bypass steam into a water cooled condenser are substantially different from that for an air cooled condenser. In a water cooled condenser the bypass steam is admitted in the steam dome. The bypass steam as well as the turbine exhaust steam is condensed outside the tubes. In an air cooled condenser the bypass steam is admitted in the large diameter steam duct. The bypass, as well as the turbine exhaust steam (normal operation), is condensed inside the tubes. There are similarities and differences in the requirements for admission of bypass steam into a water cooled and air cooled condenser. The differences must be identified and addressed to ensure safe and reliable performance of the condenser.

INTRODUCTION

In the past decade hundreds of combined cycle plants have been commissioned worldwide. In a combined cycle plant, the steam surface condenser must condense the turbine exhaust steam (normal operation) as well as the bypass steam (steam turbine bypass operation). When the steam turbine is out of service the HP and LP steam from the HRSG is attemperated in a Pressure Reducing Desuperheating (PRD) valve and then admitted into the condenser. HP & LP steam from each HRSG is attemperated in a PRD valve and then admitted to the condenser through a HP & LP bypass header. In applications with multiple HRSGs the LP steam lines are sometimes combined, attemperated in a PRD valve and then admitted to the condenser through a LP bypass header. In certain low-pressure bypass application, the PRD valve is altogether eliminated and bypass steam at relatively high temperature is admitted into the condenser.

Downstream of the PRD valve the total bypass steam flow can be as high as 150%-200% of the design turbine exhaust flow, the pressure anywhere between 25 psig-250 psig, the enthalpy anywhere between 1190 Btu/lb to 1225 Btu/lb and the duration of bypass operation can vary from a few hours to a few weeks. Elevated or low bypass steam temperature, moisture in the bypass steam can cause structural damage to condenser internals.

The method of admission of the bypass steam, the mode of bypass operation and possible mechanisms of failure are different for water cooled and air cooled condensers as described in the following section.

WATER COOLED CONDENSERS

In water cooled condensers, HP and LP bypass steam is introduced in the steam dome through bypass headers that extend along the length of the condenser. As shown in Figure 1, the bypass headers extend along the length of the tubes as much as possible so as to distribute the bypass steam evenly along the entire cross section of the tube bundle.

The bypass headers are equipped with the smallest permissible orifices, designed per the guidelines from EPRI, to minimize the damaging effects of the high velocity steam jet. The orifices in the bypass headers are pointed away from the turbine internals or the condenser tubes and oriented so as to avoid a direct line of sight between the orifice and the active tubes. Any structural members in close vicinity of the orifice are wrapped with stainless steel for impingement protection.

The bypass headers are supported at regular intervals along the length. Provisions are included to accommodate thermal expansion of the header during bypass operation. A drain connection is located at the end of the bypass header to drain the condensate collected in the header. Any condensate collected in the bypass header is drained. Improper drainage would lead to pockets of moisture in the bypass flow which could damage the tubes.

Improper mixing of spray water and the superheated steam in the PRD valve or in the line downstream of the PRD valve can cause structural damage to the water cooled condenser. Insufficient spray water in the PRD valve can lead to high bypass steam temperatures that can damage the condenser steam dome internals, turbine exhaust internals and the expansion joint between the condenser and the turbine. Excess spray water can lead to pockets of moisture in the bypass steam expanding from the orifices of the bypass headers. Steam, entrained with water droplets, travelling at high velocities can damage tubes. A number of combined cycle plants commissioned in 2001-2005 time frame suffered severe tube damage due to improper mixing of spray water in the PRD valve. However proper PRD valve temperature feedback control has played a major role in reducing damage in bypass operation.

The impact of increased temperature of bypass steam in the condenser is minimized by the use of a spray curtain. A spray curtain is located below the expansion joint and above the bypass headers. When the condenser is pressed into bypass operation the spray curtain is deployed. The spray curtain sprays a fine spray of condensate over the bypass header as shown in Figure 1. The condensate spray cools any high temperature bypass steam migrating towards the turbine exhaust to a lower temperature, typically 180°F. Stainless steel expansion joints are more resistant to fluctuations in temperature, but rubber expansion joints especially neoprene rubber expansion joints are vulnerable to higher temperatures. The spray curtain protects the turbine exhaust hood, rubber expansion joint, and the steam dome internals from excursions in bypass steam temperatures. The condensate spray also cools the bypass steam traveling towards the tubes. This cooling action minimizes the differential expansion between the shell and the tubes. The tube bundles are often equipped with two rows of 14 BWG or 16 BWG carbon steel dummy tubes that extend between the first and the last support tubes. These two rows of dummy tubes take the brunt of the damaging effects of the steam impingement during regular and bypass operation.

The amount of spray water added to the superheated steam in the PRD valve dictates the superheat in the steam. HEI standards recommend a superheat of 25°F - 75°F in the bypass steam. Condensers are prone to tube failures when the bypass steam has very low superheat or is wet. This problem worsens as the bypass header pressure or pressure downstream of the PRD valve increases. The maximum bypass header pressure recommended by HEI standards is 250 psig. At such high pressures, to avoid damage to condenser internals, a very tight control has to be enforced on the amount of superheat in the bypass steam.

The bypass steam flow is substantially higher than the regular turbine exhaust steam flow with a corresponding increase in heat duty. As a result, the condenser pressure in bypass operation is higher than that during normal steam turbine operation. During hot summer months with high circulating water inlet temperatures the condenser pressure in bypass operation can exceed the operational limit of the steam jet evacuation package. To avoid problems the first stage steam jet must be designed to operate under a wide range of condenser operating pressures. The pressure in bypass operation may exceed the trip setting of the steam turbine making it difficult to transition from bypass operation to normal turbine operation. Such design and operational issues must be evaluated and addressed during initial design phase of the project.

AIR COOLED CONDENSERS

In an ACC the bypass steam is admitted into the main steam duct. As shown in Figure 2, the bypass steam is introduced through a bypass sparger located within the steam duct. One of the most significant differences between a water cooled condenser and an ACC is the distance between the point of bypass steam admission and the heat transfer surface. Due to the close proximity afforded by the water cooled option and the relatively high mass of the water filled tubes, surface condensers can accept higher energy levels for bypass operation than an ACC can. To avoid running costly bypass piping, the location of the bypass connections on the main steam duct is typically in the vicinity of the steam turbine. This means that once the bypass steam is admitted into the main duct, this steam must travel the length of the main duct, the distribution manifolds, up the risers and through the upper distribution headers before contacting the heat transfer surface. These distances can be up to several hundred feet in some cases. Therefore, to avoid excessive thermal expansion provisions, the energy content of the bypass steam is generally limited to about 1170 Btu/lb.

A sparger of some form is typically utilized to accommodate the last pressure reduction as the steam enters the main duct. The spargers are either standard drilled hole spargers or lower noise stacked plate spargers. The size and location of these spargers are important considerations. Because the spargers penetrate the main duct, they can be obstacles for normal steam flow during turbine operation and cause excessive pressure drop. To mitigate this, the sparger may be placed within an expansion bell on the side of the steam duct. This will allow the sparger to be partially or completely withdrawn from the normal flow path of steam flowing from the turbine to the ACC. The concerns regarding safe distances for impingement that apply to water cooled condensers also apply to air cooled condensers. It is also important to avoid locating the bypass connections too close to expansion joints within the steam duct system. Vibrations resulting from bypass operation can cause high cycle fatigue failures of metallic expansion joints.

Because of the lower bypass energy requirements associated with air cooled condensers, the PRD valve may require more range than those for water cooled condensers. Typically, the maximum bypass header pressure (upstream of the sparger) is 50 psia. As this steam (50 psia & 1170 Btu/lb) expands through the sparger into the vacuum steam space of the ACC, the temperature will reduce to less than 250 ^{o}F. As the bypass steam condenses within the tubes, the ACC is immune from problems associated with tube damage.

The air cooled condenser is sensitive to excursions in temperatures. Insufficient addition of spray water in the PRD valve or improper mixing of spray water can cause high steam temperatures. Long lengths of steam ducts and risers can lead to excessive thermal expansion which can exceed the capabilities of the expansion joints or the thermal expansion provisions for ducting and finned tube bundles. The excessive thermal expansion can damage the supports and entire ACC itself. Bypass steam with excessive high temperature can damage the turbine internals and the expansion joint between the turbine and the condenser.

A spray curtain can be installed downstream of the expansion joint, located between the turbine exhaust and the condenser steam inlet, to protect the steam turbine from excessive temperatures during bypass operation. As stated earlier in the paper, when the bypass steam enters the steam duct a fine spray of condensate is sprayed towards the bypass header. Any bypass steam migrating towards the turbine exhaust is cooled by the condensate spray, typically to 180°F. The turbine internals and the expansion joint are protected from the harmful effects of the high temperature bypass steam.

Excessive spray water admitted in the PRD valve or condensate collected in the bypass header piping between the PRD valve and the ACC may drain into the ACC steam duct. This condensate drains into the main duct and is collected by the low point drain system.

As with the water cooled condenser, in an air cooled condenser the heat duty in bypass operation can be higher than that in normal operation resulting in a higher condenser pressure. Hot ambient temperature, air in leakage combined with high heat duty can result in relatively high condenser pressure that may exceed the trip setting of the steam turbine making it difficult to transition from bypass operation to normal turbine operation. Such design and operational issues must be evaluated and addressed during initial design phase of the project.

CONCLUSION

The requirements for admission of bypass steam into a water cooled condenser are substantially different from that for an air cooled condenser. The water cooled condenser is more prone to damage from excessive or low superheat and excessive moisture content in the bypass steam. An air cooled condenser is prone to excessive superheat in the bypass steam. The method of admission of bypass steam into the water cooled or air cooled condenser is significantly different. The requirements for bypass hardware and operation are different for a water cooled and an air cooled condenser. The similarities and differences must be carefully identified and addressed to ensure safe and reliable performance of the water cooled or the air cooled condenser.

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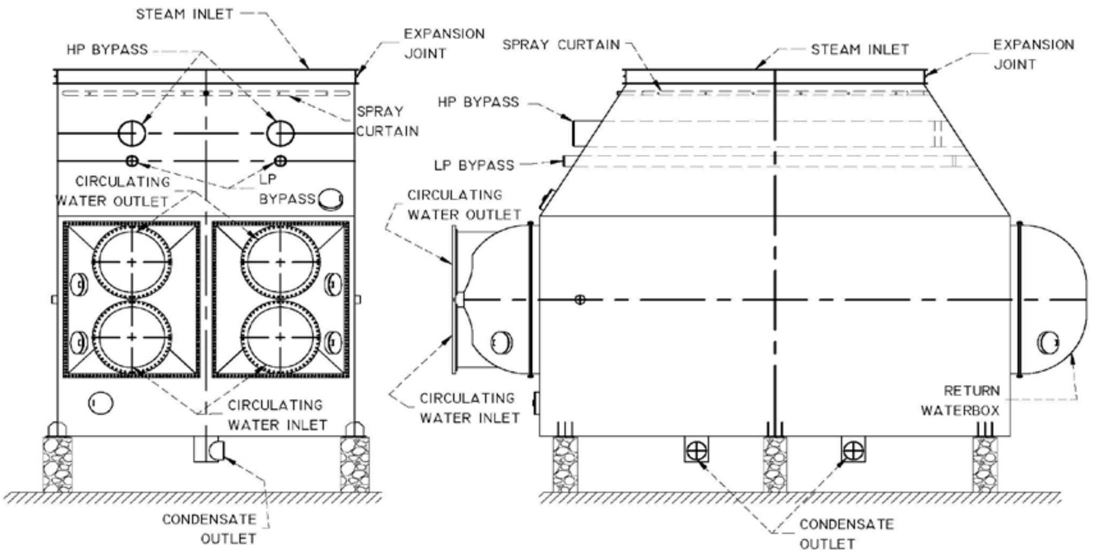

FIGURE 1: ADMISSION OF BYPASS STEAM INTO A WATER COOLED CONDENSER

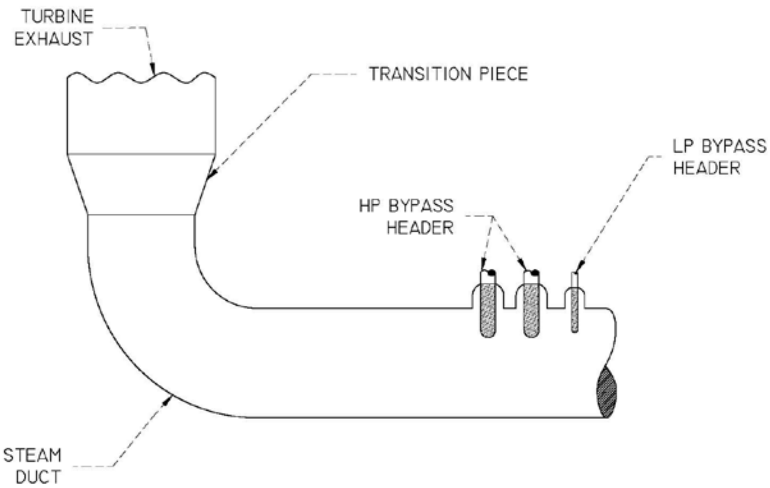

FIGURE 2: ADMISSION OF BYPASS STEAM INTO THE STEAM DUCT OF AN AIR COOLED CONDENSER

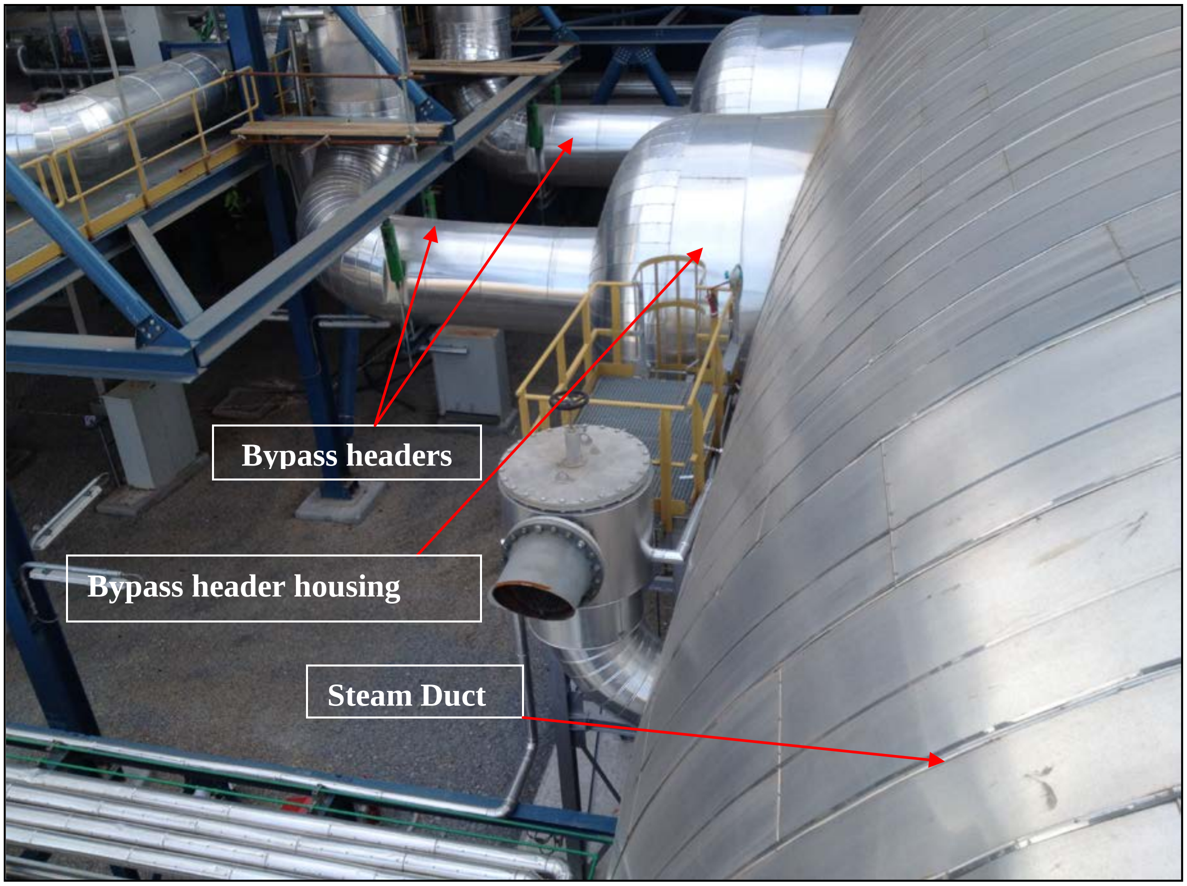

FIGURE 3: PHOTOGRAPH OF BYPASS HEADER EXTENDING INTO THE STEAM DUCT OF AN AIR COOLED CONDENSER