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System analysis of superheated and reheated heating surfaces of utility boilers

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Abstract

In recent years, with the continuous optimization of power energy structure in China, thermal power units are developing towards large capacity, and ultra supercritical units have gradually become the main units of power plants. Although the thermal efficiency of units has been greatly improved, at the same time, it also brings security risks to all levels of heating surfaces of boilers.At the same time, due to the boiler design and operation will cause a variety of thermal deviation,Some of the heating surfaces may cause overheating tube explosion, resulting in boiler shutdown for maintenance and affecting the power generation efficiency.This paper mainly introduces the superheater and reheater, analyzes their structural characteristics, summarizes the causes and influencing factors of thermal deviation, puts forward the regulation method of superheated steam temperature and reheated steam temperature, and gives suggestions for safe operation of power plant boilers.

Keywords

Superheater,Thermal deviation,Steam temperature regulation.

1. Introduction

Boilers rely on heating surfaces for heat transfer, which are heat exchange components.It includes evaporation heating surface, superheating heating surface, water and air preheating heating surface.The superheater and the reheater account for more than 50% of the total heat capacity of the boiler.

2. Overview of superheater and reheater

2.1. Function of superheater and reheater

Steam superheater is an important part of boiler. Its function is to heat saturated steam or micro superheated steam to qualified steam with a certain degree of superheat, and it is required to ensure that the superheated steam temperature changes within the allowable range when the boiler operates under variable working conditions.

Increasing the initial temperature and pressure of steam can improve the thermal efficiency of power plant cycle, but the further increase of initial temperature is limited by the thermal properties of metal materials, so alloy steel is used to further increase the initial temperature of steam.The further increase of initial pressure is limited by the exhaust temperature of steam turbine. In order to improve the cycle thermal efficiency and reduce the exhaust temperature, reheater can be used.The function of reheater is to heat the exhaust steam of high-pressure cylinder of steam turbine to be equal to or close to the superheated steam temperature, and then send it to the intermediate pressure cylinder and low-pressure cylinder of the steam

turbine for work, so as to improve the circulating thermal efficiency of the power plant and reduce the steam humidity of the last stage blade of the steam turbine.

The first reheat can increase the cycle thermal efficiency by 4% - 5%, and the second reheat can increase about 2%.The boiler units with ultra-high pressure and above parameters generally adopt primary reheat. Because of the complexity of the system, the secondary reheat system can only be used when the steam parameters are very high.

2.2. Working conditions of superheater and reheater

The outlet steam temperature of superheated steam and reheated steam is the same (usually 540-600 ℃).The superheater and reheater are usually located near the furnace outlet and inside the furnace where the flue gas temperature is higher, so the heat load is high.High temperature flue gas (usually 1100-600 ℃) carries fly ash at a certain speed, which is easy to cause abrasion and corrosion on the outer wall of the pipe.The temperature of reheated steam is basically the same as that of superheated steam.However, the pressure of reheated steam is lower than that of superheated steam, which is about 20% - 25% of that of superheated steam, and its flow rate is about 80% of that of superheated steam.Therefore, the working environment of reheater in boiler is the worst.

3. Structural characteristics of superheater and reheater

3.1. Classification

Superheater and reheater can be divided into convection superheater, platen superheater and radiant superheater.

3.2. Convection superheater

The convective superheater is mainly convective heat transfer, with dense serpentine tube bundle, which is arranged in the convection flue (horizontal flue and tail flue).The flue gas velocity of convective superheater should be appropriate. If the flue gas velocity is too large, the tube will be seriously worn, and if it is too small, the heat transfer coefficient will be small, which can not meet the requirements of heat absorption.Therefore, in order to increase the heat transfer coefficient, the flue gas velocity is usually set at 10-15m/s in the high temperature section.In the low temperature section,the flue gas velocity is usually set at 6-9m/s, which can reduce the wear of fly ash on the pipe wall.In order to ensure that the tube wall of superheater and reheater can be well cooled, a certain mass flow rate should be guaranteed in the tube, but the increase of flow rate will increase the resistance of working medium.Therefore, the mass flow rate of convective superheater is generally controlled at 800-1000kg/(m^2·s), while for reheater, the mass flow rate is generally controlled at 250-400kg/(m^2·s). In addition, when the flue width is limited, in order to meet the flue and steam flow rate at the same time, the serpentine tube of superheater is often adopted with multi tube coil type, which can reduce the steam flow rate under the premise of constant flue gas velocity[1].

3.3. Platen superheater

The platen superheater not only absorbs the direct radiation of flame, but also absorbs the convective heat release of flue gas. It is arranged at the furnace outlet or upper furnace, which is also called semi radiant superheater (reheater).The platen superheater absorbs the radiation heat transfer in the furnace, effectively reduces the flue gas temperature at the furnace outlet, and prevents the convection superheater from slagging.The platen superheater can work reliably in the flue gas temperature range of 1000-1300 ℃.Compared with the convective superheater, the flue gas temperature increases, the heat transfer temperature difference increases, the heating area can be reduced, and the metal consumption is reduced.When the boiler load changes, the combination of platen superheater and convection superheater can

improve the steam temperature variation characteristics.The safety of platen superheater is poor, so it is necessary to monitor and control the metal wall temperature at the steam outlet of platen heating surface.

3.4. Radiant superheater

The radiant superheater is mainly used for radiative heat transfer and is arranged on the inner wall of the furnace.In order to arrange enough superheated heating surface in the furnace, it is necessary to arrange radiant superheater or reheater.The superheated heat absorption share of large capacity and high parameter boilers is more than 50%.Radiant superheater should be considered for units above 300 MW.Due to the high heat load in the furnace, the working conditions of the radiant superheater are very bad. In order to improve the working conditions, the radiant superheater is usually used as a low-temperature heating surface, which is arranged in the upper part of the furnace far away from the flame center and with a slightly lower heat load.

4. Thermal deviation analysis

4.1. Causes of thermal deviation

The difference in enthalpy is called the difference in enthalpy.The ratio of the enthalpy increase of the working medium in the parallel tube of the heating surface to the average enthalpy increase of the working medium in the parallel tube of the heating surface is called the thermal deviation coefficient.The greater the deviation of thermal deviation coefficient from 1, the greater the thermal deviation. When the thermal deviation coefficient is equal to 1, it indicates that there is no thermal deviation.But this situation is only true under ideal operating conditions.Although the average temperature of steam at the outlet of the tube group meets the design requirements, some tubes (deviation tubes) on the heating surface have excessive heat absorption, which leads to the metal overheating of the heating surface tubes, resulting in high temperature creep damage and even tube burst.The main causes of thermal deviation are thermal inhomogeneity, structure inhomogeneity and hydraulic inhomogeneity.

4.2. Influencing factors of thermal deviation

4.2.1 Thermal heterogeneity

Thermal inhomogeneity is caused by two factors.On the one hand, because the heating surface is polluted, ash and slagging on the heating surface will cause serious uneven heat absorption between pipes, and slagging or ash deposition in some pipes will increase the heat absorption of other pipes.On the other hand, the uneven distribution of temperature field and velocity field on the flue gas side is mainly caused by the following three points.

(1) The radiative and convective heat transfer is uneven.The uneven distribution of furnace temperature leads to uneven temperature distribution of convection flue.

(2) Due to burner design or boiler operation, the wind speed and pulverized coal concentration are uneven, and the flame center is shifted.Most power station boilers in China adopt the tangential firing mode.In other words,the fuel is introduced from the lower four corners of the furnace at a high speed, resulting in the strong mixing of fuel, air and flue gas, forming a rotating air flow moving from bottom to top in the furnace.However, there is still some residual rotation at the exit of the furnace, which results in the deviation of smoke velocity and temperature on both sides of the horizontal flue.Due to the uneven concentration of pulverized coal and the difference of primary and secondary air velocity of burners arranged at four corners, the heat load of each burner is inconsistent and the flame center is skewed. Due to the poor combustion organization in the furnace, the mixing of pulverized coal and air is delayed, and the continuous

combustion of pulverized coal exists in the upper part of the furnace and even in the local area of the superheater, resulting in uneven heat absorption on the convective heating surface[2].

(3) The flue gas corridor is formed by uneven transverse pitch of convective heating surface.When the pitch is larger than other parts, the resistance of flue gas is small and the velocity of flue gas increases several times, forming a "flue gas corridor".Due to the increase of heat in the heat transfer tube between the two sides of the flue gas, the thickness of the heat transfer tube increases.Finally, the heat absorption is increased.

4.2.2 Uneven structure

The uneven structure mainly refers to the uneven heating area in the same heating surface tube group.There are four reasons for this phenomenon.

(1) There is a great difference in the angle coefficient of flue gas radiation for each row of tubes, which leads to the uneven radiation heating area of each row of tubes.In general, the angle coefficient of the front tube is the largest and that of the rear tube is the smallest.

(2) Generally, the transverse spacing of superheater tubes is large, but the longitudinal intercept is small, which is easy to cause ash deposition and reduce the heating surface.

(3) There is no barrier between the front tube and the rear tube, and the convective heat absorption capacity is more than that of the middle tube.

(4) For example, the outer ring tube of platen superheater is longer than the inner ring tube.

4.2.3 Hydraulic heterogeneity

There are three factors that cause hydraulic inhomogeneity.

(1) The coupling effect.In other words, the pressure difference between the inlet and outlet of each pipe coil varies along the header static pressure, resulting in uneven hydraulic pressure.

(2) The heat absorption of the tube is uneven.When the pressure difference is equal, the steam temperature of the pipe with more heat absorption is higher, the specific volume is larger, and the resistance is larger, so the working medium flow rate is reduced, the pipe wall cooling difference and the thermal deviation are increased.

(3) The different resistance coefficient of the pipe coil leads to the uneven hydraulic pressure.

4.3. Measures to reduce thermal deviation

Through the above analysis of the causes of thermal deviation, it is impossible to completely eliminate the thermal deviation.However, the serious thermal deviation threatens the safe operation of the boiler, so the power plant should try to reduce the degree of thermal deviation.The measures to reduce the thermal deviation are mainly considered from the perspective of operation and structural design.

4.3.1 Operation measures

First of all, to ensure the balance of wind and powder, to avoid flame center deflection.Secondly, the burner should be put into operation reasonably according to the load change to make the distribution of flue gas in temperature field and velocity field as uniform as possible.Finally, soot blowing should be carried out in time to reduce ash deposition and slagging[3].

4.3.2 Structural measures

(1) In order to reduce the enthalpy increase of each stage superheater and reduce the deviation of outlet steam temperature, intermediate header is used for uniform mixing between stages.

(2) In order to reduce the influence of uneven heat absorption on the left and right sides, the steam of the left and right pipe groups are crossed and transposed.

(3) In order to reduce the difference of pressure distribution, the U-type connection should be used to reduce the difference between the two pipes.

(4) Properly balance the length and heat absorption of each pipe, increase the pipe diameter of some pipe sections, and reduce its resistance.

(5) According to the load change, the burner should be put into operation reasonably to make the distribution of flue gas in temperature field and velocity field as uniform as possible.

(6) For platen superheater, the size of flue gas space in front of platen or tube bundle should be reduced to reduce the difference of flue gas space between each platen.The water-cooled or steam-cooled positioning tube is used to fix the heating surface of each panel or piece to prevent it from swinging, and to fix the flue gas space and stabilize the heat transfer[4].

5. .Superheated steam temperature regulation method

5.1. Factors affecting steam temperature change

5.1.1 Boiler load

For the radiant superheater, with the increase of boiler load, the fuel quantity and induced air volume will increase, and the radiation heat transfer will also increase. However, since the fuel quantity is directly proportional to the steam quantity, and the furnace temperature has not been greatly increased, the increase of evaporation capacity will be greater than the increase of radiation amount.Moreover, with the increase of the induced air volume, most of the heat is taken away by the flue gas in the furnace.As a result, the steam temperature of radiant heating surface decreases.

As for the convection superheater, the boiler load increases, the fuel quantity increases, and the flue gas temperature at the furnace outlet increases. However, the increase of fuel quantity will also cause the increase of induced air volume. At this time, the amount and temperature of flue gas flowing through the convective superheater will increase, so the superheated steam temperature of the convection superheater will increase.The increase of temperature will lead to the increase of radiation.When the boiler load increases to a certain extent, the heat absorbed and radiated by the convective heating surface reach a balance, and the temperature of superheated steam is no longer increased.

In the superheater system of large-scale utility boiler, the share of radiant heat absorption is small, and the steam temperature characteristics of the whole superheater are convective.

5.1.2 Air coefficient

With the increase of excess air coefficient, the air flow into the furnace increases, the furnace temperature level decreases, the radiation heat transfer weakens, and the outlet steam temperature of radiant superheater decreases.For the convection superheater, the amount of flue gas generated by combustion increases, the velocity of flue gas increases, and the convective heat transfer is strengthened, resulting in the increase of superheated steam temperature at the outlet.The temperature of the whole superheater system will rise.

5.1.3 Feed water temperature

In order to keep the boiler load unchanged, the amount of coal fired increases, the amount of flue gas in the furnace increases, the flue gas temperature at the outlet increases, and the steam temperature at the outlet of convective heating surface increases.However, the outlet steam temperature of radiant heating surface has little effect.The temperature of the whole superheater will rise.Operation experience shows that the feed water temperature decreases by 10℃, the superheated steam temperature increases by 4-5℃, and the coal consumption increases by 0.65%.Generally, the operation method of reducing load is adopted to ensure the safety of superheater.

5.1.4 Fuel properties

The more moisture and ash in the fuel, the higher the outlet steam temperature.This is because the evaporation of moisture in the furnace will absorb part of the heat, which will reduce the furnace temperature. At the same time, the increase of moisture will lead to the increase of flue gas volume, increase the flue gas flow rate, reduce the heat absorption capacity of radiation

superheater, and increase the steam temperature at the outlet of convective heating surface.In addition, when the pulverized coal becomes coarser or the volatile matter of coal decreases,the flame center moves up and the superheated steam temperature increases.

5.1.5 Flame center position

When the flame center position moves upward, the radiant heat absorption share of the furnace decreases, the heat transfer temperature difference of the superheater arranged in the upper part of the furnace and in the horizontal flue increases, and the absorbed heat increases, while the steam volume does not change, so the steam temperature at the outlet of the superheater will rise.

5.1.6 Contamination of heating surface

The slagging or ash deposition on the heating surface of the furnace increases the fuel consumption and reduces the radiation heat transfer in the furnace.The results show that the flue gas temperature in the superheater area increases, the flue gas volume increases, the flue gas velocity increases, the convective heat transfer increases, and the superheated steam temperature increases.The slagging or ash deposition of superheater itself will lead to the decrease of steam temperature.

5.1.7 Other situations

With the increase of saturated steam or blowdown, fuel consumption, flue gas volume, flue gas velocity and heat transfer capacity increase, resulting in the increase of superheated steam temperature.When the water level of the steam drum is too high, the steam humidity increases, and the water vaporization in the steam needs to consume additional heat, and the superheated steam temperature drops.

5.2. Necessity of steam temperature regulation

If the steam temperature is too high, the pipe wall will overheat, the metal creep speed will be accelerated, and the service life will be reduced.If the steam temperature is too low, the cycle thermal efficiency of the power plant will be reduced by about 0.5% when the superheated air temperature drops by 10 ℃.If the steam temperature is too low, the exhaust humidity of the steam turbine will increase, which will affect the safety of the last stage blade of the steam turbine.Therefore, boiler temperature regulation is very important.

5.3. Method of superheated steam temperature regulation

The regulation methods of superheated steam temperature of power plant boilers in China are divided into steam side regulation and flue gas side regulation.The steam side regulation can only reduce the temperature, but can not raise the temperature. There are mainly surface desuperheater and water spray desuperheater. While the flue gas side regulation can not only reduce the temperature, but also increase the temperature, mainly the swing burner[5].

The working principle of surface desuperheater is a kind of tube shell heat exchanger. The desuperheating water goes inside the pipe and the steam flows between the tubes in the shell. The steam is cooled by feed water or boiler water to achieve the purpose of regulating steam temperature.The advantage is that the water vapor does not contact with each other, and the disadvantage is that the sensitivity of temperature regulation is poor and there is the possibility of leakage. It is generally used in low and medium pressure boilers.

The working principle of spray desuperheater is that water is directly injected into the steam, and the injected water absorbs the heat of steam in the process of heating, evaporation and overheating, so as to reduce the steam temperature.It has the advantages of simple structure, sensitive adjustment, large temperature range, small pressure loss, easy automation and high reliability.The disadvantage is that the water quality of desuperheating is high, and boiler feed water is generally used.It is suitable for the regulation of superheated steam temperature, not suitable for the regulation of reheated steam temperature.

The working principle of the swing burner is to change the position of the flame center, so as to change the flue gas temperature at the furnace outlet and adjust the superheated or reheated steam temperature.When the flame nozzle moves up and the flame center moves up, the heat absorption in the furnace decreases, and the flue gas temperature and steam temperature at the furnace outlet increase.The utility model has the advantages of convenient adjustment, high sensitivity and no additional heating surface and power consumption.The disadvantage is that the boiler efficiency decreases or slagging.The swing burner is only used as a means of rough adjustment of steam temperature, and spray desuperheater should be used for fine adjustment.

6. Reheat steam temperature regulation method

6.1. Steam temperature characteristics of reheater

The reheater system of large utility boiler has more obvious convection characteristics.Because the volume of reheater is large, the flow rate of working medium is slow, and it is arranged in the low temperature area of flue gas, and the heat transfer temperature difference is small, so the delay time of reheat steam temperature change is long.Because of the low pressure and small specific heat of reheater steam, the temperature of reheater changes greatly under the change of working conditions. When the unit operates under constant pressure mode, the exhaust steam temperature of high-pressure cylinder increases with the increase of group load.In addition, the higher the enthalpy of the steam turbine is, the higher the exhaust temperature of the main cylinder is.

6.2. Method of reheat steam temperature regulation

When the load changes, the reheat steam temperature changes more dramatically than the superheated steam temperature.Moreover, the reheater using water spray regulation will reduce the cycle thermal efficiency of the unit.Therefore, spray desuperheating is no longer the main means of reheat steam temperature regulation.The main regulation methods of reheat steam temperature include flue gas recirculation, swing burner, flue gas baffle, steam steam heat exchanger and steam bypass method.

The working principle of flue gas recirculation is that a part of the flue gas with the temperature of about 250-350℃ behind the economizer is drawn out by the recycling fan and then sent back to the furnace chamber, so as to change the heat absorption ratio between the radiation heating surface and the convective heating surface, so as to achieve the purpose of temperature regulation.It has the advantages of large adjustment range, small hysteresis, high sensitivity, uniform furnace heat load, lower water wall temperature and lower NO_X emission.The disadvantage is that the power consumption of the recirculation fan increases and the wear is large, which has an adverse effect on the ignition of the burner.It is suitable for steam temperature regulation of boilers with obvious convective heat transfer characteristics.

The flue gas baffle is used to adjust the steam temperature by changing the flue gas flow, which is divided into bypass flue and parallel flue.When the load decreases, the proportion of flue gas flow through the reheater is increased.When the load increases, the proportion of flue gas flow through the reheater is reduced.The advantages are simple structure and convenient operation.The disadvantage is the nonlinear relationship between the opening of baffle and the change of steam temperature. When the baffle is just opened, the amount of flue gas increases rapidly and the steam temperature changes greatly[6].When it is close to the full open position, the amount of flue gas increases slowly and the change of steam temperature is small.In order to prevent the baffle from deformation, the flue gas baffle should be arranged in the area where the flue gas temperature is lower than 400℃.

Steam steam heat exchanger is a kind of heat exchanger which uses superheated steam to heat reheat steam.The advantage is that there is no wear and tear and is suitable for all kinds of

fuels.The disadvantage is that the structure is complex, which increases the resistance of superheater system and increases the steel consumption of boiler.It is suitable for large capacity boilers with radiant superheater as main part and total steam temperature characteristic as radiation characteristic.

The reheater is divided into two groups by steam bypass method. The first stage is used as the regulating stage, and the second stage is placed in the high temperature part of the flue.The two stages are separated by other heating surfaces.The reheat steam temperature is regulated by changing the steam flow through the first reheater.There is no working fluid passing through the reheater when the steam turbine is load shedding or the unit is started and stopped.The superheated steam should be introduced into the reheater through the rapid temperature and pressure reduction device to protect the heating surface of the reheater.The bypass system can be used to achieve the above purpose.

7. Conclusion

In conclusion, superheated heating surface and reheating heating surface play an important role in boiler heat transfer.However, due to the boiler operation and structural design and other factors, part of the tube bundle will produce thermal deviation, which is the necessary guarantee for the safe operation of power plant boiler.At the same time, various steam temperature regulation methods have their own advantages and disadvantages, which should be used together in the actual operation of the power plant,In order to maximize the role.

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