Thermal Analysis of Components of Diverter Damper Used in Waste Heat Recovery Boiler System

Swapnil S. Kachore1 M. S. Tufail2
1 M. Tech Scholar 2 Professor
1,2 Department of Mechanical Engineering
1,2 YCCE, Nagpur, Maharashtra - India

Abstract— Waste heat recovery boiler system is better option for recovering heat from unused engine exhaust. Diverter dampers are used to divert the flue gases from engine exhaust either to the waste heat recovery boiler system or to the bypass system. We have considered the diverter damper with 200 mm diameter opening. The media which is the flue gases from the engine exhaust having temperature of around 500°C. This paper discusses the thermal analysis of the diverter damper which gives us the temperature distribution and thermal stresses induced in it. Steady state thermal analysis is assumed. By using the analysis software Ansys Workbench V14.0, color results are generated.

Key words: diverter damper; waste heat recovery boiler system, thermal analysis, ansys

I. INTRODUCTION

Waste heat recovery boiler systems are used to recover the heat energy from the flue gases of the engine, which goes in vain most of the cases. The flue gases from the exhaust of the engine can be utilized in the waste heat recovery boiler system. The heat energy from the engine exhaust can be utilized to generate the electricity or to preheat the medium. For the main system to work continuously there has to be diverter damper to divert the flue gases to the environment in case there is maintenance in the waste heat recovery boiler system.

Md. A. A. Mamun, Subrato Biswas studied the waste heat recovery system using an organic Rankine cycle. The environment friendly plant recovers the unused engine exhaust and generates electricity on continuous basis displacing large amount of CO2 yearly, without interfering the production process. In a closed cycle, he generated vapor expanded in turbine that drives generator. The organic working medium is again used to preheat the organic liquid before vaporizing. The low temperature heat is normally discharged to the atmosphere. The organic liquid has low evaporation energy and no longer requires superheating [1].

Pramod Bhatt, Anirudh Gupta studied that heat transfer is the study of thermal energy transport within a medium or among neighbouring media by molecular interaction, fluid motion, and electromagnetic waves, resulting from a spatial variation in temperature. Thermal analysis of hollow duct is done computationally using Altair Hyper works Software. Simple Analytical results were obtained for conduction and convection through cylindrical hollow duct which can be used to build up thermal circuit. The material of pipe provides conductive resistance and air provides convective resistance. Hence this is a mix mode of heat transfer. The heat transfer takes place in one dimension only and properties are considered to be isotropic. The cylindrical duct is assumed to be made of steel having known thermal conductivity and density. The surrounding of pipe has known convective heat transfer coefficient and temperature. The results obtain on hyper view are for heat flux, temperature gradient and grid temperature [2].

Hyuntae Shin, Daeehee Kim, Hyungsun Ahn, Sangmin Choi, Gichul Myoung have shown the general arrangement of the HRSG of the plant. There have been several reports of damage on casing and tubes in the HRSG, which include broken casing, snapped stiffeners and elongated fin tubes. Finite element stress analysis was conducted using ANSYS workbench V.12. Field measurements and combined fluid flow and thermal stress analysis were carried out to understand repeated thermal loading and its behavior on the HRSG casing during the start up. Analysis were conducted at two moments, when gas turbine reached to full load and wall temperature increased to its corresponding peak and steady state [3].

A. Mohaer, A. Noroozi, S. Norouzi researched that combined cycle power plant have become a serious alternative for standard coal and oil-fired power plant because of their high thermal efficiency. The effect of using turning vanes on the performance of bypass exhaust system in combined cycle or exhaust system in gas turbine cycle is evaluated. For combined cycle power plant, the diverter box used to direct the exhaust gas of the gas turbine either into waste heat recovery boiler or when running under open cycle mode, exits directly to the bypass stack. The effect of diverter box turning vanes on the energy loss and pressure reduction in exhaust system of a combined cycle is investigated [4].

Niyati Patil, Mukund Kavade, Amol Patil discussed that, related to global warming and availability of primary energy source, there is requirement to reduce CO2 emissions and energy consumption. Important part is there should be increased use of waste heat of industrial application. Heat recovery steam generator produces steam from another process to produce electricity. The combination of the gas turbine and Rankine cycle is called as combine cycle. The flue gas flow in the gas turbine and HRSG is analyzed [5].

Naimul Hasan, Jitendra Nath Rai and Bharat Bhushan Arora researched that, combined cycle gas turbine consists of two units: steam turbine unit and gas turbine unit. The gas turbine unit is fired first. The hot exhaust gas is used to operate the boiler of the steam turbine generating system. Conversion of the hot gases from the exhaust of the gas turbine to heat required for the boiler is done by the heat recovery steam generator unit. A model of CCGT was developed and variation of efficiency by varying various parameters is studied [6].

II. DIVERTER DAMPER

Diverter damper is used in waste heat recovery boiler system to divert the flue gases from the engine. For the waste heat recovery boiler system there may be chances of
maintenance and the flue gases are coming directly to the waste heat recovery boiler. So, whenever such situation occurs we have to stop the whole system. This should not happen because whole plant can’t be stopped because of such periodic maintenance. So, the diverter damper is used intermediate between the waste heat recovery boiler system and the engine exhaust to divert the flue gases directly to the bypass system without stopping the whole plant.

Diverter damper is a box having flap to close the one opening at a time and other remain open. The medium is flue gases with temperature of 500°C

III. MODES OF HEAT TRANSFER

Heat transfer which is defined as the transmission of energy from one region to another as a result of temperature gradient takes place by the following three modes:

- Conduction,
- Convection and
- Radiation

1) Conduction: Conduction is the transfer of heat from one part of substance to another part of the same substance, or from one substance to another in physical contact with it, without appreciable displacement of molecules forming the substance

2) Convection: Convection is the transfer of heat within a fluid by mixing of one portion of the fluid with another.

3) Radiation: Radiation is the transfer of heat through space or matter by means other than conduction and convection.

A. **Fourier’s Law of Heat Conduction:**

Fourier’s law of heat conduction is an empirical law based on observation and states as follows:

“The rate of flow of heat through a simple homogeneous solid is directly proportional to the area of the section at right angles to the direction of heat flow, and to change of temperature with respect to the length of the path of the heat flow”.

Mathematically it can be represented by the equation:

\[ Q \propto A \frac{dt}{dx} \]

Where,

- \( Q \) = Heat flow through a body per unit time (in watts), W,
- \( A \) = Surface area of heat flow (perpendicular to the direction of heat flow), m²,
- \( dt \) = Temperature differences of the faces of block (homogeneous solid) of thickness “dx” through which heat flow, °C or K,
- \( dx \) = Thickness of body in the direction of flow, m.

Thus,

\[ Q = -K \times A \times \frac{dt}{dx} \]

Where,

\( K \) = Constant of proportionality and is known as thermal conductivity of the body.

The –ve sign of \( K \) (in equation 5.1) is to take care of the decreasing temperature along with the direction of increasing thickness. The temperature gradient is always negative along positive x direction and, therefore the value as \( Q \) becomes +ve.

**B. Assumptions:**

The following are the assumptions, on which the Fourier’s law is based.

1) Conduction of heat takes place under steady state conditions.
2) The heat flow is unidirectional.
3) The temperature gradient is constant and the temperature profile is linear.
4) There is no internal heat generation.
5) The bounding surfaces are isothermal in character.
6) The material is homogeneous and isotropic. (i.e. the value of thermal conductivity is constant in all the directions)

C. **Free Convection:**

Free or natural convection is the process of heat transfer which occurs due to movement of fluid particles by density change associated with temperature differential in a fluid. This mode of heat transfer occurs very commonly.

The rate of heat transfer is calculated using the general convection equation given below,

\[ Q = h A (t_2 - t_1) \]

Where,

- \( Q \) = Heat transfer,
- \( h \) = Convection coefficient, W/m²°C ,
- \( A \) = Area, m²,
- \( t_2 \) = Temperature of fluid at distance well removed from the surface.

IV. **STRESSES DUE TO CHANGE IN TEMPERATURE (THERMAL STRESSES):**

Whenever there is some increase or decrease in the temperature of a body, it causes the body to expand or contract. A little consideration will show that if the body is allowed to expand or contract freely, with rise or fall of temperature, no stresses are induced in the body. But, if the deformation of the body is prevented, some stresses are induced in the body. Such stresses are known as thermal stresses.

Let, \( l \) = Original length of the body,
\( t \) = rise or fall in temperature, and
\( \alpha \) = Coefficient of thermal expansion,

Therefore,

Increase or decrease in length = \( \delta l = l \alpha t \)

If the ends of the body are fixed to rigid support, so that its expansion is prevented, then compressive strain induced in the body,

\[ \varepsilon_c = \frac{\delta l}{l} = \frac{(l \alpha t)}{l} = \alpha t \]

Therefore,

Thermal stress,

\[ \sigma_{th} = \varepsilon_c E \]

Where,

- \( \varepsilon_c \) = \( (l \alpha t)/l \)
- \( \sigma_{th} \) = Thermal stress
- \( E \) = Modulus of elasticity

- \( Q \) = Heat transfer,
- \( H \) = Convection coefficient, W/m²°C ,
- \( A \) = Area, m²,
- \( t_2 \) = Temperature of fluid at distance well removed from the surface.
V. THERMAL STRESSES IN COMPONENTS

A. Thermal Stress in Cylindrical Part:

Thermal Circuit:

\[ T_1 \rightarrow \frac{1}{R_{TH_1}} \rightarrow T_2 \rightarrow \frac{1}{R_{TH_2}} \rightarrow T_3 \]

\[ R_{TH_1} = \text{Conduction resistance} = \frac{\ln(R_2/R_1)}{2\pi KL} \]

\[ R_{TH_2} = \text{Convective Resistance} = \frac{1}{h(2\pi R_2 \times L)} \]

Therefore,

\[ Q = \text{Rate of heat transfer} = \frac{\Delta T}{R_{TH_1} + R_{TH_2}} \]

Now,

\[ \sigma = E \times \alpha \times \Delta T \]

B. Thermal Stress in Casing Plate:

Thermal Circuit:

\[ T_1 \rightarrow \frac{1}{R_{TH_1}} \rightarrow T_2 \rightarrow \frac{1}{R_{TH_2}} \rightarrow T_3 \]

\[ R_{TH_1} = \text{Conductive resistance} = \frac{t}{KA} \]

\[ R_{TH_2} = \text{Convective resistance} = \frac{1}{hA} \]

\[ Q = \frac{(T_1 - T_3)}{(t/KA + 1/hA)} \]

And

Thermal stress in the plate,

\[ \sigma = E \times \alpha \times \Delta T \]

VI. RESULT

The result obtained by the analysis software Ansys Workbench V 14.0 showing the temperature distribution and the thermal stresses developed on the component.
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The thermal analysis of the diverter damper is done showing the temperature distribution from maximum 500°C to minimum of 495°C.

Thermal stresses are calculated for considering the separate parts of the diverter damper, cylindrical part, flap of damper, casing plate of damper, which are within the limits of yield stress. So, the diverter damper can continuously be used for operation of diverting the flue gases.

The color results generated gives the better idea of stress distribution on the flap of the damper and the casing of the damper.

REFERENCES


