Process Modeling of Reheat Furnace

Prof. SabbirHusen N. Akhunji, Prof. Dipesh S. Vyas, and Prof. Rajesh Zadfiya

Abstract-- **Combustion Process and Heat Transfer of reheat furnace process is studied. The predicted slab temperatures are compared with a range of desired slab temperatures and the slab requiring the greatest time to be heated to its desired temperature is defined. Mathematical Modeling of Reheat Furnace considering various parameters such as furnace geometry, slab geometry, slab material and implementation in LabVIEW in terms of simulator.**
Keywords: Combustion process, reheat furnace, slab geometry, LabVIEW.

I. Introduction

The main function of a continuously reheating furnace is to raise the temperature of steel slab, typically to between 900ºC and 1250ºC, until it is plastic enough to be pressed or rolled to the desired section, size or shape, The furnace must also meet specific requirements and objectives in terms of stock heating rates for metallurgical and productivity reasons. In continuous reheating, the steel stock forms a continuous flow of material and is heated to the desired temperature as it travels through the furnace.
In a conventional method for controlling temperature of a slab, the gas temperature of the furnace is controlled by using the temperature of each zone of the furnace. Generally, in the temperature control of a continuously heating furnace it is requisite that metal be uniformly heated to a temperature adapted to a rolling thereof and be able to be supplied corresponding to the rolling velocity required in the rolling. For this purpose, in a continuously heating furnace there has been adopted an automatic combustion controlling system, which is, however, to control the atmospheric temperature within the furnace, but is not to control the temperature itself of the object being heated[1].

II. DISCRIPTION OF REHEATING FURNACE

1) Basic Reheating Furnace Parts:

Furnaces that heat metal parts (slabs) prior to hot-working processes such as rolling or forging is called pre-forming reheat furnaces. In these furnaces, the fundamental idea is to heat the slabs to a prescribed temperature without very large temperature gradients. This is to ensure correct performance of the metal parts subsequent to reheating. Due to the elevated temperature in the furnace chamber, radiation is the dominant mode of heat transfer from the furnace to the slab. In addition, there is convection heat transfer from the hot gases to the slab. The heat transfer within the slabs is by conduction.

All the furnaces possess the features as shown in figure [1].

- A refractory chamber constructed of insulating material for retaining heat at the high operating temperatures.
- A hearth to support or carry the steel. This can consist of refractory materials or an arrangement of metallic supports that may be water-cooled.
- Burners that use liquid or gaseous fuels to raise and maintain the temperature in the chamber. Methods of removing the combustion exhaust gases from the chamber.
- A method of introducing and removing the steel from the chamber.
- These facilities depend on the size and type of furnace, the shape and size of the steel being processed, and the general layout of the rolling mill.
- Common systems include roller tables, conveyors, charging machines and furnace pushers.

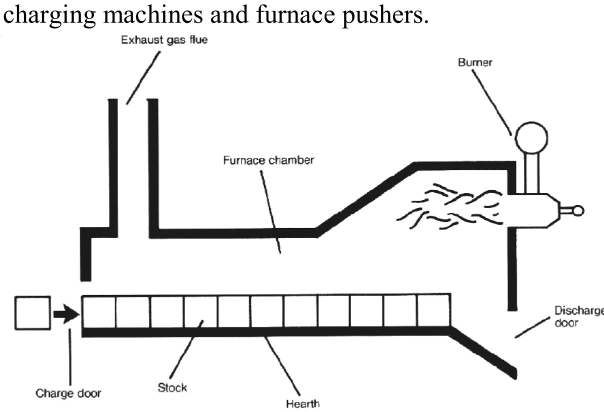

Figure 1 Furnace Feature [3]

2) Case Study for 3-zones pusher type Reheating Furnace:

- Basic Reheat Furnace Description:

Figure [2] shows the pusher type continuous reheating furnace, which is divided into three zones, Preheating zone, Heating zone and Soaking zone. An outlet of preheating zone is an inlet of heating zone and outlet of heating zone is inlet of soaking zone.
To assure proper heating of the slabs, the temperature of each furnace zone must be close to predefined set-points, in function of the rolling program and the operational parameters of the furnace. In the Recuperative zone and preheating zone there are no burners: energy is transferred to the slabs by hot gases. The other zones have several burners of two types: flat and volume burners. The preheating zone provides 40% of the total energy supplied to the slabs,

978-1-4673-1719-1/12/$31.00©2013IEEE

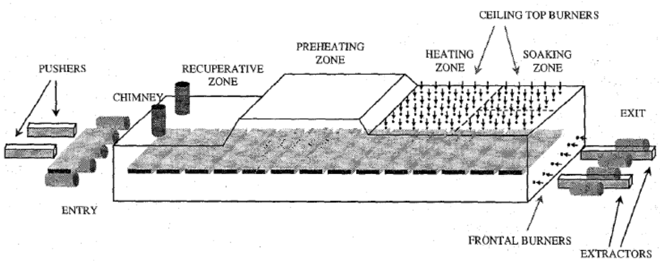

Figure 2 Basic Reheat Furnace [2]

producing a great rise in the surface temperature of slabs, and creating high temperature gradients within them. In the heating zone there is also a great supply of energy, but the increase in the slab temperature is smaller than in the preheating zone, because the surface temperature of the slab is similar to the zone temperature, so the energy fluxes are smaller. Finally, the soaking zone is used to avoid temperature gradients within the slabs.

- Parameter Consideration for Modeling:

1. Sensor Placements:

Zone	No. of Sensors	Position of Sensor in (meter)
Soaking	3	1.66 - 2.9 - 3.2
Heating	3	8 - 9.1 - 11
Preheating	2	19.2 - 24.8

2. Zonal Distribution
   Preheating zone: 16 meter
   Heating zone: 9 meter
   Soaking zone: 5 meter
3. Burners
   Soaking zone: 6 burners
   Heating zone: 5 + 5 burners
4. Slab Geometry
   Here,
   l = length of slab
   a = width of slab
   b = thickness of slab
   Typically, for a slab in a reheating furnace, the slabs length is large compared with its width and thickness. This implies, in turn, that heat transfer along the furnace.

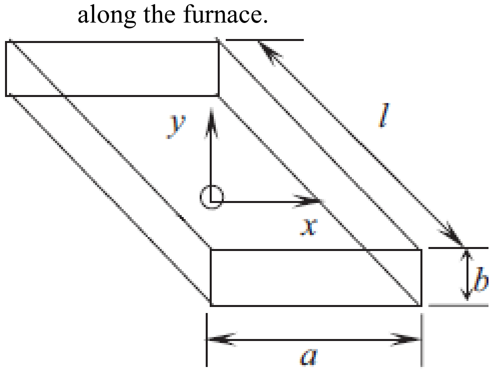

Figure 3 Slab Geometry

Fundamentals of Heat Transfer in Reheat Furnace:

Specific Heat: Specific heat is denoted as Cps. Units of specific heat are J/lbsºC and J/kg K. The value of specific heat is depending on the temperature of material and temperature of gas as shown below.

$$Cps = 425 + 0.733Ts \quad ; \text{ for } 20^\circ C \le Ts \le 600^\circ C$$

$$Cps = 666 - \left(\frac{13002}{Ts - 738}\right) ; \text{ for } 600^\circ C \le Ts \le 735^\circ C$$

$$Cps = 545 - \left(\frac{17820}{Ts - 731}\right) ; \text{ for } 735^\circ C \le Ts \le 900^\circ C$$

$$Cps = 650 \quad ; \text{ for } Ts > 900\ ^\circ C$$

Heat Transfer in the Reheat Furnace:

Between 50 to 70 percent of the total heat is transferred in the radiant section. The gas temperature will depend on the fuel used and the amount of excess air. For gaseous fuels around 20% excess air is normally used and 25% for liquid fuels. In a reheat furnace, heat transfer to the slab is both by convection and radiation. However, at the elevated temperatures encountered in these furnaces, radiation is the dominant mode, accounting for as much as 90% of the total heat transfer in the chamber. Hence it has to be modeled accurately taking into account the varying wall and gas temperatures along the length of the furnace and the corresponding change in the surface temperature and properties of the slabs, as it is dependent on all these.

The cross section of the furnace is shown in figure [4], in which the different ways of heat transfer to the steel in a reheating furnace are shown.

- Radiation from the flame, hot combustion products and the furnace walls and roof.
- Convection due to the movement of hot gases over the stock surface.

Radiation Heat Transfer Coefficient:

Effect of Time: Figure [5] shows the heat balance model of a heated object in any heating zone of a continuously reheating furnace.

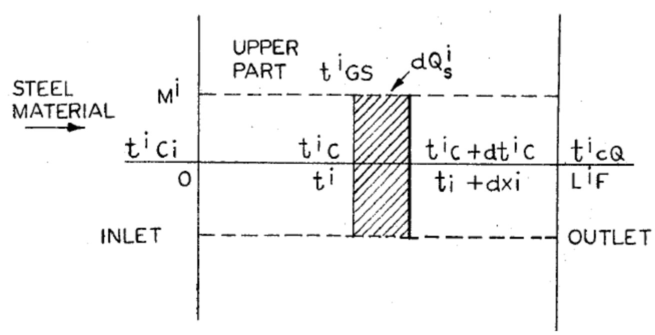

Figure 5 Small Section of Slab [1]

Temperature of the heated object at the outlet of the soaking zone is controlled by the velocity on the basis of the relation of the formula,

$$Vs = F(Ts', Tso, Tsi, D, P) . \qquad (1)$$

Where,

Ts' is an objective temperature for extracting the heated object

Tso is a heating temperature in soaking zone

Tsi is a temperature of a heated object at the soaking zone inlet

D is dimension of the heated object

P is physical constant of the heated object

The heat transmission as shown in Figure [4] shows small section of the heated object is given by,

$$dQ = l^i dx^i H(T_{gs}{}^i - T_c{}^i)\ . \quad (2)$$

Quantity of heat given to the heated object,

$$dQ = M^i C_p{}^i [(T_c{}^{i+1} + dT_c{}^{i+1}) - T_c{}^i]\ . \quad (3)$$

Where,

M_i = Treated amount of heated object in the i-heating zone (kg/hr)

Cp_i = Specific heat of the object in the i-heating zone (kCal/kg°C)

dX_i = Distance of a heated object in the i-heating zone from soaking zone (m)

Tc_i = Temperature of a heated object at the distance X in the i-heating zone (°C)

Hi = Heat Transfer Coefficient in the i-heating zone

Td = Resident time (min)

Here, mass M_i is in kg/hour. Per hour change in mass is called load to reheat furnace. By introducing resident time in the above equation, the mass can be manipulated only in KG and resident time will be in hour. Resident time is defined as the slab required the greatest time to achieve desired temperature at particular position.

So,

$$dQ = MC_p{}^i [(T_c{}^{i+1} + dT_c{}^{i+1}) - T_c{}^i] \times T_d\ . \quad (4)$$

Where T_d is resident time in hour and M is mass per unit area in kg.

III. Mathematical Implementation in LabVIEW

LabVIEW:

LabVIEW is the centerpiece of graphical system design and provides engineers and scientists with the tools you need to create and deploy measurement and control systems.

Hardware Integration with LabVIEW:

- I/O and Communication Connect to any instrument or sensor with built-in libraries and thousands of instrument drivers Plug-and-Play Hardware.
- Plug-and-Play Hardware seamlessly integrates NI plug-and-play devices for USB, PCI, PXI, Wi-Fi, Ethernet, GPIB, and more.

Multiple Programming Approaches:

- Code Reuse Integrate text-based code and DLLs or easily incorporate native and third-party .m files.
- Various Design Patterns. Incorporate additional models of computation such as dynamic simulation diagrams and state charts.

Data Storage and Reporting:

- File I/O Designed for Engineering Data Focus on your data and not converting formats with built-in support for a wide variety of file types.
- Flexible Reporting Tools Share your results by generating reports from your acquired data.

Now from equation [2] and equation [4],

$$l^i dx^i H(T_{gs}{}^i - T_c{}^i) = MC_p{}^i [(T_c{}^{i+1} + dT_c{}^{i+1}) - T_c{}^i] \times T_d\ . \quad (5)$$

Here, in this case furnace is of 30 meter long and it is divided into 30 equal parts for mathematical modeling. Furnace is having 3 meter of entering pusher and 3 meter of exit pusher, so the total effective length of modeling is, 30-6= 24meter. Material specific heat Cps=0.155 J/lbs °C. Furnace capacity is of 40Tonne, so mass per unit 1 meter length is 1333.33kg. Output temperature required is 1050 °C.

Based on the parameters given above, the heat transfer equation [5] is implemented in LabVIEW as real-time process.

IV. Simulation Results

For the given standard data the modeling of reheating furnace is done in LabVIEW. Figure [4] shows the input data of reheat furnace, total fuel consumption in liter per hour, ton per hour and total fuel consumption in liter.

Two PI controllers are controlling the Soaking zone and Heating zone fuel flow rates. Here, in this case soaking zone is given highest priority than heating zone. There are no burners in preheating zone, so no PI controller for preheating zone.

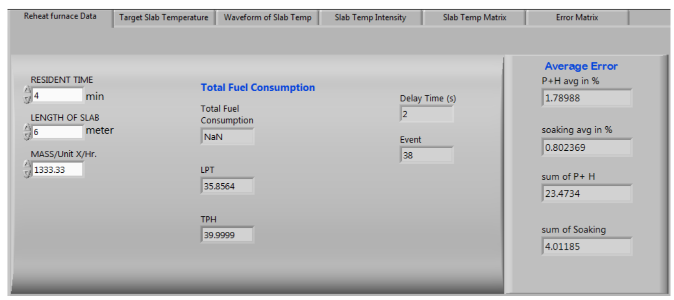

Figure 4 Reheat Furnace Data

The required heat treatment curve is decided by metallurgical department, those slab temperatures are setpoints to the reheating furnace process. The figure [5] shows the setpoint curve of slab temperature.

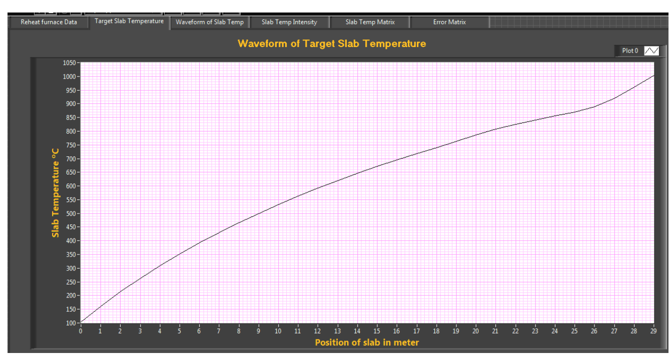

Figure 5 Desired Slab Temp Curve

The slab is treated in three zone pusher type reheat furnace with variable load. The event time is varying as per the delay between two consecutive push button pressed is called delay time. Event time is changing as per furnace load. In modeling of furnace slab position tracking and slab temperature is measured. Slab temperature matrix of 30 × 30 is generated using mathematical calculations and different heat treatment curve for different slab number and position of slab is plotted as shown in figure [6].

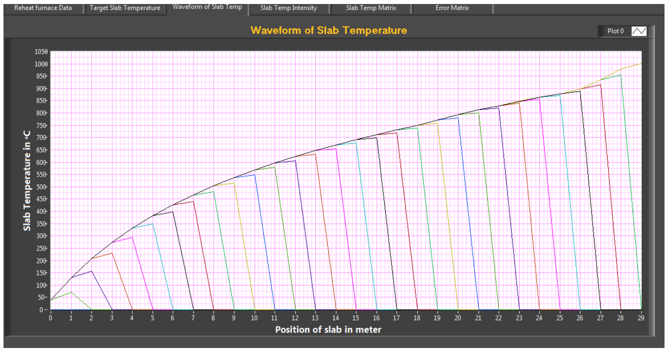

Figure 6 Slab Temperature curve for each 30 positions

From the equation [5] of the heat transfer, from the value of previous gas temperature and slab temperature the current slab temperature is calculated as per resident time of the slab. The temperature of the slab at the end of the preheating zone, that is, at the inlet of the heating zone is determined using physical constant and dimension of the heated object given in advance by detecting the atmospheric temperature in the preheating zone and the moving velocity of the heated object. Thus the determined average temperature at the preheating zone outlet of the heated object is then used for the base of the heating control of the heating zone. The heat distribution pattern is shown in figure [7].

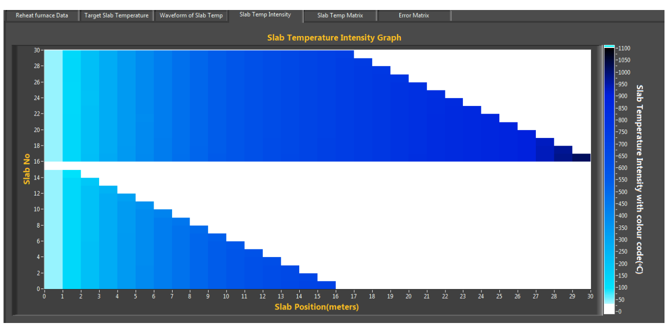

Figure 7 Heat Distribution Curve

V. References

[1] Hiroshi Matun and Toshiya morisue, United States Patent, "*Heating Controlling System In a Multizone Type Continuously Heating Furnace*", Yawate Iron & Steel Co., Ltd., Tokyo, Japan, Dec. 1971.

[2] D. F. Garcia, M. Sierra, R. Rodriguez, A. Campos, R. Dim, *"Development of Scalable Real-time Observers for Continuous Reheating Furnaces Based on Mathematical Modeling Techniques"* , Department of Applied Physics Campus de Viesques, Gijbn, E-33205 SPAIN

[3] Energy Efficiency Guide for Industry in Asia-www.energye_ciencyasia.org. Thermal Energy Equipment: Furnaces and Refractories"

[4] Hyun Suk KO, Jung-Su Kim, Tae Woong Yoon Mokeun Lim, Dae Ryuk Yang, Ik Soo Jun, "*Modeling and Predictive Control of a Reheating Furnace*", American Control Conference Chicago., June 2000

[5] J. Harish "*Computational and modeling of reheat furnace*" A Thesis submitted for the degree of Master of Science in the Faculty of Engineering in IISC, Bangalore., December 2000

[6] John C. Price, Roanoke, Va., United States Patent, "*Furnace Temperature Control*", General Electric Company., Salem Va., Mar. 24, 1981.