Nonlinear dynamic model of steam boiler furnace

Mikhail Yu. Livshits[1,*], *A.* H.Elnour Mohammmad[1]

[1]Samara State Technical University, Heat and Power Engineering Department, Russia

Abstract. This paper describe a nonlinear dynamic model for furnace boiler and its addressed to be the first part of other system components which will be developed with control structure for a typical boiler, which will be used for educational purposes and research studies. This paper shows the variation of furnace dynamics (pressure, Temperature and mass flow rate) when variation in fuel mass flow rate occurs.

1 Introduction

Boiler has an unsteady state operation due to the variation in power demand. During the unsteady operation of the boiler steam, a pulsatory flow of the flue gas is created. This pulsatory flow allows the occurrence of certain pressure rhythmic variations inside the furnace leading to negative effects upon the air-flue gas circuit safety and efficiency in operation. [1]

Knowing the dynamic characteristics of the furnace is useful to develop its control system. The most practical way to know the dynamic properties of the furnace is simulation. Performing test runs is almost impossible because of the safety and economic reasons [2] the simulation model is based on the mass, heat and momentum conservation principles. The present paper is an extension of the paper [1], [2].

This paper discusses the development of a simulation toolbox for a typical furnace with standard configuration. The heart of a plant simulation is its modeling block, which for a boiler is comprised of highly nonlinear and complex algebraic, and differential equation [3]

To design a simulator, the programming language and the required software should first be selected. Modeling and programming can be run using any of the major programming languages. This method requires advanced techniques in programming or the simulator will not be economic or flexible. An alternate idea is to use simulator software to simulate and analyze the necessary calculations; this would be a better method for training and other applications.

One of the best software packages for simulation purposes is software environment MATLAB®.

---

* Corresponding author: entcom@samgtu.ru

2 Mathematical model of the furnace

The mathematical model was developed from the mass, energy balances and the heat transfer from hot flue gases to water and steam model and the flue gas flow through the boiler model. *[3]*

- Combustion heat balance:

$$VF\ \partial(\rho g\ hg)/\partial t = WA\ hA + WF\ CF + Wg\ hg - Weg\ heg\ RS \tag{1}$$
$$(1 + y/100) - Qir - Qis;$$

- combustion mass balance:

$$VF\ \partial\rho g/\partial t = WA + WF + Wg - Weg; \tag{2}$$

- flue gas flow through the boiler:

$$Weg = kf\ PG; \tag{3}$$

- furnace gas pressure:

$$Pg = Rg\ \rho g\ Tg; \tag{4}$$

-simulink model equations:

$$heg = XF / \rho eg, \tag{5}$$

$$Tg = \left(\frac{hEG - href}{Cpg}\right) + Tref, \tag{6}$$

$$Qir = \theta\,k\,VF\,Tg^{4}\ Weg/Pg, \tag{7}$$

$$Qis = (1 - \theta)\,k\,VF\,Tg^{4}\ Weg/Pg, \tag{8}$$

$$Qgs = Qis + kgs\,Weg^{0,6}\ (Tg - Tst), \tag{9}$$

$$Tgr = Tg + ((Qis - Qgs))/(Cgs\,Weg\,), \tag{10}$$

$$Qrs = Krs\,WEG^{0.6}\ (Tgr - Trh), \tag{11}$$

$$Tge = Tgr - Qgs / (Cgs\,Weg\,), \tag{12}$$

$$Tgl = Tge - 1/(Cgs\ Weg)\ Qes \tag{13}$$

$$Qes = Kes\,Weg^{0.6}\ (Tge - Tet), \tag{14}$$

$$y = 100\ ((WA + Wg - WF\ Rs\,))/(WF\ RS\,) \tag{15}$$

State equations:

$$VF\ \partial XF/\partial t = 1/VF\ (CF\ WF + hA\,WA + \ldots$$
$$.+hG\,Wg - Weg\,heg\,RS\,(1 + y/100) - Qir - Qis, \tag{16}$$

$$\partial \rho g / \partial t = 1/\mathrm{VF}\,(\mathrm{WF} + \mathrm{WA} + \mathrm{Wg} - \mathrm{Weg}), \qquad (17)$$

where: VF -furnace Volume $[\mathrm{m}^3]$; ρg -exhaust gas density $[\mathrm{kg/m}^3]$; hg -inlet gas enthalpy $[\mathrm{kj/kg}]$; heg -exhaust gas enthalpy $[\mathrm{kj/kg}]$; hA -air enthalpy $[\mathrm{kj/kg}]$; WA -mass flow rate of the inlet air $[\mathrm{kg/sec}]$; WF -mass flow rate of the inlet fuel $[\mathrm{kg/sec}]$; Wg -mass flow rate of the gas to the furnace $[\mathrm{kg/sec}]$; CF -fuel calorific value $[\mathrm{J/kg}]$; Rs - stoichiometric air/fuel volume ratio; Qir -heat transfer to the riser $[\mathrm{J/s}]$; Qis -heat transfer by radiation to the superheated $[\mathrm{J/s}]$; Weg -mass flow of exhaust gas; Kf -friction coefficient (m sec); Kgs- an experimental coefficient(J/kg°K); Krs- an experimental coefficient(J/kg°K); href- reference exhaust gases enthalpy condition (J/kg); Tref-reference exhaust gases temperature condition(˚K); σ-Stefan-Boltzman constant; Pg -furnace air pressure $[\mathrm{Pa}]$; ; Tg -furnace air temperture (˚K); Reg-ideal gas constant for exhaust gases; Qgs -total heat transfer to the superheater[J/sec]; Qrs -heat transfer to the reheater[J/sec]; Qes -heat transfer to the economizer(J/sec); T-gas temperature at the superheater(˚K); Tgr -gas temperature at the reheater(˚K); Tge -gas temperature at the economizer(˚K); Tgl -boiler exhaust gas temperature(˚K).

3 Simulink Model

Simulink model have been developed from the mathematical equations (1)-(19). The dynamic behavior of the furnace has been found out introducing certain variation laws of the control input which stands for the fuel mass flow rate WF and specifying the time variation of the gas pressure inside the furnace.

Conclusion

In order to illustrate the dynamic behavior of the model, computer Simulation was carried out and responses to changes in inputs were obtained. One input has been changed at a time while others were kept constant. Figures (1 to 4) illustrate the responses of the state variables and input variables for a 15% Decrease in fuel input. From the figures, the response follows the general behavior of the dynamics of the furnace as proven on literature and it concluded that the simulation model depict the dynamics of furnace quite well and it can be used further as a part of boiler simulation toolbox.
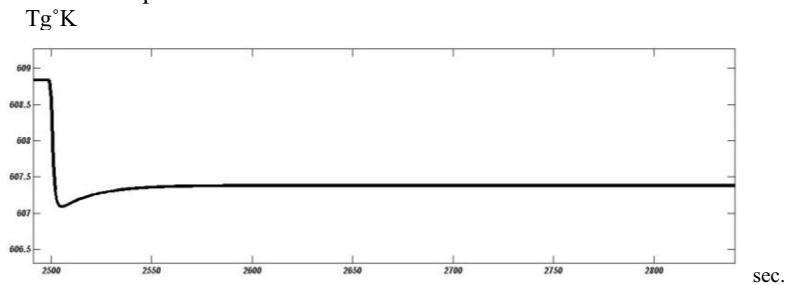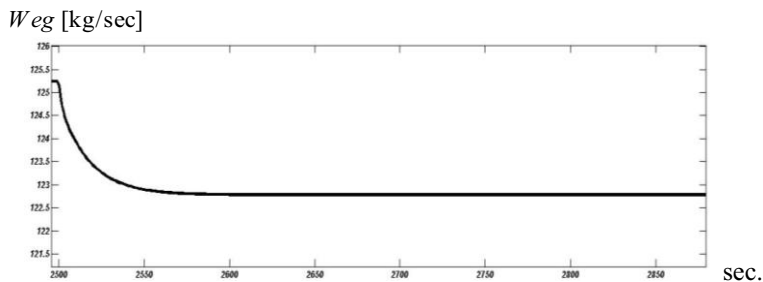

Fig. 1. The change of exhaust gas temperature Tg˚K with 15% change in fuel flow rate WF [kg/S]**.**
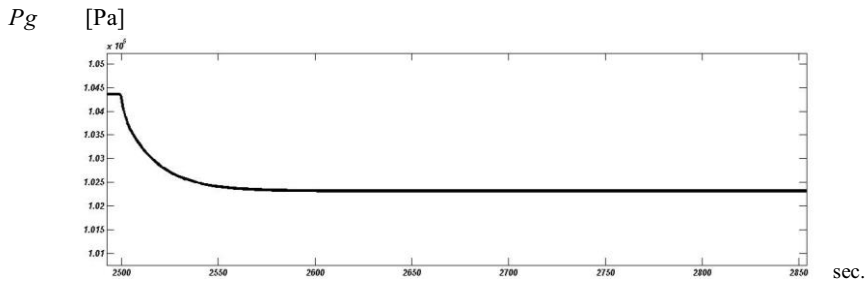
Pg [Pa]

Fig. 2. The change of exhaust gas pressure Pg [Pa] with 15% change in fuel flow rate WF [kg/S].

hg [kj/kg]
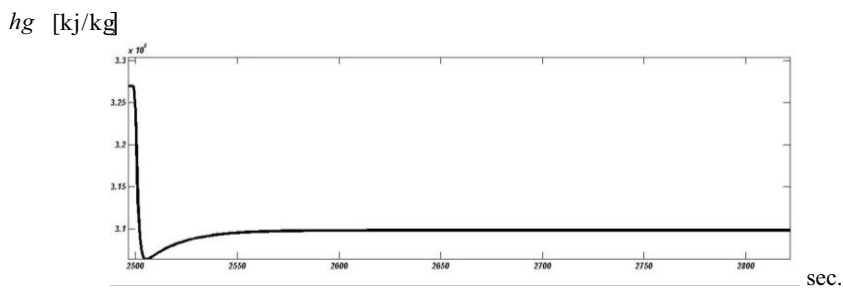
Fig. 3. The change of exhaust gas enthalpy with 15% change in fuel flow rate WF [kg/S].

Weg [kg/sec]

Fig. 4. The change of exhaust gas mass flow rate with 15% change in fuel flow rate WF [kg/S].

References

1. F. P. Ion, V. Ion, Technologies in Machine Building Galati, 23 (2012)
2. V.I. Ion, S. Craciun, Modelling and Optimization in the Machines Building Field MOCM-99, **2**, 143 (2003)
3. A.Salehi, A.R. Seifi.and A.A. Safavi, An Interdisciplinary Journal of Research, Theories and Observations, **9**(1), 99 (2008)
4. K.L. Chien, E.I. Ergin, C. Ling, A. Lee, Transactions of ASME, **80**, 1809 (1958)
5. Neaga C., et al., Works of the National Conference on Thermotechnics, May 23-24, 1997
6. Tuomas Kataja, Irdzhe Majanne, 14th Nordic Process Control Workshop, Sirkka-Liisa Ichia-Jounela (ed.), August 2007.