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Combustion Process Modelling and Control

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Modelovanie a riadenie procesov spaľovania

This paper deals with realization of combustion control system on programmable logic controllers. Control system design is based on analysis of the current state of combustion control systems in technological device of raw material processing area. Control system design is composed of two subsystems. First subsystem is represented by software system for measured data processing and for data processing from simulation of the combustion mathematical model. Outputs are parameters for setting of controller algorithms. Second subsystem consists from programme modules. The programme module is presented by specific control algorithm, for example proportional regulation, programmed proportional regulation, proportional regulation with correction on the oxygen in waste gas, and so on. According to the specific combustion control requirements it is possible built-up concrete control system by programme modules. The programme modules were programmed by Automation studio that is used for development, debugging and testing software for B&R controllers.

Key words: *combustion control, mathematical model, programmable logic controller*

Introduction

Technological processes of raw processing include many processes of transfer, accumulation and transformation of mass, energy and momentum. Combustion process is a typical transfer process. Fuel (e.g. natural gas, fuel oil, coal, coke) and oxidizer (generally air) are inputs to the combustion process. The air using is given its easy availability. Disadvantage of air using is big content of nitrogen. Due to the nitrogen volume it is combustion temperature lower. Waste gas is output from combustion process. Specific parameters of waste gas are volume, composition and temperature (Terpak, 2001).

Combustion processes are realised into continual and periodical device. Continual devices are following rotary retort furnace, agglomerating plant, continuous heating furnace, heating boiler etc., and periodical devices are hot-blast stove, car-type furnace, muffle furnace, coke oven etc. The individual device is represented typical form of control combustion, for example ratio control, program control, ratio control with correction on oxygen etc.

The cost of fossil fuel has increased constantly. Efficient combustion control system is possible to fuel economy. For realisation of the combustion control system on the PLC is more important system for its design, creation and testing.

Control system

Control system design is composed of two subsystems. First subsystem is represented by software system for measured data processing and for data processing from simulation of the combustion mathematical model. Outputs are parameters for setting of controller algorithms. Second subsystem consists from programme modules.

Combustion mathematical model

Basic of the analysis technological processes and of the synthesis control of technological processes is mathematical model. The model we can use for many cases, for example analysis of the process properties, analysis and design of the optimal operating mode, design of the new technologies, design of the technological equipment, indirect control, prediction and predetermination, optimalization and simulation (Turns, 1996; Moran, 1992; Rutherford, 1999).

From chemical point of view is combustion process oxidisation of fuel. The stoichiometric quantity of oxidiser is just that amount needed to completely burn a quantity of fuel. If more than a stoichiometric quantity of oxidizer is supplied, the mixture is said to be fuel lean, while supplying less than the stoichiometric oxidizer- (or air-) fuel ratio (mass) is determined by writing simple atom balances, assuming that the fuel reacts (CO, H_2, C_xH_y etc.) to form an ideal set of products (CO_2, H_2O, N_2 etc.).

The air surplus is commonly used to indicate quantitatively whether a fuel-oxidizer (air) mixture is rich, lean, or stoichiometric. The air surplus is defined as

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$$m = V_{air} / (V_{air})_{stoic} \quad (1)$$

where V_{air} is air volume for combustion [m^3], $(V_{air})_{stoic}$ is stoichiometric air volume for combustion [m^3].

The adiabatic flame temperature is determined from heat balance. If a fuel-air mixture burns adiabatically at constant pressure, the absolute enthalpy of the reactants at the initial state (T=298 K, P=101325 Pa) equals the absolute enthalpy of the products at the final state ($T=T_{ad}$, P=101325 Pa), e.i.

$$H_{react}(298,P) = H_{prod}(T_{ad},P) \quad (2)$$

where H_{react} is enthalpy of reactants and H_{prod} is enthalpy of products [$J.mol^{-1}$] of combustion process (Terpák, 2004; Terpák, 2005).

For lean combustion, nothing new is involved as we need employ only atom balance. For rich combustion, however, we employ a single equilibrium reaction, $CO+H_2O= CO_2+H_2$, the so-called water-gas shift reaction, to account for the simultaneous presence of the incomplete products of combustion, CO and H_2 (Turns, 1996; Moran, 1992).

The algorithm was realized for air surplus m ≥ 1 and m < 1 by the iteration method based on thermal balance. Algorithm for air surplus m ≥ 1 consists of the following steps of computation:

1 Start,
2 Stoichiometric value of air and air/fuel ratio,
3 Waste gas volume and composition,
4 Enthalpy of the reactants,
5 Assumption of adiabatic temperature,
6 Specific heat by the assumption of adiabatic temperature,
7 New adiabatic temperature,
8 Comparison of assumption and computation adiabatic temperature,
9 If absolute value of different temperature is greater than precision, then new assumption of adiabatic temperature and go to step 6,
10 If absolute value of different temperature is smaller than precision, then go to step 11,
11 Real temperature of waste gas,
12 End.

Algorithm for air surplus m < 1 consists of the following steps of computation:

1 Start,
2 Stoichiometric value of air and air/fuel ratio,
3 Theoretical waste gas species volume,
4 Different between theoretical and real volume of oxygen,
5 Enthalpy of the reactants,
6 Assumption of real temperature,
7 Equillibrium constant of water-gas reaction by the real temperature,
8 Volume of CO, H_2, CO_2, H_2O,
9 Waste gas volume and composition,
10 Chemical heat of CO and H_2,
11 Assumption of adiabatic temperature,
12 Specific heat by the assumption of adiabatic temperature,
13 New adiabatic temperature,
14 Comparison of assumption and computation adiabatic temperature,
15 If absolute value of different temperature is greater than precision, then new assumption of adiabatic temperature and a go to step 12,
16 If absolute value of different temperature is smaller than precision, then go to step 17,
17 New real temperature,
18 If absolute value of different real temperature is greater than precision, then new assumption of adiabatic temperature and a go to step 7,
19 If absolute value of different temperature is smaller than precision, then go to step 20,
20 End.

Neighbourhood of air surplus m = 1 is area of real combustion. For this condition it used the same algorithms as for air surplus m < 1 but oxygen ratio for combustion is defined equation

$$x_{O2} = A_0 + A_1\, m \quad (3)$$

where A_1, A_2 is coefficients from experimental data of concrete combustion device.

On figure 1 is showed output from simulation of combustion mathematical model.

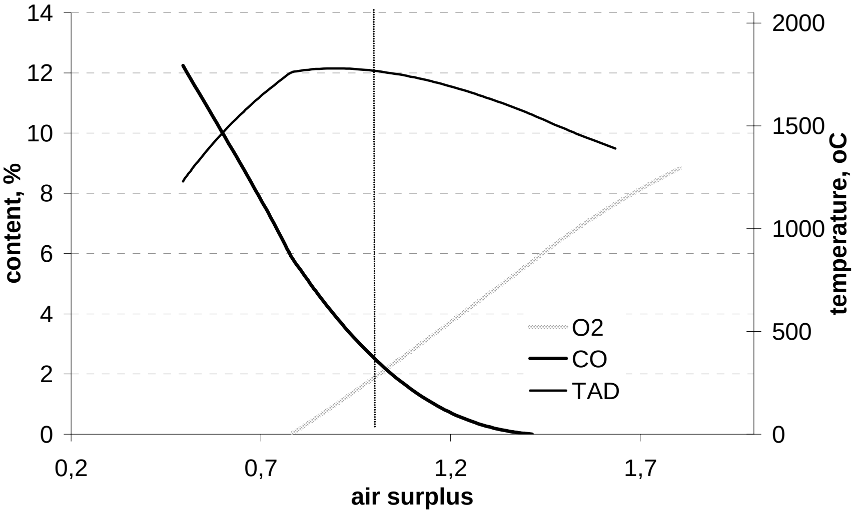


Fig. 1. Mathematical model simulation.

Programme module

The design of combustion control system is given by the requirement of specific combustion device. Due to the different requirement is developed modular system. Modules combination enables build up concrete control system. Modular system consists from following module:

- Ratio control,
- Ratio control with correction on oxygen,
- Ratio control with correction on temperature,
- Program control,
- Extremum control (minimum of sum oxygen and combustible component in waste gas),
- Extremum control (maximum combustion temperature),
- PID regulator,
- Combustion process.

Control system created has next behaviours:

- *Modularity* – Design of control system go from modules. From modules it is possible built up more complex control systems (Fig. 2).
- *Extensibility* – This system is extensible. According to the new modules requirement is possible appended next modules.
- *Synthesis* – Individual modules has exactly defined input and output which makes interface for connecting modules.
- *Simulation* – Created combustion mathematical model allows new control combustion system tested and set up.

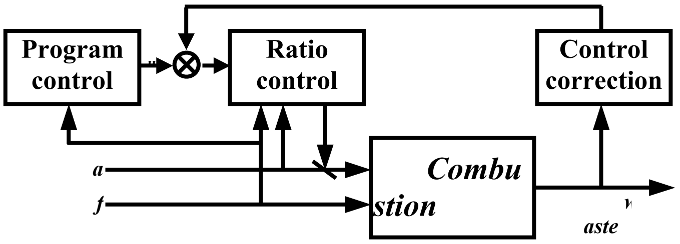
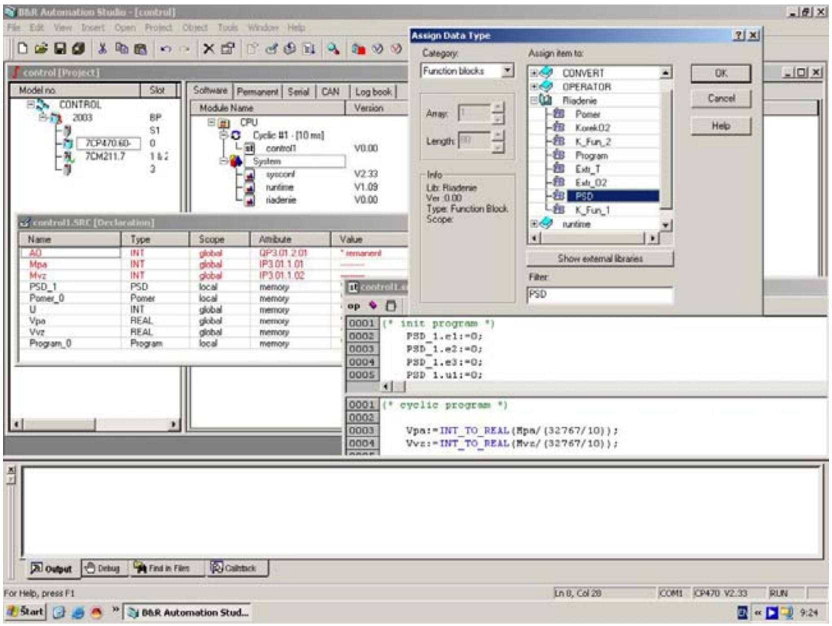


Fig. 2. Control system.

Implementation

The B&R programmable logic controller was using for implementation. The programme modules were programmed by Automation studio that is used for development, debugging and testing software for B&R controllers [Kwasniewski 2002]. Automation studio is user friendly and support user library creation (Fig. 3).



Name	Type	Scope	Attribute	Value
AO	INT	global	QP3.01.2.01	* remanent
Mpa	INT	global	IP3.01.1.01	———
Mvz	INT	global	IP3.01.1.02	———
PSD_1	PSD	local	memory	
Pomer_0	Pomer	local	memory	
U	INT	global	memory	
Vpa	REAL	global	memory	
Vvz	REAL	global	memory	
Program_0	Program	local	memory	

```
(* init program *)
  PSD_1.e1:=0;
  PSD_1.e2:=0;
  PSD_1.e3:=0;
  PSD_1.u1:=0;
```

```
(* cyclic program *)

  Vpa:=INT_TO_REAL(Mpa/(32767/10));
  Vvz:=INT_TO_REAL(Mvz/(32767/10));
```

Fig. 3. Automation Studio.

Conclusion

Combustion mathematical model was realised by Delphi and verify on the gas earth simulation (Fig. 1). Tools for approximation of measurement data was realised too. The program modules were programmed and verified (Fig. 4) in Automation studio.

The advantages of described system are modularity, extensibility and simple synthesis of the control systems.

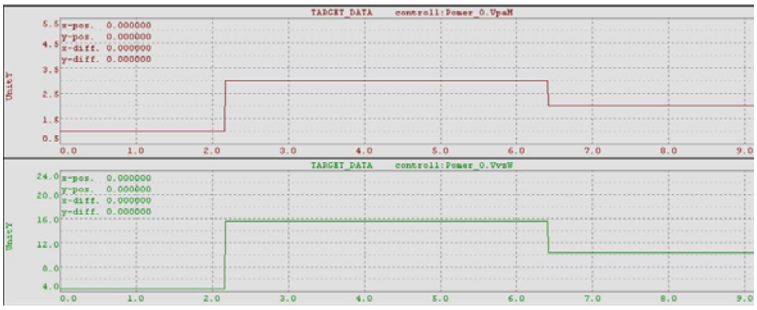


Fig. 4. Simulation of system control.

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