Boiler Control

The objective of most boiler plant used in the process industries is to raise steam for heating purposes, electricity production usually being of a secondary consideration. It is normal practice to produce and distribute the steam throughout the works at specific pressures, reducing it locally as required. Mains pressures are typically designated as being high (> 20 bar), intermediate (approximately 10 bar) and low pressure (< 5 bar gauge).

Most boilers used for raising steam are of the water tube type. In essence, they consist of many tubes, usually hundreds but maybe thousands, through which boiling water is circulated, as depicted in Figure 25.1. The boiler tubes, referred to as risers, are exposed to high temperatures in the combustion chamber where heat transfer takes place by a combination of radiation in the flame zone and convection in the exhaust gases. Most boilers have a steam drum. This acts as a header for the water entering the risers and as a disengagement space for the steam/water mixture leaving them. Fresh water is fed into the drum to compensate for the steam being withdrawn. It is not uncommon for the boiler feed water to be preheated in an economiser, by heat exchange with the flue gases, and for the steam produced to be further heated in a superheater.

There is much variety in both design and capacity of boilers. The nature of the fuel, whether it be gas, oil or pulverised coal, is fundamental to burner design and to the provision for fuel injection and air flow. Capacity ranges from a few hundred kW up to a thousand MW. From a control point of view the issues are much the same irrespective of feed type or capacity, although the complexity of the schemes used tends to increase with size. This is because with large boiler plant there is more scope for making significant savings through marginal increases in efficiency.

Coping with variable steam demand and the consequences thereof is the dominant design consideration. Demand can be subject to frequent, sudden and large changes as major steam users come on and off stream, although the capacity of the steam mains goes some way to averaging out the fluctuations. The steam flow is nevertheless wild. Boiler control essentially reduces to five main activities:

- Controlling steam supply pressure by manipulating the fuel flow rate
- Maintaining the correct fuel to air ratio
- Maintaining the water level in the boiler's drum
- Satisfying various environmental and safety criteria
- Maximising efficiency of combustion

Schemes for the control of a boiler taking these various factors into account are developed in this chapter. For a more comprehensive treatment the reader is referred to the text by Dukelow (1991).

33.1 Basis of Control

The most common strategy is to supply steam to the main at a constant pressure. A feedback loop may be used to manipulate the gas/oil flow, as shown in Figure 33.1. Thus, if the steam pressure drops the fuel flow is increased, and *vice versa*.

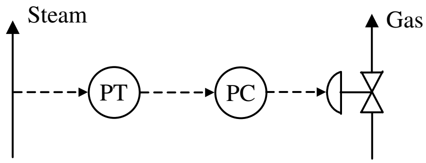

Fig. 33.1 Simple feedback control of steam pressure

To reject disturbances in the gas /oil supply system it is normal to use a slave loop in a cascade strategy, as depicted in Figure 33.2.

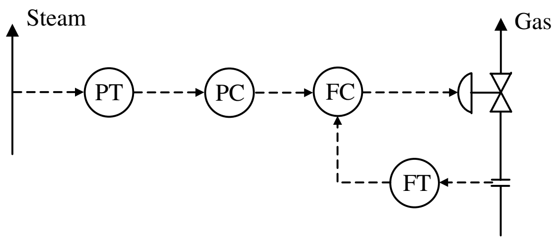

Fig. 33.2 Cascade control with slave loop for gas flow

Clearly, for combustion purposes, it is necessary to maintain the air flow in proportion to the fuel flow. This may be done directly using a ratio controller as shown in Figure 33.3.

Alternatively, it may be done indirectly using a ratio station and a flow controller, as depicted in Figure 33.4.

Note that disturbances in the air supply system are rejected in both direct and indirect approaches.

It is essential that the water level be maintained in the drum to ensure circulation through the boiler tubes and hence their physical protection. This is normally achieved by means of a cascade strategy, with the slave loop manipulating the boiler feed rate, and is discussed fully in Chapter 25.

A further complication with drum level control is the "swell" effect. Following a sudden decrease in steam pressure, the water in the drum flashes off and the bubbles formed temporarily increase its volume. This leads to an apparent increase in drum level even though the mass of water in the drum is decreasing. This is best countered by measuring drum level by means of pressure difference, as depicted in Figure 25.1, and by ensuring that the drum is large enough to accommodate any swell effects.

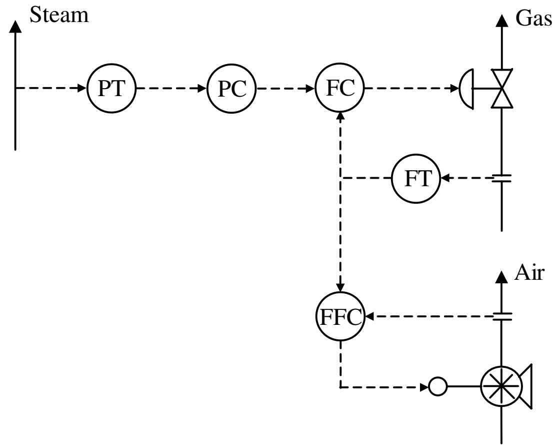

Fig. 33.3 Cascade control with ratio control between gas and air slave loops

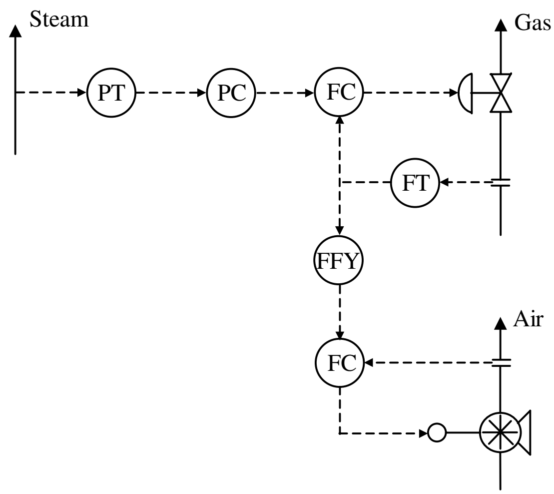

Fig. 33.4 Cascade control with indirect ratio control between slave loops

33.2 Signal Selection

There are important health and safety constraints in the operation of boiler plant. Incomplete combustion of fuel oil and pulverised coal leads to the emission of smoke, which essentially consists of particulates, and deposition of soot. The particulates are harmful to health and the soot deposits are a potential fire hazard. Also, incomplete combustion of gas, oil or coal produces carbon monoxide (CO) which is toxic, as opposed to carbon dioxide (CO_2). The CO can cause explosions when the hot flue gases come into contact with fresh air in the stack.

These effects are best countered by ensuring that there is always an excess of air present in relation to the stoichiometric requirements for combustion. This is particularly important when the fuel flow is being manipulated to meet changes in steam demand. An elegant approach to this problem is depicted in Figure 33.5.

Assume the system is at steady state and consider the effect of an increase in steam demand. The resultant decrease in pressure in the steam main would cause the output of PC47, which is the desired value of the gas flow, to increase. The low signal selector routes the lower of its two inputs to the set point of FC47A, the gas flow controller. Since the output of ratio station FFY47A is unchanged, it is this signal that would be routed through to FC47A, the gas flow remaining constant.

However, the high signal select routes the increase in desired gas flow through to ratio station FFY47B which multiplies it by a scaling factor R, the required air to gas ratio, to determine the corresponding desired air flow. This would then be applied to the set point of FC47B, the air flow controller. As the air flow increases, the ratio station FFY47A multiplies it by the reciprocal of R to determine the allowable gas flow. Since this signal would be lower than the output of PC47 it is routed through to the set point of FC47A which increases the gas flow. A new equilibrium would be established at which, provided the various elements have been calibrated correctly, the outputs of PC47 and FFY47A would be equal.

This scheme guarantees that, following an increase in steam demand, the increase in air flow leads the increase in fuel. A similar analysis reveals that, following a decrease in steam demand, the decrease in air flow lags behind the decrease in gas flow.

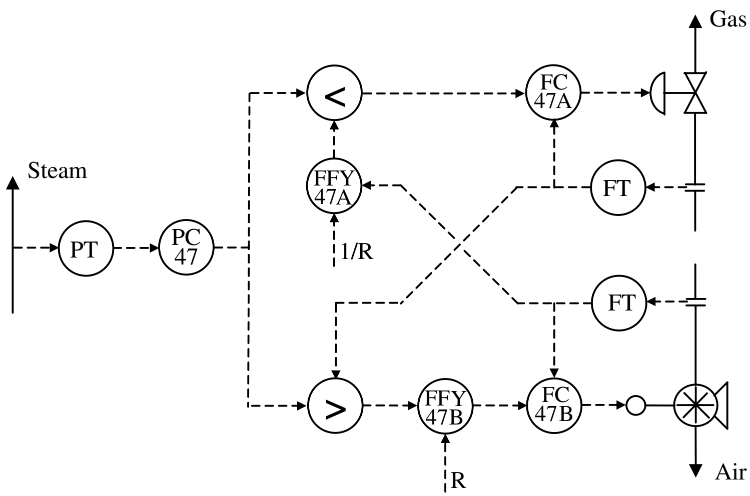

Fig. 33.5 Cascade and ratio control with signal selection

33.3 Ratio Trimming

The efficiency of boilers and their environmental impact are closely related. High flame temperatures are essential for efficient combustion. As stated, it is also necessary to have an excess of oxygen to prevent incomplete combustion. Given that air is 79% nitrogen, which is inert, it can be seen that only small amounts of excess oxygen will lead to significant dilution of the combustion process. This dilution reduces the flame temperature, leading to cooler combustion gases and less effective heat transfer to the water in the tubes. The excess must therefore be as small as is practicable.

However, low flame temperatures are desirable from an environmental perspective. The lower the temperature the less the scope for production of the NO_X gases (NO, N_2O_2 and NO_2). Also, most organic fuels contain sulphurous compounds, not necessarily in trace quantities. Again, low flame temperatures tend to mitigate against production of the SO_X gases (SO_2 and SO_3). All three forms of gaseous oxides, CO_X, NO_X and SO_X, contribute to global warming (greenhouse) effects and acid rain.

There is, therefore, a trade off between high efficiency and low oxide emissions. In practice, boiler plant is normally operated with some 1.0–1.5% excess air in relation to the stoichiometric requirements for complete combustion. The amount of excess air is normally monitored by measuring the amount of oxygen in the flue gas using a zirconium oxide based sensor. The output from the analyser is used to trim the air flow by adjusting the scaling factors R and 1/R applied by the ratio stations to the set points of the flow controllers. There are various ways of realising this.

- R may be adjusted by a ratio station in direct proportion to the O_2 concentration.
- R is the output of a PID controller AC47 whose set point is the desired oxygen concentration in the flue gas, as depicted in Figure 33.6.
- As above, except that the reference ratio R_r is externally preset and multiplied by a scaling factor which is the controller output as depicted in Figure 33.7. This output would normally be about unity and limited to a narrow band of, say, 0.98 to 1.02.

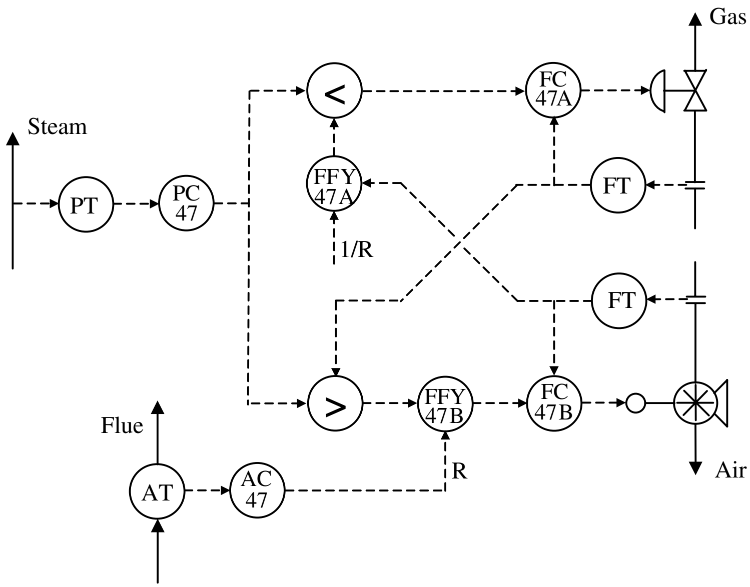

Fig. 33.6 Cascade control with signal selection and ratio trimming

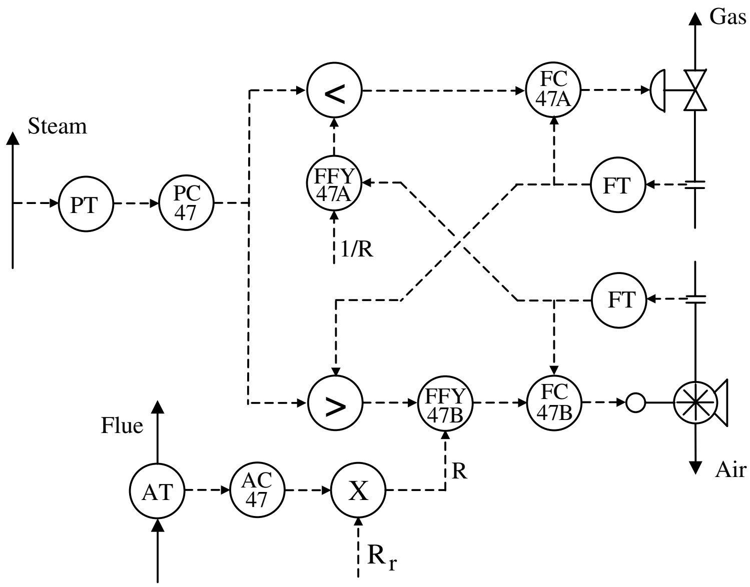

Fig. 33.7 Cascade control with alternative approach to ratio trimming

- As above, except that the reference ratio R_r is incremented by addition of the controller output. This output would normally be about zero and limited to a narrow band according to the calibration of the instrumentation.

An important bonus of the technique of using the oxygen content of the flue gas to trim the ratio setting is that it will respond to changes in the composition of the fuel. Suppose the composition changes such that the stoichiometric requirement increases, *i.e.* more oxygen is required per unit amount of gas. This will manifest itself in a reduction of the oxygen content of the flue gas resulting in the ratio being trimmed upwards to increase the air flow.

Also note that, for environmental purposes, it is common practice to monitor the carbon monoxide content of the flue gas and to use that as an input to a trip system which, in extreme circumstances, will shut down the boiler plant. CO monitoring also provides a useful means of cross checking the effectiveness of the O_2 based ratio trimming.

33.4 Comments

The boiler plant described is typical of that used in the process industries for steam raising and, as such, its control system is relatively simple. In the power industry, where the objective is to produce steam for driving turbines and generators, the boilers have very much greater capacity and steam pressures of 50 bar are not uncommon. Boiler plant is more highly integrated, involving economisers and superheaters, whilst ancillaries and back-up plant are more extensive. The control systems used on these boilers are more sophisticated with feedforward control, load scheduling, stand-by arrangements, *etc.*