Fast-acting shut-off and control ball valve application for control of gas flow rate to power plant boilers

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Abstract. The work describes the design and algorithms for controlling the fast-acting shut-off and control ball valve calculation of the reliability of the natural gas flow control system for the power plant boiler. Its application makes it possible to improve the quality of fuel combustion control, as well as to reduce the quantity of shut-off and control valves of gas channel, which in turn also leads to improvement of reliability of the system as a whole.

1. Introduction
The proposed fast-acting shut-off and control ball valve (FSCBV) is designed for use in gas storage systems of thermal power plants for control of natural gas consumption to burners of steam or hot water boiler.

Application of FSCBV allows to significantly reduce quantity and nomenclature of shut-off and control valves of gas line, as well as to improve the quality of fuel combustion control in boilers.

The design of the article includes elements: ball crane, fast-action insert, electromagnetic clutch, electric drive [1]. One of the differences of the device from the known one is the use of the position indicator of the valve locking element, which makes it possible to assess the state of the device in any mode of operation.

Gas consumption networks of thermal power plants (TPP) in the section of gas pipelines within boilers include several threads, each of which consists of elements: gate valve at the inlet, control valve of pressure of the 1 stage, silencer, control valve of pressure of the 2 stage, silencer and gate valve at the outlet. Safety discharge valves and output gate valve with an electric drive are arranged on the outlet gas pipeline.

On the straight section of the gas pipeline within the boiler, the following is installed:
- Orifice plate for measurement of gas flow rate per boiler;
- Shut-off valve - general-purpose safety shut-off valve connected with process interlocking and boiler protection;
- Gas supply valve (GSV) - for control of gas pressure on the boiler.

A manual gate valve and plug valve with an electric drive are installed on branch to each burner of the boiler. Besides, the boiler gas pipeline has flanges for plug installation, compressed air tie-in for gas pipeline blowdown and blowout plugs.

The structure of the described diagram is shown in figure 1.
1 - Motor-operated gate valve; 2 – contraction; 3 – general-purpose safety shut-off valve; 4 - gas supply valve; 5 - valve with safety plug; 6 - plug valve with the electric drive; 7 - manual gate valve.

Figure 1. Typical gas supply diagram.

Rules [1] allow alternative versions of implementation of gas supply schemes with the use of electrified gate valves and electrically driven fast-acting shut-off valves (FSV) before the burner provided that the common-cell safety valve is maintained.

The circular of the Department of Science and Technology "UES of Russia" C 03-97 (T) by item 1.13 provided for the possibility to develop industrial production of electrically driven fast-acting shut-off and control valves (FSCV), combining the functions of GSSV and CV and their installation for reconstructed operating gas supply systems of boilers.

2. Methods
The scheme is proposed with the use of FSCBV (fast-acting shut-off and control valve), which ensures compliance with the requirements and minimizes the costs of adjusting the protection and interlocking schemes to the current rules.

When using FSCBV, the following requirements are met [1]:
- The tightness of "A" class lock;
- Shut-off function response speed up to 1 sec;
- Compliance with the requirement "power supply shutdown shall cause valve closing (opening) without additional power supply from other external sources";
- GSSV material is made of steel based on operating gas pressure up to GDP.

At the same time, the costs for ensuring explosion safety of boilers during reconstruction works on gas pipelines within the boiler, protection schemes and interlocks are minimized, as:
- Works on the design of pipelines within the boiler are excluded by a specialized organization;
- Costs for purchase of fast-acting shut-off valves (AMAX type) and technical means of digital state control of shut-off and control valves are excluded;
- Costs for purchase of certified pipelines, electrodes, bends, etc., are excluded;
- Costs for project expertise, acceptance commissions of Rostekhnadzor are excluded;
- Costs for installation and adjustment works are significantly reduced.

FSCBV design is shown on figure 2: ball valve consisting of housing and ball locking element installed in it, electric drive with the drive shaft, fast-action insert connecting spindle of ball element, and the drive shaft of electric drive, position alarm mechanism. Fast-action insert design provides rigid a connection of spindle and drives shaft in gas flow rate control mode, as well as disconnection of the drive shaft and spindle with the subsequent forced fast rotation of ball locking element due to torsion spring at the removal of power supply voltage from the fast-action insert.
FSCBV is controlled by electric signals remotely and from the local control board. The main modes are:
- Change of ball shutoff element position during boiler normal operation
- Opening of electromagnetic clutch inside the fast-action insert for fast closing of the FSCBV at actuation of the boiler unit protection or at the check of the protection circuit
- Initialization of the position of the locking ball element at the first actuation of the FSCBV or after protection actuation.

The authors have developed and tested algorithms for control of FSCBV in all modes of boiler operation.

An example of a mnemonic diagram for the automated workplace monitor of the heat board is shown in figure 2. The mnemonic diagram shows the information on the position of shut-off and control valves, as well as values of process parameters (pressure, temperature, gas flow rate).
In accordance with the system reliability requirements [2], the availability factor of the Software Technical Complex (STC) shall be at least 0.99 with a maintenance period of 1 month. The diagram of reliability calculation using FSCBV is shown in figure 4.

As a result of the calculations, the probability of failure-free operation of the system is determined to be 0.991.

In order to determine the required materials for making the fast-action insert elements, equivalent stresses acting in the article elements are determined. Figure 5 shows the finite element split grid for strength calculation. The maximum length of the element side is 5 mm, the number of elements 6724. The number of knots is equal to 2109.

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As a result of static calculation of strength, the distribution of equivalent stresses by Mises is obtained, at the same time minimum and maximum values are 2.24 MPa and 38.26 MPa respectively. Application of special design of electromagnetic coupling in the insert speed of operation makes it possible to manually control the position of shut-off element in place by rotation of electric drive hand wheel without power supply need. The specified function allows us to safely perform adjustment of limit switches and position alarm mechanism, as well as manual control of the product after actuation of the protection circuit and absence of power supply.

When the voltage is released from the control circuit of the FSCBV, the coupling is disengaged, which in turn opens the shafts of the ball valve and the electric drive, and the valve returns to the closed position by means of the spring.

It is shown that in the flow rate range corresponding to the nominal operation mode of the boiler, the flow characteristic is linear. At low angles of FSCBV opening, the flow characteristic has a smoothly increasing character, which allows using of FSCBV for gas flow control in the boring mode without using additional bypass gas pipelines.

The FSCBV tests were carried out on the bench, the structure of which is shown in figure 6. The test bench verifies the correct control of the position of the shut-off element, the correct installation of the limit switches, as well as the life of the control and shut-off function.

The prototype control unit (PCU) allows us to manually act on the FSCBV: to open or close the valve, to start or stop the power supply to the electromagnetic coupling.

The PIM position alarm mechanism installed on the housing generates a current signal of the ball shut off element position in the range of 4-20 mA, which is supplied to the PLC and a switch indicator for visual monitoring of the prototype position.

The electromagnetic coupling as part of the fast-action insert has a power supply voltage of 24 V DC and is controlled with PLC and PCU.

Figure 7 shows block diagrams of FSCBV control in the manual (a) and automatic mode (b).
3. Results and Discussion
As a result of the tests, it was shown that the reliability of the product and the actual characteristics of the resourcefully meet the requirements of the regulatory documents and the indicators specified in the Design Statement of Work.

4. Conclusion
The use of FSCBV allows to significantly reduce costs for modernization of gas supply schemes of power units, improve operating characteristics of boilers, as well as simplify maintenance of gas units.

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