Virtual simulator of a boiler room

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Abstract. The use of virtual simulators, computer models of equipment and production processes, is already a necessity in the modern world. Teachers of KubSTU have developed and tested a virtual simulator of a hot-water boiler for theoretical training and development of skills in the work of both future and current thermal power engineers. This simulator is not only an effective learning tool but also the basis for creating a remote control system for a complex production facility, which is a boiler room.

1. Introduction

Currently, there are many computer simulators for training boiler-house personnel and students for working with heat-power equipment, including training in emergency situations. However, most of these simulators are presented in the form of thermal diagrams or flat schematic images of boilers and other auxiliary equipment. Such programs can improve the skills of students, as well as gain an understanding of the relationships between the various elements of the boiler room (or the boiler itself) and their influence on each other. However, without moving to the most realistic visual display of the equipment under study using three-dimensional models, it will not be possible to achieve truly effective training in accordance with modern requirements. Moreover, the use of such simulators becomes obligatory for a number of industrial enterprises.

Teachers of the Kuban State Technological University have developed a specialized virtual simulator for a hot water boiler (VSHWB) that meets modern requirements \cite{1}. The VSHWB training complex is designed to develop skills for working with the equipment of a hot water boiler room, as well as studying individual elements and equipment. The visual image and placement of elements of the boiler room are identical to real solutions (figures 1, 2).

This makes it possible to simplify and accelerate the transition from a theoretical study of boiler plants and auxiliary equipment to practical experience. The calculation of the main parameters of the heat power equipment and of the boiler room thermal circuit is based on mathematical dependencies and fundamentally coincides with the real characteristics of the facility, but it uses certain assumptions and limitations. These assumptions allow us to speed up the system operation. This happens while maintaining the correspondence between the data obtained in the model and during the operation of the existing facility in real conditions.

At the same time, the acquisition of primary operating experience takes place in virtual mode, saving the working time of the personnel, ensuring absolute safety when committing incorrect or erroneous actions that are unacceptable at a real facility.
Figure 1. Photo of a real boiler house.

Figure 2. Screenshot of the virtual simulator.
2. Research object description
The object of modeling is a boiler room. The boiler house has two main boilers with a capacity of 418 kW and one summer boiler with a capacity of 154 kW. The heat load is set at 600 kW for heating and 100 kW for hot water supply (HWS). The main fuel is natural gas with an inlet pressure of 25 kPa. The reserve fuel is diesel. It is fed by gravity from a tank installed outside the boiler room. Smoke removal is carried out due to stack draft through a chimney which is 15m high. A chemical water treatment system is provided at the boiler room due to an automatic system based on Na cation exchange. The circulation of the coolant in the supply and return piping is provided by a group of network pumps.

3. Methodology
The mathematical model that establishes the relationship between the control members, control objects, as well as indicating devices, in general, is as follows:

\[ F_{ij} = (\sum K_i) \cdot S_j \]  

where \( F_{ij} \) is the desired function, which can be either instrument readings or certain operations, for example, turning on the boiler or opening the valve;

\( K_i, S_j \) are input parameters, which are used as calculated values (temperature, pressure, etc.), and logical coefficients (1 - “on”; 0 - “off”).

It is obvious, that the model (1) contains both additive and multiplicative components, which allows one to take into account both quantitative and qualitative characteristics of the described processes. The proposed model is effective due to its simplicity and accuracy acceptable for practical calculations. Calibration of the model and its verification was carried out on the basis of a real-life hot-water boiler, which served as a prototype when creating the simulator. The calculated characteristics showed good convergence with real data, and the calculation error is permissible for educational purposes.

4. Simulator functionality
Functionally designed virtual simulator consists of the following sections:

1. Theoretical study of the following documents: hot water and steam boiler designs, designs of main and auxiliary equipment of the boiler room, instructions for the operators of the boiler room, safety rules for the operation of thermal power plants.
2. Practical study of structural elements of a boiler room taking into account their location in the boiler room. The effectiveness of training is provided by visual identity to the real equipment used.
3. Virtual study of the start and stop modes of the boiler room. Testing the knowledge of the start and stop mode of the boiler room.
4. Study of the personnel actions in emergency situations. Testing of knowledge of emergency procedures.

In the theory section, the user is provided with the necessary theoretical information for the successful study of the basic regulatory documents and safety rules. This knowledge is required for the personnel working with thermal power plants. In addition, brief information on the basic designs of boilers and auxiliary equipment is given [2].

After this, we provide the possibility of intermediate control of the studied material. Control is carried out using theoretical tests for each subsection.

In the start and stop simulator there are two modes - “Study” and “Exam”.

In the “Study” mode, the sequence of operations is strictly regulated and is accompanied by different prompts. These prompts appear in the upper corner of the screen when it is necessary to perform any actions. The learner's task is to remember the sequence of operations in order to start and stop the boiler.

The sequence of operations depends on the initial state. The simulator provides the following initial conditions:
1. Initial start-up of the boiler room after installation. In this mode, all pipelines require filling. It is necessary to start the “summer” boiler and the corresponding “summer” network pump.

2. Starting a gas-fired boiler room in summer. In this mode, all heating mains are filled with water, the gas pipeline is empty. It is necessary to start the “summer” boiler and the corresponding “summer” network pump.

3. Start-up of a boiler room in summer on reserve fuel. In this mode, all heating mains are filled with water, the fuel line with diesel fuel is empty. It is necessary to start the “summer” boiler and the corresponding “summer” network pump.

4. Start-up of a gas-fired boiler room in winter. In this mode, all heating mains are filled with water, the gas pipeline is empty. Both large boilers and associated mains pumps must be started.

5. Start-up of a boiler room in winter with reserve fuel. In this mode, all heating mains are filled with water, the fuel line with diesel fuel is empty. Both large boilers and associated mains pumps must be started.

6. Stop of a boiler room in winter on gas fuel. In this mode, all heating mains are filled with water; the gas pipeline is under pressure. Both boilers are in operation. It is necessary to stop the boilers and accessories, as well as to blow out the gas line.

   In the section “Emergencies” the following typical accidents are currently provided:
   - There is no voltage at the input;
   - The accident of boiler number 1;
   - The accident of boiler number 2;
   - The accident of boiler number 3.

   The system also provides for the “Study” of emergency situations and the “Exam” mode.

   The algorithm of operations before working in the “Study” mode is displayed on the screen in the form of a notepad with the tasks recorded in it. These tasks are crossed out as they are performed.

   In the “Exam” mode, there are no prompts in the form of a notebook. Only three errors are allowed during the course of a particular procedure. After completing all the necessary tasks, an assessment of the learner's actions is displayed on the screen.

   The simulator allows us to acquire skills while working with the heat and power equipment of the boiler room, simulating the operation of a real object. There is a multi-user mode, in which two or more people can train at the same time. This greatly expands training opportunities. The integration of this virtual simulator into the training system for heat supplying organizations will significantly reduce the risk of accidents associated with errors of personnel, and will also help develop an action plan for employees in case of emergency situations.

   The developed virtual simulator of a hot-water boiler room has already been introduced into the educational process when preparing bachelors and masters in the fields of heat power engineering and heat engineering at the Kuban State Technological University and is demonstrating its effectiveness. This software product is not the first one developed by teachers of the department of heat power engineering and heat engineering. A series of programs have been created and are actively used both in the educational process and in scientific research to determine the thermodynamic properties of air, water and water vapor, as well as to calculate the thermal circuits of gas turbine and combined cycle plants online [3, 4].

   In addition, it is planned that the mathematical model implemented in a computer simulator will serve as the basis for creating a remote control system for a boiler room, which will be the so-called digital double.

5. Conclusion

Teachers of KubSTU have developed and tested a virtual simulator of a hot-water boiler for theoretical training and development of skills in the work of both future and current thermal power engineers. This simulator is not only an effective learning tool, but also the basis for creating a remote control system for a complex production facility, which is a boiler room.
Reference
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