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SIMULATION MODELS IN INSTRUMENT SPECIALIST TRAINING

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Abstract: An approach to computer-based training of instrumentation users based upon simulation models of typical control objects is described. The approach provides effective learning and positive transfer of instrumentation operation skills. Simulation models of typical processes are described as well as the emulated measurement, continuous control and discrete control systems.
Keywords: Training, instrumentation, simulation model

1 INTRODUCTION

According to statistics existing [1], the percentage of operators' errors among all accident causes (e.g. in hydrocarbon industry) ranges between 22% and 55% subject to loss measure. For an average oil refinery this amounts more than $1,000,000 of annual loss [2]. It is no secret either, that unsatisfactory mastering of instrumentation handling procedures, which grow more and more sophisticated in state-of-the-art process control systems, plays the key role in erroneous process operation. Thus, according to [3], the lack of knowledge and skills of control system operation correlates with the errors in emergency causes identification, which amount to more than 25% of all operators' errors.

It is well known that Computer-Based Training Simulators (**CBTS**) is an effective tool of operators' professional skills forming and strengthening. CBTS involve operators into controlling a process model, whose dynamic response is close to the process's one, and the control environment resembles a real control system as regards to information sensing, organizing and processing mechanisms of operator's decision-making process. Naturally, the considerable part of CBTS methodological background is dedicated to training the skills of safe and efficient instrumentation handling. At the same time, CBTS for process operators are very expensive (ca. $1,000,000 for a process medium by volume of modeling). Above all, this is accounted by considerable diversity of processes as well as by appreciable labor inputs on modeling while developing CBTS for a specific process. Therefore, despite the popularity of CBTS in oil refining, chemistry, petrochemistry, pulp and paper production and other industries, they are not still as widespread as are, for instance, the simulators for atomic power stations and aircraft, the application of which is mandatory due to health and safety legislation.

At the same time, the skills necessary for measurement and instrument specialist basically exceed process operator's skills in instrumentation handling, on one hand, and almost concur for all processes and follows from their common features as control objects rather than from their specific nature, on the other hand. It is also clear that traditional (declarative) approach to instrumentation study cannot be considered as sufficient, because the weight of operating skills (especially of controller tuning) in the subject matter is too big to be mastered without specific training tools. As it is well known, the problem of mastering the skills of optimal controller tuning belongs to the most sophisticated ones owing to the objective difficulty of human foreseeing the response of a complex dynamic process. At the same time, instrument specialists (as well as process operators) training at the real plant is hardly possible owing to immense cost of inexperienced person's errors.

The paper presents an approach to instrument specialists training on the basis of CBTS provided with dynamic models of standard control objects. Simulation models of such objects as well as of necessary instrumentation are described; the experience of CBTS application is discussed.

2 SIMULATION IN ENGINEERING AND INSTRUMENT SPECIALIST TRAINING

Traditionally, simulation models were applied in various tasks of process engineering. One of the developed streamlines in this area is control system testing, mainly at the stage of new system commissioning. At that, the system under testing can either exist or be emulated. In the first case, complex testing of the control system, including both control strategy and controllers' parameters, can be undertaken by replacing real process outputs by the simulated ones. In the second case, only control strategy can be tested. In both cases one can speak about considerable acceleration of new control system startup owing to preliminary detection and elimination of configuring and tuning errors [4].

Furthermore, this approach allows solving the problem of optimizing the control system structure under specific standard procedures (such as process startup, shutdown, operation mode changes, etc.) and selecting optimal actuator characteristics. System parameter values are adjusted for various process operation modes; the prospect and feasibility of advanced control introduction is studied. Thereupon, application of simulation models for evaluating optimal control structure and multilinked controller parameters must be mentioned [5].

According to existing estimates [4], computer-based training of process operators and instrument specialists at the stage of new process or new control system commissioning more than covers CBTS costs only owing to cutting down startup period. In this case, it is basically important that process operating personnel gets an opportunity to practice new instrumentation upon simulation models with adequate dynamic responses. Convincing examples of the benefits of such training are recited in [6-8]. However, all experience accumulated in this field does not go beyond the scope of specific processes simulation and cannot be recognized as a standard solution of the problem. At the same time, the development of a CBTS intended for training the skills of process measurement and instrumentation systems operation seems both feasible and necessary.

Such CBTS developed by the author and his colleagues is described in [9] with special attention paid to its hardware, functionality, and information flows structure as well as to instrument specialists training procedures. This CBTS consists of a simulation platform and a wide range of process models. In the next section we describe a set of basic simulation models especially developed for measurement and instrument specialist training. They implement a wide spectrum of basic and advanced control techniques.

3 SIMULATION MODELS FOR INSTRUMENT SPECIALIST TRAINING

As it was mentioned above, the specificity of measurement and instrument specialists training allows conducting it on the basis of typical processes, which reflect generic features of objects under control and use various types of control loops. Here we describe a set of such models, which cover both basic and some elements of advanced control.

3.1 Liquid level with self-regulation

A tank with an inlet flow controlled is modeled. Its outlet flow is manipulated by a pneumatic control valve driven by a level control loop. The model contains all necessary elements of process equipment and measurement and instrumentation system: inlet and outlet block valves, input flow pump, DP cell and I/P transducer for tank level measurement. The simulation model recalculates the liquid level and the flows subject to control valves positions and pressure differentials over the valves. The process is self-regulated owing to tank’s hydrostatic head.

The trainee practices in controlling the tank’s level. He/she studies transients of tank level and bottom pressure under manual control, static characteristics of DP cell and I/P transducer, outlet flow features under linear or equal-percent control valves. Liquid level transients are monitored under inlet/outlet losses or ramping, under sensor, transducer, controller and control valve malfunctions, as well as under tank area and liquid density changes. Moreover, the simulation model provides training in P and PI-controller tuning under the changes of load and tank filling time.

3.2 Liquid level without self-regulation

This process is the same as the previous one; the only difference is that the outlet flow is pumped by a constant speed pump. This removes self-regulation effect. The trainee makes sure in the differences in controlling the level with and without self-regulation by studying transients under mass unbalance between inlet and outlet flows, flow loss or ramping, tank area change. Some P and PI-controller tuning exercises under various tank filling times and loads are also included.

3.3 Heat exchanger

Process flow, at constant temperature, enters the heat exchanger of shell and tube type through block and control valves. Cooling water flow is controlled subject to the process flow temperature at the tube outlet. Beside the flow rates, outlet temperatures of process flow and cooling water are simulated.

The training provides studying temperature transients under process or water flow losses, process flow or heat capacity changes and heat transfer surface fouling. The trainee also practices in tuning P, PI and (if necessary) PID temperature controllers under load changes and compares the results with the experience of level controller tuning.

3.4 Flow loop

A liquid flow pumped through a constant speed pump and a flow rate controller is simulated. Flow rate as well as pump suction and discharge pressures and the pressure downstream of the control valve are measured. The trainee studies (i) flow rate and pressures transients under pump malfunctions and suction pressure changes, (ii) P flow controller tuning with and without digital filter, (iii) PI flow controller tuning under load changes in comparison with level and temperature controllers tuning (see 3.1-3.3).

3.5 Continuous reactor

An exothermic reactor with a jacket for removing reaction heat is simulated. Reactant flow enters the reactor through block and controlled valves. The weight concentration of the reacted product is measured by an instrument located in the reactor's effluent line. Cooling water, at ambient temperature, enters the jacket through a block valve; its flow rate is regulated by a control valve driven by a controller, which measures the temperature at the center of the reactor bed.

The training includes the investigation of reaction temperature, cooling water and product composition transients under reactant flow and cooling water losses or changes and catalyst deactivation. The trainee masters PI temperature controller tuning under load changes and PID temperature controller tuning under reactant flow rate or reaction temperature increases.

3.6 Cascading control of gas fired heater

A gas fired heater, which heats a liquid charge flow with a fixed inlet temperature, is simulated. The charge flow is split into multiple flow paths. The charge outlet temperature is controlled by changing gas flow rate under possible disturbances in its pressure and heating value. Air rate, fuel/air ratio, furnace draft and burner management are assumed to be regulated for optimum combustion efficiency, heat transfer and safe operation; their adjustment lies beyond the scope of training. The cascade control loop is implemented, in which the "slave" controls fuel gas pressure. It receives the remote setpoint from the "master" temperature controller, which maintains constant charge outlet temperature. Such loop considerably improves process performance.

The training includes (i) single-loop temperature control system tuning, (ii) investigation of product output temperature's transients under the changes of setpoint, load, fuel gas pressure or heating value for local temperature control, (iii) independent tuning of master controller and slave control loop, (iv) switching and disconnecting the cascade control loop, (iv) investigation of output temperature's transients under the changes of setpoint, load, fuel gas pressure or calorific power for cascading temperature control.

3.7 Feedforward control

A mixing/blending process consists of three tanks. Tank 1 mixes two streams, each maintained by flow control loop. The first stream contains a fraction of chemical; the second one is pure water. The effluent from the Tank 1 is pumped through a control valve to Tank 2, where it is mixed with the stream, which is almost pure chemical the same as enters Tank 1. The effluent from the Tank 2 is pumped through a control valve to Tank 3, where it is mixed with a stream, which also contains some fraction of the same chemical. The flow rates of the chemical to Tanks 2 and 3 are measured but not controlled. The effluent from Tank 3 is pumped away through a control valve. The liquid level in each tank is maintained by individual level control loops. The composition of Tank 3 effluent is measured. The control objective is maintaining the value of chemical's concentration in Tank 3 effluent close to constant. The following control schemes are studied.

3.7.1 Concentration cascading flow

The concentration of the chemical in Tank 3 effluent is measured. The output of concentration controller drives the remote setpoimt of flow controller, which sets the necessary amount of water into Tank 1. The trainee studies concentration transients under the changes of master concentration controller's setpoint, flow rate and concentration of chemical at tank inlets.

3.7.2 Steady-state feedforward compensation

The foregoing control scheme proves to be ineffective under variations in the Tank 2 feed rate. The compensation scheme proposed provides measuring Tank 2 feed rate and adding its scaled value to the output of handset station, which adjusts the concentration of the process output. The adder's output is connected to the remote setpoint of water flow controller. Scaling and adder's coefficients are calculated to compensate for the change in the amount of the chemical entering Tank 2. Composition transients are studied with respect to water flow setpoint changes and chemical's concentration fluctuations in the feed to all three tanks. The trainee compares these transients with the ones for case 3.7.1.

3.7.3 Dynamic feedforward compensation

A lead/lag relay between scaler's output and adder's input (see 3.7.2) is introduced. The trainee studies composition transients under the changes of chemical's fraction in the feed of all three tanks.

3.7.4 Steady-state feedforward compensation with feedback trim

Under more frequent changes of chemical's fraction in the flow streams, it looks reasonable to combine the schemes 3.7.1 and 3.7.2. In this case, water flow setpoint is recalculated by adding scaled disturbance and the chemical's concentration at Tank 3 outlet. Concentration transients are studied with respect to the changes of chemical's composition setpoint, feed rates and concentrations.

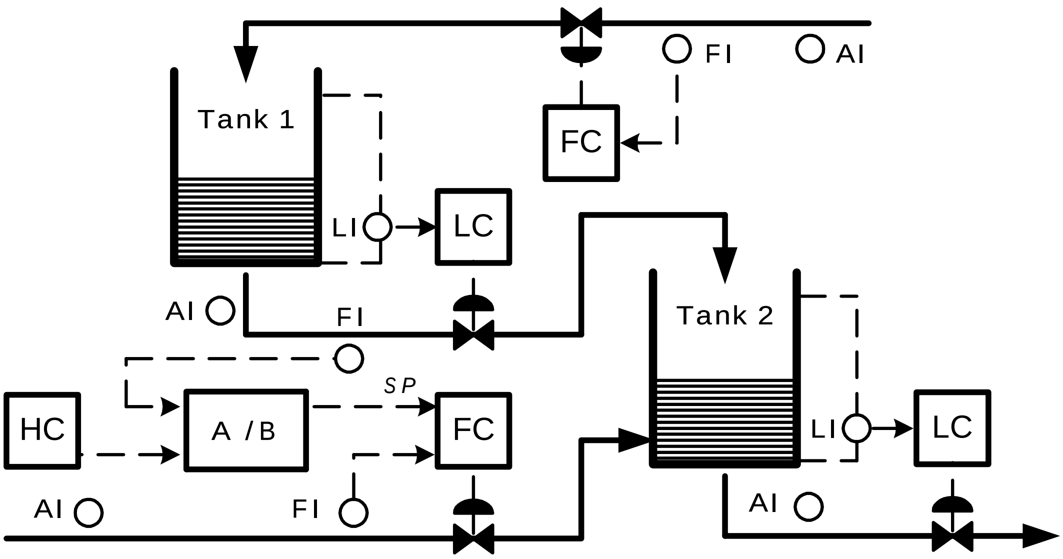

Figure 1. Two-tank blending process with ratio control

3.7.5 Dynamic feedforward compensation with feedback trim

This is the combination of schemes 3.7.1 and 3.7.3. The trainee studies the responses of Tank 3 outlet concentration with respect to the changes of chemical's composition setpoint, feed rates and concentrations.

3.8 Ratio control

A two-tank blending process (see Figure 1) is simulated. Each input flow stream contains specified concentration of a key chemical. Tank 1 has a single input flow maintained by a flow controller. This flow contains a constant weight fraction (ca. 90%) of the chemical concerned. Mass balance in Tank 1 is maintained by a level controller, whose valve is located in the line between Tanks 1 and 2. In Tank 2, the flow from Tank 1 is mixed with a second flow, maintained by flow controller. This flow contains constant weight fraction (ca.10%) of the chemical. The liquid level in Tank 2 is maintained by level controller with the valve located at tank's outlet.

3.8.1 Ratio control using handset station

One way to maintain the weight fraction of the chemical in Tank 2 outlet flow is to ensure a fixed mathematical relationship between both Tank 2 inlet flows. Taking into account that the flow from Tank 1 to Tank 2 is measured but not controlled, this can be accomplished by introducing a special ratio control block. This block provides (i) measuring the rate of Tank 1 outlet flow, (ii) multiplying its value by the ratio factor specified by a handset station, and (iii) sending the multiplication result to the remote setpoint of the flow controller, which controls the second flow to Tank 2.

The training includes sizing and calibration of the ratio relay and investigation of the blend's composition responses subject to the changes of Tank 1 and Tank 2 feed concentrations and Tank 1 feed flow rate.

3.8.2 Ratio control with feedback trim

Frequent changes of the concerned chemical's concentrations in both input streams require permanent adjustments of handset station. This can be avoided by the substitution of a concentration controller for the handset station so that the changes detected in the outlet fraction automatically cause a correction in the flow ratio. The affect of specified ratio, flow rates and compositions on the objective concentration is studied.

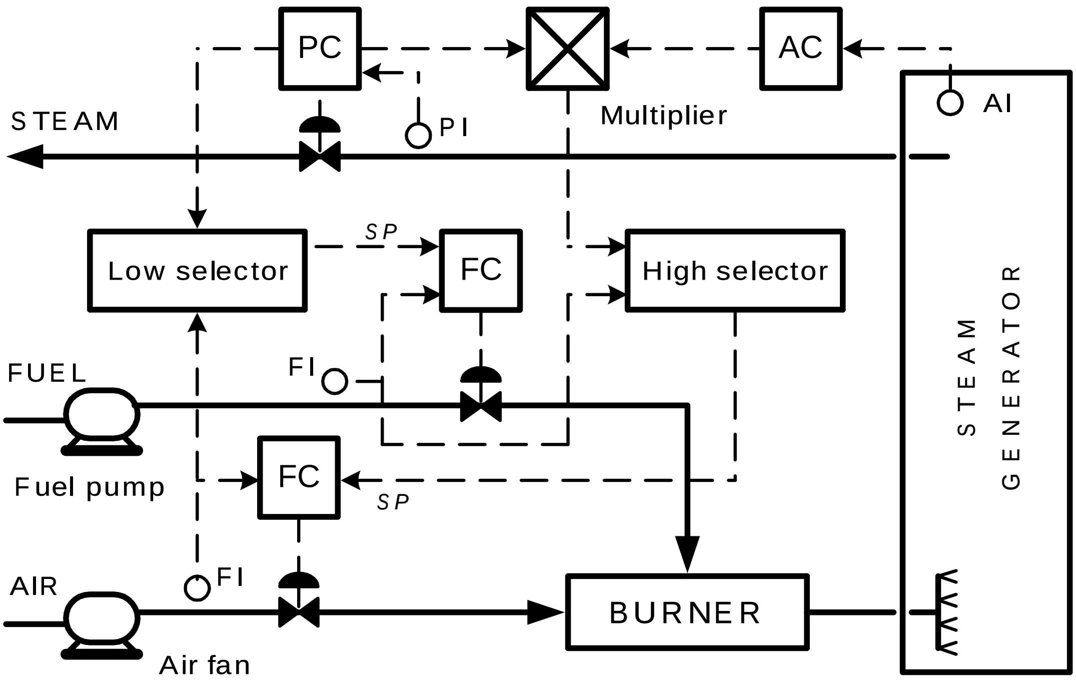

Figure 2. Steam generator with selector control.

3.9 Selector control

A boiler, which generates steam with specified pressure, is simulated (see Figure 2). The steam is generated owing to the combustion of fuel oil in a fired heater with air ventilation. Fuel/air ratio is controlled using a cross-selector scheme. Steam pressure is measured at the header by a pressure transmitter and fed to a pressure controller, whose output goes to a multiplier and a low selector. The second input to the multiplier comes from output of an excess oxygen controller, which adjusts fuel/air ratio to maintain specified weight percentage of oxygen in the stack gases. The multiplier's output feeds into one side of a high selector. The other input of the high selector comes from the fuel rate measurement. The output of the high selector drives the setpoint of the air controller, whose associated control loop acts to maintain the air rate called for by the pressure controller as corrected by the excess oxygen controller. The second input to the low selector is the air flow measurement, while its output feeds into the remote setpoint of the fuel controller. The fuel controller's flow loop maintains the fuel rate needed to maintain the steam header pressure. In normal operation mode both fuel and air are controlled by the master controller of steam pressure with correction from excess oxygen controller. Low selector ensures that the fuel rate does not exceed actual air flow, while high selector provides air rate never becoming less than the fuel rate.

The training includes comparative study of excess oxygen responses with and without cross-selection subject to the changes of setpoint and steam demand rate, fuel pump and air fan failures.

4 THE EXPERIENCE OF CBTS APPLICATION

The typical process models described were realized within a computer-based training complex together with a wide range of process models. They were tested while training measurement and instrument specialists and students of the biggest Russian petrochemical company (Angarsk, Russia). During recent 5 years almost all process operators and instrument specialists took primary and periodical training courses. Company's top management has emphasized considerable improvement of operators and instrument specialists skills and process operation efficiency, as well as the decrease of accident rate. The economic efficiency of personnel's computer-based training was estimated as $2,000,000.

5 CONCLUSION

The approach to process operators and instrument specialsts training combines state-of-the-art computer-based training technologies based on processes and instrumentation simulation with applicability to a wide range of industries. Application of a standardized CBTS, which contains typical process models as well as basic and advanced control facilities, allows vital improvement of process operators and instrument specialists training.

REFERENCES

[1] One hundred largest losses: A Thirty-Year Review of Property Damage Losses in the Hydrocarbon-Chemical Industries, M&M Protection Consultants, 9-15 Editions, 1986-93.

[2] V.Dozortsev, N.Shestakov, Substantiation of the possibility and economic expediency of developing a standard computer-based simulator for process operators training, presented to 5th Euromedia Conference "*Euromedia'2000"* (Antwerp, 8-10. May 2000).

[3] J.M. Van Eekhout, W.B. Rouse, Human Errors in Detection? Diagnosis, and Compensation for Failures in Engine Control Room of a Supertanker, *IEEE Trans. System, Man, and Cybernetics* **11** (12) (1981) 813-816.

[4] D.C. Pathe, Simulator a Key to Successful Plant Start-Up, *Oil and Gas Journal* **84** (14) (1986) 49-53.

[5] V.Mahalec, et al., Dynamic Simulation Applications in Process Control Design, in: *Proceedings of the 19th Annual Control Conference of Purdue University* (W.Lafayette, IN, 1993), p. 107-124.

[6] W. Barnet, Training Paves the Way from Analog to Digital Distributed Control, *Control Magazine* (June 1997), www.controlmagazine.com/0197/c0580197.html.

[7] S.S. Godbole, G.F. Malan, Low-Cost/Risk for Verifying Modifications to Dynamic Plant Operation and Instrumentation & Control System Resulting from Steam Generator Replacement, *Proc. 4th Intern. Conference on Simulation Methods in Nuclear Engng.* (Montreal, Canada, 1993).

[8] E.P. Lander, Improper Training Can be Explosive, *INTECH / Training: The Edge.* ISA Publication. (1993) 18-21.

[9] V. Dozortsev, D. Kneller, N. Shestakov, A simulation complex for instrument specialist training, in: *Proceedings of the XVI IMEKO World Congress* (Vienna, 26-28. Sept. 2000).

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