XVI IMEKO World Congress
Measurement - Supports Science - Improves Technology - Protects Environment ... and Provides Employment - Now and in the Future
Vienna, AUSTRIA, 2000, September 25-28

A SIMULATION COMPLEX FOR INSTRUMENT SPECIALIST TRAINING

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Abstract: A computer-based simulation complex intended for training instrumentation users (process operators, instrument specialists, measurement engineers and students of technical universities) on the basis of simulation models of typical control objects is described. The methodology of computer-based training, which provides high level of learning and positive transfer of skills of safe and efficient work with measurement and control systems, is applied. The experience of the training complex's application is discussed.
Keywords: Instrumentation, training simulaton complex, training didactics.

1 INTRODUCTION

The reliable and qualitative work of process instrumentation is a key issue of plant's safe and efficient operation. Industrial accident rate analysis [1] is evidence of the high percentage of operators' errors (22-55% of all failures and accidents). Most of erroneous operations are in their turn caused by inadequate evaluation of measurement instrument readings and incorrect operations with control system. This concerns also plant instrumentation specialists who are responsible for measurement and control system tuning.

Computer-based training (**CBT**) of process operators now finds wider applications owing to essentially new opportunities for the users in the world of modern information technologies. This concerns all traditionally emphasized components of CBT, namely simulation models, information models (operator interfaces), and teaching models implemented with the help of state-of-the-art computer-based teaching facilities. At the same time, vast variety and complexity of processes make these products extremely expensive. Potential clients can afford buying a full-scale computer-based training simulator (**CBTS**) only in cases of considerable industrial and environmental risks or under specific organizational considerations (new process unit commissioning, process or control system modernization, etc).

The situation in measurement and instrumentation specialists training looks different. Personnel's activities in this case concern typical behavior of processes as objects under control (sluggishness, time delays, stability, etc.) rather than their distinctive features. The set of basic instrumentation facilities is quite formalizable and can be realized as complete CBT toolkit. Possible applications of CBTS in this field look quite promising owing to wide variety of potential users, because the skills of measurement and control systems operation is at some extent necessary to all operative personnel of process units. At the same time, the standardizing of training tasks and tools together with the opportunity of enriching the CBTS with new models and control algorithms turns it into a powerful and competitive tool of personnel training. The role of process CBT becomes especially important at the stage of new process or control systems commissioning [2], where CBTS allows saving time (and money) during process startup and thus covers its own cost.

The paper describes a specialized computer-based training complex (named ***CTC-M***) developed by the authors. The complex is intended for training process operators, instrument specialists and students the skills of safe and efficient work with measurement and control systems. ***CTC-M*** is based upon the set of mathematical models of typical processes, which allow the trainee mastering all primary tools of measurement and control systems. The experience of ***CTC-M*** applications is also discussed.

2 THE STRUCTURE OF STANDARD CBTS

While developing a standard CBTS [3] the following issues look paramount:

- The trainee acquires skills during the course of specific, "virtual" activities, which simulates actual activities in measurement and control system operation at real process unit.

- Functional and information-flow structure of CBTS must comply with the substance of skills formation.
- The model of technical system (process plus measurement and control system) must include standard elements of measurement and control system as well as process model, which represents typical responses of the process as a dynamic object under control.
- CBTS is to be provided with a wide set of training exercises on measurement and control system tuning as well as on typical instrumentation failures and malfunctions, which ensure the completeness of skills acquired.
- The training tools must provide both self-training and the training in cooperation or under the control of a training manager (instructor).
- The skills of measurement and control system operation must be trained not only using *standard* processes models but, if necessary, the models of any process units. Therefore, CBTS must be easy to enrich with new process models.

Figure 1 depicts functional and information-flow diagram of CBTS for instrument specialist training. The diagram includes trainee's and instructor's interfaces ant a model of technical system, which, in its turn, consists of measurement and control system model and a model of the object under control ("extended process model"). The latter model can be subdivided into process model and the models of sensing and signal conditioning, information processing and effectuation [4].

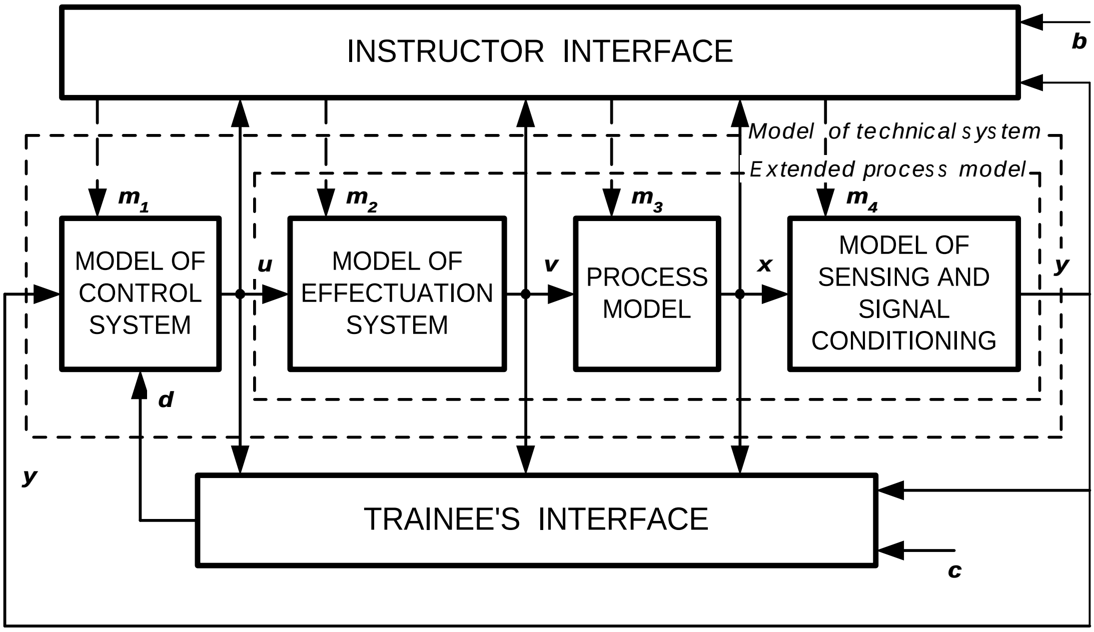

Figure 1. Functional and information-flow diagram of CBTS

User interfaces are developed subject to the specificity of user's functions. The information representation and dialog subsystems are emphasized; the latter provides user's interaction with all related components of human-machine training system. In trainee's interface, instrument specialist's interventions into technical system's operation $\boldsymbol{c}$ are processed by dialog subsystem into output variables $\boldsymbol{d}$ of trainee's interface, which are sent to control system simulated. In its turn, control signals $\boldsymbol{u}$ and observation signals simulated (measurements) $\boldsymbol{y}$ return to trainee's interface.

The structure of technical system allows standardization of various stages of CBTS development due to emphasizing standard, pre-fabricated elements to be configured in specific training applications and unique, custom components, mainly mathematical models of various processes. Vector $\boldsymbol{d}$ together with the observations vector $\boldsymbol{y}$ is converted by control system's model into control signals $\boldsymbol{u}$ subject to possible instructor's interventions $\boldsymbol{m_1}$ into control system's operation. Further, effectuation model, subject to possible instructor's interventions $\boldsymbol{m_2}$, elaborates the vector $\boldsymbol{v}$ of actuator positions. In its turn, these signals are converted by process model into the values $\boldsymbol{x}$ of flows and other physical variables (temperatures, pressures, levels, compositions, etc.). Possible instructor's interventions $\boldsymbol{m_3}$, which simulate instrumentation malfunctions, feedstock, material and ambient changes, are also taken into consideration here. Finally, measurement system model converts the vectors $\boldsymbol{u}$ and $\boldsymbol{x}$ into observations $\boldsymbol{y}$ subject to possible instructor's actions $\boldsymbol{m_4}$, which simulate various instrumentation malfunctions.

Instructor interface of a standard CBTS provides automated tools of training session management and supports such tasks as process and control system monitoring, trainee's activities supervision, interventions into technical system's operation, running training event log, saving, loading and activation of current technical system's states, computer-based analysis of training results and trainees' qualification. The representation and dialog subsystems can be also emphasized in instructor interface. The dialog subsystem converts vector $\boldsymbol{b}$ of instructor's impacts into the interventions $\boldsymbol{M} = \{\boldsymbol{m_1}, \boldsymbol{m_2}, \boldsymbol{m_3}, \boldsymbol{m_4}\}$, which are accessible to corresponding components of technical system. The instructor by way of his/her interface has an access to all signals generated by the technical system and to trainee's control impacts $\boldsymbol{d}$.

3 *CTC-M* – A TRAINING COMPLEX FOR INSTRUMENT SPECIALISTS

In this section we present a state-of-the-art simulation platform certified in 1997 as ***CTC-M*** (Multifunctional Computer-based Training Complex) [5]. It is realized on IBM compatible PC under Windows NT operational system with client/server network architecture. The platform provides opportunities of linking with real DCS (Distributed Control System) and precise emulation of operator interfaces. Minimal volume of RAM is 24 MB, HD 100 MB. An instructor station and several trainees' stations working simultaneously with various models may be connected with a LAN. The ***CTC-M*** software is written in C++.

The complex is supplied with configurator of trainee interfaces emulated. It allows computer-aided development of interfaces, which have the following properties:

- displaying information about process simulated and controlling the process in user-friendly way and in compliance with existing standards
- screens hierarchy, which allows easy search of information of necessary types and levels
- using color, sound and blinking for emphasizing information about process variable deviations from normal values
- basic and advanced control systems adjustment
- displaying process information in the form of current values (numeric or graphical) of its variables or as historic trends
- maintaining training event log, in which all trainee's and instructor's interventions into control system are reflected as well as all process deviations from normal operation mode.

3.1 Trainee's station

Besides the opportunity of developing operator interfaces, which comply with distinctive features and requirements of specific control systems, ***CTC-M*** is provided with a generic operator interface. This interface contains all typical tools of information representation and process control. The trainee acquires process information on various levels: process unit overview, areas and groups of equipment, etc. down to detailed information about each instrument, controller or switch, which allows monitoring and changing (within operator's competence) all adjustable parameters of process equipment and instrumentation.

Information on each level of generic interface can be displayed in any of 4 types of screens: process flow diagrams, status screens, trends, and alarm screens. Flow diagram is graphic representation of process equipment, pipes and instrumentation with current instrument readings and indication of control devices operation mode (e.g., On/Off for a switch or Manual/Automatic for a controller). Status screen is an analog of control board typical for processes where no DCS is still installed. Trend screens display families of historic trends thus providing operator with information necessary for analyzing process behavior and predicting its evolution. Alarm screens present information about all deviations of normal operation modes; therefore the information about all current disturbances is available for the trainee.

3.2 Instructor station

Instructor workstation is provided with high functionality for effective training session preparation and management as well as training results analysis. Its main functions are as follows:

- Allocating various simulation models to various trainee's workstations
- Loading various initial conditions for each model (e.g., Normal Operation Mode or "Cold" Startup)
- Model Start/Stop/Freeze function
- Simulation speed adjustment (real-time, accelerated, or slowed-down)
- Monitoring of process variables and historic trends from all trainees' workstations

- Simulation of process equipment and instrumentation malfunctions
- Remote control functions
- Snapshot functions (automatic and manual)
- Scenario functions (developing, saving and running scenarios of time-dependent interventions into process operation)
- Event log functions (recording, filtering, editing, printing, etc.).

In case of multiple trainees' workstations the instructor can control them simultaneously by displaying information from different workstations in various windows of instructor interface.

Owing to initial condition save/load functions and scenario services, the instructor has an opportunity of on-line saving and activation of any conditions of process simulated as well as time sequences of such conditions. It is a powerful tool of accumulating training and teaching experience and developing its methodological foundations. Thus, ***CTC-M*** is an open system, which can be extended and improved by the user according to accumulation of training experience, modernization of process equipment, instrumentation or process operation procedures.

3.3 The library of standard processes and instrumentation

CTC-M is provided with a library of simulation models of typical processes [6]. The processes included in the toolkit for instrument specialist training look quite simple and transparent from technological point of view and demonstrate a wide range of tools for basic and advanced process control.

The following 5 processes demonstrate distinctive features of *basic control*:

- **Liquid level with self-regulation**. Training includes tank level control. The trainee 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. The simulation model also provides training in P and PI-controller tuning under the changes of load and tank filling time.
- **Liquid level without self-regulation**. The trainee investigates the differences in controlling the level with and without self-regulation. Transients under mass unbalance between inlet and outlet flows, flow loss or ramping and tank area change are studied. Exercises on P and PI-controller tuning under various loads and tank filling times are included.
- **Heat exchanger**. 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 PID temperature controllers under load changes and compares the results with the experience of level controller tuning.
- **Flow loop** with constant speed pump. 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.
- **Continuos chemical reactor**. The training includes the investigation of reaction temperature, cooling water and product composition transients under process parameters changes. The trainee masters PI temperature controller tuning under load changes and PID temperature controller tuning under reactant flow rate or reaction temperature increases.

The following 4 plants are simulated in ***CTC-M*** for *advanced control* training purposes:

- **Gas-fired heater**. Cascading control of outlet process flow temperature due to gas fuel pressure is applied. Training includes (i) single-loop temperature control system tuning, (ii) investigation of product output temperature's transients under the changes of various process parameters, (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 process parameters.
- **Mixing process**. A chemical is mixed with water in 3 sequential tanks. Feedforward control scheme is applied in 5 versions: (i) cascading control of water flow to the 1st tank due to end product composition, (ii) steady-state feedforward compensation; (iii) dynamic feedforward compensation (iv) steady-state feedforward compensation with feedback trim; (v) dynamic feedforward compensation with feedback trim.
- **Two-tank blending process**. Blending 2 flows with various concentrations of target component in 2 sequential tanks is simulated. Ratio control with handset station or with feedback trim is applied.

- **Steam generator**. Selector control scheme is applied for controlling fuel and air flows to burners in order to maintain specified value of steam pressure.

4 THE CBT PROCEDURES FOR INSTRUMENT SPECIALISTS

The techniques of computer-based training of process operators and instrument specialists based upon the model of industrial operators' base and complex skills formation was described in [7]. This technique includes special exercises on formation and strengthening of the skills of troubleshooting, event cause detection and consequence compensation, as well as drilling intended for strengthening special abilities and skills in process transients analysis and basic and advanced controllers tuning. The technique also provides testing trainees' abilities, knowledges, and skills in safe and efficient work with instrumentation.

A set of training exercises on formation and strengthening of necessary skills in the field of process instrumentation is proposed [6]. The structure of a training exercise complies with the substance and the sequence of operator's actions in process of decision-making as well as with didactic method of prior forecast fixing [7], which considerably improves training efficiency and trainees' motivation.

CTC-M is used since 1994 for training instrument specialists and students of chemical engineering and process control in Angarsk Petrochemical Company (Angarsk, Russia). During recent 5 years almost all operative personnel of the company has passed through initial, repeated and periodic training. Annual revenue owing to CBTS application was estimated by Company's Top Management as $500,000.

5 CONCLUSION

The structure of a multifunctional computer-based simulator intended for training operating personnel the skills of safe and efficient operation was substantiated. Main functional blocks of ***CTC-M*** were described. Based upon interactive real-time simulation of typical processes with wide set of basic and advanced control facilities, the complex can be applied to training and certifying the personnel of chemical processes and power plants as well as the students of chemical engineering, process automation, measurement and other technical specialties.

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