ROMANIAN EXPERIENCE ON CANDU 600 FUELLING MACHINE TESTING

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Rezumat. *Maşina de Încărcat/Descărcat combustibil nuclear CANDU 600 este un mecanism complex care trebuie să funcţioneze în condiţii de securitate şi înaltă fiabilitate în reactorul CANDU. Procesele de testare şi punere în funcţiune a acestui echipament nuclear răspund înaltelor standarde ale cerinţelor unei Centrale Nuclearo-Electrice folosind facilităţi tehnologice speciale, instrumente de măsură moderne precum şi resurse IT adecvate pentru achiziţia şi procesarea datelor. Lucrarea prezintă experienţa Institutului de Cercetări Nucleare Piteşti, România, în testarea Maşinii de Încărcat / Descărcat CANDU 600, inclusiv facilităţile implicate, şi în dezvoltarea a patru simulatoare: două dedicate antrenării operatorilor Maşinii de Încărcat/Descărcat CANDU 600 şi alte două pentru simularea unor semnale de proces şi acţionări specifice.*

Abstract. *The CANDU 600 Fuelling Machine is a complex mechanism which must run in safety conditions and with high reliability in the CANDU Reactor. The testing and commissioning process of this nuclear equipment meets the high standards of NPP's requirements using special technological facilities, modern measurement instruments as well as appropriate IT resources for data acquisition and processing. The paper presents the experience of the Institute for Nuclear Research Piteşti, Romania, in testing CANDU 600 Fuelling Machines, including the implied facilities, and in development of four simulators: two dedicated to training the CANDU 600 Fuelling Machine Operators, and another two to simulate some process signals and actions.*

Keywords: CANDU Fuelling Machine; Testing; Simulator

1. Introduction

The testing and commissioning process of nuclear equipment meets the high standards of NPP's requirements using special technological facilities, modern measurement instruments as well as appropriate IT resources for data acquisition and processing, and reporting following client requirements.

The Institute for Nuclear Research (SCN) Piteşti, Romania, has the capabilities for studing, designing and conducting the equipment testing activities for nuclear power industry [1]. These activities are carried out under Integrated Quality Management System, official accredited by Lloyd's Register for ISO 9001-2000. The testing facilities and high qualified staff are licensed by the Romanian National Regulatory Authority for Nuclear Activity [2].

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As shown in Fig. 1, the CANDU 600 Fuelling Machine (CANDU F/M) is a very complex equipment, used to charge and discharge the nuclear fuel with the CANDU reactor in operation.

Fig. 1. CANDU 600 Fuelling Machine (partial view).

At the ends of a horizontal fuel channel, two F/Ms work, in tandem: the first receives the new fuel bundles from the "New Fuel Loading Port" and charges it, and the second discharges the spent fuel bundles to the "Spent Fuel Discharge Port". The CANDU F/M must run in safety conditions and with high reliability of service, thereby contributing to maintaining the reactor at full power. Testing for acceptance of this robot is important with respect to both safety and economics.

As a first veritable challenge, but also as a national and European premiere, at SCN Piteşti, were successfully tested two CANDU F/Ms for the Romanian Nuclear Power Plant (NPP) Cernavoda - Unit 2 [3]. Further, it was developed a numerical simulator of the CANDU F/M driving desk, a special PC application dedicated to training the CANDU F/M Operators [4].

In present, for the same training goal, at SCN Piteşti it is developing a hardware & software experimental simulator of the Fuel Handling (F/H) System [5], [6], [7].

2. Testing Facilities for CANDU F/M

The CANDU F/M testing facilities at SCN Piteşti were built up following a Romanian project, based on technical documents elaborated by AECL Canada, such as:

- two thermo-mechanical loops (hot and cold) with pressure tubes and end fittings, where light water flows are circulated with the parameters of real pressure tube, Fig. 2; the test channels are loaded with fuel bundles, shield plugs and closure plugs;

The cold loop performances (in the testing sections): process fluid: demineralised water (pH = 9.5÷10.5); flow: ~ 21 kg/s; pressure: ~110 bar; temperature: 20°C–110°C.

The hot loop performances (in the testing sections): process fluid: demineralised water (pH = 9.5 ÷10.5); flow: ~ 23.5 kg/s; pressure: ~110 bar; temperature: ~ 300°C.

Fig. 2. F/M testing rig: thermo-mechanical loops (partial view).

- a valve station and an oil power pack to activate the F/M head actuators, Fig.3;

Fig. 3. F/M testing rig: valve station (partial view).

- bridge, carriage and catenary to perform the centring and fixing of the F/M head on the end fitting, Fig.4;

Fig. 4. F/M testing rig: bridge, carriage and catenary (partial view).

- control room panels and computer control system compatible with F/M head, Fig.5.

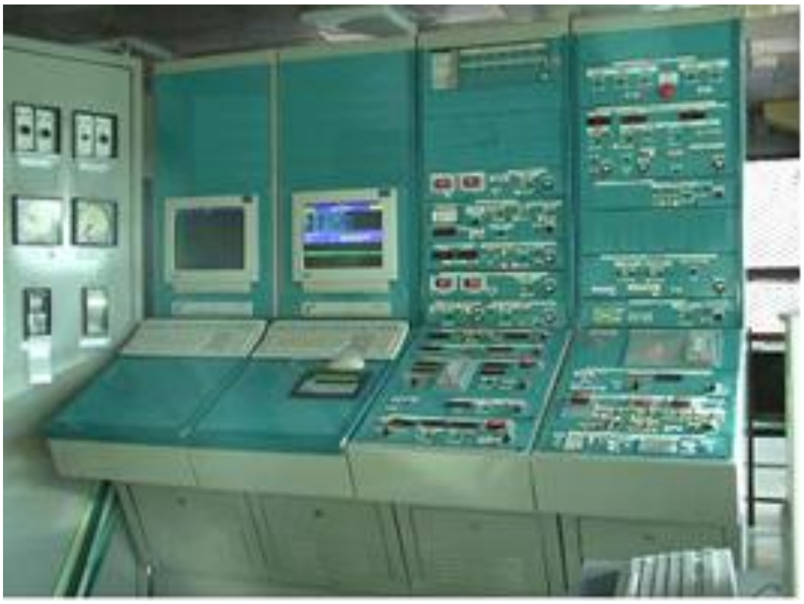

Fig. 5. F/M testing rig: control room (partial view).

In any technical conditions the computer control system provides: specific functions to control testing process as: supervising technological tests parameters, generating commands, recording data etc.; equal functional charges for all the system items; ergonomically space distribution for peripherals; modular design that improves reliability and offers functional assurances; system development with minimal hardware and software changes.

Testing of the F/Ms #4 and #5, and of the RAM #7 for Cernavoda NPP Unit 2 was performed on the test section having similar facilities to those of the fuel channel from reactor (closure plug, shield plug, 12 fuel bundles), after providing of the process parameters (T = 300°C, p = 110 bar, Q = 23.5 ÷ 24.5 kg/s), the fuelling machine head performed automatically and repeated, without any intervention of the operator, the Special JOB R6 - a program to change the nuclear fuel similar to reactor program. During these tests, the accurate execution of the specific steps of each component part of the F/M, and of the interconnections between components has been checked. In the same time, operations were performed to prove the safety in operation of the F/M head, both of the eventual operating errors and regarding the reliability and the strength of the F/M head components, within the time limits attached to them.

The tests were performed under the control of a Computer System in Automatic Mode. For the F/M testing acceptance, only the normal operator action is permitted, but not any emergency manual intervention. Made under the Quality Assurance Program's requirements [8], the tests were supervised and reported as a Romanian success by an AECL team. Let us remind here that today the Institute for Nuclear Research Pitești is accredited by Lloyd's Register for ISO 9001-2008. By its endowment the F/M test rig function could be extended in order to perform other kinds of activities such as: personnel training, failure simulation, etc.

3. Numerical simulator of the CANDU fuelling machine driving desk

The Numerical Simulator of the CANDU fuelling machine driving desk is a special PC program (software application) that simulates the graphics and the functions/ operations of the main desk of the Computer Control System, Fig. 6.

The main program's characteristics are [4]:

- it offers a realistic, graphical simulation of the Computer Control System's desk at 1:4 scale (compare Fig. 5 and Fig. 6);
- it offers a graphical and functional simulation of all objects from the desk: 12 linear and nonlinear analogue instruments (ammeters); 21 digital instruments (voltmeters); 37 two/ three vertical positions switches; 27 two/ three/ four/ five horizontal positions switches; 160 white/ yellow/ orange/ red/ green coloured lamps; 2 PC Colour Displays; 2 PC 101 Windows Keyboards; 1 Handy (special dedicated) Keyboard.

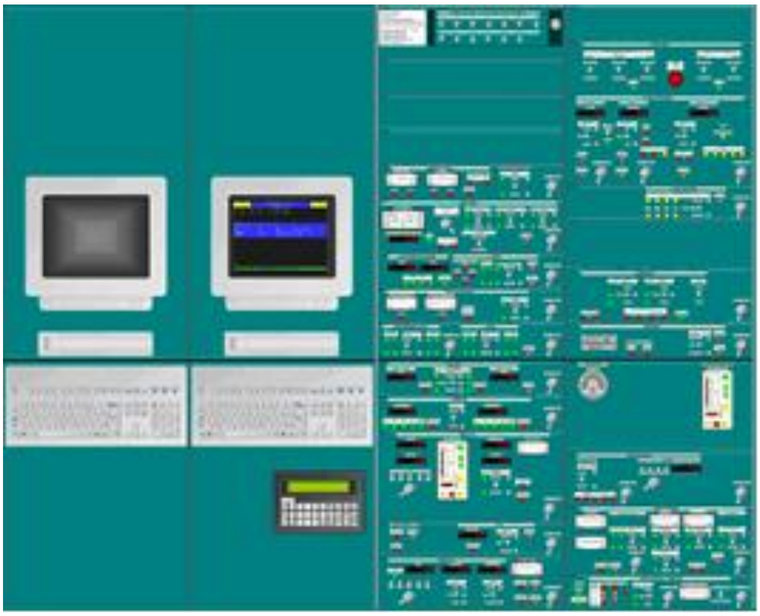

Fig.6. Graphics of the numerical simulator.

The program is dedicated to simulate:

- check, setup and calibration for the CANDU F/M components' instrumentation: snout clamp; snout probes; magazine position; high pressure drain valve; B-RAM: position, force, speed and pressure; Latch-RAM: position, force, speed and pressure; C-RAM: position, force, speed and pressure; feelers, retractors and separators fuel stops;
- running the Special JOB R6 in cold and hot conditions.

For an accurate and realistical "response" of the F/M and of the testing rig components at the operator's commands, the authors developed and implemented in the specialized software application the mathematical models of all physical phenomena which take place, i.e.:

- the time evolutions of the thermodynamically and hydraulically parameters: temperature, pressure, flow, fluid's leakage;
- the exactly mechanical positions and speeds of the CANDU Fuelling Machine components: snout clamp; snout probes; magazine position; high pressure drain valve; B-RAM: position, force, speed and pressure; Latch-RAM: position, force, speed and pressure; C-RAM: position, force, speed and pressure; feelers, retractors and separators fuel stops; shield plugs, CANDU fuel bundles etc.;
- the calibration functions for all linear and nonlinear analogue instruments (ammeters) and digital instruments (voltmeters);
- the logical and sequential automation rules for switches and lamps.

The program works with over 2000 variables and constants, well: 103 analogue inputs (AI), 138 digital inputs (DI), 68 digital outputs (DO), 19 flags (FL), 186 set points (SP), 57 technical tolerances, 149 technological constants (CT) etc.

Statistically, the numerical simulator uses (in the Delphi programmable language): 124 graphical objects of TImage type; 363 graphical objects of TShape type; 69 graphical objects of TLabel type; 114 graphical objects of TSpeedButton type; 777 procedures; 205 functions etc.

4. Fuel handling experimental simulator

The equipment is an experimental model dedicated to practical verification of technical solutions in achieving an "Independent F/H Simulator" (see Fig.7).

Fig.7. The experimental model of the simulator.

Analyzing different variants of simulator, of the complexity level desired to be reached, and of the training program existing now in the plant, the authors have identified the following advantages, both economical and with impact on quality of the training process [7]:

- Allowing license and re-license of the operator in an environment without risks, similar to reactor control room, where the operators can focus on the process free of responsibility stress in case of first time operation into a real and dangerous potential installation;
- Concentration and reduction of the training period, and also increasing the training students flow, and thus enabling the staff to cope with it at the administrative level;

- Consolidation of students' professional knowledge and release of the operation stress in high risk condition;
- Accommodation of future operator with the entire operation set taking place in the control room during refueling activities, and especially with the operations in manual regime, that are performed in the plant only in event condition;
- Execution of the control desks such as to remake in detail the aspect and structure of desks from reactor control room, so as the future operator, after the end of the training program, would be able to operate directly and easily the real installation;
- Simulation of a large events set in exploitation of FHS that requires the operator to understand, to find out and to apply, on short term, the solutions to normalize these condition;

This practical execution enables us to establish the requirements and details for both the real hardware simulator, and, especially, for the software packages to be designed and implemented in it. It will be established general models for courses, questionnaires and automated tests, whose difficulty increases gradually during training, and that allow a rigorous monitoring of the training level achieved by the operators. It will also be designed and tested before implementation, a broad set of F/H operation incidents, requiring the operator to understand, to find and quickly implement solutions needed to normalize the event.

The experimental simulator model comprises three parts: two parts designed for command and control and, a part designed for the process computer. It reproduces the minimal necessary of equipments and apparatus existing in the control room of the Cernavoda CANDU reactor needed to simulate, partially but coherent, the response of the technological installations involved by the Fuel Handling System. The covered technological area will focus exclusively on the simulation of F/M head’s operation during his service at the fuel channel, situation considered to be sufficient to meet the purposes of the experimental model.

Basically, the experimental model allows the accurate execution of the entire set of operations that usually take place during fuelling, in automatic and manual mode, but limited to fuel channel operation, whether the machine works upstream or downstream, with fresh fuel supplies, or burned fuel.

The software structure is represented on the one hand by the applications dedicated to simulate I/O signals, and on the other hand by the applications needed in the data streams’ transmission.

The whole software development strategy focuses on the real-time fault tolerance and fairness execution of the specified functions.

The main programming languages and platforms are ISaGRAF and LabView. Some obtained results are saved as a Microsoft Access database.

5. Another two simulators

As we have shown, the hardware and software simulators described above are mainly dedicated to operators training.

For process applications, at SCN Piteşti were also developed and implemented another two hardware simulators, an electrical one, Fig. 8, and a mechanical one, Fig. 9.

As a parallel system generating signals and performing actions, the Electrical Simulator and the Mechanical Simulator are used in the F/M testing rig to provide some important initial adjustments for the effective F/M tests.

In the present, at SCN Piteşti, we are working to improve the technical performances of all these F/M testing facilities, the most recent example being the 2.1 MW electrical heater [9], [10].

Fig. 8. The Electrical Simulator.

Fig. 9. The Mechanical Simulator installed at the valve station

Conclusions

Involved in the development of nuclear energy, the Institute for Nuclear Research Piteşti represents the technical support for the safe and economical operations of the Romanian nuclear power plants, in respect with the international agreements on the safety of nuclear installations.

The Institute always had and still has as a main task sustaining research and other activities related to the peaceful utilization of nuclear energy. In this respect, testing the Fuelling Machines at SCN Piteşti is a part of the overall program to assimilate, in Romania, the CANDU technology.

Having developed methods, computer codes, and its own experimental infrastructure directed towards the making of end-products, technologies or services with applications in the nuclear power plants area, the Institute for Nuclear Research, Piteşti, has the facilities, the staff and the experience to perform possible co-operations with any CANDU Reactor owner in the testing, theoretical modelling, simulation and training directions.

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