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OUT OF REACTOR TESTING TECHNOLOGIES OF F/M HEADS – ROMANIAN EXPERIENCE FUNCTIONAL TESTING OF TELESCOPIC CYLINDER RAM ASSEMBLY

Serban Constantin VALECA[1],
Virgil COJOCARU[2]

Rezumat. *Testarea capetelor MID (maşina de încărcat/descărcat) înainte de introducerea lor în reactorul CANDU este o activitate de maximă importanță în procesul de punere în funcțiune a centralei nucleare – electrice. De reuşita acestei activități ce se derulează pe perioada de 9 luni pentru un cap MID, depinde exploatarea în condiții de siguranță şi putere maximă a reactorului. Finalizarea testării capetelor MID pentru Unitatea 2 de la Cernavodă, certifică atât buna funcționare a maşinilor cât si capacitatea personalului si a tehnologiei existente la ICN Piteşti de a realiza activități de o mare complexitate pentru centralele nucleare, testarea mașinilor reprezentând o premiere națională si europeană.*

Abstract. *Testing of F/M Heads (loaded/unloaded car) before installing them in the CANDU reactor is a task of utmost importance in the process of commissioning the nuclear power plant. Maximum capacity reactor operation in safe conditions depends on successfully testing of the F/M Heads. Completion of F/M Heads Testing for Cernavoda Unit 2, certifies both the proper functioning of the machinery as well as the ability of the staff and existing technology from INR Piteşti to achieve complex activities for nuclear power plant, F/M Heads testing being a national and European premiere.*

Keywords: CANDU, Fuelling Machine Head, testing rig, acceptance test

1. Introduction

CANDU reactors are PHWR type (Pressure Heavy Water Reactor) reactors using natural UO_2 fuel and heavy water as a coolant and moderator.

An important feature of this type of reactor is the fact that it does not require to be shut down in order to be refueled. The fuel change is done automatically, while the reactor is operational, by two loading/downloading machines [Fuelling Machines Heads].

Two F/M Heads, which work in tandem, are used in a CANDU 600 reactor: one introduces fresh fuel in the reactor fuel channel; while the other receives the spent (burned) fuel.

The proper operation in safe conditions of F/M Heads is one of the conditions that determine the efficient and secure operation of the CANDU NPP; the on-time fuel

[1]Title: Prof. PhD Eng. University of Piteşti, Piteşti, Romania (serban.valeca@nuclear.ro).
[2]Eng., INR Piteşti, Piteşti, Romania (virgil.cojocaru@nuclear.ro).

change allowing operation at maximum capacity of the reactor, and a malfunction of F/M Heads while being coupled on the channel of the reactor is resulting in system failure.

The occurrence of these failures has major implications locally (radiation exposure of operating personnel and repair teams, material costs) but also nationally (stop in electric power supply to the national network).

For this reason the Fuelling Machine Heads require screening and rigorous testing before their installation into the reactor, in order to have the guarantee of their good functioning while operating in the fuel channel - this is an implicit condition of nuclear safety.

For this purpose machines go through several pre-acceptance and acceptance tests, during which they are adjusted, calibrated and functionally checked.

The testing of the Fuelling Machines Heads for CANDU plants all over the world, including Cernavoda NPP Unit 1 was performed in the AECL Laboratories, Canada.

The Fuelling Machine Heads used For Cernavoda NPP Unit 2 have been tested between 2003 and 2005, as a national premiere at Institute for Nuclear Research, Piteşti.

2. The Fuelling Machine Head (loaded / unloaded)

The F/M Heads (fig. 1) is an electro-mechanic-hydraulic system which through its components [i.e. the snout assembly, the separators assembly, cartridge housing, telescopic cylinders assembly (TCA)] achieves the loading / unloading of the CANDU reactor, with a high degree of reliability under operational and radiological safety conditions.

In a CANDU reactor, the F/M Heads work in tandem: a F/M Head receives fresh fuel from the fuel gate, transports and loads it into the fuel channel, while the other F/M Head receives the spent fuel and transports into burned fuel gate.

In this context, the F/M Head can be considered a pressure vessel, namely as a component of the primary heat transport system, allowing fuel handling in the core area of the nuclear reactor.

In a full cycle of exchanging nuclear fuel with the reactor in operation, F/M Head follows the steps:

- Preparation for coupling on the fuel gates
- Coupling to load the magazine with the required new fuel bundles;
- Transferring of the new fuel to the reactor;
- Pressurizing the magazine housing;

- Positioning, coupling on the fuel channel and opening it;
- Performing the exchange of fuel (loading of the fresh fuel, unloading spent fuel);
- Closing the fuel channel and decoupling of the end fitting;
- Transporting the spent fuel to its burned fuel gate and downloading.

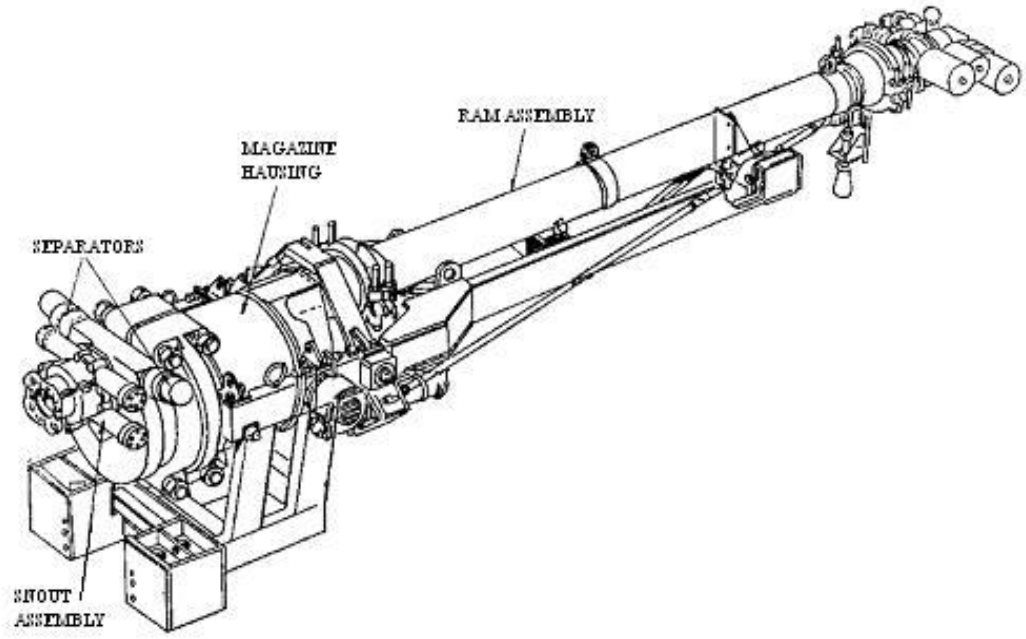

Fig. 1. Fuelling Machine Head.

The F/M Head is one of the most important equipment of the nuclear Fuel Handling System, the proper operation in safety and maximum efficiency conditions of the entire system depending on its proper operation and precision.

3. Fuelling Machine Heads testing rig

Performed under national assimilation program of CANDU technology, the test rig from INR Piteşti was put in operation in December 1989.

The project was of Romanian conception, while the design themes were developed based on the testing requirements/specification received from AECL Canada.

The testing rig of F/M Heads (fig. 2) consists of a set of systems and equipment that simulates thermo-hydraulic parameters (pressure, flow rate, temperature) of a fuel channel from the center of the reactor and provides the working parameters - similar to those needed to operate a F/M Head – in order to change the fuel in the nuclear power plant.

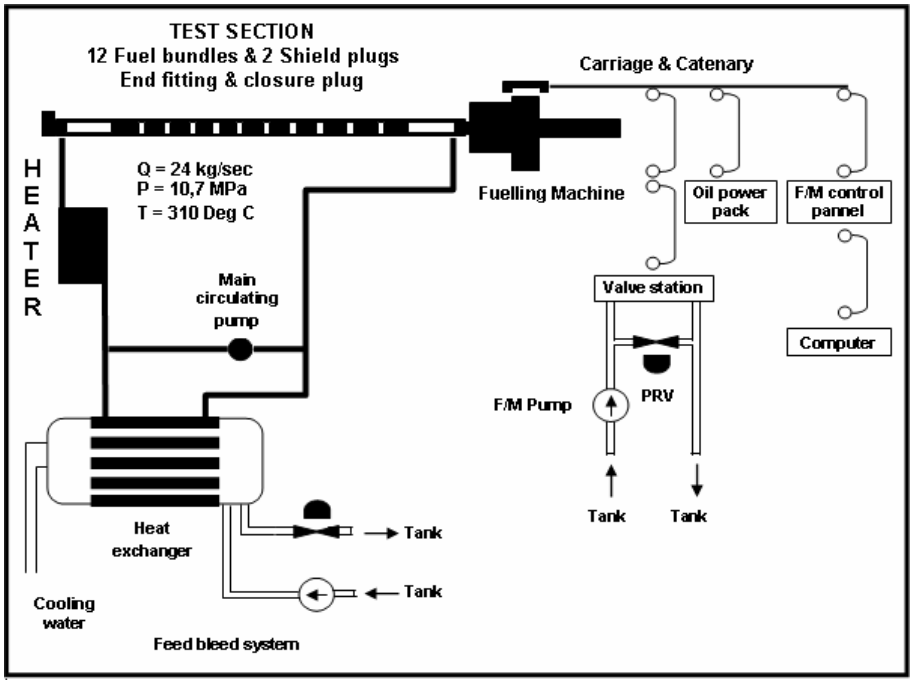

Fig. 2. Test rig.

The test rig of F/M Heads can be divided into three functional systems:

- The telescopic cylinders assembly test rig (TCA),
- Thermo-hydraulic loops (hot and cold),
- Power supply and driving systems F/M Head.

During testing, in order to achieve the operating conditions of fuel channel in the reactor, the testing channel is fitted with:

- 12 actual fuel bundles;
- A closure plug, fitted at the channel end where the F/M Head engages.
- Two biological shield plugs that act on the one hand, to keep the fuel bundles string in the flowing area and on the other hand to create the pressure drop on the fuel channel, required to push the fuel train when changing the fuel.

According to the testing requirements, the testing rig has to provide the following parameters for testing channel and F/M Head operation [1]:

Working fluid from the test:

Hot Loop	Cold Loop
$Q = 24 \pm 0.6$ kg/s	$Q = 20.79 \pm 0.6$ kg/s
$P = 107 – 11.1$ MPa	$P = 10.7 – 11.1$ MPa
$T = 307 – 315$ °C	$T = 10 – 121$ °C.

Feeding and driving the F/M Head with H_2O is done using three pressure levels, (see table no. 1), with a 10 μm filter level and a 45 l/min flow rate to feed the magazine and 45 l/min for moving of the telescopic cylinders:

Table 1. F/M head supply pressure.

No.	*Pressure supply* [bar]		*Discharge pressure* [bar]	
1.	Low	34.5	Low	0
2.	Average	79	Parking	32
3.	High	162	Intermediate	110
			High	114

For driving the F/M Head with oil; the testing rig provides the following oil parameters:

- Pressure = 125 bar
- Flow rate = 34 l/min
- Temperature = 30°C – 60°C
- Filtering level = 15 μm.

4. Testing of F/M Head

Testing of the F/M Head resides in performing tests and adjustments on the F/M Head components and achieving a number of fuel changes in the automatic mode at pressure, temperature and flow condition similar to those from the channel of the reactor core.

The tests are performed following the R6 special programme steps, similar to the loading program structure of the CANDU reactor fuel channel.

The R6 Special Programme includes a series of changes related to structural features of the testing rig (e.g. only one F/M Head can be connected downstream on the fuel channel, it cannot work in tandem), or to the testing programme logic (the loading / unloading sequences from the fresh/burned fuel gates are missing).

The F/M Head testing can be grouped into four stages:

- the functional testing of the telescopic cylinders assembly (TCA);
- making adjustments to F/M assemblies and setting up the work parameters;
- performing of the pre-acceptance tests (cold and hot);
- performing of the acceptance tests (cold and hot).

The functional test for TCA is a checking all mechanical components of the telescopic cylinder assembly to certify its safe operation before installing it on the F/M Head in order to execute the final acceptance test.

The functional test includes three stages, as follows:

- a 300 cycles test, performed using the hydraulic control and monitoring system of the rig;
- disassembling of the TCA for the quality control and inspection of its components;
- a 50 cycles test performed using the command and control system of the TCA.

4.1. The 300 cycles test

The 300 cycles test is a mechanical running in of the cinematic chain for transmitting the motion from the hydraulic motor of each cylinder to the subassemblies of the B and latch telescopic cylinders.

The supply of the hydraulic engines corresponding to the B and latch telescopic cylinders for this test is made from the command and control system of the testing rig, that provides the speeds, flows and pressure required for driving the cylinders.

To perform this test, the TCA is connected to the water, oil and power supply of the telescopic cylinders rig, which provides water and oil filtered with a 10 μm grade efficiency and following parameters:

Demineralized water:	$Q = 18.3 \pm 27$ l/min
	$P = 10.34$ MPa
	$pH = 9.5 \div 10.5$
Oil:	$Q = 18.2$ l/min
	$P = 4.3$ MPa

The rig is equipped with the necessary hydraulic equipment (valves, distributors, flow controllers) to perform all command and control functions required for monitoring the movement of the B telescopic cylinder during cycling as well as to actuate the lubrication system of the cylinders (close circuit system).

The test consists of automatic cycling of the telescopic cylinders at high speed on 123.5 inches distance, in advancing/retreating cycles.

The travelled distance covering the maximum displacement in the reactor during normal operation of the B telescopic cylinder that takes up the biological shield plug (RBW position – 122.6 inches).

During these tests, after 10, 20, 50, 100, 200 and 300 cycles, as well at the beginning and end of the test, the following checks and measurements (considered as acceptance criteria) are performed:

- Water flow of sealing ball
- Water flow of MIX circuit
- Manual drive torque of the B telescopic cylinder

The TCA 5, TCA 6 assemblies for F/M Head no. 4, F/M Head no.5 and TCA 7 assembly (spare set) for Cernavoda NPP Unit 2 have been tested on testing facilities at INR Pitesti.

Referring to TCA 5 assembly testing, the torque values measured at the manual driving of B telescopic cylinder are presented below (in table no.2) – worth noting is that the maximum allowable torque is 4 Nm, the measurements being done on the axis of the auxiliary / emergency actuator.

Table 2. RAM 5 drive torque values

No. (Distance) [inches]	Torque [Nm]					
	10 cycles	20 cycles	50 cycles	100 cycles	200 cycles	300 cycles
1(0)	3,6	4	4	3,9	2,9	2,9
2(10)	3,5	4	4	3,9	2,8	2,8
3(20)	4	4	4	3,8	2,8	2,7
4(30)	4	4	3,8	3,7	2,8	2,7
5(40)	4	4	4	3,8	2,8	2,6
6(50)	3,8	4	4	3,9	2,8	2,7
7(60)	3,8	4	4	3,8	2,8	2,6
8(70)	4	4	4	3,8	2,8	2,7
9(80)	4	4	4	3,7	2,8	2,7
10(90)	4	4	4	3,8	2,9	2,8
11(100)	4	4	4	3,8	2,9	2,8
12(110)	4	4	4	3,9	2,9	2,8
13(120)	4	4	4	3,9	2,9	2,9
14(120)	3,5	3,5	3,5	3,7	2,7	2,7
15(110)	3,5	3,5	3,5	3,6	2,7	2,7
16(100)	3,5	3,5	3,5	3,7	2,6	2,7
17(90)	3,5	3,5	3,5	3,7	2,6	2,7
18(80)	3,5	3,5	3,5	3,6	2,6	2,6
19(70)	3,5	3,5	3,5	3,6	2,6	2,6
20(60)	3,5	3,5	3,5	3,6	2,6	2,6
21(50)	3,5	3,5	3,5	3,6	2,5	2,6
22(40)	3,5	3,5	3,5	3,5	2,5	2,6
23(30)	3,5	3,5	3,5	3,4	2,5	2,6
24(20)	3,5	3,5	3,5	3,4	2,6	2,6
25(10)	3	3,5	3,5	3,6	2,6	2,8
26(0)	3,2	3,5	3,5	3,5	2,6	2,7

The torque diagram presented in Fig 3 shows that as the drive mechanisms are run, the torque required driving them decreases. As well, as the number of cycles is increased, the driving torque value reduces [2].

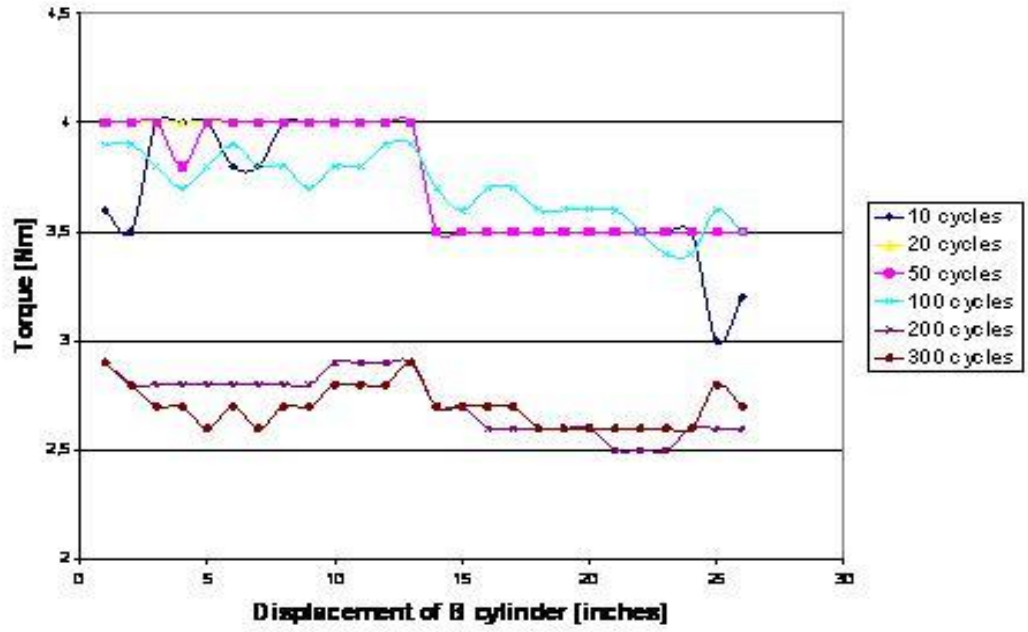

Fig. 3. Telescopic cylinder B torque diagram (TCA 5).

The graphical representation of measured driving torques for TCA 6 and TCA 7 is done in a similar fashion. For TCA 6, the driving torque graph for cylinder B is as follows (fig. 4):

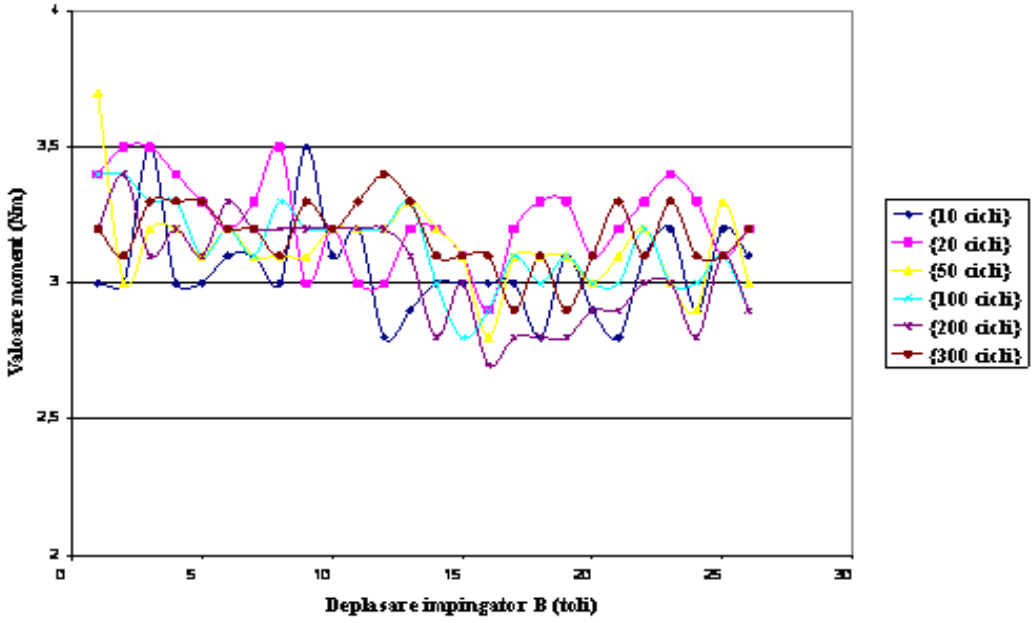

Fig. 4. Telescopic cylinder B torque diagram (TCA 6).

For TCA 7 resulted a torque distribution shown in figure no. 5:

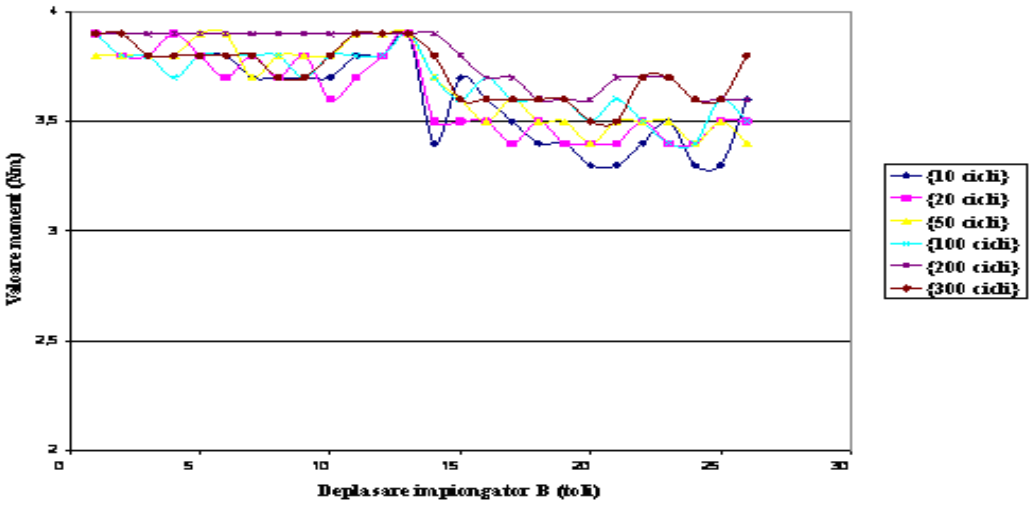

Fig. 5. Telescopic cylinder B torque diagram (TCA 7).

Analyzing the diagrams for TCA 6 and TCA 7, show a tighter torque range than the one measured for TCA 5, as well as a decreasing trend of the torque values with respect to increasing the number of cycles

It should be noted that the torque values measured are lower than the maximum allowable values by the acceptance test requirements which represents an important step for the functional acceptance tests.

4.2. The 50 cycles test

The 50 cycles test is actually, a check of the hydraulic equipment fitted on the TCA assembly, which performs the command and control of the displacement of the telescopic cylinders.

Adjustments to the hydraulic water system and electrical system were the same as the ones done for the 300 cycles test. As part of the hydraulic oil system, the hydraulic control equipment for the B and latch telescopic cylinders was adjusted - the equipment is placed in the TCA assembly.

They were adjusted to carry out the required flow rate, travel speeds of the B and latch cylinders, driving pressures, including the TRABON lubrication system.

At the end of each 50 cycles test, one advancing / retreating run with three speeds (low, medium and high) was performed, at pressure ratios corresponding to the F1 and F2 forces of B cylinder. The pressure, displacement and time parameters were recorded. The graphs representing the TCA 5 assembly testing are shown below (fig. 6, 7 and 8) [2]:

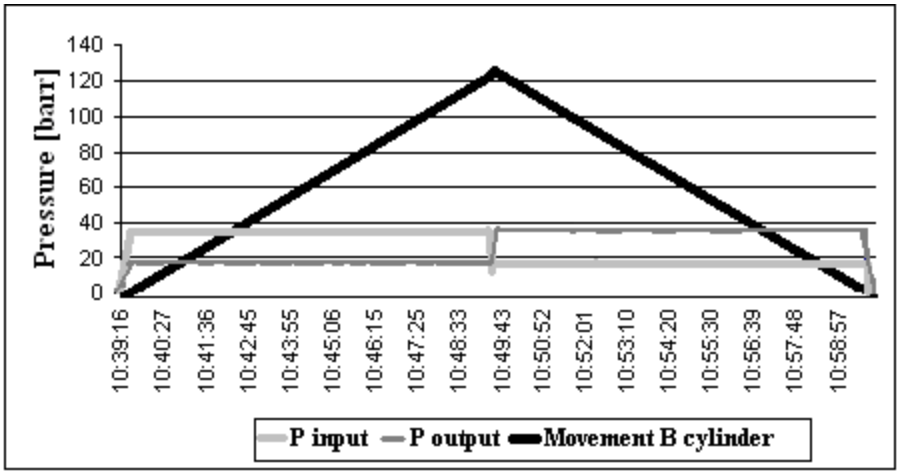

Fig. 6. Pressure diagram (advancing – retreating)/displacement of B cylinder (low speed).

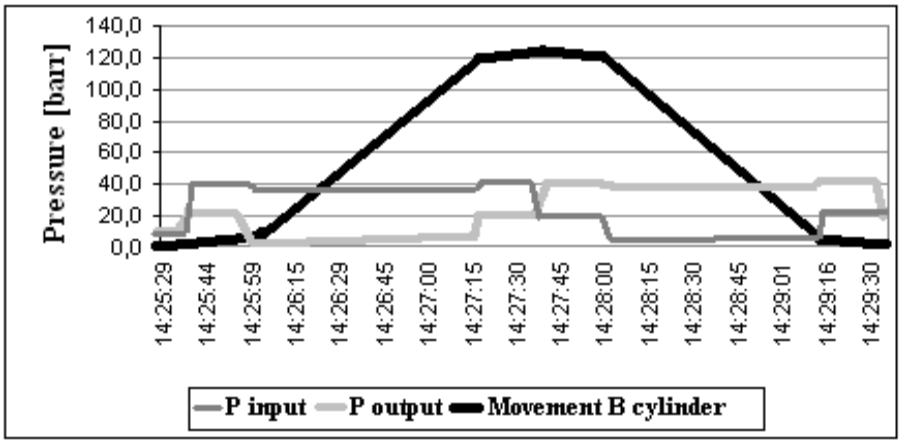

Fig. 7. Pressure diagram (advancing – retreating)/displacement of B cylinder (medium speed).

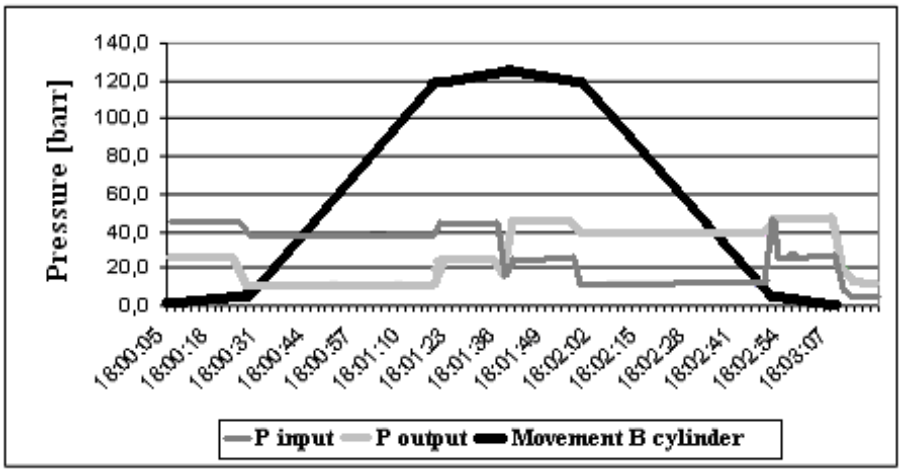

Fig. 8. Pressure diagram (advancing – retreating)/displacement of B cylinder (high speed).

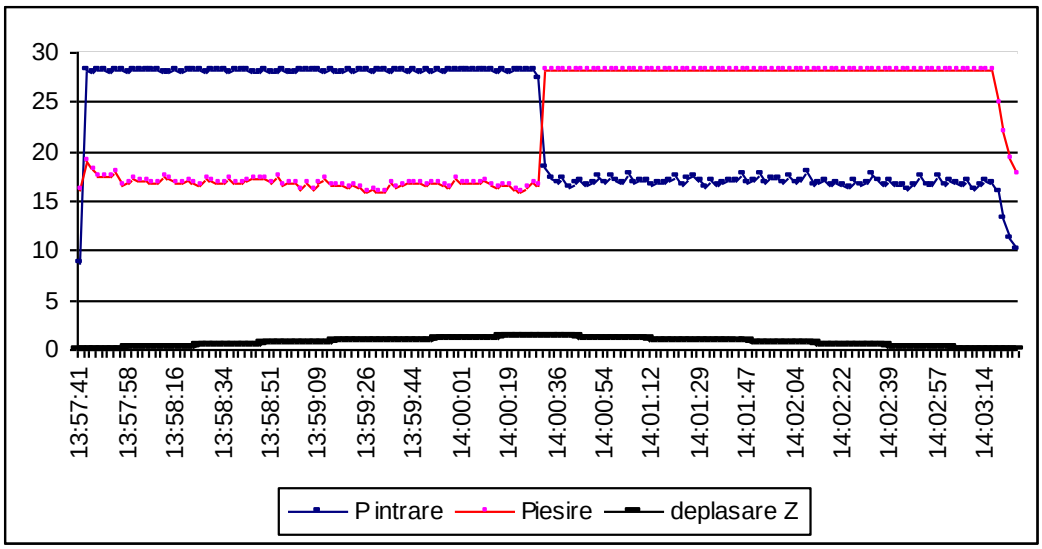

Fig. 9. Pressure diagram (advancing – retreating) / displacement of Z cylinder (TCA 5).

At the end of the test, the speed of the Latch telescopic cylinder was set and a complete advancement / retreating run was performed. Displacement, pressure, time parameters were recorded, this run is shown in Figure 9.

Upon completion of each functional test INR Piteşti drawn up a test report and a statement of test compliance. Thus, after test reports no. 74 for TCA 5, no. 270 for TCA 7 and no. 350 for TCA 6, the functional tests declared completed and accepted.

Conclusions

(1) Functional testing of the TCA assemblies represents about 30 % of the entire testing procedure of the Fuelling Machines Heads. Operations that have demonstrated the safe operation in terms of reliability and mechanical strength of the TCA assembly components within time limits allocated to these operations were also carried out.

(2) Following the requirements of the Quality Assurance Programme's requirements, the test was supervised and reported as a Romanian success by an AECL team. Please be reminded that the Institute for Nuclear Research Piteşti is accredited by Lloyd's Register for ISO9001-2000

(3) Fuelling Machines testing at INR Pitesti is a national and European premier, the potential of testing team and rig capacity from INR Piteşti for such tests, being pointed out by the AECL specialists who attended to INR and supervised the test activities of F/M Head no. 4.

Acronyms

F/M Hs	- Fuelling Machine Heads
NPP	- Nuclear Power Plant
TCA (RAM)	- Telescopic Cylinders Assembly
INR (ICN) Piteşti	- Institute for Nuclear Research Piteşti

R E F E R E N C E S

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