EXPERIMENTAL DETERMINATION OF THE MECHANICAL COMPRESSION STRENGTH FOR CANDU TYPE EXPERIMENTAL FUEL BUNDLE

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The paper presents the evolution stages of the testing technology and proves practically the laboratory reliability to carry out the strength type test. The test technology elaborated reproduce the accidental situations owning to refuelling sequences of a reactor fuel channel assembly, out of reactor, in similar geometrical and physical conditions. Have been reported the main experimental data obtained, a data analysis noted/recorded useful understanding of test fuel bundle behaviour stood to eccentric compressive loads and at the end, few conclusions. The paper can form into a reference regarding the test management and data processing and interpretation.

Keywords: mechanical resistance, test loop, side-stops simulator, carrier fuel bundle.

1. Introduction

CANDU reactor on load fuelling is performed in tandem with Fuelling Machines (F/Ms loading/unloading). One machine gets spent fuel and the other is loading new fuel. In flow loading is carried out, therefore coolant flow through fuel bundles in the pressure tube generate a hydraulic drag loading applied on the fuel bundle rods seating on the machine side-stops or accidentally, on the one side-stop.

The CANDU type fuel bundle is made of number of rods (fuel elements) circular disposed on three concentric circle in the especially geometric configured ends tape fitted to keep the necessary coolant flow spaces between them. Equipped with the bearing pads on the outer ring rods and with spacers between rods, the fuel bundle is a complex spatial structure whose ability to maintain the structural and mechanical integrity depends on the fuel channel assembly compatibility with the fuel handling and the primary heat transport systems.

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Design and acceptance of a CANDU experimental fuel bundle requires out of reactor testing [1] complying with the thermo-hydraulics of the reactor fuel channel.

An out of reactor test loop and the afferent devices for nuclear fuel testing using light water with representative parameters (pressure, temperature and flow) for CANDU 6 reactor operation have been built at the Institute for Nuclear Research from Piteşti.

The paper relieve the new evaluation technology of the mechanical compression strength for accidental loads of CANDU type experimental fuel bundle and its application to assess the mechanical strength of the carrier fuel bundle. The type test carried out is one of the acceptance tests required to validate production of the carrier fuel bundle and proof practically the lab capacity to adjust to technological development.

2. Evolution of testing technology

2.1 Technique and technologies applied

a) The test technique assumes checking of the structural resistance of the fuel bundle tested for a hydraulically drag loading greater than the maximum allowable force reached during refuelling sequence, support condition made on the two F/M side-stops and applying of a maximum allowable drag force reached during refuelling sequence in accidental support condition made on single side-stop.

b) Checking technology of keeping the structural integrity and ranging the deformations resulted in test fuel bundle assumes to carry out a combined/complex strength test whereon a single test fuel bundle is using stood first to a strength test on to side-stops and then, removing one of the side-stops, to a strength test on one side-stop.

2.2 Design of the devices

The detail analysis of the tests development carried out previous in the high pressure hot loop and of the results got proved that the technological processes have been affected [2] by the limitation of the measurement capability (analogue transducers, ranges non-correlative with measured values, defective processing of the results), by the relative great uncertainties of the got data and by the limitation of the design solution: using of a hand-made force transducer, the up-taking way of the compression force, the shape of the side-stops simulator, its positioning, the material chosen for the side-stops, inappropriate materials couple.

The continuous improvement of the devices together with their testing led to the testing device assembly variant existing in the test section, showed in the figure 1.

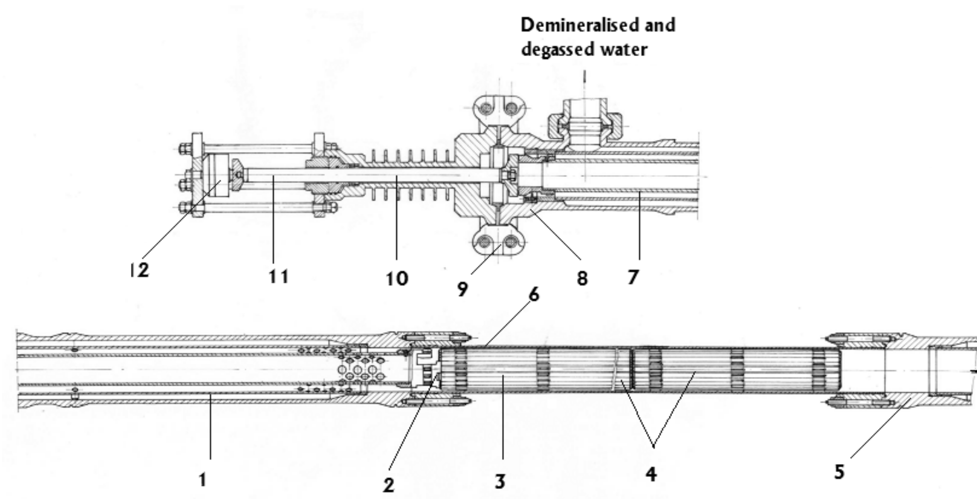

Fig. 1 Test section equipped for the strength test on 2 (1) side-stops (stop)

Can be observed, from figure, that the working agent, demineralised and degassed water at temperature and pressure set by procedure enter by upstream end fitting (5) of the test section, in the pressure tube (6), passing through nuclear fuel bundle string made of 11 additional fuel bundles (4) and of testing fuel bundle (3), get into downstream end fitting (8) wherefrom exit towards inlet collector of the hot pressure loop. The test fuel bundle (3) is supporting direct on the side-stops/stop (2), the component of the side-stops simulator (7) free supported at both ends in linner tube (1) of the downstream end fitting (8). The side-stops simulator (7) and entire nuclear fuel bundle string is free supported on rod (11) central placed versus linner tube (1) of the downstream end fitting (8) on the compression plug of the force cell (12). The rod (11) get central and sealed through to the special sealing cover (10) mounted sealed on the downstream end fitting (8) inlet using the 6″ Graylock type high pressure connector (9). It transmit the compressive stress generated by the static stress given by the fluid pressure downstream of the test section and by the drag hydraulic force given by the fluid flowing through the fuel bundle string from test section.

The absolute/differential pressure transducers have been chosen according as measurement range, [3]. In this case, the measured value of a pressure drop has been considered approximate equal with pressure drop value on the fuel bundle string supported on the stops simulator (7) side-stops/stop (2).

2.3 Application of the new technology

The new technology applied inside of qualifying program of the carrier fuel bundle, [4]. Thus, the two side-stops strength test carried out on the test section configured like in the figure 1, the fuel bundle string and implicitly, the test fuel bundle, being supported on the subassembly performed by the side-stops simulator – rod – force cell compression plug. When the operation parameters set by procedure has reached, the flow rate on the test section equipped and instrumented has increased slowly. During minimum ten minutes as keeping up the test recorded/noted the operation parameters, the absolute outlet/inlet pressure in/out test section, pressure drop on the fuel bundle string supported on the side-stops and the values supplied by the compressive stress instrumentation chain. After cooling, testing section disassembled in the inlet area in the downstream end fitting and one of two side-stops removed without intervention over testing fuel bundle. After reassembling on the test section (figure 1) the strength test on one side-stop completed, complying the working procedure from the previous test and the new flow rate value.

At the end, the test fuel bundle and the additional fuel bundles have been dimensional checked if they are complying with acceptance criteria specified.Titlurile capitolelor lucrării se numerotează dacă este cazul, se scriu cu litere mici (12 pct.), bold.

Prezentarea va fi clară şi concisă, iar simbolurile utilizate vor fi definite în cadrul unei liste de simboluri (dacă este cazul). Se va folosi Sistemul Internațional (SI) de unități de măsură. Nu se acceptă descrieri de aparate şi instalații.

3. The experimental results

After new technology applied for each test, the experimental recorded/ noted data have been put into scheduled limits, [3].

The carrier test fuel bundle strength stood to strength type test was easy pull out from the test channel, even endured visible dimensional changes. It has allowed after dimensional check, [4].

4. The recorded / noted data analysis

Inside of the gained results interpretation, for each test calculated:

- hydraulic drag force:

$$F_{\Delta p} = \Delta p \cdot S_{tp} \tag{1}$$

- static load due to measured value of the absolute pressure, at pressure tube outlet:

$$F_{av} = p_{av} \cdot S_t \tag{2}$$

- total compressive stress calculated as the sum between the hydraulic drag force and static load given by the pressure at downstream end fitting inlet:

$$F_t = F_{\Delta p} + F_{av} \tag{3}$$

where: - Δp, drop pressure on the fuel bundle string supported on side-stops/stop, measured values;

- S_{tp}, the internal section of the pressure tube, average value calculated;

- P_{av}, the absolute pressure at downstream end fitting inlet, close by the side-stops, measured values;

- S_t, plan area of the rod, which transfer stress to the force cell.

For each test performed, during increase of the specified flow rate value, noted that the measured force value F_m is lower than the calculated total force value F_t.

For two side-stops strength test, has drawn out diagram the variations of the calculated/measured forces ($F_{\Delta p}$, F_{av}, F_t, F_m) versus the pressure drop during slow increasing period of the flow rate, figure 2, and keeping period of the scheduled operation test parameters, figure 3.

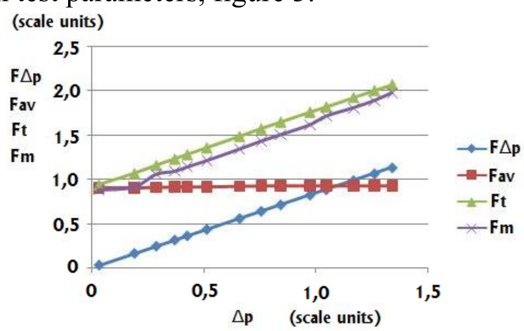

Fig.2 Calculated / measured forces variation versus pressure drop evolution (two side-stops strength test – during increase of the flow rate)

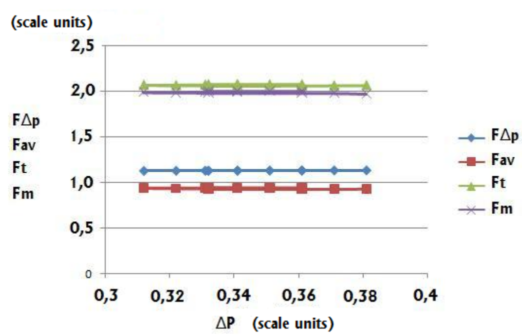

Fig. 3 Calculated / measured forces variation versus pressure drop evolution (two side-stops strength test – keeping between the scheduled parameters)

During flow rate increase in test section noted a main increase of the difference between the calculated total force and measured force values: $\Delta F = F_t - F_m$ (ΔF reached after first flow rate increase stages about 75% greater than average value of ΔF* specific for keeping of the operation regime between the scheduled test parameters.

Forward, the ΔF value oscillated step by step in sense of its decreasing and, at the ending, near to reaching the flowing scheduled regime, quickly decreased to a value near to average value of ΔF*.

During test performing, the string has been asymmetric stood to specific compressive stress. From figure 3 is observing that in the first half effective execution of two side-stops strength test, ΔF value between the calculated compressive force value (F_t) and measured force (F_m) oscillate slowly (about ± 2,5%) around the average ΔF* value. Forward, ΔF value is reducing step by step, finally, being about 14% less than ΔF* average value. During the effective test the hydraulic drag force $F_{\Delta p}$ is keeping approximately constant versus oscillations of the drop pressure value and the compressive static stress F_{av}, generated by the absolute pressure from downstream end fitting, is increasing slowly nearly invisible (figure 3).

For the one side-stop strength test, has drawn-out the variations of the calculated/measured forces ($F_{\Delta p}$, F_{av}, F_t, F_m) according as pressure drop during slowly increasing period of the flow rate, figure 4 and during keeping of operation regime in scheduled test parameters, figure 5.

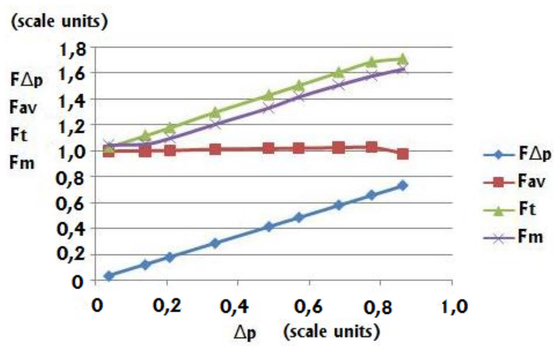

Fig. 4 Variation of calculated/ measured forces versus pressure drop evolution (one side-stop strength test – during flow rate increase)

Find out that during flow rate increase in test section obtained, in this case too, a main increase of the difference between the calculated total force and measured force values: $\Delta F = F_t - F_m$. In case of one side-stop strength test and, ΔF value is increasing step by step, at the half increasing period of the flow rate on the test section, reaching a value 50 % greater approximately of ΔF* average value. In the next flow rate increasing stages ΔF oscillates slowly around this maximum value, at the ending, near to reach of specified flow rate value, quickly decrease (similar to case of two side-stops strength test) to a value close by ΔF* average value.

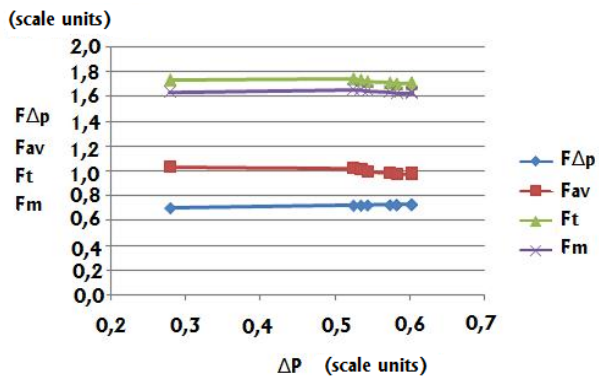

Fig. 5 Variation of calculated/measured forces versus pressure drop evolution (one side-stop strength test – during keeping of flow rate between scheduled parameters)

During performing of the properly test, the fuel bundle string had been stood asymmetric to specified compressive stress. From figure 5 finding out that the strength test properly begin with a tension condition in the elastic domain of the fuel bundle string. End plates bending of the fuel bundles string and of the test fuel bundle especially have major contribution, in the first half effective testing period to response elastic component decrease of the fuel bundle string about 28% of ΔF*average value. On ending, ΔF value reduced oscillating slowly to specific average ΔF* value. The ΔF oscillations noted, before its reducing on the test ending, to specific average ΔF* value (one side-stop strength test) have been determined by the elastic-plastic response of the fuel bundle string loaded and by the wear force variation in rod sealing, the force controlled by absolute pressure variation in downstream end fitting of the test section. The hydraulic drag force $F_{\Delta p}$ increased slowly versus the pressure drop variation during testing (figure 5) from minimum scheduled value to maximum limit. However, the outlet absolute pressure from test section decreased slowly, the static compressive force F_{av} (the load applied on the rod head) increased slowly versus the pressure drop variation during testing (figure 5) due to decrease of the absolute pressure value at downstream end fitting inlet and implicitly, due to decrease of the wear force value in the sealing.

5. Conclusions

Changes made over testing devices are the result of the experience gained after numerous out of reactor tests using experimental nuclear fuel. Personal contribution materialized in: design and execution of new devices, change of the experimental assemblies, integral replacement of the instrumentation, coordination of the specific test procedures and instructions kit elaboration, coordination of the qualifying tests for test technology, coordination of the strength type test inside of qualifying program for the carrier fuel bundle.

Performing, at representatives parameters (pressure, temperature and flow rate) for CANDU 6 reactor operation condition, of the strength type test on the carrier fuel bundle attested its structural stability for mechanical loads induced accidentally during refuelling sequence. The experimental data analysis proved that the difference identified between the calculated compression forces values and measured ones (ΔF) at each/any stage/moment of testing process is mostly due to the elastic response component of the fuel bundle string and in the slighter degree to the wear forces from system. End plates bending of the carrier fuel bundle for each test had major contribution to response elastic component decrease of the fuel bundle string stood to compressive load, justifying the ΔF evolution during both stage increase period of the flow rate in test section to come in the scheduled flowing regime and effective test periods. At the end of each test, ΔF difference stabilizes reaching the average value (ΔF^*) specific to scheduled flow regime. The characteristic average value of ΔF is greater in the two side-stops strength test, the difference being mostly due to elastic component of the structure as a fuel bundle string response to the compressive stress.

REFERENCES

[1] *D. Stănilă, Elena Gheorghiu, C. Gheorghiu, et.al.,* Specificatii pentru testele tip in afara reactorului (Technical specifications for the out of reactor type tests), Internal Report no.1383, Institute for Nuclear Research Piteşti, 1983.

[2] *T. Gyongyoşi, I. Cremene, et.al.,* Imbunatatiri aduse metodelor de testare in afara reactorului in vederea testarii fasciculului transportor (Improvements to out of reactor testing techniques for carrier fuel bundle testing), Internal Report no.4372, Institute for Nuclear Research Piteşti, 1994.

[3] *T. Gyongyoşi, Gh. Ionescu, Gh. Deloreanu, C. Doca, et.al.,* Testarea in afara reactorului a fasciculului transportor. Dispozitive si instrumentatie (Out of reactor testing of the carrier fuel bundle. Devices and instrumentation), Internal Report no.5076, Institute for Nuclear Research Piteşti, 1997.

[4] *T. Gyongyoşi, Gh. Deloreanu, Gh. Ionescu, et.al,* Testul tip de rezistenta pe fascicul transportor (Strength type test on the carrier fuel bundle), Internal Report no.5256, Institute for Nuclear Research, 1998.