HYDRAULIC AND HYDRODYNAMIC TESTS FOR DESIGN EVALUATION OF RESEARCH REACTORS FUEL ELEMENTS

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ABSTRACT

During the design steps of research reactors fuel elements some tests are usually necessary to verify its design, i.e.: its hydraulic characteristics, dynamical response and structural integrity.
The hydraulic tests are developed in order to know the pressure drops characteristics of different parts or elements of the prototype and of the whole fuel element. Also, some tests are carried out to obtain the velocity distribution of the coolant water across different prototype's sections.
The hydrodynamic tests scopes are the assessment of the dynamical characteristics of the fuel elements and their components and its dynamical response considering the forces generated by the coolant flowing water at different flow rate conditions.
Endurance tests are also necessary to qualify the structural design of the FE prototypes and their corresponding clamp tools, verifying the whole system structural integrity and wear processes influences.
To carry out these tests a special test facility is needed to obtain a proper representation of the hydraulic and geometric boundary conditions of the fuel element. In some cases changes on the fuel element prototype or dummy are necessary to assure that the data results are representative of the case under study.
Different kind of sensors are mounted on the test section and also on the fuel element itself when necessary. Some examples of the instrumentation used are strain gauges, displacement transducers, absolute and differential pressure transducers, pitot tubes, etc. The obtained data are, for example, plates´ vibration amplitudes and frequencies, whole bundle displacement characterization, pressure drops and flow velocity measurements.
The Experimental Low Pressure Loop is a hydraulic loop located at CNEA´s Constituyentes Atomic Center and is the test facility where different kind of tests are performed in order to support and evaluate the design of research reactor fuel elements.
A brief description of the facility, and examples of the tests performed and results obtained are presented in this paper.

INTRODUCTION

The design of research reactors Fuel Elements (FE) should take into account, and make compatible, three kind of requirements: nuclear, thermohydraulics and structural requirements. The nuclear design considers heat generation and impose, for example, geometric and neutronic flux distribution requirements. Thermohydraulic design considerations, such as coolant water flow rates, temperatures and pressure drops, are related with heat extraction. Finally, the structural design should satisfy the nuclear and thermohydraulic considerations assuring the FE structural integrity in a safe and economic way and considering also, for example, the manufacture, inspections, handling and storage of the FE.

In order to support the final design of the FE, different kind of tests are necessary to verify design hypothesis, hydraulic characteristics, dynamical response, structural integrity and safety margins. To assess the pressure drops on different parts or elements of the FE and of the FE as a whole, hydraulic tests are carried out. Also, some tests are performed to obtain the velocity distribution of the coolant water across different prototype's sections. Hydrodynamic tests determine the dynamical characteristics of the FE and its components and the dynamical response considering the forces generated by the coolant flowing water at different flow rate conditions. Endurance tests are performed to qualify the structural design of FE prototypes.

The results obtained from all these tests confirm, or not, the design hypothesis done and give a feedback to the designers.

To carry out the hydraulic and hydrodynamic tests a special test facility is needed to obtain a proper representation of the hydraulic and geometric boundary conditions that the FE will have in service into the reactor core.

CONSTITUYENTES ATOMIC CENTER HYDRAULIC TEST FACILITY

The Experimental Low Pressure Loop (ELPL) is a hydraulic loop located at CNEA´s Constituyentes Atomic Center and is the test facility where different kind of tests are performed in order to support and evaluate the design of fuel elements. The ELPL became operative in 1978 and since then numerous tests were carried out over full scale FE prototypes either for Nuclear Power Plants or Research Reactors Facilities. A flow sheet of the ELPL is presented in Figure 1.

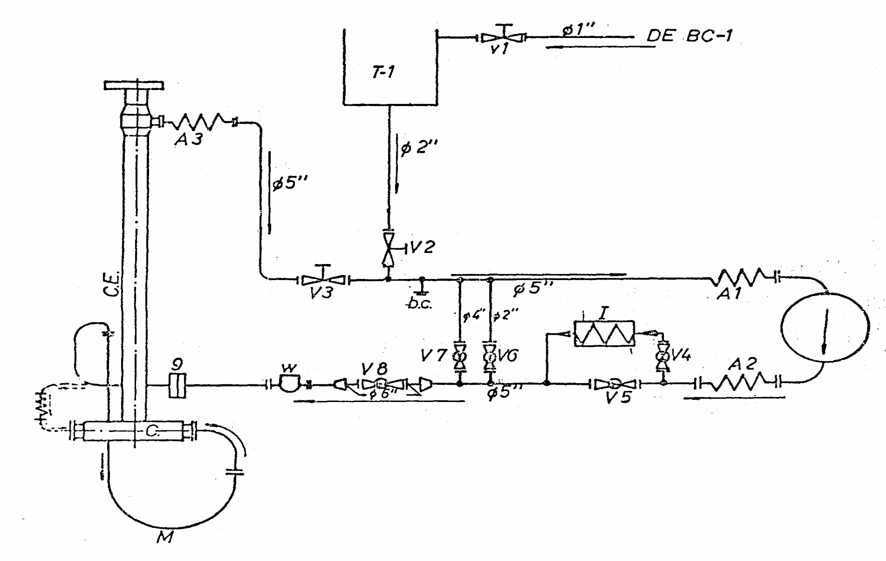

Figure 1: ELPL flow sheet

The ELPL has nowadays a maximum flow rate of 200 m^3/h, by means of a centrifugal pump powered by a 150 KW electric motor with 3000 RPM and operates at a static pressure of 1.6 MPa. The test facility operates with demineralized water with a range of test temperatures between 50 and 70 ºC. As can be seen in Figure 1, the flow rate in the test section is regulated with a valve (V8) and two by-pass lines (valves V6 and V7) and the temperature is controlled using a shell and tube type heat exchanger with fresh water as coolant fluid in the shell side flow (valves V4 and V5).

These operational characteristics allows the performance of tests for the argentine's designed research reactors at real operational conditions. For Nuclear Power Plant's FE the obtained results must be extrapolated from the test conditions to reactor conditions but it is possible to simulate the real dynamic pressure conditions to obtain the characteristic dynamic response of the FE.

Dedicated tests sections are manufactured for every FE prototype tested, and in some cases tests sections to accommodate more than one FE prototypes are necessary to obtain the required results. A view of the bottom part of a test section can be seen in Figure II, while a diagram of one of the test sections used for the characterization of a plate type FE for a research reactor is presented in Figure III.

Figure II: bottom part of a test section in the ELPL

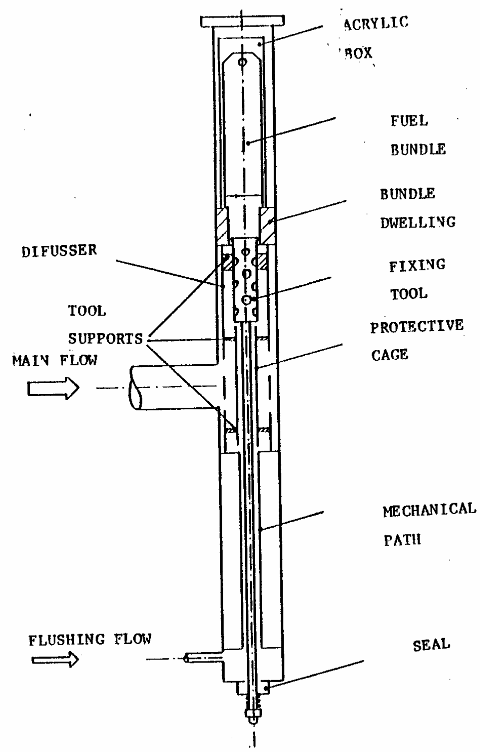

Figure III: Test section for the hydraulic and hydrodynamic characterization of a plate type FE

TESTS PERFORMED AT THE ELPL

The dynamical characterization of a FE is generally performed in three stages:

i) determination of natural modes of vibration, with their corresponding frequencies, and damping values in air;
ii) the same as i) but in quiescent water for added mass coefficients and fluid damping assessment;
iii) hydrodynamic tests to verify the dynamic behavior of the FE simulating the in-service forces generated by the coolant flowing water at different flow rate conditions.

Different kind of transducers are installed on the FE and on the tests section to obtain the required data.

Piezoelectric accelerometers can be used for the determination of natural frequencies and vibration modes, both in air and in quiescent water, using for example the impact technique to excite the plates or the whole FE with a white noise spectrum and obtain the dynamic response.

Water-proof strain-gages on different plates and at different heights of the plates are bonded so that the influence of flow induced vibration mechanisms (turbulence, vortex shedding and fluidelastic instability) can be determined and characterized. Also, displacement transducers (LVDTs) are used to measure the relative displacement between the FE and the test section so that possible impacts between adjacent FEs can be predicted. The strain-gages and displacement transducers signal analysis allow a complete vibration characterization using power spectral density (PSD) spectrums that contains amplitude and frequency composition data.

Two frequency spectrum (RMS amplitude of vibration vs. frequency) obtained from strain-gages bonded at different positions of a plate in a test at 100% of the nominal flow of a FE can be seen in Figure IV.

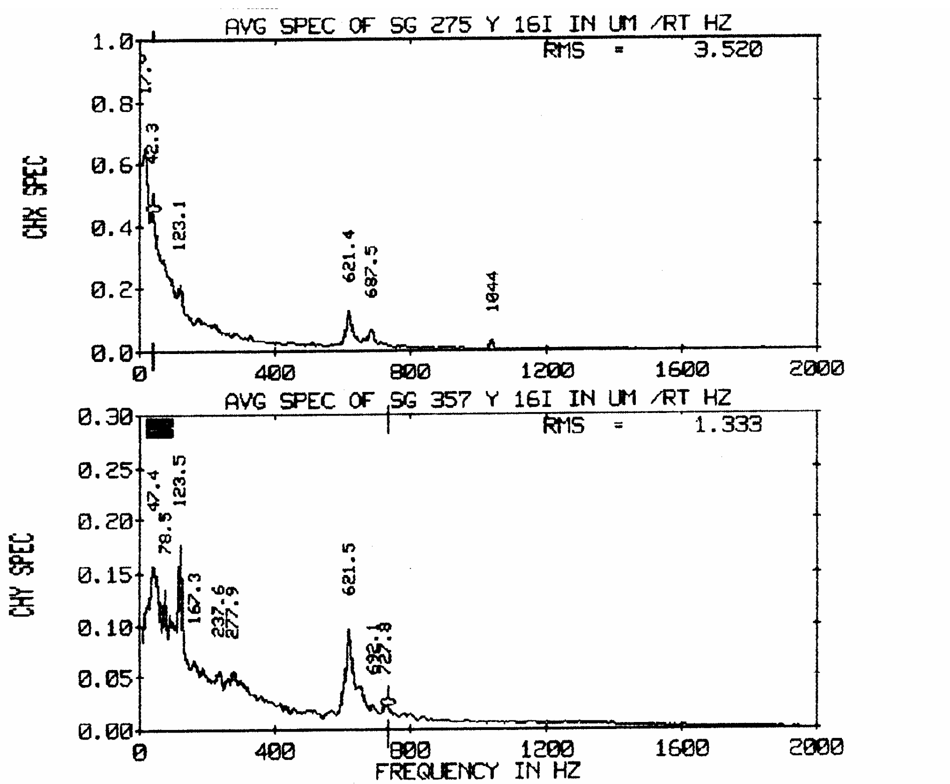

Figure IV: Frequency spectrums of a plate obtained from bonded strain gages

For research reactors FE, tests flow rates may vary between the 60 and more than 200% of the nominal flow. In this case the flow rate range was varied between 60% and 240% of the nominal flow trying to reach the critical flow velocity for fluidelastic instability of the plates. Figure V results shows that there was no evidence of a sudden increase in the vibration amplitudes, nor a change from the obtained relatively broad-band spectrum to a narrow-band spectrum (not showed), indicating that he critical flow velocity was not reached. A photograph of one of the bonded strain-gages is presented in Figure VI.

The strain-gage data could also be used to obtain a complete characterization of the induced amplitude and frequency change with different flow rates of the end plate's vortex-shedding. For example, a vortex shedding frequency peak at 621 Hz was identified in the Figure IV spectrums. The control of this phenomena is important to avoid any resonance into the whole operational flow rate that could damage the FE.

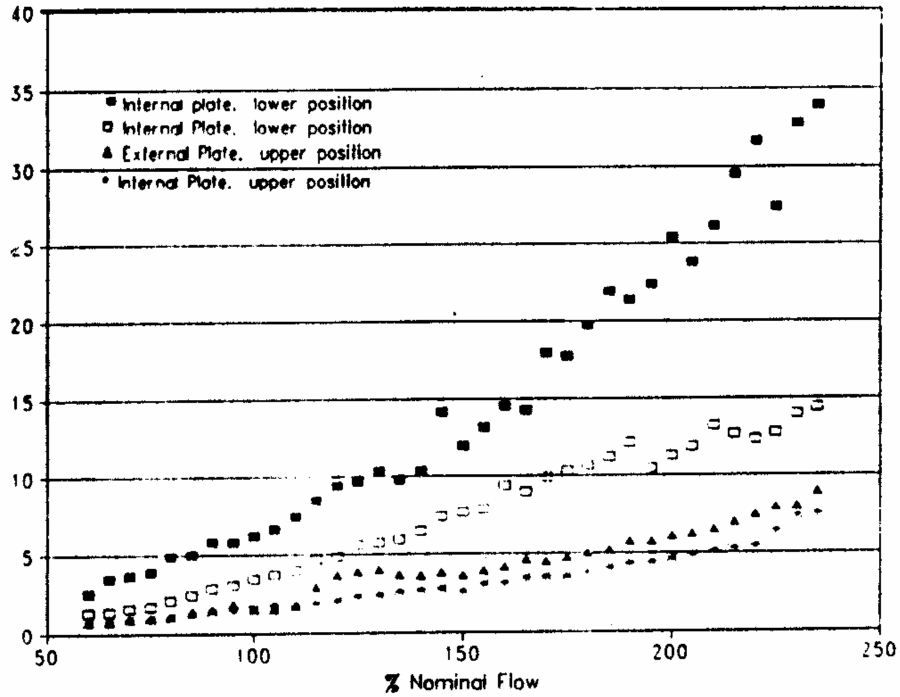

Figure V: RMS amplitude of vibration of different plates of a FE prototype vs. flow rate

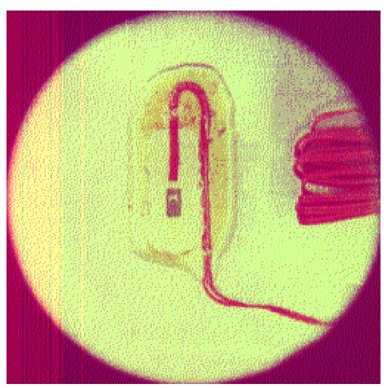

Figure VI: A water-proof strain-gage bonded on a plate of a FE prototype

In some cases, tests are not carried out over a whole FE prototype but over a certain device, as may be a FE clamp tool in order to determine its hydraulic behaviour and its dynamical response under the hydrodynamic excitations resulting from an adequate reproduction of the geometric and hydraulic conditions the clamp device will have to support at the lower plenum of the reactor core.

The hydraulic tests usually include pressure drops characterisation and flow velocity measurements. Pressure drops are measured by means of absolute and differential pressure transducers located at different positions of the test section to obtain data of the whole FE or from its components. Figure VII presents the pressure drops results obtained for a FE and for the assembly FE plus clamp tool.

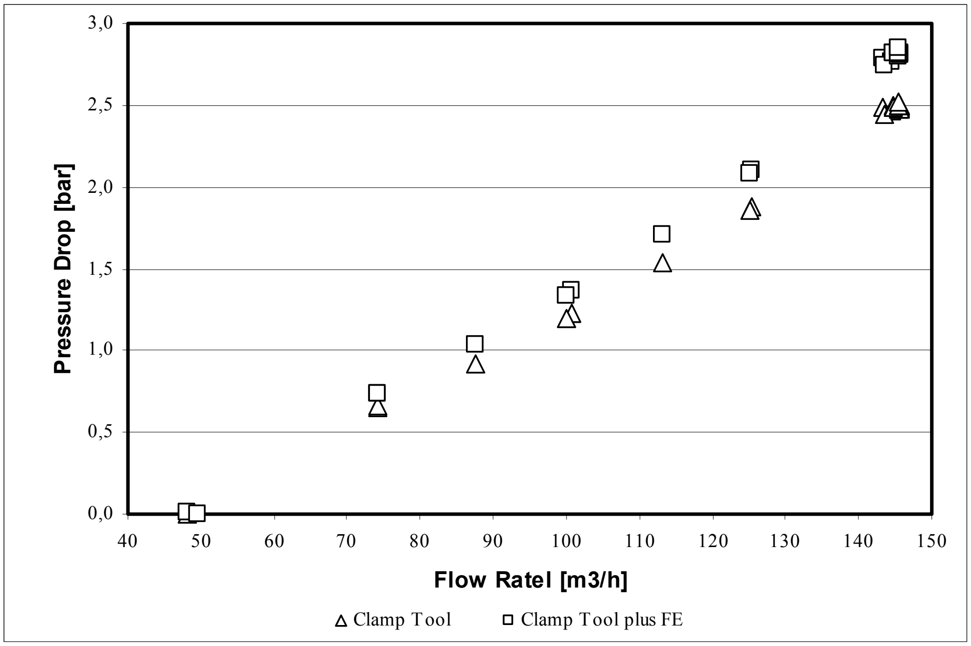

Figure VII: Pressure drops vs flow rate of a clamp tool and an assembly FE plus clamp tool

To verify the coolant flowing water velocities two types of tests are carried out:

a) flow velocity measurements to obtain the velocity profile between plates at the plates' inlet zone;
b) flow velocity measurements just downstream the plates.

A view of a measurement device used to obtain the velocity profile at the plates' inlet zone from dynamic pressure measurements is presented in Figure VIII, while a view of a Pitot tube installed in the test section for flow velocity measurements at the top of the FE is shown in Figure IX. Velocity measurements of the coolant flow between plates obtained with a Pitot tube in a test of a three side by side arrangement of FEs is presented in Figure X. The measurements correspond to velocities just downstream the plates.

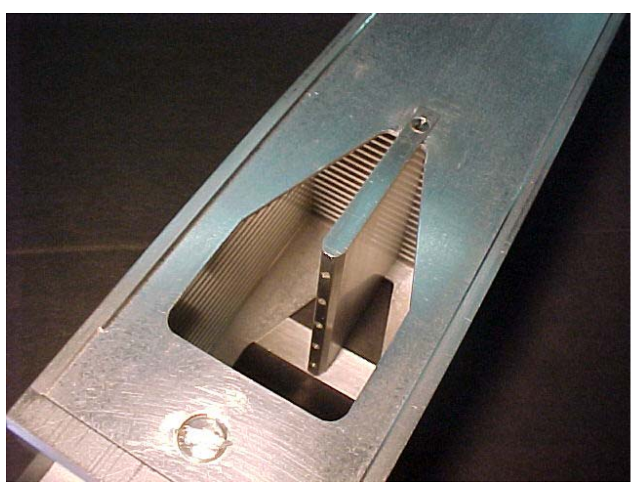

Figure VIII: flow velocity measurement device view

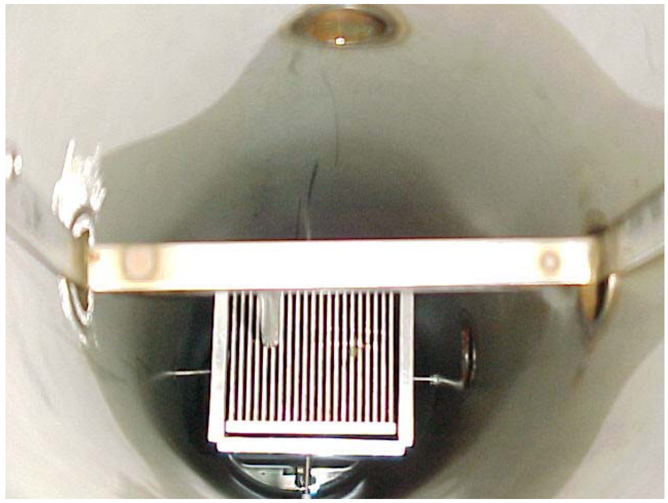

Figure IX: Pitot tube on the top of the FE prototype for velocity profile measurements

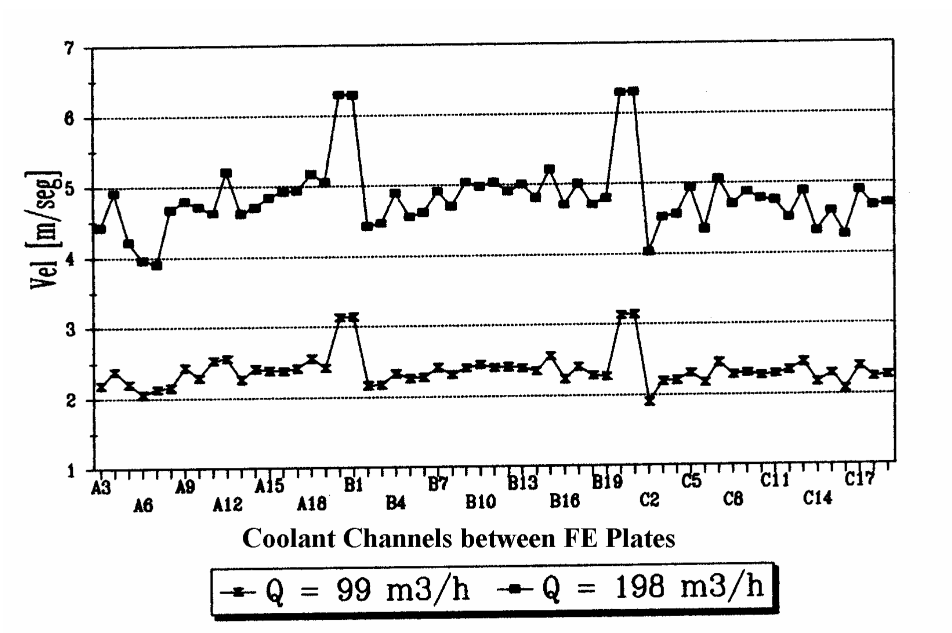

Figure X: Coolant flow velocity between plates of an arrange of three FEs

Finally, endurance tests of more than 200 hours have been performed to qualify the structural design of FE prototypes and their corresponding clamp tools, verifying the whole system structural integrity and wear processes influences.

CONCLUDING REMARKS

The Experimental Low Pressure Loop (ELPL) is a hydraulic loop located at CNEA´s Constituyentes Atomic Center and is the test facility where different kind of tests are performed in order to support and evaluate the design of research reactor fuel elements.

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