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EXPERIMENTAL INVESTIGATION OF CRITICAL VELOCITY IN FUEL ELEMENT FOR THE RMB REACTOR

Alfredo José Alvim de Castro
Delvonei Alves de Andrade
Nuclear Research Center, CEN- Instituto de Pesquisas Energéticas e Nucleares, IPEN/CNEN
Avenida Lineu Prestes, 2242 – Cidade Universitária – CEP 05508-000 – São Paulo /SP - Brazil
ajcastro@ipen.br
delvonei@ipen.br

Abstract. *The fuel elements of a MTR (Material Testing Reactor) type nuclear reactor are mostly composed of aluminum-coated fuel plates containing the core of uranium silica (U_3Si_2) dispersed in an aluminum matrix. These plates have a thickness of the order of millimeters and are much longer in relation to their thickness. They are arranged in parallel inside the fuel element assembly to form channel gaps between them of only a few millimeters wide through which the coolant flows. This configuration, combined with the need for a flow at high flow rates to ensure the cooling of the fuel element in operation, may create problems of mechanical failure of fuel plate due to the vibration induced by the flow in the channels. In the case of critical velocity, excessive permanent deflections of the plates can cause blockage of the flow channel in the reactor core and, lead to overheating in the plates. For this work an experimental loop capable of high volume flows and a test section that simulates a plate-like fuel element with three cooling channels was developed. The dimensions of the test section were based on the dimensions of the Fuel Element of the Brazilian Multipurpose Reactor (RMB), whose project is being coordinated by the National Commission of Nuclear Energy (CNEN). The experiments performed had the objective of reaching Miller's critical velocity condition. The critical velocity was reached with 14.5 m/s leading to the consequent plastic deformation of the flow channel plates.*

Keywords: *Critical Velocity, Plate-type Fuel Element, Experimental Analysis, Material Testing Reactor*

1. INTRODUCTION

The fuel elements of a MTR (Material Testing Reactor) type nuclear reactor are mostly composed of aluminum-coated fuel plates containing a uranium silica (U_3Si_2) core dispersed in an aluminum matrix. These plates have a thickness of the order of millimeters and are much longer in relation to their thickness. They are arranged in parallel in the assembly forming the fuel element, so as to form channels between them a few millimeters thick, through which the cooling fluid flows (light water or heavy water), as can be observed in the assembly scheme of Fig.1, Torres et al. (2003).

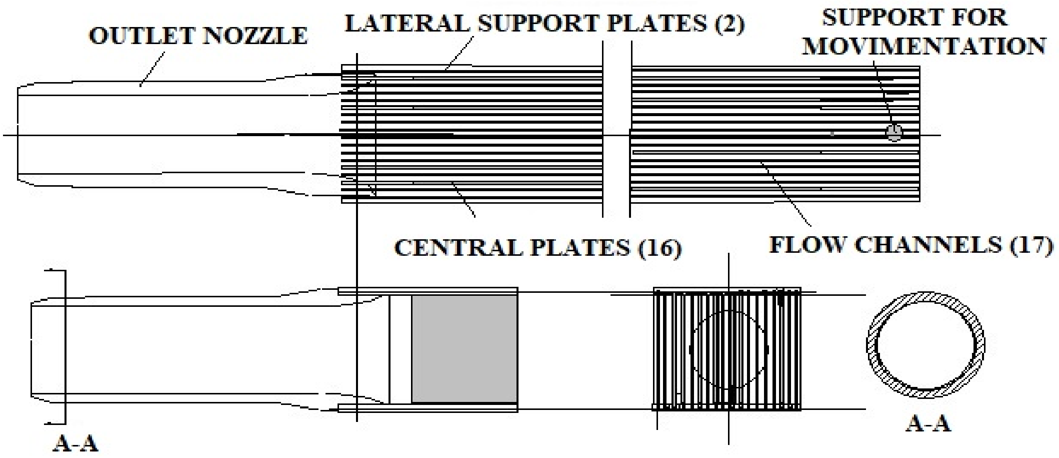

Figure 1. Flat plates Fuel Element assembly schematic

This configuration, coupled with the need for higher flow rates to ensure the cooling of the plates in operation, can generate mechanical failure problems of the fuel plates due to the vibrations induced by the flow in the channels and, consequently, accidents of serious proportions. Most nuclear reactor cores do not have ideal flow conditions. Factors such as plate roughness, manufacturing tolerances, turbulence, nonuniform axial flow and pressure fluctuations produced by the main pump and other process equipment cause these distortions. For this reason, a uniform distribution of coolant flow through each channel of the plate-like fuel element can not be assumed. Miller (1958), one of the pioneers of fuel plate stability research, describes the collapse of the plates as being due to the difference in velocities between adjacent channels. This difference in velocity produces a pressure difference between both sides of a plate. When the resulting pressure is large enough for the plate to withstand, maximum deflection and plastic deformation occur.

The collapse of the fuel plates originates from the vibrations induced by the flow. When the fluid flows through very narrow channels, the pressure energy is converted into (kinetic) velocity energy and creates a suction force on the wall. When the wall can move as in the case of parallel flat fuel plates, the cross section of the channel decreases by obstructing the flow. The flow obstruction increases the local pressure with the flow trying to overcome the constriction. In this way, the fuel plate is pushed open the cross section of the flow. This action of pulling and pushing the plate acts periodically, vibrating the structure that can lead to large plate deflections and localized overheating.

Critical velocity is the speed at which the rectangular plates will deflect and collapse as a result of flow induced vibrations and the asymmetric distribution of pressures within the fuel element. Although there is no rupture of the fuel plates during collapse, excessive permanent deflections on the sides of the plates can cause blockage of the flow in the reactor core and lead to overheating in the plates.

The Brazilian Multipurpose Reactor (RMB) should use a nucleus composed of parallel plates fuel elements typical of MTR type research reactors. The present work had as main objective the experimental investigation of the phenomenon of collapse of fuel plates and development of a methodology to detect the occurrence of critical velocity in fuel plates with the channel geometry of the fuel element that is being designed for the RMB.

2. EXPERIMENTAL SETUP

For the study of plate collapsing, critical velocity detection and analysis of the coupling fluid structure in flat plates, it was decided for a test section model that simulated the fuel element with the basic dimensional characteristics from the Brazilian Multipurpose Reactor(RMB) design.

The test section model consists of two aluminum plates, six aluminum spacers and two acrylic plates mounted on a sandwich structure that divides the rectangular flow section into three identical cooling channels. An inlet length of 100 mm and a 50 mm outlet length of the channels were placed to simulate the inlet and outlet nozzles of the fuel element in the test section. The test section has the free top and bottom with dimensions of 850 mm x 100.5 mm x 30.5 mm. The model of the fuel element has one of the aluminum plates instrumented with extensometers of 350 Ohm in three positions: inlet (SG1), center (SG3) and outlet (SG5) of the cooling channels. The strain gauges serve as the primary method for detecting plate deflection due to direct contact. In Figure 2, the acrylic plate, the instrumented aluminum plate, the aluminum spacer, the sandwich structure and a cross section of the model are shown. The flow section with three channels of coolant, 70.5 mm x 2.45 mm can be observed at section A-A and detail B.

The static pressure measurement serves as a secondary method for the detection of plate collapse. This is due to the changes in the characteristics of loss of load in the channels due to the deformation of the plates. The model is equipped with static pressure taps at axial intervals along the acrylic plates (PT1, PT2, PT3 and PT4). The static pressure measurement in the cooling channel was measured with four piezoresistive microsensors (P1, P2, P3 and P4) installed on the external acrylic plate to the flow channel next the aluminum plate with the strain gauge sensors.

However it must be stressed that the flow characteristics of RMB are significantly different of the two plate model test section. The fuel element of RMB has twenty two (22) fuel plates and nineteen (19) flow channels, Silva (2013). We chose to work with the two-plate model test section to accentuate the effects of velocity difference between the center and lateral channels, Ho et al. (2014).

To perform the experiments, the element model is mounted vertically in the test section and is mechanically fixed to the top of the inlet chamber (D= 500 mm, h= 635 mm) by means of an aluminum disc of diameter (D= 250 mm, thickness= 5 mm).

This inlet chamber is constructed of aluminum and forms a Plenum which promotes the damping of pressure fluctuations from the experimental loop and a flow with uniform speed in the inlet nozzle of the element model. On the outside of the element model is a square aluminum channel (250 mm x 250 mm x h= 940 mm) with polycarbonate windows, which has the main function of allowing the return of the flow to the experimental loop, outlet and sealing the instrumentation of the model and visualization. The test section for the experiments is shown in Fig.3.

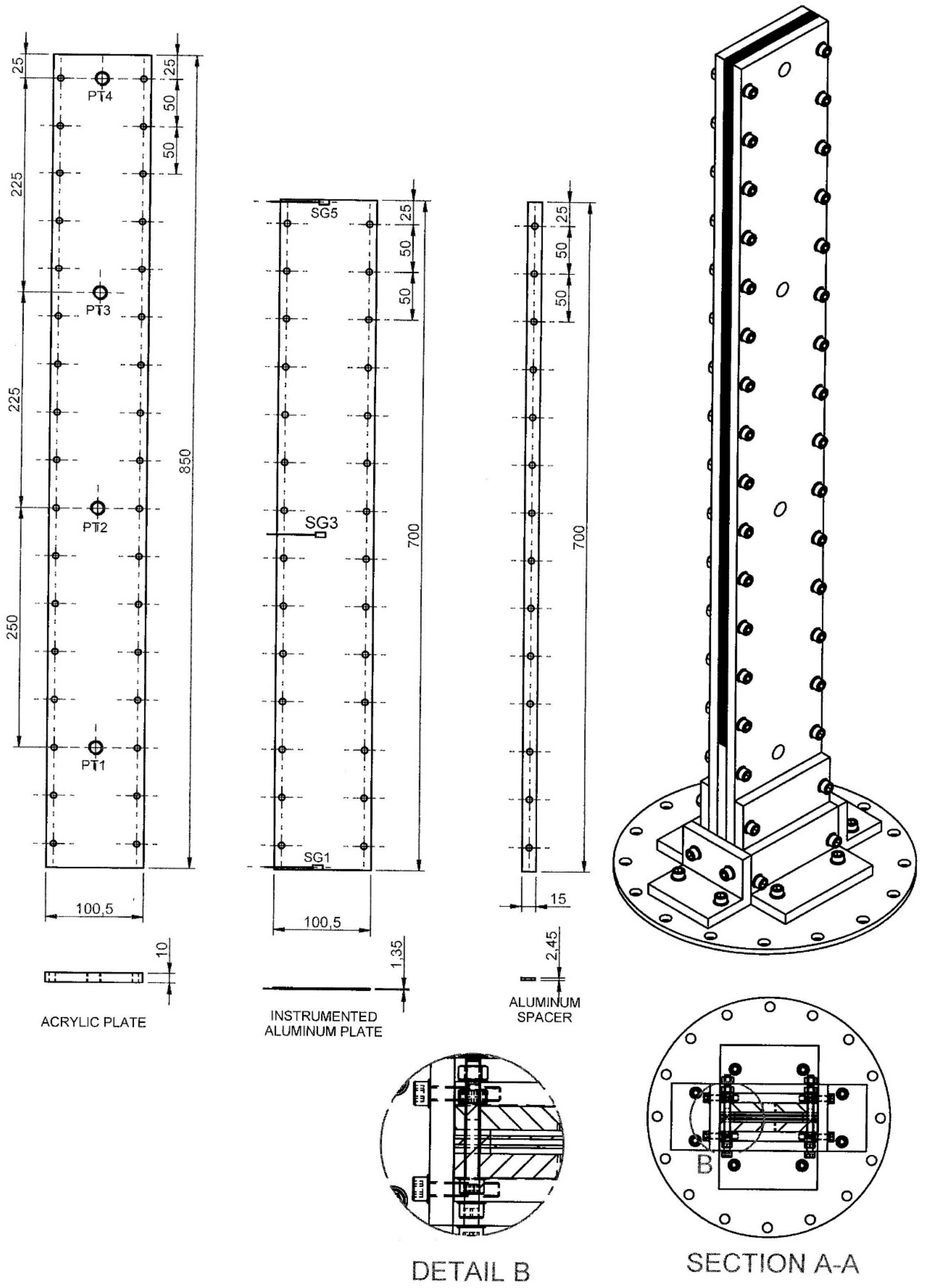

Figure 2. Model of the Fuel Element type flat plates

For the investigation of critical velocity in two plate fuel element models, a new experimental test loop was developed and assembled at the Nuclear Engineering Center (CEN), Fig.4. The experimental loop has a tank of 2.5 m^3, a pump (B1) with capacity of 100 m^3/h of volumetric flow rate and 60 meters of manometric height, test section, orifice plate (PO) flow meter, filters, heat exchanger, deaerator, globe valve, butterfly valves, manometers and industrial PVC pipes. (D=110mm, D= 85mm and D= 60mm). The fluid used in the experimental loop is distilled water.

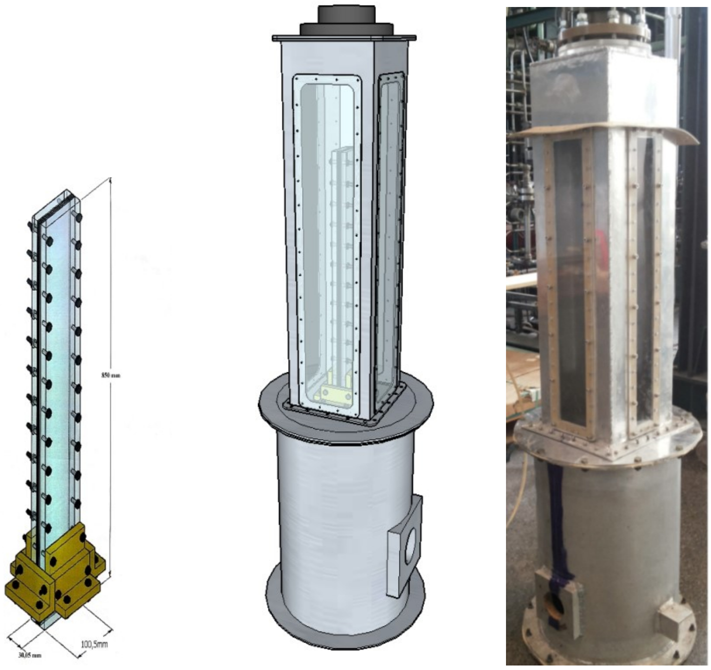

Figure3. Schematic and photo from Test Section

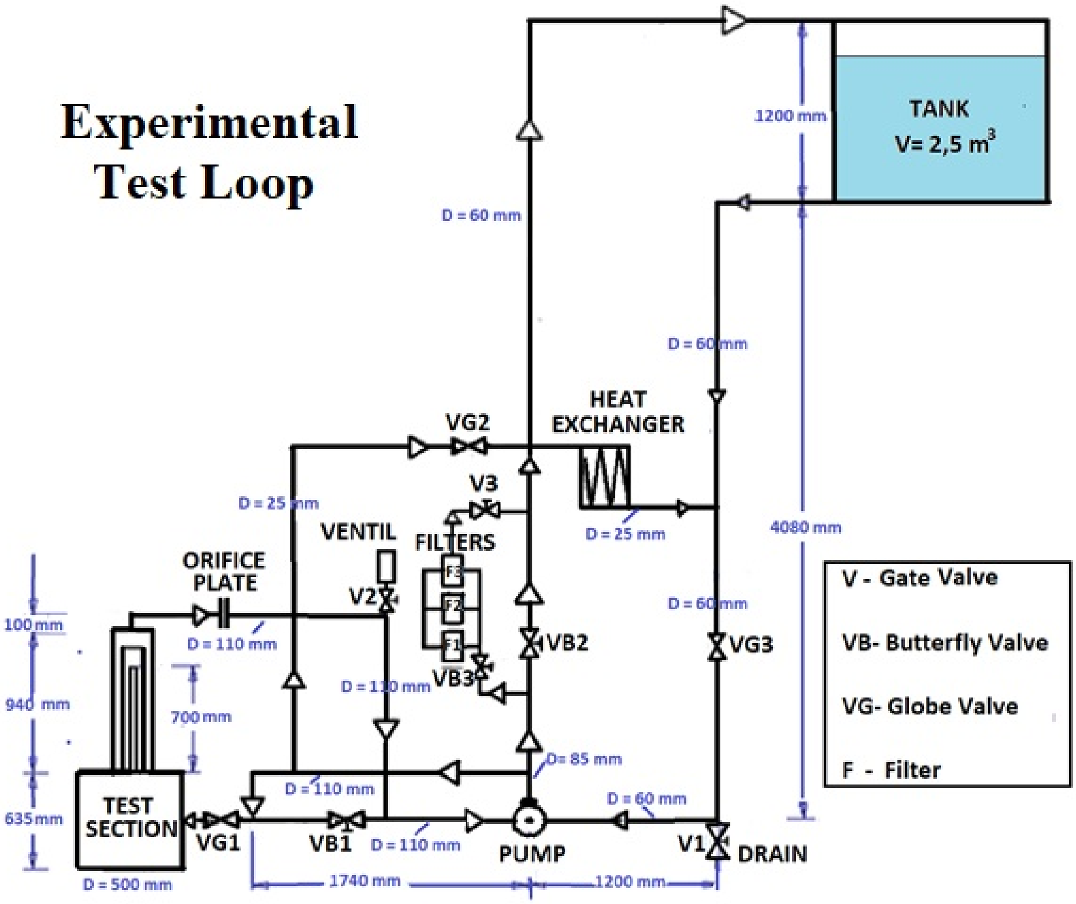

Figure4. Experimental Test Loop

The experimental loop was designed to provide the operating conditions required for the critical velocity and plate collapse experiments with the test section of the three-channel flow simulator model with two aluminum flat plates based on the design dimensions of the RMB fuel element.

3. EXPERIMENTS

Initial experimental data were taken considering mean velocities in the channels of the two plates fuel element model from 7.0 m/s to approximately 12.0 m/s. In this initial phase, the main objective was to test the operation of the experimental loop, to verify the reproducibility of the signals of the strain gauge and pressure sensors signals. For several days, the circuit was operated and the signals proved to be quite reliable, reproducible and unaffected by spurious noise from the power grid. After each operation, the signals of the strain gauge returned to the initial condition demonstrating that there were no plastic deformations of the plates.

In the second phase of the experiments the objective was to reaching the condition of plate colapse and the detection of the critical velocity. In this phase, we started the experiments with the average velocity of the channels around 6.5 m/s. At each actuation on the globe valve to increase the flow of the circuit and consequently the average velocity in the channels, the signals from the process sensors in steady state condition were monitored and recorded at a sampling frequency of 1200 Hz for 10 seconds. The strain sensors were monitored and recorded with the same frequency but with a longer sampling time. This velocity was increased by 1.0 m/s with each step. From the average velocity around 13.0 m/s, we promoted increases of 0.5 m/s and recorded the signals during the transient operation of the globe valve for a period of 30 seconds for the process signals and at least of 60 seconds for the strain gauge signals. We reached the maximum flow condition in the circuit with the average velocity in the channel of 15.0 m/s.

4. RESULTS AND DISCUSSION

Figure 5 shows the pressure drop curve between the inlet and outlet in the test section, ΔP, against channel mean velocity. In this curve, it can be observed that during the experiments there was a linear tendency of increase of ΔP. From the velocity 14.0 m/s there was a decrease in the hydraulic resistance of the test section, which is a consequence of the collapse of the plates due to the plastic deformations in the flow channels. This effect was also observed by Ho et al. (2004).

In the experiments, it can be observed that the signals of the extensometers showed a behavior of increase of deformations with the average velocity of the channel of a continuous and gradual way. It was observed the higher deformations in the middle of the test section (SG3) and lower in the output (SG5). From 14.0m/s, the increase of deformations by velocity gain has jumped. This can be observed mainly when the velocity varied from 14.0 to 14.5 m/s, Figs. 6, 7, 8 and 9. It is assumed that this was the starting point for the plates collapse and the beginning of the plastic deformation.

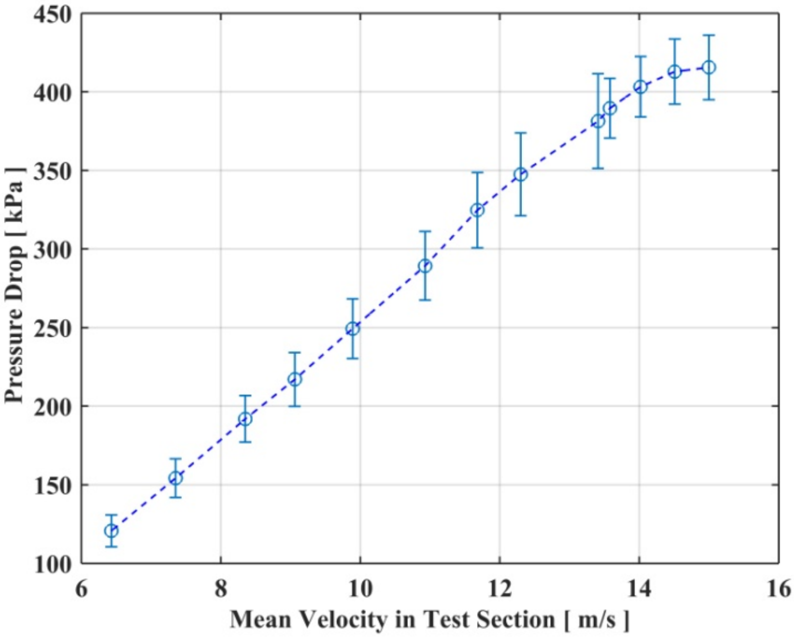

Figure 5. Pressure drop in the Test Section

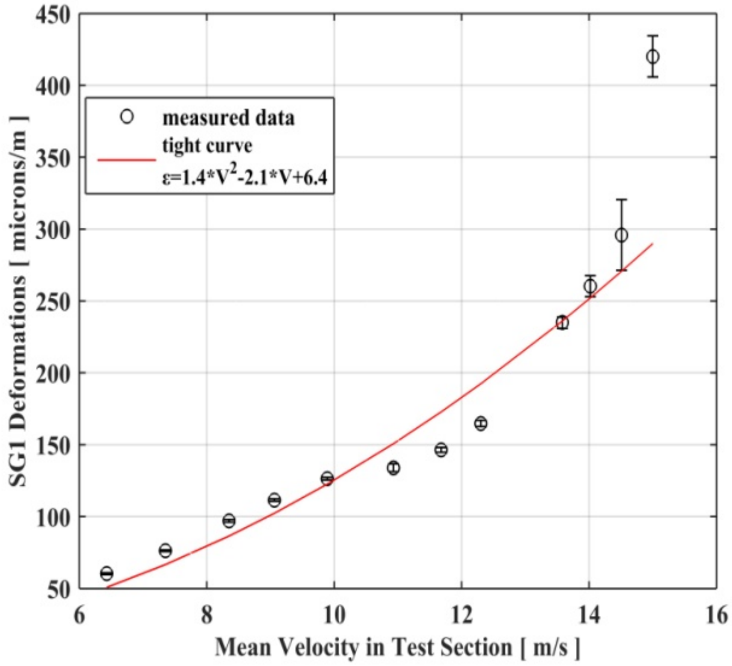

Figure 6. Deformations in the inlet (SG1) of the Test Section

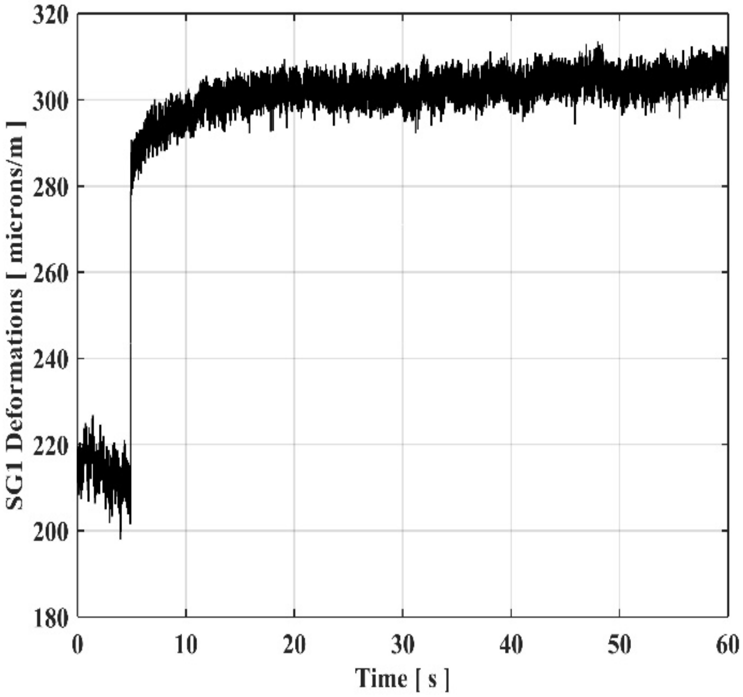

Figure 7. SG1 Signal transient from 14.0 to 14.5 m/s

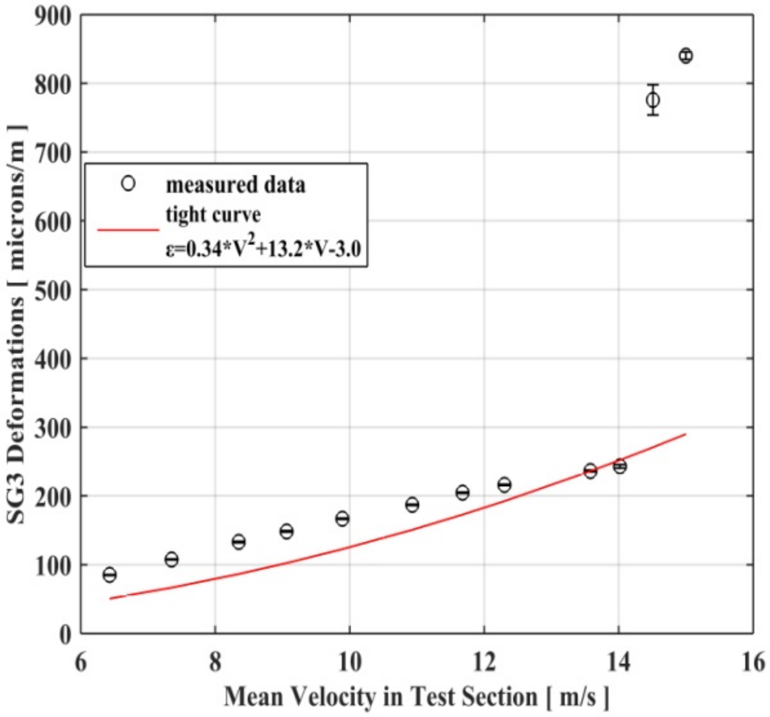

Figure 8. Deformations in the middle (SG3) of the Test Section

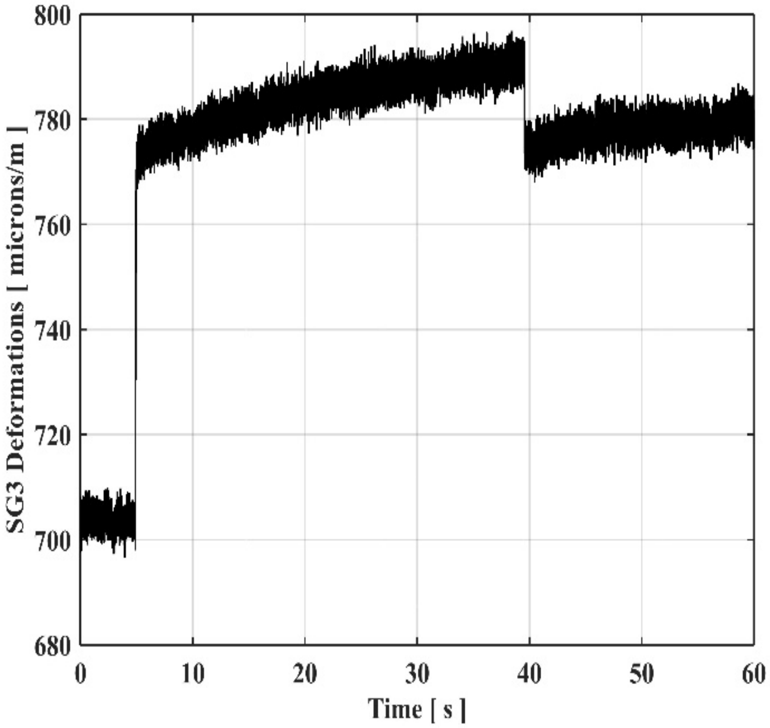

Figure 9. SG3 Signal transient from 14,0 to 14,5 m/s

Fig.10 shows a picture of the channels of the test section inlet after the critical velocity experiments. The deformation of the central channel is clearly seen blocking the lateral channels.

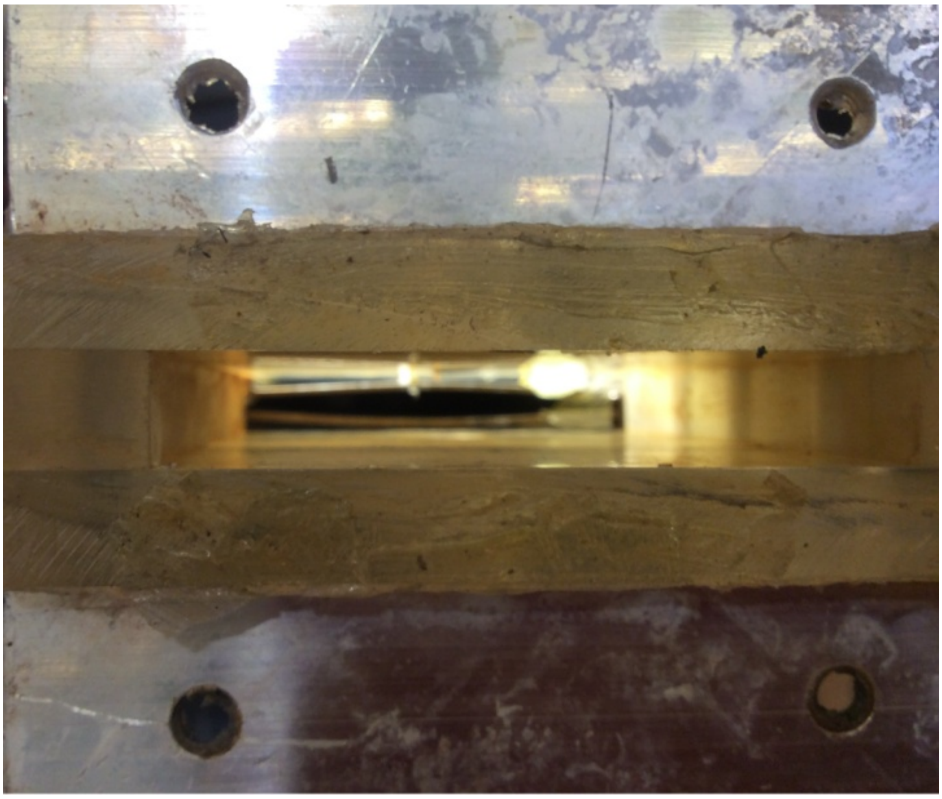

Figure10. Test Section after critical velocity experiment

5. CONCLUSIONS

The experiments performed reached Miller's critical velocity condition. There was collapse and consequent plastic deformation of the plates forming the flow channel with the average speed of the test section of 14.5 m / s. The collapse of the plates occurred with the speed equivalent to 85.5% of the value calculated by the Miller equation that was 17.0 m/s. This result is compatible with the experiments of Ho et al. (2004).

The signals of the strain gauges showed a behavior of the plate deformations, proportional to the squared velocity up to 14.0 m/s, in accordance with the hypotheses of the Miller model (1958), which uses the Euler-Bernoulli equation applied to the wide beam theory. It was observed that at speeds up 14.0 m/s the deformations spiked as the plates failed. This fact was used to characterize the occurrence of plates collapse and occurrence of the critical velocity at 14.5 m/s. This technique of plate collapse characterization is unique for critical velocity detection experiments.

The occurrence of critical velocity was observed visually during the disassembly of the test section, illustrated and discussed in the results analysis presented in this work. Blockage of the channels was also observed by means of the pressure drop plot against the mean velocity of the test section. There was a drop in the hydraulic resistance of the test section due to the increase of the cross-section of flow in the central channel.

6. ACNOWLEDGEMENTS

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7. REFERENCES

Andrade, D.A., Castro, A.J.A., et al, 2014. "*Report Research Project CNPq n. 481193/2012-0 -Experimental Test Loop to study Critical Velocity and Flow induced Vibrations of reactor parallel-plate fuel assemblies*", São Paulo, Brazil.

Ho, M., Hong, G., Mack, and A.N.F.,2004. *"Experimental investigation of flow-induced vibration in a parallel plate reactor fuel assembly*". 15th Australian Fluid Mechanics Conference, The University of Sydney, 4p., Australian.

Miller, D.R., 1958.. " *Critical flow velocities for collapse of reactor parallel-plate fuel assemblies*", Knolls Atomic Power Laboratory Report*,* United States Atomic Energy Commission contract n° W-31-109 Eng-52, New York

Silva, J.E.R., 2013."*RMB-N01-00-PC-10300-RD-006-Revisão 0B* **-** *Descrição do projeto de concepção do núcleo, componentes, estruturas e instalações associadas ao núcleo do Reator Multipropósito Brasileiro- RMB".* IPEN , Brazil.

Torres, W.M., Umbehaum, P.EA., Andrade, D.A., and Souza, J.A.B., 2003. *"A MTR fuel element flow distribution measurement preliminary results",in Proceedings of 2003 International Meeting on Reduced Enrichment for Research and Test Reactor,* 6 p., Chicago, USA.

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