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Research paper

Accelerometers data processing for boiling onset detection on the LIPAc beam stopper

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HIGHLIGHTS

- A deuteron beam dump cooled with water is monitored with an accelerometer.
- Local boiling onset detection is used as a safety interlock to shut down the beam.
- Turbulent noise at high flows mixes with the boiling signal.
- RMS is not a usable parameter to discriminate boiling onset in this case.
- A feature of the frequency distribution is used as a trigger safety signal.

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ABSTRACT

The LIPAc (Linear IFMIF Prototype Accelerator) is a prototype that ends in a dump made of copper with conical shape and cooled by water moving at high speed on the outer surface.

In case the beam reaches the dump with abnormal misalignment or offset, the local temperatures at the water-copper surface will give rise to boiling onset which can be used as a warning flag before an excessive thermal stress distribution could endanger the mechanical integrity of the Beam Dump.

Previous experiments having the same goal were carried out with hydrophones to detect the onset of boiling [doi:10.1016/j.fusengdes.2015.01.011]. The current article deals with the treatment of the signal coming from an accelerometer.

The article will go into detail of data treatment to refine the detection of the boiling onset, even if noise coming from external or undesired sources is mixed with the boiling signal, which prevents in this case the use of the RMS as a monitoring parameter.

Recommendations are given for the implementation in the cooling system of the LIPAc Beam Dump to be installed in Rokkasho.

1. Introduction

The International Fusion Materials Irradiation Facility, also known as IFMIF, will be a test facility in which candidate materials for the use in fusion reactors can be fully qualified. The LIPAc (Linear IFMIF Prototype Accelerator) is a prototype of one of the two IFMIF accelerators [1]. Its objective is to validate the low energy part (9 MeV) of the IFMIF linacs (40 MeV, 125 mA of D+ beam in continuous wave). It will not have a target and hence a dump is needed to stop the deuteron beam.

The LIPAc BD (Beam Dump) which stops the deuteron beam consists of a cone made of copper, whose inner surface absorbs a power of 1.12 MW, with up to 2.5 MW/m^2 peak power density in nominal conditions. This piece is cooled by water in counter-beam direction at high velocity through an annular channel formed between it and a second piece (shroud or outer cone) [2].

The shape of the beam and the deviations from nominal value, give rise to areas within the inner cone where higher temperatures and thermal stresses may be reached, situations that do compromise the mechanical stability of the whole piece. The pressure has been chosen to have near-saturation conditions, therefore when the temperature in the cone-water interface exceeds a certain threshold boiling occurs and its detection can trigger a safety interlock to stop the beam. So the prompt identification of the boiling onset plays an important role in the alarm subsystem.

This boiling onset can be detected by means of hydrophones introduced in the cooling water, as described in a previous article [3]. Here we explore the suitability of accelerometers to perform

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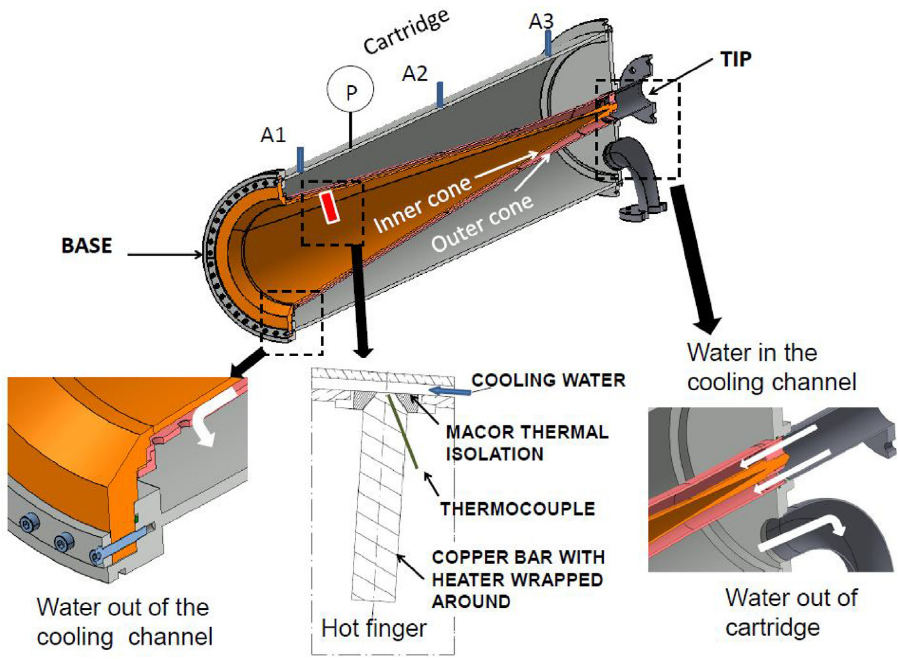

Fig. 1. Cross section of the BD cartridge prototype. A1, A2, A3 are the accelerometer locations.

this task. These sensors possess some operative advantages: (1) they can be attached to the external surface of the pressure vessel, not requiring penetration of the wall; (2) their high frequency response is less sensitive to common external acoustic noises which become largely damped by the massive structure; (3) their response is essentially independent of where they are placed on the structure; (4) the same sensor can be used to monitor flow induced vibrations (low frequency) and boiling (high frequency); (5) finally, there are a wide range of available models in the market that are radiation hard at the levels expected in the installation. This work describes the signal treatment that is required for the boiling onset detection when the raw signal is mixed with random bursts occurring as a consequence of high speed flows, vortex shedding, cavitation and/or remaining gases in the circuit.

There are key works in fusion components cooling systems where accelerometers are used, such as the Plasma Facing Components analysis carried out for the ITER divertor [4], which demonstrates the suitability of accelerometers signals to detect Critical Heat Flux (CHF) precursors. The whole range of subcooled boiling can be studied with accelerometers [5], in circular channels with and without turbulence promoters. In comparison with such studies, the current work features a more slender geometry prone to vibrations [6] and therefore to the appearance of noise mixed with the boiling signal.

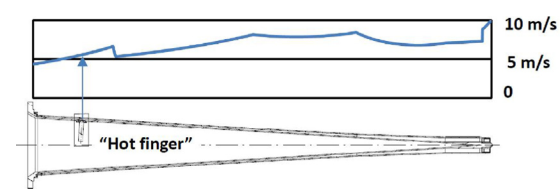

Fig. 2. Water speed profile in the cooling channel (between cones).

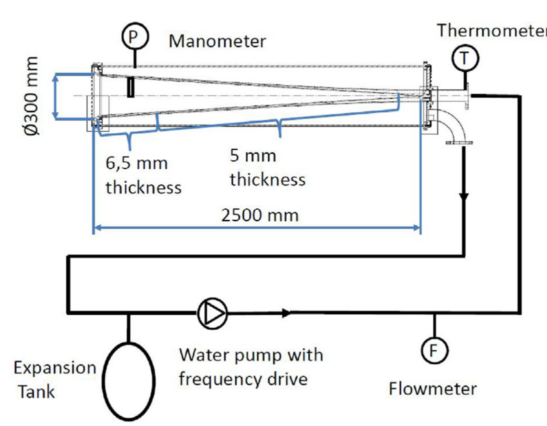

Fig. 3. Simplified sketch of cooling circuit. Thickness of the inner cone wall.

2. Description of the experimental setup

2.1. Prototype of the BD

The device on which the tests have been performed is a 1:1 model of the final version to be installed in the Rokkasho facility, which is thoroughly described in [7]. As can be seen in Figs. 1 and 3 the BD consists of a 2.5 m long inner cone with an aperture of 0.3 m and a wall of 5 mm in most of it, except the 500 mm near the base with 6.5 mm thickness and the zone of the tip with increasing thickness to provide robustness for mechanical support.

The cooling channel between the inner cone and the shroud has a varying gap from a maximum of 23 mm near the tip up to a minimum of 5.5 mm at 500 mm from the base of the cone. The outer cone or shroud is actually a succession of truncated cones, so the speed is kept in values that would provide an acceptable heat transfer coefficient to remove the power of the beam with reasonable temperature gradients. With the nominal flow (108 m^3/h), the speed ranges from 9.9 m/s at the tip zone up to 4.3 m/s near the base (Fig. 2).

The water gets out of the cooling channel in the area of the flange, through holes made on the shroud, and returns backwards to exit the cartridge through the volume defined between the outer cone and the external cylinder (diameter of 0.5 m). The three main components (cones and cylinder) share the same geometric axis, which is placed horizontally.