Experimental Studies on the Occurrence of a Water-Hammer in an Evacuated Beam Tube

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Among the safety considerations in the design and approval phase of experiments at the new Garching research reactor FRM-II the question of consequences of a potential water-leak into the beamline system plays a crucial role. Whereas the neutron beam lines inside the reactor operate with a He-gas filling at a pressure of 1.2 bar, thus providing a damping medium for eventually intruding water from the moderator vessel or the light-water pool, the through-going beam tube SR6 of the planned fission fragment accelerator MAFF will be operated under high-vacuum conditions. Although by design any rupture of the beam tube can be ruled out, we nevertheless investigated the effect of a hypothetical water leakage into the evacuated beam tube. In such a case the intruding water will be accelerated into the vacuum volume with a water-to-gas vaporization phase transition in the first moments of the leakage.

In order to obtain experimental information on this scenario, we installed a test setup at the Accelerator Laboratory in Garching. It mainly consists of two tubes with a length of 6 m each and an inner diameter of 250 mm (wall thickness 2 mm), one of them being mounted vertically and the second one mounted in a horizontal position (see fig. 1). The two tubes are connected to each other with an exchangeable foil separating the two volumes.

During the tests the vertical tube is (partly) filled with water, while the horizontal tube is evacuated to about 10^{-2} mbar. The pressure in the vertical tube is then increased by pressurized air up to the rupture point of the foil, thus simulating a water leakage into the evacuated beam tube of the fission fragment accelerator, which will have the same inner diameter. Due to its vapor pressure, a part of the intruding water vaporizes and the resulting water-vapor mixture expanding into the evacuated tube is accelerated towards its end flange, where its impact is detected. For this purpose the end flange can be equipped with rupture foils similar to those separating the two tubes, thus allowing to characterize the impact of the accelerated water-gas mixture either being below or above the (separately determined) rupture pressure of the end flange foil. When performing the tests it has to be taken into account that the water leakage from the vertical into the horizontal tube would lead to an under-pressure at the top side of the vertical tube, hence hindering the acceleration of the intruding water into the evacuated tube. So the height of the compressed air column in the vertical tube has to be matched to the pressure needed for rupturing the foil in order to finally achieve normal air pressure in both tubes after the expansion.

In a series of tests a stack of two Mylar foils (each with a thickness of 25 μm and a diameter of 100 mm) were used to separate the water-filled from the evacuated tube. Two similar foils were mounted on the central opening of the end flange. Separate calibration measurements resulted in a over-pressure of about 3.5 bar needed for rupturing the foils. The vertical tube was filled with water up to a height of 3.8 m. Repeated tests with this configuration did not result in a rupture of the end flange foils, thus allowing the first coarse conclusion that the potential 'water-hammer' of the accelerated, expanding water-gas mixture can be estimated to less than about 3.5 bar.

In order to obtain more quantitative insight into the water-leakage process, a second type of experiments was performed with improved diagnostics. This time the impact pressure at the end flange was measured with a set of four strain gauges (RS components, model 632-180, 5 mm length) mounted in the center of a massive, 8mm thick aluminum end flange. The strain gauges translate the bending of the end flange under the impact of the expanding water into an electronical signal, which is then detected with a digitizing oscilloscope. The calibration of the setup was done applying static water pressure from 0 to 10 bar. Under identical conditions as before with the end flange foils, this setup yielded a signal with an amplitude of 360 mV, corresponding to a pressure of 1.7 bar, hence much lower than the predictions of simple estimates for the 'water-hammer'. This first result will now be studied systematically in more detail. The impact pressure will be investigated as a function of the leak area as well as of the residual pressure in the evacuated tube and the initial pressure in the vertical tube. More information on the vaporization phase transition just at the rupture point of the foil will be obtained by monitoring this moment with a high-speed camera.

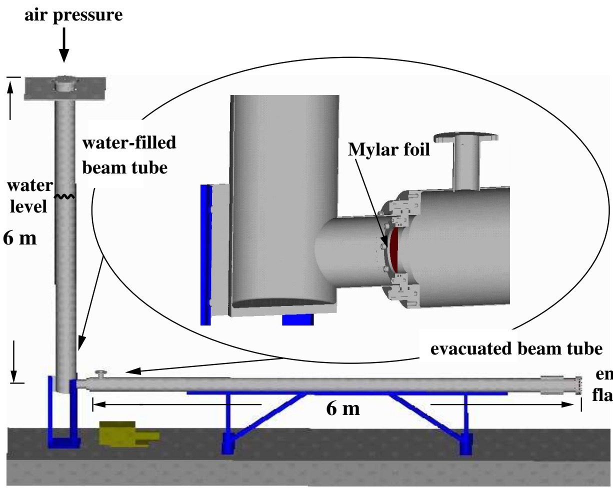

Fig. 1: Experimental setup used for the simulation of a water hammer in an evacuated beam tube.