Development of pressure wave mitigation technique by using microbubbles to realize mercury target for high power pulsed spallation neutron source

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1. Overview

Atomic nuclei break up and various kinds of secondary particles are generated, when the proton beams accelerated to almost the same speed with the light collide with atoms of the target material. The neutron which is one kind of the secondary particles enables to detect the light elements and the phenomena that could hardly be done by using the X-ray in the past. At the Materials and Life science experimental Facility (MLF) in J-PARC (http://j-parc.jp/), the spallation neutron source that uses mercury as the target material is in operation. Mercury has the excellent properties of good neutron yield and the small radiation damage. When the proton beam is injected into the mercury target, the thermal expansion due to the abrupt temperature rise in mercury generates pressure waves that reach up to ca. 50 MPa. The pressure waves cause the cavitation damage on the vessel wall surface contact with mercury and shorten the lifetime of the mercury target vessel. Mechanism of the damage generation and its growth process were, therefore, investigated and the technique to mitigate the pressure waves and the cavitation damage. As well, the in-situ diagnostic technique on the pressure waves was developed.

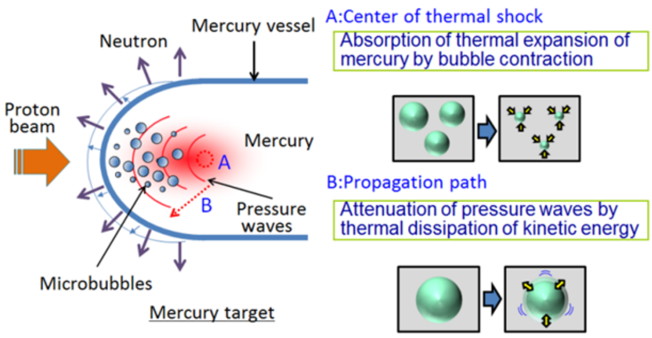

Fig.1 Mechanism of pressure wave mitigation by microbubbles

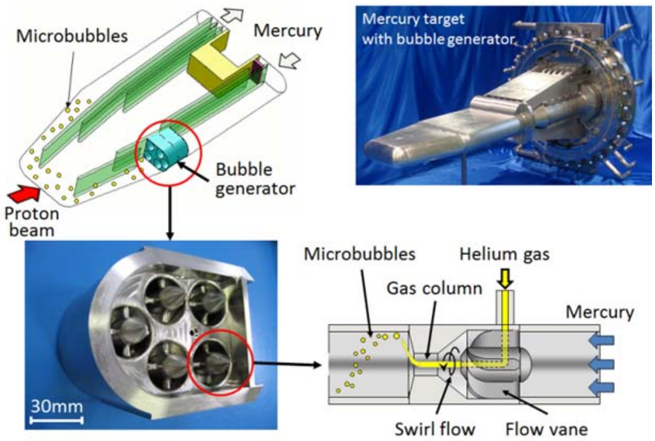

Fig.2 Mercury target and bubble generator

2. Technical Features

The inception condition and accumulation behavior of the cavitation damage due to pressure waves were investigated in detail and the prediction method was proposed based on experimental results obtained by the electro-magnetic impact testing machine which was developed to simulate the dynamic response of the target vessel wall to pressure waves. Based on this investigation, it was found that the target vessel had the possibility to fail before its designed lifetime. The pressure wave mitigation technique using microbubbles was developed focusing on the absorption of the thermal expansion of the mercury by the bubble contraction and the attenuation of pressure waves by the thermal dissipation of the kinetic energy (Fig.1). The dynamic response of the microbubbles and the interaction were analyzed by numerical analyses in macro, mezzo and micro scales and the most optimal size and population of the microbubbles for pressure wave mitigation were evaluated.

However, it was difficult to inject microbubbles into the flowing mercury because it had the high surface tension, low wettability and large density, etc. We carried out various elemental tests and finally succeeded in developing the bubble generator (Fig.2) which could generate microbubbles of optimal size in mercury. The gas column of helium made at the center of the swirl flow of mercury is bended and broken down to microbubbles by shear stress and sudden pressure change at the exit of the reduced flow channel. Several bubble generators were arranged in parallel making those swirl direction alternatively to vanish the swirl flow at the downstream, which minimizes the coalescences of microbubbles.

To distribute microbubbles in the required region in mercury whose density is 13 times higher than that of water, microbubbles motion in flowing mercury was evaluated by numerical simulations and verified by the experimental results carried out using a mock-up model of the mercury target loop. Based on these results, we decided the target structure which realizes the microbubble distribution to mitigate the pressure waves effectively.

The noncontact monitoring system to measure the dynamic response of the mercury target remotely in the high radiation field was developed. When proton beams were injected into the mercury target, the vibration of the target vessel could be measured in-situ (Fig.3) and the effect of microbubbles to mitigate pressure waves was demonstrated for the first time in the world.

3. Summary

The unprecedented mercury target was completed and the stable and long operation of the pulsed neutron source with the highest beam power in the world will be realized. It is expected that the mercury target can contribute to the creation of the innovative outcome that leads the field of the materials and life sciences in the world.

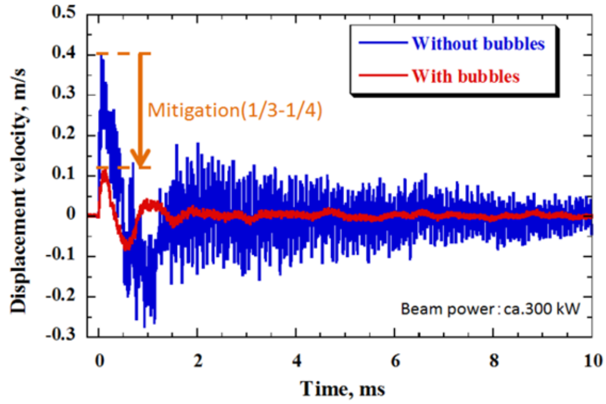

Fig.3 Vibration of the mercury target vessel by proton beam injection