Fusion Engineering and Design 102 (2016) 108–111

Contents lists available at ScienceDirect

Fusion Engineering and Design

journal homepage: www.elsevier.com/locate/fusengdes

Laser reflection measurement on liquid lithium flow surface

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HIGHLIGHTS

- We have been studying a liquid lithium surface wave fluctuation for IFMIF.
- We developed a new method using laser to measure the lithium surface.
- The result from the laser method was compared with the result of previous study using contact probe method.
- The result from the laser method was obtained a new phenomenon that was not measure by the probe method.
- Proof of principle experiment of laser method was performed successfully.

ARTICLE INFO

Article history:
Received 2 October 2014
Received in revised form 3 September 2015
Accepted 21 September 2015
Available online 29 November 2015

Keywords:
IFMIF
Liquid lithium jet
Surface fluctuation
Laser reflection method

ABSTRACT

In the international fusion materials irradiation facility (IFMIF), 14 MeV neutrons are generated by 40 MeV deuteron beam injection into a high-speed free surface liquid lithium (Li) plane jet, which flows along a vertical concave wall in vacuum. Measurement of the free surface flow or of the fluctuation in thickness is a key issue for stable neutron generation and for safety of Li target system. In the present study, a laser reflection method for the measurement of surface wave of the Li jet is proposed and tested experimentally. The method enables us to obtain time variation of wave shapes and surface fluctuations in two dimensions. As a result, it was found that slope angles of waves in transverse direction are steeper than those in flow direction, and that the surface fluctuation consists of two components of long waves and very short waves. It was confirmed that with using the present laser method, very similar wave characteristics obtained by the probe method. Although the laser method need to be improved the data processing, and that proof of principle experiment of the method was performed successfully.

1. Introduction

In the international fusion materials irradiation facility (IFMIF) [1], 14 MeV neutrons are generated by two 40 MeV, 125 mA deuteron beams injected into a high-speed liquid lithium (Li) plane jet. The Li target assembly consists of a two-stage contraction nozzle based on the Shima model [2] and an open channel. The liquid Li jet is 25 mm in depth and 260 mm in width and flows along a vertical concave back-wall with a curvature radius of 250 mm. The deuteron beams irradiate a region at about 175 mm downstream from nozzle exit. Although the Li flow velocity of more than 15 m/s is necessary to remove the heat flux, the free surface flow might be unstable due to such high velocity. However, the jet thickness variation must be suppressed as small as possible, so as to yield high quality neutron fluxes and to ensure the safety of Li target system.

The experiments on the Li flow were conducted using the liquid Li circulation facility at Osaka University. The test section containing the nozzle and the flow channel was designed 1/2.5 scale of the Li target of the IFMIF. Liquid Li is designed to flow vertically in IFMIF, but one in the Osaka loop flow horizontally.

An electro-contact probe apparatus which is called the probe developed by our laboratory was used for a contact measurement of surface fluctuation of the Li jet [3]. As a result, local surface structure of Li jet such as wave heights and contact frequencies, were accurately measured by the probe [4–7]. However, the measurement of the probe has some problems. For example, surface wave might be cluttered with the probe, and the whole of surface wave is difficult to grasp due to one dimensional scanning property at a fixed point. In addition, scanning of the probe takes long time. Since Li is circulated under high temperature and high radioactive vacuum environment, development of non-contact measurement method

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http://dx.doi.org/10.1016/j.fusengdes.2015.09.019

is highly expected. The non-contact measurement method like PIV (Particle Imaging Velocimetry) or stereo method using two video cameras were tested to measure the Li surface velocity distribution and three-dimensional shape of the Li surface [8–10]. However the optical measurement of the liquid Li which is a specular object was very difficult due to the requirement of very large dynamic range on the image pick-up devices. Recently a laser based distance meter which uses an optical frequency comb was tried by Japan Atomic Energy Agency (JAEA) to measure the surface fluctuation of Li with a successful measurement of the fluctuation of one dimensional height like a probe method [11].

In the present study, a laser reflection method for a measurement of the surface wave of the Li jet is proposed and tested experimentally. The method is a technique to measure fluctuation of jet thickness from a reflected point of laser beam, which represents a slope angle of fluid surface. The present paper will report on the principle and the data of the measurement and the comparison with the previous probe data [7].

2. Experiment

2.1. Measurement method

Fig. 1 shows the principle of the laser refraction method for measurement of surface wave of the Li jet. A diffuser plate with a hole in the center is placed above the liquid Li surface. When the surface with slope angle θ is irradiated by a laser beam through the hole, the laser beam is reflected and a reflected laser beam illuminates a point on the plate. The slope angle is equal to an angle of incident or reflection and is indicated in Eq. (1).

$$\theta = \frac{1}{2}\tan^{-1}\frac{d}{h} \tag{1}$$

Here, h is the height from the surface to the plate and d is the position of reflection point and is distance from the center. The equation means that if the height h from the surface is known, we can get the slope angle θ of the surface wave.

The position of reflection point d is separated into each components d_x and d_y of X–Y coordinate. In this paper, X and Y axis indicate transverse and flow direction, respectively.

In addition, the fluctuation of the wave thickness can be calculated from the slope angle θ and the traveling velocity of the free surface $(dl/dt)_{wave}$. Here, the traveling velocity is assumed as the flow velocity of the Li jet.

$$\frac{dh}{dt} = \frac{dh}{dl}\cdot\left(\frac{dl}{dt}\right)_{wave} \tag{2}$$

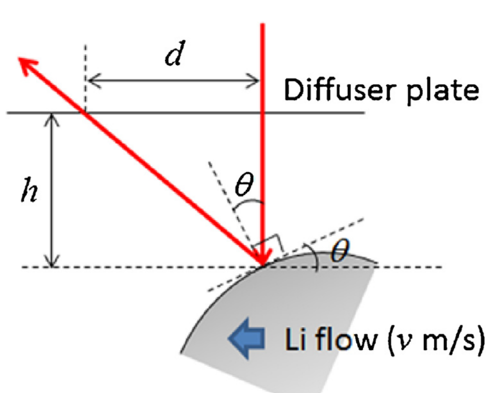

Fig. 1. Principle of the laser reflection method.

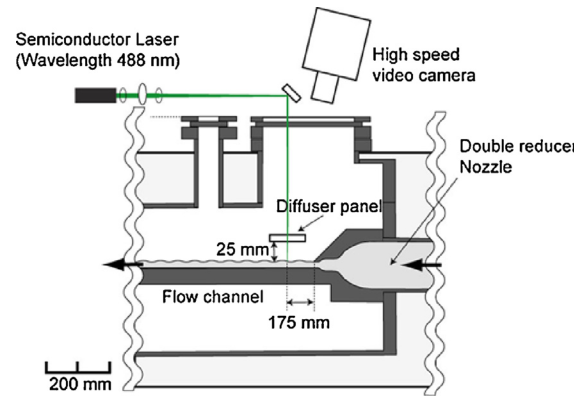

Fig. 2. The test section of liquid Li circulation loop at Osaka University and the experimental set up for laser reflection method.

The slope angle is represented by following equation of thickness variation dh to moving length dl of surface wave.

$$\tan\theta = \frac{dh}{dl} \tag{3}$$

The present method is fairly new in the point that enables us to obtain not only the wave height but also two-dimensional surface shape information.

2.2. Experiment

Fig. 2 shows the schematics of test section of liquid Li circulation loop at Osaka University and the experimental set up for laser reflection method. Liquid Li is blown out from exhaust nozzle which is the width in 70 mm and the thickness in 10 mm horizontally.

A diffuser plate with a hole was installed at the height of 25 mm from the Li surface and the hole was located at 175 mm downstream from nozzle exit. The location at 175 mm corresponds to the beam illumination axis in IFMIF. The diffuser plate is made of rectangular pyrex glass of 59 mm wide, 65 mm long and 2 mm thick, and can read slop angle up to 25°.

In the experiment, a semiconductor laser (LBX-488-50-C, Oxxius Ltd.) with wavelength in 488 nm was employed as an optical source. The laser beam was collimated by two lenses and was focused on the Li surface by a lens with 1000 mm focal length. The spot size is focused smaller than 0.1 mm. The laser beam is irradiated the flow channel vertically.

The reflected light on the diffuser plate was recorded using a high speed video camera (HSV, FASTCAM SA1.1, Phtoron Ltd.). The experimental and measurement condition for the HSV is shown Table 1. In this experiment, the differential time dt in the Eq. (2) corresponds to inverse number of frame rate of HSV.

3. Results and discussion

Fig. 3 shows one of the frames taken with HSV. In this picture, liquid Li flow from right to left. The incident laser beam into the center hole was reflected on the Li surface and it appeared as a spot at lower right of the center hole on the diffuser plate. X–Y

Table 1
Experimental condition.

Items	Set values
Flow velocity [m/s]	3, 5, 7, 9, 11, 13,15
Ar pressure [MPa]	0.12
Li temperature [degree]	300
Frame rate [fps]	54,000
Exposure time [s]	1/101,000