LIQUID METAL DROPLETS SYSTEMS FOR APPLICATION IN TOKAMAKS AND PLASMA DEVICES

A.V. DEDOV, A.I ARISTOV, S.D. FEDOROVICH, V.P. BUDAEV

National Research University "MPEI", Russian Federation, Moscow

Email: DedovAV@mpei.ru

INTRODUCTION

The use of liquid metals as materials for the in-vessel components of fusion reactors is one of the promising solutions to the problem of plasma-wall interaction, when there is a risk of erosion of solid materials under the a plasma load [1]. Liquid metal in-vessel components in tokamaks and other fusion devices are proposed to be used with capillary-porous systems (CPS), systems with injection of a droplet stream or jets of liquid metal into edge plasma.

In experiments on tokamaks [2], a jet system for the flow of liquid metal droplets into a peripheral plasma was used. When injecting a stream of liquid metal droplets into the plasma, there are several advantages: no conditions for closing currents through the droplet stream and, therefore, there are no MHD effects on the trajectory of the liquid metal in the plasma; recycling increasing, conditions arise for plasma shielding of increased plasma load due to evaporation of droplets away from the walls in comparison with lithium CPS. The use of liquid metal droplet systems has some advantages in comparison with the analog injection system of lithium powder (for example, used in record discharges in the EAST tokamak). All the mentioned advantages of liquid metal droplets systems determine the relevance of testing such systems in plasma devices and tokamaks. In this paper, based on a brief overview of the test results of jet and droplet liquid metal systems in tokamaks and test facilities, the technological parameters of a droplets liquid liquid for testing in a plasma steady-state device are selected. The experimental results of testing a galinstan liquid metal droplets system in the PLM plasma divertor simulator are presented.

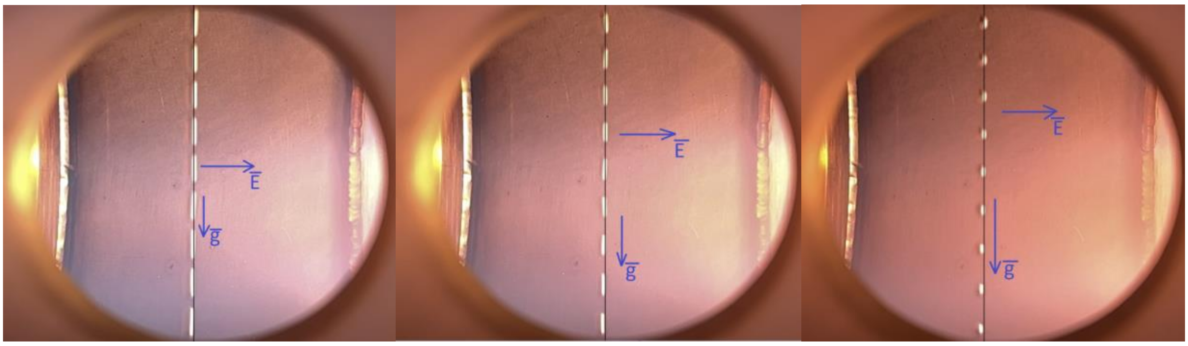
1. APPLICATION OF LIQUID METAL DROPLETS IN TOKAMAKS AND PLASMA DEVICES

The practical creating of a liquid metal limiter in a tokamak was demonstrated in [2]. The limiter was performed by a stream of droplets with a diameter of 2-4 mm, consisting of separate jets of gallium arranged in two rows. A comparative analysis of the main plasma parameters was performed when using a liquid gallium limiter and when using a graphite limiter with a similar geometry. The gallium limiter provided increased radiation losses at the initial stage of the discharge, but in the middle phase of the discharge their level significantly decreased compared to the graphite analog.

In [3], the design of a lithium injector with an ultrasonic oscillation generation method is described. During the tests of the lithium injector on the tokamak, it was installed in the equatorial nozzle of the tokamak chamber from the outside. According to the sequence of recorded video frames, taking into account the angle of observation, the authors analyzed the velocity distribution in the plasma flow. The droplet velocity before cleaning the injector with a glow discharge ranged from 2.8 m/s to 6.4 m/s. The speed after cleaning the injector reached 11 m/s. The conceptual design of the liquid metal divertor system is described in [4] as applied to the FFHR-d1 fusion device. The REVOLVER-D divertor system uses a stream of liquid tin in the divertor area. This installation provides several methods of flow generation, and, in particular, in droplets mode. The effect of the temperature of a liquid metal on the flow rate and vapor pressure of the metal was also studied. The authors note the possibility of maintaining the vapor pressure within the requirement <0.0024 Pa ($T < 1200$ K) while maintaining a flow velocity of at least 5 m/s. Thus, the vapor pressure of the liquid metal remains low compared to the pressure of residual helium and hydrogen isotopes. The analysis of the above-mentioned results made it possible to select the parameters for the experimental liquid droplets system (droplet size, droplet velocity during passage through the plasma, parameters of evaporation of material from the droplet surface) for testing in PLM plasma device.

2. INJECTION OF LIQUID METAL DROPLETS IN THE PLM DEVICE

In the PLM device [5] (magnetic plasma divertor simulator device), galinstan liquid alloy (GaInSn) was injected into a steady-state plasma with parameters relevant to tokamak edge plasma (plasma density ~2 10^{12} cm^{-3}, electron temperature ~2 eV). The droplets falling into the plasma column were registered by camera, the charge of the metal droplets was estimated by their deflection and shape change using a numerical model. When falling in a vacuum (without plasma), the droplets had an elongated shape in the form of a cylinder. When moving through the plasma, the droplets acquired an electric charge and, under the influence of the electric field in the plasma (generated by the current between the cathode and the anode), the trajectory deviated from the vertical. A change in the shape of droplets was registered in the plasma: the droplets took a spherical shape. With an increase in the plasma discharge current (which led to an increase in plasma concentration), the cylindrical shape of the droplet changes upon entry into the plasma – the length of the cylinder decreases, taking a shape close to spherical in the lower part of the discharge (Fig. 1). Then, according to the results of experiments, the charge of the droplets was determined. The charge was determined from the deviations of the trajectories of the droplets from the vertical, and from the counteraction of Coulomb forces and surface tension forces.



(a) (b) (c)

Fig. 1. Photographs (optical image) of the liquid droplet flow in the plasma of the PLM, observation through a horizontal diagnostic window, discharge current: (a) Ip =1 A; (b) Ip=3 A;(c) Ip=13.9 A. The vertical is plotted as a dark line along the acceleration vector of gravity g, E is the vector of electric field in plasma

The obtained droplet charge values by the two methods showed a good correspondence between each other. As the plasma discharge current increased, the droplet charge varied from $1.5*10^{-7}$ Kl to $5.0*10^{-7}$ Kl. The value of the resulting charge will be used to estimate the trajectory of liquid metal droplets during passage in a tokamak, including in a tokamak reactor. Conclusion based on the test results of jet and droplets liquid metal systems in tokamaks and test facilities, the technological parameters of the droplets liquid metal flow were selected for testing in PLM plasma device- plasma divertor simulator. Experimental tests of liquid galinstan liquid metal droplets have been fulfilled in PLM. It has been shown that droplets flow parameters such as droplet size and velocity can be controlled. Numerical simulation shows the possibility of using metals in the chamber without significant degradation of vacuum conditions.

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