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Magnetohydrodynamic experimental design and program for Chinese liquid metal LiPb experimental loop DRAGON-IV

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ABSTRACT

To investigate the key issues of the liquid metal LiPb blankets, liquid metal LiPb experimental loop is necessary equipment, and the magnetohydrodynamic (MHD) experiment is one of the important parts for investigation of the LiPb flow characteristics under the magnetic field of the magnetic confinement fusion reactors. Considering the design features of the LiPb blanket and the engineering feasibility, the MHD experiment duct was developed for Chinese liquid metal LiPb experimental loop DRAGON-IV. In this paper, the design scheme and parameters for MHD experiment duct were given. The performance analyses about MHD flow characteristics and stress were presented. And future MHD experiment program was specified.

1. Introduction

Because of many advantages such as relatively simple design, adequate tritium breeding ratio and high heat removal, liquid metal breeder blanket concept has become a topic of great interest in fusion reactor blanket design [1–5]. A series of fusion reactors (named FDS series) have been designed and assessed by the FDS Team in China [6–10], and a series of liquid metal (LM) LiPb blanket concepts based on the up-to-date fusion technology have been developed correspondingly [11–13]. As the development of ITER project, liquid metal LiPb test blanket module (TBM) has become a key research field for China, Europe and US [14–17].

In these LiPb blanket designs, LiPb is considered as tritium breeder only or as breeder and coolant. However, fusion reactor condition is a strong magnetic field, high temperature, strong corrosive and irradiation environment. The liquid metal LiPb flows in blanket causing many challenging technical problems, such as compatibility between LiPb and structural materials, liquid metal magnetohydrodynamics (MHD) effect and so on. So it is very necessary to do corresponding experiments for studying the key issues of liquid metal blankets. A series of liquid metal LiPb loops named DRAGON series loops have been designed by FDS team [18]. And the LiPb loop DRAGON-IV is a multifunctional forced convection LiPb loop. The experiments of high temperature corrosion, stress corrosion, MHD effect and small module test of blanket will be carried out on this loop.

The motion of liquid metal in fusion reactor strong magnetic field causes serious MHD effects [19–22], which have dramatic impacts on velocity distribution, heat transfer characteristics, pressure drop and the required pumping power for the cooling system. Therefore, the LM MHD effect is one of the key issues in making an optimal design for LM blanket. Some MHD effect experiment studies are on going in the world [23–27]. And the MHD experiment based on LiPb loop DRAGON-IV will be carried out in China.

In this paper, the design scheme and main parameters of the MHD experimental duct are given. The LiPb flow characteristics, temperature and stress distributions of the duct are analyzed by the magnetic thermal-hydraulics coupling code MTC [28] and the commercial finite element program ANSYS [29].

2. Design of the MHD experimental duct

2.1. Design objectives and principles

Since MHD effect is one of the key issues in making an optimal design for LM blanket, the goal of the MHD experiment based on DRAGON-IV loop is to investigate the flow characteristics of LiPb in the duct relevant to blanket design, and to develop the control and measurement technology for blanket research.

The principle is to demonstrate the characteristics of present blanket design as far as possible. And the engineering feasibility must be considered synchronously. So the mature material and device technologies are adopted in the MHD experimental

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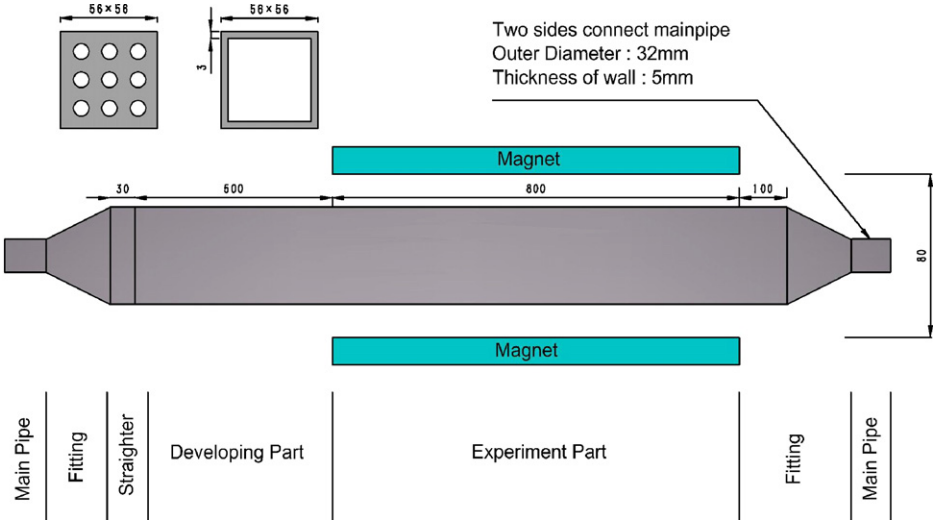

Fig. 1. Design scheme of the experimental duct.

duct. And the design is flexible possibly to meet the needs when upgrade.

2.2. Scheme and main parameters of the MHD experiment

The square duct for MHD experiment is first designated in the DRAGON-IV loop with round duct as its main duct. Fig. 1 shows the design scheme of the experimental duct. The main parameters of the MHD experiment are shown in Table 1. The space between the magnetic poles is 80 mm, the inner and outer dimension of the square experimental duct is 50 and 56 mm respectively. The main duct of loop and MHD experimental duct are connected by duct fittings. A flow straightener is installed at the entrance of the MHD duct to make the flow homogenized. The length of the test section is 1400 mm, including 600 mm flow developing region and 800 mm experimental test region. The magnetic field is 2 T in the middle of the magnet with length of 400 mm. The profile of magnetic field on the axial line of magnet is shown in Fig. 2.

The temperature of the duct is much higher than the surrounding temperature, and the gap between the duct and magnetic pole is 12 mm. The magnetic field will become unstable when the surrounding temperature is higher than 60 °C, so the heat insulation measure is needed. The heat insulator with the thickness of 7 mm is installed out of the duct, and a air cooled system is used to make sure the device stable.

2.3. The characteristics of MHD flow and the measurement technique

In order to investigate the MHD flow characteristics in the flow channel of blanket, like the flow in cores, in thin boundary layers or in complex geometry ducts, some parameters must be measured, such as velocity, pressure and temperature. Since LiPb is opaque liquid, some well-developed velocity measurement techniques for classical transports fluids such as water or gas cannot be used to measure the velocity of LiPb flow. The potential difference probes were used to investigate flow field in some liquid metal experimental ducts [30–32]. The movement of electrically conducting fluids in the externally applied magnetic field induces electric fields that are measurable as electric potential differences between two or more thin sensor tips at the head of the probe. Based on this, a more suitable method is being developed to measure the velocity field in LiPb experimental duct of DRAGON-IV loop. And pressure sensor and thermocouple will be employed to measure the pressure distribution of the flow and temperature in the duct.

Table 1
Main parameters of the MHD experiment duct.

Parameters	
Liquid metal	Li17-Pb83
Material of the duct	316L steel
Maximal magnetic field (T)	2
Space of magnetic field (mm)	80 × 200 × 800
Operating temperature (°C)	300–350
Inner and outer dimension of the experimental duct (mm)	50/56
Average velocity (m/s)	~1
Hartmann number (Ha)	~1000
Interaction number (N)	~1000
Reynolds number (Re)	~200,000
Thickness of the heat insulator (mm)	7

3. Analysis of the design

In order to verify the feasibility of the experiment design scheme, some analyses must be carried out. The MHD pressure drop in the experimental duct is related to the pumping power of the loop. Air cooled system is related to the surrounding temperature of magnet, and the stress of the duct must be evaluated.

3.1. MHD pressure drop

There are two components of the pressure drop in the experimental duct, one is the pressure drop of the MHD fully developed flow, and the other is the 3D pressure drop under the fringing magnetic field regions. Since the experimental duct is square duct, the

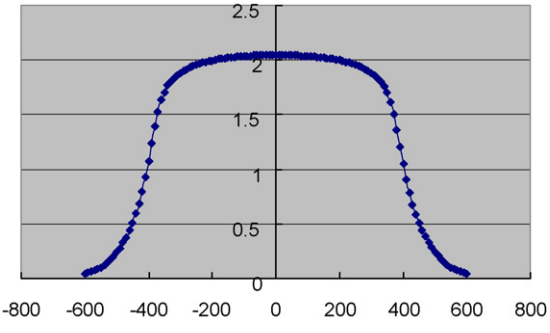

Fig. 2. Profile of the magnetic field on the axial line of magnet.