§5. Test Results of a Solenoid Valve for Supersonic Cluster Beam Injection in LHD

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A new fueling method of SuperSonic Cluster Beam (SSCB) injection is being developed for LHD. SSCB is an improved version of Cluster Jet Injection (CJI) developed in a Chinese tokamak HL-2M[1]. CJI is based on the Supersonic Molecular Beam Injection (SMBI) developed in HL-1A tokamak, where high-pressure gas of a few MPa is injected through the fast solenoid valve equipped with the Laval nozzle. In CJI, the valve and the fuel gas are cooled to ~ 77 K by liquid nitrogen. Then the hydrogen cluster jet, which is expected to be beneficial for deeper penetration of the fuel particles, is easily formed. Deeper penetration and a higher fueling efficiency of CJI compared with SMBI have been reported[1]. In SSCB, the valve and the fuel gas will be cooled to below 77 K by a Gifford-McMahon type cryostat. A solenoid valve of Parker-Hannifin Pulse Valve Series 99B08 with a 0.76 mm diameter orifice has been chosen for SSCB. Before installing SSCB on LHD, it is necessary to know the basic parameters, *e.g.* the velocity and the spreading width of the gas flow, the flow rate of the valve, and the clustering condition. Preliminary experiments have been carried out in a similar manner reported in Ref. 2.

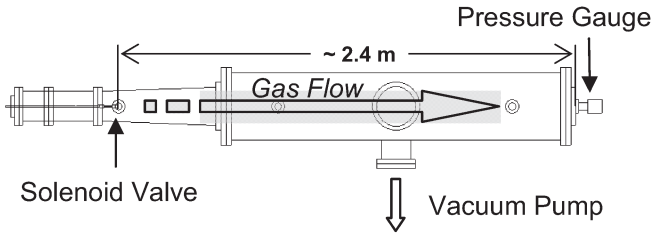

Fig.1. Experimental setup for the gas flow velocity measurement. The distance from the solenoid valve to the pressure gauge is ~ 2.4 m.

The experimental setup is shown in Fig. 1. The valve is set inside the vacuum chamber. The valve cooling system is not yet installed. The pressure in the vacuum chamber, p_1, is measured by the MKS Baratron capacitance manometer (MODEL#617A) set at the opposite side of the valve. When the valve is open, the gas flows from left to right in Fig. 1 and reaches the pressure gauge. Various gasses of hydrogen, helium, methane, neon, and argon are used in the experiment.

Typical waveforms are depicted in Fig. 2, where argon is used as the working gas and the plenum pressure, p_{plenum}, is increased from 0.5 to 5.0 MPa. In this series, the valve is opened from t = 0 s to 0.1 s. At the position of the pressure gauge, which is ~ 2.4 m (= L) apart from the valve, p_1 begins to increase at t ~ 0.007 s and finally reaches the maximum at t ~ 0.107 s. The delay time of ~ 0.007 s, which is similar for various p_{plenum}, corresponds to the time expected from the sonic speed of argon of C_s ~ 330 m/s at 298 K, *i.e.* L/C_s ~ 0.007s. Unexpected peaks appear when p_{plenum} is increased to above 2 MPa in the case of argon. For example in Fig. 2, two large peaks are recognized at t ~ 0.01 s and t ~ 0.03 s and these peaks evolve as p_{plenum} increases. The waveform is qualitatively kept unchanged as long as p_{plenum} is fixed, as shown in Fig. 3, where the pulse length is increased from 0.005 s to 0.1 s at p_{plenum} ~ 4 MPa. Similar phenomena are also observed in the experiments with other gasses except helium. Although the reason why these peaks appear is remained as an open question, our working hypothesis is that it is an indication of clustering. This will be examined after installing the valve cooling system, which enables us to cool the gas to its boiling point.

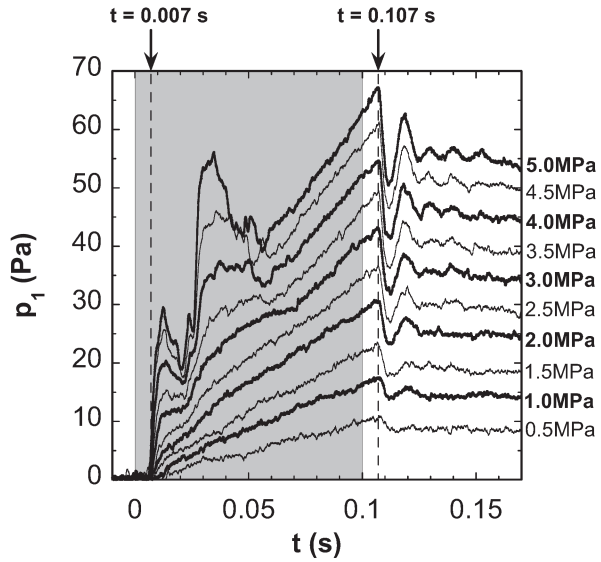

Fig.2. Typical waveforms of argon gas puff experiment. The plenum pressure is scanned from 0.5 MPa to 5.0 MPa, while the gas puff pulse length of 0.1 s (t = 0 – 0.1 s) is kept unchanged.

1) L. Yao et al.: Nucl. Fusion **47** (2007) 139
2) J. Miyazawa, H. Yamada and M. Matsuoka: NIFS-MEMO-41

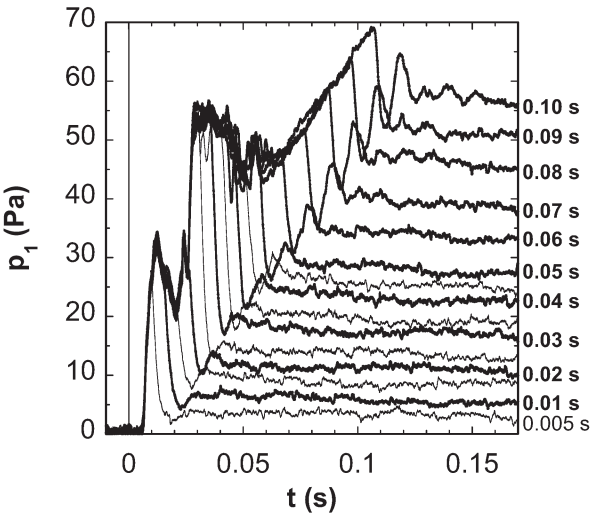

Fig.3. Results of the pulse length scan experiment. The gas puff pulse length is increased from 0.005 to 0.1 s. The working gas is argon and the plenum pressure is fixed at ~ 4 MPa.