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Gas Flow Velocity of the Direct Gas Puff

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Abstract

Gas flow velocity of a piezo-valve used in the Large Helical Device has been measured in a test chamber of 3.6 m long. Various gasses of hydrogen, helium, methane, neon, nitrogen and argon are used in the experiment. In the direct gas puff configuration, where the gas flow directly reaches the target, the Mach number increases with the mass of the gas molecule and/or the primary pressure of the piezo-valve. The maximum Mach number of over 1.5 is obtained with the methane. In the normal gas puff configuration, where the injected gas suffers from reflection and/or absorption by materials, the gas flow velocity remains at sound velocity, even with the methane.

Keywords: gas flow velocity, direct gas puff, sound velocity, supersonic, LHD, experiment

1. Introduction

Gas puffing is the most basic technique to control the plasma density and utilized from the beginning of the fusion study. Recently, a supersonic gas puffing (supersonic molecular beam injection in [1-4], and supersonic pulsed gas injection in [5-7]) has been proposed to realize the high fueling efficiency with a supersonic high-density cloud of neutrals. Due to the collective effect of the high-density cloud that cools the plasma surface of a small area, the penetration depth is expected to be deeper than that of the ordinary spread gas puffing. In the Tore Supra tokamak, for example, a fueling efficiency of 30 – 50 % was achieved [7]. Also in LHD, a supersonic gas puff experiment is scheduled in near future [8]. As a preparatory step, a piezo-valve has been inserted inside the vacuum vessel of LHD, while other valves are located on the port apart from the plasma. The gas flux puffed from the inserted piezo-valve directly reaches the plasma surface without suffering reflection and/or absorption by the materials like vacuum vessel wall. Therefore we call this a 'direct gas puff' (DGP). Although the gas flux supplied by the inserted piezo-valve is not necessarily supersonic at this moment, the effect of geometrical arrangement of gas puffing can be investigated.

DGP experiment on LHD has been successfully carried out in the 6th experimental campaign (Oct. 2002 – Feb. 2003) [9]. To compare the result with the future supersonic gas

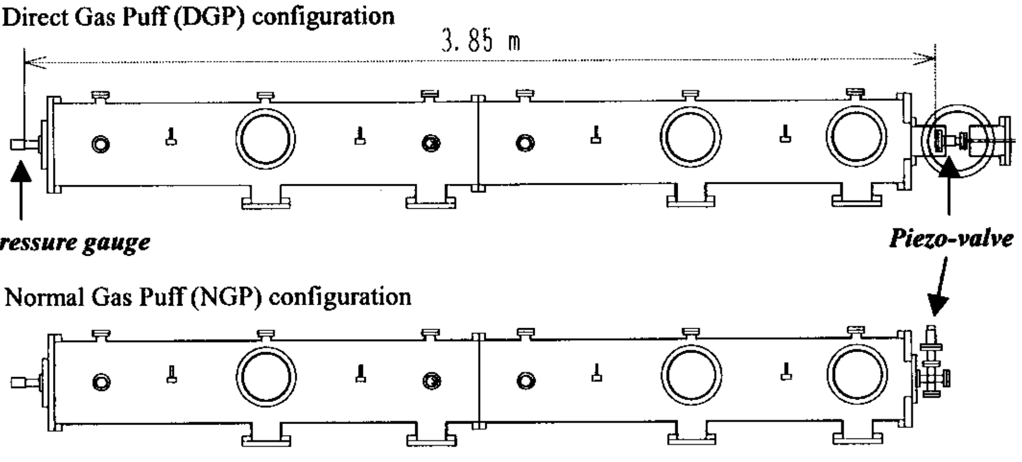

Fig. 1. Experimental setup for the gas flow velocity measurement. Two vacuum chambers of 1.8 m long and 0.344 m inner diameter are connected and used as the test chamber.

puff experiment, it is necessary to investigate the gas flow velocity of the DGP. It should be noted that the sound velocity is assumed as the flow velocity of gas puff flux, in general. The gas flow velocity has been measured using long (3.6 m) test chamber. Both of the DGP configuration and the normal gas puff (NGP) configuration are used in the experiment. The experimental results are described in this report.

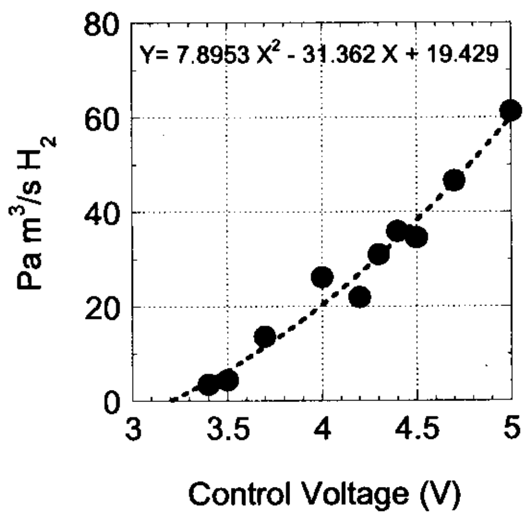

Fig. 2. Flow rate of the piezo-valve for DGP. Working gas is hydrogen. The absolute primary pressure is 0.2 MPa.

2. Experimental Setup

The experimental setup is shown in Fig. 1. In the DGP configuration, the piezo-valve is set on a side of the test chamber and the pressure gauge is set on another side (Fig. 1 (a)). Therefore, the gas flux puffed from the piezo-valve directly reaches the pressure gauge. The piezo-valve used here is what temporally removed from LHD. The flow rate of this piezo-valve has been calibrated as shown in Fig. 2. The time for full open to full close (or vice-versa) is less than one millisecond. The flow rate is directly proportional to the primary pressure of the piezo-valve, and inversely proportional to the square root of the mass of gas molecule. In the NGP configuration, another piezo-valve is set vertically on a cross-tube (Fig. 1 (b)). This piezo-valve has a similar (slightly smaller) flow rate as the piezo-valve for DGP. The gas flow in NGP configuration cannot directly reach the pressure gauge, as is in the normal gas puffing on LHD, where the piezo-valves are set on the manifold under the lower port.

The pressure gauge used here is the MKS Baratron® capacitance manometer (MODEL# 617A). The measurable pressure range is 0.133 – 1330 Pa, and the time response is less than one millisecond.

3. Flow Velocity Measurement

The concept of the flow velocity measurement is explained in Fig. 3. If the sonic gas is spreading in the test chamber immediately after the injection, the front of the pressure rise will appear at $t_0' = t_0 + L / c_s$, where t_0 is the starting time of the gas puff pulse, L = is 3.85 m is the distance from the piezo-valve to the pressure gauge and c_s is the

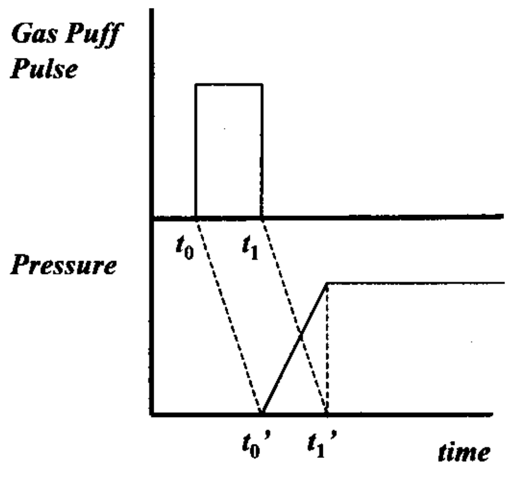

Fig. 3. Expected waveform of the pressure signal.

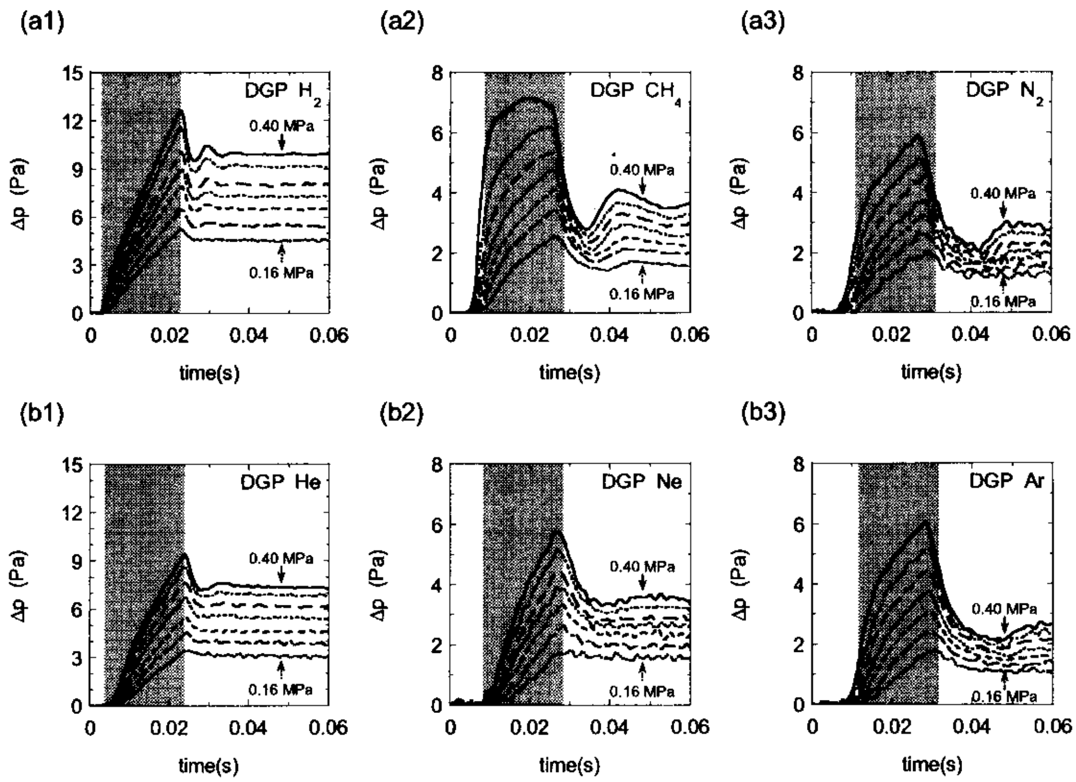

Fig. 4. Experimental results of the gas flow velocity measurement with the DGP configuration; (a1) hydrogen, (a2) methane, (a3) nitrogen, (b1) helium, (b2) neon, and (b3) argon. Shaded region denotes the time-shifted gas puff pulse width (see text). The absolute primary pressure of the piezo-valve is increased from 0.16 to 0.40 MPa, with an increment of 0.04 MPa. In each pressure, same experiment is repeated five times and shown in the figure is the averaged waveform.

sound velocity. At $t_1' = t_1 + L / c_s$, where t_1 is the end time of the gas puff pulse, the pressure signal reaches the maximum and then keeps it, as long as the vacuum pumping is stopped. On the analogy of this, we define the gas flow velocity, v_{gas}, as below;

$$v_{gas} = L / t_{delay}, \qquad (1)$$

where $t_{delay} = t_0' - t_0 = t_1' - t_1$. In the experiment, it is difficult to distinguish t_0', due to the poor resolution of the small pressure signal. Therefore, in this study, we use the time where the pressure signal reaches the maximum as t_1', for v_{gas} estimation.

Experimental results obtained with the DGP configuration are shown in Fig. 4, where hydrogen, helium, methane, neon, nitrogen, and argon are used as the working gas. Throughout the experiment, the control voltage and the pulse width are fixed to 5 V (full open) and 0.02 s, respectively. The absolute primary pressure of the piezo-valve is scanned as; 0.16, 0.20, 0.24, 0.28, and 0.40 MPa, in each cases. The vacuum pumping of 0.5 m^3/s is not stopped. Due to the large volume of the test chamber, the time constant for the pressure decrease is ~ 0.7 s and large enough compared with the time of interest (see abscissa of Fig. 4). Shaded region in Fig. 4 denotes the time-shifted gas puff pulse width, which is depicted with t';

$$t' = t + L / c_s. \qquad (2)$$

In all cases, the pressure signal begins to increase at the timing similar to, or earlier than the time-shifted gas puff pulse. Then, it takes about 0.02 s to reach the maximum, which corresponds to the gas puff pulse width.

From these results, t_{delay} is estimated as in Fig. 5 (a). It can be seen that t_{delay} decreases as the primary gas pressure increases. Mach number, $M = v_{gas} / c_s$, versus the primary pressure is shown in Fig. 5 (b). M increases with the primary gas pressure. With the light gases such as hydrogen or helium, M is about 1 even with the high primary pressure of 0.4 MPa. Large M is obtained with the heavy gas. This can be more clearly seen in Fig. 5 (c), where M is plotted with respect to the mass number of the gas molecules. Paying attention to the rare gas groups of helium, neon and argon, it can be recognized that M linearly increases with

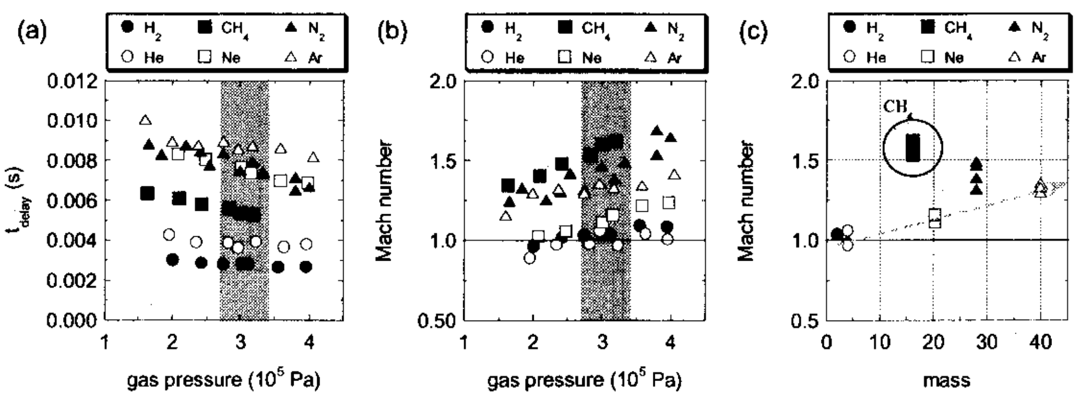

Fig. 5. (a) Measured t_{delay} and (b) the Mach number, M, as a function of the absolute primary pressure of the piezo-valve. (c) M versus the mass number of the working gas molecule, where the primary pressure is 0.27 – 0.34 MPa (corresponds to the shaded region in (a) and (b)).

the mass number. The largest M of over 1.5 is obtained with the methane gas. In the NGP configuration, on the other hand, supersonic gas flow is not realized as shown in Fig. 6, even with the methane gas.

4. Summary

Gas flow velocity of the direct gas puff has been measured using hydrogen, helium, methane, neon, nitrogen, and argon. The Mach number increases with the mass of the gas molecule and/or the primary pressure of the piezo-valve. A large Mach number exceeding 1 is obtained with methane, neon, nitrogen and argon, while it remains ~ 1 with hydrogen and helium. The largest Mach number of over 1.5 is obtained with the methane gas. The flow velocity of the normal gas puffing, where the gas flow does not directly reach the target (pressure gauge, in this case), is identical to the sound velocity, even with the methane gas.

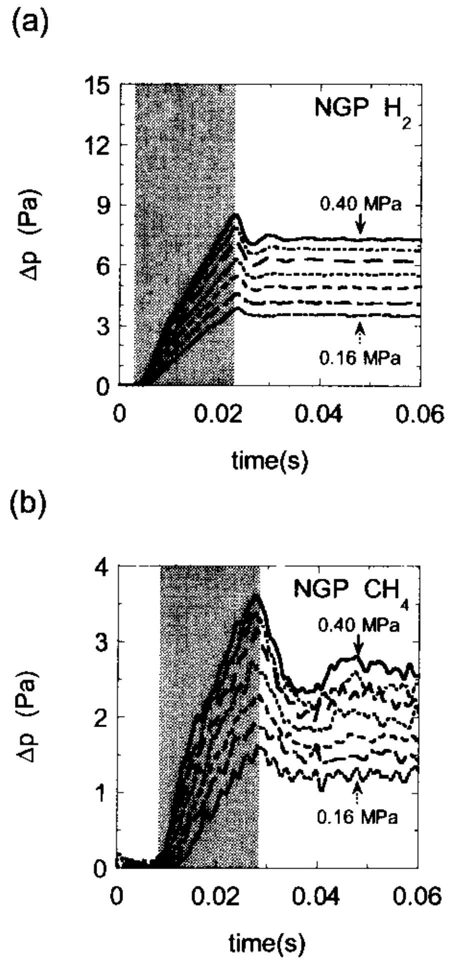

Fig. 6. Experimental results with the NGP configuration; (a) hydrogen and (b) methane. Experimental scheme is same as in DGP case shown in Fig. 4.

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