§1. Development of the Supersonic Jet Pump

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The vacuum pumping system in the fusion reactor should satisfy at least 6 requirements, *i.e.*, (1) it should have a high exhaust velocity using at most a few tens of pumps in parallel, (2) the tritium inventory in the whole system should be low enough, (3) it should have a high helium exhaust capability, (4) it should be available in the strong magnetic field environment around the fusion reactor, (5) it should have no impurity contamination to the upstream, and (6) it should be operable in steady-state.

In resent fusion experiments, the Cryopump (CP) and the Turbo Molecular Pump (TMP) are routinely used for vacuum pumping. In the fusion reactor, however, it is not as easy as recent experiments to use these conventional pumps. Tritium inventory is one of the most important issues in using CPs in a fusion reactor. From the point of view of safety, strict limitation will be imposed on the tritium inventory in the fusion reactor. In ITER, for example, the tritium inventory inside the vacuum vessel is limited to 1 kg and 120 g of this is attributed to the CPs [1]. In FFHR-d1, the DT fueling rate is expected to be ~500 Pa·m^3/s, which roughly corresponds to ~1 g/s, more or less. If the exhaust pressure is assumed to be 0.1 Pa (typical exhaust pressure in LHD is of the order of 0.01 Pa), then 5,000 m^3/s of the exhaust velocity is necessary. In LHD, for instance, an effective exhaust velocity of 200 m^3/s has been demonstrated using 18 large CPs. In the fusion reactor, therefore, at least 450 CPs similar to those used in LHD are necessary. The tritium inventory in 450 CPs is roughly estimated to be ~8 kg. This will be unacceptable. As for the helium, which is inevitably produced after DT fusion reaction, the CP is not effective and therefore we need other exhaust method. The TMP can be a strong candidate for this. However, the TMP is not necessarily suitable for the fusion reactor due to its relatively low exhaust velocity. Furthermore, it is difficult to use TMPs in a strong magnetic field environment. Diffusion pumps (DPs) basically have large exhaust velocity, where kinetic momentum of small droplets of oil or mercury is used to move the exhaust gasses to the pump exit. However, DPs have a possibility of impurity contamination. Especially, it is difficult to use mercury in Japan.

To solve the issues discussed above, a new vacuum pumping device named the Supersonic Jet Pump (SJP) (Japanese patent application No. 2015-112781) is being developed (Fig. 1). The SJP is, in essence, a CP without the regeneration process. Hydrogen isotopes become condensed on the surface of central shaft, which is cooled down to ~10 K. Then, the cylindrical piston cutter shaves off the solid hydrogen isotopes and pushes them out of the pump. The tritium inventory in the SJP can be minimized since the solid hydrogen ice is routinely removed from the pump in a short time. A part of the shaved ice is sublimated inside the pump and puffed to the central shaft through supersonic nozzles. Hydrogen clusters formed in the supersonic flow give the kinetic momentum to remaining neutrals including helium. This DP effect is expected to be effective for helium pumping.

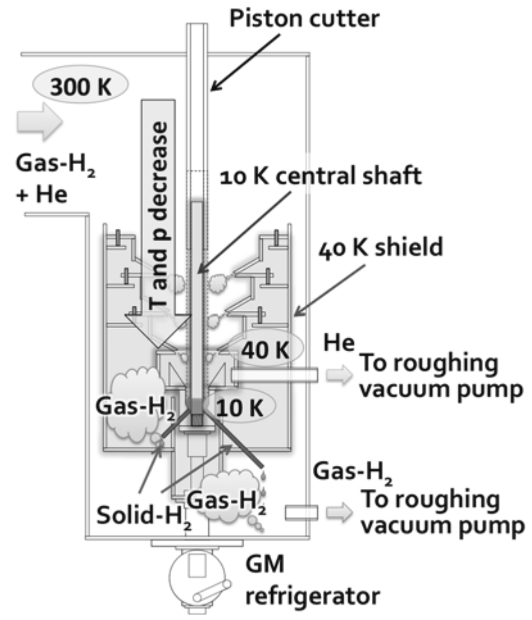

Fig. 1. A schematic view of the supersonic jet pump.

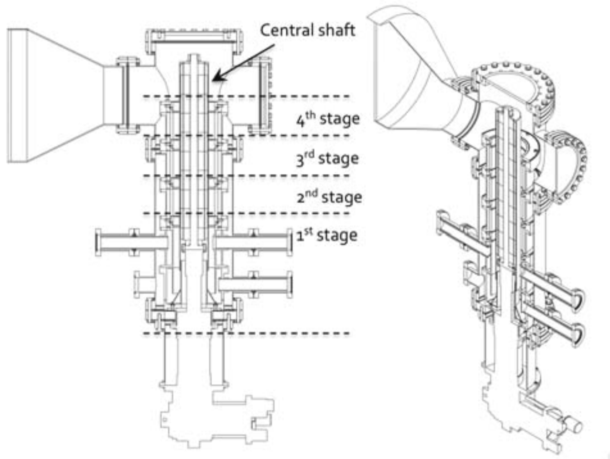

Fig. 2. CAD plots of the prototype of SJP (courtesy of Kazama Engineering Co., Ltd.).

As shown in Fig. 2, the prototype of SJP consists of several stages. Each of the stages is equipped with a circular supersonic nozzle. In FY2015, the bottom stage and the 10 K central shaft were manufactured. After installation of these into a test vacuum chamber, a cooling test will be performed in FY2016. Then, the 2nd and 3rd stages together with the cutter system will be manufactured to complete the SJP.

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1) J. Roth, et al., Plasma Phys. Control. Fusion **50** (2008) 103001.