ISSN 0915-633X

NATIONAL INSTITUTE FOR FUSION SCIENCE

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(Received – Oct. 13, 1993)

NIFS-255 Nov. 1993

RESEARCH REPORT
NIFS Series

NAGOYA, JAPAN

PROPOSED HIGH SPEED PELLET INJECTION SYSTEM "HIPEL" FOR LARGE HELICAL DEVICE

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[This paper was prepared for IEEE/NPSS 15th Symposium
on Fusion Engineering, Cape Cod, U.S.A., 1993.]

Keywords: multiple-pellet injection, Large Helical Device, two-stage gas gun, HIPEL, refueling, transport diagnostics, hydrogen/deuterium pellet, low-Z material pellet

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ABSTRACT

From the results of the simulation study including pellet ablation and 1-D transport code, it is found that a high speed pellet injector with pellet velocity of more than 3 km/s is necessary for the penetration of the pellet with diameter of 3 mm into the core region under the expected plasma condition of Large Helical Device (LHD) of heliotron/stellarator type with superconducting coils at NIFS in Japan. Therefore, a two stage pellet injector was constructed and tested successfully in order to obtain the pellet velocity range of 3 km/s. Based upon the above results, a high speed flexible multiple-pellet injection system "HIPEL" for LHD is proposed. HIPEL consists of independent (1) 10 two-stage gun barrels and (2) 10 single-stage gun barrels. It has multi purposes such as refueling and flexible density profile control, diagnostics and the other functions.

I. INTRODUCTION

A high speed pellet injector for Large Helical Device (LHD) [1] of heliotron/stellarator type with superconducting coils at NIFS of MoE in Japan has been developed with an acceleration method of two-stage gas gun. The purpose of the high speed pellet injector is (a) refueling particles in the core region of the plasma, and (b) controlling the plasma density profile of the plasma, and (c) plasma diagnostics and for the other purposes. The present level of the pellet velocity range with the two-stage gas gun is around 3 km/s, with the maximum record of 3.3 km/s. The operation of the pellet injector should be reliable and flexible, simultaneously, and it should be fully automatic during the plasma experiment of LHD which is planned to start within the fiscal year of 1998. LHD having superconducting helical and poloidal coils can be operated in steady state without necessity of current drive in contrast to tokamaks. The essential design of LHD is now in the final stage, and the superconducting helical coil will be started to be wound in the next fiscal year. The designed plasma parameters are briefly listed in Table I. When the core part of the plasma is locally heated, the temperature of up to 10 keV is expected. The confinement time is estimated with the empirical LHD scaling [2] based upon the data of the existing devices of the helical system.

Table I Designed Plasma Parameters

Temperature Te(0), Ti(0) (keV)	3 - 4, 10*)
Density (10^{20} m^{-3})	0.1 - 1
Confinement Time (s)	0.1 - 0.3**)
Average Beta Value (%)	5
Steady State Plasma	
Temperature Te(0), Ti(0) (keV)	> 1
Density (10^{20} m^{-3})	~1

*) High Ti mode.
**) LHD Scaling.

The main missions of the LHD project are (a) to investigate plasma characteristics such as transport under the reactor relevant plasma condition of helical system, (b) to optimize divert operation of helical system, (c) to demonstrate steady state operation of helical system, (d) to demonstrate average beta value of more than 5 % in a helical system, and (e) complementary study with tokamaks for understanding general physics of toroidal plasmas.

For the above missions, plasma control is one of the key subjects. Pellet injection will be useful for controlling plasma density profile and plasma pressure profile through changing the density profile.

II. PELLET ABLATION

For refueling hydrogen isotope particles in the core region of the LHD plasma, simulation study including pellet ablation and 1-D transport code [3] has been carried out. For example, following conditions are assumed: the pellet diameter is 3 mmϕ, and the central electron temperature and the average density of the target plasma are 4 keV, and 4×10^{19} m^{-3}, respectively. In this case, the particle numbers involved in the target plasma and in the pellet are 1.3×10^{21} and 8.6×10^{20}, respectively.

If the pellet velocity is 3 km/s, the pellet can reach the core region (r/a = 0.25) of the plasma as shown in Fig. 1. Although it does not reach the plasma axis, the density profile becomes peaked in 75 -100 ms after pellet injection due to particle transport.

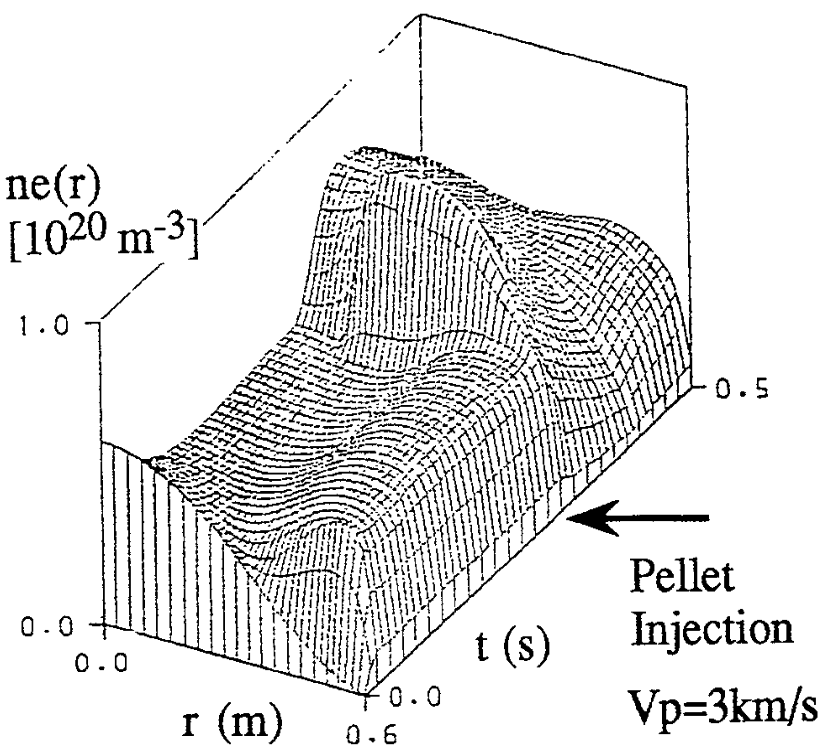


Fig.1 One example of simulation results of pellet ablation.

In case of the pellet velocity of 5 km/s, the pellet can reach the plasma axis. If the pellet velocity reduces to 1 km/s, the penetration is shallow (the pellet is completely ablated at r/a = 0.53), and the most particles are deposited in the outer part of the plasma. Thus, we decided to develop a high speed pellet injector with velocity of more than 3 km/s for the good penetration under the relatively good plasma condition.

The most reliable pellet accelerator for this aim at present is concluded to be a two-stage gas gun type. Thus, we are developing now a multiple high speed pellet injection system based upon a two-stage gas gun type.

For LHD, flexibility in various parameters such as pellet injection time interval, penetration depth, and deposited particle number, is a very important factor in addition to reliability of the device. Therefore, a multi-barrel and multi-guide-tube system is adopted. Thus, the pellet injection time intervals are arbitrary, and even all the pellets can be injected simultaneously. This will be useful for fine control of the density profile.

III. DEVELOPMENTS OF TWO-STAGE GAS GUN

A. General description of the method

For the device design, the fundamental operation was simulated mainly with the code "Quickgun" developed by S.L. Milora of ORNL [4]. The experimental results agreed generally well with the results calculated by the code, although the effective throughput area of the high pressure fast valve introducing high pressure gas to drive a piston should be adjusted semi-empirically. The calculation showed that the pump tube fill gas pressure, pump tube gas species and the piston weight are significant. The optimum condition is studied with investigating the dependence of the pellet velocity and breech pressure on the pump tube fill pressure under our experimental configuration. The schematic of the experimental device is shown in Fig. 1 with the originally developed high conductance fast valve [5]. Summary of the parameters of the tested two-stage gas gun is given in Table II. In order to attain a long-life piston, some alloys of titanium are investigated.

B. Experimental Results

The experimental results show that the fill pressure is a very sensitive parameter to the operation, and that the operation limit is governed mainly by the tensile strength limit of a pellet and in some cases, by that of a piston.

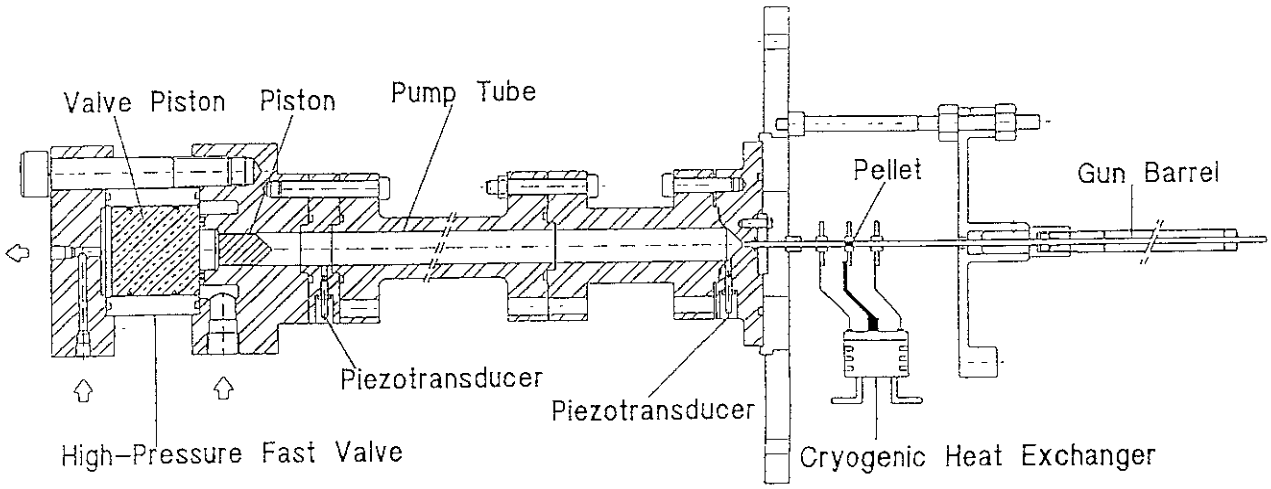


Fig. 2 Schematic of two-stage gas gun with the originally made high conductance fast valve.

Table II. Summary of parameters of two-stage gas gun

		Device 1	Device 2	Device 3	HIPEL
Pump Tube	Length (m)	1.0	1.5	0.75	0.75
	Diameter (mmϕ)	22.1	22.1	22.1	22.1
	Volume (cm^3)	400	600	300	300
	Fill Gas	He / H_2	He / H_2	He	He
	Pressure (MPa)	0.06 - 0.1	0.06 - 0.1	0.06 - 0.1	0.06 - 0.1
Launch Tube	Length (m)	1.0	1.0	1.0	1.3
	Diameter (mm)	2.0	2.0	2.0	1.5 - 3.8
Valve	ESEOD (mm)	6.0	22.0	22.0	22.0
	Rising Time (ms)	5	1	1	1
Reservoir	Volume (l)	0.75	3.8	3.0	3.0
	Pressure (MPa)	5 - 6	5 - 6	3 - 5	3 - 5
Breech	Volume (cm^3)	0.5	0.5	0.5	0.5

Thus, the operation scenario should be well organized to prevent the damage of a pellet and a piston with controlling and checking the fill gas pressure with a relatively fast controller. Examples of the deuterium pellet ejected from the two-stage gas gun are shown in Fig. 3.

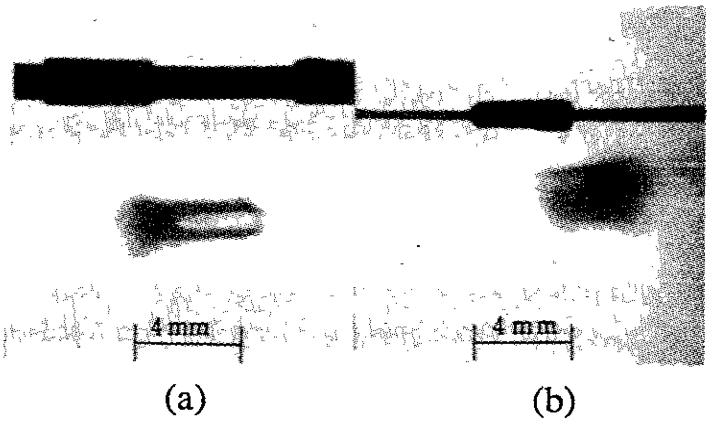


Fig. 3 Shadowgram of deuterium pellet taken with a fast stroboscope. (a) Disk type. v_p = 2340 m/s, and (b) Pipe gun type. v_p = 3210 m/s.

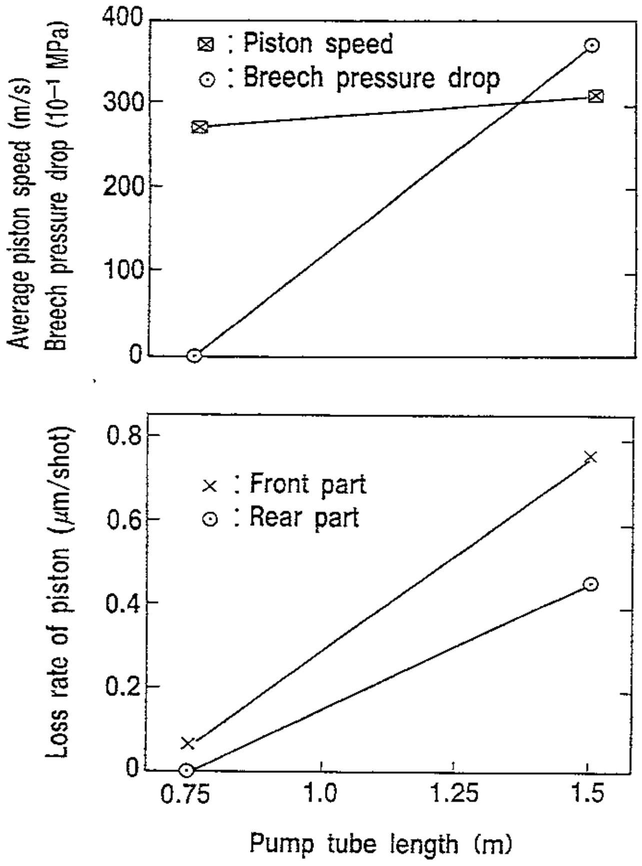


Fig. 4(a) Loss rate of the piston diameter for 0.75 m and 1.5 m pump tubes. The hardness for the former and the latter are 432 Hv and 388 Hv, respectively.

For studying the optimization of the whole system, the cases for pump tube length of 0.75 and 1.5 m are compared in Fig. 4(a). The loss rate of the piston diameter in case of 0.75 m pump tube is much reduced by a factor of more than 10 compared to the case of 1.5 m pump tube. The decrease of pellet velocity in case of 0.75 m pump tube is negligible, that is, the pellet velocity is comparable to the case of 1.5 m pump tube. These results are consistent with the simulation by "QuickGun" code as shown in Fig. 4(b), where the dependence of the breech pressure, temperature, piston velocity, achievable pellet velocity on the pump tube length is shown.

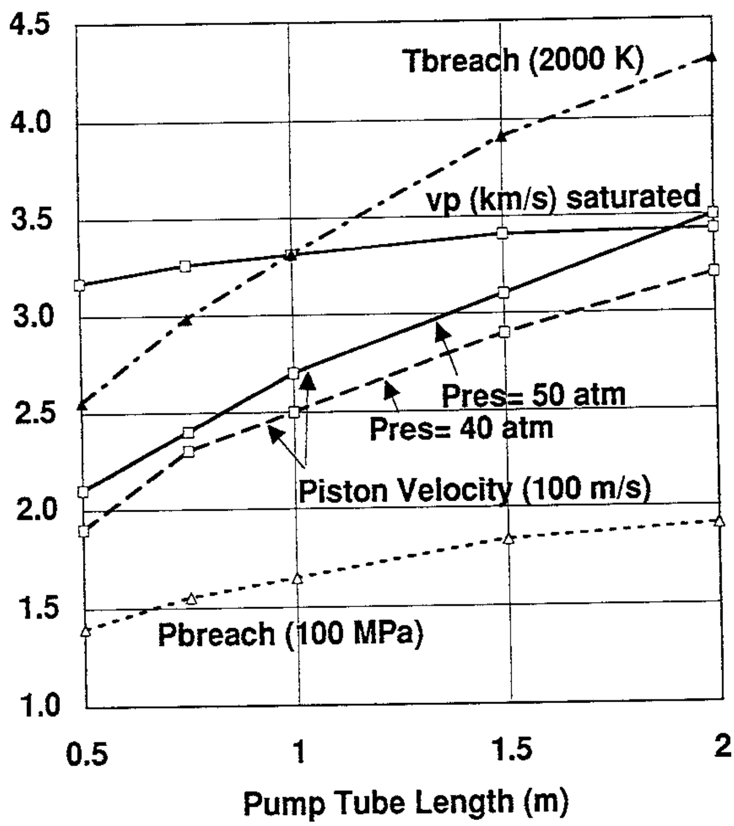
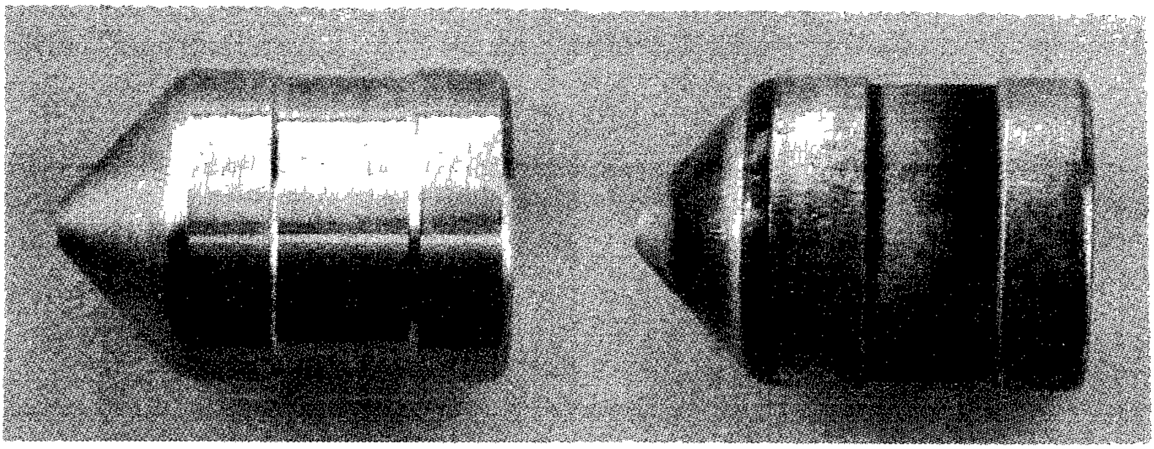


Fig. 4(b) Dependence of the breech pressure, temperature, piston velocity, achievable pellet velocity on the code .

Surface change of the piston made of titanium alloy (Ti-6Al-2Sn-4Zr-6Mo) used for these experiments is shown in Fig. 5. The weight of the piston is around 18 g. The breech pressure loss in case of 0.75 m pump tube is also negligible even after 214 shots. Thus, a long life piston for a tow-stage gas gun with an appropriate configuration of the pump tube is established for achieving the pellet velocity range of 3 km/s.



(a) (b)

Fig. 5 Photographs of piston surface of (a) new one and (b) that after 214 shots.

The pellet release pressure is one of key parameters for determining the final pellet velocity. Therefore, we carried out first the experiments changing pellet release pressure with nylon pellets. The effect of release pressure of the pellet is studied by changing the pellet surface condition. The results are shown in Fig. 6. As seen in Fig. 6, the higher pellet velocity is obtained in case of higher pellet release pressure, but the breech pressure does not depend on the pellet release pressure in this case. The latter is probably due to the low conductance of the barrel compared to the pump tube.

VI. DESIGN STUDY OF HIGH SPEED PELLET INJECTOR FOR LHD

For long life of the piston, aforementioned alloy is adequate with the appropriate pump tube, with keeping pellet velocity equal to or higher than 3 km/s.

For reliability and automatic control of the whole system, an engineering work station with VME bus is being planned, and it will be tested as the controller for the whole system including alarm functions.

For refueling, plasma control, and diagnostics of particle transport and magnetic field line in LHD, deuterium pellets and other kinds of pellets are planned to be accelerated to the velocity of more than 3 km/s. Therefore, the two-stage gas gun method will be used for various pellet injection systems in LHD.

The preliminary design of "HIPEL" (High Speed Flexible Multiple-Pellet Injector for LHD) is proposed for the purpose of the necessary refueling, the flexible density profile control, the plasma-wall interaction control and diagnostics.

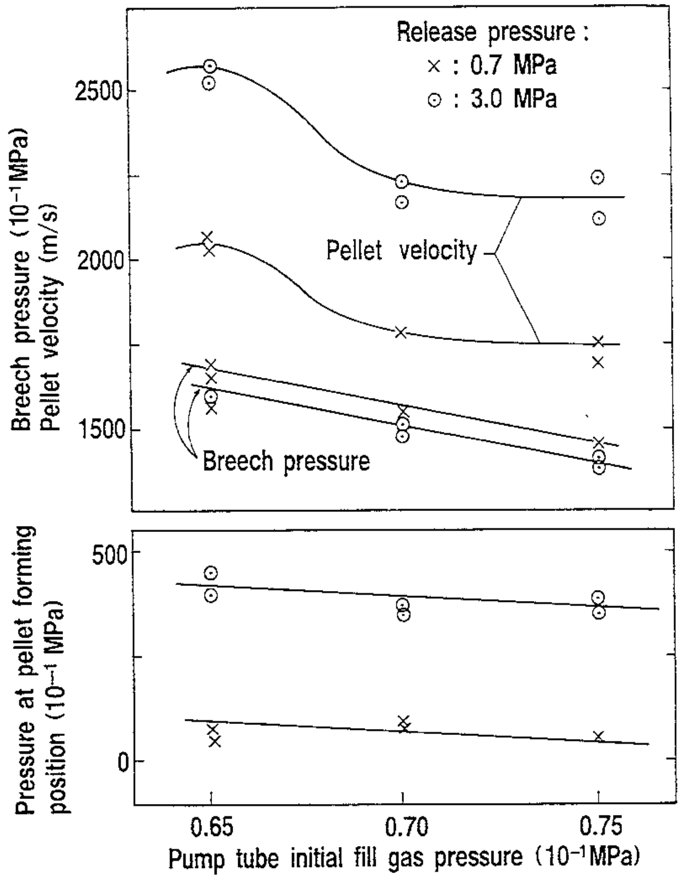


Fig. 6 Dependence of breech pressure and pellet velocity on pellet release pressure. For this experiment only, a nylon pellet of 12 mg is used. Piston mass, pump tube length, and reservoir pressure are 20.4 g, 0.75 m, and 4 MPa, respectively.

HIPEL consists of (1) 8 two-stage gun barrels and (2) 8 single-stage gun barrels for refueling and flexible density profile control, and (3) 2 two-stage gun barrels and (4) 2 single-stage gun barrels for diagnostics and the other purposes. One pair of the pellets for the refueling are identical in size. The planned values are: (a) 3.8 mmϕ, (b) 3 mmϕ, (c) 2 mmϕ, (d) 1.5 mmϕ for the above (1) and (2), respectively. For the other plasma control and the diagnostics, new pellet injectors [7] are also considered, and a preliminary design has started. The pellet size for

(3) and (4) will be in the range of 1 - 3 mmϕ. The conceptual design of the proposed HIPEL for LHD is shown in Fig. 7. The design parameters of the two-stage gas gun are also shown in Table II.

V. CONCLUSION

A two-stage pneumatic high speed pellet injector has been developed experimentally in order to prepare for the planned LHD experiments, aiming at the pellet velocity in the range of more than 3 km/s. Some optimizations of the operation have been carried out, including to search an appropriate piston material. Based upon the results obtained so far, the preliminary design of a high speed flexible multiple-pellet injection system ("HIPEL") for LHD with 10 two-stage and 10 single-stage acceleration barrels is proposed for refueling, plasma control, and diagnostics.

ACKNOWLEDGMENT

S. S would like to acknowledge Dr. S. L. Milora for providing his code and for valuable discussions. S. S and H. K would like to thank Profs. A. Iiyoshi, M. Fujiwara and O. Motojima for continuing encouragements.

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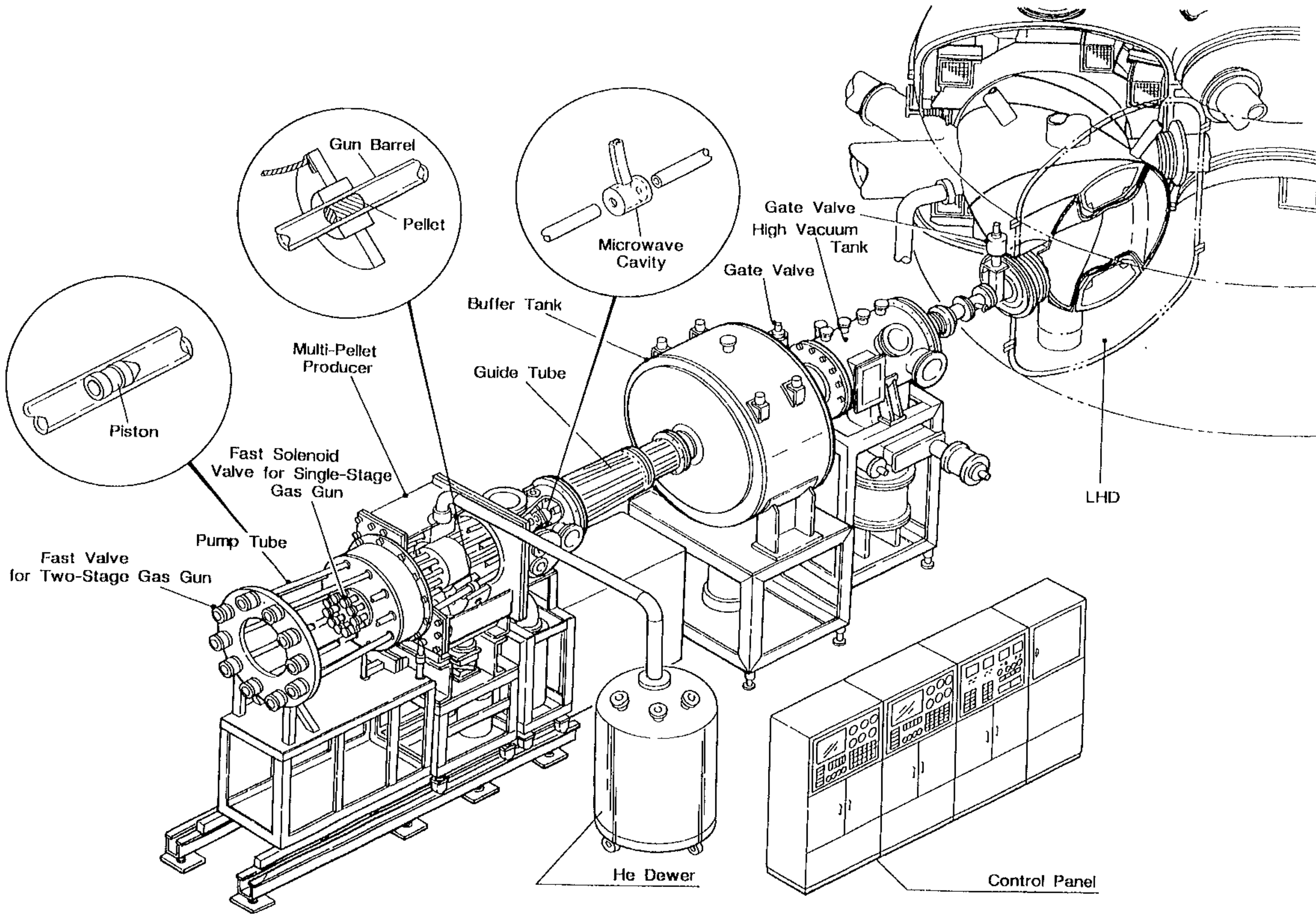

Fig. 7 Conceptual design of proposed HIPEL for LHD.

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