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AN HYDROGEN CRYOPUMP OPERATED NEAR 2,2 K
FOR THE TOKOMAK PETULA

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ABSTRACT

A prototype of a cryopump adapted to the operating conditions of the Tokomak Petula has been built and tested. We describe the chosen solutions in order to, obtain a working temperature of 2,16 K and, allow an automatic feeding of cryogenic liquids. We present results of experiments performed in either permanent or pulsed regimes of hydrogen injection. The pumping speed measured on the prototype is 3000 *ℓ/s* for hydrogen ; the pump could absorb more than 10 liters N T P of hydrogen before saturation corresponding to a three month working period for the Tokomak. The liquid helium consumption including transfer losses was 0.9 *ℓ*/day.

1. INTRODUCTION

The pumping system of currently designed Tokomak must meet the following requirements:

- High pumping speed for hydrogen and deuterium at pressures from 10^{-3} T to 10^{-8} T.
- Other gases kept at a pressure below 10^{-8} T.
- Ability to absorb large quantities of hydrogen or deuterium and in some cases possibility of recovering these gases.
- The pump must not contaminate the vacuum chamber (backflow of oil), nor create a magnetic field, or mechanical vibrations in the vicinity of the machine.

Cryogenic pumping meets most of these requirements [1], [2]. The pumping of hydrogen at pressures below 10^{-8} T necessitates a cryopumping temperature of less than 4 K [3], [4].

In the Tokomak Petula [5], a 500 l vacuum chamber permanently desorbs a gas flow of 10^{-5} T × l × s^{-1} under a pressure of 10^{-8} T. In addition, short but dense puffs of hydrogen are injected periodically (several Torr × liter over a few seconds a hundred times a day).

The pump must be capable of evacuation of the hydrogen injected into the chamber over several months without becoming saturated.

The solution adopted consists in cooling down a cryoplate by means of a bath of liquid helium brought to a temperature of about 2.16 K.

To operate at temperatures below 4.2 K, generally the pressure of the helium bath is lowered and this entails some problems when refilling (temperature fluctuation and excessive consumption of refrigerant).

The solution described here is significantly different in that the helium is brought to the required temperature whereas its pressure remains close to atmospheric pressure [6].

2. DESCRIPTION OF THE CRYOPUMP

The cryopump as illustrated in "..fig...1" shows :

- A 9.5 l nitrogen tank mainly used to cool down the shields and the chevron baffle of the cryopumping panel to about 80 K.
- A shield cooled down to about 230 K by the nitrogen vapours so as to reduce refrigerant needs.
- A 7 l helium tank extended by a channel leading to the cryopumping panel.
- A shield attached on the neck of the tank is cooled down to about 60 K by the helium vapours. This shield encases nearly all the helium tank in order to limit cryopumping by the wall at 4.2 K. A withdrawable refrigeration loop at 2.16 K is inserted through the neck of the He tank and extends to the bottom part of the helium enclosure box where it ensures the presence of a cold source at about 2.1 K.
- At the bottom of the helium box a channel communicates with the main tank through an annular space with a gap sufficiently small to permit the establishment of a temperature gradient. The gap is nevertheless large enough to enable the refrigeration loop to be mounted and dismounted and to allow filling with liquid. In this way, the unsaturated superfluid helium technique [6] is used to totally fill the channel with superfluid helium at approximately 2.16 K, thereby cooling the cryoplate by conduction down to about 2.3 K.

  The cryoplate at 2.3 K consists of a single copper disc, diameter 160 mm.
- A baffle, diameter 200 mm, placed 0.5 cm from the plate, composed of chevrons at 90°, blackened on both sides with "Nextel" 2012 paint manufactured by 3 M.
- The cryopump flange, diameter 200 mm, is at a distance of 11 cm from the baffle.

3. OPERATION OF THE INSTALLATION

The general layout of the helium circuit is shown in "..fig...2", which illustrated the two main parts, namely :

- A refrigerating circuit at 2.16 K.
- An automatic liquid helium feeding circuit.

3.1 Refrigerating circuit at 2.16 K

The helium losses in a cryopump are mainly due to thermal radiation of the various shields or baffles and to the heat load of the pumped gas. The flow of cold vapours can be used judiciously to pre-cool the counter-flow heat exchangers of a Joule Thomson type circuit able to reliquefy part of the helium used [7]. In our case, the J.T. circuit operates at a pressure sufficiently low (about 22 Torrs) to act as both a helium saver and a cold source at about 2.1 K.

"..fig...2" shows the main components of this circuit :

- At the bottom of the helium tank, the final exchanger bringing the helium at 5 bars from 4.2 K to 2.5 K before expansion from 5 bars to 0.03 bar in a calibrated orifice.
- In the neck of the helium tank, a three paths heat exchanger which recovers the enthalpy of the flow m of cold vapours.
- A dry diaphragm type compressor supplied with perfectly clean gas from the evaporation in the cryopump and in the helium storage tank.

  The flow, compressed from 1.1 to 5 bars is : $M = 65\ \mathrm{l.h^{-1}}$ NTP or $3.25 \times 10^{-3}\ \mathrm{g.s.^{-1}}$.

  A vacuum pump receiving the same flowrate at 0.03 bar and compressing it to 1.1 bar. By using a clean pump this gas could be recirculated but this equipment being not available we use an oil lubricated roughing pump which means that the gas must be recovered and purified.

3.2 Automatic liquid helium feeding circuit

To satisfy the double objective of totally automatic operation and minimum helium consumption the two following choices were made :

- Use of solenoid valves working at room temperature exclusively,
- Pre-cooling of the transfer-line without any introduction of heat in the pump helium tank.

"..fig...2" gives the flow sheet :

- When transfer is not in progress, pressures on the storage vessel and on the cryopump tank are maintained equal, with the exhaust outlets of the two connected,
- The measurement of the level in the cryopump is taken at two points, "High" and "Low", by two vapour pressure bulbs consuming only about 1 mW each.
- The filling order is given by the "Low" level indicator and triggers the following sequence: Pre-cooling of the siphon by opening the solenoid valve C until a temperature T_1 of about 20 K is reached.
- Transfer proper by closing of C and opening of B, entailing a drop in pressure in the cryopump tank while the storage dewar remains at the initial pressure (shut-off valve A closed).
- The end of siphoning is controlled by "High" level indicator.

4. EXPERIMENTAL RESULTS

4.1 Cryogenic Behaviour

During the tests the refrigeration of the cryopump was effectively maintained at 2.16 K for about 6 months. The only interruptions in operation once a month resulted in a rise in temperature to about 4.2 K when servicing the equipment and changing the storage vessel. Quantities of refrigerant consumed were established for periods of about 1 month at ultimate vacuum. The total helium consumption for the pump and storage vessel assembly, including losses during transfer, amounts to : 2.1 l per day of liquid helium, attributed as follows :

- Cryopump only (instantaneous flow, m = 23 l/h NTP = 0.79 l/day).
- Losses during transfer (1 transfer per 6 days approx.) = 0.11 l/day).
- Losses from storage dewar (with siphon permanently in position) 1.2 l/day.
- Nitrogen consumption is approximately 6 l/day.

4.2 Pumping performances

4.2.1 Ultimate vacuum "..fig...3"

The stainless steel chamber E was baked for one week at 150°C. This procedure results in out gassing fluxes for chamber, of less than 10^{-9} T l/s. At equilibrium, for a cryoplate temperature of 2.3 K, gauges J_2 and J_3 read $P_2 = 6 \, . \, 10^{-10}$ T, $P_3 = 1.6 \, . \, 10^{-9}$ T, respectively. The pumping speed of the pump was then less than 1 l/s and the ultimate pressure of the pump can be assumed to be $P_1 = 6 \, . \, 10^{-10}$ T.

4.2.2 Pumping Speed

By reading the pressure P_1 of the various gases entering through diaphragm d, the flow of gas injected can be determined and consequently the speed of the pump : $Sp = C_{gas} \, P_1/P_2$ where C is the conductance of the diaphragm for the gas in question. The measured values are given in "..table...1" and compared with the pumping speeds calculated from the following data: baffle surface area = 314 cm^2, baffle transparency = 0.23, cryosurface area at 2.3 K = 200 cm^2, pumping surface area at 80 K = 800 cm^2. $C_{gas} = 2.53 \, (M_{gas})^{1/2}$

TABLE 1

GAS	WATER VAPOUR	HYDROGEN	NITROGEN	ARGON
Calculated Speed S - l/s	6040	3200	860	720
Measured Speed S - l/s	6000	3100	1100	850

4.2.3 Saturation of the cryoplate with hydrogen

A permanent flow of hydrogen was introduced into chamber E. The flow was adjusted so that the pressure at the flange of the pump was $P_2 = 7\ 10^{-7}$ T. Hydrogen was injected until pressure P_3 started to rise rapidly. The temperature of the helium bath remained constant but the temperature of the cryoplate, which had varied slowly throughout the injection from 2.3 K to 2.4 K, rose rapidly simultaneously with the pressure. Valves V_4 and V_5 were closed and the pump was allowed to warm up to ambient temperature. By reading the pressure of the evaporated gas, the quantity of hydrogen absorbed up to saturation could be determined : q = 10.8 l NTP hydrogen.

4.2.4 Pulsed Injections

Puffs of hydrogen and nitrogen corresponding to a quantity of 12 T × l were pulsed into the pump. The pressure rose up to $7\ 10^{-4}$ Torr in 5 seconds then rapidly dropped to the initial pressure of less than 10^{-8} Torr after the injection. No increase in instantaneous consumption was detected. However, under these conditions a rise in temperature of the cryoplate from 2.3 K to 3.3 K and of the superfluid helium from 2.16 to 2.17 K was observed. It can be assumed that the helium which has a high specific heat, acted as a thermal ballast.

Conclusions

A cryopump for hydrogen can efficiently be operated below 4.2 K in totally automatic mode over long periods and with very low consumption of refrigerant. The performances obtained justify the use of such a cryopump on the Tokomak Petula in order to verify its behaviour under actual operating conditions.

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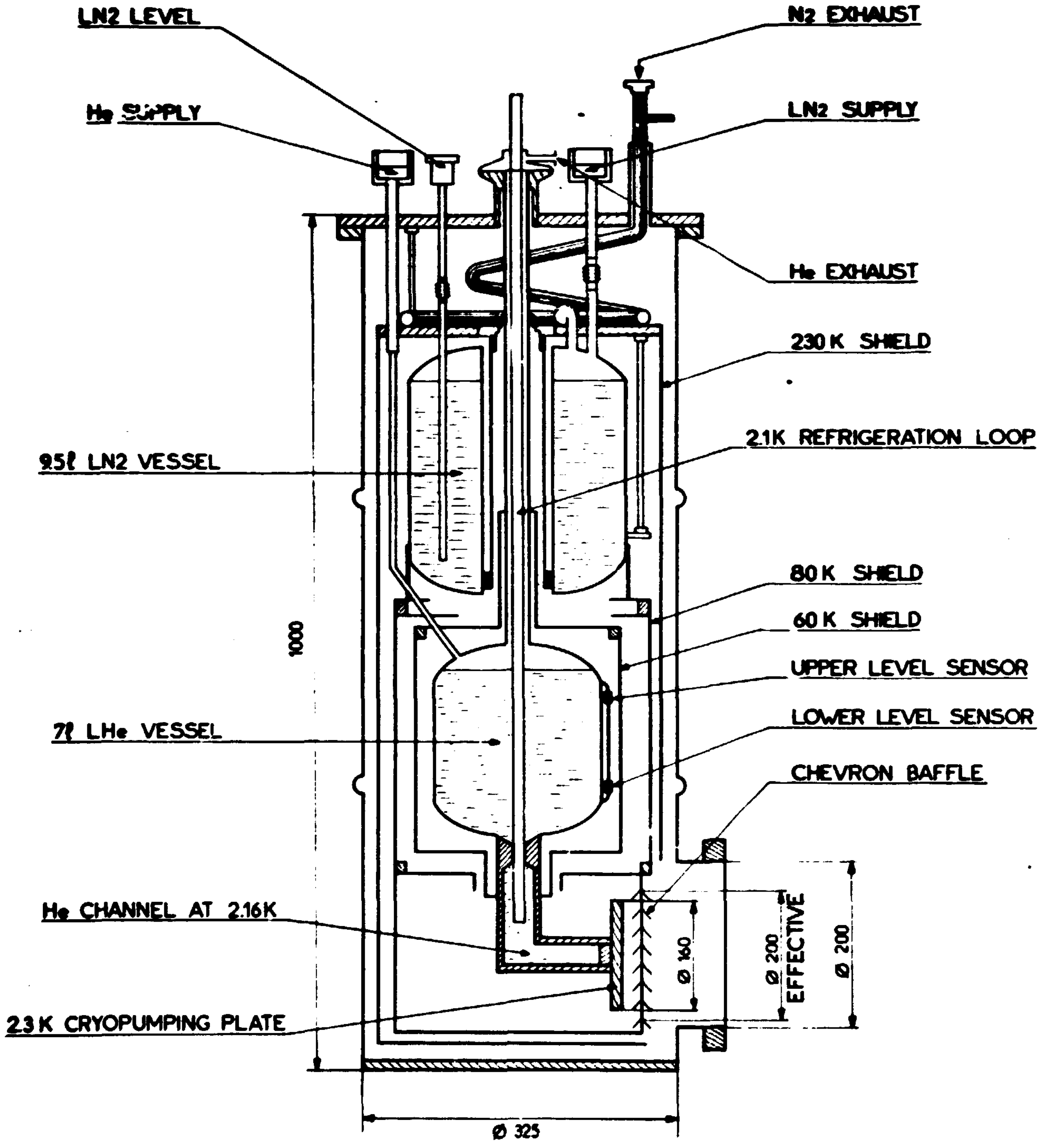


Fig.1 SCHEMATIC VIEW OF THE CRYOPUMP

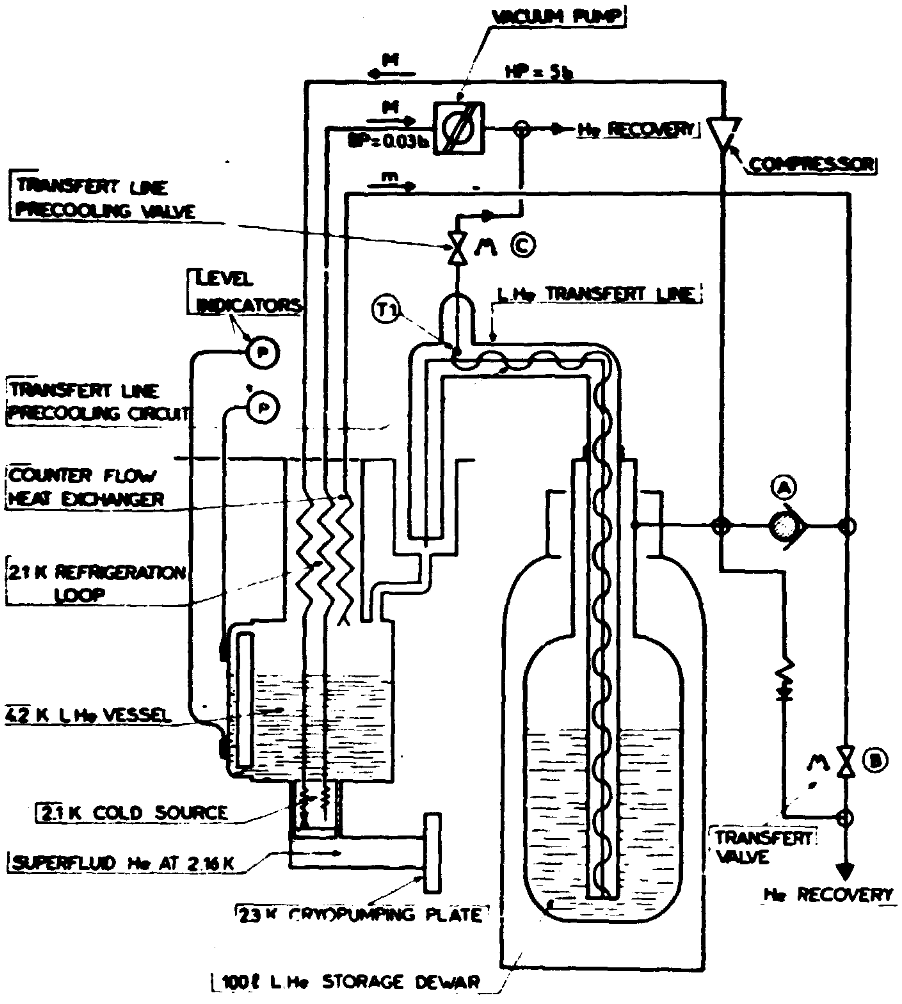
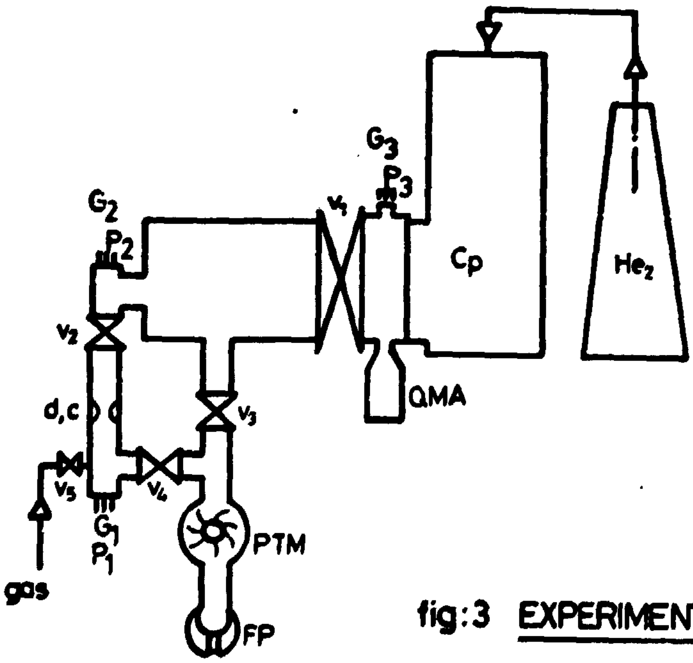


Fig. 2 HELIUM CIRCUIT FLOW SHEET



Cp = cryopump
Gi = Gauges
V = vacuum chamber
(volum V = 15 l)
(area = 3500 cm²)
d = diaphragm ϕ3mm
FP = forepump
v_i = valves
PTM = turbomolecular pump
QMA = quadrupol mass analyser

fig:3 EXPERIMENTAL SET