THE AGOR CRYOPUMPS

S.Buhler A.Horbowa
Institut de Physique Nucleaire,
B.P. 1, 91406 Orsay, France

ABSTRACT

In the AGOR cyclotron, as in other compact superconducting cyclotrons, the vacuum in the accelerating region is conductance limited by the narrow gaps of the magnet and the accelerating electrodes. It is therefore necessary to install cryopumps inside the electrodes in order to obtain sufficient pumping speed.

The AGOR cryopumps have the following original features:
1) Each cryopanel is individually cooled by a separate cryogenerator located at the top of the structure of the RF resonator outside the magnet yoke.
2) Twin heatpipes are used for heat transfer over the 3 meters distance between each cryogenerator and its associated cryopanel. The heat pipe principle allows heat transfer with very small temperature gradient. We use liquid/gaseous nitrogen for shield cooling at 80 K and liquid/gaseous hydrogen for cooling the 20 K cryopanel. A complete prototype has been constructed in the laboratory and tests have proved that sufficient refrigeration power is available at the cryopanel and that the resulting pumping speed is adequate.

INTRODUCTION

In addition to the two 1000 l/sec vacuum turbopumps connected outside the magnet yoke, three cryopanels installed inside three RF electrodes can provide high speed pumping at the accelerated region.

The three cold heads used for cooling their associated cryopanel are located at the top of the upper RF electrodes, far enough to escape the strong magnetic field. Heat transfert to the cryopanels is made from liquid/gaseous fluid running through heat pipe loops. Using the phase changing fluid properties, such a system allows important heat transfert on several meters and under almost constant temperature. For having liquid and vapor coexisting in the heat pipe, pressure and temperature conditions must keep the fluid state within its triple point and its critical point; the chosen fluid must therefore have its properties in agreement with the temperature at which we want to transfer the refrigeration power. Furthermore, in order to minimize mechanical constraints and leaking consequences, steady state operation has been chosen slightly above atmospheric pressure. So, an operating balance has been obtained at about 78 K by using NITROGEN for the loop assigned to the 80 K shield. For the 20 K cryopanel loop, the use of HYDROGEN gave us a balanced temperature of 20.3 K.

Each system can run separately. It has no moving parts and consequently no vibrations.

PROTOTYPE

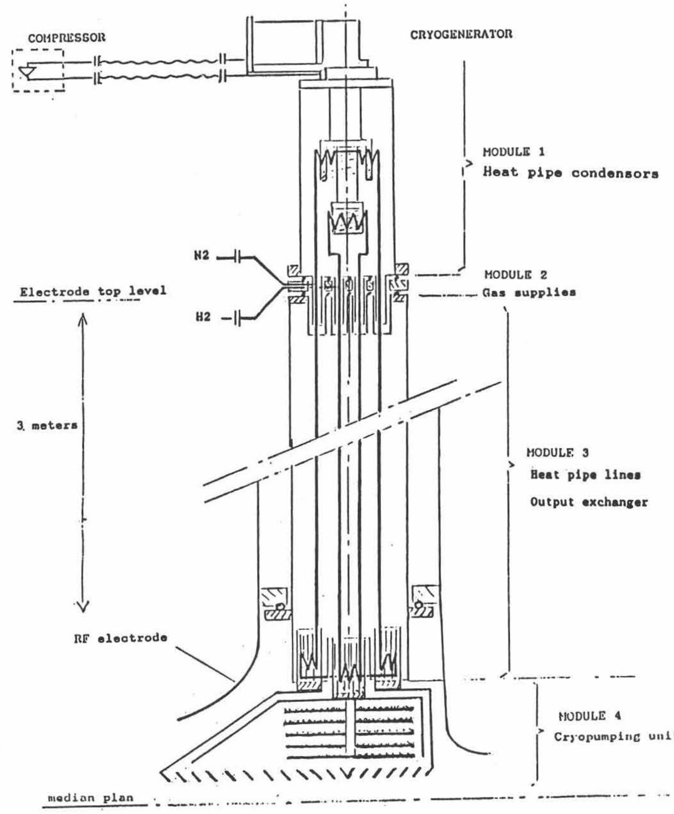

Fig. 1 AGOR cryopumping system

Because of the limited room available for setting up and maintenance, each cryopumping system will be consisting of a set of 4 modules:

_ the first and the second can be removed from the top of the york without disturbing the acceleration chamber vacuum.

_ the third and fourth modules can be taken off from the electrode bottom when the magnet plug has been lifted up.

A complete prototype has been constructed according to the main design features illustrated in Fig.1:

First module(M 1): exchanger stages connected to the cold head of a cryogenerator, these are the heat pipe parts where NITROGEN and HYDROGEN are respectively condensed.

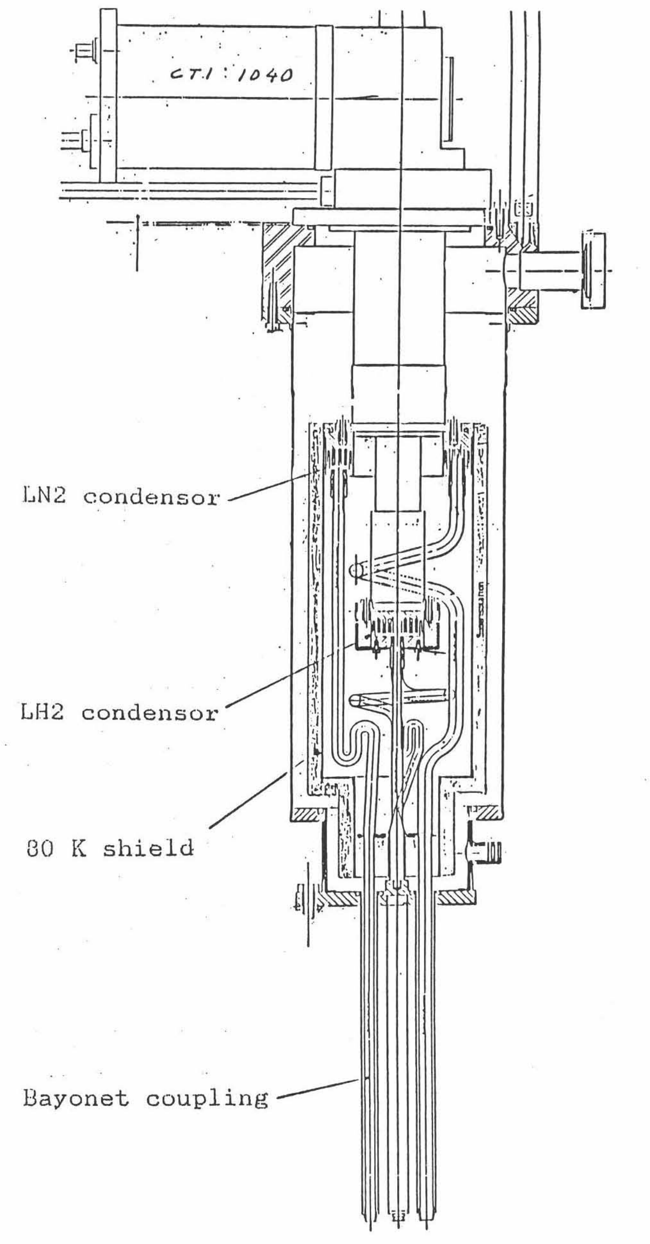

Fig. 2 First module: exchanger stages connected to the cryogenerator cold head

Second module(M 2): N2 and H2 gas supplies connected to buffer volumes and over pressure valves.

Third module(M 3): heat pipe lines themselves (3 meters length) with their associated exchanging surfaces for connecting cryopump.

Fourth module(M 4): cryopump unit itself (20 K cryopanel with activated charcoal surfaces and the 80 K shielding).

TESTS AND RESULTS

It was important to test the heat tranfer performances and the stability of the system under varied conditions, to experiment the influence of the many parameters, specially the heat pipes filling (optimum mass of gas being introduced).

Tests has been done according to three principal steps:

1) First step: checking and measurement of the refrigeration capacity of the cryogenerator (CTI model 1050 C) associated to the M 1 exchanger stages (Fig 2).

Fig 3 shows the measured refrigeration power as a function of the temperature in comparison with the theoretical characteristic of the cryogenerator.

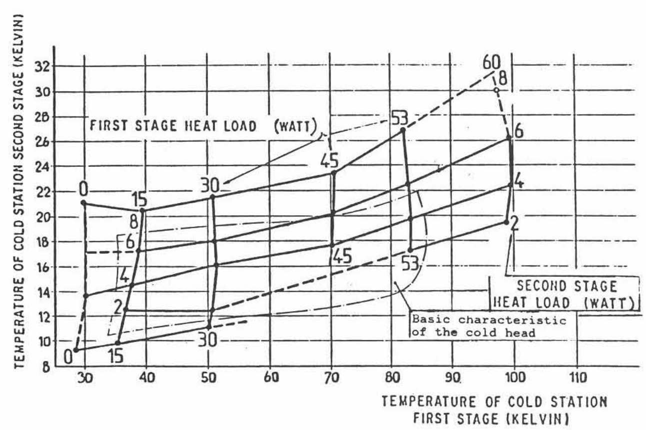

Fig. 3 Refrigeration capacity of module 1 and cryogenerator

Basic refrigeration power available is therefore 48 watt at 80 K and 4.5 watt at 20 K.

2) Second step: was a large experiment of the heat pipe functioning (optimum filling degree, temperature gradient measurements, heat load and performances, cool-down time).

The filling degree, defined as follows:

$$\frac{V}{V_o} = \frac{\text{liquid phase volume}}{\text{total heat pipe volume}} = \frac{\rho_m - \rho}{\rho' - \rho''}$$

Where ρ' = liquid phase density
ρ'' = gaseous phase density
ρ_m = average density in the heat pipe

is a main parameter which has been carefully explored. Tests have been successively done with different filling degrees, as shown in table 1, in order to find the optimum values.

The main advantage of heat transfert by heat pipe being its small temperature gradient, measurements have been done on the cryogenerator cold head and, 3 meters away, on the output exchanger. Results are shown in table 1.

Heat losses and cooling power available for cryopumping has been measured with the experimental disposal illustrated in fig. 4 .

Table 1 : Heat pipe performances

	N2 loop		H2 loop	
Fluid temperature	77.4 K		20.4 K	
Heat load (from heating resistor)	10 w	50 w	3 w	5 w
Temperature gradient (cold head/output flange)	2.5 K	6 K	0.8 K	1.2 K
Thermal losses	12 w		3 w	
Filling degree	0.2	0.35	0.14	0.3
Initial filling pressure	10 bar		10 bar	
Volume STP (liter)	40	70	30	60

Heat losses for the N2 heat pipe (12 w) are close to those predicted. In the other hand, heat losses for the H2 heat pipe (3 w) are somewhat higher than expected.

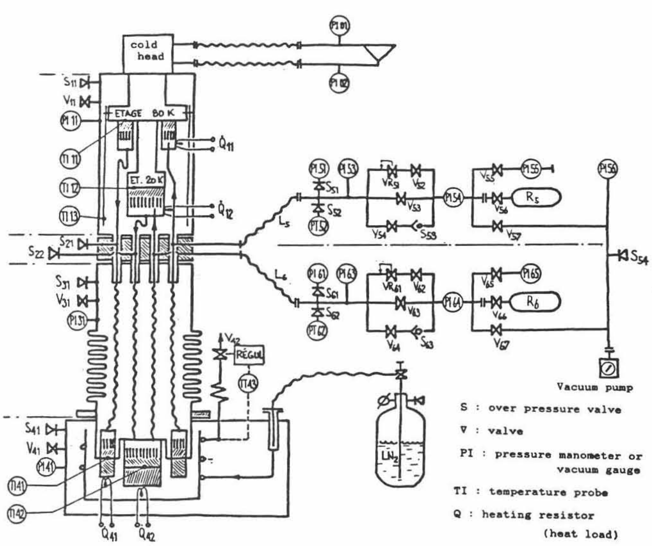

Fig. 4 Experimental set up for heat pipes testing

The significant heat load applied on ouput flange exchanger shows that we have still comfortable refrigeration power left for cryopump cooling.

Table 2 Cool-down time according to masses involved

	bare system (whithout M 4)	complete system (with pumping umit)
Masses to cool:		
_ N2 loop	3.6 kg	8.5 kg
_ H2 loop	1.5 "	3.2 "
Cool-down time (from 300 K to steady state conditions):		
_ N2 loop	2.5 hours	5.7 hours
_ H2 loop	4.5 "	6.3 "

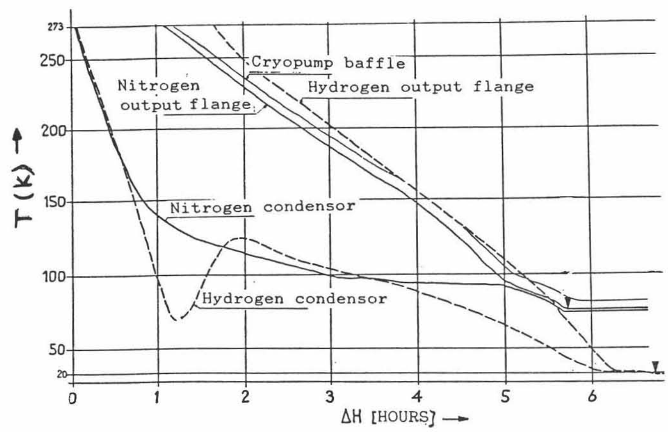

Fig. 5 Cooldown of the cryopumping system

the cool-down time is of course depending on the cooling power available and masses involved.

One should expect that cooling of the heat pipe would not occur before condensation starts. With our devices, however, we noticed an effective cooling of the output flange at substancially high temperature, due to thermosiphon circulation of the cold gas, and therefore, earlier pumping effects.

Obviously several parameters of the heat pipe system have to be astutely combined to achieve good performances and maximum reliability, for instance:

a/ Temperature gradient versus heat load

b/ Filling degree:

- An optimum amount of liquid (evaporator just flooded) will produce the smallest temperature gradient, since any build up of hydrostatic pressure will delay the vaporisation.
- A minimum mass of hydrogen involved in the process is appreciated for security reasons.
- A comfortable but acceptable filling margin will create easier maintenance and reliability in the long run.

c/ Cool-down : an optimum initial filling pressure in the heat pipe is necessary to assure an efficient cool-down.

3) third step: Pumping speed measurement for nitrogen and hydrogen have been done on a normalized test dome (french norme AFNOR and ISO). Results are shown Fig. 6.

Ultimate pressure in the unbaked stainless steel test chamber was 10-5 Pascal measured with a Bayard Alpert manometer.

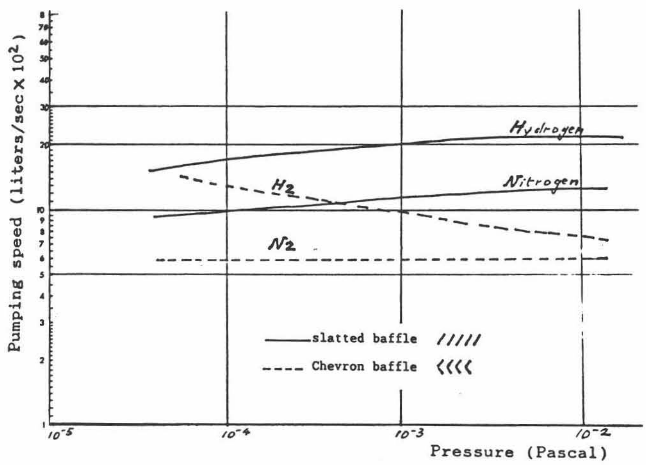

Fig. 6 Pumping speeds

Because of the comfortable margin of cooling power, the use of a slatted baffle instead of a chevron baffle allowed an increase of pumping speed by a factor of two.

For hydrogen pumping, about 100 grams of activated charcoal are used on 900 cm2 of the 20 K surface. Continuous operation with hydrogen at 4 10-2 Pascal for 82 hours resulted in a pumping speed drop of 30 % during the first ten hours. Afterwards, it remained almost constant for days.

CONCLUSIONS

The results so far obtained show that heat transfer performances (power and temperature) can allow efficient cooling for cryopumping inside the AGOR cyclotron.

The speed pumping measured (2000 l/sec for hydrogene and 1200 l/sec for nitrogen at 10-6 mbar), which are slighly over the required values, shows the adequate design of the cryopanels.

Due to the modular conception, an easy maintenance of the cryosystem should be expected.

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