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TRANSIENT THERMAL ANALYSIS OF CRYOCONDENSATION PUMP FOR JET

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ABSTRACT

A cryopump with pumping speed of 50,000 l/sec is planned to be installed in the Joint European Torus (JET) as part of the pumped divertor. The purpose of this pump is to control the plasma impurities. The pump consists of a helium panel cooled by supercritical helium and a nitrogen shield cooled by liquid nitrogen. This paper presents the following transient thermal flow analysis for this cryopump:

1. Consequences of loss of torus vacuum on helium panel.
2. Cool down of the nitrogen shield from 300 K to 80 K.

INTRODUCTION

It is proposed to install a pumped divertor inside the JET torus to control the plasma impurities. The pumping will be accomplished by a cryocondensation cryopump. Figure 1 shows the design of the proposed pump. The cryopump consists of chevron type liquid nitrogen cooled radiation shield and helium panel cooled by supercritical helium.

The purpose of the nitrogen shield is to reduce the radiation and particle load on the helium panel. The nitrogen shield is made in two parts. The outer shield consists of copper chevrons and the inner shield is a stainless steel plate. Each shield is cooled by liquid nitrogen at a pressure of 4 bar and an inlet temperature of 77 K flowing through two 19 mm ID stainless steel tubes.

The helium panel is made from slightly corrugated 20 mm diameter 0.3 mm thick stainless steel tubes. Six tubes are used in series to increase the panel area. The area of the helium panel is about 7.5 m². The helium panel is cooled by supercritical helium at a pressure of 3 bar and an inlet temperature of 4.2 K.

The details of the design of this pump are given in Obert.¹

This paper discusses two transient thermal analyses performed to improve the design and safety of this cryocondensation pump.

Figure 1. A view of JET pumped divertor cryocondensation pump.

ANALYSIS

Quench of the Cryopump Helium Panel

The steady state heat load on the helium panel at this pressure is about 50 W due to radiation from the N_2 shield. Degradation of vacuum in the torus increases the heat load on the helium panel by a factor of up to 60. The increased heat load on the panel will increase the pressure inside the helium panel and burst the panel tubes. Such an event is prevented by providing a rupture disc activated at 10 bar pressure in the helium line outside the torus. However, due to the long length of the helium panel tube, a rapid pressure increase could cause the tubes to break, before the rupture disc. Hence, an analysis was performed to calculate the expected rise of pressure inside the helium panel.

It is assumed that in the event of an accident the medium in the torus is air. The inlet flow to the helium panel is stopped as soon as loss of vacuum is detected. The heat transfer regime, and thus the heat load on the helium panel, depends on the pressure in the torus. The heat transfer mechanism depends on the mean free path of the medium and the dimensions of the pump.

- a. $p < 10^{-6}$ Pa, the heat load is by radiation heat transfer only.
- b. $10^{-6} < p < 0.1$ Pa, the heat transfer is by molecular conduction through the gas contained in the torus.
- c. $0.1 \text{ Pa} < p$, heat transfer is by natural convection.

Table 1 summarizes the relation between the torus pressure and heat flux on the helium panel.

Based on the configuration of the cryosystem, it can be assumed that the flow from the helium panel is connected to a sink at a pressure of 3 bar by a co-axial corrugated channel with OD of 3.9 cm and ID of 1.4 cm. The Moody friction factor for the corrugated channel was taken to be 0.08 based on manufacturers data. The length of the channel is 60 m.

The thermal response of the helium panel can be calculated by solution of continuity, momentum and energy equations.

Pressure and thermal response of the helium panel can now be calculated. A FORTRAN computer program QUENCH-FOR was written for a desktop computer

Table 1. Effect of pressure on heat transfer

	Pressure in Torus (Pa)	Heat Transfer (W/m ²)	Results	
			With Flow	No Out Flow
1	0.01	Molecular conduction $q'' = 2.26 p (80-T)$	$P_{\max} = 3$ bar plus ~ 1 Pa	$P = 10$ bar, $T = 5.47$ at 64 s
2	0.1	Gas conduction $q'' = 0.5 (80-T)$	$P_{\max} = 3.00086$ bar at 38 s	$P = 10$ bar, $T = 5.47$ at 64 s
3	10^3	Convection $q'' = 0.527 (80-T)^{1.25}$	$P_{\max} = 3.002$ bar at 10 s $T \simeq 80$ K at 605 s	$P = 10$ bar, $T = 5.47$ at 20 s
4	10^5	Convection $q'' = 0.527 (80-T)^{1.25}$	$P_{\max} = 3.108$ bar at 0.98 s $T \simeq 80$ K at 63 s	$P = 10$ bar, $T = 5.47$ at 2 s

q'' = Heat flux on the helium panel
 T = Temperature of the helium panel

to solve the above set of equations by an implicit numerical procedure. Properties of helium were used from Hands.²

An analysis was performed for four pressure levels covering all regimes. Two conditions were considered. With the outflow (flow out of the helium panel to a sink at 3 bar) occurring or with no outflow. The results are summarized in Table 1.

The results show that if the outflow occurs, the pressure increase in the helium panel is quite small. The rupture disc will not break. The flow resistance of the outflow channel is so small that it acts as a safety valve. If the outflow did not occur, 10 bar pressure is reached when the temperature is 5.47 K. The time required to reach this pressure is 2 s if the torus pressure is 10^5 Pa and is 1400 s, if the torus pressure is 0.01 Pa. Response of the helium panel when the torus pressure is 0.01 Pa is shown in Fig. 2. As long as the outflow occurs, the pressure in the helium panel does not increase significantly during the quench. Results obtained in this analysis agree within 20% with the approximate relation (modified to account for large friction factor in corrugated channel) presented in Miller *et al.*³

Cool Down of Nitrogen Shield

The helium panel is surrounded by a N₂ shield in the proposed JET cryocondensation pump as shown in Fig. 1. The outer N₂ shield consists of copper chevrons and the inner N₂ shield consists of a stainless steel plate. Both N₂ shields are cooled by liquid N₂ at a pressure of 4 bar and 77 K. The outer shield is directly mounted on the inner shield in the reference design.

The objective of this analysis was to investigate the consequence of cooling down the nitrogen shields from initial temperature of 300 K to 80 K by use of liquid N₂. A matter of concern was the temperature differences and resulting thermal stresses between different parts of the N₂ shield during such a cool down.

In order to analyze this problem, a computer code was developed which modeled the geometry of the N₂ shields and the phase transition of the N₂ during flow through the shield.

The governing equations and details of this model are given in Baxi.⁴ An implicit numerical procedure was used which enabled time steps of about 1 s.

Figure 2. Response of helium panel with ambient pressure = 0.01 Pa and no out flow.

The cooling tubes on the shield can be connected in a number of different ways (Fig. 3). During the cool down of the shield from 300 K to 80 K, the temperature difference of between the shields varies as a function of time, calculated by the model, as shown in Fig. 4. Results for all flow arrangements are summarized in Table 2, indicating that arrangement II results in a minimum temperature difference.

Another effect analyzed with the computer program was the effect of adding a copper layer of about 1 mm thickness to the stainless steel shield. Such a layer will reduce the steady state temperature of the stainless steel shield and also reduce the temperature difference between outer and inner shields from 82 K to 65 K during the cool down (Table 2).

Figure 3. Arrangements for connecting cooling tubes of the nitrogen shields.

Figure 4. Difference between outer shield and inner shield (Flow = 7.5 g/s, Arrangement II, Heat Load $\approx$ 1 kW).

Table 2. Effect of flow arrangement on temperature difference between chevrons and stainless steel shield 7.5 g/s flow, 1 kW heat load

Arrangement	Without Copper Layer	With 1 mm Copper Layer on Inner Shield
I	105	98
II	82	65
III	200	158
IV	87	73

Parametric studies showed that the temperature difference between the shield increased by about 5 K if the flow rate of liquid N_2 was doubled from 7.5 g/s to 15 g/s. If heat load was increased from base condition of 1 kW, the temperature difference decreased to 50 K (Tables 2 and 3).

Table 3. Effect of Flow Rate on Temperature Difference between inner and outer shields (arrangement II, with 1 mm copper layer on inner shield and heat load of 1 kW)

N_2 Flow Rate (g/s)	Temperature Difference (k)
3.75	59
7.50	65
15.00	70

This analysis shows that the temperature difference between the inner and outer N_2 can be reduced but can not be eliminated by optimizing the design. Hence it was decided to modify the design to permit small relative motion between the inner and

outer N₂ shields to reduce the stresses caused during cooldown transients. An alternative would have been to have a controlled cooldown, where N₂ gas at a controlled temperature is used to cool down the N₂ shields.

As a result of this analysis following three design modifications were suggested for the nitrogen shield design:

1. Concept of controlled cooling of the shield with a 50 K temperature difference between outlet and inlet coolant during cooldown, should be abandoned.
2. A copper layer of 1 mm equivalent thickness should be used on the stainless steel shield.
3. A sliding joint should be provided between inner and outer shield to allow relative motion of about 5 mm expected during cooldown.

CONCLUSIONS

1. Loss of vacuum in the torus does not result in rupture of the helium panel tubes.
2. There is no need to have a controlled cooling of the nitrogen shield. Liquid nitrogen can be used to cool the nitrogen shield from 300 K to 80 K.
3. Addition of copper layer on the N₂ shield will reduce the temperature differences.
4. A sliding joint between outer and inner N₂ shield is recommended to reduce stresses during cool down.
5. The flow arrangement shown in Fig. 3-II, will result in minimum temperature differences during the cooldown.

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REFERENCES

1. W. Obert, *et al.*, "JET Pumped Divertor Cryopump," Presented at the SOFT 16, London, (1990).
2. B.A. Handz, "HEPROP," 1289/79, Engineering Laboratory, Oxford University.
3. J.R. Miller, *et al.*, "Pressure Rise During the Quench of a Superconducting Magnet Using Internally Cooled Conductors," CEC Conference Proceedings, (1981) pg. 321-327.
4. C.B. Baxi, "Trip Report: Visit to JET," General Atomics Report GA-C20826, January 1992.

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