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Abstract: The reference design of JET cryopump nitrogen shield consists of an outer section made of copper chevrons fastened to two cooling tubes and an inner stainless steel section and backing plate with two cooling tubes. These tubes are fed in a parallel flow arrangement. The inlet flow is divided into two parallel paths so that both tubes on either section are always at the same temperature. This arrangement was selected due to concern about conduction between warm and cold parts of the shield during cooldown transients. If the heat loads are unequal, such a parallel flow arrangement can result in flow starvation in the path with higher heat load. This will cause large temperature differences and, ultimately, structural failure. Hence, an analysis was undertaken to investigate the conduction effects in the shield for other flow arrangements.

Thermal analysis was done using a finite element computer program developed at GA. In this analysis, a parallel flow and two series flow arrangements were compared for cooldown from 300°K to about 80°K. In order to simplify the analysis, coolant was assumed to be a N_2 gas at an inlet temperature of 80°K. The following conclusions were reached from this analysis:

1. All three flow arrangements analyzed here have similar time for cooling down the shield from 300° to 80°K. This means that the "heat exchanger effect" or radial conduction from the warm part of the shield to the cold part of the shield for series flow arrangements is not dominant.
2. Due to small conduction effects, it will be feasible to modify the design to a more stable series flow arrangement. This flow arrangement will also have minimum cooling time.
3. The inner stainless steel shield has small thermal conductivity and, hence, this part of the shield lags in cooling behind the rest of the shield. This could be remedied by adding about 1 mm layer of copper in poloidal stripes to the stainless steel fin. This will significantly reduce the cooling time of the shield, reduce the shield temperature during operation and, in turn, reduce the radiation heat load on the helium shield by a factor of about 3.

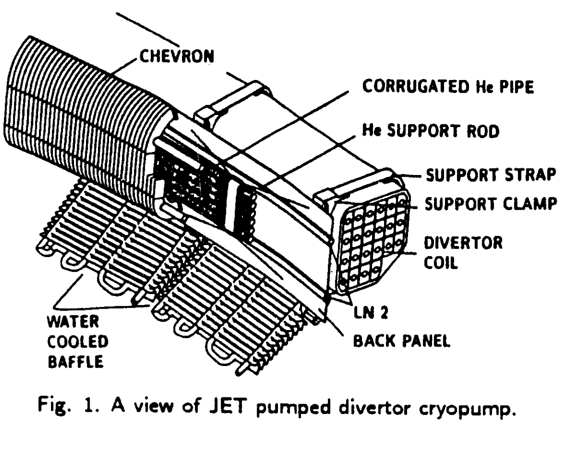

Fig. 1. A view of JET pumped divertor cryopump.

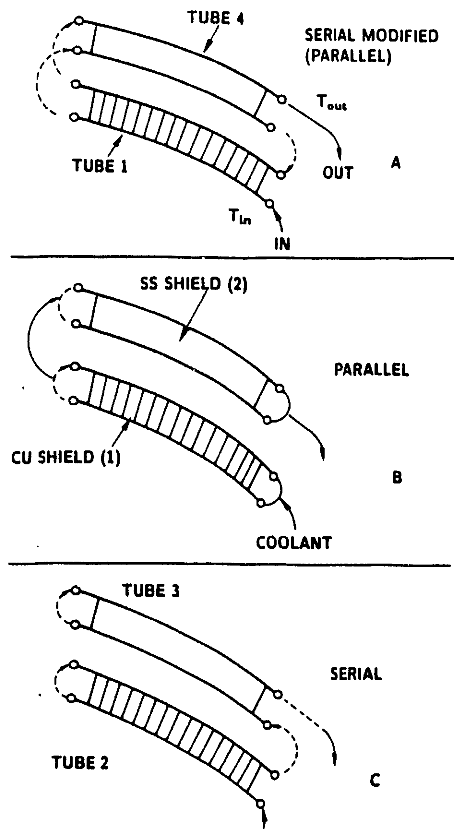

Fig. 2. Flow arrangements.

Introduction

A three-dimensional view of JET pumped divertor cryopump is shown in Fig. 1 [1]. The helium panel is surrounded by a N_2 shield. A schematics of the N_2 shield is shown in Fig. 2 and geometry details are shown in Fig. 3 [2]. The outer shield consists of copper chevrons [3]. These can be approximated by a fin 6 mm thick and 15 cm in height [1]. The inner shield and back plate consists of 3 mm thick 15 cm height stainless steel plate.

The following assumptions were made in the analysis:

1. The coolant is a nitrogen gas at a flow rate of 7.5 g/s and an inlet temperature of 80°K.
2. Specific heat of N_2 is constant and density is inversely proportional to temperature. Effect of pressure change on density was neglected.
3. Axial (in the direction of flow) conduction in the coolant, tubes, and fins was neglected.

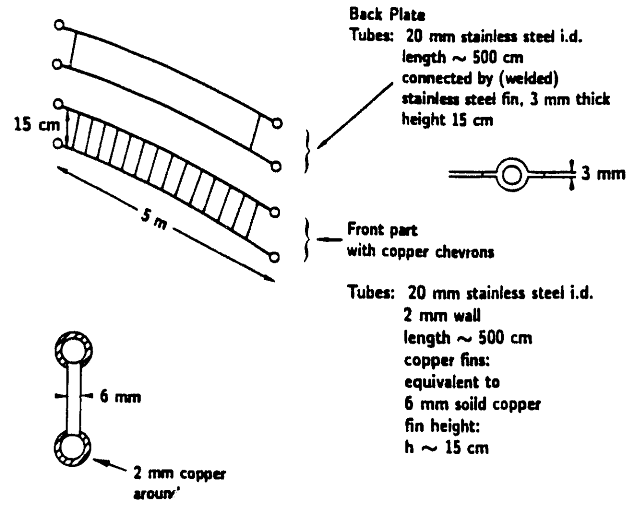

Fig. 3. Geometric details of the proposed JET nitrogen shield.

4. A radiation heat load was imposed on the shield from a source at a temperature of 300°K with an exchange factor of 0.5.

Material properties were obtained from Ref. [2].

Formulation

The formulation for this problem was similar to one done for analysis of helium shield of DIII–D cryopump [3]. The inner and outer shields were divided into axial divisions. At an axial location, each tube, each volume of the coolant, and each fin was represented by a node. Thus, we have ten coupled first-order differential equations. The formulation is described in detail in Ref. [4]. The difference equations were solved by an explicit numerical procedure.

Results and Discussion

Each of the three arrangements shown in Fig. 2 was solved for a transient cooldown. Initial temperature of the system was assumed to be 300°K, the temperature of the nitrogen gas at entrance was 80°K and the flow rate was 7.5 g/s. Radiation heat transfer from the ambient was modeled as a heat flux on one side of the shield surfaces.

In the flow Arrangement A, the flow is in series but is directed from shield to shield as shown in Fig. 2. Flow enters the lower tube of the outer (copper) shield, goes to the lower tube of the inner shield, then to the upper tube of the outer shield and finally exits through the upper tube of the inner shield. Thus, the temperatures of two tubes on either shield will be different during the cooldown transient and may degrade the performance during cooldown due to conduction from the warmer tube to the colder tube. Figure 4 shows the temperature distribution for this flow arrangement at various times during the transient.

Figure 4(a) shows the temperature distribution at 100 s after the start of the cooldown of the copper shield and tubes attached to this shield. This result shows that the temperatures of tubes on the copper shield differ by up to 36°K and will have conduction heat transfer from warmer to colder parts of the shield. The center of the shield is hotter than either tube. Figure 4(b) shows similar result for stainless steel shield and associated tubes and coolant. Comparison of Figs. 4(a) and 4(b) show that, the film drop for tubes 1 and 2 is larger than for tubes 3 and 4 due to higher thermal capacity of the copper shield and larger conduction from shield to tubes. The temperature difference between tubes on a shield is reduced with time.

In flow Arrangement B (reference design), two tubes on each shield are always at the same temperature at a given axial location and, hence, there is no radial conduction effect. However, since the flow stream is divided into two paths, flow rate through each tube is only 50%. This reduces the heat transfer coefficient (by about 42%) and, thus, reduces the cooldown rate slightly.

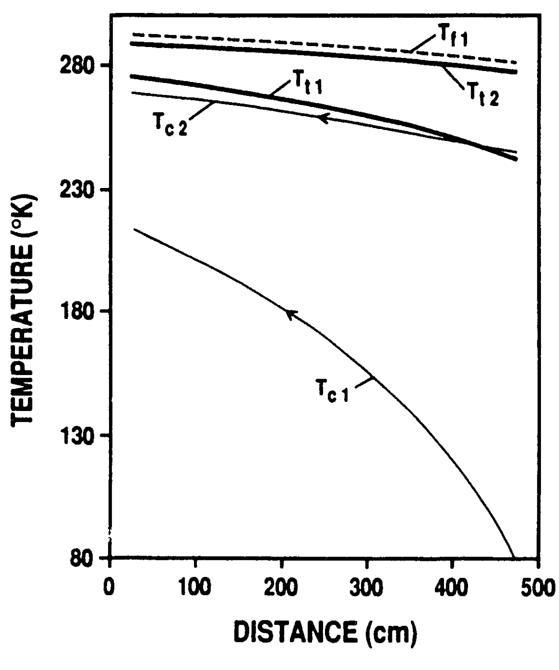

Fig. 4(a). Arrangement A: flow = 7.5 g/s, copper shield at 100 s. Arrows indicate flow direction. See Nomenclature and Fig. 2.

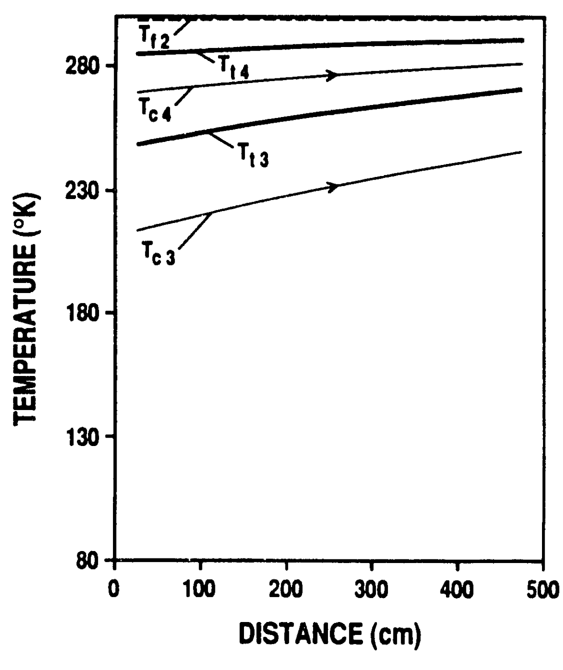

Fig. 4(b). Arrangement A: flow = 7.5 g/s, stainless steel shield at 100 s. Arrows indicate flow direction. See Nomenclature and Fig. 2.

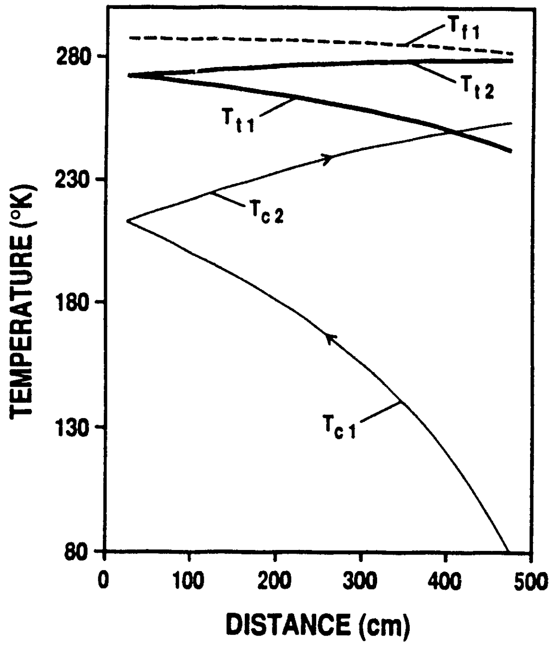

Fig. 5(a). Arrangement (series) C: flow = 7.5 g/s, copper shield at 100 s. Arrows indicate flow direction. See Nomenclature and Fig. 2.

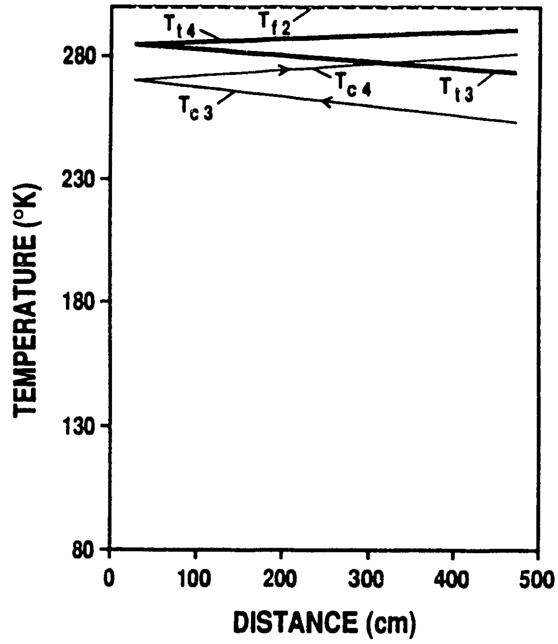

Fig. 5(b). Arrangement (series) C: flow = 7.5 g/s at 100 s for stainless steel shield. Arrows indicate flow direction. See Nomenclature and Fig. 2.

In the flow Arrangement C, flow is in series. Conduction effects will be slightly less than series parallel flow Arrangement A, but will be more than parallel flow Arrangement B. The temperature distribution for the copper shield and associated coolant and tubes at 100 s from the start of cooldown is shown in Fig. 5(a). Similar results for stainless steel shield are shown in Fig. 5(b). The temperature differences along the height of the shields are slightly smaller than for Arrangement A, resulting in smaller conduction heat transfer. The temperature distributions at 3600 s are shown in Figs. 6(a) and 6(b). The cooldown of the stainless shield lags behind the copper shield.

Cooldown rates of stainless steel fin for the three arrangements are compared in Fig. 7. These plots show that all three arrangements are similar from cooldown consideration. Arrangement C, the series arrangement, is slightly superior than the other two. Purely parallel arrangement (reference design) has the longest cooldown time.

A significant observation from this analysis is that the stainless steel shield (inner shield) lags behind the rest of the shield during cooldown for all three arrangements. This occurs due to very small thermal conductivity of stainless steel and

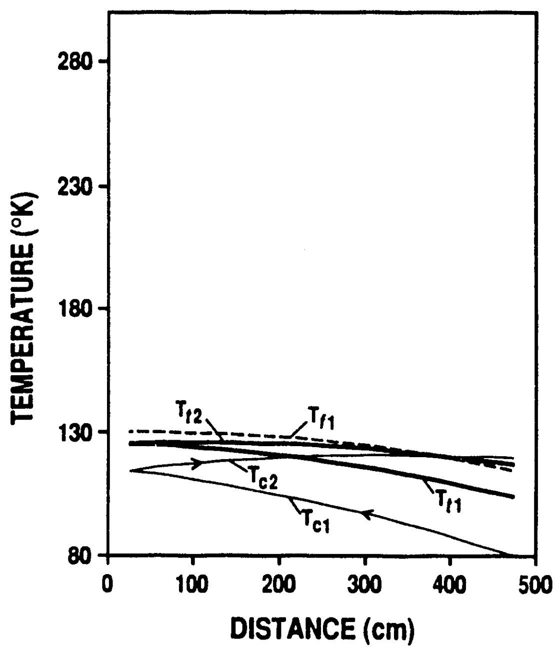

Fig. 6(a). Arrangement (series) C: flow = 7.5 g/s, copper shield at 3600 s. Arrows indicate flow direction. See Nomenclature and Fig. 2.

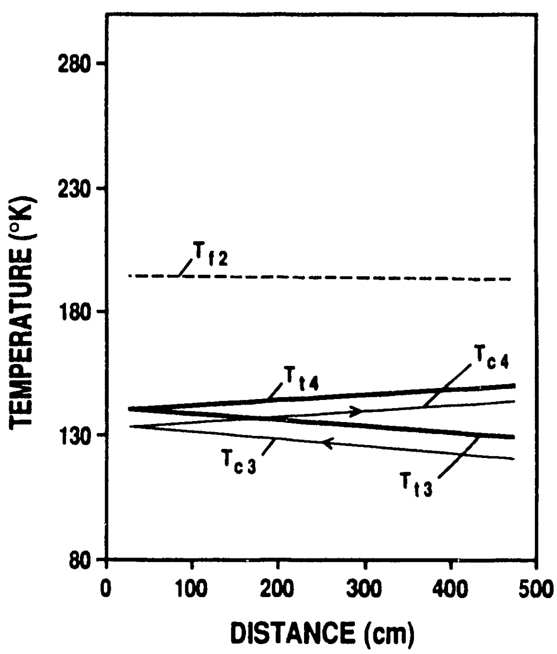

Fig. 6(b). Arrangement (series) C: flow = 7.5 g/s at 3600 s for stainless steel shield. Arrows indicate flow direction. See Nomenclature and Fig. 2.

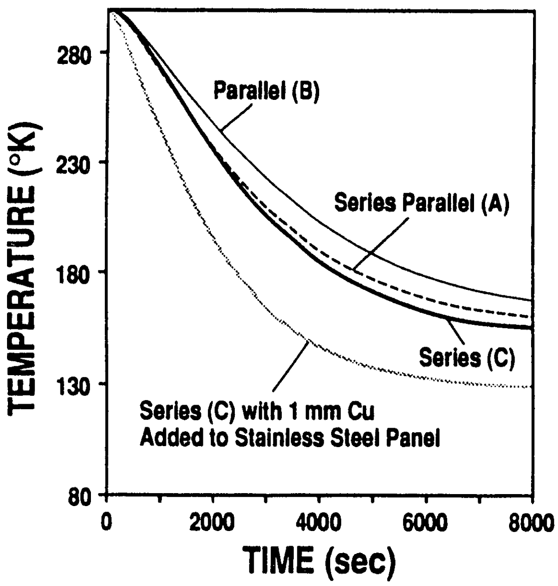

Fig. 7. Cooldown of stainless steel fin for flow rate of 7.5 g/s.

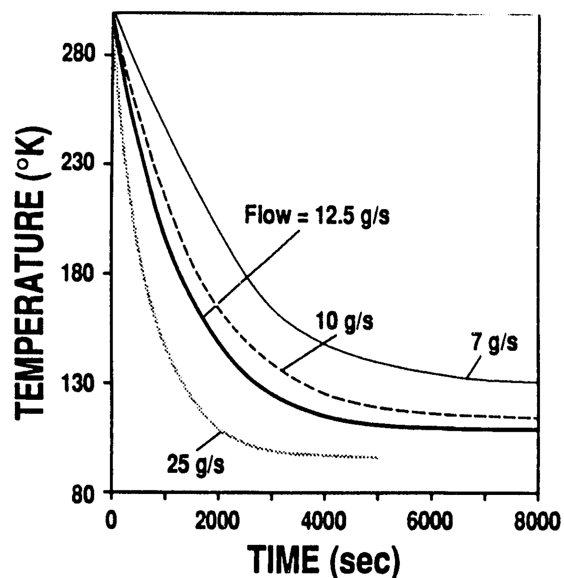

Fig. 8. Effect of flow rate on cooldown of stainless steel fin with 1 mm copper for Arrangement C (series).

relatively long conduction path between the coolant channels (15 cm) and the center of the shield.

This deficiency (high temperature of the stainless steel shield) could be remedied by adding a layer of copper to the stainless steel shield. The layer need not be continuous axially (along the length), it has to be continuous from tube to the center of the shield. Such a layer could be added by flame spraying, a process that is planned to be used for nitrogen shield of DIII–D cryopump. It is important to point out that this is essential not only for the cooldown, but also to insure that the nitrogen shield temperature is below 100°K during steady state operation. The stainless steel shield at a higher temperature will impose unnecessarily high radiation heat load on the helium shield.

The lowest curve in Fig. 7 shows the effect of a 1 mm copper layer on stainless steel shield on the cooldown of the shield. Addition of the copper layer has reduced the temperature of the shield from over 160°K to under 130°K.

Finally, effect of coolant flow rate on cooldown rate was analyzed. Figure 8 shows the effect of flow rate on cooldown of the stainless steel fin with a 1 mm copper layer for the series Arrangement C. Increasing the flow can significantly reduce the cooldown time but may not be feasible due to system limitations.

Nomenclature

T = temperature

Subscripts

c1 = coolant 1, *etc.*

$f1$ = copper fin

$f2$ = stainless steel fin

$t1$ = tube 1, *etc.*

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