Conf - 910968--39

GA-A20589
Receive

NOV 15 1991

VERIFICATION TEST FOR HELIUM PANEL OF CRYOPUMP FOR DIII-D ADVANCED DIVERTOR

by

C.B. BAXI, G.J. LAUGHON, A.R. LANGHORN,
K.M. SCHAUBEL, J.P. SMITH, A.M. GOOTGELD,
G.L. CAMPBELL, and M.M. MENON

OCTOBER 1991

GENERAL ATOMICS

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

VERIFICATION TEST FOR HELIUM PANEL OF CRYOPUMP FOR DIII-D ADVANCED DIVERTOR

by

C.B. BAXI, G.J. LAUGHON, A.R. LANGHORN,
K.M. SCHAUBEL, J.P. SMITH, A.M. GOOTGELD,
G.L. CAMPBELL, and M.M. MENON*

This is a preprint of a paper presented at the 14th IEEE
Symposium on Fusion Engineering, September 30–October 3, 1991, San Diego, California, and to be printed in
the *Proceedings*.

Work supported by
U.S. Department of Energy
Contract DE-AC03-89ER51114

*Oak Ridge National Laboratory, Oak Ridge, Tennessee

GENERAL ATOMICS PROJECT 3466
OCTOBER 1991

MASTER

GENERAL ATOMICS

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

VERIFICATION TEST FOR HELIUM PANEL OF CRYOPUMP FOR DIII-D ADVANCED DIVERTOR

C.B. Baxi, G.J. Laughon, A.R. Langhorn, K.M. Schaubel, J.P. Smith, A.M. Gootgeld, and G.L. Campbell

General Atomics
P.O. Box 85608, San Diego, California 92186-9784

M.M. Menon

Oak Ridge National Laboratory
P.O. Box 2008, Oak Ridge, Tennessee 97381

Abstract: It is planned to install a cryogenic pump in the lower divertor portion of the DIII-D tokamak with a pumping speed of 50000 ℓ/s and an exhaust of 2670 Pa- ℓ/s (20 Torr- ℓ/s). A coaxial counter flow configuration has been chosen for the helium panel of this cryogenic pump. This paper evaluates cooldown rates and fluid stability of this configuration. A prototypic test was performed at General Atomics (GA) to increase confidence in the design. It was concluded that the helium panel cooldown rate agreed quite well with analytical prediction and was within acceptable limits. The design flow rate proved stable and two-phase pressure drop can be predicted quite accurately.

Introduction

The advanced divertor [1] has been operational inside DIII-D since April 1990, and has been successfully used in bias and baffle modes. Next, it is planned to install a cryogenic pump inside the baffle chamber of the advanced divertor for particle

exhaust in order to control plasma density. The dimensions under the advanced divertor as well as the optimum orientation of the pump have been optimized using the particle transport code DEGAS [2]. The calculations show that the desired exhaust of 2670 Pa- ℓ/s (20 Torr- ℓ/s) can be obtained by providing a pumping speed of 50000 ℓ/s . A review of various pumping options indicated that the best way to achieve this pumping would be by a cryopump located under the baffle plate of the advanced divertor.

The geometry of the helium panel of the cryopump is dictated by the space available and the surface area necessary to provide the required pumping speed. A coaxial geometry consisting of standard 304 stainless tubes satisfied these conditions. This coaxial configuration (Fig. 1) posed two conditions:

1. Will the coaxial counter flow arrangement increase the cooldown time from room temperature to liquid helium temperature beyond an acceptable time of a few minutes?
2. Does the stability criteria based on the Baker diagram apply to helium and coaxial geometry?

FIG. 1. Flow directions in the coaxial helium panel.

Previous experience with cryogenic coaxial transfer lines suggested that the cooldown time may be excessive. Hence, the experiment described in this paper was performed.

Details of the cryopump design and the out-of-vessel system are described in two other papers in this meeting [3,4]. Thermal analysis undertaken to design the cryopump is described in Ref. 5.

Experimental Procedure

A schematic of the experimental set up is shown in Fig. 2. The most important part of the setup, the helium panel, was prototypic. The dimensions of the inside and outside tubes of the panel were identical to the proposed design (1.59 and 2.54 cm o.d. with 0.9 mm wall thickness). The flow path length of helium through the helium panel (10.4 m) (Fig. 2) was similar to the proposed design. The only variation was that, in the experiment, the shield was made from straight tubes, whereas in DIII-D, the helium panel will be located along an arc of a 3 m diameter circle.

The helium panel was surrounded by a liquid nitrogen-cooled radiation shield consisting of a 10 cm diameter copper tube. The nitrogen shield was contained within a vacuum chamber and separated from the vacuum chamber by super insulation.

The liquid helium supply was obtained from a 3800 ℓ Dewar at a pressure of 142 kPa (20.7 psia). Thus, the inlet condition to the helium panel could be near the design condition of 116 kPa pressure and saturated condition.

The heat input to the helium panel was simulated by passing an electric current through the outer tube of the helium panel. A power input of up to 60 W could be achieved.

In order to measure the helium flow rate accurately, the exiting helium from the helium panel was heated by a series of electrical heaters to about 300 K. The resulting gas flow was measured by a calibrated pitot tube.

The vacuum tank was evacuated to a pressure of about 1.33×10^{-3} Pa (1.0×10^{-5} Torr). Liquid nitrogen flow was started and the nitrogen shield was cooled to and maintained below 100 K. Warm helium gas was flowed through the helium panel to prevent pre-cooling of the helium panel. A heat load of 6 W was imposed on the helium panel by adjusting the voltage applied to the panel.

With the helium panel temperature slightly below 300 K, liquid helium flow was started to simulate cooldown of the panel. After the cooldown of the helium panel was completed, helium flow and heat load on the shield were varied to obtain data on flow stability and pressure drop. Helium gas was introduced in

FIG. 2. Experimental setup.

the vacuum tank to study the effect of pressure in the vacuum tank on flow stability.

Helium panel temperatures at the inlet, location "M" (Fig. 2), and at the exit were monitored with silicon diodes and recorded as a function of time. Nitrogen radiation shield temperature, vacuum tank pressure, and helium panel pressure drop and applied voltage and current were measured. The helium gas temperature (at exit) and pitot tube readings were measured and, in a few cases, the power supplied to the heaters was measured to cross check the helium flow rate by calorimetry.

Results and Comparison to Analysis

Figure 3 shows the results of the helium panel cooldown test. The helium flow rate was 3.5 g/sec at the beginning of cooldown. The inlet pressure to the experiment was constant as the panel cooled down and the quality of outlet fluid improved from gas to almost 100% liquid while the flow rate increased from 3.5 to 4.25 g/sec.

An analysis was performed at the beginning of the cryopump design phase [6] to calculate the cooldown of the cryopump from 300 K (the cryopump may attain this temperature after glow discharge). Figure 4 shows the experimental results for the panel surface temperature at location "M" (Fig. 2) obtained during rapid cooldown of the panel. The solid line shows the analytical prediction from Ref. 6.

Table 1 summarizes other data collected, such as: the pressure drop across the helium panel, pressure in the vacuum tank, and flow stability observed at various helium flow rates and

FIG. 3. Test results for rapid cooldown of helium panel (flow = 3.5 g/sec).

power inputs. The last five lines in Table 1 show the results of gas injection into the vacuum tank.

FIG. 4. Comparison of analysis and experiment for cooldown of helium panel (flow = 3.5 g/sec; temperature (K) at location "M" in Fig. 2).

Table 1: Summary of Data

He Flow (g/sec)	Heat Load (W)	Pressure Drop Across Helium Panel (Pa)	Flow Stability	Vacuum Tank Pressure (Pa)
4.50	6.	348	Stable	0.0013
4.50	12.	348	Stable	0.0013
4.50	24.	398	Stable	0.0013
4.50	44.	373	Stable	0.0013
4.00	34.	398	Stable	0.0013
4.00	38.	398	Stable	0.0013
4.00	41.	423	Stable	0.0013
3.25	0.	298	Stable	0.0013
3.25	6.	298	Stable	0.0013
3.30	11.6	298	Stable	0.0013
3.40	18.	298	Stable	0.0013
3.40	24.	298	Stable	0.0013
3.40	30.	298	Stable	0.0013
3.40	36.	—	Unstable	0.0013
5.25	0.	423	Stable	0.0013
5.25	42.	600	Stable	0.0013
5.25	48.	622	Stable	0.0013
5.25	54.	660	Stable	0.0013
5.25	59.	697	Stable	0.0013
5.25	60.	—	Unstable	0.0013
5	6.	348	Stable	0.0013
4.5	6.	361	Stable	0.0013
4.5	6.	373	Stable	0.266
4.5	6.	423	Stable	0.4
4.5	6.	—	Unstable	2.0
4.25	6.	398	Stable	0.266
4.25	6.	—	Unstable	0.4

Flow stability for two-phase flow is predicted by the Baker Diagram [7]. The results are applicable to flow in a circular tube and are based on observations for water.

The stability line based on the Baker Diagram was calculated for liquid helium flow rates between 3.25 and 5.25 g/sec and for the geometry of the ADP helium panel as shown in Fig. 5. Experimental points when the flow became unstable, are shown

FIG. 5. Flow stability for helium panel. The region above the curve is unstable.

on the same plot. (The flow instability results in sudden reduction in flow and concomitant increase in shield temperature.) The comparison in Fig. 5 indicated that, for the ADP geometry, the Baker Diagram predictions give a very good estimate. This is surprising in light of the facts that the Baker Diagram was developed for water flow through a tube, and the experiment was for a liquid helium flow through an annular geometry. These results show that, at the design flow rate of 5 g/sec, flow will be stable for heat loads up to 54 W. The expected heat load on the helium panel during operation is about 10 W.

The pressure drop for two phase flow with heat transfer can be calculated by Lockhart-Martinelli correlation [8]. This relation is complicated enough to require a computer program for calculations. For the ADP design point of 5 g/sec flow and 10 W heat input a pressure drop of 400 Pa (1.6 in. of water) had been predicted. In the experiment, the value measured was 350 Pa (1.4 in. of water).

Summary/Conclusions

The prototypic test performed has shown that the counter-flow configuration is a sound design for the advanced divertor cryogenic pump. Results confirm that a cooldown of the helium panel from 300 K to liquid helium temperature can be achieved in the few minutes available between plasma "shots." Helium flow results indicate that, at the design flow rate of 5 g/sec, flow will be stable for heat loads up to 54 W. The expected heat load on the helium panel during operation is about 10 W.

Acknowledgements

The authors wish to thank H.M. Lizarraga, D.K. Cummings, and E.J. Taylor for help with the experiment.

This work was sponsored by the U.S. Department of Energy under Contract Nos. DE-AC03-89ER51114 and DE-AC05-84OR21400.

References

- [1] M. Ali Mahdavi, "The DIII-D Collaborative Advanced Divertor Program," General Atomics Report GA-A19547 (February 1989).

- [2] M.M. Menon *et al.*, "Particle Exhaust Scheme Using an In-Vessel Cryocondensation Pump," to be published.
- [3] J. Smith *et al.*, "The Design and Fabrication of a Toroidally Continuous Cryocondensation Pump for the DIII-D Advanced Divertor," this symposium.
- [4] K. Schaubel *et al.*, "Design of the Advanced Divertor Pump Cryogenic System for DIII-D," this symposium.
- [5] C.B. Baxi *et al.*, "Thermal Design, Analysis, and Experimental Verification for a DIII-D Cryogenic Pump," presented at Second Symposium on Fusion Nuclear Technology, Karlsruhe, F.R.G., June 2-7, 1991.
- [6] C.B. Baxi *et al.*, "Thermal Analysis of a Coaxial Helium Panel of a Cryogenic Vacuum Pump for Advanced Divertor of DIII-D Tokamak," presented at 1991 Cryogenic Engineering Conference, Huntsville, Alabama, June 11-14, 1991.
- [7] O. Baker, "Multiphase Flow in Pipelines," *Oil and Gas Journal Progress Report*, 1950, pp. 156-67.
- [8] R.C. Martinelli and R.W. Lockhart, "Proposed Correlation of Data for Two Phase Flow in Pipes," *Chem. Engr. Progr.*, vol. 45, 1949, p. 39.

END

**DATE
FILMED**

01/106/192