# THE DESIGN AND TEST OF PLUG-IN CRYOPUMPS

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*Abstract*

The design and cryo-test system of a plug-in cryopump to be used in the CYCIAE-100 cyclotron is introduced. The plug-in cryopump consists of two cryopanels, a baffle, a half-opened shield, and two refrigerators. The refrigerators have a power of 83W/80K at the first stage and 7.5W/20K at the second stage. The designed pumping speed of the cryopump is 15,000 ℓ/s for nitrogen. The cryopump has been tested and the pumping speed, cooldown time, and ultimate pressure. The cryopanel heat load calculations, including the shield and baffle, have been conducted. The design parameters and experimental results are compared.

## INTRODUCTION

A pressure of $5\times10^{-6}$ Pa is necessary [1] to achieve acceptable beam losses in the CYCIAE-100 cyclotron tank [2]. To achieve this pressure, it was calculated that a pumping speed of 120,000 ℓ/s for nitrogen is required. The existing penetrations through the cyclotron magnet are too deep to provide sufficient pumping speed using commercially available pumps mounted outside the penetrations. A plug-in cryopump with design nitrogen pumping speed 15,000 ℓ/s was developed. Four pumps of this type will be used in combination with internal cryopanels, if required, to achieve the necessary pressure in the tank.

The plug-in cryopump has undergone extensive experimentation to determine several key parameters including its cool-down time, pumping speed, and ultimate pressure. This paper presents the design of the cryopump, the current development status, and discusses the experimental results.

## PLUG-IN CRYOPUMP DESIGN

An analysis of the outgassing rate of the inner surfaces of the cyclotron was conducted. For the calculations, the inner surface areas were taken as: 90 $m^2$ of iron, 51 $m^2$ of copper and 20 $m^2$ of aluminum. Conservative values for the outgassing rates of these materials were used, and a marginal factor of 1.5 was added to account for seal outgassing and other gas sources. Based on the resulting total gas load, it was calculated that a pumping speed of 120,000 ℓ/s would be required [3] to maintain the specified pressure of $5\times10^{-6}$ Pa.

Due to the complex magnet structure cyclotron has four 150 cm long, 50 cm diameter penetrations (ports) which can be used for pumping. These ports have a conductance of 10,000 ℓ/s. Commercially available cryopumps of this diameter have a pumping speed of about 10,000 ℓ/s for nitrogen [4]. When attached to these ports, the pumps would provide an effective pumping speed of 5,000 ℓ/s each. In total, a pumping speed of 20,000 ℓ/s could be achieved [5]. To improve this situation, a plug-in cryopump which could provide a greater effective pumping speed was designed.

The plug-in cryopump was designed to have a pumping speed of 15,000 ℓ/s, as well as benefitting from higher conductance since it is inserted part way up into the ports. Four plug-in cryopumps in combination with the internal cryopanels should provide the necessary total pumping speed. The cryopump cross sectional view is shown in Figure 1.

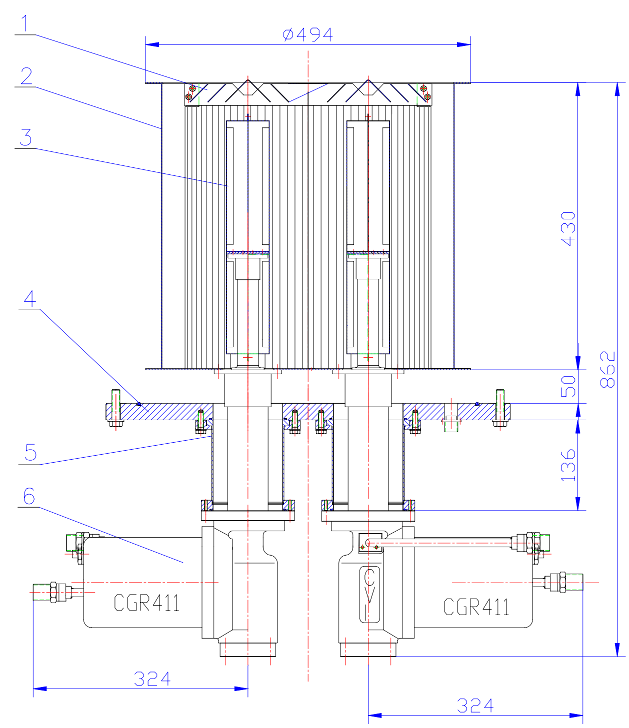


Figure 1: Plug-in Cryopump (1) half-chevron baffles, (2) shield, (3) cryopanel, (4) flange, (5) adapter, (6) GM refrigerator.

Gas particles stick to the cryopanel surface, kept at a low temperature by the CVI CGR411 refrigerators [6]. To reduce the heat load on the cryopanel and still have a reasonable conductance, half-chevron baffles [7] are used. The cryopanels are also surrounded with a cylindrical shield. A plug-in cryopump of this design has been built and performance tests were conducted. The current status and experimental results are presented below.

## STATUS

The assembly of the cryopanels, shield, baffle, and the two refrigerators was completed. The system was then inserted into the test chamber. The inner surfaces of the baffle and shield facing the cryopanel were painted black.. The test chamber is shown in Figure 2.

Figure 2: Test chamber setup.

## RESULTS

The chamber was first pumped down to a pressure of $3.2\times10^{-4}$ Pa with a turbo-molecular pump. After 3-4 hours of refrigerator operation, a pressure of $6.6\times10^{-6}$ Pa was measured. Then, with only the cryopump active, the pressure was maintained at $5.6\times10^{-5}$ Pa.

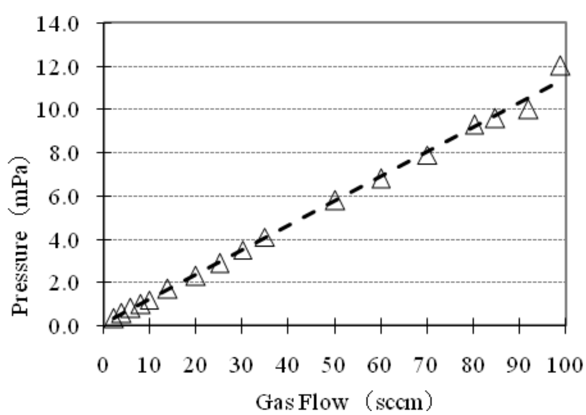


Figure 3: Test Cryopanel Pressure vs. Gas Flow.

After coating the shield and baffle, further tests were performed. A pressure of $5.0\times10^{-6}$ Pa was achieved after 3.5 hours of refrigerator operation. The temperature was 67.7 K on top of the shield and 23 K on the cryopanel. A pumping speed test was then conducted.

Figure 3 shows the dependence of pressure in the test chamber on nitrogen gas flow, bled into the chamber using a CX100 flow meter by Seven Star Co. This measurement was used as a validation of the equipment. In addition, the inverse of the slope gives the average pumping speed of 14,000 ℓ/s.

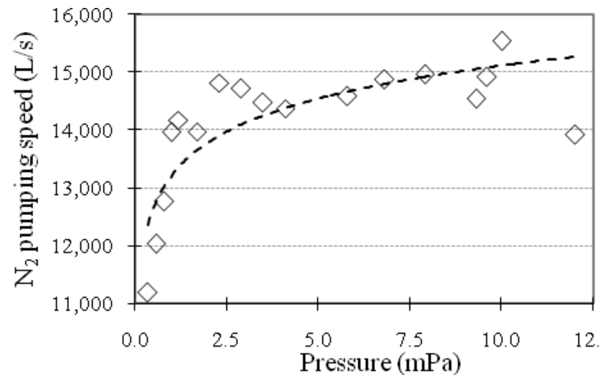


Figure 4: Test Cryopanel Pumping Speed vs. Pressure.

As can be seen in Figure 4, the pumping speed ranged from 11,000 ℓ/s at the ultimate pressure to 15,000 ℓ/s at higher pressures. Taking the average speed as 14,000 ℓ/s and given that the cryopanel surface area is 5,000 $cm^2$, we can estimate the cryopumping speed as 2.8 ℓ$s^{-1}cm^{-2}$.

## CONCLUSIONS

The plug-in cryopump performance has been demonstrated and its pumping speed has been measured. The pumping speed ranges from 11,000 ℓ/s to 15,000 ℓ/s across the experimental pressure range.

In the future, it is planned to coat the inner surface of the cryopanel with active carbon and test the pumping speed for hydrogen and other gases. Furthermore, a test of the pumping capacity of the cryopanel will be carried out.

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