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INCREASED INTENSITY HEAVY ION BEAMS AT ORIC WITH CRYOPUMPING

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Summary

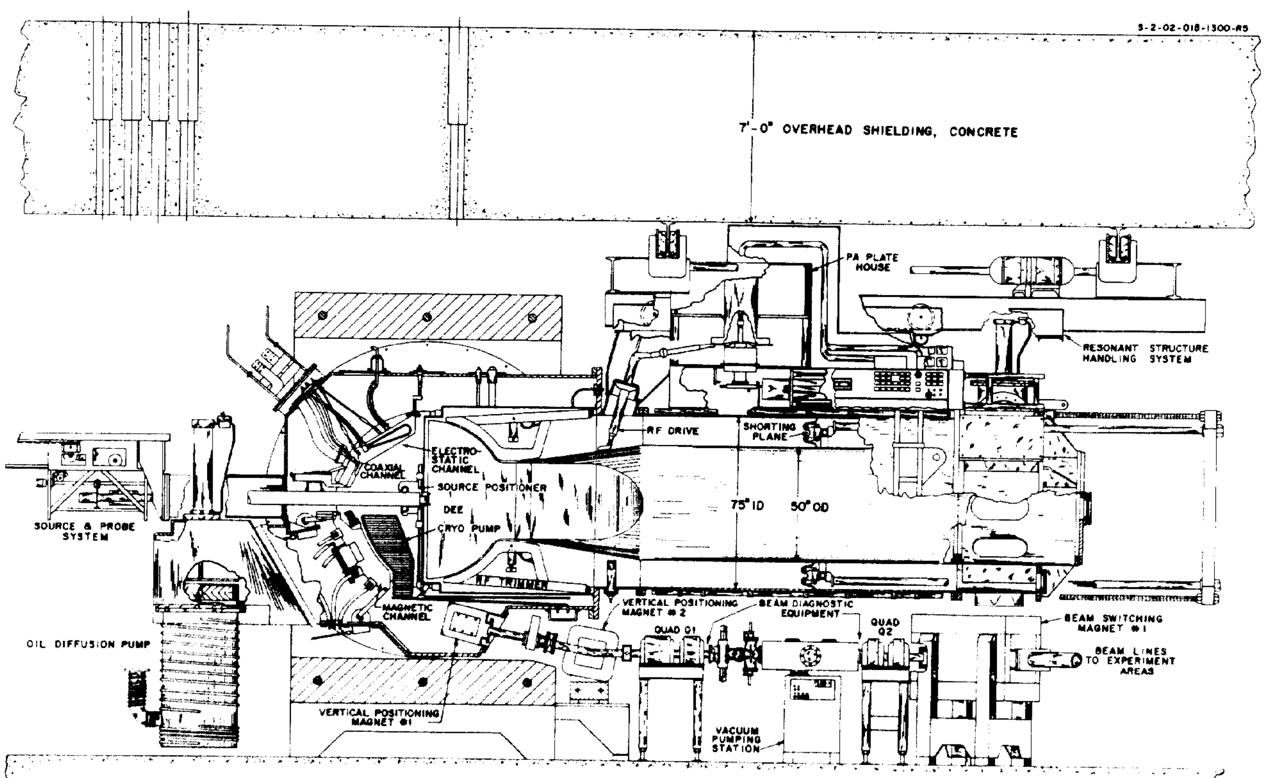
Previously reported measurements of heavy ion beam attenuation with pressure have demonstrated the need for additional pumping in the circulating beam region of the Oak Ridge Isochronous Cyclotron (ORIC).[1] Two specially designed 20°K cryopumps, located on the magnet poles, have increased the pumping speed in the circulating beam region by about a factor of 3. This has led to increased intensity for beams of heavy ions of elements that can be condensed by the cryopumps (e.g., oxygen, nitrogen, etc.). The improved vacuum has led to an increased understanding of a beam loss in the internal region of the cyclotron. Measured cross sections for beam loss and the cross section energy dependence have been determined.

Introduction

More than half of the time on the ORIC is now devoted to heavy ion research. When accelerating these heavy ion beams pressures substantially lower than those for light ion beams are required. The influence of pressure on beam intensity was measured for a few ions. These pressure data show that for a given ion and charge state the intensity improvement depends on the initial pressure. For instance, with Argon 4+ at a pressure of 4×10^{-5} torr a reduction of the pressure by a factor of 2 would yield a beam intensity increase of a factor of 200. If the initial pressure is 1×10^{-5} torr (ORIC normal pressure) a factor of 2 reduction in pressure would produce an intensity increase of about a factor of three.

To reduce the pressure, one has three parameters to work with: reduce the source gas flow rate, reduce the outgassing of the vacuum system, and increase the pumping speed. Increasing the pumping speed was selected for ORIC. The vertical section through the cyclotron, Figure 1, shows the problems with this approach. The dee, electrostatic channel, coaxial channel, and lower magnetic channel effectively block the circulating beam space from the diffusion pumps.

Calculations showed that doubling the pumping speed at the manifold (which would mean adding two more 32" diffusion pumps) would reduce the pressure at the center of the machine by ∿ 10%. For this reason two thin cryopumps located on either side of the magnet gap were designed to get high pumping speed in the circulating beam space.



ORIC, SECTION

FIG. 1. Location of ORIC cryopanels in the magnet gap between the dee and the magnetic channel of the extraction system. Prior to the installation of the cryopump the circulating beam space was pumped only by the oil diffusion pumps through the high impedance of the extraction system.

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ORIC Cryopanels

Figure 2 is a cross section through one cryopump. The 80°K chevron shield is cooled by liquid nitrogen and the 20°K panel is cooled by helium gas. Pumping is limited to one side by a shield adjacent to the circular trim coils. Superinsulation has been used to reduce the heat load to the pumps and reduce the possibility of freezing the water cooled coils. Epoxy fiberglass spacers hold the close clearances between the cooled panels and the shields. The pumps are 1-3/8" thick, leaving a beam acceleration space of 3-1/2". One unassembled cryopump is shown in Figure 3. The total free inlet area through the chevrons is about 5800 square centimeters. The copper chevron shields have been chemically oxidized to produce a flat black surface that reduces the transmission of radiant heat through the baffle to the 20°K surface. The calculated speed of the pumps, without conductance limitations, is ∿ 14,000 liters/sec for nitrogen. Pumping speed measurements with the cryopumps give an additional pumping speed at the center of the cyclotron of about 10,000 liters/sec or an increase of about a factor of three. The pumping speed for other gases is proportional to $1/\sqrt{m}$ except for hydrogen, helium and neon.

The cryopumps require a total of about 2 watts at 20°K and 600 watts at 80°K. With transfer line losses we use ∿ 2 l/hr of liquid helium and ∿ 10 l/hr of liquid nitrogen. The liquid He is supplied from a 100-liter dewar so that about 45 hr is the maximum operating time before having to change dewars. The liquid nitrogen is supplied from a 20,000-liter dewar.

On some runs the liquid helium consumption has been as high as 3 l/hr because of thermal oscillations. The oscillations were eliminated by changing the length to diameter ratio of the transfer line while observing the gas flow meter.

During the past year the pumps have been used for ∿ 25% of the available run time. The longest run during this period has been 144 hrs. Using the cryopumps on a continuous basis would increase the operating cost for liquid helium and nitrogen by about $40,000 per year. A 20°K helium refrigerator is being purchased that will reduce the yearly operating cost to about $6,000.

Operation with Cryopanels

Using extracted beam intensities before and after cool-down of the cryopanels as a measurement of improvement, we have observed gains in beam ranging from 3 to 18. The improvement depends strongly on the pressure before cool-down.

The beam intensity for $^{40}Ar^{4+}$ with and without cryopanels is shown in Figure 4. The beam intensity at 6" with cryopanels is larger by a factor of 1.4 and continues to increase up to the maximum radius where the intensity gain is ∿ 4. Similar data for $^{58}Ni^{6+}$ is shown in Figure 5, where xenon arc support gas is used to maintain an arc.[2] The ratio of beam intensities at extraction radius with and without cryopanels is about 3. A $^{58}Ni^{6+}$ beam was also obtained with krypton, argon, and neon as the arc support gas with the cryopanels on (Figure 6). The difference in the nickel beam intensities for xenon krypton, argon, and neon arc support gases at the inner radius can be explained by the sputtering process used to obtain the nickel beam. The nickel beam loss with radius is much larger with neon as the support gas than with the other gases and this is because the neon is essentially not pumped with the cryopanels.

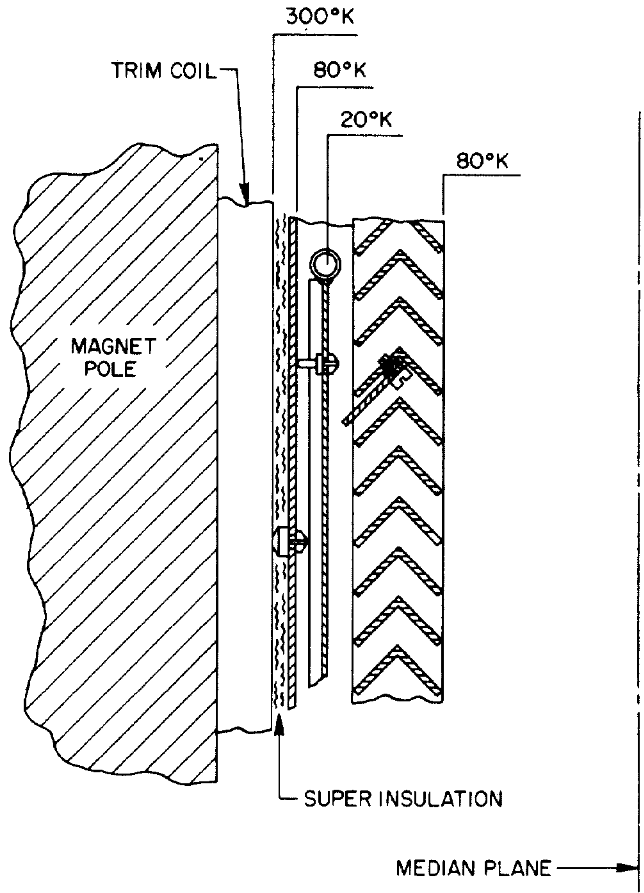

FIG. 2. Cross section of ORIC cryopanel. A mirror-image panel is located on the opposite coil.

The selection of a noncondensable arc support gas should be avoided when possible when cryopanels are being used. The nickel beam results suggest that it may be possible to mix a condensable gas with neon in the arc and obtain a larger neon beam when cryopanels are used.

Beam Loss Cross Sections

The beam attenuation experiments with the cryopanels have given new insight into the pressure dependent beam loss mechanisms for ORIC. Using the known radial dependence of the beam path length and the measured pressure as a function of radius, the cross sections can be calculated and energy excitation cross section functions determined. In a cyclotron, the path length (L) is proportional to the radius cubed.

$$L = \frac{4\pi E_0 q}{VA} \frac{r^3}{3r^2_{max}}$$

where E_0 is the energy constant for the cyclotron, q is the ion charge, r is the current probe radius, r_{max} is the maximum radius of the accelerated beam in the cyclotron, V is the voltage gain per turn, and A is the atomic mass unit. Pressure measurements on ORIC have been made at the center of the cyclotron for different gases. The pressure versus radius has not

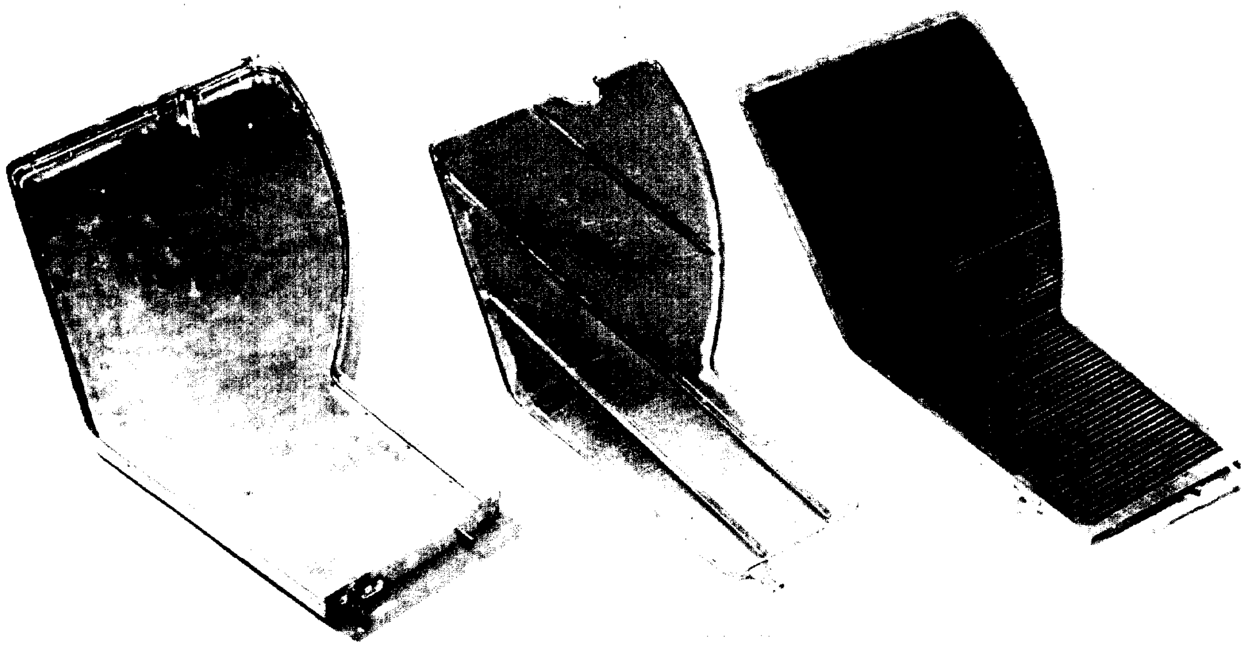

FIG. 3. Cryopanel before assembly. The 20°K panel (center) is sandwiched between the two 80°K shields. The chevron baffle (right) minimizes the radiant heat reaching the 20°K panel while allowing the entry of gas molecules from the circulating beam region.

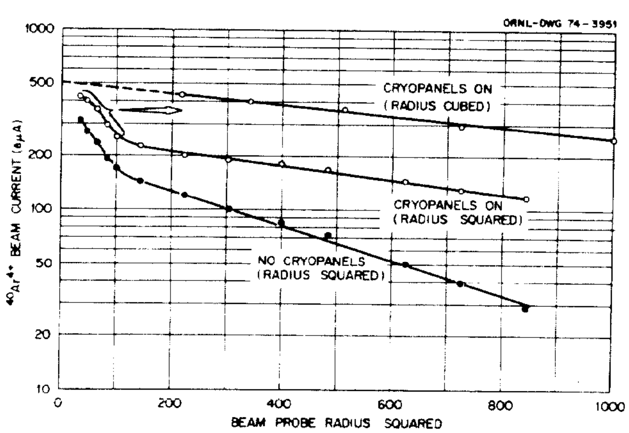

FIG. 4. The logarithm of the beam intensity versus the radius squared (in^2) is shown. The beam intensity for the first 10 inches is also plotted vs the radius cubed (in^3). The attenuation was measured with and without the ORIC cryopanels and shows a factor of 4 increase in beam intensity for the better vacuum.

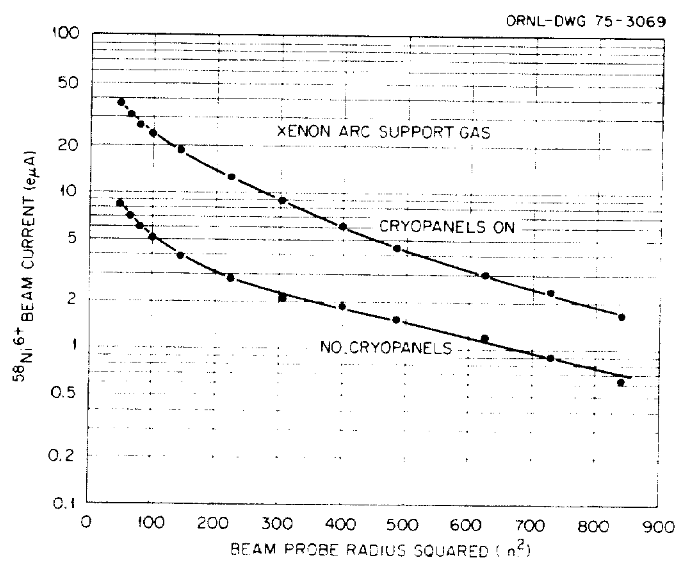

FIG. 5. The logarithm of the beam intensity of a nickel beam with and without the cryopanels is shown. The nickel beam was obtained by rebombardment of the arc chamber (made of nickel) by the xenon ions.

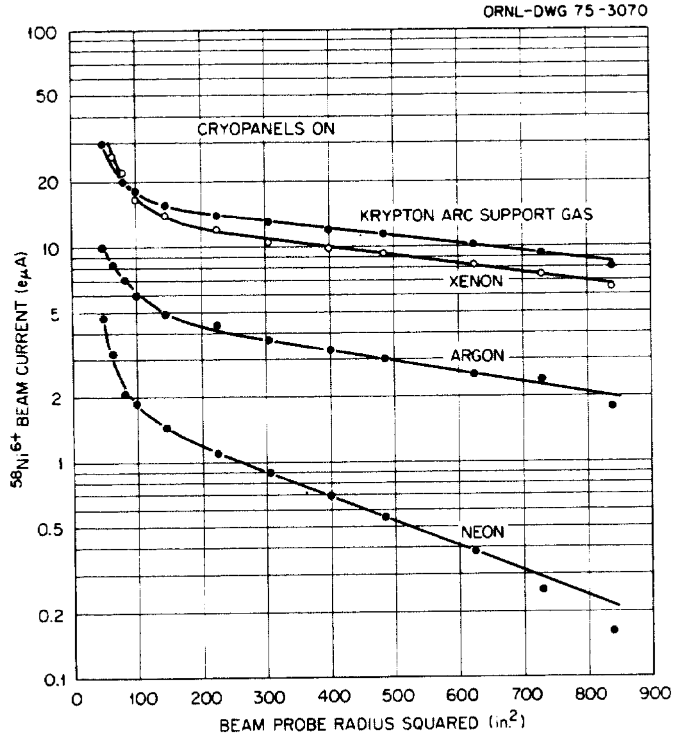

FIG. 6. The logarithm of the beam intensity of a $^{58}Ni^{6+}$ ion as a function of radius squared (in^2) with different ion source support gases and with the cryopanels on is shown. The slope of the neon curve is different from all other gases and indicates that neon is not pumped as efficiently by the cryopanels. The relative beam intensity of nickel as a function of arc support gas is explained by the phase acceptances of the rebombardment beam.

beam measured, but for our calculations we assumed it to be constant. This assumption is reasonable since the acceleration chamber pressure is conductance limited by the magnet gap and the extraction system. In Figure 4 we have plotted the logarithm of the beam intensity for $^{40}Ar^{4+}$ as a function of the radius squared and as a function of the radius cubed out to 10 inches. From $\sim$ 0 to 10 inches (100 keV/u) the logarithm of the beam intensity is decreasing approximately as the radius cubed. This implies that the cross section is constant for this region and equal to 8.0×10^{-15} cm^2. This should be compared with a pickup cross section measurement[4] made for $^{40}Ar^{4+}$ at $\sim$ 1 keV/u where it was measured to be 5.8×10^{-15} cm^2.

Beyond 10 inches the logarithm of the beam intensity varies approximately as the radius squared. This implies that the cross section is velocity dependent. Near the maximum radius of ORIC, the curve is starting to change from the radius squared dependence.

We conclude that the charge changing cross section values which are important in developing the design requirements for vacuum systems for heavy ion accelerators can now be obtained from heavy-ion cyclotron beam attenuation measurements.

References

[1]E. D. Hudson, et al., AIP Conference Proceedings, No. 9, Cyclotrons-1972, 274, American Institute of Physics (1972).

[2]E. D. Hudson, et al., Nucl. Instr. and Methods 115, 311 (1974).

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Acknowledgements

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