VACUUM PROBLEMS RELATED TO COLLIDING BEAM EXPERIMENTS
WITH THE CERN INTERSECTING STORAGE RINGS

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(Presented by E. Fischer)

INTRODUCTION

The vacuum system of the ISR is designed for a residual gas atmosphere of nitrogen or carbon monoxide at an average pressure of 10^{-9} torr along the whole length of the vacuum chamber. At this pressure beam losses and beam blow-up due to multiple scattering are so small that colliding beam experiments can run over 12 hours without refilling the rings. However, the pressure of 10^{-9} torr is not sufficiently low in the interaction regions. Here the protons which have been scattered on residual gas atoms or reaction products of such events will disturb the registration of the events one is looking for by causing background tracks or accidental coincidences.

For stacked beams of 20 A in each ring one expects 1.6×10^5 interactions per second per interaction region (1). This figure has to be compared with the rate of nuclear scatterings on the residual gas over a beam length of about 10 metres (2). It turns out that at a pressure of only 5×10^{-11} torr these two figures are just equal. It will, of course, be possible in many experiments to discriminate background particles by means of coincidence arrangements — the interaction region is a point source in comparison to the line source of the background particles — but there can be little doubt that the experiments will become difficult, if the rate of background events exceeds the rate of p-p interactions.

The situation becomes more difficult for certain experiments for which the momentum spread of 2% of a 20 A stack is too large. Reducing the energy spread by a factor of ten, which can be done only by reducing both currents by the same factor, reduces the interaction rate by a factor of 100, but the background events by only a factor of 10. It might, therefore, even become desirable to improve the vacuum for some experiments down to 10^{-11} or 10^{-12} torr.

PUMPING OF THE INTERACTION REGION

A working pressure of 10^{-11} torr requires pumps with a base pressure of about 10^{-12} torr. The only feasible solution seems to be liquid helium cooled cryopumps, especially since much of the gas to be pumped may be hydrogen and the required pumping speeds are in the order of several thousand litres per second.

Fig. 1 shows a possible layout of four cryopumps surrounding an interaction region. They are in the example pushed as far away from X, the intersection point, as the magnets allow, hence about 6 m on the outer arcs and about 9 m on the inner arcs. The idea is to keep the immediate surroundings of the X point free for detection apparatus. (The best cryopumping system is useless of it makes good experiments impossible).

The cryopumps must be designed in such a way that they limit the flow from the high pressure (10^{-9} torr) regions to a reasonable value without impeding the circulation of the stored proton beam. The efficiency in this respect depends on the length of a pump, its geometry and the sticking probability for molecules on the pumping surfaces. Computer work is in progress to determine the minimum length of a cryopump under different conditions and requirements. A rough estimate indicates that 500 mm will be sufficient.

Suppose the four cryopumps are « ideal » and isolate the interaction region perfectly, then there will be, of course, a pressure « bump » in the interaction region due to the outgassing from the chamber walls. The points with the pressure

peak will be in the two inner arc branches of the X region. For reason of symmetry it is sufficient to consider a single tube with two cryopumps 15 m apart. The pressure difference between a pump and the maximum pressure, the « bump », for a given length is proportional to the specific gas desorption and inversely proportional to the unit conductance of the tube.

It will be useful to consider several different but feasible vacuum chamber sections. The smaller the cross-section, within the limits imposed by the beam dimensions, the better the conditions will be for reconstructing nuclear events. There is, in this respect, a double gain from a smaller cross-section: firstly it allows putting detectors closer to the interaction region and secondly a smaller chamber permits a smaller wall thickness and the scattering of secondary particles in the chamber wall becomes less troublesome.

Unfortunately, a tube of small section has a low gas conductance and the resulting pressure bump will be greater in spite of the smaller outgassing surface. Clearly a compromise must be
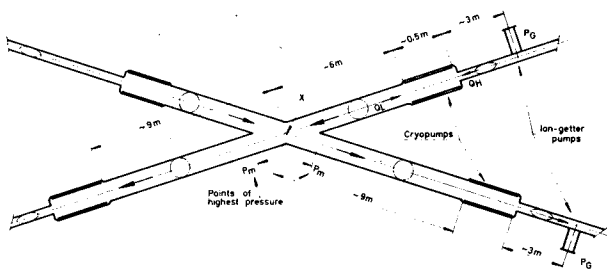

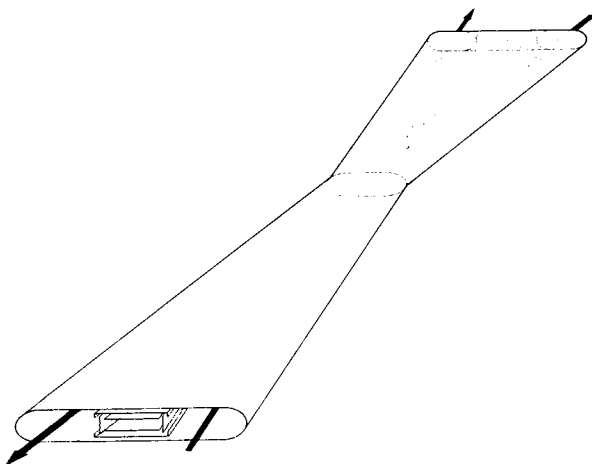Fig. 1 - Possible layout of cryopumps surrounding interaction region.

Fig. 2 - Possible arrangement of cryopumps in interaction region.

chosen. The elliptic section 160 mm × 52 mm common to the magnet chambers of the ISR is considered because it « fits » the beam fairly closely. It suffers, however, from a relatively poor conductance. As examples of sections with better conductance, circular tubes of 160 and 200 mm diameter are considered. Estimates on circular tubes of 50 and 100 mm diameter also are presented for the case that such tubes should become possible by closed orbit compression (Terwilliger scheme).

A very crucial factor is the gas desorption rate from the chamber walls. For comparison we have therefore calculated the maximum permissible desorption rate for a maximum pressure bump of 10^{-11} torr of CO or N_2 or of 10^{-10} torr of H_2. The nuclear scattering cross-section for hydrogen is about one tenth of that for nitrogen. Hence a ten times higher hydrogen pressure can be accepted.

Table I shows the results. The figures are given in torr litres per second per square centimetre (Tl/s cm^2). The distance between the cryopumps is for all examples the same, namely 15 m.

A desorption rate of 10^{-12} Tl/s cm^2 is easily obtained by means of conventional UHV techniques. With extreme, but still conventional care, 10^{-13} Tl/s cm^2 is possible (3). We hope — in fact we are doing research in this direction — to gain another order of magnitude by new techniques like vacuum firing at about 700°C of all components before assembly or special surface treatment. However a gas desorption below 10^{-14} Tl/s cm^2 may be possible only by cooling the chamber wall with liquid nitrogen.

We draw the conclusion from Table I: for circular tubes of 200 and 160 mm diameter careful conventional tecnique is sufficient. In the case of the 160 mm tube, for instance, a desorption rate of 10^{-13} Tl/s cm^2 with 30% CO and 70% H_2 which is a spectrum met in reality would give a pressure bump of 10^{-11} torr above the working pressure of the cryopumps which might also be in the order of 10^{-11} torr. For the case of the 100 mm circular or the elliptic chamber the same pressure can only be obtained by new and special techniques. Using a 50 mm tube one has either to accept a higher pressure or the tube must be cooled by liquid nitrogen. This is attractive and easy from the point of view of the vacuum engineer, but necessarily introduces additional obstancles between the interactions and the detectors.

There are still other ways of compromising. One could, for instance, if the experimental

set-up allows so, diminish the distance between the cryopumps. The pressure pump depends quadratically on this distances. It is, furthermore thinkeable to install liquid helium cooled panels close to the interaction region as shown in Fig. 2. The helium panels are shielded against thermal radiation by means of liquid nitrogen cooled panels. Such an arrangement would make a pressure in the 10^{-12} torr range for the interaction region possible without extremly low gas desorption rates. An uncorrugated chamber wall would require at least 1.5 mm thickness. With a corrugated chamber wall one could perhaps go down to 0.5 mm. The engineering difficulties of a design like in Fig. 2 are by no means small and perhaps unsolvable. This emphasizes the importance of studies of new methods of reducing the gas desorption.

Normally a getter ion pump will be operating at a distance of 3 m from each cryopump. If we assume that it has a working pressure of 2×10^{-10} torr and that the gas desorption from the chamber walls is 10^{-12} Tl/s cm², the cryopump must handle a gas influx of 10^{-8} Tl/s of CO or 3×10^{-8} Tl/s of H_2. Hence, the required pumping speed for 10^{-11} torr is 10^3 l/s for CO and 3×10^3 l/s for H_2. These requirements are easily met.

It will be necessary for some experiments to reduce the gas pressure upstream beyond the

normal cryopumps, in order to reduce the background around X from low angle gas scattering. This could be achieved by introducing into the next or perhaps the next two magnet chambers a « distributed » cryopump as shown in Fig. 3. The dotted lines indicate the normal chamber cross-section. Equally, of course it would be possible to insert additional cryopump similar to those of Fig. 1 between the magnet units further upstream.

CRYOPUMP CHARACTERISTICS

Experiments in progress at CERN have shown that the sticking coefficients for both nitrogen and hydrogen on metal surface at 4.2°K are close to unity. Typically that for hydrogen is initially about 0.7 on a clean cryosurface and rises above 0.9 as more hydrogen is deposited while that for nitrogen is always < 0.9. This means that values close to the maximum theoretical speed of a given pump are readily achieved. The cryosurface at 4.2°K will condense all gases in unlimited quantities except helium and hydrogen. When pumping hydrogen for example, initial base pressures approaching 1×10^{-12} torr are observed (this may well be the base pressure of the system and pump rather than the ultimate pressure of the pump). This base pressure is observed to rise continously as more hydrogen is condensed and, presumably, finally would reach the saturated vapour pressure of bulk hydrogen, i.e. about 10^{-7} torr at 4.2°K. The characteristics for the cryopumping of hydrogen at 2.5°K are still somewhat obscure except that they are, for all practical purposes, the same as those for 4.2°K in the initial stages of low condensate concentration. The base pressure observed were approximately linear with condensate concentration up to several monolayers and were, for 4.2°K or 2.5°K, about 3×10^{-11} torr (N_2 equiv.) at 10^{14} molecules/cm² and 1×10^{-9} torr at 10^{16} molecules/cm². This suggests that for UHV work in the 10^{-11} torr range it is necessary, when hydrogen is present, to use a cryopump at 4.2°K or lower with surface
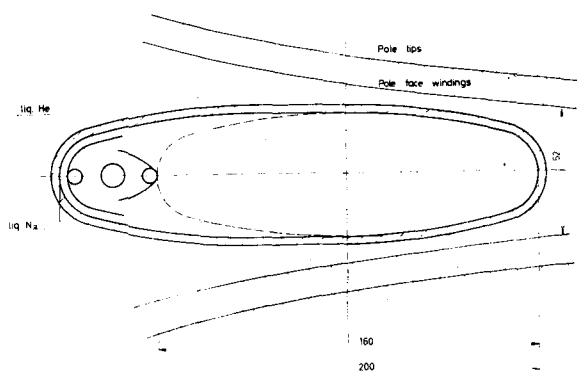

Fig. 3 - Magnet chamber with distributed cryopump.
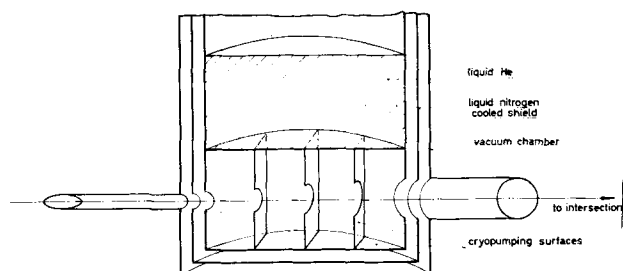
Fig. 4 - Tentative design of tubular cryopump.

TABLE I

Permissible desorption rate for a pressure bump of 10^{-11} torr of CO (N_2) or 10^{-10} torr of. H_2.

Tube	CO	H_2
∅ 50 mm	3.3×10^{-15} Tl/s cm²	1.3×10^{-13}
160 × 52	6.3×10^{-15}	2.3×10^{-13}
∅ 100	1.4×10^{-14}	6.7×10^{-13}
∅ 160	3.4×10^{-14}	1.3×10^{-12}
∅ 200	5.5×10^{-14}	2.1×10^{-13}

coverage of less than 10^{14} hydrogen molecules per cm^2.

Fig. 4 shows a proposed design of a tubular cryopump as could be used in the scheme of Fig. 1. The stored proton beam passes diametrically through a liquid helium cooled cylinder which is integral with the liquid helium reservoir. It is surrounded by a liquid nitrogen cooled radiation shield and finally by the ISR vacuum chamber. A convenient size for this pump would be about 500 mm diameter for the helium reservoir and pumping chamber, giving an overall diameter about 550 mm. The overall height could, if required, be kept less than 1 m. This pump would have an internal pumping surface area

of about 10^4 cm^2. This area could be increased considerably by inserting extra panels, as shown, and by using surfaces machined to a fine saw-tooth profile. The total flow under the most adverse conditions is about 7×10^{-8} Tl/s. This gives a lifetime for the pump in excess of 100 hours before a condensate density of 10^{14} molecules/cm^2 is reached. Such a pump could have a 50 litre helium reservoir with a consumption of about 1 litre per hour. The consumption of liquid helium would depend to a large extend on the details of the nitrogen cooled shield and could be reduced considerably by extending the latter a small dictance along the ISR vacuum chambers.

REFERENCES

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(2) B. de Raad: CERN Report AR/Int. SG/62-12 (1962).
(3) E. Fischer et al.: Proc. of the 2nd European Symposium Vacuum, Frankfurt, 1963.

DISCUSSION

AMMAN: With the present design of the machine, which is the range of angles where the interaction products (typically 15 GeV/c) can be detected?

DE RAAD: The angles in the circulating beam are at most ± 0.5 mrad. Therefore one should be able to observe scattered protons at all angles larger than about 1 mrad. For scattering angles below a few mrad one can only observe the particles which are scattered vertically, due to the width of the stacked beam.

O'NEILL: I don't agree entirely with your last remark. One can even go down to 0 mrad by using the magnetic deflection in magnets downstream of the point of interaction for off-momentum particles.

GARWIN: Does your computer program take into account the polar distribution, peaked along the forward direction, for molecular streaming out of the pipes?

FISCHER, E.: Yes, the polar distribution of the gas flow is taken into account.

GARWIN: What sticking coefficients are taken for the gases CO, N_2, CO_2, at a temperature of 300°K?

FISCHER E.: I do not know what the sticking coefficient of CO, N_2 etc. at 300°K surfaces is. But I cannot see how this figure could influence the design of the cryosystem.

GARVIN: What effect will the presence of condensed gases have on the sticking coefficient of H_2 at low fractional coverages (I believe that operation of about 2.4°K would be a good idea)?

FISCHER, E.: We have also worked with helium at 2.5°K. However, it turned out that both sticking coefficient and base pressure are not different of those at 4.2°K; at least up to a coverage of 1/10 of a monolayer. Hence, we find no advantage in going down to 2.5°K.

The conditions under which we measured the sticking coefficient of hydrogen were such that there were always other gases present too on the cryosurface. We believe, therefore, that the measurements simulated approximately the conditions as they will exist in the ISR.

The sticking coefficient of nitrogen on a 4.2°K surface has been measured and found to be 0.5 to 0.7. This is sufficient since the expected gas load of nitrogen or carbon monoxide is much smaller than that of hydrogen.

GARWIN: Has Ti evaporated on nitrogen cooled surfaces been investigated as an alternative to the helium cryopumps?

FISCHER, E.: Titanium films at liquid nitrogen temperature have been tried. We never reached, however, whit such a pump a base pressure below 10^{-11} torr.