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ACCELERATOR DEPARTMENT
Informal Report

VACUUM SYSTEM PARAMETERS FOR ISABELLE

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N O T I C E

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INTERSECTING STORAGE ACCELERATOR NOTES

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Out of the experience gained at the CERN ISR three factors stand out as must requirements for the vacuum system for ISABELLE.

1) The operating pressure should be very low, 10^{-10} Torr N_2 pressure or even lower if possible. This is to reduce Coulomb and Nuclear scattering of residual gas resulting in beam blow-up, beam life decay, beam neutralization and ion bombardment.

2) The vacuum chamber walls should be "clean", free of gas contamination which can be desorbed by ion bombardment, free electrons and protons, resulting in catastrophic pressure rise. The ISR has experienced catastrophic pressure rises (to 10^{-5} Torr) with beams of 6.5A. They estimate that in their case the beam pipe I.D. is covered by 1% of a molecular layer of gas ($\sim 10^{12}$ molecules/cm²) after baking the chamber in place at 200°C. This problem is being taken care of by raising the baking temperature to 300°C, so far it seems to be successful, although there is no guarantee that it will not recur at higher beam currents.

3) The vacuum chambers material should be degassed as well as possible to eliminate as much as possible any gas in solution in the material. Hydrogen accounts for most of it. A contribution to the chamber walls contamination is due to diffusion of gas (H_2) from within the material. At the CERN ISR, after 6 months of operation hydrogen accounts for 90% of residual gases in the beam pipe. The high concentration can be explained by gradual dilution of the other gases with time with H_2 being the principal source of gas load due to outgassing.

It is of interest to note that while the residual gas composition in the ISR is: 90% H_2 , 5% H_2O , 5% Co and N_2 this composition is different when they experience pressure rises due to beam interaction (ion bombardment) and is typically:

40% H_2 , 40% Co, 10% H_2O , 10% hydrocarbons.

Vacuum System Parameters

ISABELLE, as affecting the vacuum system, is different from the CERN ISR in so much that the accelerator will be superconducting so that each 2000 m ring will have at least 1400 m of beam pipe at helium temperature ($\sim 4^{\circ}\text{K}$). I assume for now that the straight sections are at room temperature. Now, the vacuum requirements dictated by the circulating beam behavior, namely the requirement for clean walls, make the cryogenic aspect of the machine undesirable from the vacuum point of view.

Based upon all the requirements discussed at various times and upon experience gained at the CERN ISR, a vacuum system can be built with the following parameters:

1) An average operating pressure of 10^{-10} Torr can be guaranteed around the rings with 10^{-11} Torr in the intersecting regions. It is possible that lower pressures can be obtained. However, these would not be due to different technology but would rather be the result of workmanship, care taken during leak checking, cleanliness at assembly and other tender loving care which, when the time comes, will require fanatical effort to implement.

2) An operating outgassing rate of 10^{-13} Tls/cm² can be achieved at room temperature. This would be reduced to about 10^{-14} Tls/cm² at 4°K . This outgassing rate can be achieved with a stainless steel vacuum chamber by first degassing the material in a vacuum furnace at high temperature ($>1000^{\circ}\text{C}$) or vacuum melting the material, than by subsequent baking after fabrication with a final bake at about 300°C after assembly.

Traditionally, stainless steels or Inconel have been used for synchrotron vacuum chambers. It is possible that in this case another material may be better both from the vacuum and the electromagnetic point of view.

3) Clean walls in the beam pipe with less than 1% of a molecular layer of gas as required from the ISR experience can be achieved by proper chemical cleaning at assembly and subsequent baking at about 300°C in situ.

This requirement in the case of the superconducting ISABELLE will be costly and make the design difficult as materials will need to withstand temperature swings of about 600° . Choices will have to be made to sacrifice magnet aperture for the addition of thermal insulation or heating the whole magnets to 300°C .

It is clear that to obtain the desired low level of wall contamination baking is required for a long period (~24 hrs), cool down will take a long time and the introduction of LN₂ in the dewars should not start until a good vacuum has been achieved (~10⁻³ Torr). The baking of the chambers can be accomplished by different methods: resistance elements wrapped around the chamber, using the chamber itself at the resistor, circulating superheated steam in the dewar, there may be others.

An additional problem that we have to confront is that assuming we start off with a "clean" system, it is likely to become contaminated after cool down to 4°K because of intrinsic pumping speeds of the cold walls, the source of gas coming from leaks, migration from room temperature regions, etc...

This requirement of the vacuum system is clearly a major problem which requires much thought.

4) Leaks in the system will have to be kept to a minimum. Present day leak-checking equipment can detect leak as small as 10⁻¹² std cc/sec. Claims are made for even higher sensitivity by manufacturers of equipment but should be distrusted in practice. The leak detection can be improved with higher temperatures, 10 X at 300°C, 100 X at 600°C, by the same token the remaining leaks will decrease 10 X at 4°K. All these numbers are valid using room temperature as starting point. Additional sensitivity can also be achieved by pressurizing the helium gas. Leaks through material and fabrication defects vary as

$$P (T/M)^{\frac{1}{2}}$$

where P = pressure differential

T = temperature

M = molecular mass of the gas

Use will be made of these various factors to achieve leak rates no greater than 10⁻¹⁴ std cc/sec/m

5) The pumping speeds required at these very low pressures are difficult to estimate due to the difficulty to define the pumping process as well as the origins of the gas load and its nature.

The pumping speed of any ultra-high vacuum pump is dependent on the sticking probability of a molecule impinging on the pumping surface, this coefficient is affected by many variables.

Similarly the gas load is the product of various sources such as:

Q_v = residual gas in the volume

Q_o = gas released through outgassing

Q_L = gas due to leaks

Neglecting problems of conductances, geometries, etc....the ultimate pressure in the system will be without the beam

$$P_u = \frac{Q_v + Q_o + Q_L}{S} = \frac{Q}{S}$$

where S is the effective pumping speed

With a beam circulating in the ring, P_u will be modified to P_I (operating) where

$$P_I = \frac{Q + Q_I}{S}$$

where Q_I = gas released by ion bombardment of the walls. Q_I is affected by the beam current. From R. Chasman CRISP Report 71-25

$$Q_I = \frac{K P_I I}{S}$$

where K = number of molecules released by incident ions

I = beam current

P_I = pressure with beam circulating

then

$$P_I = P_u + \frac{K I}{S} P_I$$

$$P_I = \frac{P_u}{1 - \frac{KI}{S}}$$

From the above one sees that P_I increases exponentially with increased I so that for a given K the pressure will get out of hand at a current I one might call critical. One can see that the critical current can be raised if the pumping speed S is made large. The argument also holds if K is made large by contamination, the critical current will decrease with given S .

It is then evident from the above considerations that the pumping speed chosen for the job should be very conservative because of the many variables involved.

6) The type of pumps proposed at this time for ISABELLE would consist of a combination of sputter ion pumps and sublimation pumps.

Development at Karlsruhe immersing ion pumps in LN_2 and LH_2 shows these pumps to be effective at low temperature. Similar development using titanium sublimation on LN_2 cooled surfaces by a fusion reactor group at Euratom also looks promising.

One of the problems we will have to contend with are heat leaks, and because of the desire to have long dewars while having low beam pipe conductance we will have to consider having the vacuum pumps possible immersed in the dewar.

It is clear from the above that the choice of vacuum pumps and sizes will be affected by the cryogenic aspect of the system.

7) The vacuum chamber and associated hardware will be welded construction as much as possible with as few valves, flanges, gaskets, etc. as practical. Special attention will be given to possible heat leaks, sources of vacuum leaks and contamination.

The vacuum chamber material still has to be chosen based on vacuum and electro-magnetic consideration taking into account beam interaction and superconducting eddy current effects.

A number of sectionalizing valves will be needed. This number should be minimized as they are expensive and unreliable, however, if any parts of the vacuum system has to come to atmosphere for any reason, it will need baking, hence the need for a complete cool down recycle to $4.\text{K}^0$. This aspect would warrant the need for many sectionalizing valves in the system. This subject needs discussion to arrive at a reasonable parameter.

8) The measurement of pressure at ultra-high vacuum has always been a problem. For ISABELLE we will propose the use of modulated B-A gauges controlled and monitored by the central computer system.

Gauges for these low pressures are inherently unreliable as they drift, their X-ray limits vary, etc...At the CERN ISR this problem is being partially solved by having the computer continually check on the gauge parameters and then make the necessary correction on the pressure readings taken. This system although not yet fully operational seems viable at this time.

As an aside CERN has found very close correlation between vacuum pressure measurements and radiation due to nuclear scattering at given beam current.

Conclusions

It is clear that before an engineering proposal can be worked out many questions have to be answered and many decisions made to establish the basic parameters required for the preparation of a conceptual design. This note is written to stimulate discussions on the subject and to help to generate real and reasonable parameters for ISABELLE.

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