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VACUUM REQUIREMENTS FOR LINACS

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The evacuated chamber is an intrinsic part of any accelerator and great progress has been made toward providing a reliable hard vacuum in present day machines. Linacs differ somewhat from cyclotrons in the parameters which set the vacuum requirements. The primary one is to improve the electrical breakdown condition, as linacs are usually designed for the highest field gradients that the structure will allow. It is well known that at an absolute pressure of 10^{-4} Torr, electrical breakdown occurs at very low gradients. The situation improves very rapidly as the pressure is decreased to 10^{-5} Torr, and the curve then flattens out as the pressure goes down further. For that reason, all accelerators operate at a lower pressure than this critical point and linacs at lower pressures still because of the high field gradients and small gaps.

Another parameter to be considered is the beam scattering due to residual gases in the accelerator acting as target. Here the linac has the advantage of having a very short beam path when compared with a circular machine. However, as we are specifically considering a linac for large beam currents and as scattering occurs as a product of the residual gas density in the tank and the proton beam intensity, we have to consider the problem. The air density varies linearly with pressure and temperature.

The beam loss from gas scattering results in a higher radiation background around the machine and so has to be minimized. The meson factory has the following parameters:

beam current: 1 mA average = 6×10^{15} protons/sec;

accelerator length: 660 m;

operating pressure: 10^{-6} Torr.

S. Ohnuma has estimated the beam loss to be about 10^{10} particles/sec. This number is not negligible and 10^{-6} Torr used here does not seem to be too conservative.

For the vacuum system designer, this specified pressure of 10^{-6} Torr is reasonable. It is a pressure that can be attained with off-the-shelf equipment without going to the expensive and involved techniques required for lower pressures: baking, high temperature seals, etc.

The important factors to be considered by the designer are as follows:

(1) Reliability: Because of the very high cost of non-scheduled down-time on accelerators caused by vital component failures, this is the most important criterion that should be considered in the design of a vacuum system for a long linac. The system's reliability is a direct function of the total number of components where, say,

$$R = \left(\sum_{i}^{n} r^2\right)^{1/2}$$

where r is the reliability factor for each of the n components and R is the total reliability factor. Because of the large number of components used, a high total system reliability becomes difficult to achieve and it is safe to say that although we would like to minimize the initial capital investment, it is almost inevitable that the reliability requirements will be the deciding factor when specifying pumps and components. A proper evaluation program should be set up before writing the procurement specifications for this purpose.

(2) Operation and maintenance: It is clear that any system requires attention during operation and that maintenance is an important factor in any accelerator installation. These two should be minimized here by providing the necessary controls and monitoring to prevent major failures. Also the system should be designed so that any failure of the vacuum system will not be catastrophic, that is, require a major overhaul after such failure. These facts must be kept in mind and the engineer should strive to accomplish these goals by designing the system as simply as possible, eliminating complex mechanical or electronic assemblies.

(3) Initial capital investment: This cost factor has to be weighed after all other considerations. However, it is important when one thinks of building a large linac. In our case the vacuum cost appears to be 2 to 3% of the total cost of a meson factory, or 4 to 5% of the cost of the accelerator itself. A hard fact approach will be needed during the evaluation program of components to get the most reliable ones at the lowest cost.

Today, there are two basically different pumping systems commercially available for accelerator evacuation, diffusion pumps and ion pumps. I will present here our thinking on these systems.

Diffusion pumps: The use of diffusion pumps (oil and Hg) on accelerators has been partially successful in most cases and they have some advantages over ion pumps.

(1) Their pumping speed is not affected by the nature of gases except for water vapor.

(2) Their pumping range is wide (10^{-3} to 10^{-7} Torr), eliminating the need for fancy roughing systems.

(3) They are not affected by varying gas loads and will generally take more abuse under varying conditions which is important during start-up operation.

However, these pumps have also some notable drawbacks. The oil diffusion pumps depend on traps and baffles for a clean vacuum and these are not too reliable, so that chances of oil backstreaming are present. This danger can be minimized somewhat by using mercury pumps. However, the necessary trapping temperature of $-150^{\circ}C$ (which has to be produced by refrigeration if one considers economy for continuous operation) is very unreliable because of breakdown of low temperature equipment. This can lead to contamination of the accelerating structure which can be very detrimental. First, the x ray background goes up markedly and secondly, electrical breakdown starts to occur. We can say that oil backstreaming has worse effects on linacs than on circular machines because of the high electrical gradients involved.

Ion pumps then seem to be devices which alleviate these problems, but these are not without their drawbacks also.

(1) Their starting pressure is low (10^{-4} Torr min) and even then they may overheat. This puts a high demand on the roughing system.

(2) Their initial cost is high compared to diffusion pumps, but part of the difference can be discounted when one looks at the accessories needed with diffusion pumps, and the difference in labor at installation and during operation.

(3) Ion pumps have difficulties in operating under certain conditions; e.g., rare gases, gas bursts, etc.

Against these drawbacks these pumps offer impressive advantages; e.g., clean vacuum with no contamination even in case of failure, long operating pump life with little or no maintenance, ease of installation and operation, and reliability.

These advantages make us think quite favorably of using ion pumps. They are attractive despite their higher cost and the difficulties in providing a roughing system good enough for the purpose. To rough out the structure to a minimum of 10^{-4} Torr, we plan to use Roots Blowers and have liquid nitrogen traps in the line to improve their blank-off points.

Another component worth mentioning here is the evapor-ion pump (the above discussion considered cold cathode ion pumps). These evapor-ion pumps are in use at BNL. Although they proved to be quite unreliable in their present design, they still look interesting because of their lower cost. Work is being conducted at BNL by Charles Gould to provide improvement in their reliability and life.

The cost of pumping systems was mentioned and here is a rough comparison of component cost for a 2000 ℓ/sec system. It does not include installation, operation and maintenance.

Diffusion pump	$ 8,000
Ion pump	16,000
Evapor-ion pump	13,000

FEATHERSTONE: Is the evapor-ion pump cheaper even with the elaborate Brookhaven control on it?

BLEWETT: These have been simplified. We've eliminated moving parts, and so the controls you need are simplified too.

FEATHERSTONE: Are you talking about the one that has the hot rods sticking up the middle?

GRAND: Yes, work is being done at Brookhaven as well as at CVC. They are developing this sublimation process which should make them more reliable. We'll watch these two developments and see what they are worth.

LIVDAHL: Is this the hardware cost?

GRAND: Yes, that's hardware cost only.

BLEWETT: Things might be changed a little by the use of thermo-electric baffles which the Russians are using and which appear to be simple and reliable, and with no refrigerating liquid involved.

POLK: There's no indication that they'll go down to -150°C, in fact, I don't even believe that they've gone down to -50°C in operation over a diffusion pump. The information that we received while we were in the Soviet Union was that no one had measured the baffle temperature sitting on top of a hot diffusion pump at 200-230°C.

WORSTELL: If you put in about 2 years of operating costs, I think you'll find that the ion pump will be a lot cheaper than the diffusion pump.

GRAND: These costs were only for hardware. I didn't attempt to show anything else.

LIVDAHL: Yes, but it is misleading because you've neglected these other very important features of cost, and that's why I asked about hardware. At Argonne, we have one 2400 ℓ/sec mercury diffusion pump on our system which has a baffling system and the works, including the electrical connections to the heaters, the motor starters, the interlocking circuits, indicating lights in the interlocked chain of relays, and the total cost on this one 24 in. Edwards diffusion pump system including installation and labor is higher by about 30% than the unit cost of the nine 2400 ℓ/sec ion pumps that we have. The basic thing you overlooked here is labor cost, and a few incidentals. The labor cost for putting in the ion pumps, all the control units, and the cabling was two men for one day. This totals about $100 for nine units, so this is about $10 of installation cost per unit.

WORSTELL: Also there is no forepump system in this cost.

LIVDAHL: No, but you've got to have a roughing system in either case. What I am trying to say is that these costs should be the other way around. The cost for a mercury diffusion pump system goes up to something like $15,000, and the ion pump cost comes down to something like $13,000 when you're all done. This $13,000 would be without a valve.

WORSTELL: You wouldn't use a valve?

LIVDAHL: No, I would not. These valves are more trouble than they're worth.

GOULD: This is an appropriate place to make some remarks about the evapor-ion pump. As it is presently constituted, with its wire feed, it is an obsolete device. For the ability to deliver a chemi-sorptive layer, sublimation or evaporation from a massive chunk of titanium is probably the answer in the future, rather than the sputter-ion pumps or the addition to the sputter-ion pumps. This is something we at Brookhaven would like to work on in the next year or so.

GRAND: Do you know about the sublimation addition to the vac-ion pumps?

GOULD: No, except that I think that they are worthless for long period use. The so-called sublimation addition to the vac-ion pump is nothing but the starting primers from the evapor-ion pump slightly improved, and I don't think this is the approach which you should follow. We've replaced the entire feed devices conventional in the evapor-ion pump with three chunks of titanium, 3/4 in. in diameter, mounted on tantalum rods, each fed by its own tungsten filament, with the grid and pump casing as before. Again, it's electron bombardment heating and this is with about 2000 V dc above the filament. We fire the first filament at the top, and this erodes the titanium chunk gradually, until it has almost disappeared and then we go on to the next filament and so forth. We've obtained pumping speeds of 1250 ℓ/sec for air in a standard evapor-ion pump barrel. We find that our ultimate vacuum is greatly improved when we go on to the next chunk of titanium because the next two have had a change to outgas during the pumping of this first one and we have reached pressures of 8 to 9 x 10^{-10} Torr blanked off on the second and third chunks. Recently we've decided to try, instead of electron bombardment, induction heating with an rf loop and see if that doesn't improve our performance on stability, lifetime and so forth. Irv Polk has just suggested that we try conduction heating of these "sausages". I don't know what problems we'll run into on conductively heating these things, but Dr. Herb has tried them in Wisconsin, and (to my knowledge) with no success, but this doesn't mean it can't be worked out. I'd also like to try increasing the pumping area by filling the evapor-ion pump casing with corrugated copper which is water cooled, thus doubling or tripling the effective surface area, and I think I can double or triple the pumping speed. These are two or three things we have in mind for next year.

QUESTION: What kind of lifetime do you get on these titanium slugs?

GOULD: We ran this for a period of about six months with no shutdown and no breakdowns and we had four of them in the ring, some of which gave us trouble because we didn't have adequately designed power supplies.