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XIII. ENERGY DOUBLER VACUUM SYSTEM

I. Introduction

This report is a description of the Energy Doubler vacuum system as it is now proposed. Within the next few months, the sector test vacuum system will be constructed along the lines of this description. It is undoubtedly true that we will be unhappy with some of the ideas presented here, and with the experience and data collected from the sector test, the final Energy Doubler system will be redesigned. Nevertheless, at the present time, this is our best shot.

II. Description

The Energy Doubler vacuum system is actually three different systems, each with its own particular characteristics and requirements. In this report, as much as is possible, we try to separate the different systems, and treat them individually.

1. A beam tube region, in which the beam tube is at cryogenic temperature (about 4.8 K).
2. A beam tube region, in which the beam tube is at room temperature.
3. A cryostat insulating vacuum, which is completely separate from the above two systems.

The beam tube is, of course, continuous around the ring, approximately six kilometers in circumference. The ring vacuum, both the beam tube and the insulating parts, is conveniently divided into 24 sections. Each section terminates on either end at a double turn-around box, where each satellite cryoloop also ends. At each of these points, there is a short (about 10 cm) warm section of the beam tube, and a gate sector valve. The cryostat insulating vacuum also ends at that point, and in addition, is separated at each quadrupole. Hence, the beam tube vacuum can be separated into 24 sections, plus 12 warm sections, by sector valves, each cold section being about 250-meters long. The insulating vacuum is separated permanently into approximately 200 sections, each about 30-meters long.

III. Cold Beam Tube

A. Pumps

The beam tube is pumped out when it is warm from the region near each sector valve, and at each cryogenic feed box, which is approximately mid-way between sector valves. The pumping is done with a standard pump station, slightly modified. A description of the standard pump station can be found in Section VI. Assuming normal surface phase contamination for clean but unbaked stainless steel, it should take a few hours to reach a pressure of 10^{-5} torr. This roughing is done with the sector valves closed. When the beam tube is cold the pump stations are valved off the tube. There is no other pumping of the beam tube. Calculations and measurements show that at 4.8 K there are essentially no gas phenomena in the tube. This is true even for helium, if the coverage of helium on the beam tube wall is a small fraction of a monolayer. With a pressure of 10^{-5} torr at the start of cooldown, and if the gas is condensed on the wall more or less uniformly during cooldown, the resulting wall coverage is about 10^{-3} of a monolayer. If the residual gas were all helium (the worst case, and very unlikely) this would result in an equilibrium pressure of less than 10^{-11} torr, at 4.8 K.[1]

Furthermore, if there is a small leak, the helium admitted into the beam tube through that leak would also be pumped onto the wall, very near the leak. As the buildup of helium on the wall increases, the equilibrium pressure in that region also increases, and the gas migrates to a previously clean region, close by, and is again pumped onto the wall. This phenomenon is very slow, taking hours, or perhaps even days for leaks as large as 10^{-7} torr liters/sec to move the distance of a half cell. In other words, it is impossible to give a practical definition of conductance for the cold tube, and very difficult to effectively pump the tube with lumped or periodic pumps.

B. Pressure Measurements

The pressure in the beam tube is difficult to measure for at least three reasons. First, for the same reason that it is difficult to pump the cold beam tube. Secondly, because any penetration into the tube will have a high pumping speed of its own, since it is also cold, and probably has a higher wall area to cross-sectional area ratio than the beam tube itself. And thirdly, because the measurement will be dominated by the outgassing of the warm parts of the measuring device. We have tried to solve some of these problems by the use of what is called the sniffer, which is shown in Fig. 1. During the beam tube pumpdown, the sniffer is baked at 200°C, to decrease the surface contamination. When the magnet is cold the copper sleeve in the sniffer is at 80°K, so that it is not pumping helium or hydrogen. To further decrease the background, the warm parts of the sniffer are outgassed in a vacuum furnace at 900°C before assembly into the cryostat. The conductance of the sniffer is about 10 liters/sec for hydrogen.

The sniffers will be located at each quadrupole. Every other sniffer will have a Bayard-Alpert gauge, capable of measuring of measuring down to about 2×10^{-11} torr. The other sniffers have low and medium vacuum gauges useful for monitoring the pump-down procedure. The connections are all made with Conflat type copper gasket flanges. In fact, all of the devices connected to the beam tube, except the gate valve, are all metal.

At a later time, if it proves useful to have more pumping for the beam tube, the sniffers can be fitted with small sputter ion pumps.

C. Sector Gate Valves

The sector gate valves are all operating at room temperature. They are 4" diameter nominal bore, all stainless steel, bellows sealed, and electro-pneumatically operated. The valves which are between two cold sections have elastomer seals, probably of ethylene propylene. That material has reasonable outgassing properties, takes a minimum set, and has very good radiation resistance. Reliability, space limitations, and cost dictate the use of elastomer gate seals. They are opened almost all the time, and our experience in the Main Ring has been that they stand up very well. Ethylene propylene seems to still be flexible enough to seal after a dose of 10^9 rads. Because of the high pumping speed of the cold bore, there will be very little, if any, pressure rise in the vicinity of the valve. The gate valves in the warm sections of the machine will probably be all metal, including the gate seal.

D. Interlocks

The sector gate valves are interlocked to the Bayard-Alpert gauges. They cannot be opened unless the pressure on both sides of the valve is less than some specified pressure, perhaps 10^{-8} torr, and the pressure difference between the two sides is less than 10^{-9} torr. The exact value of the set points will be determined from operating experience, but in any case, there will be no manual override of the interlock. The purpose of the interlock is to prevent a section which is cold from pumping on a section which is warm, thus contaminating the beam tube wall.

The valves are closed automatically upon pressure rise, or loss of power, either of which also generates a beam abort.

E. Beam Tube Design and Quality Control

Because of the difficulty of pumping on a cold beam tube, it is extremely important that there be no leaks, or at least very few. On the other hand, because there is no outgassing of the tube when it is cold, it seemed unnecessary to bake the tube in situ, or otherwise degas it. The only treatment is to wash the tube in caustic degreasing agent, and nitric acid pickling bath, and maintain a clean environment for it.

The tube material is Nitronic 33 sheet, with a matte 2-D finish. This finish is chosen because it has a high ratio of real surface area to apparent surface area, more than factor of three, so it has a high capacity to pump helium and hydrogen on its surface. The tube is rolled to approximate shape, machine TIG welded, drawn to final shape, and annealed. The leak test is done at Fermilab, and is specified by document 1620-ES-107248, which is included here as Appendix A.

A key point in the design of the cryostat is that there are no welds, other than the seam weld,which is made on the beam pipe and faces liquid helium. All of the welds, bellows, and seals are in the insulating vacuum. That means, for example, that a leak in a beam tube seal must be very large to be of any consequence, since the insulating vacuum is usually better than 10^{-7} torr. Tests are presently being carried out to determine if the beam tube or the seam weld is permiable to liquid helium for some reason.

The seal between the beam tubes of adjacent magnets is made with a lead coated C-seal, trapped in a rotatable, bolted flange set. The discontinuity in the beam pipe caused by the bellows is covered by a bronze cylinder shield with rf fingers for good electrical contact. This is to prevent losses due to the image currents in the wall, which may be harmful to the beam, but even more importantly, would show up as increased cryogenic heat load.

In addition to the leak check of the beam pipe at elevated temperature before assembly into the magnet, and the final leak check of the completed cryostat, each magnet is leak checked cold during and after its field mapping. When the magnet is connected in the tunnel, the seal and bellows are again checked by evacuating the beam tube, with a helium leak detector, and bagging and flooding the seal area with helium gas. The leak check is then completed by pressurizing the single-phase helium loop.

F. Miscellaneous Points Relating to Beam Stability

1. The pressure bump instability. This instability is due to a runaway of gas desorption from the beam tube walls. It is a function of beam current, geometry, pumping speed, temperature, and pressure, at least. Calculations and measurements, particularly at CERN,[2,3] indicate that the Energy Doubler could circulate five to ten amperes before wall desorption would be a problem. This is true even for large wall coverage of hydrogen or helium, and is due to the very high pumping speed of the cold wall. We conclude that the pressure bump instability will not be a problem in the cold sections of the machine.

2. Beam neutralization due to electrons. The bunched nature of the beam means that electrons are not swept out of the high-field region by ExB drift. On the other hand, electrons will clear to the wall between bunches. If the 20 nanosec gap between bunches is not sufficient, it is an easy matter to kick a few successive bunches out of the machine, making a gap of about 100 nanoseconds, which is clearly sufficient.

IV. Warm Beam Tube

The warm parts of the beam tube are the 50-meter long straight sections, and the six 14-meter long straight sections. They are assembled from 4" diameter stainless steel tube, hydrogen degassed at 900°C, and baked in situ to 300°C. The roughing is done with our normal pump station. In addition, they have 30 liter/sec sputter ion pumps at 8-meter intervals, and perhaps some titanium getter pumps. The flanging is done with copper gasket conflat flanges only.

At the interface between the warm pipe and the cold pipe there must be a lot of pumping. This is to prevent the cold region from pumping the gas from the warm sections, with the resulting wall contamination. These interface pumps will be either sublimation pumps or appendage ion pumps or ion pumps coaxial with the beam tube. Evaluations of these options are now being studied.

V. Insulating Cryostat Vacuum

For the purposes of decreasing the static heat load, the insulating vacuum should be better than 10^{-5} torr. Below this pressure, radiation and conduction across the super insulation is the dominating factor. Our experience is that in a good, leak-tight system, the vacuum is much better than that, in fact is is usually less than 10^{-7} torr.

The major difficulty in the insulating vacuum has to do with leaks and leak hunting. For a more detailed description of our techniques and experience, refer to the section on Energy Doubler Magnet Installation, Appendix C.

A. Pumps

We have chosen to use turbo-molecular pumps to rough out the insulating vacuum (see Section VI.). In the insulating space, even though the conductance is extremely low, it is profitable to pump on the space when the magnets are cold if there are leaks. This is because a large number of layers of super insulation are relatively warm, and gas which migrates to those areas can be effectively pumped.

Each half cell of the insulating vacuum is isolated from the neighboring half cells. Pump stations could be put at each end of the cell, each station pumping on two half cells. We have chosen, initially, to put pumps only one one end of each half cell. This number of pumps (approximately 100) can be increased or decreased as experience warrants.

When roughing is started, the turbo pumps are started at the same time as the rotary vane pumps, with the gate valve open. In this way, the turbo pump acts as a trap for oil vapor backstreaming out of the rotary vane pump. The first time a region is pumped it is profitable to purge a few times with dry nitrogen to remove water vapor. Cooldown is started after a final leak check, and the pressure is less than 10^{-3} torr. If there are no leaks this operation takes about 6 to 8 hours. If the super insulation has been previously pumped and let up to dry nitrogen, the pumpdown time is much faster, taking only one or two hours. If cooldown is started at too high a pressure, water vapor and other gasses condense on the super insulation, degrading the emissivity, with a concurrent increase in heat load.

B. Pressure Measurement

The pressure measurement is shown in the diagram of the pump station and explained in Section E, along with valves and interlocks.

C. Leak Checking and Quality Control

The cryostat assembly is checked for vacuum leaks at the Magnet Facility. In addition, the cryostat is tested for leaks during and after it is field mapped. Since field mapping involves a cryogenic cycle, and the use of liquid helium, this is a particularly stringent test of the vacuum.

During the time that magnets are stored, waiting for installation, they will be evacuated. This will decrease the time required for later pump down of the insulating region.

As illustrated by the section on magnet installation, we have had some trouble with leaks in the cryogenic seals between magnets. This problem is now being studied. Some of the solutions involve using different types of cryogenic seals, double seals to expedite leak detection, and different bellows arrangements. At the moment, we have no problem finding the leaks and their approximate location, but we are having difficulty pinpinting the exact locations of the leaks. The prime suspects are always the cryogenic seals, and the rather fragile bellows assemblies.

VI. Pump Stations

All of the roughing pump stations are essentially identical. There are slight variations, depending upon whether it is pumping on a beam tube or on the insulating vacuum. An insulating vacuum pump station is shown schematically in Fig. 2.

1. Pumps. The pumps are a small turbo-molecular pump of approximately 100 liters/sec capacity, backed by a direct drive two-stage rotary vane pump of approximately 10 cu ft/min capacity.

The TMP is mounted on a vertical flange (i.,e. in the horizontal position) by means of a 4" ID conflat flange. The roughing pump is mounted near the TMP by means of flexible stainless steel hose.

2. Valves. Each pump station has two electro-pneumatic gate valves of 4" ID, with conflat flanges. These are all stainless, bellows sealed valves, with elastomer O-rings of ethylene propylene. In addition, there are two hand-operated valves between the roughing pump and the TMP. These valves are used during leak

checking. The leak detector is used as the roughing pump for the TMP, and the normal roughing pump is valved off. This gives very good pumping speed to the leak detector, and is a very sensitive technique.

3. Pressure measurements. At each roughing station, there are three gauges:

   1. A thermal gauge with fast response (Pirani type) is on the roughing line.

   2. A Pirani gauge, and a high vacuum gauge, sensitive to pressures $\gtrsim 10^{-7}$ torr is on the insulating vacuum on one side of the vacuum barrier. The other side of the vacuum barrier is gauged at the other end of the half cell.

4. Interlocks. The gate valves automatically close when power is lost. In addition, they are interlocked to each Pirani gauge, to protect against loss of vacuum on either the high vacuum side, or the backing pump side. This is to protect the TMP.

Other interlocks include cooling water for the TMP, overtemperature for the TMP, and power loss to either pump. A sudden rise in the insulating vacuum will also cause a beam abort, and closing of the beam sector valves, in addition to closing the roughing gate valves and turning off the TMP. When the pumps are turned off they are automatically vented. This stops the TMP from rotating, in case there is danger of damage to the pump.

5. Power. The TMP is powered from the service buildings by a frequency converter unit. The rotary vane pumps use 208 V, 3-phase power, with contacts that are controlled from the service buildings.

VII. Conclusions

The most likely problems to arise during the sector test are:

1. Finding the exact location of leaks in the insulating vacuum.
2. Maintenance problems with the pumping stations.

We have addressed some aspects of problem 1 in the section on magnet installation. Clearly, we need more experience in this matter. During the first installation of the sector test, roughly 8% of the cryogenic seals had leaks. This performance will surely improve with time. In addition, we are developing new methods and designs to make the leak hunting procedure more exact, and simpler.

Turbo molecular pumps were chosen because of their wide range of operating pressures, and relative ease of operation. Other possibilities included diffusion pumps, cryo pumps, and ion pumps. Each one of these had operational or performance problems which made it seem likely that turbo molecular pumps were the best choice. Nevertheless, it is possible that the combination of 100 turbo pumps, and 100 roughing pumps in the Main Ring tunnel, will prove unmanageable. This is one of the major pieces of information that we can get from the sector test, where we will have twenty of each pump in the tunnel. Our experience will be a guide to future design criteria.

References

1. "Pressure Measurements in a Cryogenic Environment," D. Edwards, Jr. and P. Limon; Journal of Vacuum Science and Technology, 15 (3), May/June, 1978.

2. "A Vacuum Cold Bore Test Section at the CERN ISR," C. Benvenuti, R. Calder, N. Hilleret; CERN ISR-VA/77-19.

3. "Ion Desorption of Condensed Gases," N. Hilleret and R. Calder; CERN ISR-VA/77-33.

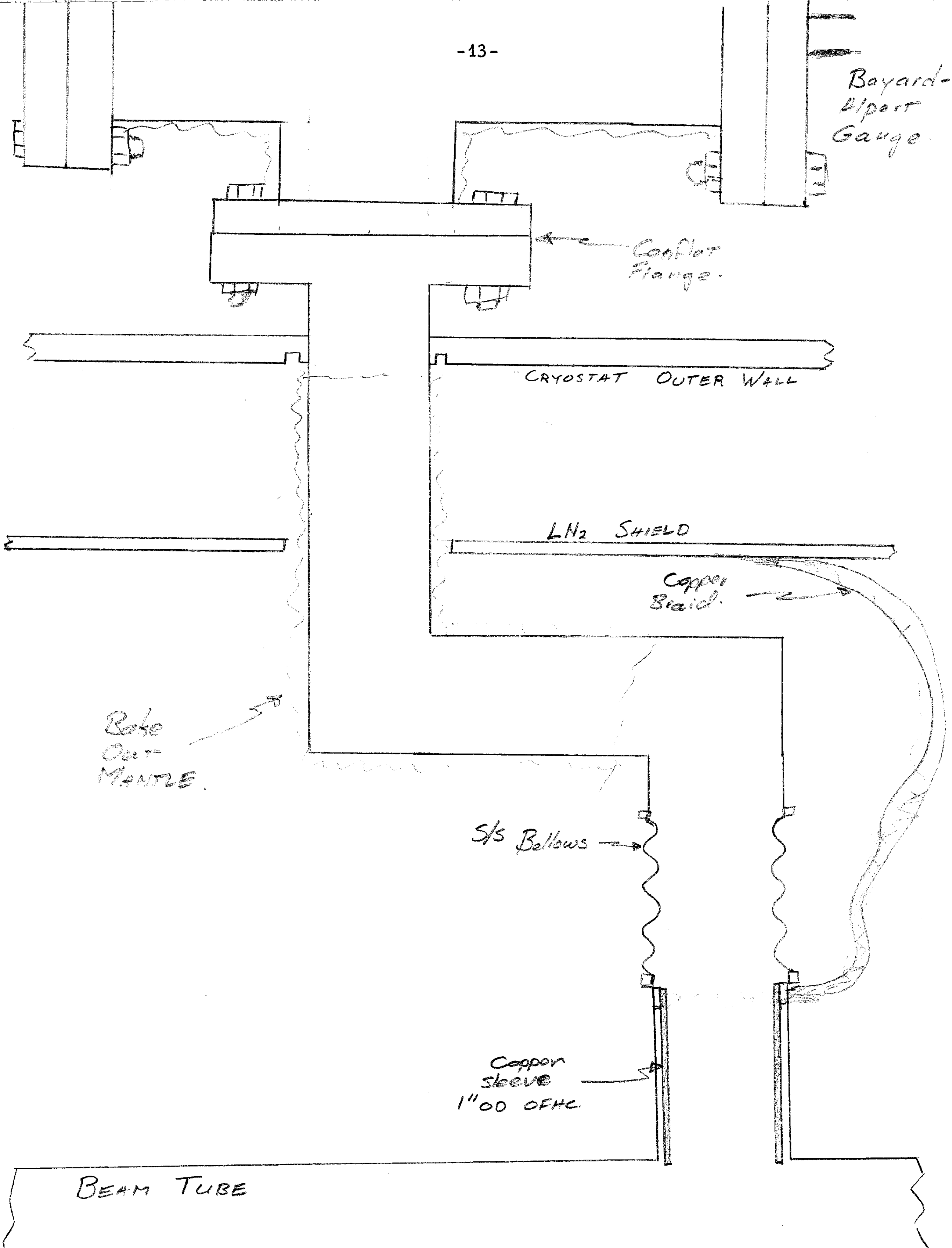

FIG. 1. BEAM TUBE SNIFFER.

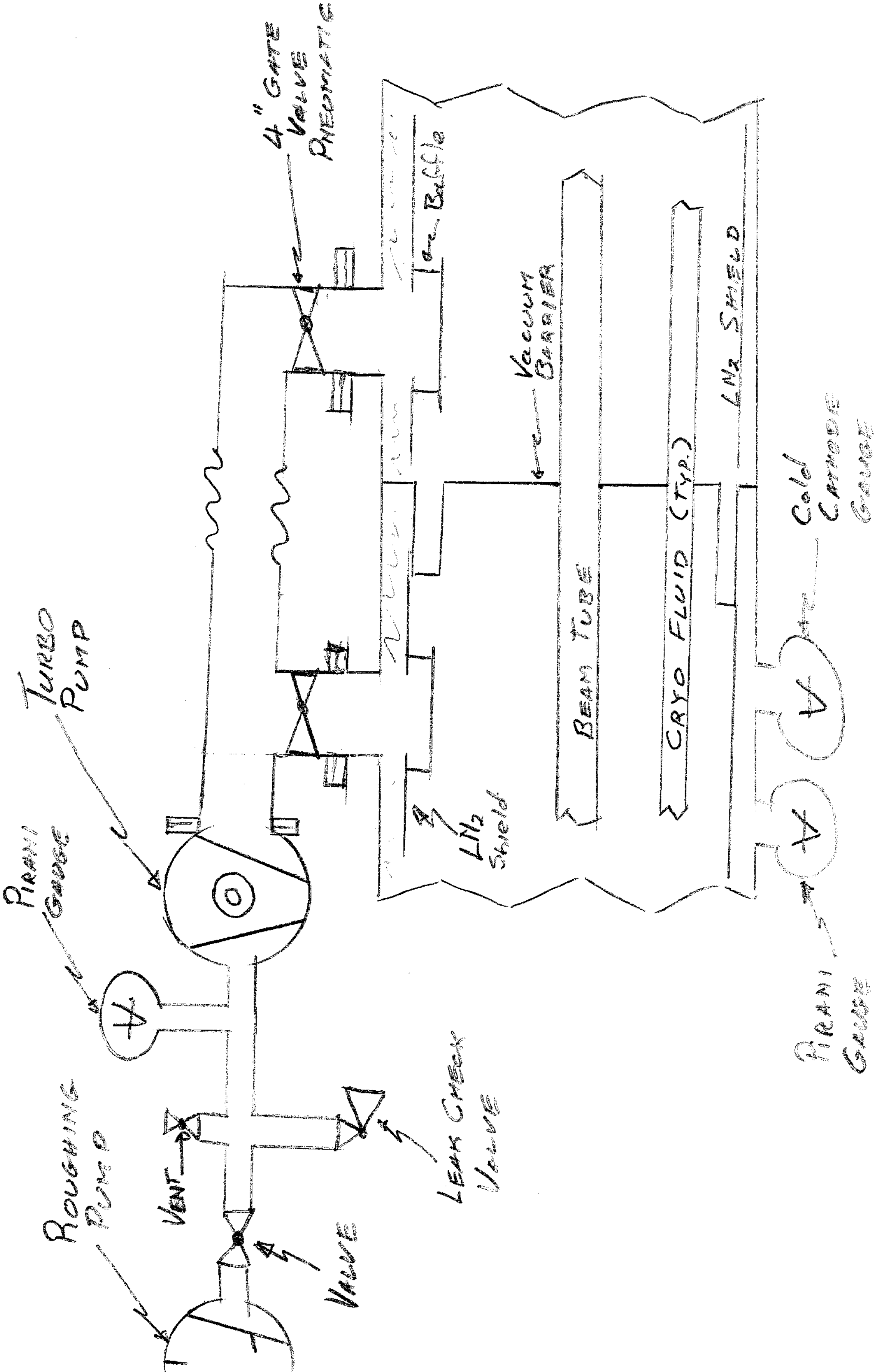

FIG. 2, PUMP STATION

REV.	DESCRIPTION	DRAWN / APPD.	DATE / DATE
A	Para. 4.3 & 4.4 was: under vacuum of ∿ 1 torr. Is: to pressure of ∿ 1 torr.		

ENERGY DOUBLER BEAM TUBE PROCESSING

1.0 SCOPE

1.1 This document covers the processing of the Energy Doubler Beam Tubes at Fermilab. Beam tubes are received in clean condition; free from dirt and grease and are metallurgically clean, and come sealed within a plastic bag. The beam tube is further protected by a cardboard shipping tube.

2.0 EQUIPMENT REQUIRED

2.1 Source of deionized water. Vacuum bake oven. End plugs and fittings which will allow for separate evacuation of both the internal volume of the beam tube and external to the beam tube; and which permit attaching a Mass Spectrometer Leak Detector (M.S.L.D.) and a Calibrated Leak unto the system. The Calibrated Leak shall be located at the position in the oven farthest from the leak detector. The M.S.L.D. shall be calibrated to A.V.S. Std. 2.1. Calibration shall be done daily during an active period of the day shift with the aim of establishing the Minimum Detectable Signal. The M.S.L.D. shall have a Minimum Detectable Leak Rate of better than 5×10^{-10} Atm. cc/sec. of helium, and shall be equipped with a strip chart recorder per A.V.S. Std. 2.1. A Calibrated Leak. Helium gas, high purity grade or better.

3.0 HANDLING REQUIREMENTS

3.1 Unpackage the beam tube taking the precautions of paragraph 3.2 below to prevent contamination of the tube during processing. Save the cardboard shipping tube for reuse.

3.2 Wear clean lint free cotton, nylon, or dacron cloth or polyethylene film gloves when handling the beam tubes. Keep work surfaces, work tables, fixtures, tools, etc. used for the beam tube processing clean and grease free. Do not use copper, zinc, cadmium, lead, tin or any alloy of these metals on the surfaces of fixtures or tools used to work on the beam tube. Chrome plated surfaces are OK. Keep tools used to work the beam tube segregated from other tools, use only on the beam tubes, and do not allow them to come in contact with any of the above listed metals.

4.0 PROCESS REQUIREMENTS

UNLESS OTHERWISE SPECIFIED			ORIGINATOR	P. LIMON	
FRACTIONS	DECIMALS	ANGLES	DRAWN	E. HAKIP	
±	±	±	CHECKED		
1. BREAK ALL SHARP EDGES 1/64 MAX. 2. DO NOT SCALE DWG. 3. DIMENSIONING IN ACCORD WITH ANSI Y14.5 STD's. √ MAX. ALL MACHINED SURFACES			APPROVED	[signature]	6-7-78
			USED ON		
			MATERIAL-		

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ENERGY DOUBLER
BEAM TUBE
PROCESSING REQUIREMENTS

SCALE	FILMED	DRAWING NUMBER		REV.
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REV.	DESCRIPTION	DRAWN / APPD	DATE / DATE

4.1 Thoroughly rinse beam tubes, internally and externally with deionized or distilled water to neutralize any residual nitric acid on the surface. Air dry.

4.2 Install in a vacuum bake oven, using end plugs and fittings which will permit separate evacuation of both the internal volume of the tube and the exterior volume, and the attachment of the M.S.L.D. and Calibrated Leak.

4.3 Evacuate external area of beam pipe to pressure of $\sim$1 torr. Fill external area with dry N_2 or Ar to approximately 7 psia. Bake at 300°C until equilibrium pressure inside beam tubes is reached. The temperature of the beam tube must be measured to insure it is at least 250°C.

4.4 Evacuate external volume to pressure of $\sim$1 torr. Open the M.S.L.D. attached to internal beam tube volume and hold at steady state for 60 seconds. Machine shall have been "warmed up" per manufacturer's instructions, and test shall be run only when the gauge reads less than 85% of the most sensitive scale.

4.4.1 Read scale units before releasing external volume vacuum. Record on Q.C. Traveler Form. Release external volume vacuum, using helium gas, and record M.S.L.D. output (scale units) on Q.C. Traveler Form. An increase in scale reading will be cause for rejection.

4.4.2 Open the Calibrated Leak. Record the following data on the Q.C. Traveler Form:

a) Date and Time of test.
b) Operator's Last Name.
c) Scale units before flooding external volume (paragraph 4.4.1 above).
d) Scale units after flooding external volume (paragraph 4.4.1 above).
e) The Minimum Detectable Signal obtained from the latest calibration (scale units).
f) The Background before opening the Calibrated Leak (Scale units).
g) The Absolute gauge response to the Calibrated Leak (Scale units).
h) The temperature corrected value of the Calibrated Leak (cc He/sec.).

4.4.3 Calculate the Minimum Detectable Leak using data recorded above, and enter into the Q.C. Traveler Form. A Minimum Detectable Leak greater than 1×10^{-9} Atm. cc/sec. of helium is cause for rejection.

UNLESS OTHERWISE SPECIFIED			ORIGINATOR		
FRACTIONS	DECIMALS	ANGLES	DRAWN		
±	±	±	CHECKED		
1. BREAK ALL SHARP EDGES 1/64 MAX. 2. DO NOT SCALE DWG. 3. DIMENSIONING IN ACCORD WITH ANSI Y14.5 STD's. MAX. ALL MACHINED SURFACES			APPROVED		
			USED ON		
			MATERIAL-		

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ENERGY DOUBLER
BEAM TUBE
PROCESSING REQUIREMENTS

SCALE	FILMED	DRAWING NUMBER		REV
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REV.	DESCRIPTION	DRAWN	DATE
		APPD.	DATE

4.5 Upon completion of the leak test, turn off the oven, and disconnect the M.S.L.D. and Calibrated Leak. Release the beam tube internal vacuum using dry grease free nitrogen gas evaporated from liquid nitrogen. Remove beam tube from oven and allow to cool while maintaining positive flow of dry degreased nitrogen gas through interior of tube. When cool, disconnect end plugs and insert closure plugs into the beam tube ends. Store beam tube within a new sealed clear plastic bag (6 mil thick, minimum) and inside the cardboard shipping tube until ready for further processing.

UNLESS OTHERWISE SPECIFIED			ORIGINATOR		
FRACTIONS	DECIMALS	ANGLES	DRAWN		
±	±	±	CHECKED		
1. BREAK ALL SHARP EDGES 1/64 MAX. 2. DO NOT SCALE DWG. 3. DIMENSIONING IN ACCORD WITH ANSI Y14.5 STD's. √ MAX. ALL MACHINED SURFACES			APPROVED		
			USED ON		
			MATERIAL-		

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ENERGY DOUBLER
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PROCESSING REQUIREMENTS

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