

Fermilab

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Fermilab Accumulator Ring Ultra-High Vacuum System

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Abstract

An average pressure of 3×10^{-10} Torr is required in order to store a beam of antiprotons (for up to 20 hours) in the Fermilab Accumulator Ring. The Accumulator Ring has a circumference of 474 m and consists of 114 main magnets which surround a continuous, stainless-steel vacuum chamber with a mean diameter of 12 cm. The Accumulator Ring is located in a below-grade tunnel which is inaccessible during normal operation. Consequently, all monitoring and control operations must be done remotely.

In this paper we describe: (1) the rationale of the Accumulator Ring's vacuum system; (2) the specific choice of pumping systems (roughing, ion and sublimation) that was selected for implementation; (3) the details of the instrumentation, control and bakeout systems (300°C) for monitoring the pressure and desorbing the vacuum chamber; and (4) the operating experience and performance of the entire system.

I. Rationale of System Design

With presently available technology of targetry and beam cooling, accumulation of antiprotons for high energy proton-antiproton collisions requires many hours of beam lifetime in the antiproton accumulating device, with maximum possible accumulation rates of about $2-3 \times 10^7$ antiprotons per second. Eventually, the collider will need to be charged with as many as 10^{12} antiprotons, implying collection times of as much as a day. Further, the collider must be recharged periodically, and provisions must be made for accidental beam loss in the collider. Considerations of nuclear interactions and multiple scattering on gas nuclei, ionization and trapping

of ions in the antiproton beam lead to design pressures in the range $1-3 \times 10^{-10}$ Torr.

Numerous constraints are placed on the system, leading to the use of non-ideal materials in many places. The location of transmission lines with wave velocities near the velocity of light required extensive areas of printed circuit boards made of copper bonded to teflon, a material that can be baked at low temperatures only and outgasses generously. Microwave resistors with alkyde coatings were installed in the vacuum, and extensive soft soldering was employed in the assembly of the beam cooling sections. Outgassing and baking tests were made of each of these materials to devise a strategy for cleaning, baking and pumping. Beam cooling pickups are cooled to 77K to reduce the noise level of the resistors terminating the pickups. Beam cooling kickers, which are of identical design to the pickups, dissipate of the order of one kW of power, so cannot be operated at low temperature. They constitute a considerable outgassing load.

The rest of the chamber was built in accordance with the standard ultra-high vacuum practices employing stainless steel and ceramics. Joints were mostly welded, either in preassembly or in final assembly in situ. Removable sections employed Conflat flanges with silver coated copper gaskets. Magnet vacuum chambers were fabricated of 316L stainless steel because of its superior (low) permeability. All stainless steel parts were degassed in vacuum at 900°C after forming and preassembly. This had the further effect of reducing the permeability created by cold work and welding. Regions employing "standard" technology are baked to 300°C; non-standard regions are baked to 150°C.

The whole vacuum system is essentially a pipe made of many different

cross sections and 474 m in length. Mean pressures seen by the beam are determined by specific outgassing rates of the surface and the conductance of the chamber sections between pumping stations. Pumps were linearly distributed along the length to optimize the mean pressure with given pumping. Both ion and sublimation pumping were employed, with typically two sublimation pumps for each ion pump. In this way, very high pumping speeds were obtained at low pressure. Non-standard regions employed extensive sublimation pumping to pump the high gas loads. Triode ion pumps were chosen for ease of starting at low pressures and their inert gas pumping ability. This method follows very closely the practice employed at the ISR and the Antiproton Accumulator ring at the European Organization for Nuclear Research¹.

The system was divided into six sectors with automatic all metal valves. See Figure 1 for the general layout of the vacuum equipment. Each sector has one roughing port with a hand operated all metal valve. The roughing stations are portable and can be used in other parts of the complex. Figure 2 shows a typical roughing station. Roughing is accomplished by pump modules consisting of a high speed turbomolecular pump backed by a two-stage mechanical pump. Both pumps are started simultaneously to prevent backstreaming of forepump oil. Automatic timers close an electropneumatic valve, turn off both pumps, and vent the roughing system if the TMP does not reach 80% of operating speed within 20 minutes. Leak detectors can be connected to a hand operated valve between the TMP and the mechanical pump.

III. Instrumentation, Bakeout and Controls

A. Bakeout System

The major specifications on the Accumulator Ring bakeout system were: (1) it should be possible to bake each component of the ring, independently, to its maximum temperature; e.g., 150°C for the stochastic cooling tanks and 300°C for the vacuum chamber. (2) Each component of the ring needs to be heated to its maximum temperature independently; e.g., the stochastic cooling tanks can only be heated (and cooled) at a rate of 8°C/hr (to minimize deleterious thermal stresses) while most other components are heated at a rate of 25°C/hr. (3) To limit the ambient temperature in the underground tunnel to <55°C, at most two sectors (2/6) of the ring can be baked to 300°C simultaneously. (4) It must be possible to initiate, monitor and control the bakeout remotely so that other work can be done during bakeout.

1) Heating Jackets

The Accumulator vacuum chamber is 474 meters in circumference. Of this length, 36% is inside magnets of different lengths and shapes. The remainder of the vacuum chamber consists of mostly 10 cm tubes and about 38 meters of 46 cm diameter vessels of different lengths. The chambers inside the magnets were baked to 300°C with a heating blanket only 7.5 mm thick because of space limitations. Reference 2 gives a detailed description of the magnet vacuum chamber heating system. The remaining 64% of the chamber which were accessible, were covered with flexible heating jackets with built in heating elements. The jackets, 51 mm thick, were custom contoured form to fit the special complex vessels. See Figure 3. The majority of the jackets were designed for a 300°C bakeout temperature. The jackets

consisted of a glass fiber cloth cover with the heating elements sewn on. A layer of ceramic fiber thermal insulation 50 mm thick is applied over the heaters, and the outer surface is made of aluminized glass fiber cloth. The heating elements were designed to give an average power of 0.75 kW/m^2 with 208 volt operation. With the 300°C vacuum chamber bakeout, the temperature of the outside surface of the jacket was about 62°C .

2) Thermocouples and Power Distribution System

A total of 1200 thermocouples are welded to the outside surfaces of the vacuum chamber, the stochastic cooling tanks, the rf cavities, etc., to monitor the temperature of each component of the ring during the bake. Type E thermocouples were selected because of the large Seebeck coefficient and their non-magnetic characteristics. Each thermocouple signal is transported 50-300' to receiving electronics placed at six discrete locations within the underground tunnel. Large gauge (16 AWG), thermocouple extension cable was chosen to transport the small thermocouple voltages (1.5-22.0 mV) with minimal signal attenuation. Measurements indicated an attenuation of less than $0.4\%/100'$, and consequently, no corrections due to attenuation losses were necessary.

An independent power system for providing current to the heating blankets is distributed throughout the Accumulator tunnel. The voltage chosen for distribution was 208 volt 3-phase system. Previous experience showed that 208 volts was the highest voltage that the heating blankets would be capable of insulating. The larger power loads (11 kW) used all three phases controlled by a contactor. The smaller loads were fed from a 6 channel solid state relay (SSR) control box. The control box was fed with 208 volts 30A and split up by using 2 SSR's per phase.

3) Bakeout System Controls

The thermocouple receiving electronics and the actuator control electronics have been incorporated into the existing accelerator control system as "standard devices". A block diagram summarizing the various inter-connections is shown in Figure 4. The bakeout is monitored and regulated by a standard Fermilab 16-bit microprocessor system which uses a multi-drop GPIB link to communicate with the thermocouple and actuator electronics in the tunnel, and a separate high-speed (10 M bit/sec) serial link to communicate with the remote control computers. The microprocessor programs and the parameters of the bake are downloaded from the control computers. Once downloaded the microprocessor system operates independently of the control computers; for example, a major "crash" of the control computers would not interrupt the microprocessor system from monitoring and regulating the bakeout.

At the start of a bake, the user specifies the length of the bake, and the heating and cooling rates and maximum temperature for each element to be baked. The microprocessor system then opens and/or closes the actuators to the power circuit for each element to achieve the desired temperature profile.

B. Vacuum Instrumentation

1) Pirani, Cold Cathode, Ion Gauges

The Accumulator Ring's vacuum instrumentation has been chosen to span the pressure range from atmospheric conditions down to 10^{-11} Torr. Pirani gauges are used above 10^{-3} Torr; cold cathodes cover the range from 2.0×10^{-3} to 1.0×10^{-8} Torr; nude ion gauges are used from 10^{-6} to 10^{-11} Torr. The transducer outputs from this instrumentation are transmitted to

a simple, modular electronics crate which is located at ground level and also contains the controls for ion pumps, sublimation pumps, and sector valves.

The controls interface adapter (CIA) crate is the modular device that converts the control and status information from vacuum devices to a CAMAC crate. For the \bar{p} system the CIA crate contains 6 different types of cards which are Pirani control, cold cathode interface, ion pump or ion gauge interface, sublimation interface, sector valve control, and SSR control card.

The Pirani card contains 6 separate channels that have outputs from 0.3 to 9 volts corresponding to 1×10^{-3} Torr to atmosphere. At 2×10^{-3} Torr an output permit is available to interlock a cold cathode channel.

The cold cathode interface card controls a six channel unit that has a separate 3 kV supply to power each cold cathode head. The current is monitored using a log amp to compress the decades covered.

The ion pumps are driven from a remotely controllable 5 kV supply @ 200 ma for each unit. The ion pump interface card can be connected to 6 supplies. The card uses 4 of the inputs from ion pump supplies for interlocking purposes. The same interface card is used to control and monitor ion gauge supplies which were designed with compatible status and analog signals.

Engineering tests were made of sublimation pump performance. The pumps employed 2 mm diameter filaments, in a standard 3-filament holder, with one filament replaced by an anode electron collector. Temperature during sublimation is controlled by regulating the electron emission (10 ma) to the anode. In operation both the initial (cold) filament

current and the regulated filament current are recorded by the control system as a way of measuring the loss of filament volume. Typically a filament lasted for 500-1000 flashes. Each flash provided 15 mTl of pumping, and pumping speed was determined by the orifice size. For a filament located in a 200 mm tube, with 200 mm opening, pumping speeds in excess of 1500 l/sec were obtained.

The sector valve control card in the CIA crate was connected to the ion pump interface cards so that a sector valve could not be opened unless a sufficient number of pumps were on and the pressure was below a desired value. The same interlock was used for the sublimation pumps and kickers.

All vacuum power supplies and controls are Fermilab designs and built to our specifications.

IV. Operating Experience

The Accumulator Ring started pump down in April, 1985 and beam commissioning studies began shortly thereafter. Using ion pumping alone (i.e., without baking the vacuum chamber and without using the sublimation pumps), a pressure of less than 10^{-8} Torr was achieved within a few days.

Over the last 4 months, the six sectors of the ring have been baked at times when no beam studies have been scheduled (typically less than 1 day per week). Thus far, most of the bakes have been done at low temperature (100-125°C) and for rather short durations (10-20 hours). Ion gauges, sublimation pumps and RGA heads are degassed near the end of the bake. Ion pumps are used to bring the system down to $<10^{-8}$ Torr and then the TSP's are sublimated. In order not to interfere with beam commissioning studies, most TSP's have been sublimated only a small number of times.

Currently the ring pressure varies between 1×10^{-11} Torr (in sections of 4" diameter pipe) to 1×10^{-9} Torr (in the area of some stochastic cooling tanks). The average ring pressure is approximately 2.8×10^{-10} Torr thereby satisfying the design requirement. See Figure 5.

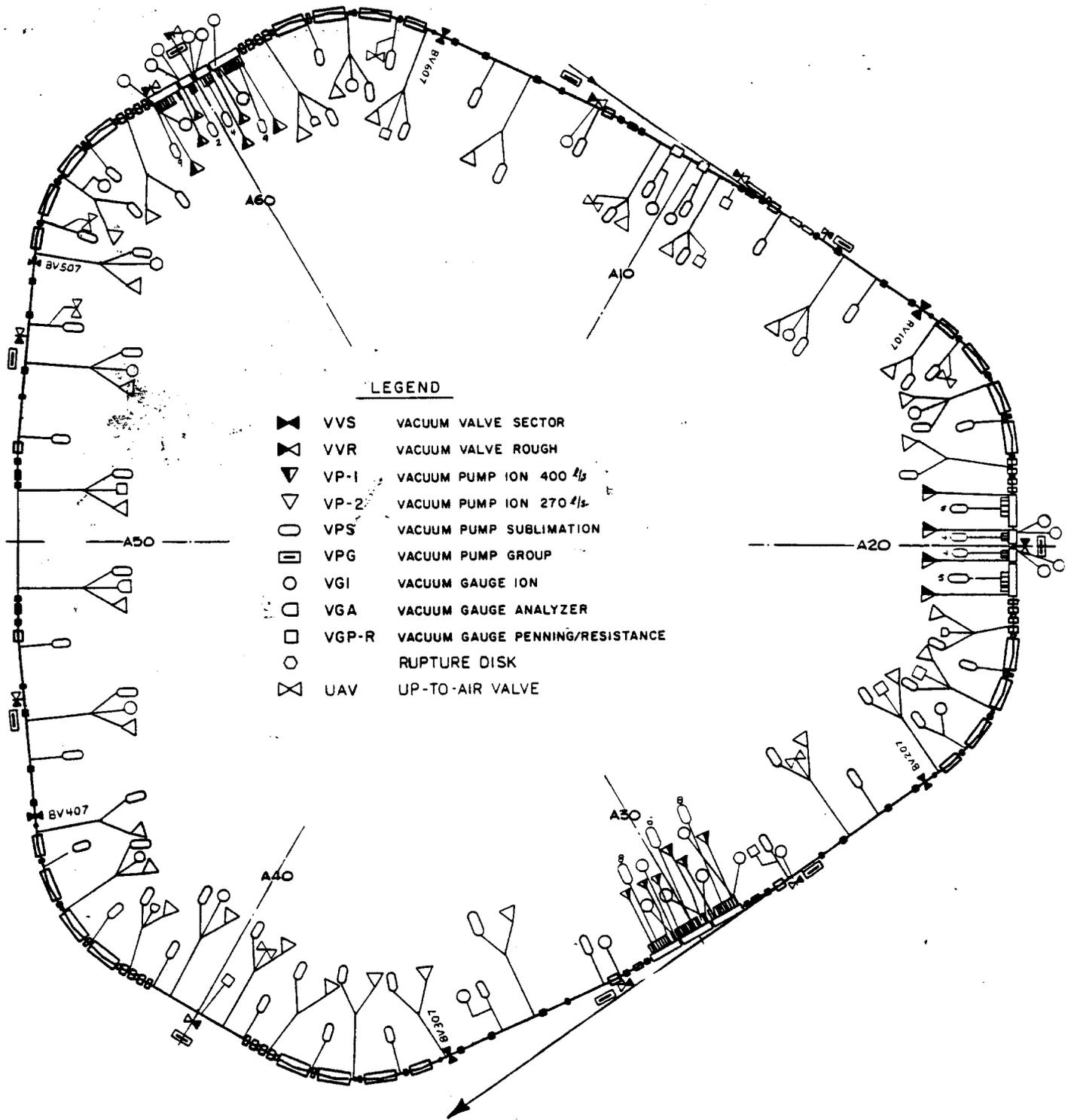
Careful hunting for and elimination of very small leaks, more moderate and prolonged baking of the vacuum chamber and more extensive sublimations of the TSP's will probably result in reducing the average pressure below the design specification.

References

1. A. Poncet, CERN private communication.
2. J.A. Satti, G.N. Lee, Fermilab Accumulator Vacuum Chamber Heating System, Journal of Vacuum Science and Technology A3, 1695, May 1985.

Figure Captions

- Figure 1. General layout of vacuum equipment in the Accumulator Ring.
- Figure 2. Rough vacuum system.
- Figure 3. Heating jackets on the stochastic cooling tanks.
- Figure 4. Bakeout control system.
- Figure 5. Accumulator Pressure Profile



LEGEND

- ⊠ VVS VACUUM VALVE SECTOR
- ⊡ VVR VACUUM VALVE ROUGH
- ▼ VP-1 VACUUM PUMP ION 400 l/s
- ▽ VP-2 VACUUM PUMP ION 270 l/s
- VPS VACUUM PUMP SUBLIMATION
- VPG VACUUM PUMP GROUP
- VGI VACUUM GAUGE ION
- VGA VACUUM GAUGE ANALYZER
- VGP-R VACUUM GAUGE PENNING/RESISTANCE
- RUPTURE DISK
- ⊠ UAV UP-TO-AIR VALVE

FIGURE 1

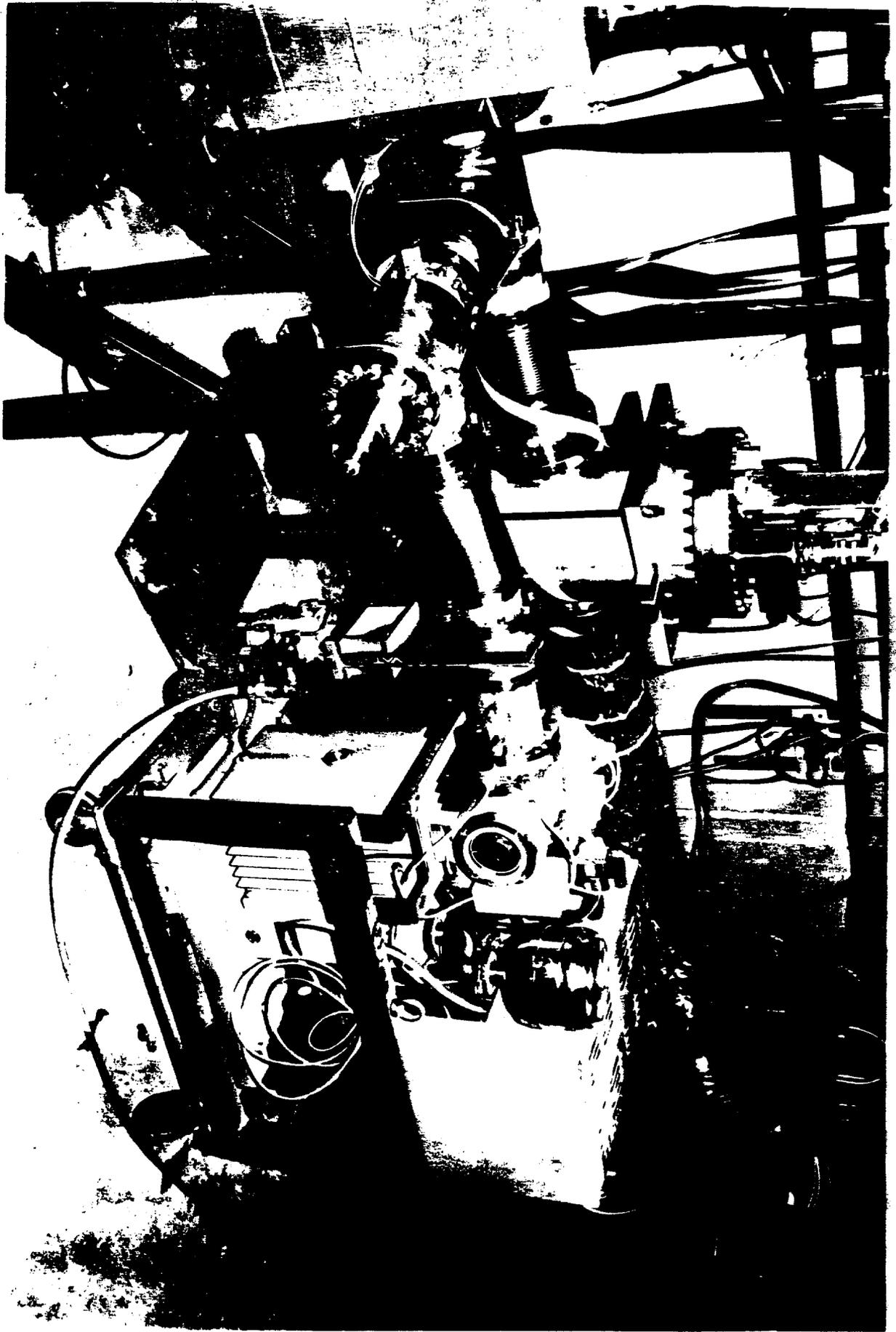


FIGURE 2



FIGURE 3

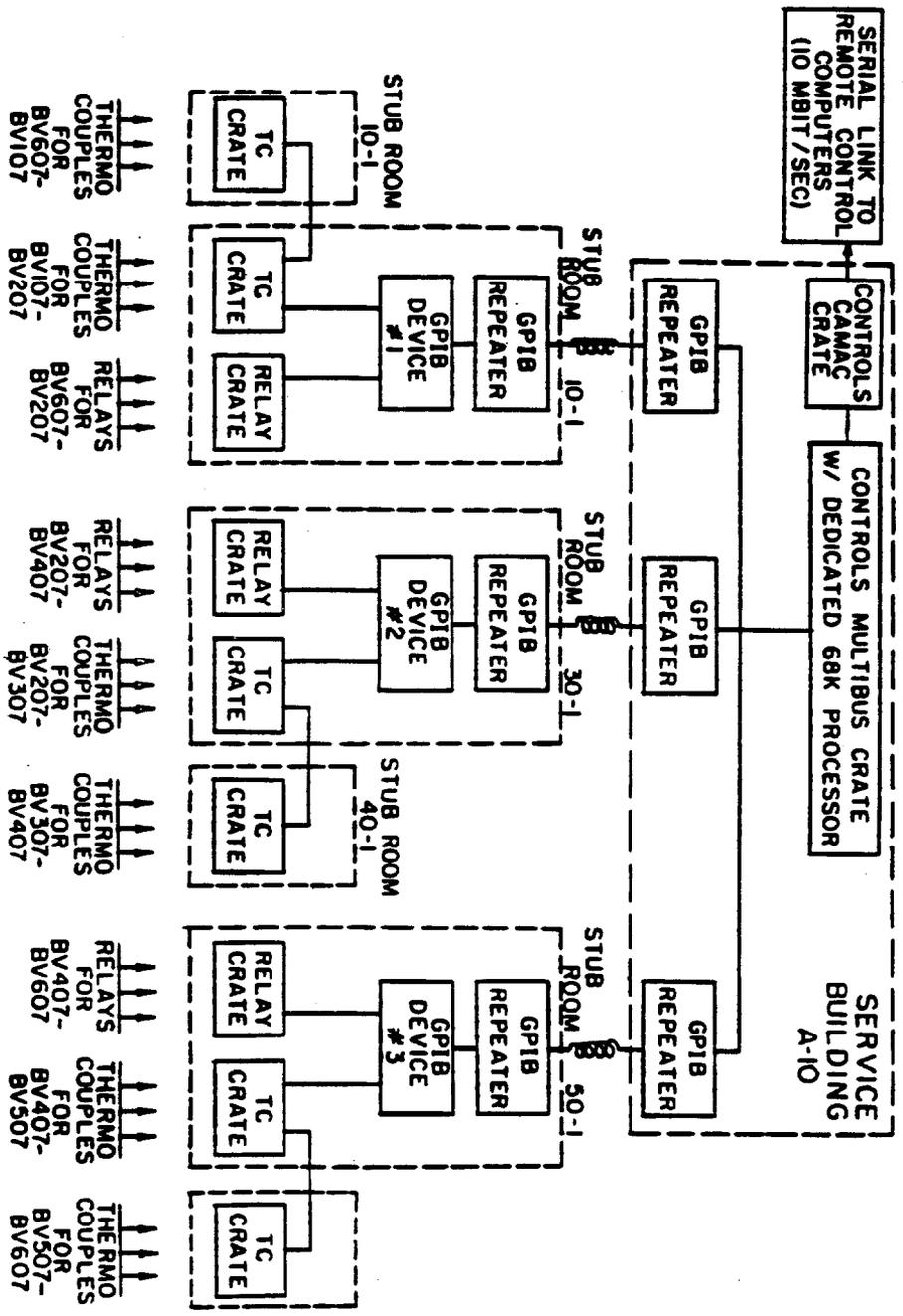


FIGURE 4

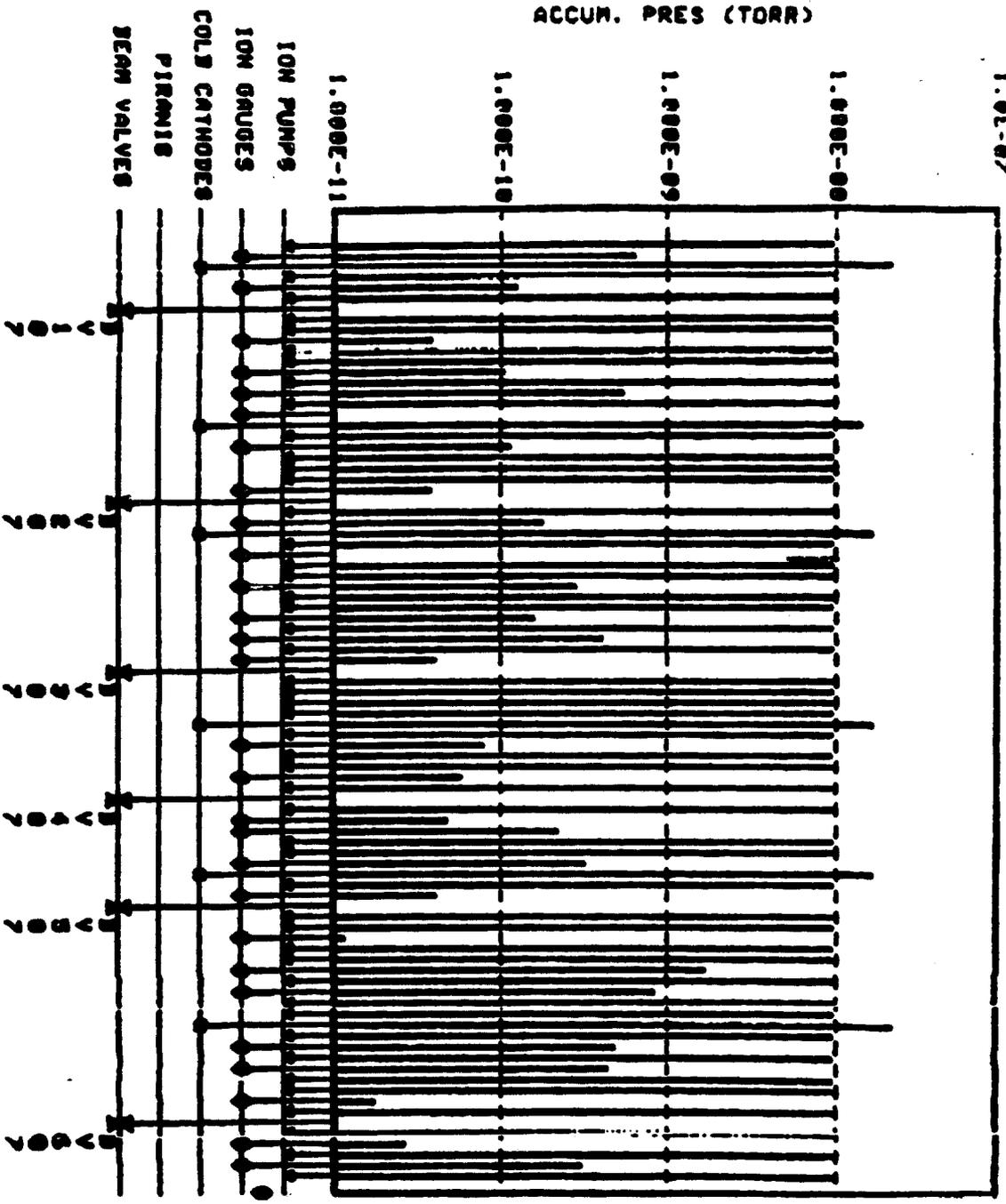
ACCUMULATOR PRESSURE PROFILE

1.0E-07

AVERAGE PRESSURE (ION PUMPS) = 1.000E-08 (ION GAUGE 1) = 2.871E-10

2

ACCUM. PRES (TORR)



OFF.

1

10/28/85

0800

Figure 5