APPENDIX XII. VACUUM SYSTEM

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A. Introduction

The decision to use the Energy Doubler as a storage ring to collide beam with the Main Ring places stringent requirements on the vacuum system. In addition, the vacuum system is unconventional because the Energy Doubler is a cold-bore machine. There are many advantages and some disadvantages of a cold-bore machine. Among the advantages are:

(i) Maximum use of the beam-tube aperture. This is an advantage even if the magnetic field is not uniform throughout the aperture, because this space can be used for injection and extraction of beam when the Energy Doubler is operating as an accelerator.

(ii) Cryopumping of all residual gases except for helium and hydrogen. The vapor pressure of hydrogen is approximately 10^{-6} Torr at 4.6K.

The major disadvantages of a cold-bore system are lack of access to the beam tube and lack of experience with cold-bore systems.

B. Pumps

Since liquid helium is readily available, it seems advantageous to use cryosorption pumps throughout the system. These pumps can have a very high pumping speed and capacity for both helium and hydrogen, and can be built into the cryostat in many places. Two possibilities are:

1. To build a small cryosorption pump coaxially with the beam tube between each magnet. This pump can easily be shielded from the beam.
2. To build a larger pump into each quadrupole cryostat. Although this scheme provides lower net pumping speed, it should be more than adequate, provided there are no helium leaks into the tube directly from the liquid-helium regions of the cryostat.

   This last point is worthy of some discussion. Thousands of dewars have been built over the last few years with no leaks. Welded or seamless stainless steel tubes should have no leaks at all, so the requirement is that there be no welds that go through from the beam tube into the liquid helium. In this case, the pumps are installed to dispose of residual hydrogen that desorbs from the walls and small helium leaks into the tube from the insulating vacuum region.

C. Beam-Off Vacuum

If there are no leaks into the beam tube from the liquid, the pumps must still be capable of handling the outgassing of the beam tube and leaks from the insulating vacuum into the tube. The beam tube itself will be chemically treated, vacuum baked, and stored in dry nitrogen before installation. With treatment of that type, outgassing rates at room temperature of hydrogen from stainless steel can be held to less than 10^{-12} Torr-liters cm^{-2} sec^{-1}. At 4.6K, the outgassing should be many orders of magnitude less. The major problem will be small leaks from the insulating vacuum region into the bore tube. A string of magnets will be leak checked when warm and with the pressure in the insulating region at one atmosphere or more. This sets a limit on leaks of $Q_{leak} \lesssim 10^{-9}$ atm-cc/sec. Sensitive regions, such as bellows and feedthroughs, can be cold-shocked to liquid-nitrogen temperatures during the leak-detection procedure. Since the insulating vacuum is between 10^{-4} and 10^{-5} Torr, undetected leaks will be small; i.e., $Q_{leak} \lesssim 10^{-13}$ atm-cc/sec. If we assume a leak rate Q_{leak} of 10^{-12} atm-cc/sec and pumps of speed s of 500 liters/sec at every quadrupole, then the peak gas density at the position of a leak (15 meters from a pump), would be less than 10^{7} helium molecules/cm^{3}, which is equivalent to a room temperature pressure of less than 2×10^{-10} Torr. This is clearly adequate for any storage ring, and would give a beam lifetime against multiple scattering and nuclear interactions of many days.

D. Beam-On Vacuum

The most severe limitation to current in the Energy Doubler will be the pressure-bump instability. Dynamically, this is caused by ions made by beam-gas collisions and accelerated to the beam-tube wall by the electrostatic potential of the beam. When the ions hit the wall, they release gas molecules that are adsorbed on the wall causing a local increase in pressure. At some beam current, $I_{critical}$, this becomes a runaway process that destroys the beam. One of the uncertainties of cold-bore systems is the possibility that the desorption coefficient, η = desorbed molecules/incident ion, might be very high. Theory predicts that for a cold-bore system with high sticking probability, the product $\eta I_{crit} \simeq 10^{4}$ amps.

The only data for desorption of hydrogen from cold surfaces have been published by Erents and McCracken.[1] They used protons of a few keV to bombard films of frozen gas and measured η to be approximately 5×10^{4} for hydrogen and helium

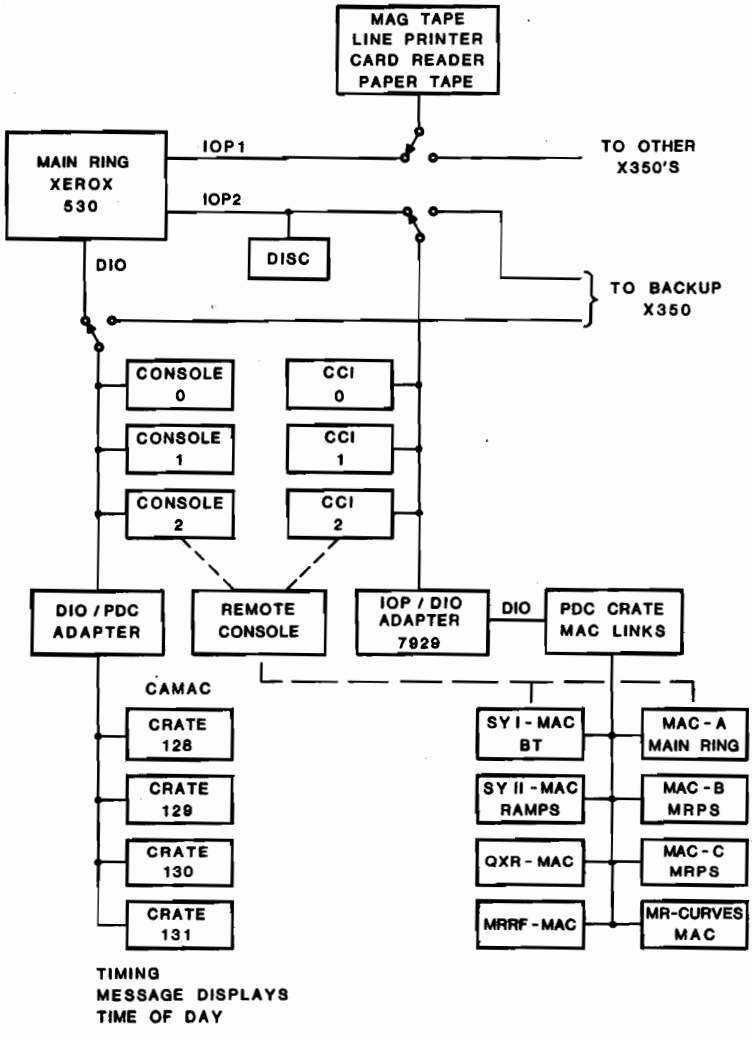

Fig. XIII-2. Main Ring and Switchyard control system.