STORAGE-RING WORK AT STANFORD

G. K. O'Neill
Princeton University

The design of the storage ring was started in 1957 at Princeton. During 1958 collaboration was begun with the Stanford partners and a detailed design was completed. Construction began in 1959. Initial testing at a pressure of 10^{-6} mm Hg was started in October 1961, and a complete assembly and baking of the ring was accomplished by the end of 1962. In October of that year a testing period started (at a base pressure in the system of 3×10^{-9} mm) which lasted about three months. It was ended by a water leak in the ultra-high vacuum system.

At present a cleaning and rebaking of the system is taking place and it is expected that operation can be started again in September of 1963.

Active members of the Princeton-Stanford storage-ring group are B. Gittelman, W.C. Barber, B. Richter and G.K. O'Neill.

Basically, the storage ring was designed to provide a test of the differential Møller cross section for electron-electron scattering as a function of angle. Since it was designed to provide a sensitive quantum-electrodynamic test, the energy was chosen to be 500 Mev. This was comparable with momentum transfers obtained in electron-nucleon scattering by Hofstadter and co-workers. Further, that energy would be optimum for strong radiation damping, necessary in the injection process, and would not be so high that rf problems would become difficult. These arguments led to the choice of 500 Mev as a good compromise.

The experiment was designed for electron-electron collisions and not for electron-positron collisions. This is connected with the 10^4 factor difference in expected intensity between positron and electron beams.

A comparison between the Princeton-Stanford storage ring and the AdA storage ring (Frascati) shows a rather fortunate difference in parameters which has made these rings complementary. The AdA ring is a low-energy (220 Mev), low-current (3×10^7 stored electrons) storage ring with a very good vacuum. Consequently, it has demonstrated long storage times and has shown up the highly energy-dependent "Touschek effect". The Princeton-Stanford ring is a higher energy (500 Mev), relatively high-current (10^{10} electrons stored) storage ring. Also, it is more efficient in injection; that is, 10^6 electrons are injected per pulse as compared with 10^2 for the AdA ring. As a consequence, at Stanford two high-current effects showed up, one effect being due to synchrotron light (see below), and the other effect being a vertical instability. An instability which may be related has been observed recently at MURA.[1]

The Princeton-Stanford storage-ring experiment, being an electron-electron-collision experiment, is in the form of a figure eight (Fig. 1). The machine has straight sections, in contrast to AdA. The magnet is of solid iron construction. It is possible, however, to raise the electron energy from 200 Mev to 500 Mev in only two minutes. An early stage of machine construction is shown in Fig. 2. The rf cavities, as shown, are split, similar to those designed by K. Robinson for the CEA machine. This permits their removal during bake-out of the vacuum chamber. They are driven by one-tube amplifiers, which get their drive from a common master oscillator. In Fig. 3, the magnet configuration without vacuum chamber is shown.

---

1. F.E. Mills, p. 368 of this volume.

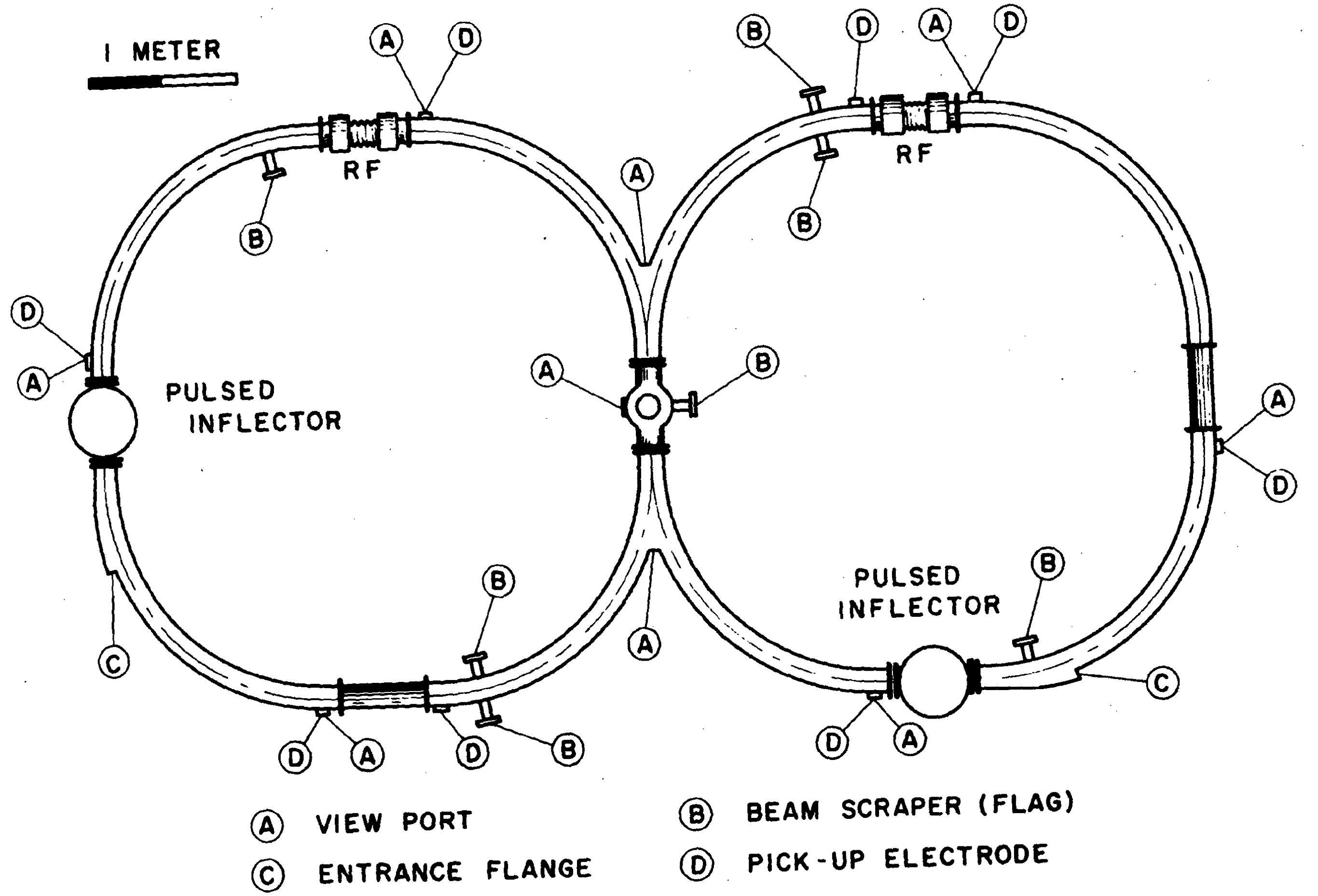


Fig. 1 - Vacuum chamber for the storage rings

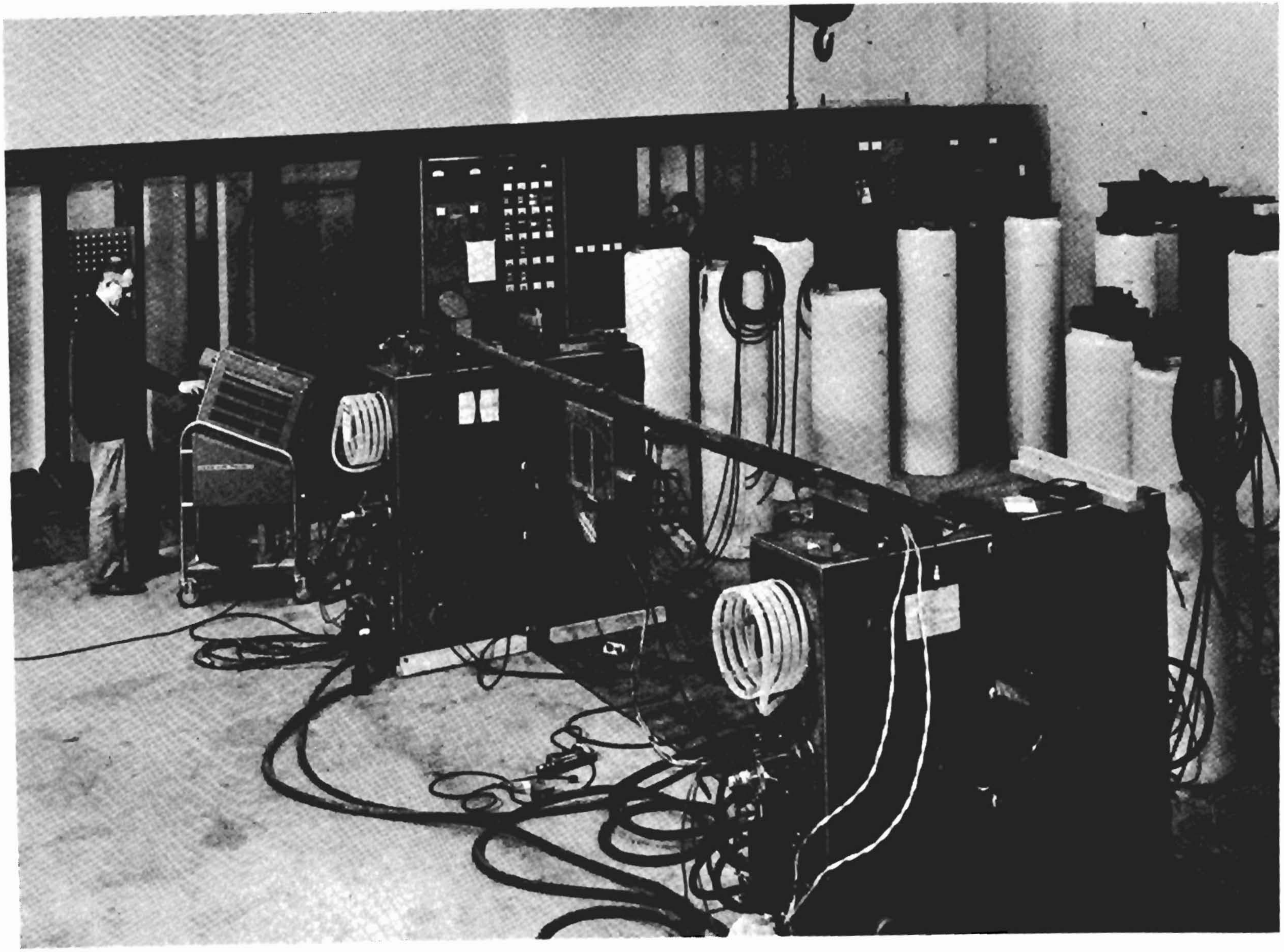


Fig. 2 - Split rf cavities for the storage rings

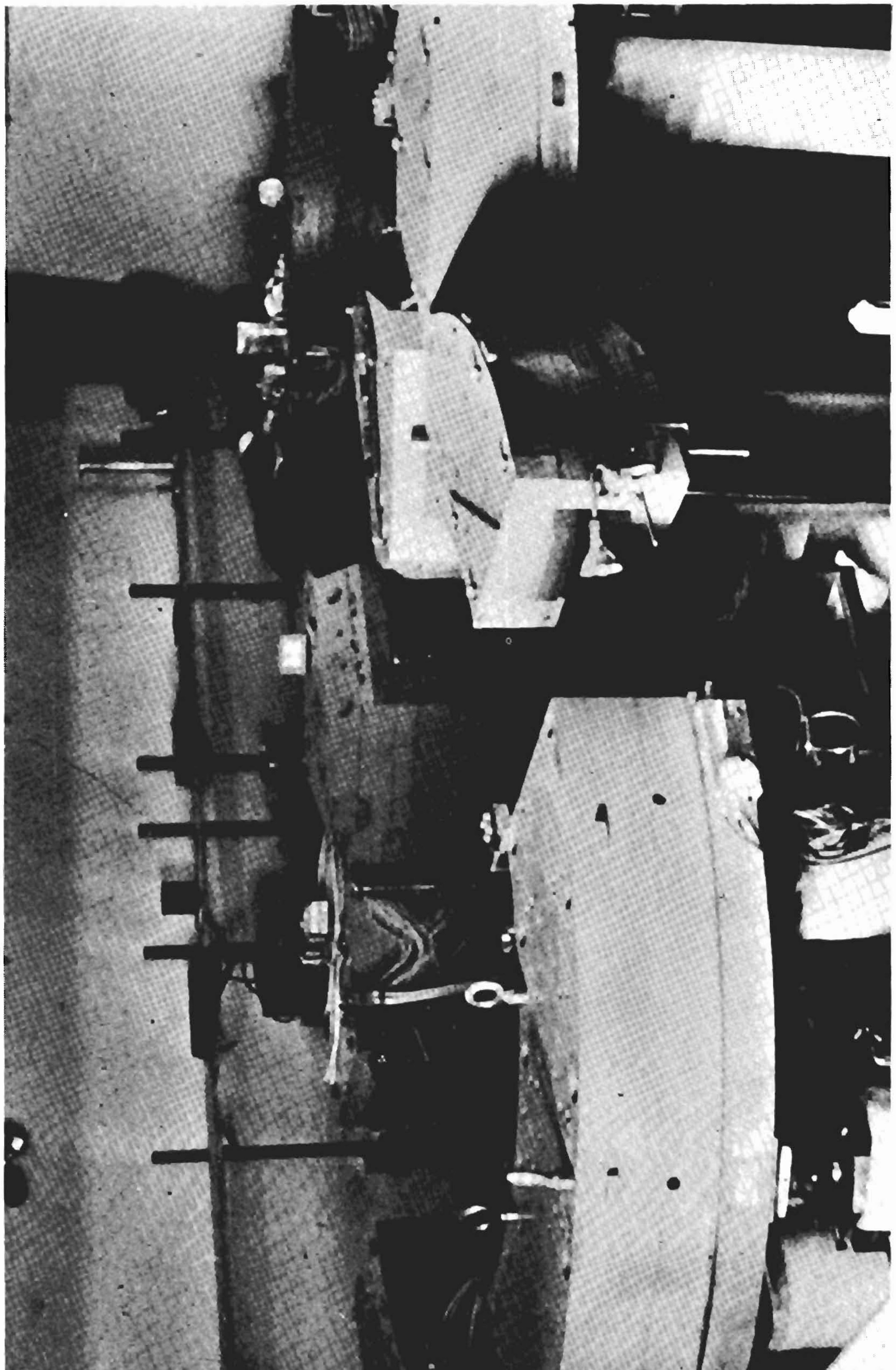


Fig. 3 - Storage-ring magnets without vacuum chamber

RCA "ramseals" are used to bring the rf power into the high-vacuum system. These seals are special metal ceramic assemblies normally made for large transmitting tubes. An example of one is shown in Fig. 4. They proved to be very reliable. The ceramic in the seal construction is shielded from possible low-energy scattered electrons and from the synchrotron light. The construction permits the use of an antimultipactoring bias which proved to be necessary in practice.

The dc-injection optics was designed in a simple fashion and will have to be improved when a switch is made to positron-electron work.

The vacuum-system experience is directly applicable to any eventual proton-storage-ring projects. This system has all the complexity of windows, probes, straight sections, clearing-field electrodes, pulsed magnets, etc., necessary for a bigger storage ring. Approximately one hundred gold ring gaskets are used in this machine, two of which are 24 in. in diameter. In general, the seals have been copied from Project Matterhorn and experience has been very satisfactory. The vacuum chamber is shown suspended in a steel spider in Fig. 5. A section of the chamber, suspended in the oven during a bake-out run, is shown in Fig. 6.

Due to the initial doubtful performance of Vac-Ion pumps, it was decided to use oil pumps. With one 25 l/s pump it was possible to reach 3×10^{-9} mm. By now, the oil pumps have been abandoned in favor of four Vac-Ion pumps of 75 l/s. With these a pumping-speed fall-off is experienced below 10^{-9} mm; however, for the present experiments, it is not necessary to obtain pressures below 10^{-8} mm Hg.

To inject electrons in the storage ring, use is made of a delay-line inflector. This gives a high injection efficiency, but has also caused

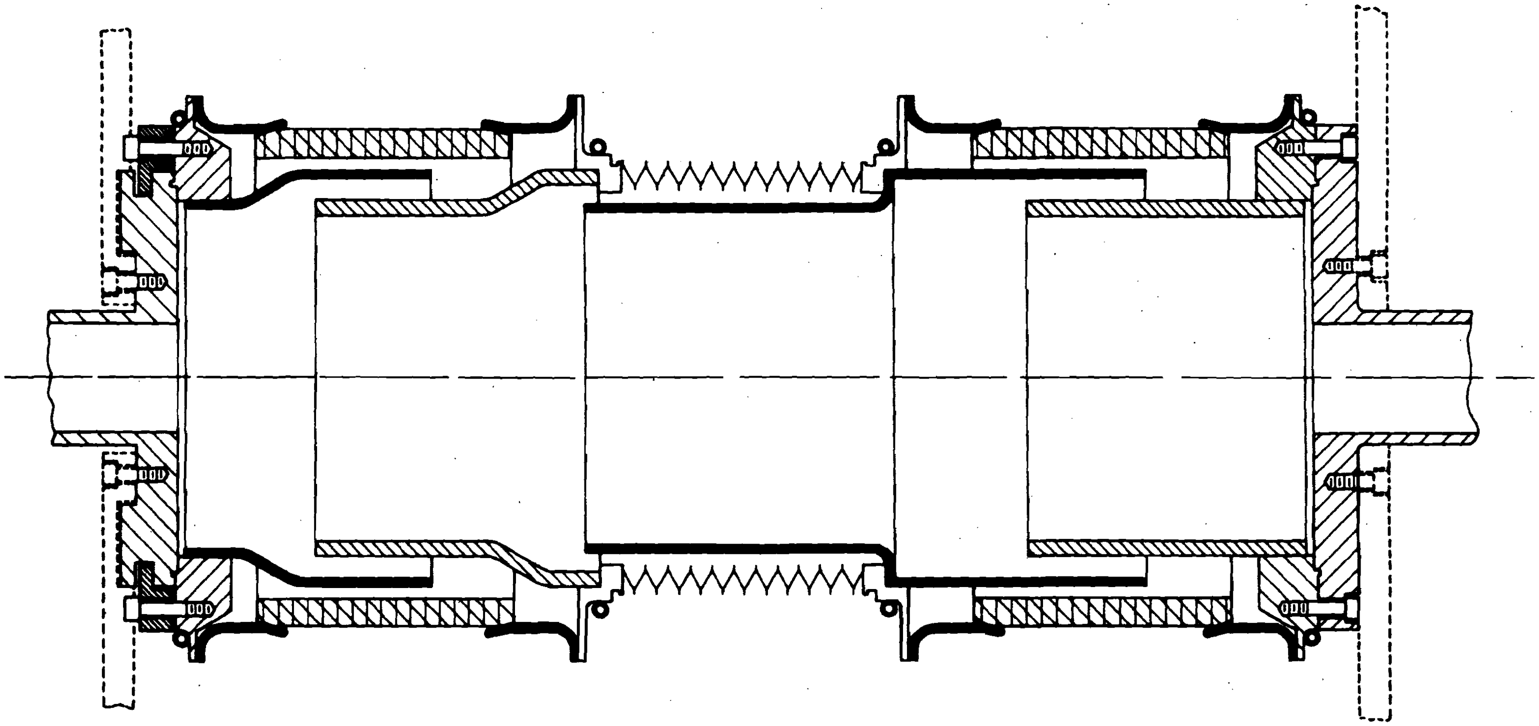


Fig. 4 - RCA "ramseals" for high-vacuum rf gaps

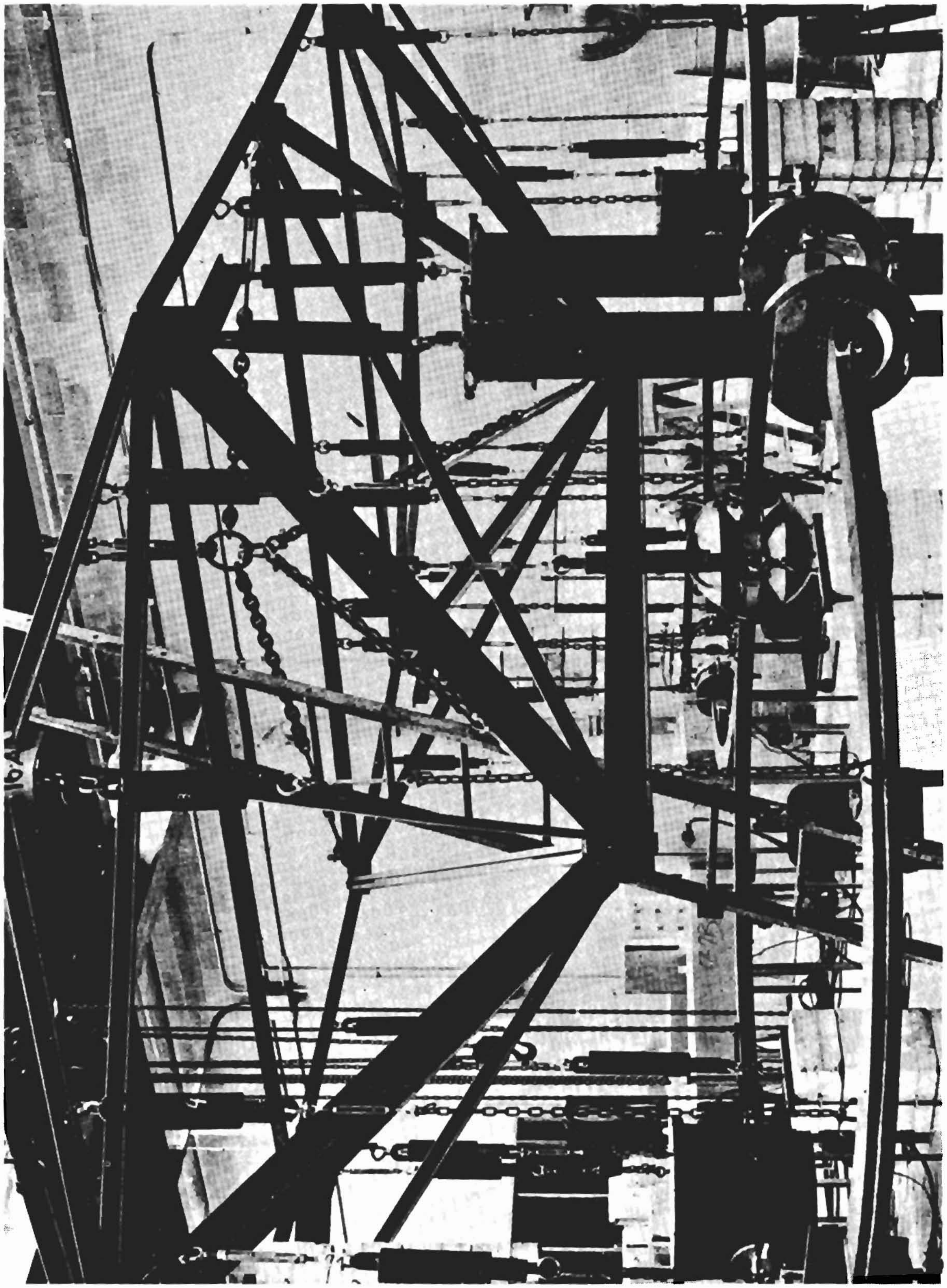


Fig 5 - Vacuum chamber suspended by the steel spider

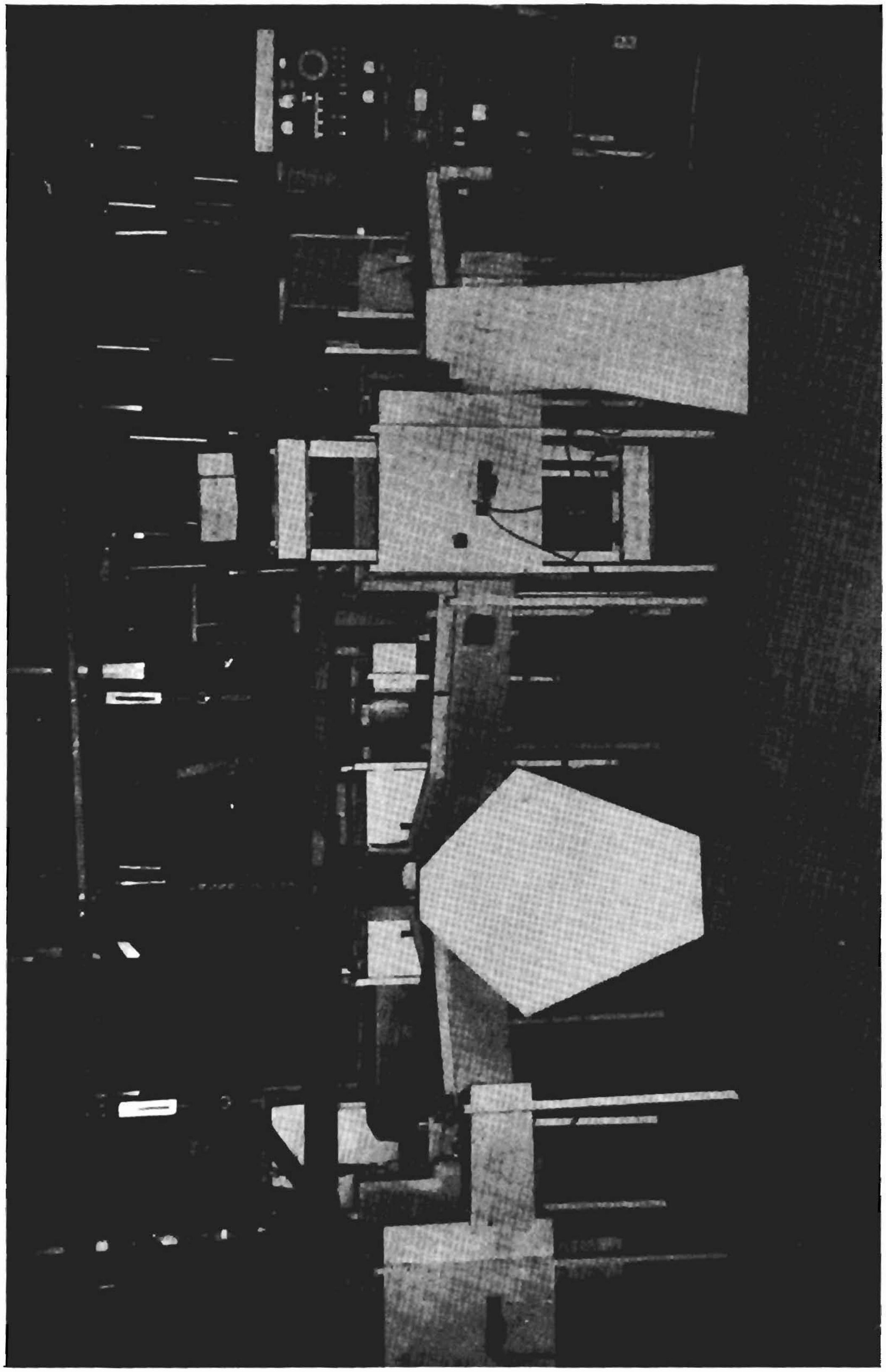


Fig. 6 - Vacuum chamber in oven during bake-out

considerable difficulties, due to the need for running the inflector in the ultra-high vacuum system. A schematic of the delay-line inflector is shown in Fig. 7. The object is to obtain a localized magnetic field of short duration. In the present case, a field of approximately 2000 gauss is obtained with a filling (and emptying) time of the magnet of about 100 nsec. The circuitry for the ferrite-core pulsed magnet is shown in Fig. 8, with the magnet proper shown in Fig. 9. Currents feeding the magnet are of the order of 5000 amp. The main problems connected with the delay-line inflector were transmission-line failure, condenser failure, overheating of the original ferrites due to a low Q value and a low curie point, electric conduction of ferrites at higher temperatures, and (possibly) ferrite contamination of the ultra-high vacuum. Recent evidence indicates that the magnet units never reached the full bake temperature in the bake times originally used. It is thought now that the vacuum contamination was a result of oil-grinding of the ferrites. It is possible to avoid condenser failures by significantly overdesigning the system. All the other problems appear to have been solved. Certainly, for any large storage-ring project, considerable attention should be given to long-term life testing of all components which go into the high vacuum. It appears that it is still advisable to build the delay-line inflector within the vacuum system instead of using thin-walled vacuum chambers.

In connection with bigger storage rings, possibly cryo-pumping may be the best approach not only to obtain a better vacuum, but also to make it unnecessary to use high bake temperatures. Further, it seems essential to be able to valve off experimental straight sections. Reliable "bake-when-closed" valves do not exist yet in large sizes, in spite of work on the subject by many groups.

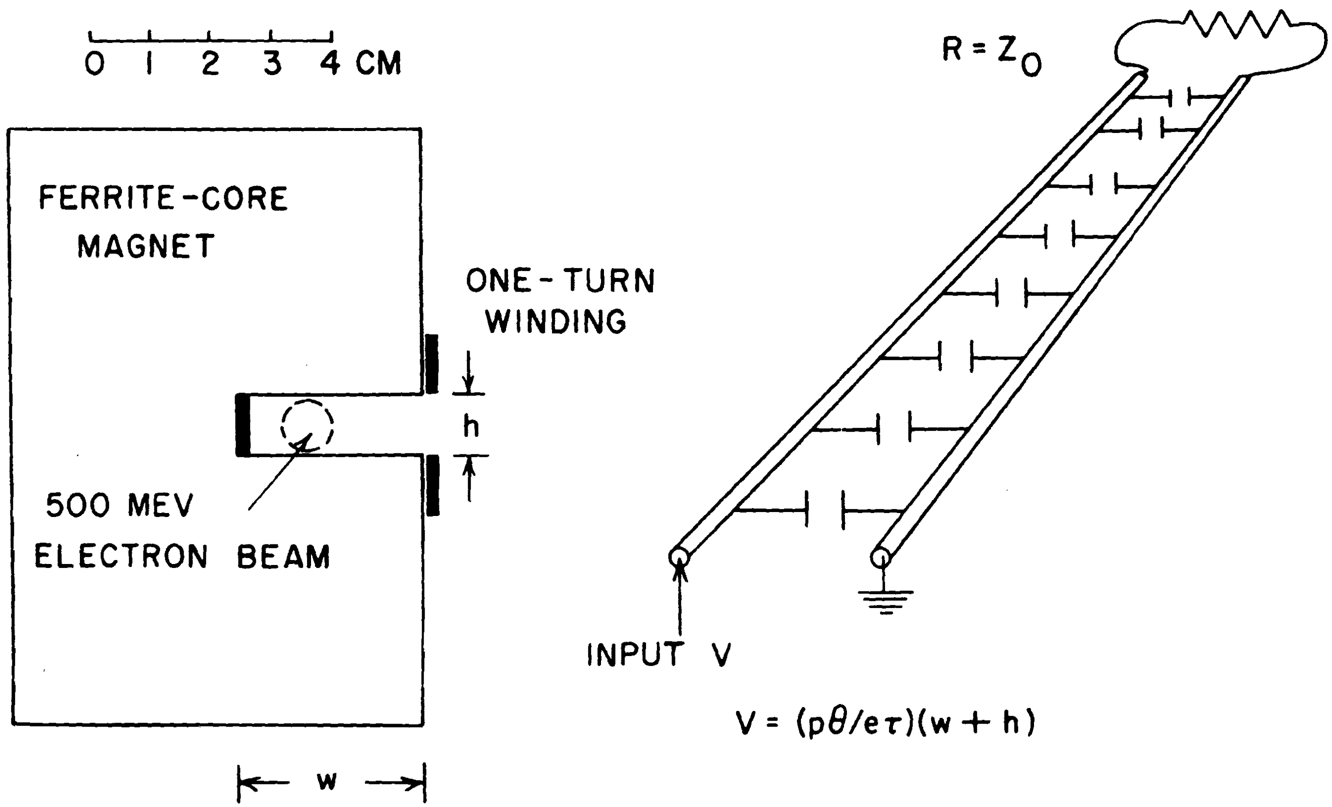


Fig. 7 - Schematic of the delay-line inflector

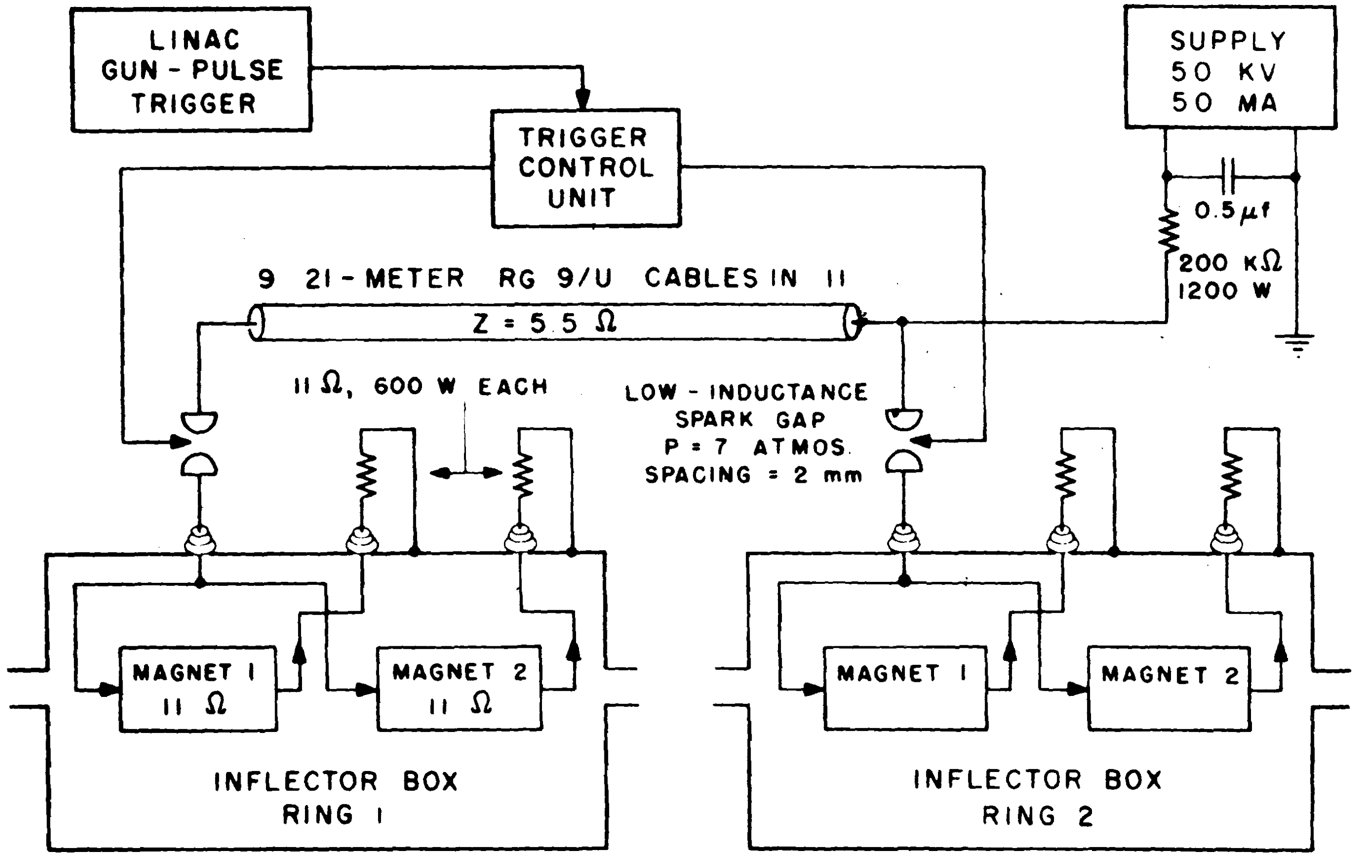


Fig. 8 - Circuit for pulsing the delay-line inflector

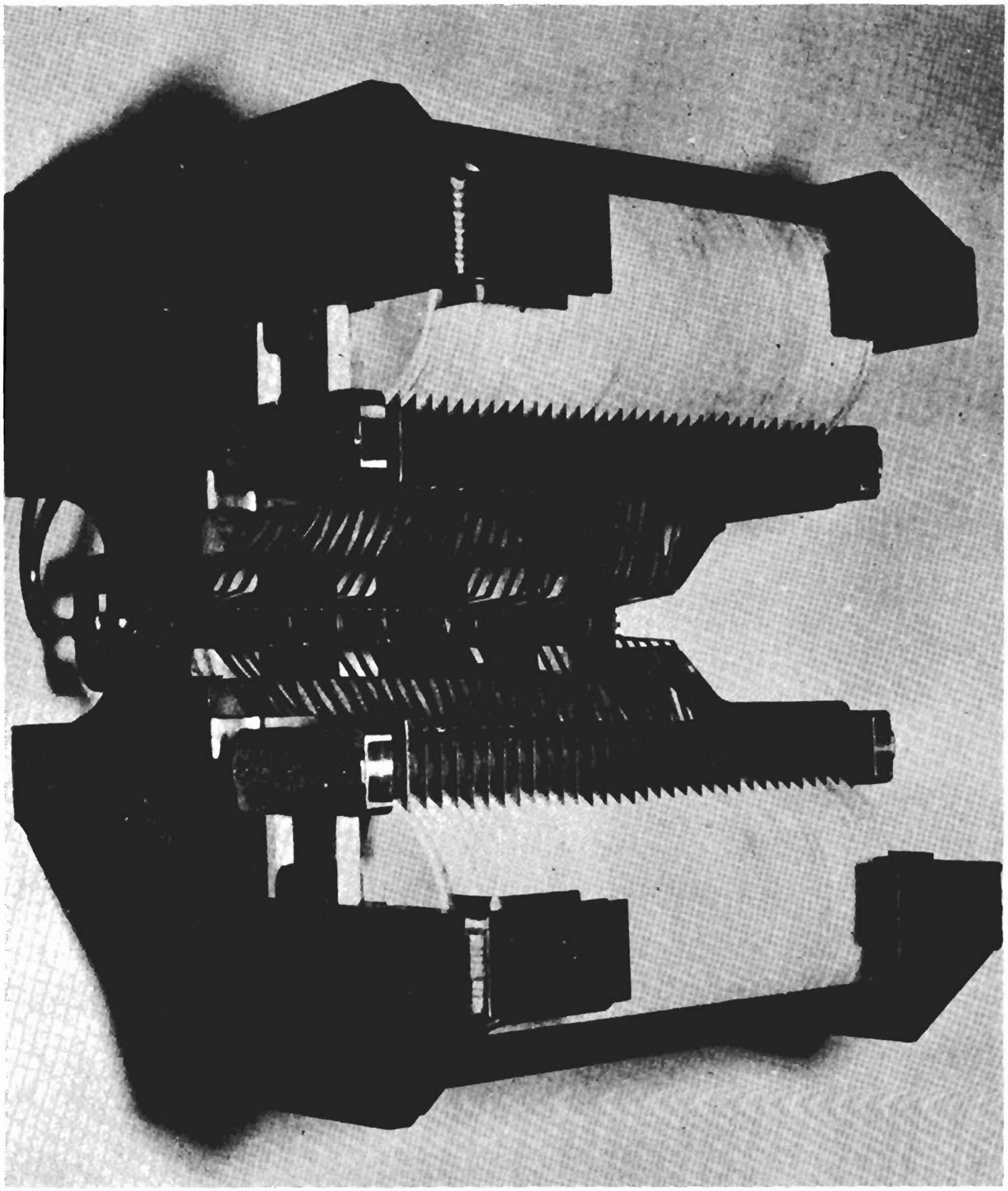


Fig. 9 - Ferrite-core inflector magnet

During tests of the Princeton-Stanford machine, two high-beam-intensity effects have been observed. The first one is a rather violent pressure rise due to the synchrotron light. Supporting evidence for this is that the effect is not related to the injector-linac operation. As soon as a few pulses are stored, there is a drastic change in the vacuum pressure. The pressure proves to be exactly proportional to the stored beam intensity. Also, it proves to be strongly energy dependent. There is roughly a fourth-power dependence on energy. Typically, a 30-ma beam with energy of about 300 Mev radiates approximately 30 watts. With this circulating beam, the pressure rises by a factor of 300 from about 3×10^{-9} mm Hg to about 10^{-6} mm Hg. That it is not a thermal effect is illustrated by the fact that the pressure doubles with a total power in the radiated synchrotron light of approximately one-tenth of a watt, distributed over 40 feet of vacuum chamber. Large photoelectric currents are found to flow to each of the clearing electrodes. Typically, values of 100 μa are observed. A guess is that the pressure rise is related to the photocurrent, in fact that the soft gamma rays from the synchrotron light make photoelectrons which are in turn responsible for cracking the pump oil.

The second effect is the high-beam-density instability. The maximum density obtained so far is of the order of 3×10^{10} electrons per cm^3, i.e., about 10^{10} electrons in a beam volume of $60 \times 0.01 \times 0.5$ cm^3. (Here the small vertical height is unproven, but scaled from Frascati observations. It could be too small by a factor of 10.) With no special manipulation, it is possible to maintain stability with this beam. But, if all clearing-electrode fields are turned on, in order to sweep out all positive ions, the beam becomes unstable at about 5×10^9 electrons per cm^3. The instability shows a rather slow vertical growth, lasting at least many milliseconds (approximately 10^5 turns or more). It has been suggested by D. Ritson that the vertical instability may be due to image-charge effects. Work at MURA and analysis by A. Sessler confirms this, although the detailed mechanism appears to be rather different from the one Ritson assumed. No attempts have been made yet to reinforce the effect by means of applied rf fields (rf "knockout") as was done at MURA. At present, an octupole magnet is available to introduce nonlinearities to eliminate the vertical instability. This will be used or, alternatively, the positive ions will be left in the system by not using the clearing electrodes.

E.D. Courant (BNL): Has the introduction of the octupole field been tried yet?

G.K. O'Neill: This has not been done. Ritson's theory suggested the need for some nonlinearities, but it seems that the vertical instability observed by the MURA group is really the same effect. The MURA storage ring certainly is a rather nonlinear machine. Therefore, it is not certain what the effect of the octupole magnet will be. However, with ions in the storage ring, sufficiently high currents have been observed for the experiment which was planned.

In considering what can be done with electron storage rings, it is useful to consider some scaling laws on the "Touschek effect", i.e., the loss of electrons in a single circulating beam due to coulomb scattering, which can transfer some energy of the radial betatron oscillations into forward motion, sufficient to remove particles from the phase-stable rf bucket.

The beam volume in a radiation-damped electron storage ring is given by

$$\text{"beam volume"} \cong E^3 R^{3/2},$$

where R is the radius of the ring and E the energy of the circulating electrons. This holds for a constant allowable $\Delta p/p$ and it assumes that the vertical size is determined by coupling of the radial betatron oscillation into the vertical motion.

With a constant rf voltage, the energy dependence becomes

$$\text{"beam volume"} \cong E^{3.5} R^{3/2} .$$

Measurements done at Frascati tend to verify this.

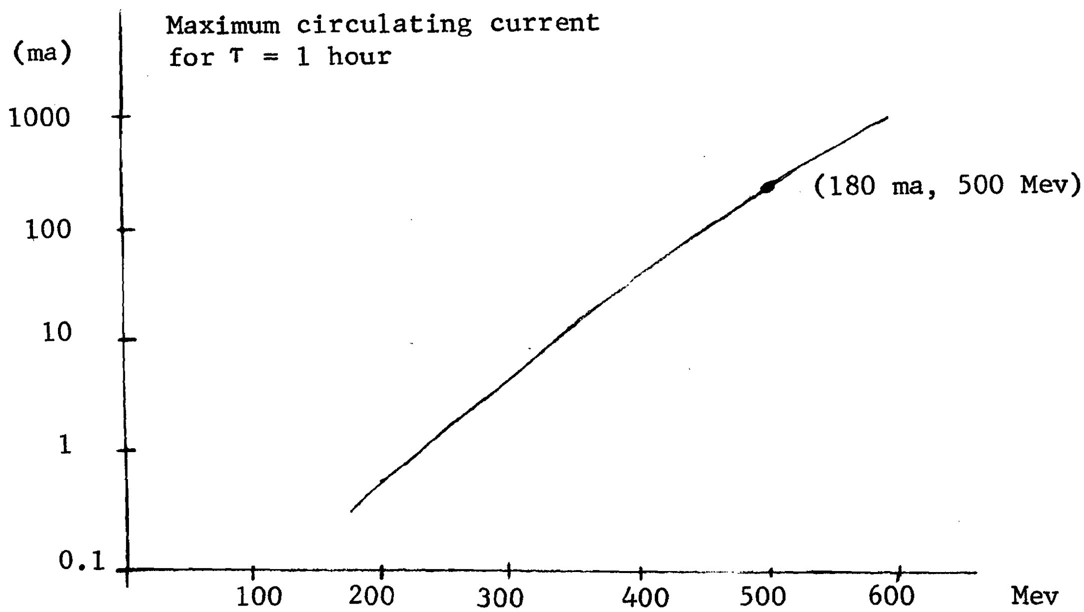
Considering all factors involved in the derivation of the "Touschek effect", it follows that, with normalization to a constant circulating current, the loss rate is dependent on energy only and not on the radius of the machine. This leads to

$$\tau_e \cong E^6 \qquad \text{for } \frac{\Delta p}{p} = \text{constant}$$

and

$$\tau_e \cong E^{5.5} \qquad \text{for constant rf voltage.}$$

The "Touschek effect" can be summarized both for the AdA machine and the Princeton-Stanford machine by the following graph, where the measured loss rates observed at Orsay are scaled to the E^6 power law. The current corresponding to the 500-Mev energy level for the Princeton-Stanford machine would be 180 ma for a one-hour lifetime. Since this is well above the measured instability point, the "Touschek effect" is dominant only below 300 Mev.



Assuming a one-hour lifetime, one should expect counting rates proportional to E^7. With constant σ, the counting rate is proportional to $E^{12} \times E^{-3}$, where the E^{-3} factor is due to the beam volume. The cross sections of interest vary as E^{-2}, leading to the E^7 power law.

Using this power law and scaling from the AdA experience, it is expected that the following counting rates can be obtained with the Princeton-Stanford ring for scattering angles above 35° in the center-of-mass system (cross sections of the order of 10^{-30} cm^2/sterad).

i(ma) for a 1-hour lifetime	E(Mev)	Counting rate
180 (probably above instability limit)	500	1 count/sec
45	400	1 count/5 sec
8	300	1 count/30 sec
0.7	200	1 count/600 sec

From this, it is obviously advantageous to work at the highest possible energy.

Discussion

M.Q. Barton (BNL): Do you hope to increase the circulating current over the 30 ma obtained so far in connection with vertical instabilities?

G.K. O'Neill: With the ions left in the system we have not observed the instability. When we turn off the clearing fields, the limit on current becomes the pressure rise. Presumably in our next runs we will be able to stack higher currents, and may see the instability even with the ions present.

C.L. Gould (BNL): Did photodesorption take place in bursts or was this a continuous evolvement?

G.K. O'Neill: It was continuous.

C.L. Gould: This effect was studied at Westinghouse by Lange and Fox in the ultraviolet region.

G.K. O'Neill: I had the impression that their results were not directly relevant to our problem. In fact, if one takes the cross sections for direct photodesorption, these prove to be too small to explain the effect. Factors of 10^4 are missing. That is why the explanation of the two-step process involving the photoelectrons seems more reasonable.

J.P. Blewett (BNL): With the vertical instability, did the beam move as a whole or was it blowing up?

G.K. O'Neill: We don't know.

J.P. Blewett: The MURA experience seems to indicate that the beam moves as a whole. In this case, it should be possible to feed back a correcting signal from a vertical pickup electrode to damp the instability.

G.K. O'Neill: Certainly sufficient time is available to do this if the beam moves coherently.

J.P. Blewett: What was the purpose of the clearing electrodes originally?

G.K. O'Neill: Calculations showed that at currents below one ampere, instabilities were possible due to trapped ions.

M.Q. Barton: Could the ions be cleared radially?

G.K. O'Neill: It is somewhat difficult to maintain an electric field which has always a component along the azimuth of the ring, which is presumably needed. With crossed electric and magnetic field, the motion would be cycloidal and it would be difficult to remove the ions.

H. Bruck (Saclay): At Orsay the injection system is separate from the ultra-high vacuum system in contrast to what is described here. A vacuum chamber with a stainless-steel window with wall thickness of 12 microns and diameter of 1 cm was used. With a pulsed septum magnet, 100 gauss over 20 cm, it is possible to perturb a closed orbit with programmed bump sufficiently into a new closed orbit in about 70 nanoseconds or in about 4 turns to accommodate injection.