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Progress Report on AdA (Frascati Storage Ring).

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Summary. — The Frascati-storage ring AdA has reached a capture rate of 8 electrons (or positrons) per second at a distance of 15 m from the synchrotron. The maximum mean life so far observed is 5 h.

In the present note we want to report on the progress made on the Frascati colliding beam experiment, which has been described earlier in this journal ([1]).

The magnet was assembled and mounted at a distance of about 15 metres from the target of the synchrotron by the end of February 1961. The arrangement is shown in Fig. 1. The magnet is supported on a tripod, which can move on rails in a direction perpendicular to the beam of the synchrotron. In this way either of the two targets placed in the doughnut of AdA, outside of its equilibrium orbit, can be exposed to the beam, thus enabling one to charge with either positrons or electrons. Small rotations of the magnet, the translational movement of the tripod as well as the movement of one of the targets can be controlled from outside the beam area. The picture shows also the relative position of the RF cavity (1), the titanium pump (2) and one of the injection ports (3). The synchrotron beam ends in a Wilson type quantameter (4).

([1]) C. BERNARDINI, G. F. CORAZZA, G. GHIGO and B. TOUSCHEK: *Nuovo Cimento*, **18**, 1293 (1960) (referred to as I).

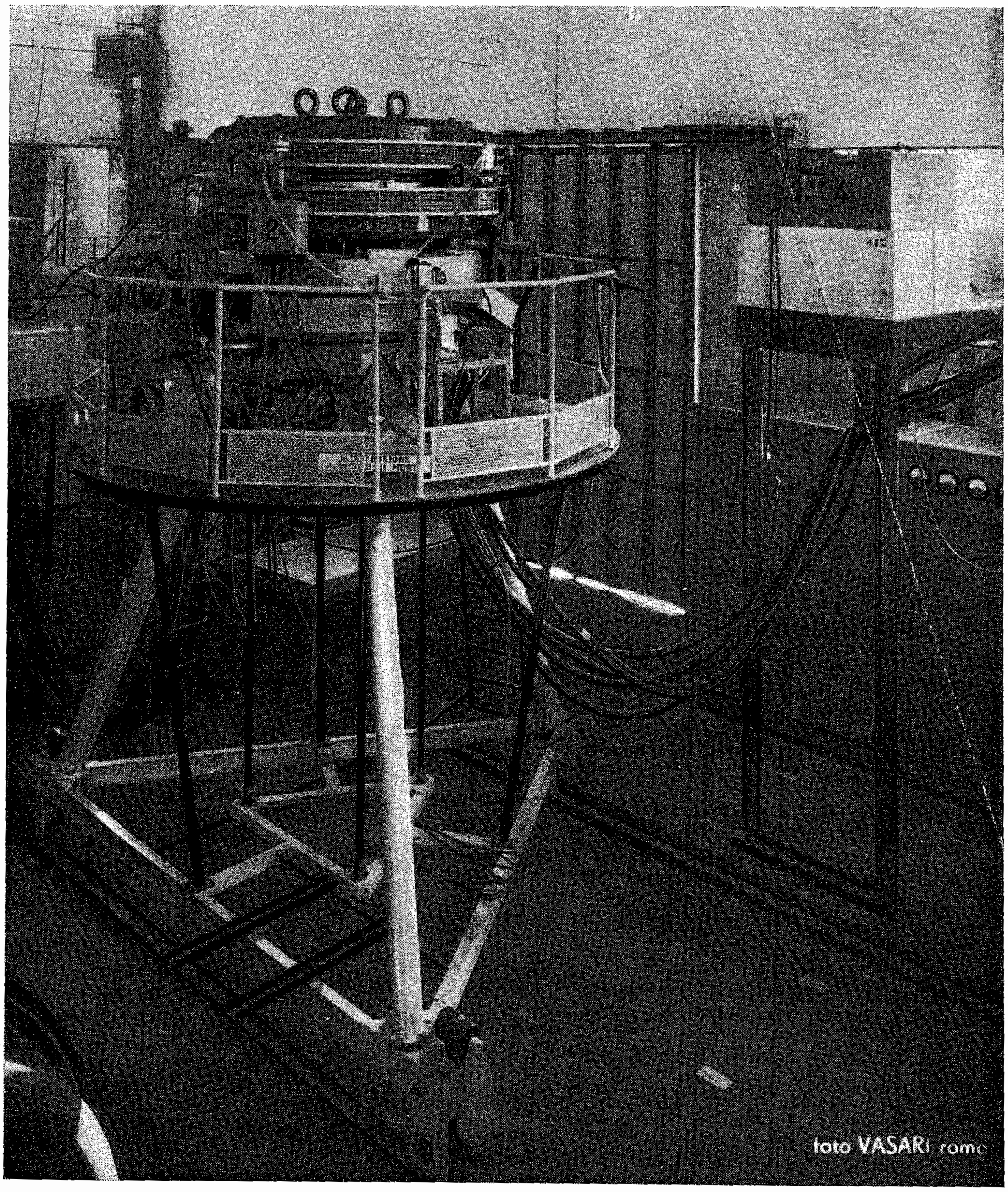

Fig. 1. – View of the storage ring.

The magnet was tested in the period from February to May 1961. This was done by studying a coasting beam of electrons or positrons. These particles were produced in a Ta-target of 1/10 radiation length of thickness, placed in the useful zone of the magnet. The beam was followed for up to about 80 revolutions by observing multiple passages of its particles through a thin scintillation counter. This experiment showed that the aperture of the magnet had a useful width of about 5 cm for electrons of energy up to about 220 MeV. Above this energy saturation sets in but a useful width of 2 cm persists for energies of about 250 MeV.

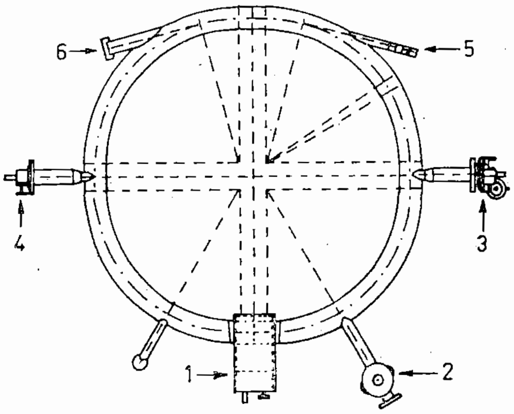

Fig. 2. – The vacuum chamber.

In May a stainless steel doughnut with the RF-cavity was introduced into the magnet. Its design is shown in Fig. 2. (1) represents the cavity (147 MHz, $Q \simeq 600$), (2) the Ti pump, (3) is the remote-controlled target, (4) the hand-controlled target and (5) and (6) are observation ports, allowing the measurement of the synchrotron radiation emitted respectively by electrons and positrons. The initial vacuum (with the radiofrequency at about 5 kV) was $5 \cdot 10^{-6}$ mm, which with time improved to about $3 \cdot 10^{-7}$ mm. A photomultiplier (6342 RCA) was mounted at the observation port (6). Calculation had shown that a circulating electron should produce a signal about 3 times the thermal background and that it should be possible to observe single electrons which circulate for at least a millisecond. By the end of May the first runs had given the following results:

1) Electrons can be accumulated and kept circulating with a lifetime of about 20 s — in agreement with the theory.

2) The energy of the stored electrons can be changed at will by changing the field in the magnet (the signal of the photomultiplier starts to diminish considerably at energies below 150 MeV). Lateral displacements of the machine do not lead to the loss of electrons.

3) Inverting the magnetic field it was found that there is no noticeable difference between electrons and positrons.

4) The capture efficiency (about 0.4 electrons/s) is a factor 12 below the calculated value (cf. I) or about below a more realistic calculation carried out later.

It was also possible to photograph the light emitted by a few stored electrons. Such a photograph is shown in Fig. 3. The radial width (1.5 mm) corresponds to the theoretical prediction for electrons of 220 MeV, and the height which is determined by the pressure of the residual gas corresponds well to the pressure at the time of the experiment.

Fig. 3. – Cross-section of the circulating beam.

In the period June-December 1961 work proceeded along two main lines: the development of a high vacuum doughnut and the search for a method of improving the capture efficiency. The latter problem reduced essentially to that of finding a way of speeding up the process by which the electrons are carried away from the target. In the previous tests the only mechanism available was the damping of the betatron and synchrotron oscillations, by which the electrons are carried away from the target at a rate of about $3 \cdot 10^{-6}$ cm/revolution. We tried to improve on this mechanism by finding other means of moving the equilibrium orbit during the time of the synchrotron pulse. We hoped to achieve displacements of the orbit of the order of millimetres in times of the order of about 0.1 μs and it was thought that this should increase the intensity by a factor of order 2, which could then be further improved by shortening the synchrotron pulse from 15 μs to about 0.1 μs, so that the expected overall improvement would have been of the order of a factor 300. A rapid displacement of the equilibrium orbit can be effected in two ways: either by modulating the frequency of the RF system or by using a pulsed magnetic field. Since the second method required fewer modifications of the existing equipment, a coil capable of producing fields of up to 500 gauss over an area of 8 cm (length) times 5 cm (width) was placed in a stainless steel box, which was welded to the doughnut in place of the second target. Experiments carried out with various methods of pulsing the coil did not give the expected results but did improve the capture efficiency by a factor 5 if the magnetic pulse (of about 2 μs duration) was fired at about 30 μs after the maximum of the γ-ray pulse. The sign of the pulsed magnetic field had no influence on this effect.

Quite a similar result was obtained by a negative 60 % modulation of the amplitude (and possibly the phase) of the RF. If the modulation lasted about 2 μs again an improvement by a factor 5 was found but only if the RF modulation was delayed by about 30 μs relative to the maximum of the γ-ray pulse. None of these effects seems to be capable of substantial improvement by shortening the duty-cycle.

Later a « gentle » modulation of the RF (— 35 % lasting about 30 μs) was tried. This has given an improvement by a factor 20, so that with maximum intensity of the synchrotron and with a distance target-target of about 15 m we can now count on a rate of capture of more than 8 electrons/s. It was also found that in a doughnut with a mean life of about 3 minutes, neither the gentle modulation, nor magnetic pulsing had a measurable influence on the lifetime.

Although so far we have not been able to understand why rapid pulsing has no immediate effect on the rate of acceptance, we do feel fairly confident that we understand the mechanism of delayed acceptance: electrons with an energy of a few MeV above the synchronous energy will spiral away from the target (under the action of their uncompensated radiation loss) at a rate which on the average is about 50 times bigger than the rate of damping of the betatron oscillations. (For electrons injected with a certain phase relative to the RF the rate of spiralling may temporarily be even more rapid). After a time of the order of 30 μs these electrons will have reached the « synchronous » energy. A suitable small perturbation can then shift them from the unstable region of the phase diagram (where the spiralling takes place) into the stable region, where they are then definitely stored.

It is felt that the « gentle » modulation method, which has only been tested for one run is still capable of further improvement.

The high vacuum doughnut was completed in December. It is made of stainless steel. The RF cavity is made of stainless steel electrolytically coated with a layer of silver. Degassing—with the Ti-pump backed by a diffusion pump with liquid air trap—proceeded over several days at temperatures of up to 350°.

When this doughnut was mounted it was found difficult (owing to overheating) to run the RF voltage beyond 5 kV. We therefore decided to test lifetimes at a lower energy of about 175 MeV. To this end the decay of a beam of 80 electrons was observed over an interval of 10 hours. The curve is shown in Fig. 4 and it is seen that the lifetime is about 5 hours, in good agreement with the value of 6 hours, which corresponds to the vacuum of $4\cdot10^{-9}$ mm Hg read on an Edwards gauge.

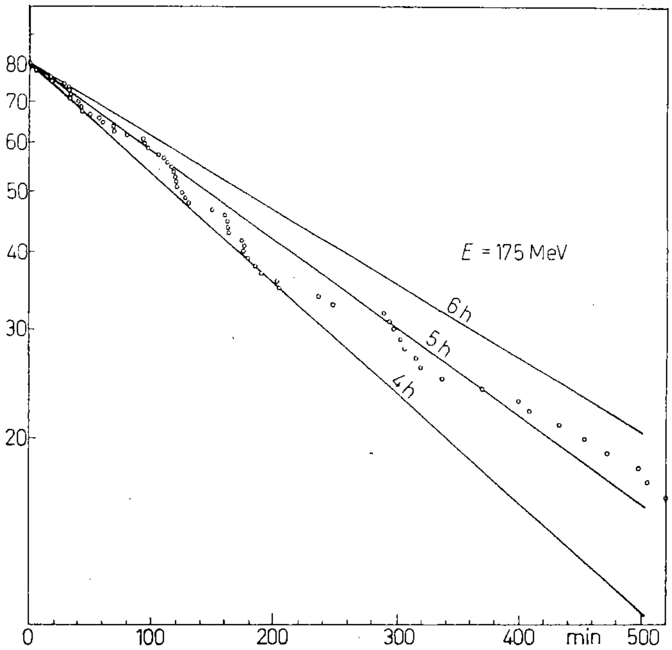

Fig. 4. – Observed decay of 82 stored electrons in AdA at 175 MeV energy. Straight lines are drawn for convenience corresponding to a lifetime of 4, 5 and 6 h. Note the apparent increase of lifetime during the period of observation. This is due to a corresponding improvement of the vacuum.

The work of the next quarter will proceed along the following lines: 1) improvement of the RF system and preparation of a new high vacuum doughnut; 2) further exploration of methods to improve the capture rate and 3) preparation of the site for the actual electron-positron experiments.

To diminish the distance target-target to about 3.5 m it is planned to mount the magnet of AdA in a cradle the design of which is shown in Fig. 5. The magnet is thus allowed to rotate around a horizontal axis, perpendicular to the synchrotron beam in such a way that the target of AdA always stays in the beam. In this way AdA will first be charged—for several hours—with positrons. With the positrons stored the magnet will then be rotated by 180° and the storage of electrons begins. Experiments which are little sensitive to the background can be started in this period. When the ring is filled with both charges the synchrotron will be switched off and the actual period of experimentation will then begin. This method of experimentation requires that 1) we improve the rate of capture by a further factor of 5, 2) that the vacuum is improved beyond 10^{-9} mm and 3) that the RF voltage is raised by at least 2 kV, *i.e.* to about 7.5 kV.

It should, however, be noted that even if none of these improvements can

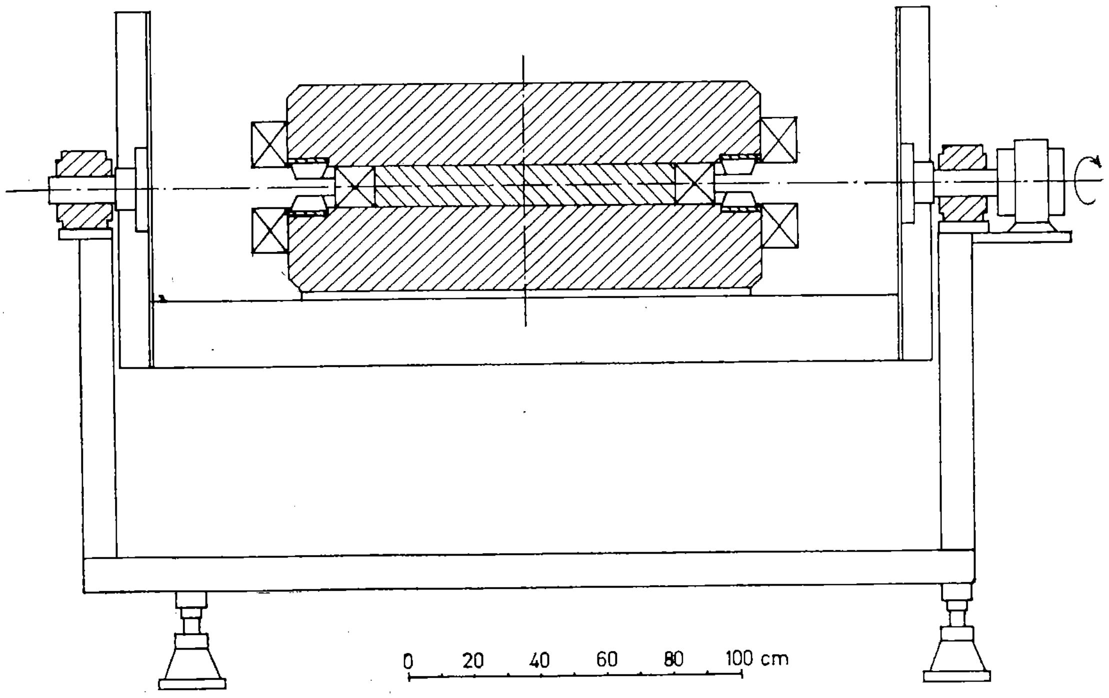

Fig. 5. – Design of the cradle for mounting AdA nearer to the synchrotron.

be realized AdA as it is would already allow for experimentation, provided that one of the existing linear accelerators of between 500 and 1000 MeV could be used as a γ-ray source.

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It is a pleasure to give our thanks for valuable help to the staff of the National Physical Laboratories in Frascati.

The authors particularly want to thank Dr. A. Massarotti and Dr. M. Puglisi for the design and construction of the RF system.

They are also grateful to Dr. G. Di Giugno for his contribution to the experimental work and Dr. F. Amman for several valuable discussions.

RIASSUNTO

L'Anello di Accumulazione AdA di Frascati ha raggiunto una capacità di cattura di 8 elettroni (o positroni) per secondo alla distanza di 15 m dal sincrotrone. La vita media massima finora osservata è di 5 h.