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POSSIBLE USE OF THE CEA DIRECTLY AS A COLLIDING BEAM FACILITY

K. W. Robinson

G. A. Voss

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MASSACHUSETTS INSTITUTE OF TECHNOLOGY
and HARVARD UNIVERSITY

CAMBRIDGE ELECTRON ACCELERATOR

CAMBRIDGE 38, MASSACHUSETTS

HARVARD UNIVERSITY
42 OXFORD STREET
CAMBRIDGE, MASS. 02138

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K. W. Robinson
G. A. Voss

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The beam storage scheme described in TM-147 has several drawbacks relative to a regular storage ring: (1) the short length of the straight sections in our synchrotron and the limited space around these make it difficult to perform a colliding beam experiment in such a straight section; (2) the machine vacuum is much poorer than that of a storage ring and consequently much higher backgrounds in the interaction region would be expected; (3) it is difficult to keep the positron and electron beams separate in the CEA ring because many of the straight sections which might contain electrostatic deflection plates are already preempted by RF cavities, targets, etc.; (4) the average luminosity of 2.7×10^{29} $(cm^2\ sec)^{-1}$ (see TM-147) must be considered an optimistic estimate and even this number is down by one or more orders of magnitude from the luminosity that Stanford quotes for its storage ring.

A modification of this scheme might overcome difficulties and make prospects for colliding beam experiments in our synchrotron more attractive.

As before, we would inject electrons and positrons in a multicycle injection scheme such as is described in TM-147. The particles will be accelerated to their maximum energy and decelerated to an energy slightly below injection energy which is of the order of 100 MeV. Some of the present damping of synchrotron oscillation will be transferred to the horizontal betatron oscillation be means of a damping magnet as described in TM-147 Thus all three kinds of oscillations (synchrotron oscillations and horizontal and vertical betatron oscillations) will be damped due to radiation processes. It should be possible to achieve electron and positron beam currents of the order of 10 - 100ma.

The problem of separating the two beams could be solved easily if only 10% of the circumference of the ring is filled and if two electrostatic beam bumps are provided at opposite sides of the ring. It may be possible to provide a conducting layer in the new type of ceramic vacuum chamber to which an electrostatic potential can be applied to separate the two beams over the whol circumference. It would then be possible to fill a larger fraction of the total circumference.

After the electron and positron beams have been accumulated in the CEA, the A.C. component of the magnet current will be turned off. The D.C. current will then be adjusted to obtain any desired energy in the range of about 1 to 5 GeV. We then propose to eject electrons and positrons simultaneously into a bypass discussed below.

Ejection is accomplished within a single turn and with 100% extraction efficiency. The electron and positron beams are made to intersect in the middle of the bypass and then injected back into the synchrotron. The particles will then continue to interact for the lifetime of the stored beams, then the cycle will be repeated.

The advantages of having the two beams collide in a suitable bypass are as follows:

1. Because the bypass consists of DC magnets and an all-metal vacuum system in which the residual gas pressure is several orders of magnitude better than that in the synchrotron proper, the background in the interaction region is greatly reduced.

2. Because the bypass includes a long unobstructed straight section, installation of any experimental equipment is greatly facilitated.

3. The value of the amplitude function (beta function) in

the interaction region can be made as small as .5" as compared to 289" in a straight section of the synchrotron. Since the incoherent beam-beam-instability-limited luminosity of a storage device is proportional to $\frac{1}{\beta}$ in the interaction region, the small size of the beta function provides great advantage.

The following section gives some technical details as to the new scheme. However, it presents only one of many possible solutions. At this time, the design is highly flexible.

A. THE BYPASS

For the sake of discussion, we assume that electrons are ejected from SS 10 (Straight Section 10) by means of a septum magnet which gives a bending angle of about 40mrads. The septum magnet is on the outside of SS 10 and the electrons leave the synchrotron through the fringing field of magnet 10 (see Figure #1) The electrons are then bent by DC-powered magnets to a path parallel to magnet #13. The bypass as a whole has complete symmetry with respect to a vertical plane through the centers of magnets 13 and 37. The first requirement which has to be fulfilled is that the additional pathlength for particles going through the bypass instead of through the synchrotron be an integral number of wavelengths of the synchrotron RF acceleration system so that particles will stay in phase with the accelerating voltage when they are put back into the ring. Figure #1 assumes the additional pathlength to be 2 RF wavelengths. Since the bypass has to be symmetrical, the momentum vector in the middle must be zero or have only a displacement component. We assume that both components of the momentum vector are zero. This is achieved by using a small gradient in the septum magnet in SS 10 and a second horizontal focusing quadrupole lens 203" downstream from SS 11 (for simplicity we describe only one-half of the bypass). There is a horizontal beam cross-over 180.5" upstream from the interaction region. A virtual vertical-beam cross-over occurs 414" upstream from the interaction region. Two quadrupole lenses located 50" and 90" from the interacting region produce second cross-overs - horizontal and vertical - in the middle of the bypass, i.e., in the interaction region. Since the system is symmetrical, the ellipses at the cross-overs change back to ellipses that match the acceptance in SS 17. The focal length of the lenses of the doublet are of the order of +50" and -30", respectively.

B. SEPARATING THE ELECTRON AND POSITRON BEAMS

The two beams are kept separate vertically between SS 35 to 40 and SS 11 to 16. This is accomplished by electrostatic deflection plates, 22" in length and 1" apart; these are mounted in SS 35 and

40 and in SS 11 and 16 and slightly shorter ones are mounted in 37, 38, 13 and 14. The resulting separation of the beams (at 5 BeV) is 200 mils. It appears possible that provision could be made for keeping the beams vertically separated throughout a greater fraction of the circumference of the ring, should this be desirable.

C. SINGLE TURN EJECTION AND INJECTION

The ejection and injection systems in SS 10 and SS 17 must be turned on in a fraction of a microsecond. They must remain on for the lifetime of the stored beam. We propose to do this by means of two kicker magnets located in SS 32 and 43. These are single-turn, ferrite, picture frame magnets. The open cross section of such magnet is 1" x 4". The length is 22". When powered with a current of 700 amps, it produces a bending angle of 1.15 milliradians and produces a distorted orbit the first time electrons and positrons travel through these magnets. The distortion is symmetrical with respect to magnet 37 where it has its maximum of .94" (.66" in the SS). The distortion is maintained by the bypass system, consequently the kicker magnets must be turned off before electrons and positrons travel through them again. If only 10% of the ring is filled, the turn-on and turn-off times of these magnets can be as long as .5 microseconds. This fact, together with the very small inductance (2.8μH) of each of these magnets, makes the powering less difficult than is the case with our present inflector. Since an orbit distortion which is symmetrical about the vertical plane through magnets 37 and 13 has a very small amplitude in SS 10 and SS 17, we might install two additional septum magnets at SS 8 and SS 19 to bend the beams into the septum magnets in SS 10 and 17. These additional septum magnets would have to bend the beams only by a few mrads. For this reason they can have a considerably smaller outer conductor which in turn makes it easier for the electrons to make the jump during the single turn ejection.

D. POSITRON FILLING

Accumulating a large circulating beam of positrons requires a sufficiently long lifetime such that the desired circulating current can be built up from small injected currents each pulse. If the RF voltage is sufficiently high that there are no losses from the quantum-induced synchrotron oscillations, the lifetime will be determined by single scattering in the vertical plane from the residual gas at the lower energy part of the acceleration cycle. If an average effective pressure of 10^{-7} mm of air can be attained, with a maximum energy of 3 GeV and a minimum energy of 100 MeV, the lifetime is calculated to be about 90 seconds.

In the CEA synchrotron, the radial betatron oscillations are antidamped by the synchrotron radiation with a damping rate of about $P_r/2U$ (rate of radiation loss/twice the energy). The effect of the damping magnet is to transfer a damping rate of P_r/U from the synchrotron oscillations to the radial betatron oscillations thereby providing a damping time of 16 milliseconds at 3 GeV, and a total damping of the radial betatron oscillations -- in one acceleration cycle with a maximum energy of 3 GeV -- of a factor of 1.4 in amplitude. At 4 BeV, this factor is 2.1 and at 5 BeV it is 4.73. The factor of 1.4 at 3 BeV is probably not sufficient to allow positrons to be injected every cycle. If we inject positrons every other cycle, with a lifetime of 90 seconds, it will be necessary to inject about 60 microamperes every other cycle to attain a circulating current of 100 milliamperes of positrons in 90 seconds.

It has been determined that the usable radial aperture of the synchrotron at 100 MeV is about 6cm. An aperture of about 3cm must be allowed at injection energy for the circulating beam, in order that the losses due to the quantum-induced width of the beam will not be excessive. Since the injected positrons must be outside the aperture of the circulating beam, there will be a radial aperture of 1.5cm available for positron injection. The injection will probably be done with a septum magnet. The equilibrium orbit will be distorted 1.5cm toward the septum magnet at the time of injection so that the aperture of the circulating beam is at the edge of the septum. After injection, the equilibrium orbit will be moved away from the septum in a time comparable to one turn, so that the injected positrons will not hit the septum on subsequent turns.

E. LUMINOSITY

The luminosity which can be attained may be governed by many factors. If the coherent instabilities can be controlled, the limit for the incoherent beam-beam effect is thought to be determined by the focussing effect ($\Delta\nu$) of one beam on the other. The luminosity which can be attained for a limit of $\Delta\nu$ varies inversely as the value of β in the interaction region. Since it is planned to have a very small value of β (comparable to one inch) in the interaction region, it is possible in principle to have quite a high luminosity. However, it may not be possible to achieve this maximum luminosity due to the size of the beams and the fact that the small size and β in the interaction region can only be effective over one RF bunch.

The radial size of the beam is determined by the equilibrium condition due to radiation damping and quantum emission and is estimated to be about 3mm at 3 GeV as measured in a synchrotron straight section. The vertical height of the beam is determined by the multiple scattering and the radiation damping. At an effective pressure of 10^{-7}mm of air, this results in a beam height of about .1mm at 3 GeV. If we assume an effective β in both planes of 2 inches in the interaction region, these dimensions will be reduced by a factor of 12 in the interaction region.

To calculate the luminosity we assume that it is possible to fill half the circumference to a peak current of 100 milliamperes in each beam. This results in a peak luminosity of about $7.2 \times 10^{31} sec^{-1} cm^{-2}$. With an effective β of 2 inches in the interaction region this produces a focussing effect of one beam on the other of $\Delta\nu = .05$ at the center of the beam.

At a pressure of 10^{-7}mm the lifetime of the stored beams at 3 GeV is about 30 minutes. It should then be possible to achieve a duty cycle of 60%. Since the circumference is assumed to be half filled, this will result in an average luminosity of $2.2 \times 10^{31} cm^{-2} sec^{-1}$.

If the simple vertical electrostatic method of separating the beam is applied between magnets 35 to 40 only, it may be possible only to fill 10% of the circumference of the ring. With 100ma of peak current, this would reduce the luminosity by a factor of 5. If the average current is limited by the RF power, it would then be possible to obtain higher peak circulating currants and increase the luminosity. A peak current of 225ma would make up for the loss of luminosity due to the 10% filling and result in a luminosity of $2 \times 10^{31} sec^{-1} cm^{-2}$.

GAV:KWR:y

Attachments (1): Figure #1

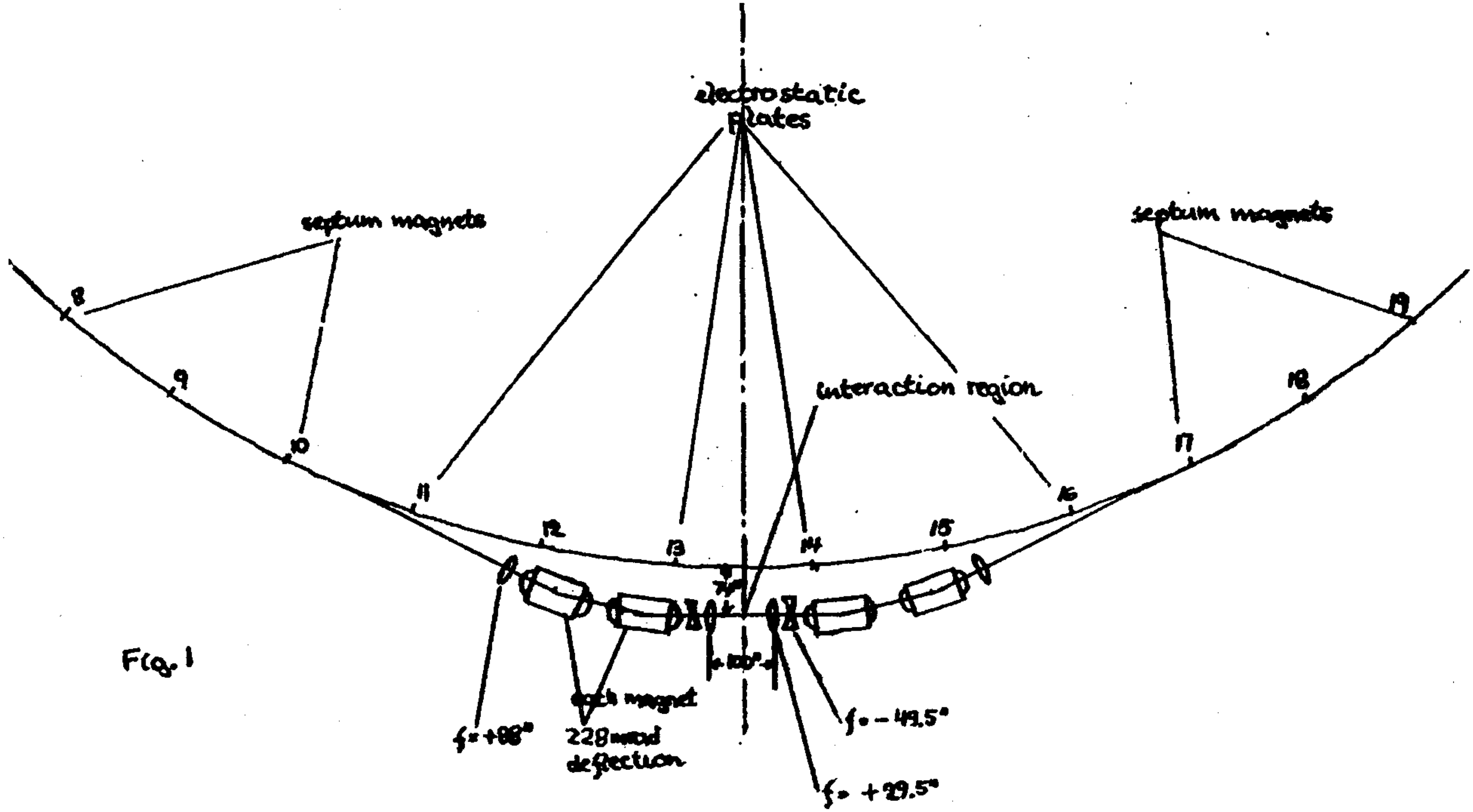
electrostatic plates
septum magnets
septum magnets
interaction region
8
9
10
11
12
13
14
15
16
17
18
19
each magnet
228 mrad
deflection
f = +88"
f = −49.5"
f = +29.5"

Fig. 1

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