PERFORMANCE OF THE CEA COLLIDING BEAM FACILITY

Presented by J. M. Paterson

Cambridge Electron Accelerator
Harvard University
Cambridge, Mass.

Introduction

The CEA Colliding Beam Facility is a 6-GeV electron synchrotron which has been modified to operate as an electron positron storage ring.[1] This facility has an operating range of 1 to 3.5 GeV in each beam and a design luminosity of 10^{31} cm^{-2}sec^{-1}.

Design Parameters

Operating Energy	1 - 3.5 GeV
RF, Harmonic No.	475 MHz, 360
No. of Bunches per Beam	120
Current per Beam	100 mA peak i.e. 30 mA avg.
Beam Lifetime	1 - 2 hours
β at Interaction Point	5 cms x 5 cms
Luminosity at 2 GeV	$\sim 10^{31}$ cm^{-2}sec^{-1}

We are at an advanced stage in this development and beam-beam collisions have been observed at low intensities. The status and the operating characteristics of the colliding beam system are given below.

Design and Operating Mode (See Fig. 1)

The major steps required in modifying the electron synchrotron to provide colliding beam capability were:

a) The addition of two damping magnets which redistribute radial damping so that both betatron and synchrotron oscillations are damped.[2]

b) The addition of a positron linac and a multicycle injection system for the accumulation of electron and positron beams.

c) The improvement of the accelerator vacuum system from 10^{-6} to 10^{-9} torr to achieve useful stored beam lifetimes.

d) The construction of a bypass on the synchrotron ring which provides a low β interaction point for increased luminosity and adequate space for detection equipment.[3]

These systems are in routine operation but the operating sequence is complex and requires further explanation. In Fig. 2 we see that there are three distinct phases in the sequence.

1) The multicycle injection and accumulation of beams with the beam energy oscillating at 60 Hz from injection to 2 GeV.

2) The transition from cycling to dc operation ending with beams at the desired operating energy.

3) The switching of the beams into an orbit which passes through the bypass.

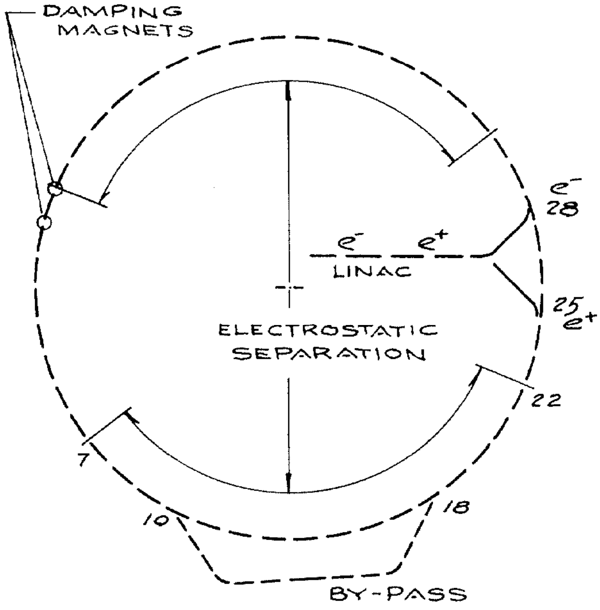

Fig. 1. Layout of CEA Colliding Beam Facility

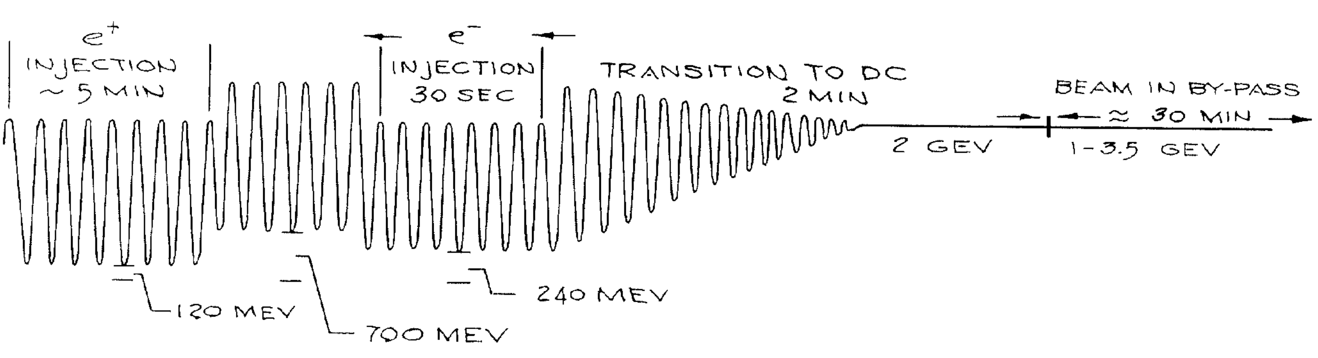

Fig. 2. Schematic of Sequence of Operations in Colliding Beam System

Injection and Accumulation of Beams

Our injection energy, 120 MeV for positrons and 240 MeV for electrons, is too low for accumulation because of insufficient damping. We therefore inject, using off-axis injection, and accelerate positrons in a normal synchrotron mode to approximately 2 GeV and decelerate back down to injection energy. At the high energy the beam is moved into the damping magnet system so that there is overall radiation damping in one cycle. The phase space occupied by the beam after one cycle is approximately 90% of that at injection. The injection process is repeated at 60Hz until we have accumulated a positron beam. Then electrons are injected in a similar manner on a counter-rotating orbit. Further details of this procedure can be found in a subsequent paper in this session of the conference.[4]

During this multicycle injection process we observed that the accumulated current was limited by a growth of the horizontal beam size. Two different instabilities which cause beam growth have been identified and controlled. One is a horizontal betatron instability which shows coherence over up to twenty bunches. This has been controlled by separating the ν values of adjacent bunches using a radiofrequency powered quadrupole. This quadrupole is powered at 32 MHz, i.e. the 24th harmonic of the circumferential frequency so that every 15th bunch has the same ν value. The maximum $\Delta\nu$ spread which can be applied is limited by injection conditions to approximately .01 and the RF power is modulated to maintain this through the acceleration cycle.

A second cause of horizontal growth has been identified as coherent phase oscillations. We have controlled this phase instability by giving each bunch a different ν_s, i.e. synchrotron oscillation per turn.[5] This was accomplished by retuning one of the sixteen accelerating cavities to the 362nd harmonic and powering it separately with approximately 1 kW of power. These instabilities and those described below are discussed in greater detail in a paper presented by A. Hofmann in the session on Beam Dynamics.[5]

Using these techniques we have accumulated 25 mA peak (8 mA avg) current of positrons and 50 - 70 mA peak (15 mA avg) of electrons. There are some indications that these currents are still limited by an instability; however we have little information as yet on this limit.

The electron and positron orbits are vertically separated throughout the cycle by an electrostatic plate system,[6] i.e. in opposing sections of the ring where the beams would overlap they are vertically separated, while at the injection region and at the damping system they are separated in time (see Fig.1). Even with 6 mm separation at 240 MeV and 2 mm at 2 GeV, the beams exert an effect on one another and this can give either electron injection difficulties or reduced lifetime for the accumulated positrons. At the present time we are capable of filling the ring with 20 mA peak without significant effect on the positrons.

DC Storage

After the injection of electrons is completed we raise the dc component of the synchrotron magnet and lower the ac component in such a way as to maintain the maximum energy at $\geq$ 2 GeV until we have dc stored beams. This process requires accurate tracking of the damping system including the beam bump which controls the orbit in the damping magnets.[7] During this transition the lifetime of the beams increases from of the order of 10 minutes to approximately 2 hours.

Toward the end of this process we observe another instability which causes either horizontal or vertical beam blow up. This instability shows no coherence between bunches and is unaffected by the rf quadrupole. A sampling scope which resolves the intensity of individual bunches also shows that the losses depend only on the intensity of the individual bunches. A dynamic feedback control system as is used at ADONE and as planned at SPEAR would be extremely difficult in our case as the gain bandwidth required to control the 100 independent bunches is very large. This instability can be controlled using Landau damping. The damping magnets in the CEA ring are non-linear and have a moderate octupole content which is insufficient. Therefore we have added an octupole magnet to the ring to increase the Landau damping and have controlled this instability up to the currents we are capable of attaining in multicycle injection.

Bypass Operation

Prior to switching the beams into the bypass we adjust the energy to match the bypass which is independently powered. Most of our operation to date has been at 2 GeV beam energy. The electrostatic plate system is also switched to a mode which gives one crossing point in the ring so that after switching into the bypass the beams cross at the interaction point. In the bypass the crossing angle can be varied from 0 to 2 mrad.

The present tune of the bypass gives a β_v of 20 cms and a β_h of 30 cms at the interaction point, the largest β's being approximately 80 meters in the quadrupoles. The vacuum in the bypass is better than in the machine and has a base pressure of 10^{-10} torr. This is important from the point of view of background to experiments including luminosity measurements.

We can switch beams into the bypass with essentially no loss due to betatron oscillations but we found that the threshold for the single bunch instability observed with dc beams in the machine was lowered. This is not yet explained as many parameters change when we have the beams in the bypass, e.g. the tune, the chromaticity, and the nonlinearity of the system. However the addition of a stronger octupole magnet in the bypass itself has overcome this difficulty and we have had peak currents of 25 mA switched into the bypass without an instability.

At the present time the most important limitation in the operation of the bypass with two beams of high intensity is the existence of many resonances in betatron oscillations which can decrease the lifetime of the beams to impractical values of minutes or in some cases seconds. At low intensities with a single beam these resonances are spaced such that operating points can be found where the lifetime exceeds 1 hour and which have reasonable operating ranges. However the addition of two intense beams on vertically separated orbits brings the operating range for a satisfactory tune below practical limits. A major part of this effect is in the reduction of vertical aperture available for the beams but beam-beam interaction may also play a role.

Much effort has been expended in trying to understand these resonances and their complex pattern. Some are narrow, others broad. Some lead to only a small decrease in τ, a factor of 2 or 3, while others reduce the lifetime to practically zero. The beam size as viewed on our TV monitor stations often does not indicate a significant change in particle density distribution near or in the core of the beam when we sit on a resonance which reduces τ. However there are also resonances which give a large increase in vertical beam size, possibly non-linear coupling resonances, which do not affect beam lifetime. The octupoles which have been added to provide increased Landau damping do produce some non-linear resonances but they are not the major source of our problems.

Many of the resonances appear as a periodic structure in the tune diagram. They are spaced by a constant $\Delta\nu$ (.005 to .02) in either the horizontal or vertical planes. This spacing corresponds to ν_{synch} or submultiples of it and these resonances move across the tune diagram as one changes the RF accelerating voltage. This leads us to believe that they are satellites (sidebands) of major linear and non-linear stop bands. Their strength should be greatly reduced by a reduction in the chromaticity ($\Delta\nu / \frac{\Delta p}{p}$) of the system. Powering the bypass sextupoles such as to lower the chromaticity does decrease the strength and number of these resonances. However, we appear to be limited in the application of the sextupoles because they are not adequately distributed in betatron phase and alignment tolerances become too critical. As a result of this we are presently installing a distributed system of 24 sextupole magnets in the main ring.

Luminosity Measurements

Notwithstanding the above problems we have been able to measure beam-beam collisions for the purpose of checking beam dimensions at the interaction region. At currents less than 2 mA peak (0.5 mA avg) in each beam we can operate with unseparated beams and have a tune which gives good lifetime and stable conditions for both beams. In this way we measured the single bremsstrahlung rate in both the e^- and e^+ zero-degree luminosity counters. The beams could be separated at the interaction region using an electrostatic beam bump and we could clearly measure the beam-beam bremsstrahlung although it was only 10 - 15% of the gas bremsstrahlung background. From these measurements and independent measurements of the β function we could calculate the aspect ratio and beam size at the low β interaction point. The aspect ratio, i.e. ratio of horizontal to vertical beam size in the synchrotron straight section, was found to be 20 ± 10 to 1. This agrees with expectations. With the present β_v of 20 cms and β_h of 30 cms this means that the beam size at the interaction point was 0.016 mm and 0.4 mm in the vertical and horizontal plane.

References

1. A. Hofmann, Proceedings 6th International Conference on High Energy Accelerators, Cambridge, Mass., 1967, p. 112.

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3. H. Mieras, Proceedings 6th International Conference on High Energy Accelerators, Cambridge, Mass., 1967, p. 119.

4. R. Averill, Proceedings this Conference.

5. A. Hofmann, Proceedings this Conference.

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7. W. Colby, Proceedings this Conference.