COLLIDING ELECTRON AND POSITRON BEAMS IN THE CEA BYPASS

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(presented by G. A. Voss)

Abstract

The status and performance of the CEA colliding beam system are described. Single beams up to 50 mA peak and 12 mA average have been successfully switched into the low-beta bypass and stored at energies up to 2.5 GeV. Lifetimes at low currents were up to 5000 s. Stable operating conditions have been found for values of beta as low as 7 cm (horizontal) and 22 cm (vertical). Preliminary luminosity measurements at lower currents and energies of 2 and 2.5 GeV are described.

Introduction

The parameters of the CEA bypass and the principle of operation have been described in the Proceedings of the VIth International Conference on High Energy Accelerators.[1), 2), 3), 4)] A Status report was given at the VIIth International Conference at Yerevan.[5)] At the time of the Yerevan Conference first observations of multicycle injection of electrons were reported. Also at that time the bypass to the CEA synchrotron had been assembled and first trials of bypass operation with electrons had been made, resulting in lifetimes of electrons going through the bypass of 25 seconds.

At the beginning of 1970, the positron injector was put into operation and studies of positron accumulation in a multicycle injection mode began. Up to the middle of 1970, tests of the colliding beam system were scheduled during one-third of the accelerator time, two-thirds of the time being used for 6-GeV electron and photon physics. In mid 1970, budget restrictions forced us to suspend conventional accelerator operation and to concentrate on the development of the colliding beam facility.

During the second half of 1970, much time was spent studying single beam instabilities in the CEA, beam-beam interactions, and performance of the bypass. First reliable luminosity measurements at beam energies of 2 + 2 GeV were done in the first half of 1971. Present status and performance are discussed in the following sections.

Positron and Electron Accumulation

It is intended to accumulate a peak circulating positron current of 100 mA in a multicycle injection mode.[6)] With a circumferential ring fill factor of 30% this corresponds to an average of 30 mA. So far the largest positron current accumulated has been 25 mA peak, 7.5 mA avg. The best positron injection rate observed so far has been 0.4 mA/s (peak current), but more commonly it is only about 0.1 mA/s. This injection rate is considerably below our original expectations of 6 mA/s. The main reason for this low rate is the existence of non-linear resonances in the multicycle filling operation which limit the possible particle amplitudes. In order to maintain a sufficiently long lifetime in the presence of these resonances it was necessary to reduce the horizontal beam size by reducing the peak energy to which the newly-injected particles are accelerated. At present we cycle the synchrotron energy up to 2 GeV (compared with 3 GeV as originally planned). This unfortunately provides much less damping of particle oscillations after injection, and together with the limited available beam aperture of about 4 cm by 2 cm, causes the relatively small injection rate. The small injection rate is partly compensated by a much longer lifetime in this cycling mode (300 s or better) than originally expected (16 s). Betatron beam instability problems during this cycling operation have been overcome by a system of sextupole lenses[7)] and we expect larger positron currents as the synchrotron vacuum is further improved.

While positrons are injected at the relatively low energy of 120 MeV, electrons are injected at 240 MeV, with fill rates larger than 50 mA/s, and problems of non-linear resonances are small as compared to those during positron injection. Electron peak currents up to 150 mA and average currents up to 20 mA have been accumulated. At present these currents seem to be limited by beam cavity interaction and beam instabilities in the synchrotron oscillation mode.

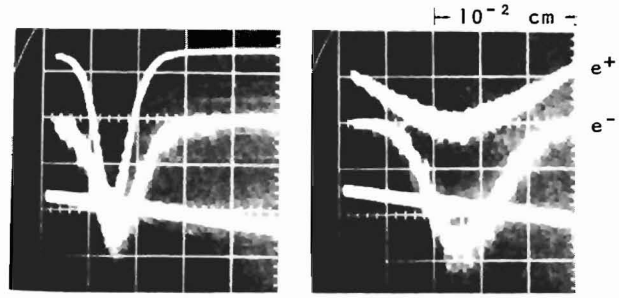
Beam-Beam Interaction

During electron multicycle injection and thereafter, physical separation with electrostatic fields of the electron beam from the already stored positron beam is necessary in order to avoid short lifetimes of the weaker of the two beams due to the incoherent space charge interaction. Without such separation, the lifetime of already stored positrons in the electron multicycle injection mode gets very short as soon as the peak electron current exceeds 3.5 mA. This beam-beam interaction effect without electrostatic separation has been measured for different average currents of electrons, i.e. different circumferential fill factors. It seems to be only dependent on the peak current over a wide range of average currents.[8] In a change of our original design we decided to have electron and positron currents cross each other at the interaction point of the bypass. (Originally we planned to have head-on collisions between both beams made possible by electrostatic plates right at the interaction point.) This change makes it necessary to have both beams cross each other in the bypassed part of the synchrotron before beams are switched into the bypass. For an electrostatic plate configuration, which provided for one beam-beam crossing, it was found that the incoherent space charge limitation during multicycle injection of electrons was only 7 mA, unacceptably low. For this reason it was decided to keep both beams entirely separated during the filling process, using an electrostatic plate configuration which provided no crossing but which is switched to a configuration with one crossing after both beams have been accumulated and stored at constant energies of 2 GeV. This switching is done within 0.1 s and without beam loss. Incoherent space charge limits at the constant energy of 2 GeV seem to be much higher than those in the multicycle injection mode.

With both beams entirely separated during multicycle injection, beam-beam interaction still can be observed. One beam acts like a quadrupole lens on the other beam, decreasing its vertical and increasing its horizontal betatron frequencies. This effect which depends only on the average currents in the beams, can drive the weaker beam into a resonance. So far we were able to maintain an average electron current of 8 mA (25% of our design current) before we adversely affect the lifetime of the positron beam.

Besides the linear $\Delta\nu$ shift produced by one beam on the other, which in principle can be corrected with a combination of electrostatic and magnetic quadrupole lenses, we also observe beam-beam interaction leading to short lifetimes of the weaker beam, which depend on the peak circulating current in the stronger beam. We found that during e^- injection, lifetimes of the already stored positron currents suddenly drop to values of about 10 - 20 s whenever the peak electron currents reach 70 - 80 mA. We presently assume that this effect is due to non-linearity in focusing produced by one beam on the other.

Space charge interaction between electron and positron beams in the dc storage mode are much smaller than in the multicycle injection mode and have not yet been investigated quantitatively. It is apparent though that the main effect is a diffuse increase in beam size of the weaker of the two beams when both beams are <u>not</u> vertically separated. Only in the case of very large beam size increase is there any effect on the lifetime. The beam size increase can be observed even with very small currents (Fig. 1). No clear threshold current has been measured so far. With electrostatic separation of both beams, but with one crossing at the low-beta interaction point, no effects have been observed (with peak currents up to 20 mA) which could be clearly identified as space charge interaction.



(a) (b)

Fig. 1. The horizontal axis represents the vertical beam height of 2-GeV positron and electron beams as measured at the interaction point. Beam currents were approximately 3.5 mA peak, 1 mA avg. (a) With electrostatically separated beams and one crossing at the interaction point. (b) Without electrostatic separation.

<u>Bypass Operation</u>

Switching of beams into the bypass with no switching loss and good beam lifetimes thereafter was only achieved after a considerable amount of work on first-turn steering procedures through the bypass (to optimize physical apertures), measurements and optimization of betatron phase space and momentum matching, and extensive studies leading to some understanding of the nonlinear resonance limitations in the bypass operation.[9] With beams of 2 GeV, switching of beams into the bypass can be done with no or small switching losses, and beam lifetimes are comparable to the lifetimes in the synchrotron before beams are switched into the bypass. At higher energy avoiding switching losses becomes more difficult.

Longest measured beam lifetimes while going through the bypass have been 5000 s (compared with 7000 s in the synchrotron only). Beam lifetimes are strongly current-dependent (varying up to a factor of 3) due to the outgassing effect of synchrotron radiation. Since the synchrotron ring is still frequently let up to air to allow installation of different devices, and since the vacuum improvement program is still not completed (bake-out facilities for all vacuum chambers, straight section tanks, rf accelerating cavities), no systematic study of synchrotron radiation outgassing has been made yet. The vacuum and lifetimes of beams are expected to further improve significantly.

One important parameter of the bypass is the value of the beta function at the interaction point since it is one of the parameters determining the obtainable luminosity. Various "tunes" of the bypass have been tried out and stable operating conditions with good lifetimes have been obtained with 2-GeV beams with horizontal beta values as small as 7 cm and vertical beta values of 22 cm. As described in Ref. 9, beam energy and smallness of the amplitude function are subject to limitations from non-linear resonances. Largest single beam currents (2 GeV) stably stored in the bypass have been 50 mA peak, 12 mA average; two-beam operation in the bypass has been accomplished with the stronger of the two beams up to 18 mA peak.

First Luminosity Measurements

Luminosity has been measured using single photon bremsstrahlung. The schematic set-up is shown in Fig. 2.

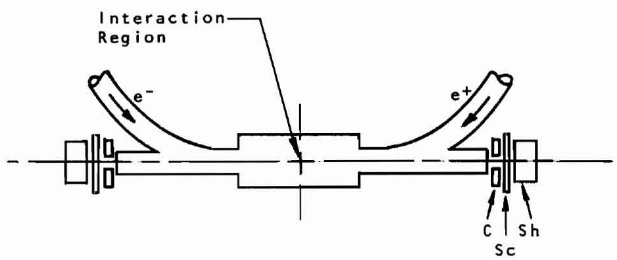


Fig. 2. Schematic diagram of central portion of bypass and luminosity monitor system. The zero-degree monitors at east and west include a collimator C, a vetoing scintillation counter Sc, and a shower counter Sh.

The small height of the bunches at the interaction point (less than .01 cm) and the shortness of the bunches (of the order of 5 cm) present some special problems in adjusting the electrostatic plate separation system for beam-beam collisions at the interaction point. Figure 3 shows a schematic diagram of the crossing beam geometry

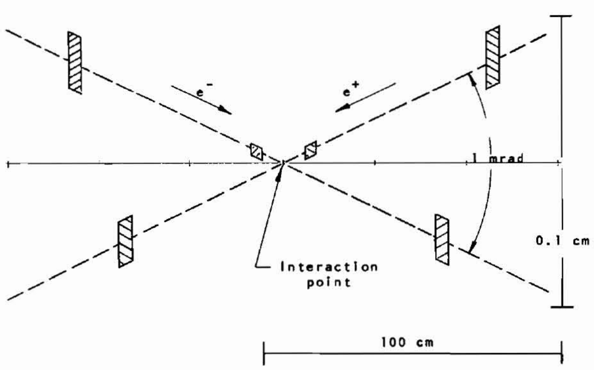


Fig. 3. Schematic diagram of the beam geometry at the interaction point. Note that the vertical scale is 1000 times the horizontal scale.

with vertical dimensions magnified by a factor of 1000. For optimum luminosity, electron and positron bunches have to arrive at the interaction point - defined as the center of the bypass and the point of smallest value of the amplitude function - simultaneously. Also the vertically separated orbits have to be adjusted so as to provide maximum overlap between bunches of both beams.

By measuring the time of passage of electron and positron bunches through beam monitors close to the interaction point, it was verified that electrons and positrons meet within ±1 cm of the interaction point. An electrostatic beam bump further permits the motion of the vertical beam position of both beams with respect to each other at the interaction point. This allows variation from a zero luminosity condition to a condition with maximum luminosity with only small adjustments in the vertical beam positions (0.02 cm). The proper vertical beam-bump adjustment is checked by moving a 7-micron-thick carbon fiber rapidly through the beams at the interaction point and observing the bremsstrahlung events produced by both beams as a function of time. Figure 4 shows these bremsstrahlung events as a function of time for (a) a zero luminosity condition, and (b) the condition for maximum luminosity. The carbon fiber measurement

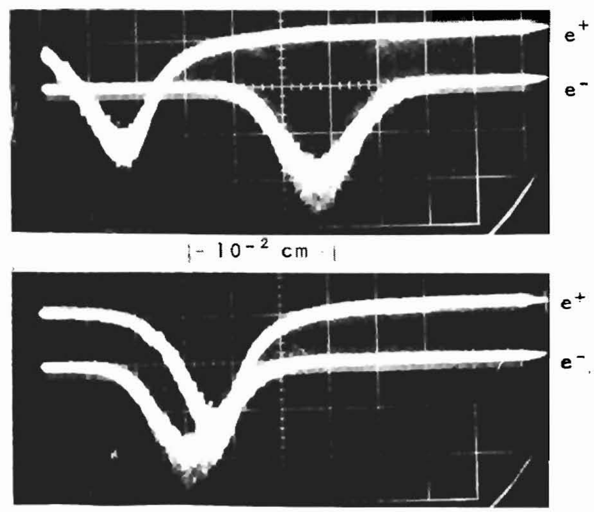


Fig. 4. Measurement of vertical positions of e^+ and e^- beams at center of the bypass. Vertical position of beam is indicated by position of pulse along the horizontal axis. Upper and lower traces represent e^+ and e^- beams respectively. Top view: before adjusting vertical positions. Bottom view: after adjusting the electrostatic separation plates.

has been essential in the analysis of the properties and performance of the low-beta bypass. Spills from the carbon fiber indicate beam height and position and allow for optimizing both. Tilting the fiber allows for horizontal beam size measurements. The fiber measurements cause only very small beam loss (of the order of 2% per traversal) and have become indispensable.

Figure 5 shows a luminosity measurement done with beams, each with an energy of 2 GeV. After subtraction of the gas background which was about 6 times as large as the maximum luminosity counts, the number of bremsstrahlung events is shown as a function of the vertical electrostatic beam bump. The maximum number of counts corresponds to a luminosity of 1×10^{27} cm^{-2} s^{-1} and is in

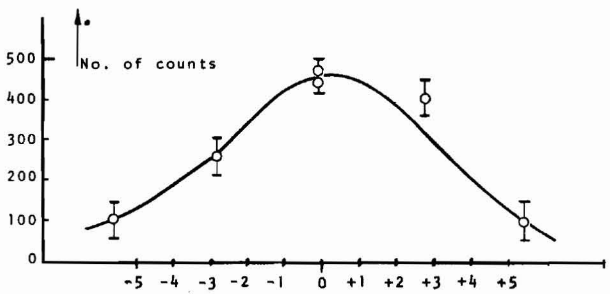


Fig. 5. Background-corrected count as a function of vertical displacement of e^+ beam relative to e^- beam. Counting period: 10s. Zero value of displacement is the absolute value determined independently with the aid of a transverse fiber flicked through the beams.

agreement with the currents and measured beam sizes at the interaction point (in this case .05 cm wide and .0075 cm high). Beam currents in this measurement were only 2 mA and 10 mA peak for e^+ and e^- respectively; the overlapping portion of both beams along the circumference was only 100 ns (i.e. only 48 electron bunches collided with 48 positron bunches). Measurements were carried out with a tune for which values of beta function were 20 cm horizontal and 30 cm vertical.

Background in this measurement is mostly due to bremsstrahlung produced in the residual gas of the bypass straight section. Although the base pressure without beams is in the 10^{-11} Torr range in this part of the bypass, outgassing due to synchrotron radiation from circulating beams increases gas pressure to values in the 10^{-9} Torr range.

Present Status and Future Plans

We are presently working on increasing the luminosity to a useful value of $\sim 10^{28}$ cm^{-2} sec^{-1} and in shaking down a rather complicated system. The first colliding beam experiment will be done with BOLD (bypass online detector), a nonmagnetic detector which uses wire spark chambers and shower counters as the principal elements. Two quadrants out of the total of four have already been mounted at the interaction region (Fig. 6), and measurements of the background counts in various trigger counters and cosmic ray rejection counters have commenced. The two remaining quadrants are ready for installation. A magnetic detector (MAGNOLIA), using a longitudinal magnetic field together with wire spark chambers, proportional counters and scintillation counters for momentum determination and better particle identification, is presently under construction and will replace the BOLD detector at some future time.

The presently available radiofrequency power in the accelerator makes beam storage possible up to energies of 3.5 GeV and beams with this energy have indeed already been stored in the synchrotron. To achieve satisfactory operation, two of the original 3" quadrupoles in the center of the bypass had to be replaced by 4" quadrupoles of better quality. As a result storage is presently limited to beams of less than 2.8 GeV. A rebuilding of this center section with stronger and better quadrupoles is planned.

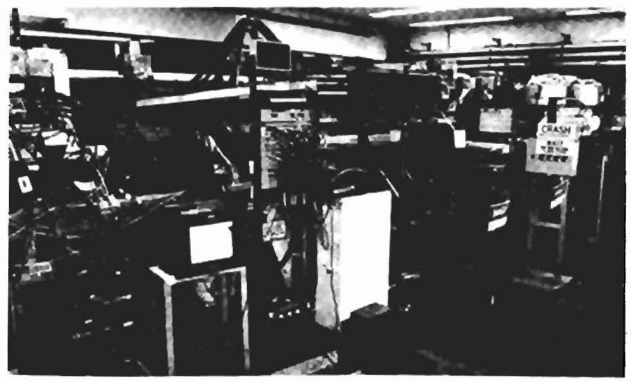


Fig. 6. Bypass interaction range with two of the four BOLD quadrants mounted in place.

References

1) A. Hofmann *et al.*, "The Colliding Beam Project at the CEA", Proceedings 6th International Conference on High Energy Accelerators, Cambridge, Mass., U.S.A., 1967, CEAL-2000, p.112.

2) H. Mieras *et al.*, "A Design of the CEA Colliding Beam Bypass", Proceedings 6th International Conference on High Energy Accelerators, CEAL-2000, p.119.

3) A. Hofmann *et al.*, "Design and Performance of the Damping System for Beam Storage in the CEA", Proceedings 6th International Conference on High Energy Accelerators, CEAL-2000, p.123.

4) K. W. Robinson, "Radiation Effects in Multicycle Injection", Proceedings 6th International Conference on High Energy Accelerators, CEAL-2000, p.148.

5) G-A. Voss, "Status of the CEA Bypass for Colliding Beams", 7th International Conference on High Energy Accelerators, Yerevan, Armenia, U.S.S.R., 1969, to be published.

6) R. J. Averill *et al.*, "Positron-Electron Multicycle Injection at the CEA Colliding

Beam Project", Proceedings 1971 Particle Accelerator Conference, Chicago, Illinois, U.S.A., IEEE Trans. on Nucl. Sci., NS 18-3, 221, 1971.

7) R. J. Averill *et al.*, "Synchrotron and Betatron Instabilities of Stored Beams in the CEA", Proceedings this conference.

8) A. Hofmann, "Beam Instabilities Observed at the CEA", Proceedings 1971 Particle Accelerator Conference, IEEE Trans. on Nucl. Sci. NS 18-3, 1035, 1971.

9) R. J. Averill *et al.*, "Performance of the CEA Low-Beta Bypass", Proceedings this conference.

DISCUSSION

F. AMMAN : Which is the ratio between the two-beam vertical separation and the beam width in the high-beta region ?

G.A. VOSS : Separation of beams at the place of max. β_V is about 3 mm; the horizontal size at 2 GeV is about 2.5 mm at that point.

H. BRUCK : What wave-number shift $\Delta\nu$ have you at maximum luminosity ?

G.A. VOSS : The shift, $\Delta\nu = 0.05$ (theoretical design number).

K.H. REICH : Up to what fraction of the bore radius did you obtain the field accuracy of 10^{-5} and by what means ?

G.A. VOSS : 12 and 20 pole content have been reduced to about 10^{-6} of the quadrupole field over the beam aperture (25 % of the quadrupole bore) with the help of poleface windings.