

AN EXTERNAL BEAM FROM THE CORNELL
10 GEV SYNCHROTRON*

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Summary

The electron beam at the Cornell 10 GeV Synchrotron has been extracted using a quadrupole and octupole magnet to drive the beam into a half-integral stop band. Extraction is then effected by three septum magnets. An achromatic transport system delivers the external electron beam into either of two experimental areas producing a focused spot at the experimental target of the order of 1 millimeter square with a divergence of $\pm .3$ milliradians. At 10 GeV an electron beam with an intensity of 2×10^{10} electrons per pulse and a duty factor of 10% has been obtained. Our extraction efficiency is 85% at 5 GeV and falls to 70% at 10 GeV. By using only the septa, up to 1% of the beam can be extracted without interfering with an internally made photon beam, thus allowing simultaneous use of external electron and photon beams.

Extraction

The electron beam is driven into a resonance by a quadrupole-octupole combination and extracted from the synchrotron by three septum magnets. The quadrupole is pulsed at the end of the acceleration cycle and lowers the radial betatron frequency of the synchrotron from the normal operating value of 10.68 to the 10.50 resonance. A simultaneously pulsed octupole magnet introduces a non-linear field that increases the rate at which electrons with large betatron oscillations spiral away from the central orbit.

The first septum is a C magnet located .654 in. inside the central orbit and has a one-turn winding with a thickness of 1/32 in. on the beam side of the magnet. (See Fig. 1) As the betatron oscillations grow, most of the electrons are able to jump the 1/32 in. copper strip and enter the field of the first septum magnet, which then bends them 1 milliradian away from the central orbit. This bend allows the electrons to enter the aperture of the second septum, which is located 48 ft. downstream and .75 in. inside the central orbit. The second septum bends the electrons 5 milliradians toward the central orbit and into the aperture of the third septum located 36 ft. downstream and 2.095 in. outside the central orbit. Here the electrons are bent 5 milliradians away from the central orbit and onto the extraction axis.

Design calculations for the phase space of the extracted beam predict a radial phase space of ± 10 mils and $\pm .4$ milliradians and a horizontal phase space of ± 5 mils and $\pm .5$ milliradians. Experimentally, we measured a radial phase space of ± 19 mils and $\pm .9$ milliradians, and a vertical phase space of ± 25 mils and $\pm .5$ milliradians. At present, the extracted beam has a phase space suitable for our use and no effort has been made to resolve these discrepancies.

We have extracted a 10 GeV electron beam with intensity of 2×10^{10} electron/pulse at 60 c/s. Our

*Work supported by the National Science Foundation.

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extraction efficiency is about 85% at 5 GeV, 80% at 8 GeV and 70% at 10 GeV. This fall in extraction efficiency is caused by a loss in machine aperture at high excitation and by scraping on the septum magnets resulting from the increase in the size of the internal beam with energy as radiation fluctuations and betatron anti-damping become important.

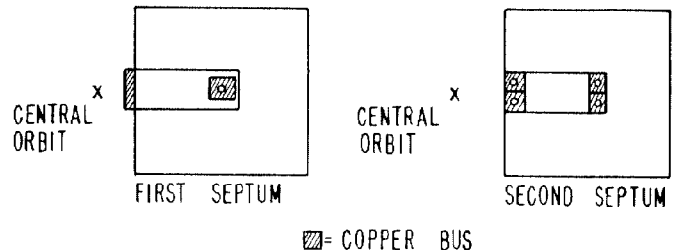


FIG. 1 CROSS SECTION OF SEPTUM MAGNETS

Transport System (Fig. 2)

An achromatic transport system has been designed and constructed which establishes two beam lines designated EXIT A and EXIT B. To service the EXIT B line, the external beam is deflected a total of 10.83 degrees by four identical bending magnets (B1, B2, B3, B4). The front quadrupole pair (Q1, Q2) brings the beam to an intermediate focus at Q3B. Since the extracted beam passes through the radially defocusing fringe field of the synchrotron magnets, Q1 is chosen to be radially focusing and Q2 vertically focusing. The use of an intermediate focus reduces the required aperture of the bending magnets and facilitates tuning of the transport system by reducing the degrees of freedom. Q3B is a radially focusing quadrupole and compensates for the momentum dispersion introduced by the four bending magnets in the EXIT B line. The electron beam is focused at the EXIT B experimental target by using the quadrupole triplet Q4B Q5B Q6B.

To service the EXIT A beam line, the field in the second bending magnet (B2) is reversed causing the beam to emerge parallel to the extraction axis. Two more bending magnets of opposite sign bend the beam onto an axis which coincides with a photon beam line that services the EXIT A experimental area and originates from an internal target in the synchrotron. The front quadrupole pair (Q1, Q2) is adjusted for an intermediate focus at Q3A. The quadrupoles Q3A (vertically focusing) and Q4A (horizontally focusing) are required in order to compensate for the momentum dispersion of the system. Two quadrupoles are needed because of the non-symmetrical arrangement of the bending magnets. The electron beam is focused at the EXIT A experimental target by using the quadrupole pair Q5A, Q6A. A system of TV monitors and remotely controlled flags coated with phosphor allow the observation of the electron beam at most of the quadrupoles. Vertical and horizontal corrections can be made by tuning small steering magnets at the beginning and near the end of the beam

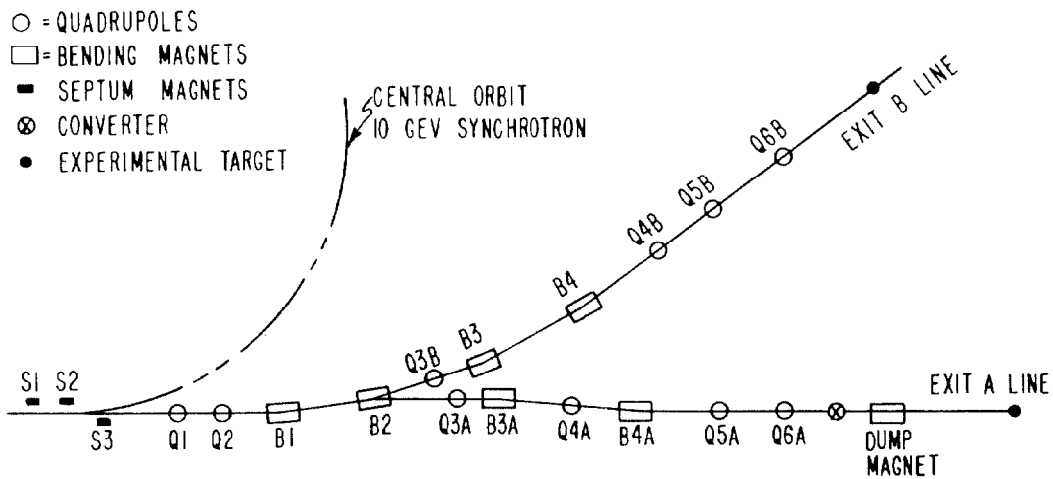


FIG. 2 SEPTUM MAGNETS AND TRANSPORT SYSTEM

lines. The EXIT B beam has been focused at the experimental target to produce a spot of the order of 1 millimeter square with a divergence of $\pm .3$ milliradians.

After Q6A, a remote-controlled converter has been installed which produces a photon beam from the electron beam. Downstream of the converter a dump magnet bends the electron beam downward into a beam stop. At low electron beam intensities, the field of the dump magnet may be reversed and the degraded electrons detected by an array of tagging counters located above the axis of the dump magnet. With this facility either an intense photon beam or a weak tagged photon beam can be made from the extracted electron beam and delivered to the EXIT A experimental area in addition to the internally made photon beam mentioned previously.

By turning off the extraction quadrupole, 1% of the internal synchrotron beam can be extracted without interfering with a prime experimenter who is using an internally made photon beam. Thus two experiments can run simultaneously instead of the usual parasitic operation by which each synchrotron pulse is delivered to one or the other of the two experiments. This simultaneous mode of operation has proved extremely valuable.

Construction

The quadrupole and octupole are laminated iron magnets 15.5 in. long with a 2 in. inscribed diameter aperture. The coils consist of one turn per pole of water cooled 1/4 in. square copper bus.

The septum magnets are laminated C magnets with apertures 1/2 in. high and 3/4 in. wide. (See Fig. 1) The first and third septum magnets are 14.25 in. long and the second is 18.25 in. long. The first septum magnet has one turn which, on the beam side of the magnet, consists of a sheet of 1/32 in. copper; it is cooled by transverse conduction into two thin-walled stainless steel tubes that run parallel to it. The rest of the turn consists of 3/8 in. water cooled

copper bus. The field outside the septum is less than 4% of the field inside the gap and has a negligible effect on the synchrotron beam. The second and third septum magnets have two turns of 1/4 in. square water cooled bus forming a 1/4 by 1/2 in. current sheet.

Power Supplies

The extraction quadrupole and octupole require peak currents at 10 GeV of 1100 and 200 amps respectively. They are driven by transistorized power supplies located out of the radiation area and have rise times of less than .5 milliseconds and flat top pulse widths of 2.5 milliseconds.

The driving circuits for the septa each consist of a transformer with the main synchrotron magnet current (440 amps peak to peak AC and 220 amps DC at 10 GeV) in the primary and a septum magnet in the secondary. An external DC power source supplies the correct amount of DC in the secondary to balance the transformer, thus reproducing the synchrotron magnet current waveform in the septum scaled by the turns ratio of the transformer. This allows the septum magnets to track the energy of the extracted electrons. Small adjustments to the septa steering can be made by varying the DC supply current without affecting the main synchrotron beam. At 10 GeV, the three septa require peak currents of 1070, 1830 and 2200 amperes respectively. The septum power supplies are located in a high-radiation area where transistorized supplies cannot operate reliably. Special high current, low reverse voltage rectifier diodes were used in these supplies to reduce the effects of radiation.

The bending magnets and quadrupoles in the beam transport system are driven by commercial 12 kilowatt Hobart welders which have been current stabilized by using fast voltage and slow current feedback loops to drive the saturable reactors of the welder. These supplies have current stability in the .1% range and have proven to be very reliable.