THE EXTERNAL PROTON BEAM FOR THE PRINCETON-PENNSYLVANIA ACCELERATOR*

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Summary

The beam extraction system being built for the Princeton-Pennsylvania 3-Bev weak foccussing proton synchrotron is a resonant system using the $\nu_r = 2/3$ resonance. This system has the advantages of high efficiency and small emittance, and requires that only the final extraction magnet, or septum magnet, need be plunged.

The first proposal to use the $\nu_r = 2/3$ non-linear resonance for extracting the beam from a weak focussing synchrotron was made by Turrin[1] who suggested that the pole-face windings be divided and used to provide the second harmonic in the radial gradient of "n" required to excite the oscillations. Because we wished to preserve the flexibility of our pole-face winding control system and to avoid adding to its complexity, we decided to perform this function with four short current-sheet magnets placed in four of our eight short straight sections. These excitation magnets, as we call them, have an aperture about 8 cm x 24 cm and are 30 cm long. The two halves of the winding are separately powered (see Figs. 1 and 2) so that a quadrupole field to adjust the tune of the betatron oscillations to the resonance can be generated, superposed onto a non-linear or "hexapole" field which drives the oscillations so that their amplitude grows approximately exponentially. The required quadrupole gradient is about 85 gauss/cm. The non-linear field is a hexapole field of magnitude about 10 gauss/cm^2 in the center, softening to a uniform gradient of about 25 gauss/cm at the edges. The polarities of the "hexapole" component are alternated from one magnet to the next so that a second harmonic in the radial gradient of "n" is produced. The magnets are powered by transistor amplifiers capable of providing 150 amperes at 50 volts. This system is shown schematically in Fig. 3.

The beam is guided out of the accelerator at a long straight section containing a septum magnet which we call the extraction magnet. In order for the beam to clear the next synchrotron magnet downstream, the field in the 4 1/2 foot long extraction magnet must be 14 kilogauss. For high extraction efficiency, the septum must be narrow in comparison with the width of the channel. Our extraction magnet has a channel one inch wide by one-half inch high. The septum is 0.5 cm thick with the current-carrying part constructed of four turns of 1/8" square copper tubing. The peak current per conductor is 3500 amperes and the duty factor designed for is 20%. Because this magnet is located only a quadrant downstream from the inflector, it must be plunged in order for the injected charge to be maximized. The required stroke is 2 inches at 19 cps. For this reason, the iron yoke is made as small as possible without increasing the stray fields. Present plans call for powering it with a transistor amplifier.

The properties of this extraction system have been studied extensively by the use of digital computers[2]. One program, designed to run very fast, is being used to study the extent of the region of stability as a function of the parameters. The properties of the extracted beam and the extraction efficiency estimates are being derived from a program which takes into account in detail the irregularities in the radial field gradient or "n" of the synchrotron magnet. The fields in the synchrotron magnets are computed from a 9th order polynomial in x and z which had been fitted to the measured fields, and the fields in the excitation magnets are computed from a truncated (40 terms) two-dimensional Fourier series which had been derived from the idealized boundary conditions. Except near the edges of the magnet, these latter fields checked measured fields within the error of measurement. The orbits of the protons are then computed by a Runge-Kutta-Gill program which uses the exact (not linearized) equations of motion. Because the slope of the orbits is everywhere small, it has been found that one integration step per magnet is sufficient. On an IBM 7094 this FORTRAN program requires about one second to integrate around one full turn of the synchrotron. Fig. 4 is a phase plane plot of the oscillations as computed by this program and plotted at the azimuth of the extraction magnet. Eight protons are represented and each is plotted every third turn, when the maximum of the oscillation occurs at the azimuth of the extraction magnet. Two protons strike the septum and are lost, the remaining six enter the channel. The position in the channel which one of the lost particles would have occupied is also shown. Since the particles entering the channel are spread along a narrow line in the phase plane, the emittance is very small - of the order of one micron-radian.

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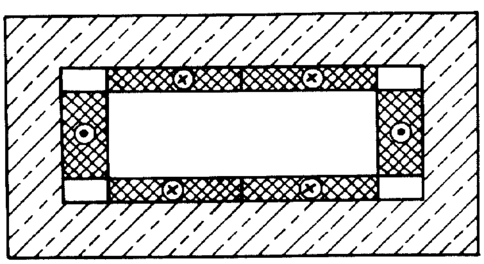
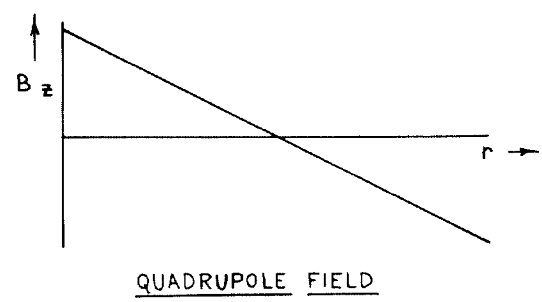
Status

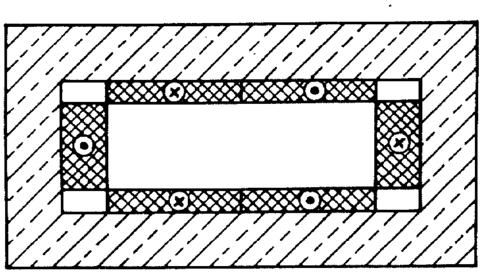
As of March 1965, the four excitation magnets have been installed in the synchrotron and are being connected to their power supplies. Fig. 5 is a photograph of one unit just before installation. An experimental model of the extraction magnet (Fig. 6) with the thin septum has been operated and some field measurements have been obtained. The emphasis is on the fringing field. The mechanism for plunging the extraction magnet is being actively designed. It is hoped that an extracted beam will be available this fall.

References

1. A. Turrin, Nuovo Cimento 8, 511, (1958)
2. Performed at the Princeton University Computer Center, supported in part by NSF grant NSF-GP 579.







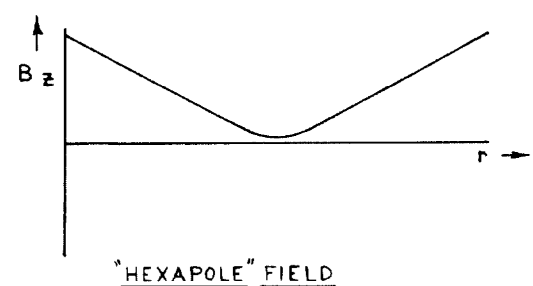


Fig. 1. Section through an excitation magnet showing directions of current flow for quadrupole and "hexapole" fields. In actual use, the currents are superposed to give a combined field.

Fig. 2. Graphs of quadrupole and "hexapole" fields on the median plane. These are combined when the currents are superposed. These two components are separately controllable.

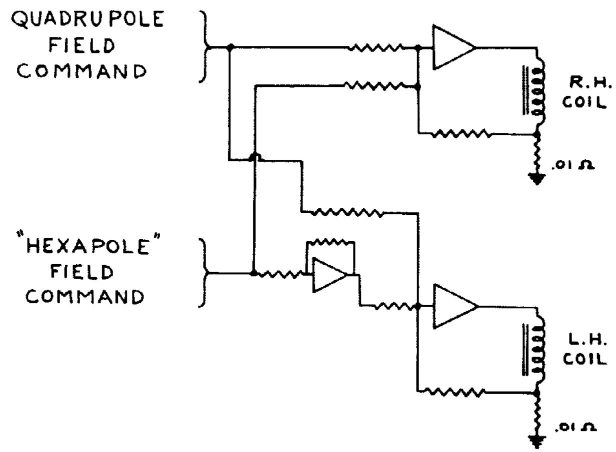


Fig. 3. Schematic of the power supply for an excitation magnet illustrating the control arrangement for quadrupole and "hexapole" field components.

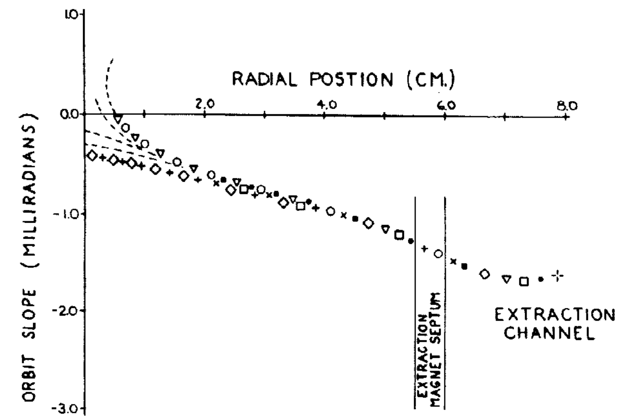


Fig. 4. Computed phase plot of exponentially growing radial betatron oscillations at the azimuth of the extraction magnet, showing 8 protons. The symbol at R = 7.8 cm represents the position the proton previously designated (+) would have if it had not been lost on the septum. An extraction efficiency of about 75% is indicated as 6 of the protons clear the septum.

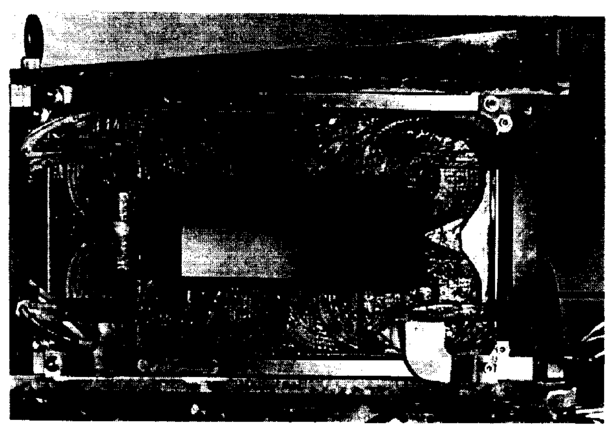


Fig. 5. Photograph of one of the four excitation magnets.

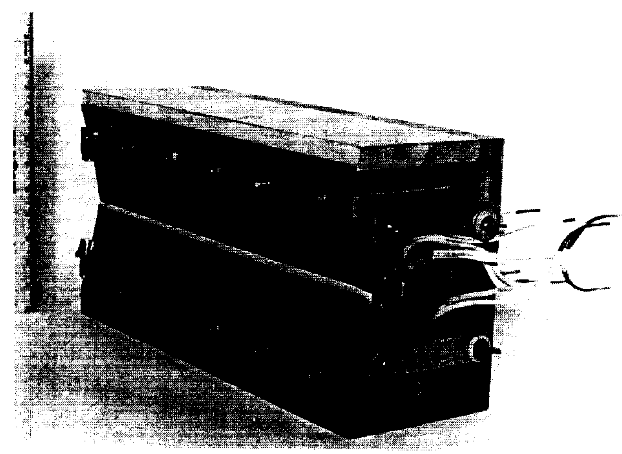


Fig. 6. Photograph of an experimental model of an extraction magnet which has a field of 14,000 gauss, 20% duty factor, and a 0.5 cm septum.