VARIABLE-DISPERSION ELECTRON SPECTROMETER FOR THE SCA/FEL

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Abstract

A variable-dispersion electron spectrometer is being installed for use by the Stanford Superconducting Accelerator in conjunction with its Free Electron Laser program. The system has been designed to operate with electron beam energies from 20 MeV to 200 MeV, with a maximum energy resolution of 0.01% FWHM. The maximum energy acceptance is approximately ± 5%, as determined by the bending magnet aperture. Resolution is controlled by adjusting the focal conditions at the entrance to a 90° bending magnet, while the dispersion is controlled by changing the magnitude and polarity of the field in a quadrupole magnet which immediately follows the bending magnet.

Introduction

An unusual spectrometer system is being installed as part of a new beam dump for the SCA/FEL. The design goals for the spectrometer were that it be able to analyze electron beams with energies from 20 to 200 MeV with three operating modes: high resolution, low resolution, and no resolution. In the high-resolution mode, the design goal was a resolution of 0.01% FWHM. This mode will be used for analyzing the beam directly from the Superconducting Linear Accelerator (SCA). The low-resolution mode as intended to have an energy acceptance of nearly ± 5%, with a resolution of approximately 0.2 %. This mode will be used to analyze the spent beam from the Free Electron Laser (FEL). A third mode was also desired, in which the beam can be focussed to a relatively small spot regardless of the energy spread. Using this mode will allow one to make substantial adjustments to the accelerator and/or FEL without having to adjust the spectrometer.

Background

The momentum resolution of a 90° sector magnet is highest when the beam is focussed to a small waist at the entrance to the magnet, and is zero when the beam has a waist at the center of the magnet. Quadrupoles before the bending magnet can thus be used to vary the resolution from zero up to the maximum which is possible given the beam emittance and resolution of the detection system. Quadrupoles following the bending magnet can be used to change the dispersion at the detection plane. A defocussing quadrupole will increase the dispersion by accentuating the bend-induced angular spread, while a focussing quadrupole will counteract this divergence and reduce the dispersion at the detection plane.

The system was designed using the computer programs TRANSPORT[1] and POISSON.[2] TRANSPORT does beam-envelope ray-tracing, and can include second-order terms. This program was used to determine the positions and strengths of the quadrupoles in order to achieve the design goals for all three modes. POISSON is a finite-element program used for analyzing electromagnets, and was used to design the bending magnet and the quadrupole which immediately follows it. Existing quadrupoles were judged to be suitable for the other locations.

Design

The layout for the final design is shown in Figure 1. The two quadrupoles before the bend allow the resolution to be varied over a wide range while keeping the beam size small in the non-bend plane. The bending magnet design is a "window frame", chosen for its simplicity and good field uniformity. Calculations using POISSON predict that the field will be uniform to 0.01 % over the central 5 cm of the aperture, and uniform to 0.025 % over the central 9 cm. Measurements of the central field versus current show a deviation from linearity of 1 % at 7000 gauss, demonstrating the absence of any significant saturation effects up to the design maximum of 6670 gauss.

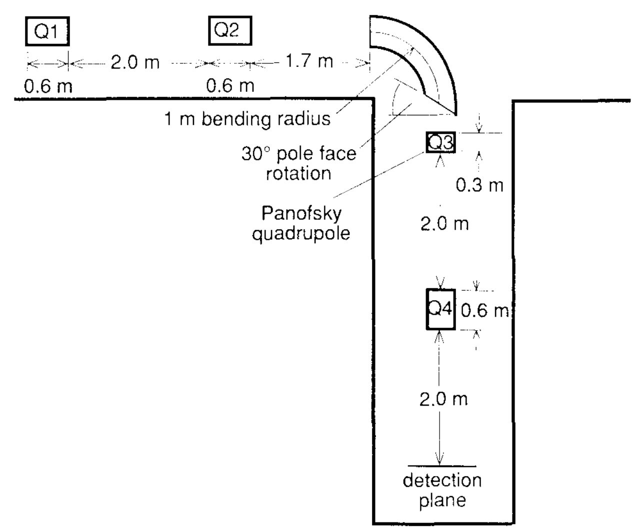

Figure 1. Physical layout of the system components.

In order to vary the dispersion, there must be an adjustable quadrupole following the bending magnet. This quadrupole must be defocussing for high dispersion, and focussing for low dispersion. In fact, this quadrupole would have to be very strong in order to reduce the dispersion to a manageable level when operating with a beam having an energy spread of a few percent. To reduce the field strength required from this quadrupole in the low-resolution mode, the output pole face of the bending magnet was rotated by 30°. This provides focussing which reduces the dispersion of the bending magnet. The field strength requirements for the third quadrupole are now symmetrical: the sign changes but the magnitude stays the same when going from high-resolution mode to low-resolution mode. The fourth quadrupole is turned off for the low-resolution mode, and is set to be strongly defocussing for the high-resolution mode. The resulting maximum dispersion gives rise to a 2 mm shift at the detection plane for a change in energy of 0.01 %.

The quadrupole which immediately follows the bending magnet must have an aperture in the bend plane which is equal to that of the bending magnet. Since this is nearly 4 inches across, the quadrupole would be quite bulky and expensive if its aperture were circular. Instead, a so-called "window frame" or "Panofsky" quadrupole[3,4] with an aspect ratio of 4:1 is being used. A cross section of this magnet is shown in Figure 2. An idealized version of a Panofsky quadrupole would consist of uniform current sheets lining a rectangular aperture in an infinitely permeable material. In this case a perfect quadrupole field is ensured by symmetry, rather than by the shaping of pole faces as in a conventional quadrupole. Coils of finite thickness do not destroy the symmetry, provided that the current density is uniform. Perpendicularity of the walls forming the aperture is crucial to maintaining the proper symmetry.

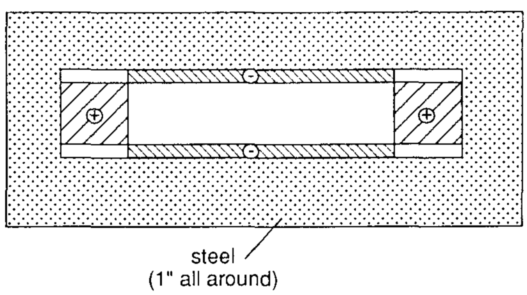

Figure 2. Schematic cross-section of the Panofsky quadrupole.

Beam profile plots for the three operating modes are shown in Figures 3 through 5. The plots are for an energy of 100 MeV, with a normalized emittance of 20 π mm mr, and a nearly parallel beam at the entrance to the first quadrupole. The quantity plotted is the full width at half-maximum, as computed by TRANSPORT. For each mode, the width is shown for a beam with no energy spread and for a beam with a FWHM energy spread as indicated in the figure. The beam profile in the non-bend plane is similar in all three cases. The first two quadrupoles give a small, weakly converging beam which is not much affected by the other magnets. In the high-resolution mode, when the last 2 quadrupoles are strongly focussing in the non-bend plane, a waist is formed near the detection plane.

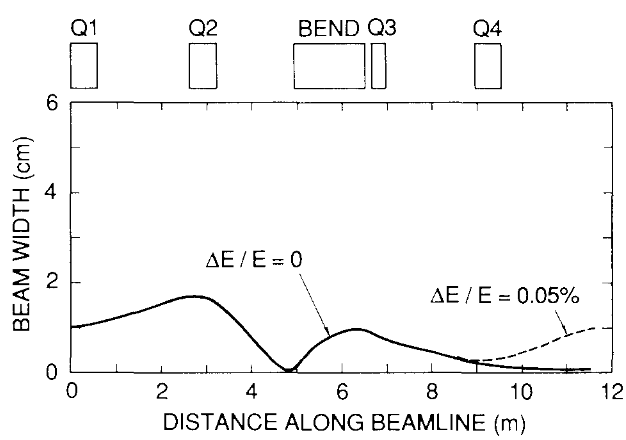

Figure 3. Beam profile (FWHM) for a 100-MeV beam with a normalized emittance of 20 π mm-mr, shown for the spectrometer set in the high-resolution mode.

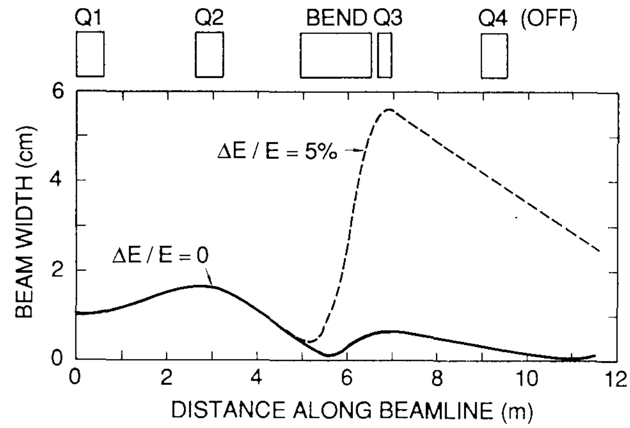

Figure 4. Beam profile for the same beam parameters as Figure 3, but with the spectrometer in the low-resolution mode.

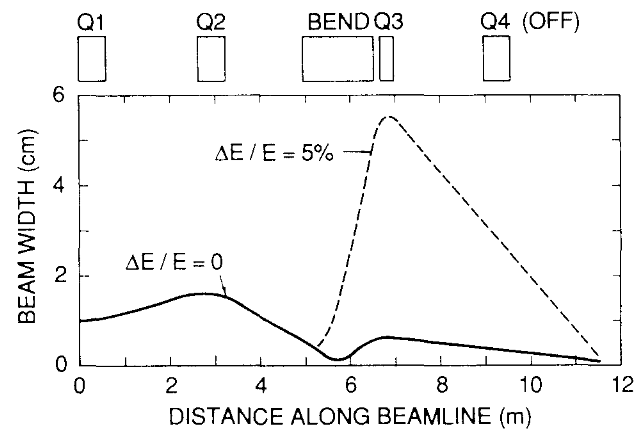

Figure 5. Beam profile for the same beam parameters as Figure 3, but with the spectrometer in the no-resolution mode.

Status

The bending magnet and its power supply have been built and bench-tested. The Panofsky quadrupole has been assembled and checked for mechanical accuracy. The other quadrupoles were already in our possession. Nearly all of the support structures and beamline components have been fabricated, and installation is scheduled to take place in October of 1988. Testing with an electron beam will take place in November or December.

Conclusion

An electron spectrometer has been designed for the SCA/FEL which allows the resolution and dispersion to be varied over a wide range. This spectrometer should prove to be a valuable diagnostic of the electron beam, both directly from the accelerator and after interaction with the Free Electron Laser. In addition, the no-resolution mode will allow it to be used as a simple dump magnet regardless of the energy spectrum.

Acknowledgements

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References

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