A FAST CYCLOTRON BEAM EMITTANCE MEASURING DEVICE *

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Abstract

A fast emittance and beam profile measuring device for charged particle beams of energies up to about 30 MeV protons is described. It makes use of digitally driven compact beam deflection magnets which deliver sufficiently deflecting triangular wave fields up to frequencies of 1 kHz. Two-dimensional emittances or beam profiles can be produced with 16 frames per second on an oscilloscope. Alternatively, the data can be transferred to a PDP-11 computer with 0.3 frames per second.

Introduction

Besides beam intensity and rough profile determination by television pictures from fluorescent viewers, there is, especially in low background experiments, a need for exact profile and emittance measurements. Furthermore, such a device helps to transport the beam in the beam guiding system. The measuring device described in this article operates with three compact beam deflection magnets delivering triangular or sawtooth wave fields which sweep the beams over stationary slits. Further applications of this system are beam positioning, homogeneous irradiation of targets and beam shuttering.

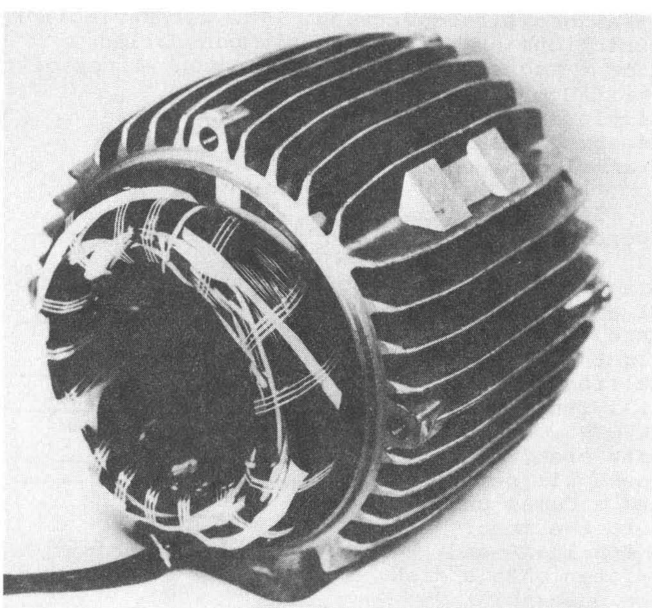

Fig. 1 The deflection magnet (without additional cooling)

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Beam Steering Unit

The magnet (Fig. 1) consists of an electromotor-stator (Umgußstator BN 112M/2 poles, 24 slots), similar to that of Benaroya and Ramler[1] and Bechtold, et al.[2], provided with special windings. The geometrical dimensions are: length of the sheet-iron core 142 mm, inner diameter 92 mm, and outer diameter 215 mm including the cooling ribs. The winding is bipolar and two-phase and the two identical phases are rotated 90° against each other. This makes possible the independent settings of the horizontal and vertical field components and beam deflections in the corresponding directions. Contrary to Ref. 2, we have not chosen a sinusoidal distribution of turns related to the azimuthal angle of the slot because of its difficult fabrication. The demands for optimum homogeneity of the field and maximum use of the winding volume led us experimentally to the following winding distribution: in each phase and pole four neighbouring slots bear 57 turns of enamelled copper wire (1 mm diameter) and the four following slots, right and left, each bear 27 turns. The same current flows through all turns in the same direction. The opposite pole has a symmetrical winding with an opposite current direction. Each phase has a resistance of 6Ω (at 23°) and an inductance of 50 mH. The field inhomogeneity $\Delta B/B$ in the center of the deflector is smaller than ±0.5% within a diameter of 45 mm and smaller than ±0.5% within a diameter of 30 mm. The effective field length (SCOFF) is 187 mm and the magnetic field per ampere amounts to $5.6 \cdot 10^{-3}\,TA^{-1}$. The mean rise of temperature in the turns at continuous operation without any additional cooling reaches a (just tolerable) value of 112°C at 6A while the rise at the inner diameter of the sheet-iron core is 62°.

In a second version of the steering magnet, the winding space has been sealed and filled with a thin silicone oil (AK 10) so that the heat can better be conducted from the windings to the housing, which is water-cooled from the outside. The current input to one phase can be augmented in that way to about 12A (corresponding to 1.2 kW), effecting a mean rise of temperature in the turns of 102°C. The aluminum tube (ID 84 mm), which on the one side seals the winding space and on the other side serves as a vacuum housing for the beam, rises 50°C. This nearly maximum current input of 12A leads to a magnetic field of $6.7 \cdot 10^{-2}$ T, which makes possible beam deflection of ±15 mm/m at the maximum energies of the Hamburg Isochronous Cyclotron ($\rho \cdot B_{max}$ = 0.84 Vs/m, corresponding to 17 MeV deutrons).

For higher sweep velocities the resistance of the magnet can be diminished to 1.5Ω and the inductance to 12.5 mH by parallel connecting of corresponding turns. In this case, a stainless steel tube of 85 mm diameter and 0.2 mm thickness serves as a vacuum housing.

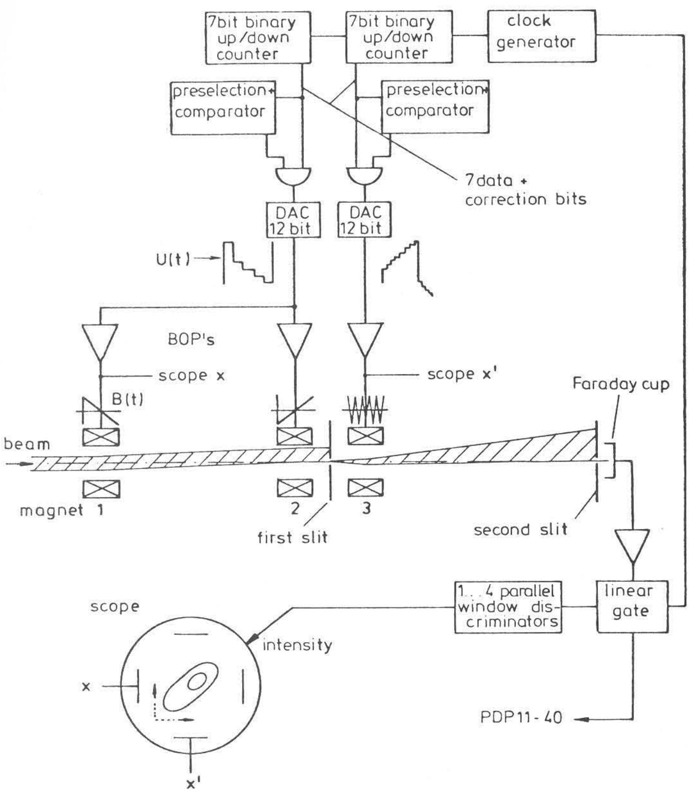

Fig. 2 Schematic of the emittance measuring device.

Beam Emittance Measurement

The beam measuring device is shown schematically in Fig. 2. In principle it is similar to that of Sluyters, et al.[3] The first two identical magnets with opposite polarity generate a horizontal displacement x of the beam which is proportional to the magnetic field. That fraction of the beam that passes the first 1 mm wide vertical slit is scanned by the third magnet across a second 1 mm vertical slit in front of the Faraday cup. The displacement which corresponds to the original angle x' between that beam fraction and the optical axis is also proportional to the magnetic field.

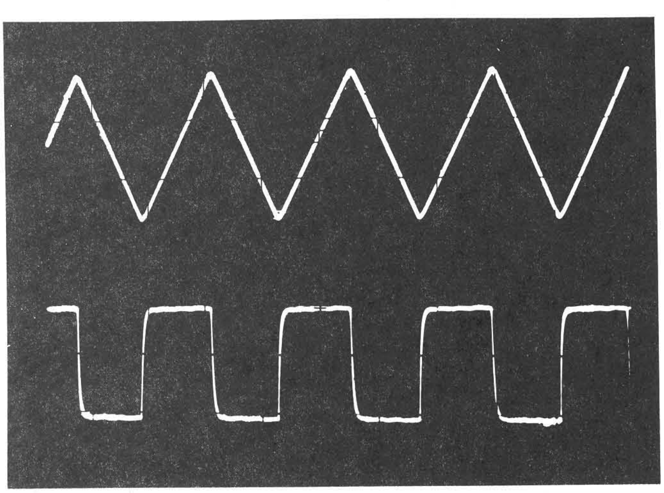

Fig. 3 The triangular wave current of 1 kHz and ±5.5 A through the magnet (above) and the corresponding signal from an induction coil in the field (below).

For vertical emittance measurements the two vertical slits are exchanged for horizontal ones by remote control and the other set of magnet phases is excited.

The magnets are driven by digitally controlled bipolar operational amplifiers: BOP ±72 V, ±5.5 A. The magnets 1 and 2 deliver "slow" sawtooth wave fields, and magnet 3 a "quick" triangular one. A current control of the magnets is not possible because of the high reactive current at high frequencies. Therefore, the digital processing unit (Fig. 2) provides a voltage form which leads to the desired current shape for a fixed frequency. We have reached so far a full emittance display in 1/16 s with magnetic field amplitudes of $\pm 8.5 \cdot 10^{-3}$ T. These values can be further improved by the use of several BOP's. Fig. 3 shows the nearly optimum triangular wave current at 1 kHz (upper trace) and the corresponding signal from an induction coil in the field (lower trace). The screen of the emittance display consists of 128 × 128 points. For computer operation with 0.3 frames per second, the amplitudes are $1.6 \cdot 10^{-2}$ T.

The output of the Faraday cup is connected to a preamplifier by a short coax line which allows beams of about 1 nA to be measured. Another amplifier 30 m away increases the signals to maximum 8 V before a linear gate produces 128 × 128 beam pulses per frame with definite rise times.

The display of the emittance is performed in two ways. First, the pulses are applied to 4 parallel window discriminators with variable thresholds. Their outputs control the intensity of an oscilloscope trace. The two deflection directions are synchronously controlled with the x or x' magnets. So up to 4 contour lines of the emittance can be displayed simultaneously with 16 frames per second.

In the computer operation the 128 × 128 pulses are transferred in 3.28 s at a rate of 5 kHz into the first of eight ADC's of the multiparameter analyzing system OCTOPUS. Then the data are fed over a push-pull memory and a Camac crate into the memory of a PDP 11-40 and written onto a disk. The push-pull memory consists of two halves, each with 256 16-bit words, and works automatically in the so-called ping-pong mode.

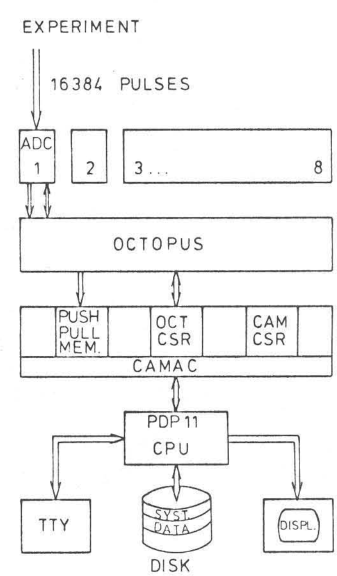

Fig. 4 Schematic of data transfer to and from the computer.

OCTOPUS allows a data transfer rate of 100 kHz but the 32 k - memory at present limits the rate to 5 kHz because not all data can be stored in the memory simultaneously. The 16,384 points of one frame are investigated for completeness and then transformed into a screen matrix. All the data input is made by the software program "PINPON", which also makes possible the data analysis in dialogue form. The analysis includes the two-dimensional display of the intensity whereby the size of the points is proportional to the intensity, the setting of markers at the n(10)% - values of the maximum row intensity, and the display of parts of the matrix with preselected windows. In general, one figure can be produced in about half a minute. Figs. 5a & 5b show some two dimensional horizontal emittance figures measured with 20 MeV protons. The screen is reduced in these cases to 64 × 64 points by averaging over every 4 points with the computer.

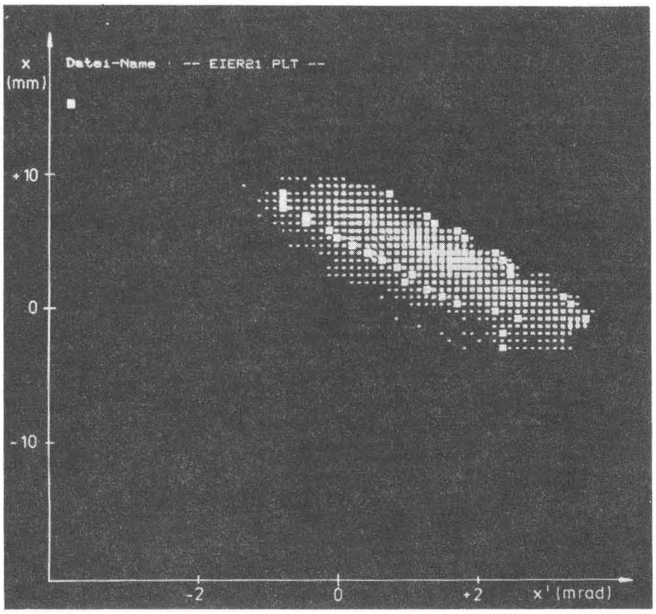

Fig. 5a Two-dimensional horizontal emittance figure with intensity profile measured with 20 MeV protons. The larger single dots mark the 10% intensity values of each row.

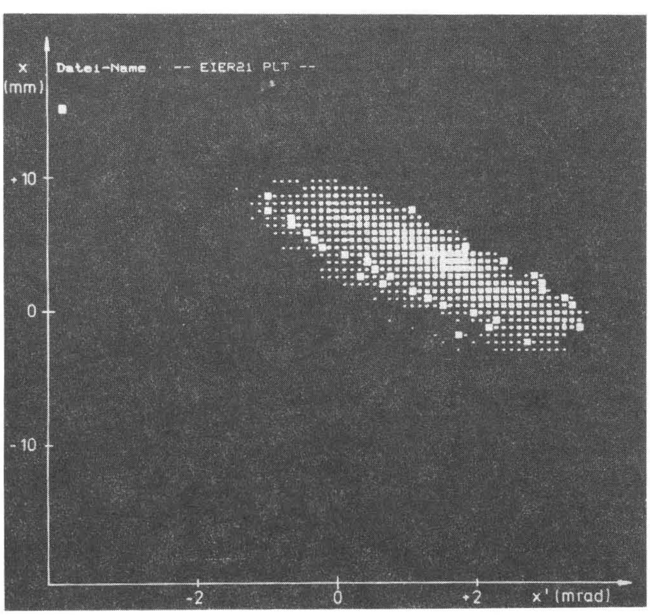

Fig. 5b The same as in Fig. 5a, with 5% markers.

For beam profile measurements we use one x-y magnet and sweep the beam line by line over a diaphragm of 1 mm diameter and a following Faraday cup. The magnet phases and the oscilloscope are again synchronously controlled. In the same way as described above we get 16 frames per second (standing image) with 4 simultaneous intensity contour lines on the scope. Fig 6 shows such a beam profile display for 20 MeV protons.

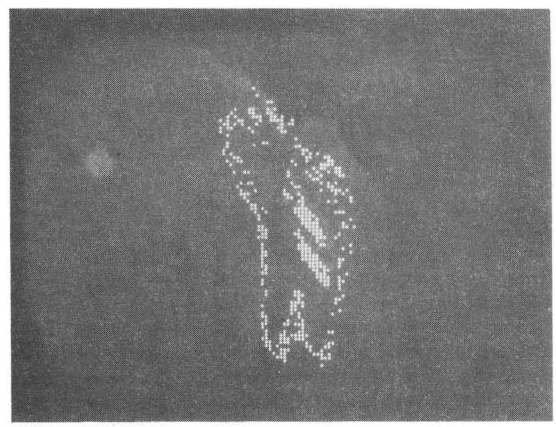

Fig. 6 Profile display of a 20 MeV proton beam with two window discriminators (one contour line and two intensity peaks). The height of the figure is about 25 mm.

The measurement of 4-dimensional emittances in the (x-x'−y-y')−space is possible too if two diaphragms instead of the slits are used and all magnet phases are excited in a suitable way.

References

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