A SYSTEM FOR EMITTANCE MEASURING AND MONITORING AT THE JÜLICH ISOCHRONOUS CYCLOTRON

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ABSTRACT

The emittance-measuring device of the Jülich Isochronous Cyclotron has been completely rebuilt and improved to be operated in two modes: In the first mode the whole beam-density profile or its section at a preset density is presented on a XY-recorder in 140 seconds. In the second mode, when using an oscillating magnetic field, the emittance is displayed on a XY-storage oscilloscope in about 10 seconds. The first mode is used for precise emittance measurements. The second mode is an important aid to the operator when adjusting the beam on to the optical axis of the beam-handling system.

INTRODUCTION

The automatic beam-emittance-measuring device at the Jülich Isochronous Cyclotron has been extensively used in the past to match the cyclotron beam to the beam-handling system, which includes a rather complicated double monochromator of high resolving power [1]. This work has been done in co-operation with the cyclotron manufacturer, AEG [2,3]. The original beam-emittance-measuring device [4] used the two slit method with two slits at a distance of 2 m from each other.

For several reasons it has been decided to leave a system for emittance measuring and monitoring in the beam line:

1. The Jülich Isochronous Cyclotron is an energy-variable machine. The emittance, i.e., the size and the position of the virtual sources and their variation with beam energy, has to be controlled to obtain a proper matching of the extracted beam to the beam-handling system. Tuning the cyclotron parameters to get the smallest possible emittance is the only way to minimize the second- and higher-order aberrations, which diminish the resolving power and the transmission of the double monochromator, as well as to

minimize the energy spread of secondary nuclear reaction particles due to kinematics.
2. A slight variation of the coordinates of the beam center occurs when varying the cyclotron energy. Steering magnets have to be tuned to position the beam along the optical axis of the beam-handling system. Their function has to be controlled by the emittance-measuring equipment.
3. Last but not least the emittance-measuring equipment is an important aid for improvement programs at the cyclotron, and it helps to locate malfunctioning cyclotron components in the daily operation.

To fulfill all these requirements the original system was modified and rebuilt in the following way:

1. The system was shortened to 1 m so it could be placed in the beam line.
2. The original mode of operation (mode 1) using the two-slit method has been improved and is still used for precise emittance measurements.
3. A second mode of operation (mode 2) for quick emittance monitoring has been added. This mode uses two slits and an oscillating magnetic field and is similar to that reported by R.W. Allison et al [5].

BASIC DESIGN AND CONSTRUCTION

The emittance-measuring device is located in the so called injection system (see fig.1) which comprises the extraction elements of the cyclotron and the first part of the beam-handling system. The injection system is designed to allow and to control the proper matching of the cyclotron beam to the beam-handling system, especially to the double monochromator at the entrance slit DS1. The emittance-measuring device can be operated in two modes. In both modes the partially integrated beam density functions [6] $D(x,\Theta)$ and $D(y,\Phi)$ are recorded.

The first mode of operation (see fig.2) was already used in the original emittance-measuring device [4]. Using the two-slit method with a drift length of now 1 m between the slits an automated ten-step cycle drives the first slit S1 to 10 different positions and sweeps the second slit S2 through the aperture. The intensity I transmitted through both slits is measured by a faraday cup. Two signals are produced. One signal is the position of the first slit. This signal can be modulated by the beam intensity I. The other signal is the displacement of both slits (S2-S1) relatively to each other and is proportional to the beam angle

$$\alpha \sim (S2-S1). \tag{1}$$

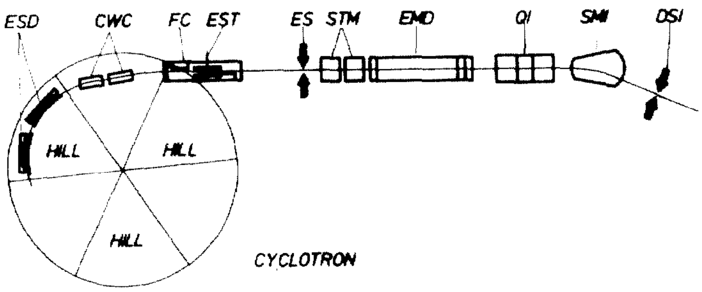

Fig.1 Schematic layout of the injection system
ESD electrostatic deflectors (2), CWC compensated weakening channels (2), FC focusing channel, EST electrostatic steerer, ES slit at cyclotron exit, STM steering magnets (2), EMD emittance-measuring device, Q1 quadrupole doublet, SM1 switching magnet, DS1 entrance slit of the double monochromator

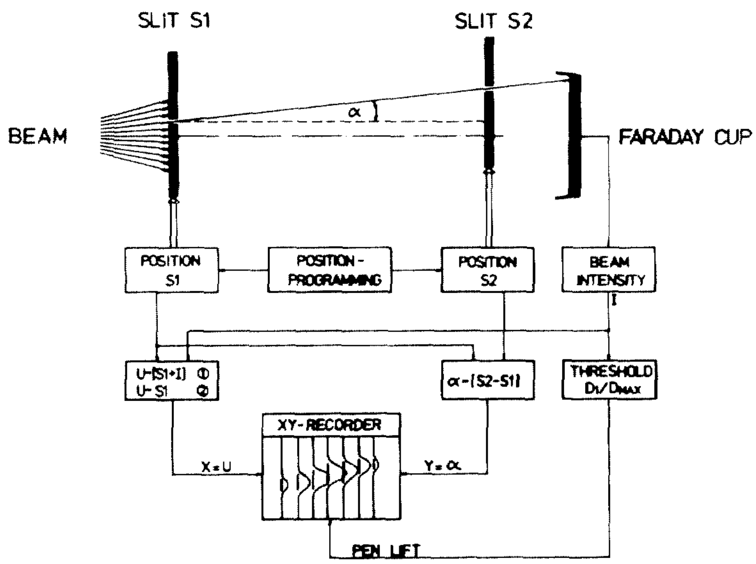

Fig.2 Block diagram for the operation in mode 1

Both signals are used in two ways to obtain an emittance display. In case they are directly fed to an XY-recorder and the position signal is modulated by the beam intensity I, an intensity distribution for ten positions of slit S1 is obtained. In case a threshold for the beam intensity I is set, and there is no modulation of the position signal by the beam intensity, the XY-recorder displays a straight line at ten positions of slit S1. These ten lines start and end when the beam intensity exceeds and undergoes the above threshold. The threshold can be set in percent of the maximum of the total density distribution $D(x,\Theta)$ or $D(y,\Phi)$. This second way of emittance display has been added for ease of evaluation.

The second mode of operation (see fig.3) uses a magnetic field B^* between the slits which oscillates at 50 Hz. The position programming unit drives the two slits parallel through the aperture. The part of the beam which is screened out by the first slit is swept across the second slit by the alternating field. A signal from a field-pick-up coil is integrated and transformed to a signal which is proportional to the beam angle

$$\alpha \sim B^*/B\varrho \, . \tag{2}$$

$B\varrho$ is the magnetic rigidity of the cyclotron beam. This signal and the position of the slits are fed to a storage oscilloscope. The oscilloscope beam is intensified in case the beam intensity in the faraday cup exceeds a first threshold ($D1/D_{max}$) and is intensified more in case the beam intensity exceeds a second threshold ($D2/D_{max}$, $D1<D2$). The $B\varrho$-value of the cyclotron beam is fed to the electronics by a DA-converter. The thresholds $D1,2/D_{max}$ are set in percent of the maximum density D_{max} in the density distribution $D(x,\Theta)$ or $D(y,\Phi)$.

The mechanical components of the device have already been described [4]. The magnet which produces the alternating field is a H-type magnet of 0.20 m effective length and has rectangular poles. The homogeneity is better than 1 % in the area which is needed for emittance measurements. The iron of the magnet is composed of single-type stamped-iron laminations. Each of the two coils consists of 162 turns of 1 mm thick and 15 mm high copper band. The inductance of the magnet is part of a 50 Hz-resonant circuit, which is energized by a transformer. The amplitude of the oscillating current is about 30A which produces a B^*_{max} of 1.2 kG. Fig. 4 shows the emittance-measuring device as is used now at the Jülich Isochronous Cyclotron ready for measuring the beam emittance in the (x,Θ)-plane. The device can be turned by 90° to measure the emittance in the (y,Φ)-plane.

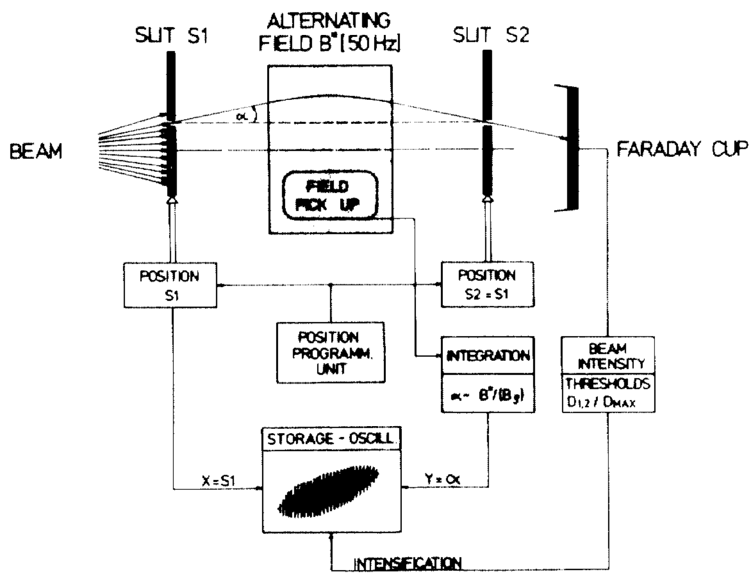

Fig.3 Block diagram for the operation in mode 2

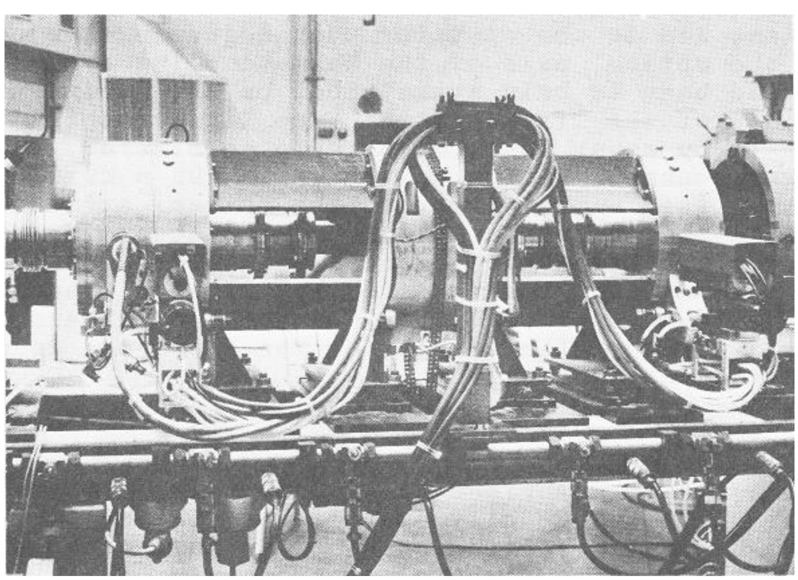

Fig.4 View of the emittance-measuring device

TYPICAL RESULTS

The results of the first mode of operation are suited for an exact evaluation of the emittance measurements. The results for the two ways of display using an XY-recorder are shown together in fig. 5. Each display takes about 140 seconds. In this mode the equipment resolution for typical emittances (~ 20 mm·mrad) and typical beam distributions of the external beam is estimated to be better than 10 %. In the second mode of operation the equipment resolution is about 15 %, but each display only takes about 10 seconds. The second mode is therefore suited for quick emittance monitoring and survey of relatively fast variations in the density distributions $D(x,\Theta)$ or $D(y,\Phi)$. A typical result is shown in fig. 6, where the horizontal emittance of the cyclotron beam is displayed. The two thresholds $D1,2/D_{max}$ are set to 25 and 80 %, respectively, resulting in two equidensity-contours.

When the second threshold is set to more than 95 %, an equidensity contour around the very top of the density distribution is displayed. This top is very sensitive to the variation of certain cyclotron parameters. Correlating the coordinates of the top of the density distributions to the variation of cyclotron parameters is a good tool for trouble-shooting malfunctioning cyclotron components. The quick emittance monitoring is also an important aid to the operator when adjusting the beam on to the optical axis of the beam-handling system. The extracted beam is held symmetrical on the horizontal slit jaws of the first slit ES (see fig.2) at the cyclotron exit by means of an electrostatic steerer in the focusing channel. During energy variation a maximum angular offset with respect to the optical axis of 2 mrad in the horizontal plane occurs. According to this offset in the horizontal plane and a slight offset in the vertical plane the two steering magnets - each steering in both planes - have to be tuned. Their function can be controlled easily by the emittance measuring device in mode 2 operation.

CONCLUSION

The system described in this report plays an important role in the daily operation of the cyclotron. Because of its versatile design it is suited for exact beam emittance measurements as well as for quick emittance monitoring when tuning up the beam or trouble-shooting cyclotron components. It will be most useful for further cyclotron-development programs.

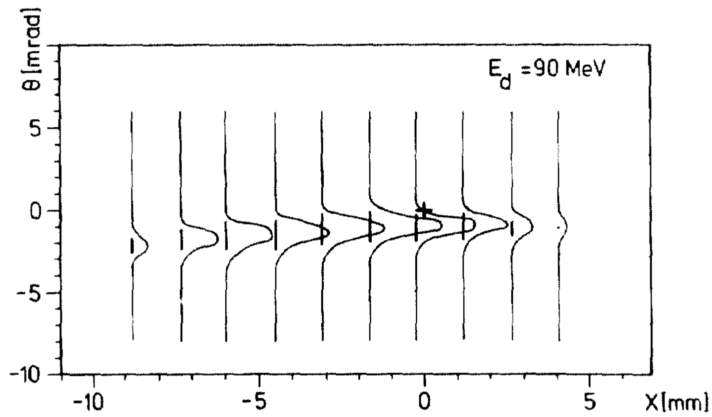

Fig.5 Horizontal emittance of the cyclotron beam displayed in the two ways of mode 1 operation

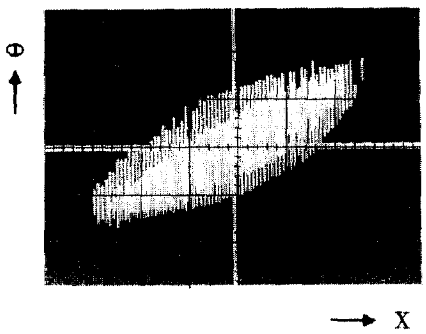

Fig.6 Horizontal emittance of the cyclotron beam displayed in the mode 2 operation

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DISCUSSION

HENDRY: I wonder how much the emittance actually does change, say, going over some energy range on your machine? You mentioned that it was in fact a function of the energy.

REICH: It is going from about 10 mm-mrad up to 22 in the whole energy range--that we measured about one and a half or two years ago. So maybe that answers your question.

HENDRY: That is true for both planes?

REICH: That is only true for the horizontal plane. The vertical plane stays stable up at about 18-22 mm-mrad.

BLOSSER: Is that for a fixed number of turns?

REICH: Right.