Emittance measurements at the Jülich isochronous cyclotron (JULIC)

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Presented by W. Kuhlmann

ABSTRACT

The emittance-measuring device (EMA) for the Jülich Isochronous Cyclotron (JULIC) is described. The EMA works on the principle of the two-slit method and operates automatically.

Measuring of phase-space areas in radial or vertical direction takes about 2 min. High-power beams of up to 90 MeV deuterons at 20 μA and 180 MeV α-particles at 10 μA may be analysed. The acceptance is 1250 mm mrad resulting from a position range of 50 mm for both slits. The analysing slits consist of carbon-shielded copper.

A preliminary survey of the properties of the external beam is given with respect to phase-space areas for deuterons and protons. The measured emittances for 80% beam intensity are less than 20 mm mrad in both planes if the cyclotron is carefully adjusted.

1. INTRODUCTION

In February of this year for the first time a deuteron beam was extracted from the Jülich Isochronous Cyclotron after the extraction devices had been mounted by the AEG. It is not the aim of this paper to discuss details because there is another paper[1] concerning extraction.

For measuring beam specifications, fixed in a contract between the industrial manufacturer (AEG) and the Institut für Kernphysik, an emittance-measuring system suitable for automatic operation was designed.

2. THE DEVICE FOR MEASURING PHASE-SPACE AREA

For the sake of accuracy and simplicity the two-slit method[2] was chosen. The principle is shown in Fig. 1.

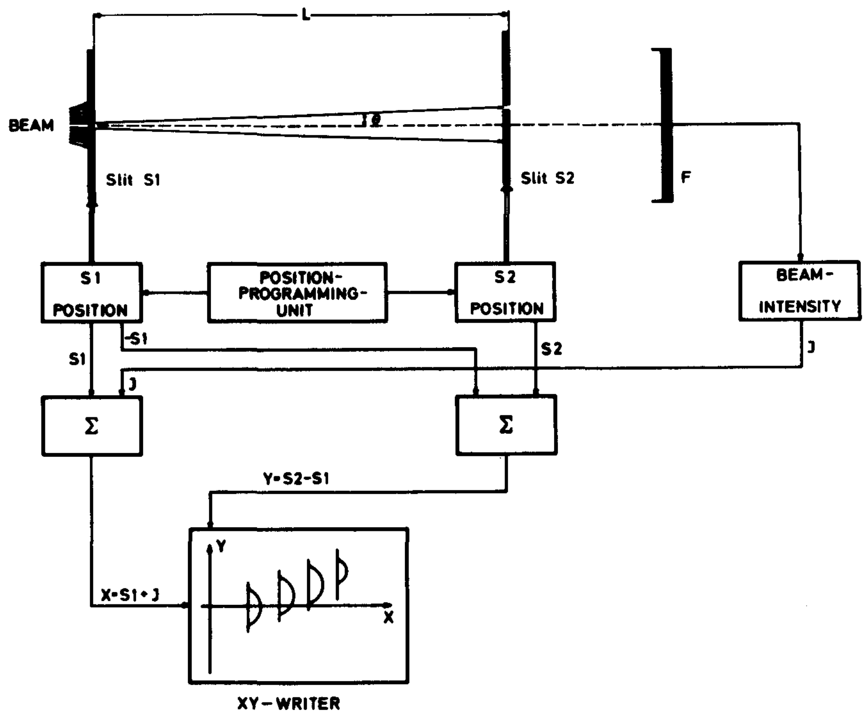

Fig. 1. Principle of the emittance-measuring device (EMA) (L: *drift length;* F: *Faraday cup; S1, S2: position signals of slit S1, S2;* J: *beam intensity)*

About 1·60 m after leaving the vacuum chamber of the cyclotron, the beam impinges upon a first slit $S1$. The part of the beam passing $S1$ is analysed by the second movable slit $S2$. The distance between the two slits is $L \approx 2$ m.

The automatic measuring process is controlled by the position-programming unit which places the first slit in a certain position $S1$ and moves the second slit $S2$ continuously over a range of ±25 mm. At the same time the intensity of the beam transmitted by $S2$ is measured as a function of its position $S2$, in the fixed Faraday Cup F, thereby giving the required information about the beam intensity as a function of the angle

$$\theta = (S2 - S1)/L \tag{1}$$

After producing the signal $Y = \text{const} \times (S2 - S1)$ by an operational amplifier, Y is plotted on the vertical axis of the XY-writer. On the horizontal axis of the writer, modulated with the beam intensity J, is plotted:

$$X = S1 + J \tag{2}$$

After completing the measurement at the first position $S1$ the position-programming unit sets the first slit to a second position and the process continues as before. Altogether there are 10 equidistant positions for the first slit, which may be chosen in the range of ±25 mm.

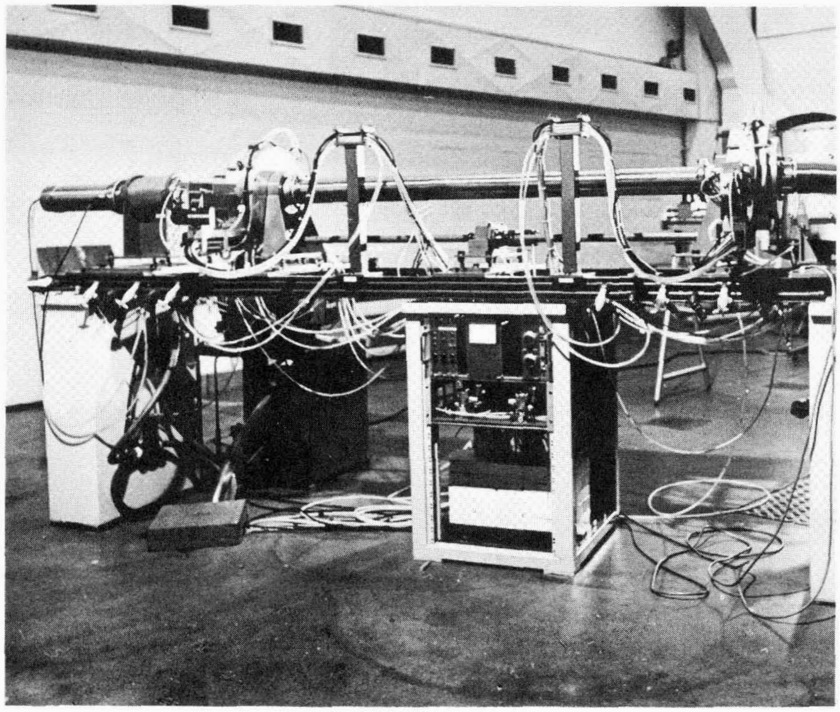

Fig. 2. View of the EMA

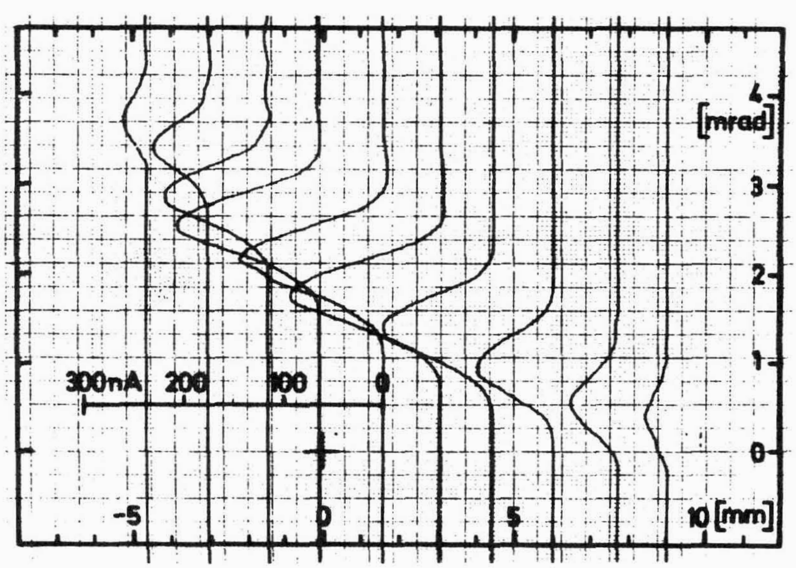

Fig. 3. Current-density distribution in phase-space

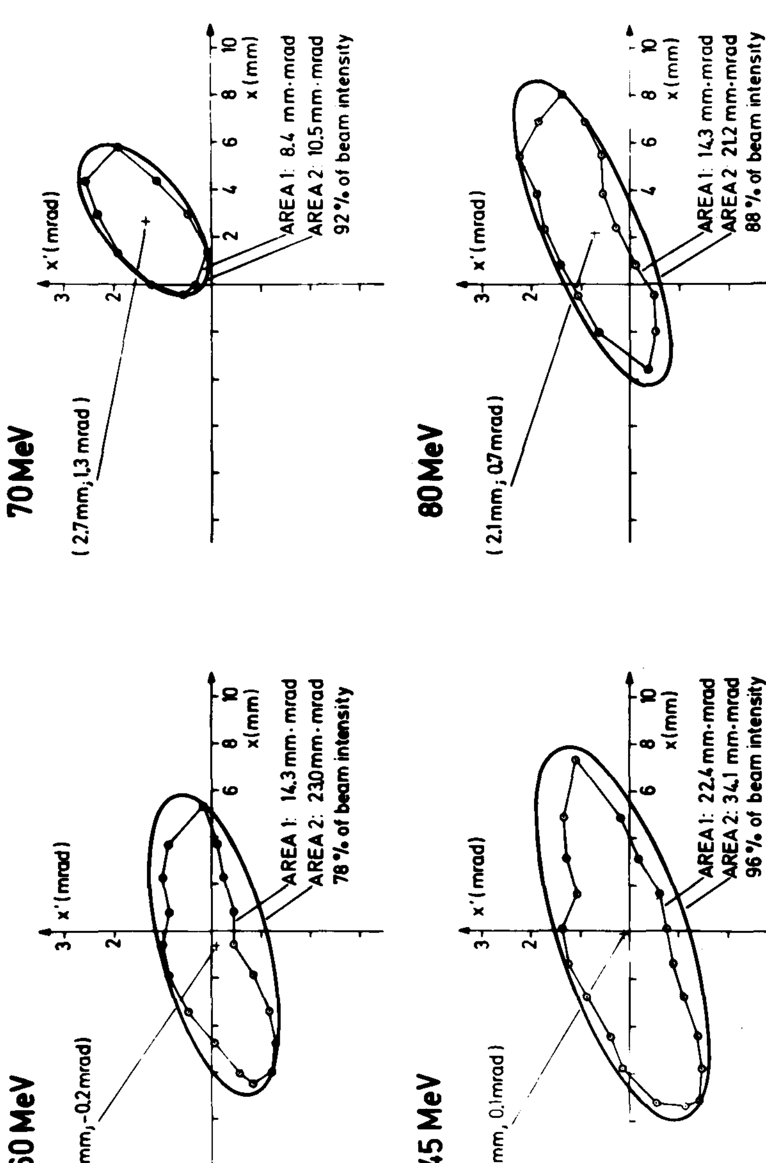

Fig. 4. Radial phase-space areas for deuterons (experimental points given at $J = 0{\cdot}1 J_{max}$ *where* J_{max} *is the maximum current density of the corresponding current-density distribution as in Fig. 3)*

In the way mentioned above, the device produces the phase-space-current-density diagram shown schematically in the block '*XY*-writer' in Fig. 1.

The whole slit system can be rotated through 90° by remote control, so that density distributions in the *z*-direction (vertical plane) can be measured as well.

The acceptance of the device was designed to account for all possible cases of beam directions and emittances out of the cyclotron. We chose as the acceptance 1250 mm mrad. The slit heights are 50 mm each. The slit widths are manually adjustable in the range from 0·1 to 3 mm. The positioning accuracy of the slits is better than 0·1 mm.

As a consequence of the energy range of the Jülich Isochronous Cyclotron, the device was constructed to measure deuterons in the energy range from 45 MeV to 90 MeV at beam intensities of up to ~20 μA or α-particles of up to 10 μA in the range from 90 MeV to 180 MeV. Therefore, the water-cooled slits were constructed for a power dissipation of 2·0 kW. To stop 90 MeV deuterons 7 mm-thick square-edged copper slits were used. To reduce problems of power dissipation, long-lived radioactivity and neutron background, 25 mm-thick carbon shields which would also stop the possible beams were mounted in front of each slit.

Fig. 2 shows a physical view of the assembly; there are two identical slit chambers, with the drift-pipe between them, and the Faraday cup. At the chambers the driving assembly is mounted.

In Fig. 3 a photograph of a measured density distribution in phase-space is shown. On the horizontal axis 10 discrete *X*-positions are recorded. These are modulated with the beam intensity as a function of slit-position *S*2 which is written in the vertical direction.

It takes ~100 s to get such a density distribution. For interpretation one draws lines of equal current density and gets thereby the phase-space area of interest. The error in phase-space area is usually less than 5%, depending slightly on the beam properties.

3. FIRST RESULTS

The results in this section are preliminary because at the moment there are still many cyclotron parameters not yet known exactly enough with respect to their influence on the beam quality. Futhermore, the frequency-stability of the rf-system is $\sim 2{\cdot}5 \times 10^{-5}$. This has an important influence on beam quality. On the other hand recent measurements showed an oscillation of beam angle with an amplitude of up to 0·3 mrad at frequencies between 7 Hz and 20 Hz. Therefore, the results will probably improve as soon as the planned improvements of the cyclotron are completed.

At the moment, however, if the cyclotron is 'well adjusted',[1] usually at least 80% of the beam intensity is within the phase-space areas shown in Figs. 4 to 7.

3.1. *Deuterons*

In Fig. 4 phase-space areas in the horizontal plane at four deuteron energies distributed over the available energy range[3] are shown. The experimental points correspond to 10% of the maximum current density in the diagram. The experimental points are surrounded by ellipses minimised with respect to their

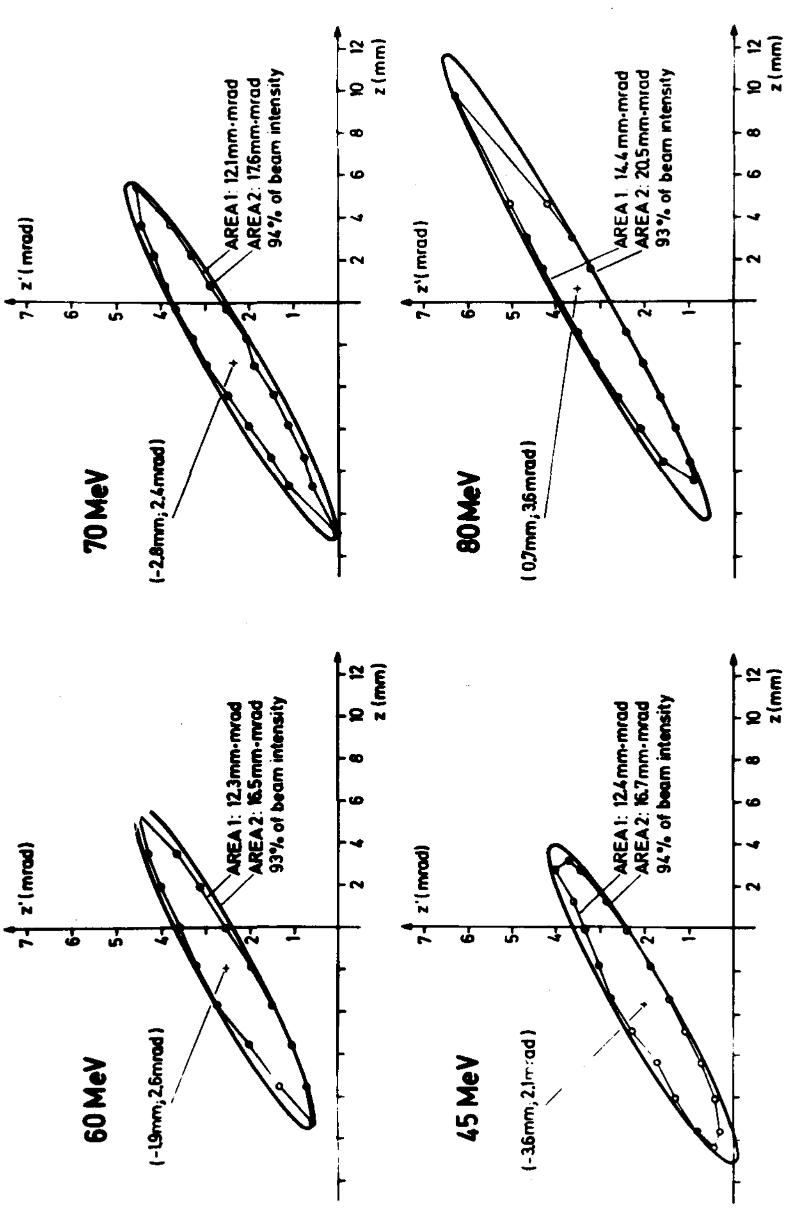

Fig. 5. Vertical phase-space areas for deuterons (refer to Fig. 4)

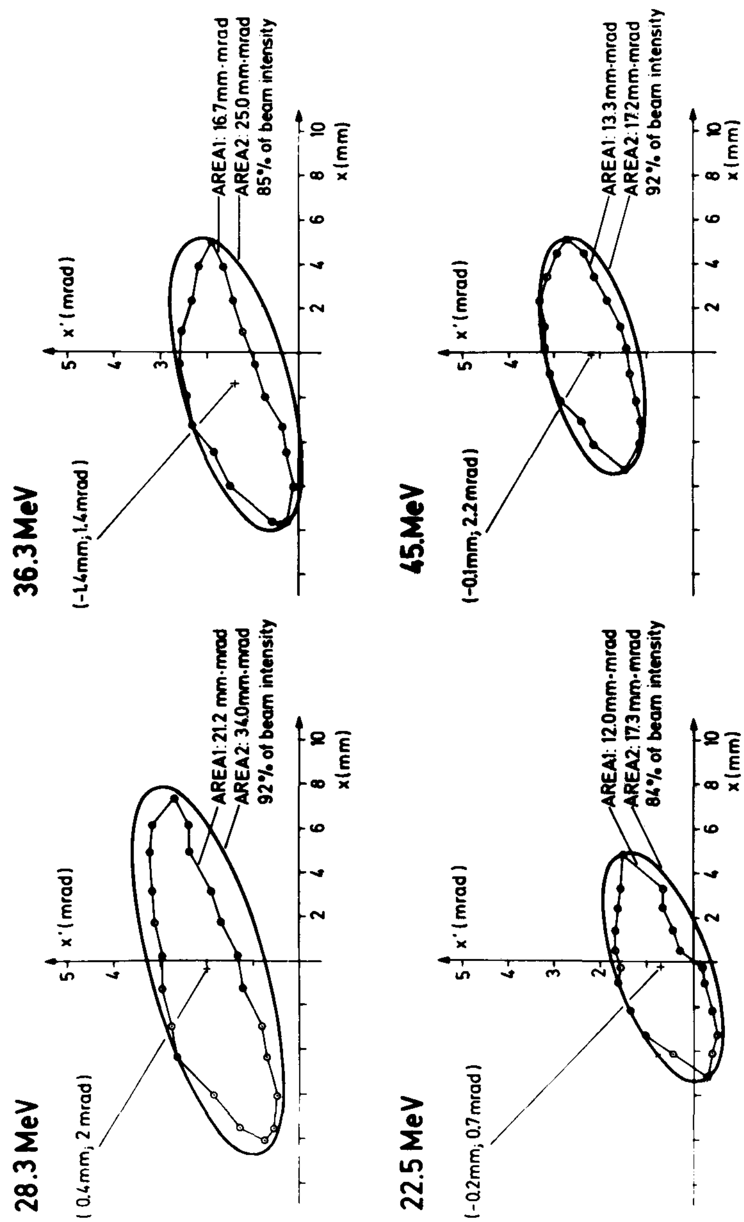

Fig. 6. Radial phase-space areas for protons (refer to Fig. 4)

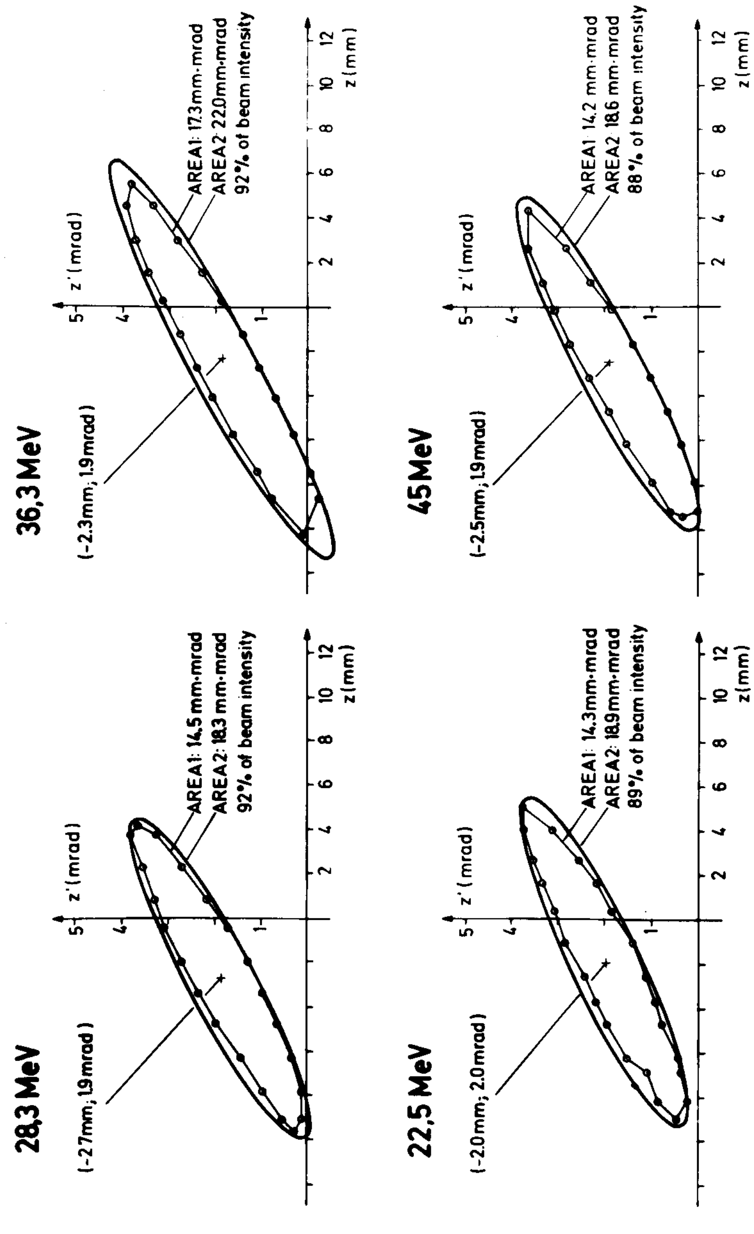

Fig. 7. Vertical phase-space areas for protons (refer to Fig. 4)

phase-space area. The parameters of the ellipses are used for ion-optics computations. The measurements were taken with a beam intensity of ~5 μA.

Varying the energy of the cyclotron the change in beam angle is less than ±3 mrad, when the beam position at the first slit is kept fixed by an electrostatic deflector mounted in the focusing channel of the cyclotron.[1]

The error in defining the X, X'-points is less than the size of the drawn points. In Fig. 5 the corresponding results for the vertical plane are shown. The beam leaves the cyclotron with an angle of inclination of about +2 mrad to +3 mrad.

3.2. *Protons*

In Fig. 6 are shown phase-space areas at proton energies which are representative for the proton energy range at Jülich (22·5 MeV to 45 MeV).

These measurements were made with intensities between 0·8 μA and 6 μA. Fig. 7 shows the corresponding results for the vertical plane.

As in the case of deuterons the beam comes out of the cyclotron in a slightly upward direction.

The measurements with α-particles and $^3He^{++}$ ions are in preparation and will be published later.

ACKNOWLEDGEMENTS

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DISCUSSION

Speaker addressed: W. Kuhlmann (Jülich)

Question by R. S. Livingston (ORNL): How much beam power can be handled by your emittance-measuring system?

Answer: The system was designed for about 2·0 kW, the maximum expected beam power. Beams of 20 μA of deuterons up to 90 MeV have been handled.

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