CONTROL OF BETATRON OSCILLATIONS IN A CYCLOTRON BY USE OF AN ON-LINE COMPUTER

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Summary

A system is described which is used to control radial betatron oscillations in the Karlsruhe AVF Cyclotron. The output of a radial current density target is digitized and fed into the memory of a CDC 3100 on-line computer. As different orbits are separated up to extraction radius in the Karlsruhe cyclotron they can be indentified by a computer program. Their radii can either be displayed on an oscilloscope screen or used for further calculations in order to obtain information on necessary corrections of the magnetic field.

Introduction

The importance of radial betatron oscillations in a cyclotron for achieving high extraction efficiency and high quality external beams has been stressed by many authors (cf. e.g. Blosser[1], Kranenburg et al.[2]).
Methodes employed for measuring radial amplitudes are shadow measurements of two probes against each other and radial beam density measurements with a differential target (cf. Clark[3], Richardson[4], p. 64 ff). While the former method is very time-consuming, the latter appears advantageous when single orbits can be distinguished over the total range of radii such as is the case in the Karlsruhe Isochronous Cyclotron.
Very accurate information on radial amplitudes and ν_r can be derived from radial beam density records as the one shown in Fig. 1, but the analysis of such a measurement is again a tedious and time-consuming job. Therefore a method was developed that uses the CDC 3100 on-line computer facility of the cyclotron laboratory for analysing the radial beam density.

Description of the Method

The principle of the data transfer to and from the computer is shown in Fig. 2. The inner finger of the radial beam density probe is directly connected to the input of an ADC which is coupled to the computer via a data channel. Each time a convert signal is applied the instantaneous value of the current is digitized and stored in the computer memory. The convert signal is derived from a light chopper fixed to the precision lead screw that moves the target inside the cyclotron. Sample distance is 0.1 mm. Data in the computer memory can be displayed on an oscilloscope screen. Fig. 3 shows three sections of a radial beam density scan as it appears on the screen of the display unit. Computation starts when the target has travelled the whole way from near center to maximum radius. After smoothing the measured values the maxima of the current density are identified and the corresponding radii calculated. When this has been done for the whole range of radii the distances of neighbouring orbits are calculated and checked for smoothness. By setting certain jump keys at the computer console the distances of neighbouring orbits can be shown on the display. An example of this is given in Fig. 4. At this point the data can also be manually corrected when it is evident from the display that either orbits have been omitted or spurious orbits have been found. In a next step the squares of the radii are fitted to the following expression by a least squares method

$$r_K^2 = A\ (K + K_o) - BK^2 \qquad (K = 0,1,\ \dots\ n)$$

where n + 1 is the number of orbits which have been identified. A, K_o and B are the parameters to be adjusted. A is connected to the energy gain per turn δE, the mass m and the orbit frequency ω of the particles by

$$A = \frac{2\ \delta E}{m\omega^2}$$

K_o takes account of the fact that the measurement does not start at zero radius, while B accounts for the increase of the magnetic field and the decrease of the energy gain per turn with increasing radius. A, K_o and B can be printed on the computer console typewriter. Then the differences

$$x_K = r_K - \sqrt{A\ (K + K_o) - BK^2}$$

are calculated and displayed. Fig. 5 shows an example of the radial betatron oscillations as they appear on the oscilloscope screen. Large negative x values are always obtained at small radii. This is probably due to the fact that there is a dip in the magnetic field near r = 120 mm which drives the particles out of phase and reduces the energy gain per turn.
The main difficulty in programming was met in the orbit identification section. It is due to the fact, obvious from Fig. 1, that orbits at small radii are well separated while a considerable

overlap occurs at larger radii. Criteria sensitive enough to distinguish orbits at large radii tend to introduce spurious orbits near the center. Total computation time is 10 to 20 sec as compared to approximately 60 sec travel time of the target from r = 70 mm to r = 1040 mm.

Conclusion

The advantage of the procedure described above is seen in that it provides detailed and accurate information on the radial oscillation pattern in very short time. It therefore offers the possibility to see immediately the influence of a parameter change on the radial oscillations and could make the measurement of radial oscillations an every day tool of cyclotron beam diagnostic. The method has though a natural limitation as the separation of orbits will disappear in the precessional maxima for large radial amplitudes. For the Karlsruhe cyclotron this will happen at amplitudes exceeding 6 mm.
It is intended to extend the method to measuring axial oscillations with many-fingered targets.

Acknowledgements

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References

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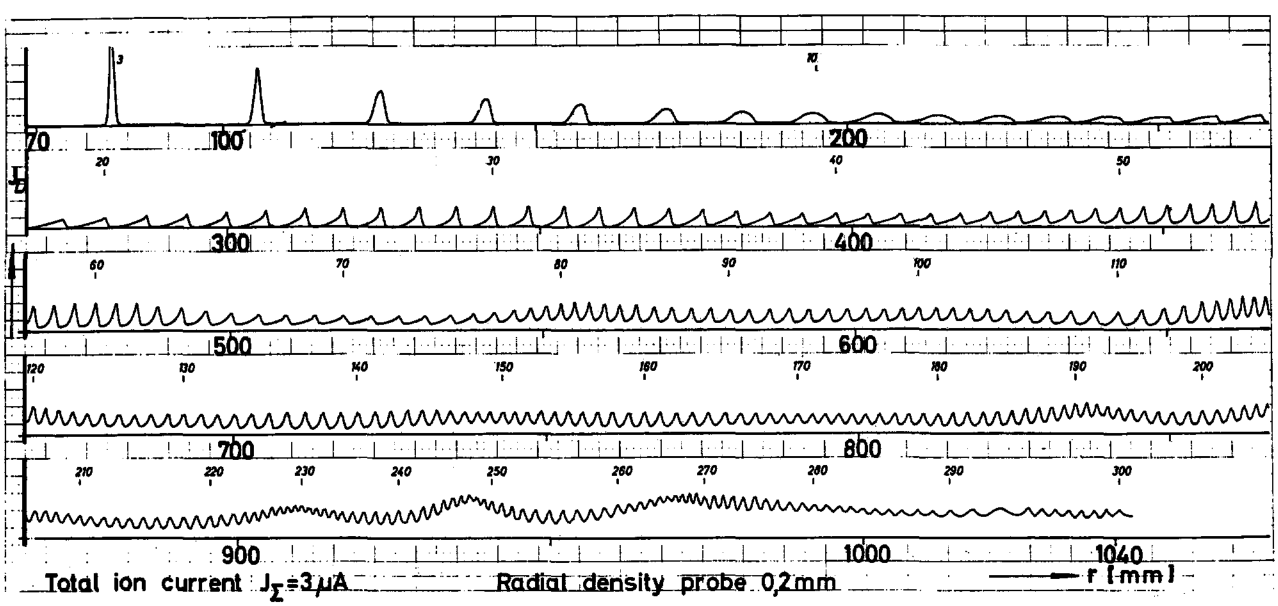


Fig. 1. Radial beam density in the Karlsruhe Isochronous Cyclotron. Large numbers below trace indicate the radius in mm, small numbers above give the turn number counted from machine center. Measurement was made with a Siemens Oscillomink recorder of 800 Hz nominal bandwidth.

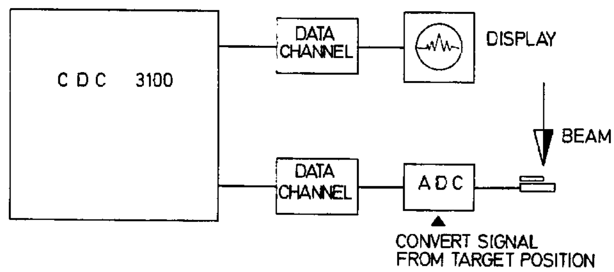
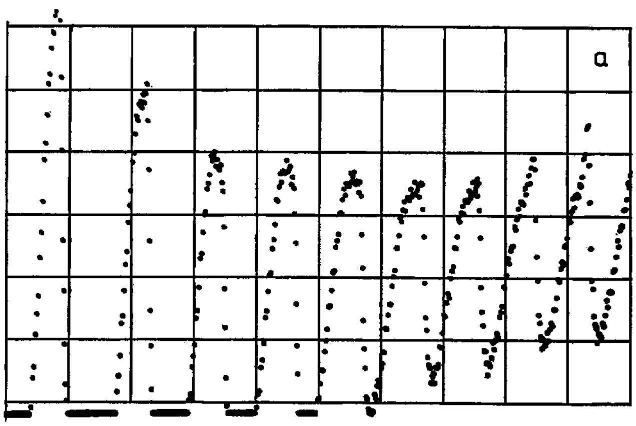


Fig. 2. Schematic of data transfer to and from the computer.



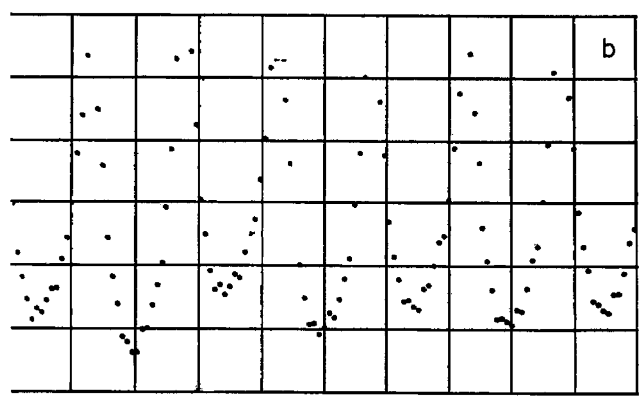
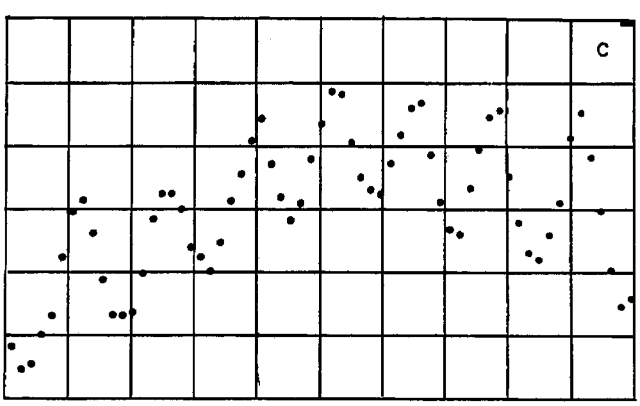


Fig. 3. Digitized radial beam density as shown on the computer display unit.
a) r = 140 to r = 240 mm
b) r = 440 to r = 466 mm
c) r = 845 to r = 858 mm



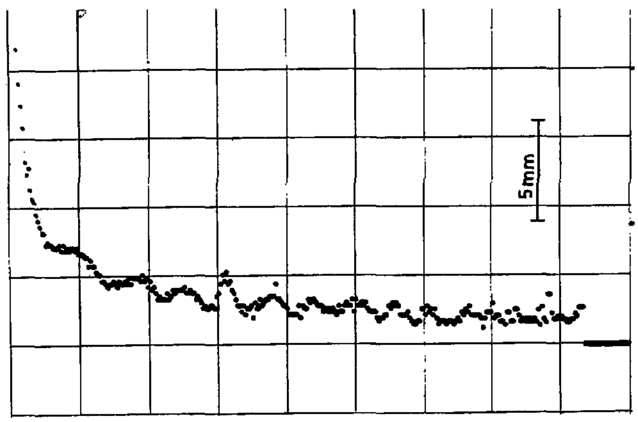


Fig. 4. Distances of neighboring orbits shown on computer display.

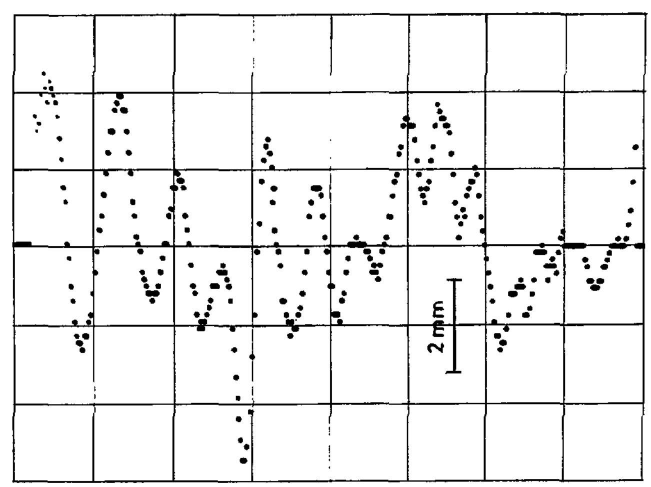


Fig. 5. Radial betatron oscillations shown on computer display.