AUTOMATIC ISOCHRONISATION AND COMPUTER AIDED CENTERING IN THE VICKSI CYCLOTRON

G. Hinderer
Hahn-Meitner-Institut Berlin
Glienicker Str. 1oo
1 - Berlin - 39
Germany

Summary

Starting from precalculated settings for the trim coils the magnetic field is automatically isochronized via a measurement of the beam phase history with the ten capacitive phase probes in the extraction-valley (see fig.1) and an online computer routine which uses a calculated correction matrix. The beam centering is done with a radially localized first harmonic field bump and observed via measurement with the two radial differential probes. Programs for automatically finding the turn positions and calculating the amplitude and phase of the harmonic bump are developed.

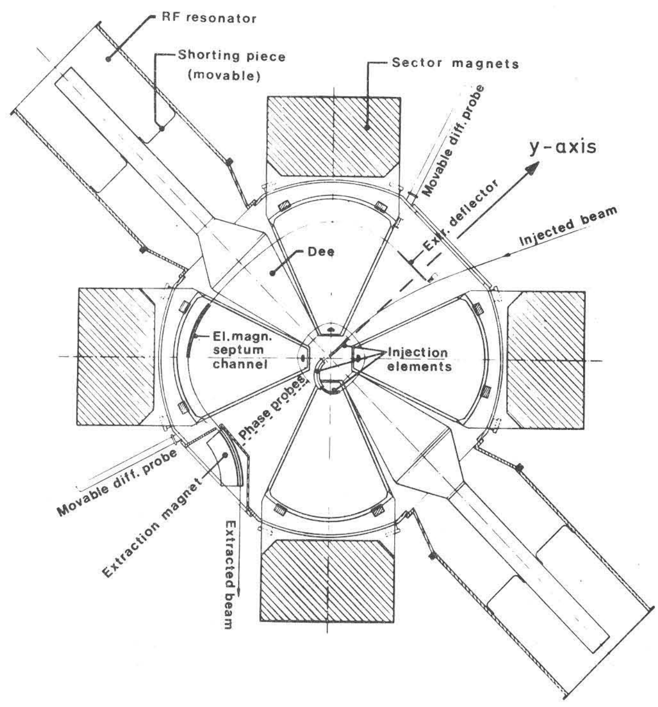

Fig.1: Plan view of the VICKSI cyclotron

Precalculations of cyclotron settings

The FORTRAN program PARSET was developed by Scanditronix to calculate parameter settings and other interesting properties of the VICKSI cyclotron. It was converted to be used on our control computer. Input from the teletype is the particle to be accelerated and the final energy. The operator makes the choice for the charge state, harmonic number, and the turn separation at injection. On disk files there are stored about 25,000 numbers which are the extract of extensive field measurements done during the period of construction. The program calculates within six minutes on the PDP 11/40 control computer

a) primary settings for all parameters for the actual beam,
b) a control matrix for field isochronisation, and
c) ν_r vs. average radius
   $\langle B \rangle$ vs. average radius
   E_{kin} vs. average radius.

The calculated settings can be transferred to the database and set all together by one action on the touch panel at the control desk. Other data, like the magnetic rigidity of the injected and extracted beam, are input for other programs which calculate the settings of the beam guiding system.

On-line programs

For diagnostic purposes and optimisation of the settings, a series of on-line programs was written with the interpreter MUMTI [1]). They are submitted to the main program EVA which overlays the selected programs via commands. Some of these programs are presented below.

Automatic isochronisation

The currents for the trim coils precalculated with PARSET are accurate enough to accelerate the beam to extraction radius by only tuning the main field (a few per mil) and the injection phase. With the phase measuring system [2]) and the program PHOP, the RF-phase of the beam at the radii of the ten capacitive phase probes in the extraction valley can be measured, and the magnetic field can be isochronized automatically to a desired phase curve.

The required change of trim coil currents is determined with the control matrix calculated in PARSET. To get this control matrix, first the transfer matrix A is calculated which is the correlation between a small change of parameters (trim coil currents) and the resulting change of the beam phase at the positions of the phase probes. Vice versa, the control matrix C gives the change of the parameters which is needed if a certain change of the beam phase is desired. If the number of parameters equals the number of phase probes (measuring points), then clearly $C=A^{-1}$. If we have less parameters than measuring points then a least square fit can be applied which is mathematically identical to using the control matrix $C = (A^T A)^{-1} A^T$ [3]).
In the isochronisation process we use all ten phase probes and eight parameters (trim coil no. 2 to 10 and main field; trim coils 3,4 and 5,6 are coupled together).

For the first few accelerated beams, the total phase variation after adjusting the main field was about 50 degrees. As the phase curve had always the same shape this information was put back to PARSET demanding a radially dependent "Soll-phase". This reduced the variation to 10 - 20 degrees. Within one to three iteration steps with the program PHOP this can be reduced to about 2 degrees. Fig. 2 shows a record of such an isochronisation procedure.

type input. Before the next beam period these field quantities will be taken into the database as system variables which can then be hooked to the knobs and varied continuously like any other accelerator parameter.

The precalculated harmonic settings of PARSET are such to get about zero first harmonic in the extraction region around the $\nu_r=1$ point. This results in a non - zero first harmonic

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CM1>ISO

          PROBEN-NR      AMPLITUDE          PHASE

               1       0.1032287E+01     0.6990179E+01
               2       0.1156105E+01     0.6962343E+01
               3       0.1594204E+01     0.7521699E+01
               4       0.1542209E+01     0.8310515E+01
               5       0.1660185E+01     0.9724001E+01
               6       0.1667888E+01     0.1062570E+02
               7       0.1777199E+01     0.1231388E+02
               8       0.1778487E+01     0.1423993E+02
               9       0.1415347E+01     0.1544034E+02
              10       0.1056798E+01     0.1919652E+02
EINHEITLICHE SOLL-PHASE ? (J/N); CR=
RUECKSPR. NACH CM1>J
SOLL-PHASE :
P:=7.0
AUSGABE DER AENDERUNGEN ?
(J/N)>J
*GEWUENSCHTE PHASEN-AENDERUNGEN (GRAD)*
    -0.7856750E-02     -0.3012543E-01     0.4173595E+00     0.1048412E+01
     0.2179201E+01      0.2900558E+01     0.4251104E+01     0.5791942E+01
     0.6752274E+01      0.9757218E+01
*ERRECHNETE PARAMETER-AENDERUNGEN (AMP)*
 TSZ2   :    -0.1145074E+01      TSZ3   :    0.1334082E+00
 TSZ4   :     0.1334082E+00      TSZ5   :   -0.9503761E-01
 TSZ6   :    -0.9503761E-01      TSZ7   :    0.2174056E+00
 TSZ8   :     0.5353037E+00      TSZ9   :   -0.1067075E+01
 TSZ10  :     0.1837759E+01      DIPZ1  :    0.2831327E+00
AENDERUNGEN DURCHFUEHREN ??
(J/N)>J
CM1>ISO

          PROBEN-NR      AMPLITUDE          PHASE

               1       0.1014812E+01     0.7063282E+01
               2       0.1175949E+01     0.6983491E+01
               3       0.1624456E+01     0.7347232E+01
               4       0.1539463E+01     0.6931036E+01
               5       0.1664801E+01     0.7491165E+01
               6       0.1737494E+01     0.7420575E+01
               7       0.1811187E+01     0.7996587E+01
               8       0.1761727E+01     0.8214952E+01
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              10       0.1134179E+01     0.8981407E+01
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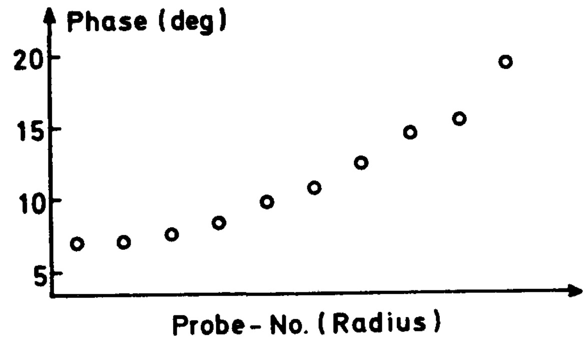

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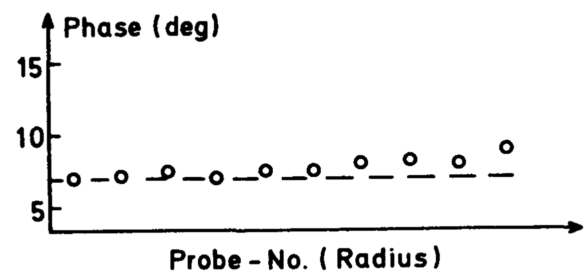

Fig.2: Example of automatic isochronisation: After calling the program PHOP the sub-command ISO is executed which results first in a measurement with all 10 phase probes. A phase of 7.0 degrees (which is the measured phase of probe 1) is demanded as common "Soll-phase" for all probes. The calculated parameter changes may be printed. After application of the changes another measurement shows the result.

Centering in the VICKSI cyclotron

The magnetic injection and extraction elements give rise to a first harmonic distortion of the magnetic field. To compensate this effect, the inner trim coils 2 and 3 and the outer coil 11 are operated with separated power supplies for each magnet as combined trim and harmonic coils. In addition, the balance of the main field is accomplished with main harmonic coils. The program HARMSET is used to transform these four currents of each coil into the physically relevant quantities BO (average field contribution), B1A and B1P (amplitude and phase of first harmonic contribution), and B2A (amplitude of second harmonic) and vice versa. Till now, a change of these parameters was achieved via tele-

during the main part of acceleration. The corresponding magnetic center changes rapidly in phase and amplitude in the injection region. At medium radii it is displaced by about 10 to 20 mm towards the injection valley and turning back to the cyclotron center at high radii. The projection of this movement of the magnetic center on the injection-extraction valley axis (Y-axis, see fig. 1) can be determined by a measurement of the turn positions with the two movable differential probes. With the aid of the program CENTPL, the movement of the orbit center along the Y-axis is calculated from the measured turn positions and plotted on a Tektronix 611 scope. An example is given in fig. 3. As the orbit center oscillates around the magnetic center, the mean behavior of this curve gives the motion of the magnetic center.

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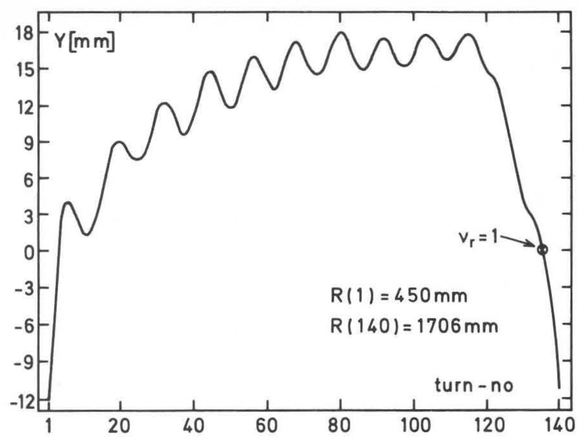

Fig.3: Measured projection of the orbit center motion on the injection-extraction valley axis (Y-axis)

The oscillation on fig. 3 shows that the corresponding beam was not well centered. The centering can be improved by proper settings of harmonic coil 2 and 3. To avoid backward influence on the already optimized injection elements we use a radially localized first harmonic created with a combination of coil 2 and 3 both having the same amplitude but opposite phase. This harmonic field bump has gaussian shape extending from 50 to 60 cm average radius. The effect of a change of such a bump can be seen on the radial turn plots in fig. 4.

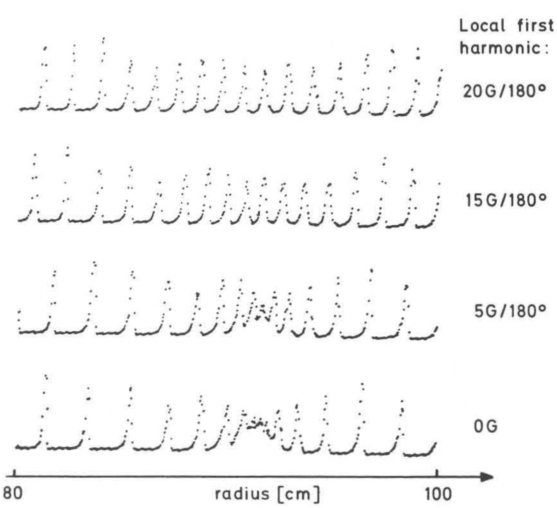

Fig.4: Influence of a radially localized first harmonic field bump on the beam centering. The turn patterns are taken outside the region of the bump.

Programs for semi-automatic determination of the proper amplitude and phase of the harmonic field bump are developed, but not fully tested. A crucial condition for practical use of such an automatic procedure is a quick way of finding the positions of the turns. Since August '78 the turn patterns taken with the differential probes are available to the control computer. Before that time the patterns were only stored on the Tektronix scope, and turns had to be determined manually with a cursor. During a continuous run of a probe (10 mm/sec), the current on the probe is now measured in steps of 0.2 mm by a microprocessor. The program AUTOTURN analyses a complete turn pattern from injection to extraction in about 90 sec, and the turns found are indicated on the scope. In that program, first the turn pattern is smoothed by weighted averaging over about 2 mm (~half turn width). Then relative maxima, which must be above a certain threshold, are found. The absolute minimum between two successive maxima is determined and must be a certain ratio below these maxima. The turn positions are then calculated using the data between minima. A warning is given if the area of one turn differs too much from the average area.

Standard parameters normally are used; however the operator may change the smoothing or the thresholds if the turn finding was not successful. The program was tested so far with replays of turn patterns of very different quality which were taken the last days of the previous beam period. All these patterns could be analysed with the standard parameters.

The procedure to get the proper field bump for centering is similar to the method used for isochronisation. The separations of the turns for about one radial oscillation period around 100 cm radius are considered as measuring points. The amplitude and phase of the harmonic bump are the parameters. In that case we use a measured transfer matrix which is the influence of two orthogonal field bump variations on the Δr-curve taken with either the injection or the extraction radial probe. The control matrix is calculated according to the formula given in the previous section. From the Δr-curve to be optimized, first the $1/r$ dependency is subtracted and then the control matrix is applied resulting in the parameters for the field bump.

Until now, centering was always done manually by variation of the amplitude and phase of the field bump while observing the resulting turn pattern on the scope. In the next beam period in fall, I hope we can finally test the centering programs and make full use of them.

References

1) W. Busse, The Computer-Aided Control System of the VICKSI Accelerators, contribution F-1 to this conference

2) G.C.L. van Heusden et al., A Multi-Input Phase Measuring System, contribution D-24 to this conference

3) F. Schutte, On the Beam Control of an Isochronous Cyclotron, Thesis Eindhoven University of Technology (1973), p. 57