MODIFICATION OF THE CENTER REGION FOR BETTER BEAM QUALITY AT JULIC

J. Linz, P. Wucherer, and J. Reich

Institute for Nuclear Physics of Kernforschungsanlage Jülich, 517 Jülich, W.-Germany

Abstract

The effect of precessional mixing on the external beam quality is studied using deflecting plates on the third turn for the variation of the radial coherent betatron amplitude. A detailed comparison between experiment and calculation for the features of the present center region proves the validity of the IONAN calculation. The proposed modification of the center region should improve the present radial coherent betatron amplitude from now 3 mm to 1 mm and should have additional advantages as for instance a smaller contribution of the center region optics to the radial incoherent betatron amplitude and a much slower variation of the radial coherent amplitude with the RF voltage.

1. Introduction

The high degree of precessional mixing and the present radial coherent betatron amplitude deteriorate the external beam quality remarkably and give the reason for its poor reproducibility. Former emittance measurements[1]) revealed for instance a nonsystematic variation of the radial emittance in the range $10<\varepsilon_x<30$ mm·mrad. The external beam quality is the key factor with respect to the accuracy and the feasibility of nuclear reaction experiments. To achieve good energy resolution in experiments, using solid state detectors, the Jülich double monochromator[2]), which has an energy resolution $\Delta E(FWHM)/E \sim 10^{-4}$, is applied. Mainly an improvement of the energy spread of the cyclotron beam would enhance the transmission through this system by the same order of magnitude. Furthermore, as is pointed out in another paper of this conference[3]), an improvement of the external beam quality would directly pay off with respect to the performance of the combined system beamline/spectrograph, which is in progress at JULIC.

2. Method of Calculation and Experiment

To study the present center region and to design its modification for better beam quality, the following methods have been applied: The radial motion of particles in the center region was calculated with the program IONAN. IONAN applies a homogeneous magnetic field and a time dependent electrical square well field according to the location and the width of the accelerating gaps. To study the effect of precessional mixing on the external beam quality and to find the location of the center of the radial motion, an active variation of the coherent radial betatron amplitude was needed. Therefore screened deflecting plates were placed between the sixth and the first accelerating gap at the third turn (see also figure5) and operated at DC-voltages up to 5 kV. The radial coherent betatron amplitude A_C was extracted from beam density records, which were taken in a radius region where ν_r stays constant. The difference Δr between successive turns numbered n has been fitted according to

$$\Delta r = C/r + A_C\left[\sin(\phi_O+n\delta) - \sin(\phi_O+(n-1)\delta)\right] \quad (1)$$

where $\delta = 2\Pi(\nu_r-1)$, C depends on the energy gain per turn and ϕ_O is a phase constant. To study the beam phase, time spectra of prompt γ's, originating from a radially movable target, were taken with respect to the RF. All experiments were performed at a cyclotron energy of 60 MeV deuterons.

3. The Effect of Precessional Mixing on the External Beam Quality

The effect of precessional mixing[4,5]) which deteriorates the external beam quality, takes place, if a beam burst with an appropriately large phase width and a coherent betatron amplitude $A_C \neq 0$ encounters a radial betatron frequency $\nu_r \neq 1$ in a large number of revolutions. Since according to their different phase, different portions of the beam burst see different energy gains per turn, the beam burst becomes distributed to several turns. According to their different turn number the different portions of the beam burst reach the extraction radius each at a different phase of the coherent betatron oscillation, which in turn gives rise to a larger radial emittance for larger coherent amplitudes A_C.

To study this effect radial emittance measurements were taken with a device described in [6]) at different voltages V_{DP} of the deflecting plates, which in turn means for different amplitudes A_C. Figure 1 shows the results. The error bars in the figure were estimated from the accuracy of the measuring device. The beam phase with respect to the RF was left so far in its starting condition, as only the frequency was changed a little for optimum transmission through the extraction elements. The beam phase versus the turn number is displayed in the inset of figure 1. With re-

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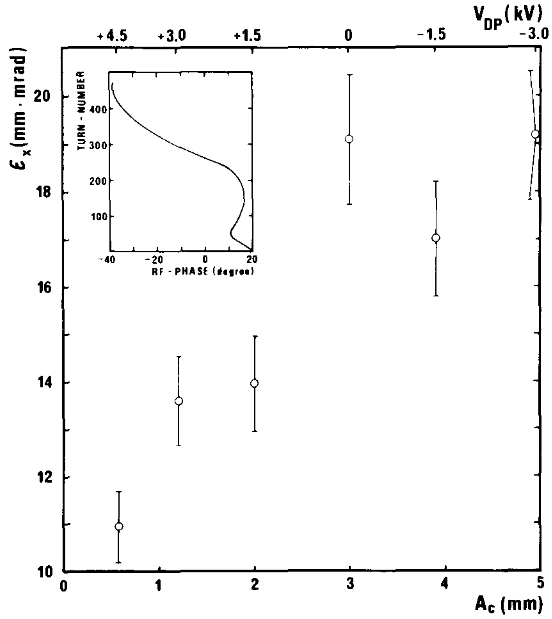


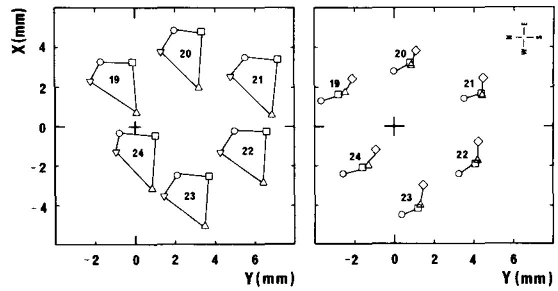
Figure 1: Horizontal emittance ε_x for about 75% beam intensity at different radial coherent amplitudes A_c

spect to the nominal value of the RF-voltage an improvement of the radial beam emittance within a factor of 1.7 can be extracted. At the same time the transmission through the double monochromator was enhanced by approximately the same factor, which in turn means an improvement of the momentum width of the beam. These results already give an estimate for the improvement of the external beam quality, which can be achieved by a modification of the center region.

4. Comparison between Experiment and Calculation for the Present Center Region

A reference paper, which describes the design of the present center region, is not available. Therefore it was necessary to study the present center region carefully and to obtain a check of the validity of the calculation method.

To start with the radial coherent betatron amplitude, figure 2a shows for the present center region the centers of curvature for particles with different RF starting phases in the accepted region $-90^o \leq \Psi_o \leq -30^o$ just after every accelerating gap during the 4th turn. The centers of curvature for different starting phases but the same gap number are interconnected to facilitate identification. The largest dimension in the resulting patterns is a measure for the contribution of the center region optics to the incoherent radial betatron amplitude A_I. If one assumes, that all starting phases would have equidense population, this contribution to the incoherent amplitude A_I would already amount to approximately 1.5 mm. The center of gravity of all the patterns in figure 2a, taken as a whole, represents the center of the radial motion. This means in turn, that with higher turn number the described patterns approach this point and finally fall onto it. The distance between this point and the machine center represents the radial coherent betatron amplitude A_c, which was evaluated from figure 2a to be 3 mm. This result agrees with the experimental value (see figure 3, lower part).



(a) (b)

Figure 2: Centers of curvature for particles with a different starting phase during the 4th turn for the present (a) and for the modified (b) center region. Starting phases ψ_o: ▽ -90^o, ○ -65^o, □ -45^o, △ -30^o, ◇ -20^o

The location of the center of the radial motion was determined in the following way: The center of the radial motion was calculated for different voltages V_{DP} at the deflecting plates, taking into account their geometry (see upper part of figure 3). The corresponding radial coherent amplitudes A_c have been extracted and are displayed in the solid curve of the lower part of figure 3. Since this curve is in good agreement with the experimental points, the typical location of the center of the radial motion was taken to be at the position for $V_{DP}=0$ in the upper part of figure 3. The difference at higher deflection voltages may come from the following fact: Due to the deflection the beam bursts encounter phase shifts with respect to the RF. This has not been taken into account in the calculation.

As a further comparison between experiment and calculation, the RF-voltage was varied in a ± 10% range with respect to the nominal voltage V_o. For each voltage the co-

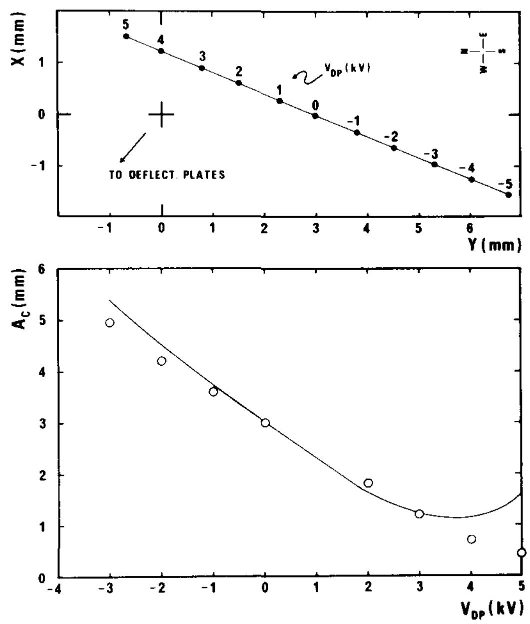


Figure 3: The location of the center of the radial motion and the coherent amplitude A_C for different voltages at the deflecting plates

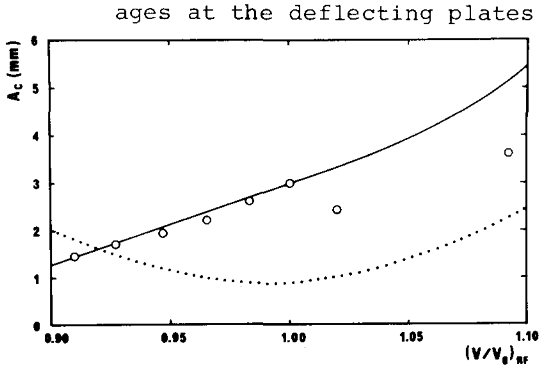


Figure 4: Coherent amplitude A_C versus RF-voltage. Circles refer to experimental values. The dotted line represents A_C for the modified center region

herent amplitude A_C was determined. Figure 4 shows the results for experiment and calculation, which are in good agreement for $(V/V_O)_{RF} \lesssim 1$. Up to now we do not have any meaningful explanation for the discrepancy in the region $(V/V_O)_{RF} \gtrsim 1$. Looking at the figure 4, one might suggest an improvement of the amplitude A_C by lowering the nominal RF-voltage. This would not solve the problem, since at $(V/V_O)_{RF}=0.9$ the internal beam current is diminished by approximately two orders of magnitude. This occurs mainly because later phases are then peeled off at the posts in the center region.

The calculation shows that the accepted starting phase range $-90^O \lesssim \psi_O \lesssim -30^O$ is compressed during acceleration to a phase width of 35^O. Using the method with prompt γ's, phase widths of 25^O at FWHM and 35^O at 10% of the maximum intensity were recorded.

5. The Proposed Modification of the Center Region

To keep the technical expense as low as possible, the modification had to take into account the following constraints:

1) Only the exchangeable parts of the dee tips should be modified. These parts are approximately 15 cm long in the radial direction.
2) The position of the ion source should only be displaced in a region of 3 by 3 mm.
3) The maximum change in the magnetic center field should be less than 10 parts in 1000 with respect to the present situation.

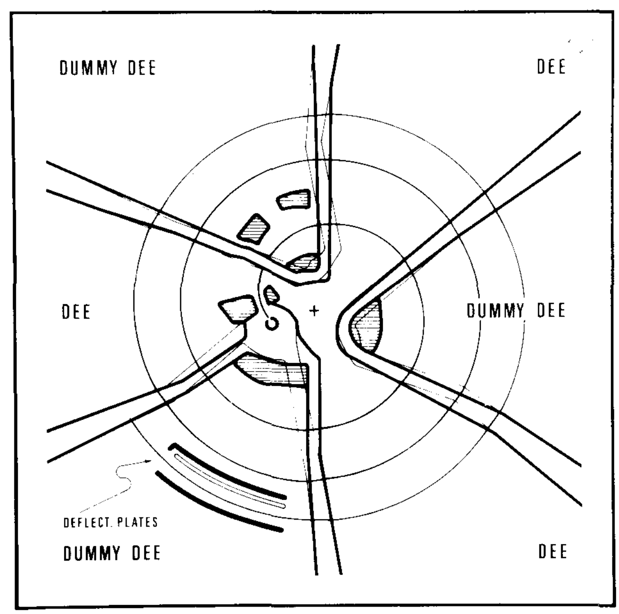


Figure 5: The modified center region (thick lines) in comparison to the present one (thin lines)

In iterative IONAN runs a modified center region has been obtained, which is presented in figure 5 by thick lines, whereas the thin lines show the present center region. In this figure also the orbit for a -45^O starting phase is shown for the present center region. For the new design the magnetic center field was lowered by 3 parts in 1000. The modified center region accepts a starting phase range $-65^O \lesssim \psi_O \lesssim -20^O$, which again is compressed to a 35^O phase width during the further acceleration. The shift of the starting phase range in the direction of the peak voltage should improve the output of the ion source. As can be seen in figure 2b, the centering of the beam has become much better now. The radial coherent betatron amplitude A_C is less than 1 mm. Also the contribution of the center region optics to the incoherent amplitude A_I improved to about 1 mm. The present center region shows a smaller coherent amplitude at a lower RF-voltage, whereas the modified center region reveals a minimum in A_C at the nominal voltage (see dotted line in figure 4).

Another advantage of the proposed modification is the following: The contribution of the center region optics to the incoherent amplitude A_I does practically not change at up to a 10% higher RF-voltage, although the starting phase range increases by up to another ten degrees. The present design revealed a 40% enhancement of this contribution at a 10% higher RF-voltage. Since the change of the coherent amplitude A_C with the RF-voltage is by far less steep as for the present design, the above feature can be used to provide higher beam currents, if necessary.

The axial focusing of the proposed new center region is compared with the present design in figure 6. A trapezoidal distri-

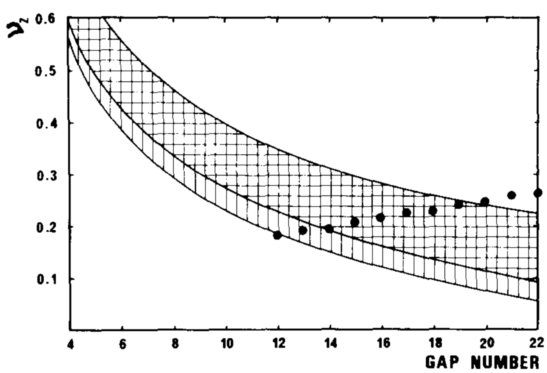


Figure 6: The regions of the electric axial focusing ν_z for the phase range of the present (hatched horizontally) and the modified (hatched vertically) center region. Full circles show the magnetic axial focusing

bution of the electrical field as given in[7]) was used in the calculation. The lower and upper borderlines of the horizontally hatched region correspond to -90^o and -30^o starting phases of the present center region and those of the vertically hatched region to -65^o and -20^o of the proposed modified center region, respectively. The axial amplitude is approximately proportional to $1/\sqrt{\nu_z}$. If one assumes, that the present design has an axial amplitude, which just fills the available gap height the population loss L of the different phases of the modified center region (refered to as ν_{z2}) has been estimated in case $\nu_{z2} \leq \nu_{z1}$ from $L=1-\sqrt{\nu_{z1}/\nu_{z2}}$ at the point, where the weakest focusing occurs. This is the case around gap number 10, when the axial magnetic focusing (full circles) is taken into account. An over-all loss of approximately 10% was estimated. On the other hand the output of the ion source follows a $V^{3/2}$-law. Taking the cosine acceleration voltage, the proposed new center region should produce approximately 25% more ion source output. Therefore the new center region should provide even more beam current than the present one.

6. Conclusion

The results of experiment and calculation, which were performed for the present center region, show a good agreement. The advantages of the proposed modified center region with respect to the external beam quality are obvious. New dee tips can be manufactured at comparatively low costs. Therefore we intend to realize the proposed modification without a further more detailed investigation of the center region fields. We will proceed with a program for further stabilization of the cyclotron parameters and the development of a better beam phase control. This program will be even more valuable after an improvement of the beam quality is achieved with the proposed modification of the center region.

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References

1) W.R. Kuhlmann, J. Bojowald, C. Mayer-Böricke, J. Reich. Proc. of the Fifth Intern. Cyclotron Conference, Oxford (1969) p. 348
2) J. Reich, C.U. Mayer-Böricke, K.L. Brown, F.E. Johnson, AIP Conf. Proc. no. 9 (1972) p. 407
3) J. Reich, S. Martin, D. Protic, G. Riepe, Contribution to this Conference.
4) H.G. Blosser, Proc. of the Fifth Intern. Cyclotron Conference, Oxford (1969) p.257
5) H. Thimmel, Internal AEG-Report (1973)
6) J. Bojowald, H. Borsch, W. Kuhlmann, J. Reich, A. Retz, AIP Conf. Proc. no. 9 (1972) p. 399
7) J.M. van Nieuwland, and N. Hazewindus, Philips. Res. Repts 29 (1974) 528