Proposed use of a storage ring to improve the microscopic duty factor of a cyclotron*

Byron T. Wright
University of California, Los Angeles, U.S.A.

ABSTRACT

A cyclotron beam is introduced into a storage ring. The revolution periods in the cyclotron and in the storage ring are different and are adjusted so that after several cycles there is a beam circulating in the storage ring at all azimuths. A second harmonic in the storage ring magnetic field causes the beam to drift toward an electostatic deflector. The drift rate is adjusted so that the beam which is transferred into the storage ring on a given rf cycle will enter the deflector over many revolutions. Beam exists at all azimuths in the storage ring, so some beam is entering the electrostatic deflector at all times.

A practical example is described in which a beam which initially has a 10% microscopic duty factor is converted into a beam whose minimum and maximum instantaneous values are 28% and 170% of the time average value. The rms deviation from the average value is less than 10%.

1. INTRODUCTION

Storage rings have been mentioned[1,2] as a means of increasing the microscopic duty factor, but without suggestion of a workable scheme to do so. In this paper, through the use of a particular example, a method is described which is based on the direct transfer of a cyclotron beam into a storage ring by stripping negative ions to positive ions. The cyclotron period and the storage ring period are different and are adjusted so that after several cycles beam exists at all azimuths in the storage ring. The storage magnetic field has a second harmonic. The centres of curvature of all the ions in this field are adjusted to be off the plane of symmetry on one side, so there is a drift of all the orbits in one direction toward an electrostatic deflector. The drift rate is adjusted so that ions which are injected into the storage field during

* Supported in part by the U.S. Atomic Energy Commission

a particular rf cycle will enter the deflecting channel over many revolutions. Beam exists at all azimuths in the storage ring, so some beam is entering the deflector at all times. In fact, generally speaking, beam from several different rf pulses will be entering the deflecting channel at all times.

2. GENERAL DESCRIPTION

The method outlined above will be elucidated by considering an example. Fig. 1 shows a four-sector cyclotron which has a circumference at the final

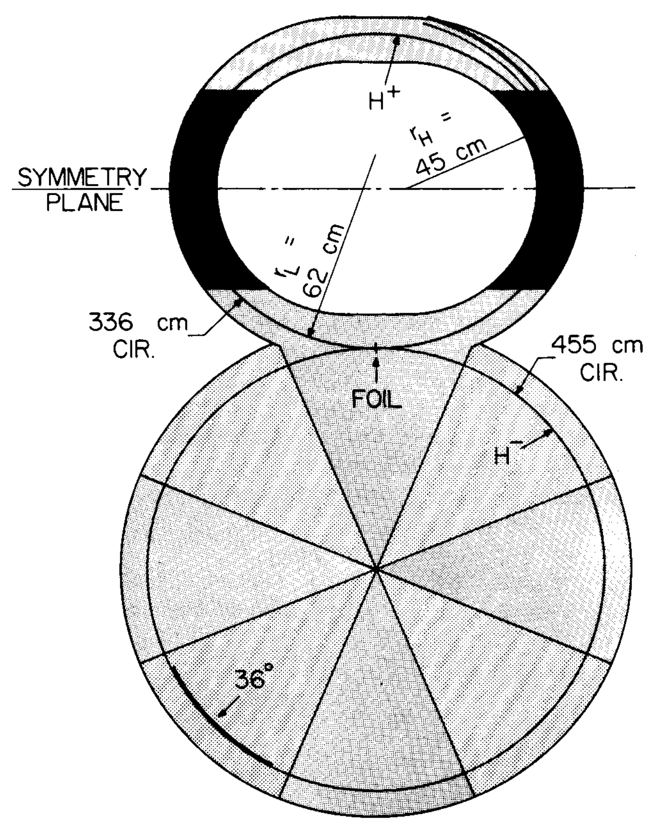

Fig. 1. General layout showing the relation of the storage ring to the cyclotron

radius of 455 cm. One of the magnetic hills is extended and forms part of the storage ring whose circumference is 336 cm. The radii of curvature of the ions in the storage field are r_L = 62 cm and r_H 45 cm and the ions cross the field boundary at an angle of 45°. The storage field provides axial stability. The ions complete an axial oscillation in 2·12 revolutions if one assumes a step change in field at the boundary.

The duty factor of the cyclotron is taken to be 10%, so the length of the pulse at the final radius is 45·5 cm. Fig. 2 shows the azimuthal disposition

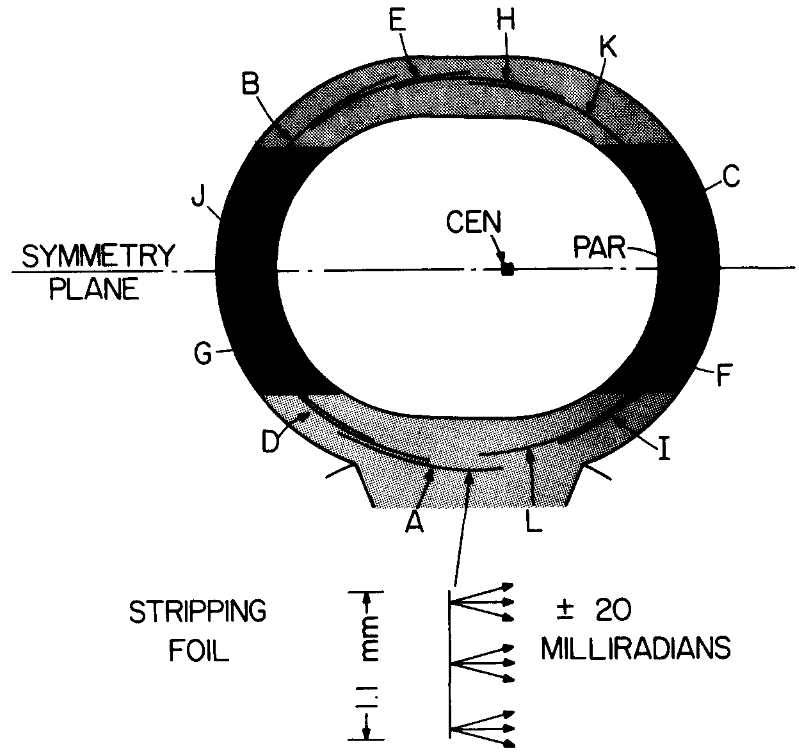

Fig. 2. The azimuthal disposition in the storage ring of twelve cyclotron pulses is shown

of pulses after twelve have been injected into the ring. Two pulses exist at the same azimuths over half the ring and it is clear that fifteen pulses will fill the ring.

It is assumed that the stripping foil extends 1·1 mm in the radial direction and that the beam intensity over the foil is uniform both in radius and in angular spread within a range ± 20 mrad. With the stripping foil positioned as shown in Fig. 1, and after the particles enter the higher magnetic field, the location of their centres of curvature is indicated by the blob marked CEN in Fig. 2. The actual position of the individual particles after having completed *exactly one-quarter revolution* in the storage ring is shown by the blob PAR.

The blob PAR is shown in more detail at the bottom of Fig. 3. The particles extend 25 mm in a direction parallel to the plane of symmetry due to their initial angular spread in the horizontal plane. The initial radial dimension of 1·1 mm is reduced to 0·8 mm due to their entrance into a stronger magnetic field. The slight curvature at the top and bottom is due to the angular spread. The actual shape of PAR is henceforth approximated by a rectangle.

Due to the second harmonic in the storage field, particles off the plane of symmetry will drift in a direction parallel to that plane. The group PAR, Fig. 3, bottom, would have some particles drifting in each direction. However,

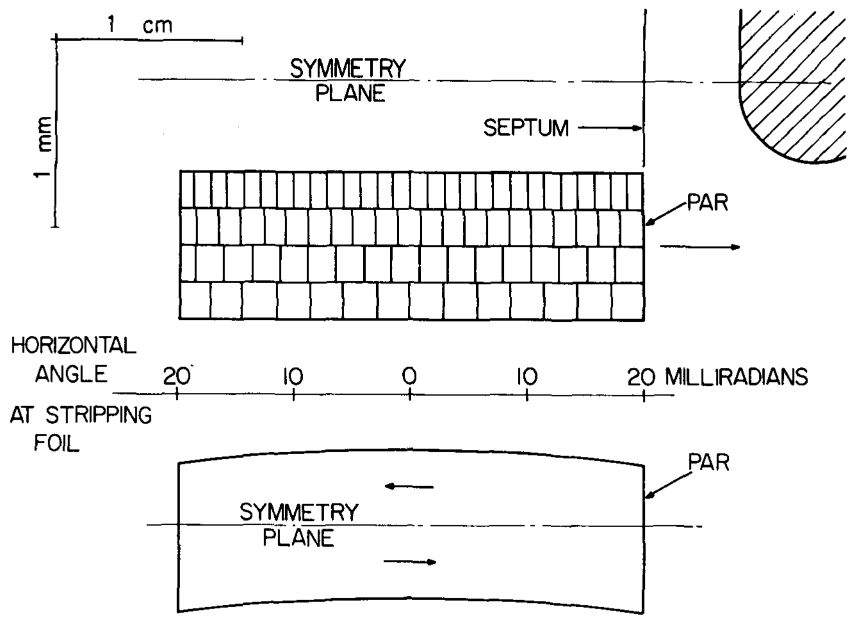

Fig. 3. The disposition of particles with respect to the deflector and the plane of symmetry after having made exactly one-quarter revolution *in the storage field is shown. The group at the top is properly positioned so that all drift toward the deflector. Also the drift rate is such that particles will enter the deflector for many revolutions*

by a small motion of the stripping foil and slight adjustment of magnetic field, the group PAR may be shifted to the position shown at the top of Fig. 3. Here the group is divided into four subgroups and the drift per revolution of each subgroup is shown. The sketch indicates that from a given rf pulse, particles from the lowest subgroup will enter the deflector for 14 revolutions, while those from the uppermost subgroup will enter for 28 revolutions.

Finally, if one assumes that the beam intensity does not vary with azimuth, the relative intensity vs. time of the output current may be obtained. The lower part of Fig. 4 indicates the detailed contribution of various pulses to the output. The letters A, B, C, etc., order the sequence of cyclotron pulses which contribute to output current. The numbers following the bars designate the number of revolutions made in the storage field. The numbers over the bars indicate the intensity contribution.

At the top of Fig. 4 the beam intensity vs. time is shown. The minimum is 28% and the maximum 170% of the average value. The rms deviation from the average is less than 10%.

3. CONCLUSION

By considering a particular example, and the use of a special method of injection, it is shown that a storage ring may be used to increase considerably the microscopic duty factor of a cyclotron beam. The method should be of broader applicability, including cases which involve electrostatic inflection of positive ions.

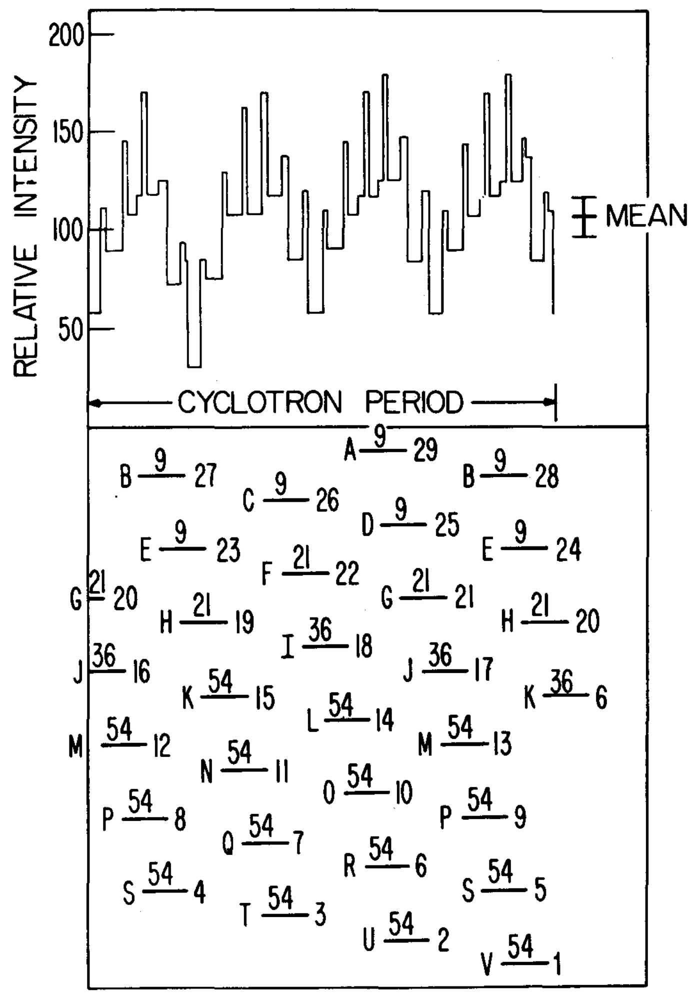

Fig. 4. Beam intensity vs. time (upper) and the detailed composition thereof (lower). The error bar by MEAN indicates the rms deviation of the instantaneous current from the mean value

DISCUSSION

Speaker addressed: B. T. Wright (UCLA)

Question by A. A. Kolomensky (Lebedev Institute): Have you estimated quantitatively the efficiency of injection of positive ions into the storage ring by means of an electrostatic inflector? It seems to me that this efficiency may be relatively low unless some sophisticated methods are used.
Answer: I don't know what the efficiency would be, but probably it would not be high.

REFERENCES

1. Eisberg, R. M., NAS-NRC **656**, 289, (1959).
2. Yavin, A. I., *Nucl. Instr. Meth.* **18, 19**, 610, (1962).