EXPERIMENTAL RESULTS FROM THE TRIUMF CENTRAL REGION CYCLOTRON

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The beam performance obtained up to now in the TRIUMF central region cyclotron is described. A stable beam of 12μA H^- ions has been obtained at the full radius of 30 in out of a DC beam of 100μA given by the ion source. 90% of the beam injected into a 30° phase interval has been kept within a vertical distance of ±0.4 in from the geometric midplane during acceleration, and the radial turn positions measured along three azimuths agree to within ±0.15 in with the theoretical "centered beam positions" for all phases between 0° and 30°.

The central region cyclotron is a full scale model of the central region of the TRIUMF meson factory[1] and has been built to test the design of various components and to study experimentally the beam performance along the injection line and during the first 6 accelerated turns. The H^- ions are produced by an Ehlers type ion source capable of delivering 2mA. After being accelerated through a 300kV electrostatic tube the ions travel along a 70 foot electrostatic transport line and are then injected axially into the machine. The complexity of the injection line[2] is similar to that of the TRIUMF injection line with buncher and chopper systems provided. The beam is bent into the median plane by means of a spiral inflector[3]. The initial orbit centers are positioned with respect to the magnet centre by adjusting a radial steering deflector and by slight adjustments to the injection energy. Moveable differential probes along the 0°, 90° and 270° azimuths (see fig. 1) allow the measurement of the radial beam position and profile, and the vertical beam structure can be observed on scintilators placed on the 90° and 270° probes.

The measurements to date have been performed with slits placed directly after the ion source, which reduced the vertical and horizontal emittances to 30% and the current to 10% of their nominal values. This was done to provide more stable beam conditions, to reduce the energy spread introduced by the chopper to less than ±0.1%, and to avoid masking the "central trajectory" properties of the accelerated beam by large emittance effects. About 80μA DC were transmitted through the 0.06 in chopper slit out of 100μA leaving the ion source. With the chopper and buncher energized it was possible to obtain 15μA of pulsed beam with a pulse width of 40° RF. No losses were observed between the chopper slit and deflector exit. Fig 2a) and 2b) show the shape of an unaccelerated beam on the scintillator at 90° and 270° with neither chopper nor buncher excited. Exciting the chopper had little effect, exciting the buncher increased the vertical beam size at 270° as shown in fig. 2c. This is mainly due to an energy spread of ± 0.3% introduced by the buncher and to the dispersion of the inflector.

Due to the large radius of the first orbits and to the low magnetic focussing in the central region we expected large vertical coherent oscillations to build up as a consequence of small vertical dee misalignements[4] and of small residual radial magnetic field components[5]. Dee misalignments of 0.05 in or an average B_r component of 1 G could excite coherent oscillation amplitudes of 0.6 in and result in the loss of a large fraction of the beam. As a matter of fact acceleration to full radius was achieved only after having compensated for the residual vertical perturbations by means of voltage differences across the 10 pairs of vertical correction plates sketched in fig. 1 and by exciting some pairs of upper and lower trimming coils in opposition. A beam injected with a phase interval from 0° to 40° could be transmitted up to full radius through the vertical 0.8 in gap between correction plates with an efficiency of about 85%. The transmission was 95% for a 20° wide phase interval. It is planned to double the vertical gap between the plates to improve the transmission and to accept a larger initial beam emittance. The beam spots obtained at each half turn with a beam of 40° phase width are given in fig. 3. The effect of the phase dependent electric focussing, predominant in our central region, is very clearly seen. From the radial position of the waist at the 4th turn (90°) and the phase independent small beam size at the first turn (270°) it is possible to calculate that the +15° phase particles see an average ν_z^2 around 0.04 in good agreement with theory[6].

To check our dee misalignment theory[4], we displaced one dee vertically by 0.1". The voltage change required on the correction plates to compensate for this is shown in fig. 4 and can be compared with the theoretical values. The criterion used to adjust the correction plate voltages is to minimize the phase dependent coherent effects at each half turn. The agreement between theoretical and experimental values is quite good.

For the radial studies the aim was to obtain a well centered beam within a 30° phase interval. Numerical calculations[7] based on the measured magnetic field and on the electric field configuration calculated with a three dimensional relaxation program gave the radii of centered orbits at the azimuths 0°, 90° and 270° (see fig 5). This figure found for the 0° phase can be used for the other phases too. The measured maximum and minimum radii observed along the three azimuth were plotted on the curves for the corresponding turns: a well centered beam that is in agreement with calculation would give points that are vertically in a straight line. Fig. 5 shows an experimental operating condition where particles of 0°, 20°, and 30° of phase are centered to within 0.15 in during turns 2 to 5. The deviation at the 6th turn is due to the particles entering the distorted electric field region at the edge of the resonator gap.

The radial longitudinal coupling effect[8] has been studied experimentally. It is important for us because we accelerate in the fifth harmonic. It can be shown that displacement of the initial orbit centers by .3 in in the negative y direction (see fig. 6) gives a substantial reduction of the radial beam size along the 0° azimuth. The effect observed on a 30° phase interval beam is plotted in fig. 6 and the comparison with a simple analytical theory assuming a uniform magnetic field and an infinitesimal dee gap transit time appears to be quite satisfactory.

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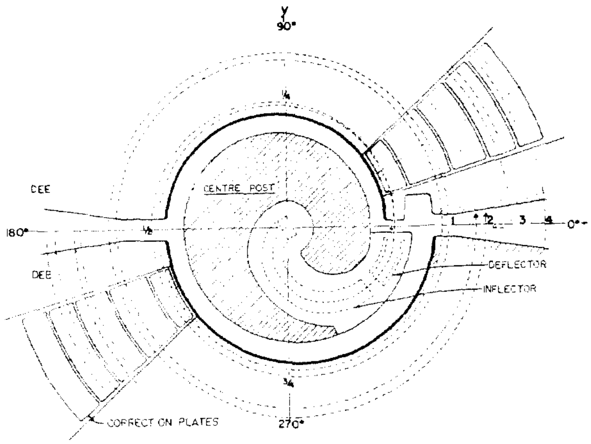

Fig. 1. Central region layout.

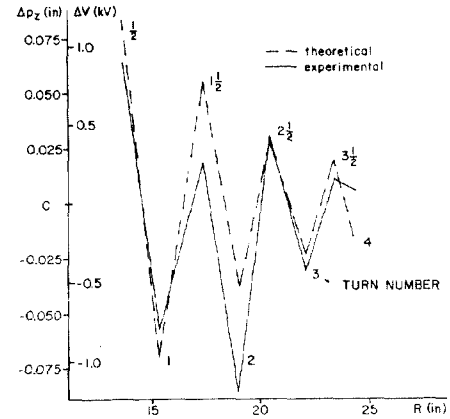

Fig. 4. Theoretical impulses and their equivalent measured voltages correcting for a vertical dee misalignment of 0.1 in.

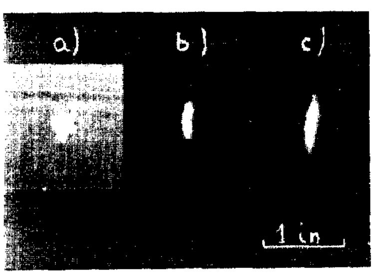

Fig. 2. Unaccelerated beam at a) 90°, b) 270° after injection, c) shows the beam at 270° with buncher operating.

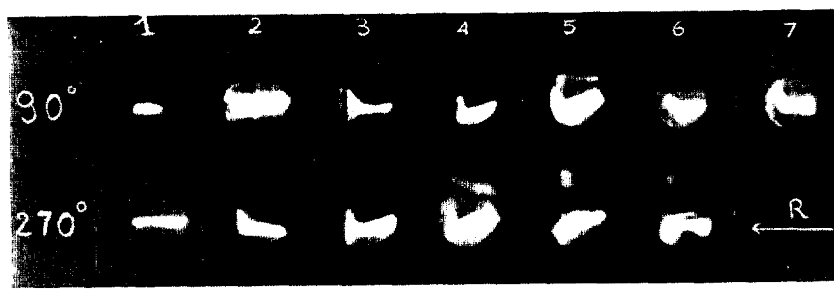

Fig. 3. Beam spots on scintillators of 1 in diameter taken at 90° and 270° over the first 7 turns.

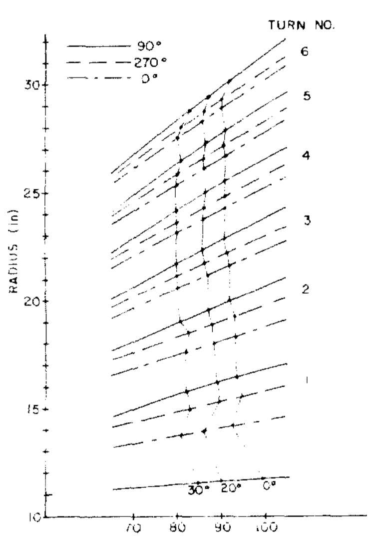

Fig. 5. Measured beam positions are plotted on the theoretical curves calculated for a centered beam: when the plotted points lie above each other the beam is well centered.

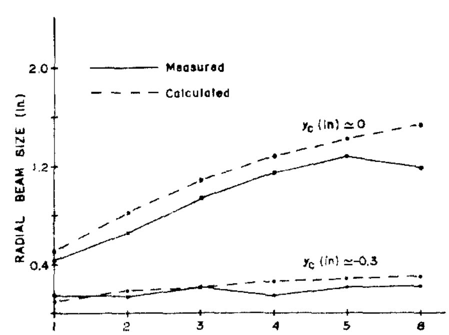

Fig. 6. Illustrates the size of a 30° wide beam along the 0° azimuth for two different displacements yc of the orbit centers normal to the dee gap. The effect of radial longitudinal coupling is evident.