Reducing Emittance Growth from Resonance Passage in the 500MeV Cyclotron

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Abstract

The cyclotron vertical tune is measured by scanning the trim coil radial field. A peak of the vertical tune at cyclotron radius of around 235 inches confirmed the $\nu_r - \nu_z = 1$ coupling resonance passage. To avoid the passage, the vertical tune at 235 inches is reduced using the trim coil axial field. The result shows that both the coherent and incoherent oscillation are removed after the correction.

Introduction

TRIUMF 500 MeV cyclotron tune diagram, calculated from the magnetic field survey data shows that the $\nu_r - \nu_z = 1$ resonance passage happens at around 166 MeV and 291 MeV. The exchange of both coherent and incoherent oscillation amplitude in the vertical and horizontal direction while passing the resonance will increase the beam loss in the cyclotron.

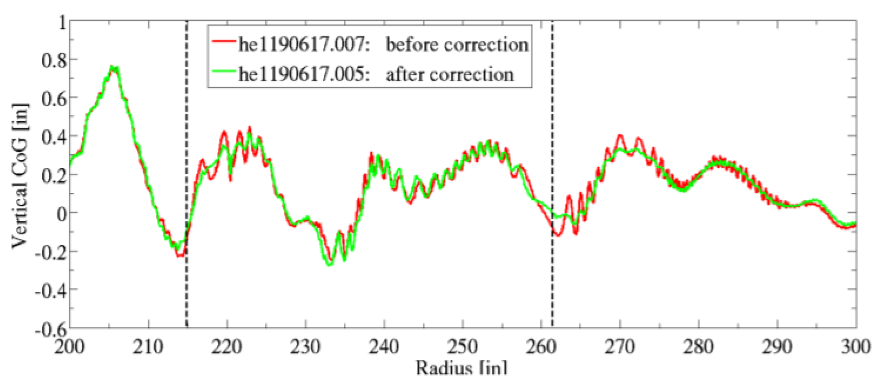

Figure 1: HE1 probe measured vertical centre-of-gravity vs. radial position, before and after correction of the resonance. The reappearance of the coherent oscillation after resonance correction indicates an unknown resonance passage.

Method

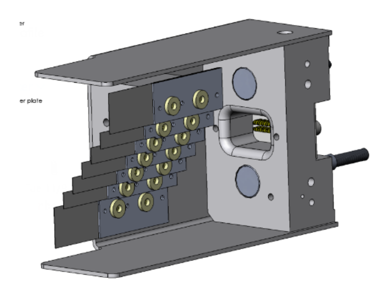

Figure 2: Measure the beam vertical center of gravity using the 7 finger HE2 probe.

The beam center orbit is deflected vertically by the radial magnetic field. For the same radial field, a larger vertical tune will produce a smaller vertical displacement.

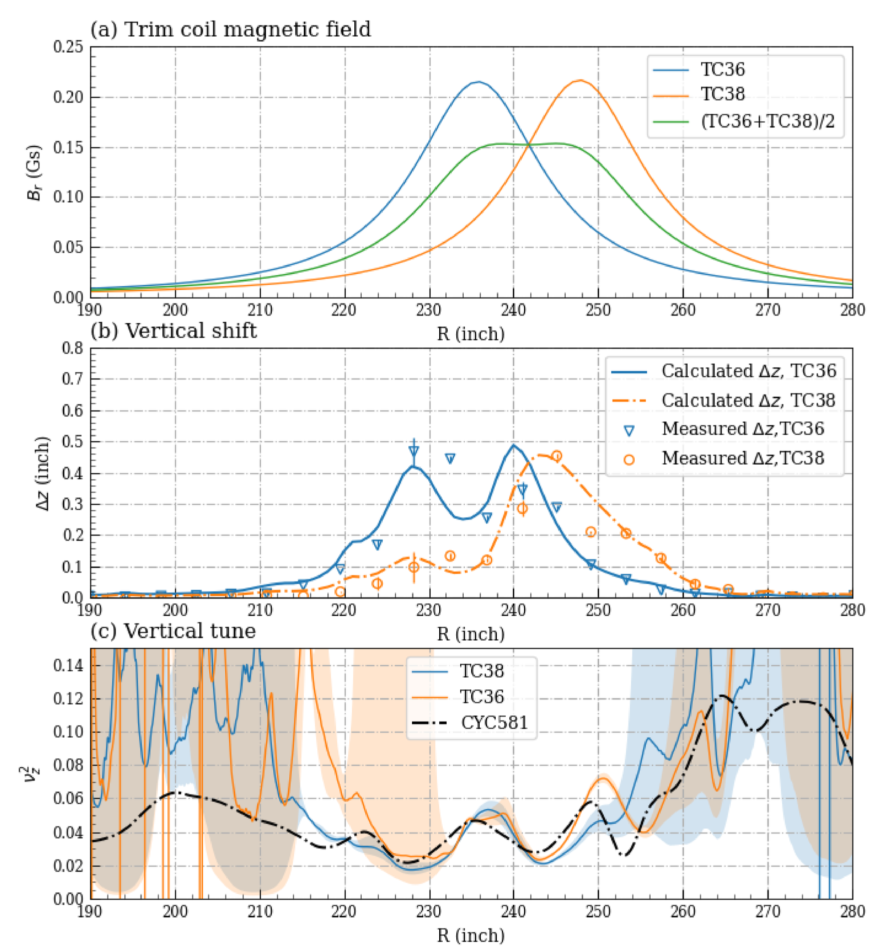

Figure 3: Vertical tune by scanning trim coil radial field. CYC581 is the tune calculated from the field survey data. The colored area shows the error, which is larger at lower field region.

For a N sector cyclotron with spiral angle of ξ, the radial and vertical tune is given as

$$\begin{aligned} \nu_r^2 &= 1 + k + \frac{3N^2}{(N^2-1)(N^2-4)} F\left(1 + \tan^2\xi\right) \\ \nu_z^2 &= -k + \frac{N^2}{(N^2-1)} F\left(1 + 2\tan^2\xi\right) \end{aligned} \quad (1)$$

where the field index $k = \frac{R}{B}\frac{dB}{dR}$. Except for the TC used for tune correction, we should also adjusting other TCs to maintain the isochronism.

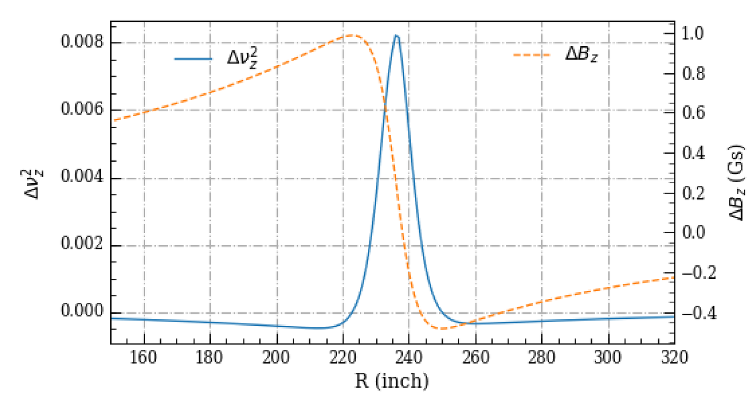

Figure 4: Vertical tune contributed by the trim coil axial field.

Results and Discussion

4.1 vertical tune

The vertical tune measured by scanning the 5 pairs of trim coil is shown below. The scanning step is 5 At (ampere-turns). An increase of 20 At produces a beam vertical displacement of about half an inch, which is enough for the tune measurement.

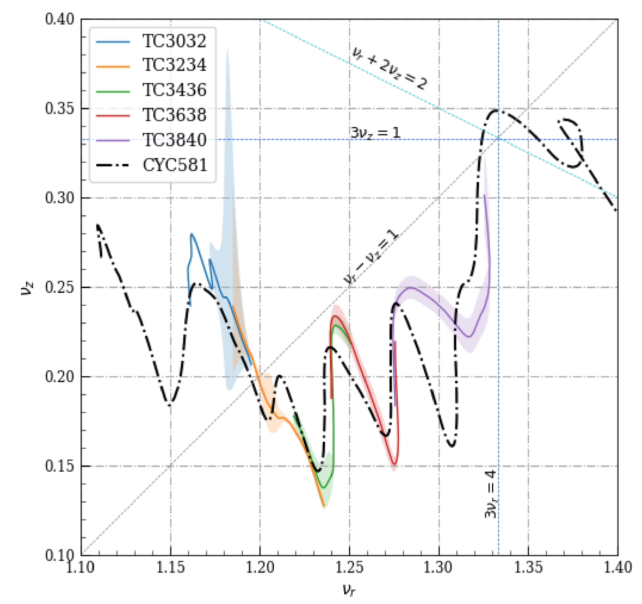

Figure 5: Tune diagram measured using 5 pairs of trim coils.

4.2 vertical tune correction

By adjusting the axial field of TC36, we corrected the vertical tune bump around 235" which approaches the linear coupling resonance. The isochronism is maintained by using 3 other TCs.

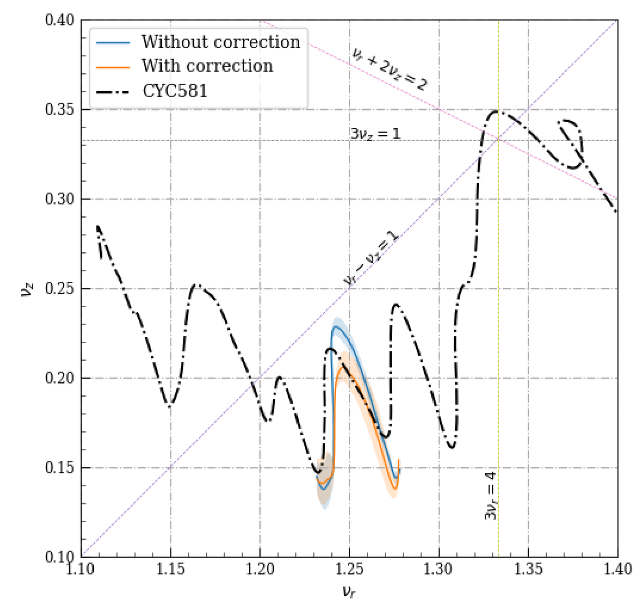

Figure 6: Tune diagram with and without correction.

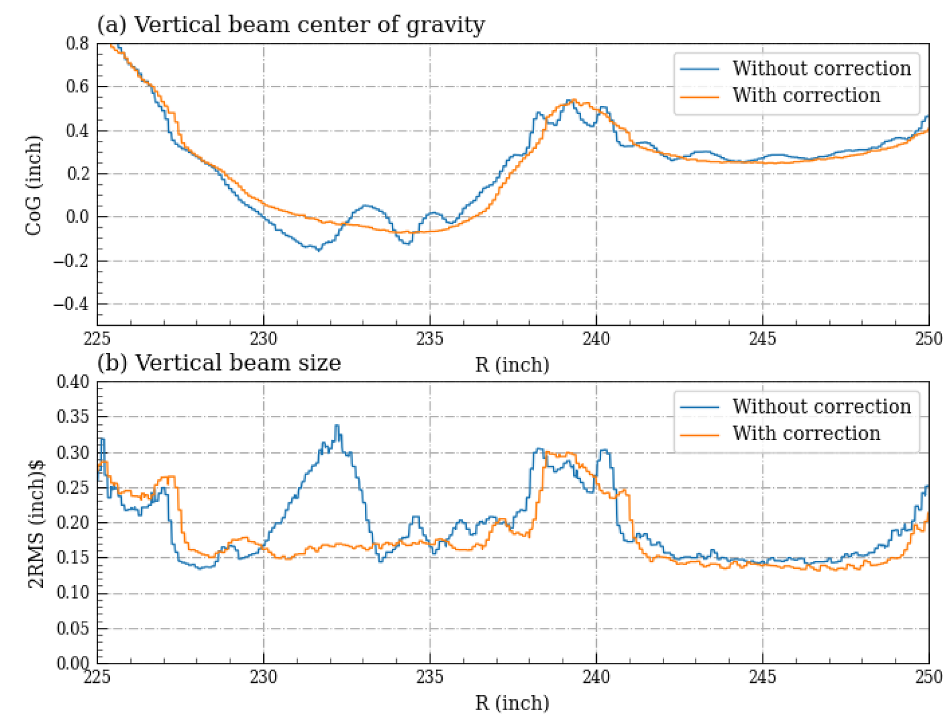

Figure 7: Coherent oscillation and beam size with deflector detuned.

We run the cyclotron at the new trim coil setting and measured the efficiency of the resonance correction studied by Yi-Nong. The efficiency was observed by introducing a beam radial centering error by detuning of deflector at injection and validated at high intensity by trimming of vertical beam halo with the vertical flag.

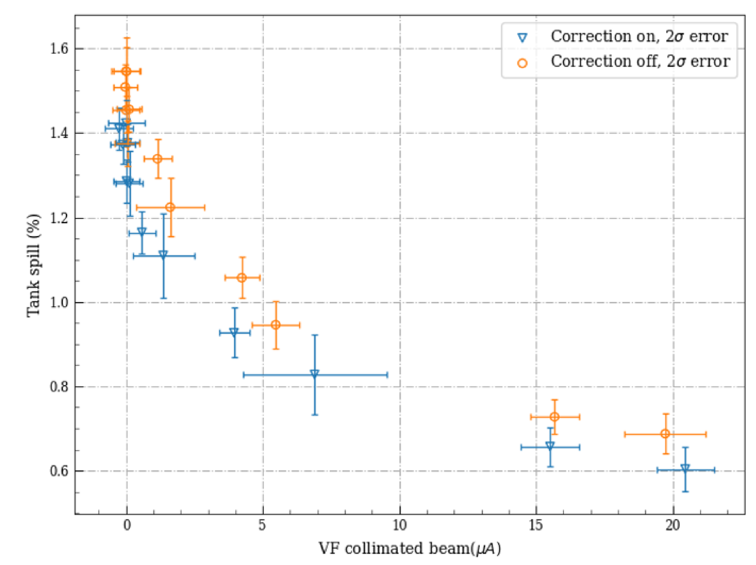

Figure 8: Tank spill (beam loss) under different vertical flag angle.

Conclusion

A peak of vertical tune at cyclotron radius of around 235" confirms the $\nu_r - \nu_z = 1$ coupling resonance passage. After correcting the vertical tune, the coherent oscillation in the vertical direction at 235" disappears, that leads to reduction of vertical beam size and beam losses in the cyclotron.

Discovery,
accelerated