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Summary Report on the Transition Crossing for MI

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Abstract

The working group evaluates the problems related to transition energy crossing in the main injector for Tevatron at Fermilab. We found that the dominant problem arises from the nonlinear synchrotron motion and the microwave instability at the transition energy region. γ_T jump such that $\dot{\gamma}_T \geq 1000$ sec^{-1} seems sufficient to obtain satisfactory transition energy crossing. To avoid longitudinal and transverse microwave instability, the maximum tolerable broad–band impedances can be derived. A possible imaginary γ_T lattice has also been studied. Some possible further studies are suggested.

The main injector for Tevatron is designed to accelerator p or $\bar{p}$ from 8 GeV to 150 GeV. In a medium energy range accelerator, the transition energy crossing is an important, longitudinal beam–dynamical problem. There are two possible scenarios for the lattice design, i.e. transition crossing lattice or transitionless lattice. There are many accelerators such as AGS, CPS, JPS, Fermilab Booster, etc., where the transition energy crossing is a routine operation. To avoid longitudinal bunch dilution and beam loss, CPS and Fermilab Booster have γ_T jump schemes. The working group evaluates the problem related to the transition crossing in the main injector design. Here I summarize problems and solutions to the γ_T crossing.

I. Beam Dynamics at γ_T Region

It is known that the synchrotron motion of particles at the transition energy is dominated by the microwave instability and nonlinear dependence of the phase slip factor, η.

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These phenomena can be described by two times scales, i.e. the characteristic time and the nonlinear time. For the main injector, the characteristic time[1] and the nonlinear time[2] are respectively given by

$$\tau_c \simeq 2\left(\frac{V_{rf}\cos\phi_0}{2.78[MV]\cos[37.6^o]}\right)^{-1/3} \text{ ms} \tag{1}$$

$$\tau_{NL} \simeq \frac{(\alpha_1 + \frac{3}{2})\gamma_T}{\dot{\gamma}}\sqrt{6}\,\sigma_\delta \simeq 1.5 \text{ ms} \tag{2}$$

Within the characteristic time around the transition energy region, the bunch synchrotron motion is frozen. The bunch is then sensitive to microwave instability. Besides, particle motion in the bunch may experience defocusing synchrotron motion due to the nonlinear dependence of phase slip factor η on the momentum.

Particle tracking simulation[3] indicates that particle loss will be about 20% and the emittance growth[3,4] can be a factor of $2 \sim 3$. Thus γ_T jump is inevitable (careful analysis shows that the dependence of the transition energy on the betatron amplitude due to space charge,[3,4] sextupole, octupole, etc. is not important).

II. γ_T Jump

A γ_T jump scheme has been proposed for the MI. The γ_T jump scheme[5] can be summarized in the following,

$$\Delta\gamma_T = -0.069\left(\int G d\ell[KG]\right)^2 \tag{3}$$

$$\hat{X}_p = 2.2 + 4.8(\Delta\gamma_T)^{1/2} \text{ [meters]} \tag{4}$$

With $\Delta\gamma_T = 1$, the maximum dispersion will be 7 m. The corresponding momentum width is

$$J_\delta = 2.45\times10^{-3}\left(\frac{S}{0.4\ evsec}\right)^{1/2}\Delta\gamma_T^{-1/4}\left(\frac{V\cos\phi_0}{2.78[MV]\cos[37.5^o]}\right)^{1/4} \tag{5}$$

Thus the required momentum aperture is about 40 mm. Transverse phase space tracking calculation at the transition energy region for $500 \sim 1000$ turns will be important to define the available dynamical aperture.[6]

The minimum transition energy jump is $\Delta\gamma_T \geq \max(2\dot{\gamma}\tau_c, 2\dot{\gamma}\tau_{NL})$. The maximum $\Delta\gamma_T$ is determined by the dynamical aperture limitation. These two conditions give us

$\Delta\gamma_T \geq 1$. The minimum number of turns N_a, for the γ_T jump which minimizes transverse phase space area growth is given by[7]

$$\frac{\Delta X_p}{N_a} \cdot \sigma_\delta << A_\beta \tag{6}$$

where A_β is the betatron amplitude. One expects the minimum jumping time should be about 0.5 ms which gives 1% nonadiabatic change in transverse phase space. Thus one can obtain $\dot{\gamma}_T \leq 2000$ sec^{-1}, which is 10 times larger than the nominal $\dot{\gamma}$. Numerical simulation[3] shows that

$$\Delta\gamma_T \cong 1.5(S/0.4evsec)^{1/2} = 4\gamma_T\hat{\delta} \simeq 2\dot{\gamma}\tau_{NL} \tag{7}$$

are sufficient to maintain the bunch area. Here $\hat{\delta} = 2.5\ \sigma_\delta$. Thus the nonlinear effect dictates longitudinal beam dynamics at the transition energy crossing.

III. Longitudinal and Transverse Microwave Instabilities After γ_T Jump

After the transition γ_T jump, the microwave instability threshold may still be small due to small $|\eta|$, where

$$|\eta| \simeq \frac{\Delta\gamma_T}{\gamma_T^3} \tag{8}$$

The longitudinal and transverse impedance threshold is given by,[8]

$$\left|\frac{Z_\parallel}{n}\right| \leq 10\left(\frac{S}{0.4evsec}\right)^{3/2}\left(\frac{V\cos\delta_0}{2.78[MV]\cos[37.6^o]}\right)^{1/4}\left(\frac{N}{6\times10^{10}}\right)^{-1}\Delta\gamma_T^{3/4}[\Omega] \tag{9}$$

$$|Z_\perp| \leq 2.3\left[\frac{M\Omega}{m}\right]\left(\frac{S}{0.4evsec}\right)\left(\frac{N}{6\times10^{10}}\right)^{-1}|(n-\nu)\eta - \xi\nu| \tag{10}$$

Thus the impedance budget is still important even when γ_T jump schemes is used.

IV. Imaginary Transition Lattice

Recently Trbojevic et al.[9] worked out a lattice with imaginary transition γ_T. The lattice has regular lattice properties. However, the following lists of problems should be worked out.

a) Chromatic correction scheme
b) Off-momentum behavior of the lattice, i.e. $\gamma_T(\delta)$, $Q_{x,y}(\delta)$, $\beta_{x,y}(\delta)$, $X_p(\delta)$ etc.
c) Tunability
d) Slow extraction efficiency
e) Tolerance to error

f) Tracking of dynamical aperture.

Items (a), (b) and (c) have been studied by Trbojevic and myself. The tunability and off–momentum behaviors of the lattice are good. Items (d), (e) and (f) are yet to be studied.

V. Experiments to Test the Longitudinal Beam–Dynamics

Most of the analysis in the workshop are carried out through the particle tracking calculations. It is important to test the validity of the tracking program. Several experiments were carried out recently in FNAL.[10]

VI. Conclusion

The working group has worked out the requirement of γ_T jump criteria for main injector. With appropriate γ_T jump, transition energy will not be the performance limitation. We have also obtained the criteria for the betatron phase space adiabaticity in the γ_T jump. We obtain then the maximum achievable $\dot{\gamma}_T$. We found that the γ_T jump can enhance the transition energy crossing by a factor of 10, i.e. $\dot{\gamma}_T \simeq 10\dot{\gamma}$. Depending on $\Delta\gamma_T$, the impedance threshold should be carefully controlled after γ_T jump.

Several beam dynamical experiments has been contemplated and reported in the proceeding of the workshop.

References

1) S.Y. Lee and J.M. Wang, IEEE Transactions on Nucl. Science, NS 32, 2323 (1985).
2) S.Y. Lee and J. Wei, "Nonlinear Synchrotron Motion Near Transition Energy in RHIC", EPAC proceedings p. 764 (1988).
3) A. Bogacz, these proceedings.
   J. Wei, these proceedings.
4) B. Ng, FNAL–TM1670.
5) S. Holmes, these proceedings.
6) "Transverse Tracking Calculations", these proceedings.
7) S. Peggs, these proceedings.
8) B. Ng, these proceedings.
9) D. Trbojevic, these proceedings.
10) K. Meisner, Ioamis Kourbanis, these proceedings.