Measurement of Tune Spread in the Tevatron versus Octupole Strength

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A experiment was performed in the Tevatron to measure the tune spread versus octupole strength. The experiment is sensitive to the relationship between octupole strength and current in the T:OZF circuit and to the octupole (and other non-linear focusing fields) in the Tevatron. The major motivation for the experiment was to determine the value of octupole excitation that minimizes the tune spread: this value is an estimate of the value required to obtain "zero" total octupole excitation in the extraction process.

The experiment was performed using the strip-line kickers at A17 and the resonant Schottky pickups. The horizontal proton kicker was excited with a sine-wave from a vector signal analyzer (HP-89440A) and the horizontal proton signal was received. The gating circuitry normally used to select proton or antiproton bunches was by-passed. The response function was measured and recorded on a floppy disk. Measurements were initially made with a 200 Hz span (0.250 Hz frequency bins) and later with a 100 Hz span (0.125 Hz frequency bins).

The data was all obtained at flattop (800 GeV) with Q39S and Q39C set to correct the 1/2 integer stop band and QXR (the extraction regulation system) turned off. No attempt was made to examine sensitivity to closed orbit, chromaticity, or any other machine parameters other than the zero harmonic octupoles. The tune varied slightly (presumably because of feed-down effects from the octupoles), but was approximately constant at 19.472 (only the fractional part was measured). The beam emittance was not measured because the flying wires were not working when these data were taken.

The analysis of the data was accomplished by replotting the data from the floppy disk. The peak amplitude and the full width at 25% of the peak height were measured. Figs. 1-7 show some of the data that was obtained. The vertical scales in Figs. 1-7 are adjusted so that the data span 80% of the full height of the screen. The hardware requires the markers to be a measured points, so the the width measured is not exactly at 25% of full height.

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Fig. 1. Tune spectrum with T:OZF set to 11 C49 units.

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Fig. 2. Tune spectrum with T:OZF set to -3 C49 units.

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Fig. 3. Tune spectrum with T:OZF set to -5 C49 units.

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Fig. 4. Tune spectrum with T:OZF set to -5 C49 units.

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Fig. 5. Tune spectrum with T:OZF set to -7 C49 units.

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Fig. 6. Tune spectrum with T:OZF set to -9 C49 units.

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Fig. 7. Tune spectrum with T:OZF set to --20 C49 units.

The data is summarized by Fig. 8, which shows the measured line width versus octupole setting. Also shown is an approximate theoretical expectation of 0.28 Hz/A (the position of the line is arbitrary—only the slope is relevant). The line slope is determined from the following expression for the tune spread due to octupoles:

$$\Delta\nu = \frac{3}{8\pi} E J \quad [1]$$

where E is the octupole strength and is defined as:

$$E = \frac{\beta_0}{|B\rho|} \oint_c \left[\frac{\beta(z)}{\beta_0} \right]^2 \frac{B'''(z)}{6} dz \quad [2]$$

and z is the distance along the closed orbit, $\beta(z)$ is the beta function, $\beta_0 = 100$ m is an arbitrary reference beta function, $|B\rho|$ is the magnetic rigidity of the beam and $B'''(z)$ is the 3rd derivative (octupole term) of the field. An evaluation of E at 800 GeV for the octupoles powered by T:OZF yields:

$$E = 42.15 I_{OZF} \text{ m}^{-2} \quad [3]$$

The quantity J is the action and is given by

$$J = \frac{\beta_0}{2\beta_r\gamma_r} \left(\frac{\varepsilon_N}{\pi} \right) \quad [4]$$

where ε_N is the normalized emittance and $\beta_r\gamma_r$ is the relativistic factor p/m . A value of $\varepsilon_N = 20\pi$ at 800 GeV/c yields

$$\Delta\nu = 0.28 \text{ Hz/A} \quad [5]$$

Fig. 8. The full line width at 25% maximum is shown for all the spectra taken. Different symbols are used for the two different frequency resolutions.

Fig. 9 shows the peak response (linear amplitude) determined from each spectrum. These data are expected to contain the same information as those in Fig. 8 since the area under the tune line should be a constant, independent of octupole setting. However, the peak amplitude data has different systematic errors and is a complementary measurement. Fig. 10 shows the peak response times the line width (this is the same data as was shown in Figs. 8 and 9). This quantity, a crude approximation to the integral under the line, is approximately constant for the measurements that were made. It appears that the measurements made with a finer frequency resolution yield a lower value ($74.2 \pm 3.2 \text{ Hz}$ for 100 Hz full scale versus $92.3 \pm 2.1 \text{ Hz}$ for 200 Hz full scale). The reason for the difference is not understood.

Fig. 9. The peak response versus octupole strength is shown.

Fig. 10. The peak response times the line width measured at 25% height.

The width data was fit to the phenomenological form:

$$\Delta v = \sqrt{s^2(I_{OZF} - I_{Off})^2 + (\Delta f_0)^2} \quad [6]$$

The result of this fit is given in Table I. The errors plotted in Fig. 11 were chosen to be 0.5 Hz for each measurement. The size of the error was chosen to yield a reasonable chi-

squared for the fit. The fitted result for the slope of the widths (0.305 Hz/A) is much closer to the estimated value of 0.28 Hz/A for a 20π mm-mrad beam than could reasonably be expected.

Fig. 11 The data for the widths of the tune lines is shown with the fitted curved described in the text.

Table I. Results of the fit for the tune line widths.

Parameter	Value	Error	Units
s	0.305	0.010	Hz/A
I_{off}	-8.70	0.61	A
Δf_0	2.34	0.20	Hz
c^2	12.59		

The value of the octupole current required to minimize the tune spread is:

$$\begin{aligned}
 I_{off} &= -8.70 \pm 0.61 \text{ A} \\
 &= -5.57 \pm 0.39 \text{ C49 Units}
 \end{aligned}
 \tag{7}$$

SUMMARY

A measurement of the octupole current required to minimize the tune spread in the Tevatron has been made. A precise value for the current may be obtained by using a phenomenological form to fit the data. The change in tune width with octupole excitation agrees approximately with the theoretical expectation.