Fermilab

TM-1258
0430.000

MAIN RING BUNCH NARROWING FOR $\bar{p}$ PRODUCTION WITHOUT RF COUNTERPHASING

J. Griffin and J. MacLachlan

May 1984

We describe here a technique for generating narrow proton bunches for $\bar{p}$ production without counterphasing the Main Ring rf. This procedure is apparently as effective as the previously proposed procedure and it offers several advantages, listed here.

1. No rf counterphasing is required. The procedure is very simple.

2. The total time required for the procedure is less than 5 msec during which the Fourier identity is never lost. The beam-rf phase lock loop can continue to operate normally during the procedure and there does not appear to be any great advantage in going to the flattop oscillator before bunch narrowing. Therefore, the entire bunch narrowing time is reduced from about 200 msec to about 5 msec, so if other limitations could be overcome the $\bar{p}$ production rate could be increased by about 10%.

3. While the bunches must pass through a low momentum state where they may be subject to microwave instability disturbance, they remain in that state only a very short time, so unless the blow-up is extremely fast the effect may be minimized.

The procedure can be described in three simple steps.

1. Start with bunches matched to 1 MV bucket at the beginning of flattop.

2. Turn the rf off for about 160 turns, during which time the bunch shears to a diagonal distribution while local phase space density is preserved.

3. Turn the rf back on at 4 MV. The sheared (and consequently mismatched) distribution rotates coherently to a narrow distribution in slightly more than one quarter of a synchrotron phase oscillation period, or about 77 turns.

The procedure is optimized by adjusting the off time, or shearing time. The optimum value is a function of the initial longitudinal emittance and rf voltage. Approximate notions of how the sequence should proceed can be seen in the following example.

Start with a bunch of 0.2 eV-sec matched to a 1 MV bucket at 120 GeV. The bucket height is 157 MeV. A bunch matched to the bucket will have a bunch height ΔE=40.5 MeV and a full length of 3.2 nsec (bucket length 18.8 nsec). This is shown roughly to scale in Figure 1a. The bucket height of a 4 MV bucket will be 314 MeV, twice that of a the 1 MV bucket. Such a bucket is shown to the same scale in Fig. 1b. If the 0.2 eV-sec bunch is to have a final bunch length in the 4 MV bucket of 0.7 nsec, the maximum energy of the narrow bunch will have to be slightly greater than 182 MeV. Particles reaching 185 MeV must travel on the ellipse shown dashed within the bucket. The ellipse has a full length of 7.54 nsec. (This corresponds to a half-angle $\phi=0.4\pi$ radians within the bucket. Particles starting from the abcissa at this angle will reach an energy $\Delta E=\Delta E_b \sin \phi/2$ = 185 MeV). The rf must remain off just long enough so that particles near the maximum energy deviations in the bunch move over and just touch the 185 MeV ellipse. This is shown in Figure 1c. This figure is easy to sketch because particles on the abcissa (zero energy offset) do not shear at all. The maximum energy particles must move ahead and behind by about 3.7 nsec. From this we find the time required

$$\frac{\Delta T}{T} = \eta \frac{\Delta p}{p}$$

$$\eta=0.0028$$

$$\frac{\Delta P}{P} = \frac{40.5\text{x}10^6}{120.9\text{x}10^9} = 3.35\text{x}10^{-4}$$

$$\frac{\Delta T}{T} = 9.38 \times 10^{-7}$$

$$T = \frac{3.7\text{x}10^{-9}}{9.4\text{x}10^{-7}} = 3.9 \text{ msec or } 188 \text{ turns}$$

The sheared distribution is a little asymmetric with many particles of slightly lower than maximum energy reaching the ellipse also. This is perhaps good because these are the particles which will have the longest phase oscillation period when the rf is turned back on and the rotation will be clockwise, so since they are a bit ahead at the start, they can afford to fall back a bit in the succeeding rotation and still "fall into line". The next step, of course, is to turn on the rf at 4 MV and allow the sheared distribution to rotate to a narrow vertical distribution. This is shown in Figure 1 d. The synchrotron phase oscillation is 5.2 msec so the rotation indicated will require about 1.5 msec or about 72 turns.

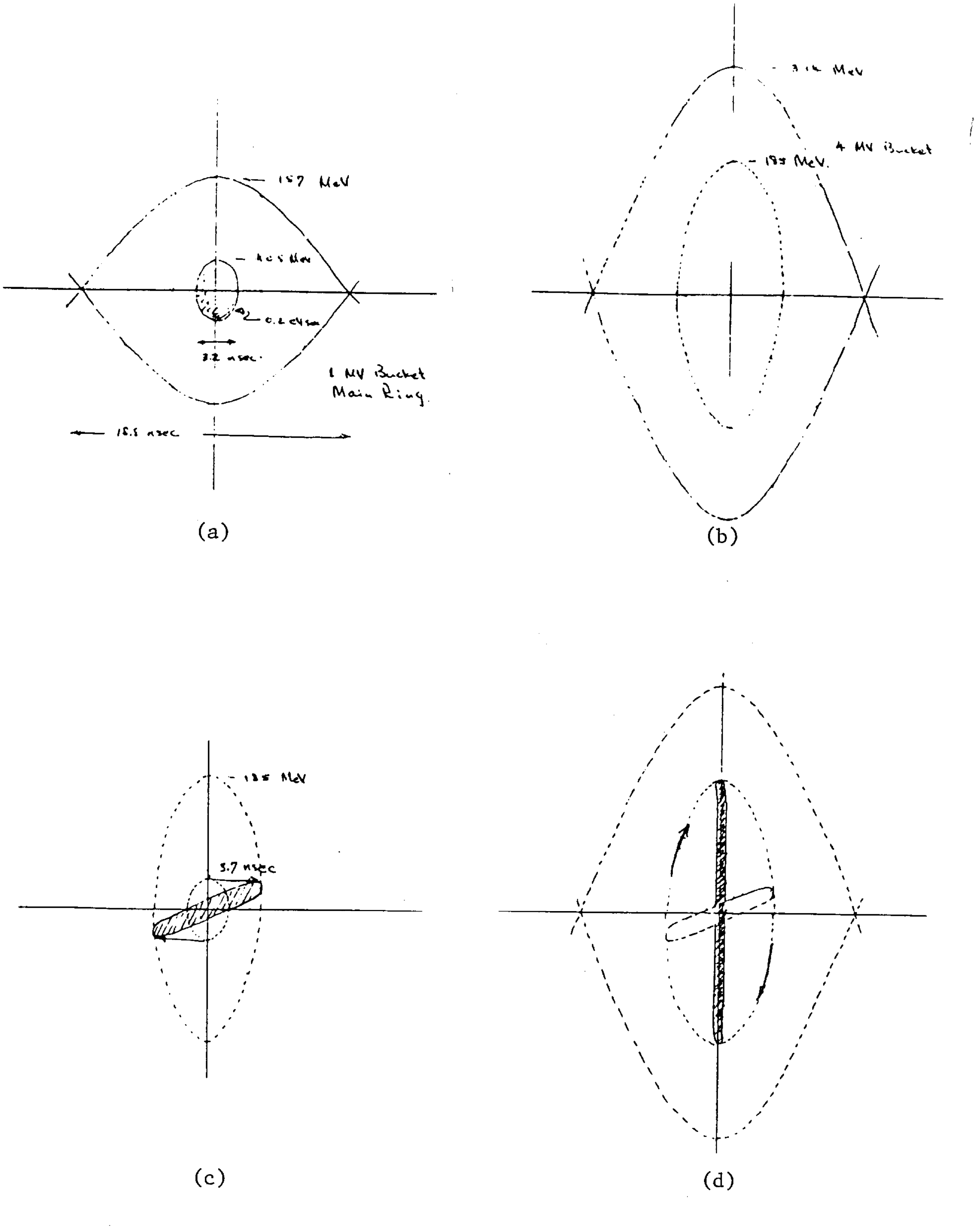


Figure 1. Four steps in bunch narrowing for $\bar{p}$ production without counterphasing.

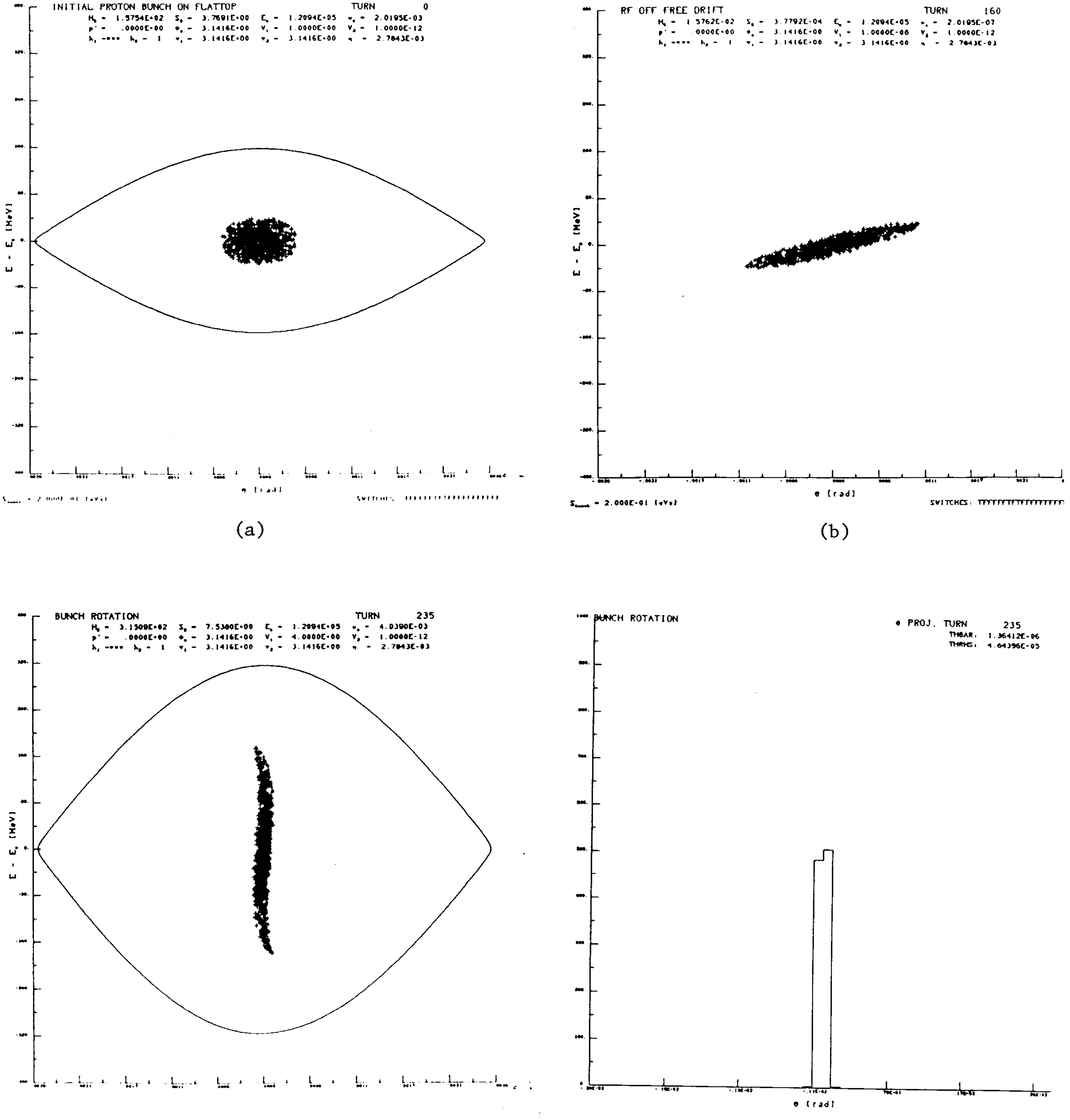
This sequence of steps is intended only to illustrate the idea. A real simulation using one thousand points and a parabolic distribution has been completed and is shown in Figure 2. Optimum times found in the simulation are 160 turns for shearing time and 75 turns for rotation in the 4 MV bucket. The final rms bunch length is shown in Figure 2a to be 4.84×10^{-5} radians. This is the angular region of the entire ring occupied by this bunch. Translated to time, the bunch has a projected 4σ length of 0.65 nsec. The minimum bunch length achieved for a similar bunch using counterphased rf (simulation) is 0.6 nsec.

Figure 3 shows the (one σ) energy height of the bunch during this procedure. It shows the energy spread remaining constant during shearing and only going through a minimum during the first phase of rotation. This may be a bit misleading because, while the energy spread of the entire distribution remains constant during shearing the local energy spread of any point along the bunch is decreasing as the shearing proceeds. In any case the low momentum condition persists for a much shorter period of time than in the counterphasing procedure.

In Figure 4 curves are shown for the bunch length as a function of shear time for 0.2 and 0.3 eV-sec bunches. The minima in the curves are broad for a given emittance indicating non-criticality of adjustment, but they are clearly not the same for all emittances.

Comments

The bunch narrowing procedure outlined in this note is clearly simpler and as effective as the rf counterphasing procedure, and much faster. Two minor problems with the rf system should be mentioned. First, the rf cavities must remain tuned and ready to come on at maximum level during the three millisecond shear period. If the error signals from the local phase detectors to the bias supplies drift appreciably during this period the required maximum rf voltage may not be achieved. It would seem reasonable to attack this problem by placing track-and-hold units in the bias supply error signal paths. Since the procedure occurs at constant frequency on flattop, with minimal cw beam loading, the error signals should be very small in any case, or they could be made small by adjustment of the ferrite tuning program. Secondly, transient beam loading of the tuned rf system will continue, only slightly diminished by bunch broadening, during the 3 msec shear period. If it is not compensated for, bunches approaching the end of the batch will be decelerated and distorted slightly. With 2×10^{10} protons per bunch the maximum rf voltage developed during passage will be about 154 keV. In 150 turns this results in 23 MeV of deceleration of bunches at the end of the train, out of 40 MeV bunch energy half height, so the effect is not negligible. With the cavities tuned and waiting, it should be a simple matter to continue the beam loading compensation even with the rf off. The biggest complication is the changing Fourier decomposition of the beam during shearing. This kind of compensation has been discussed in $\bar{p}$ Note 382. Figure 5 shows the h=53 Fourier amplitude during the shearing and rotation.



(a)

(b)

(c)

(d)

Figure 2. Computer simulation of bunch narrowing.

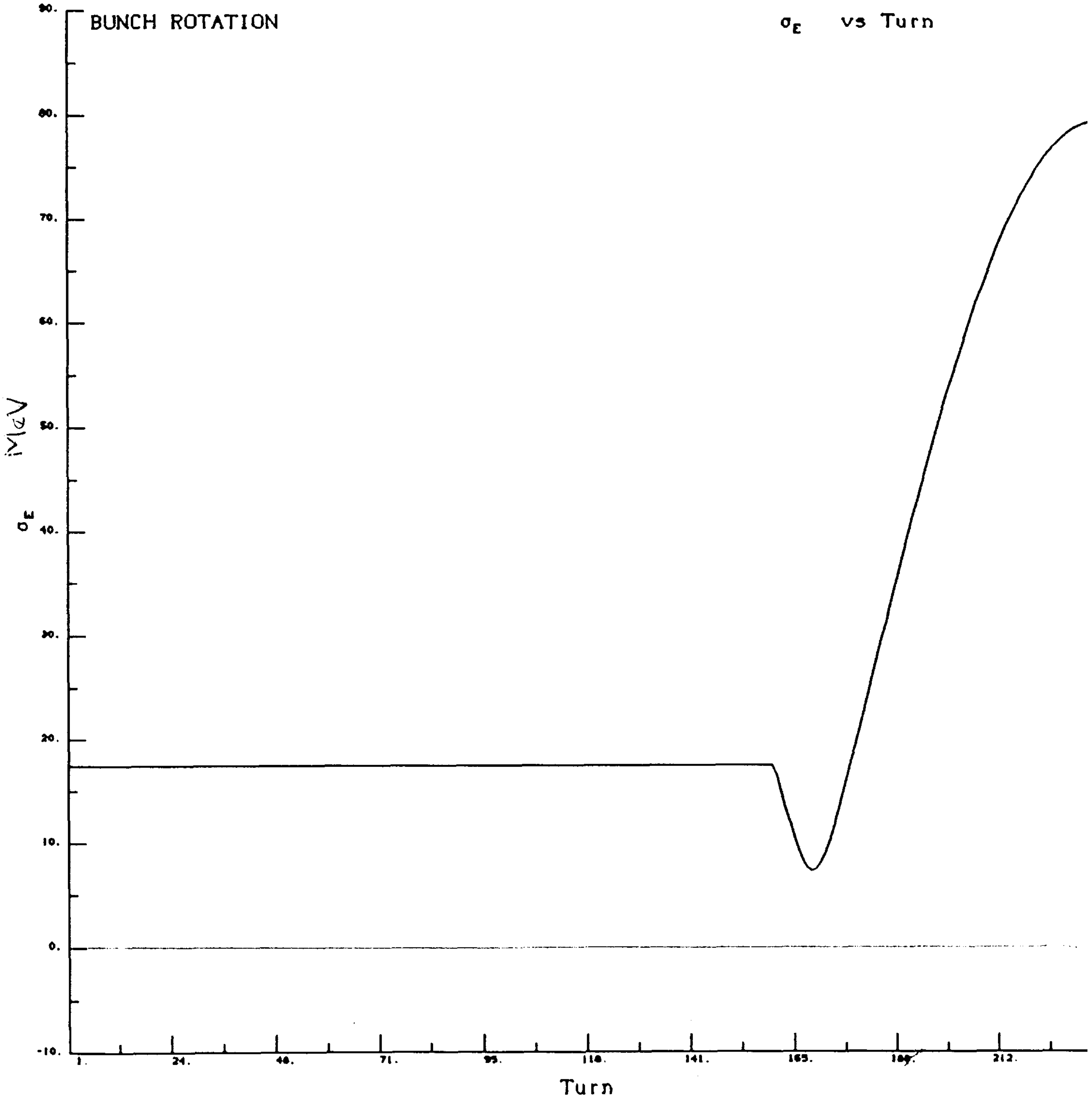


Figure 3. Energy half height (one σ) of charge distribution (0.2 eV-sec) during bunch rotation.

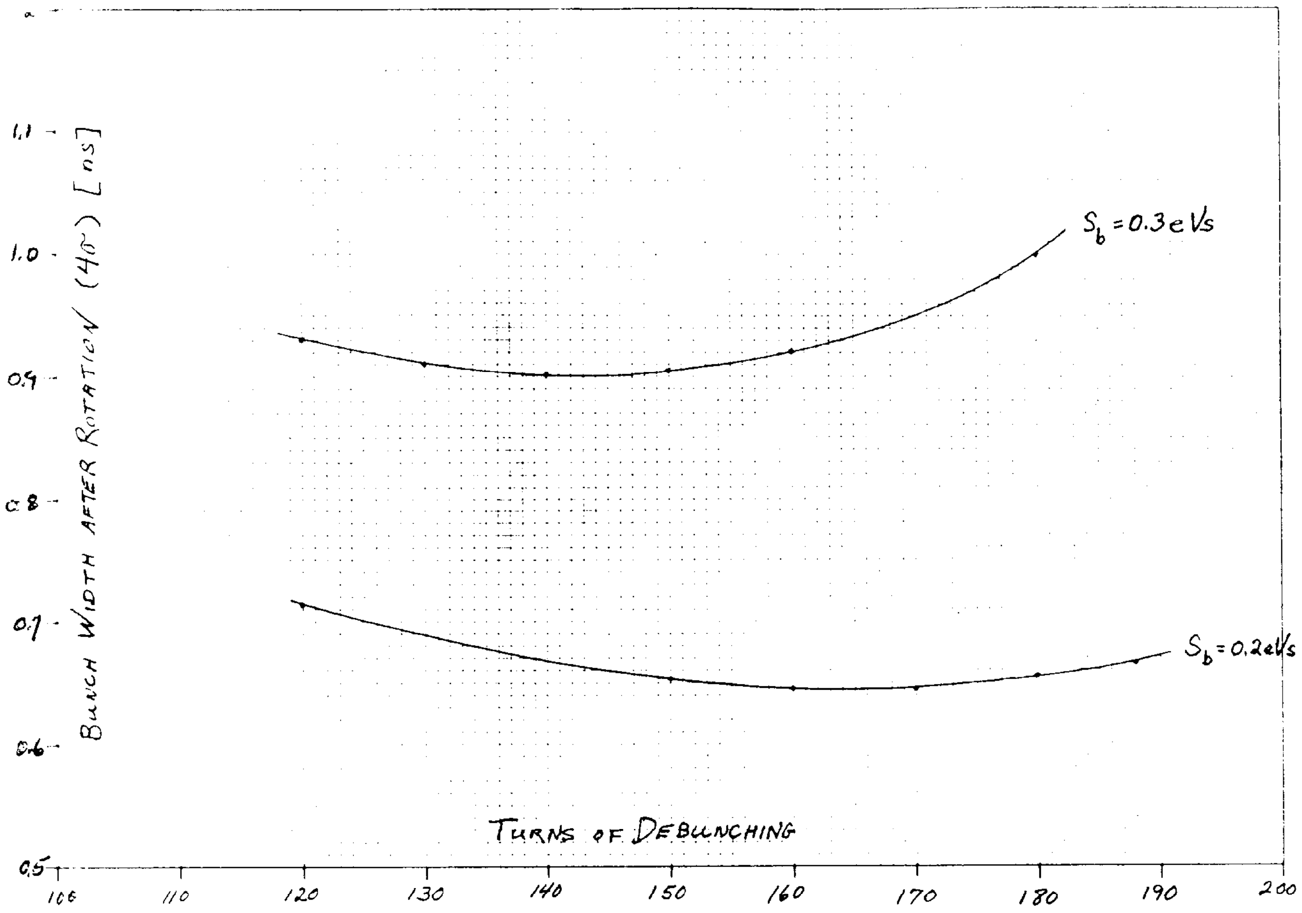


Figure 4. Minimum bunch length after rotation as a function of shearing time for 0.2 and 0.3 eV-sec initial emittance.

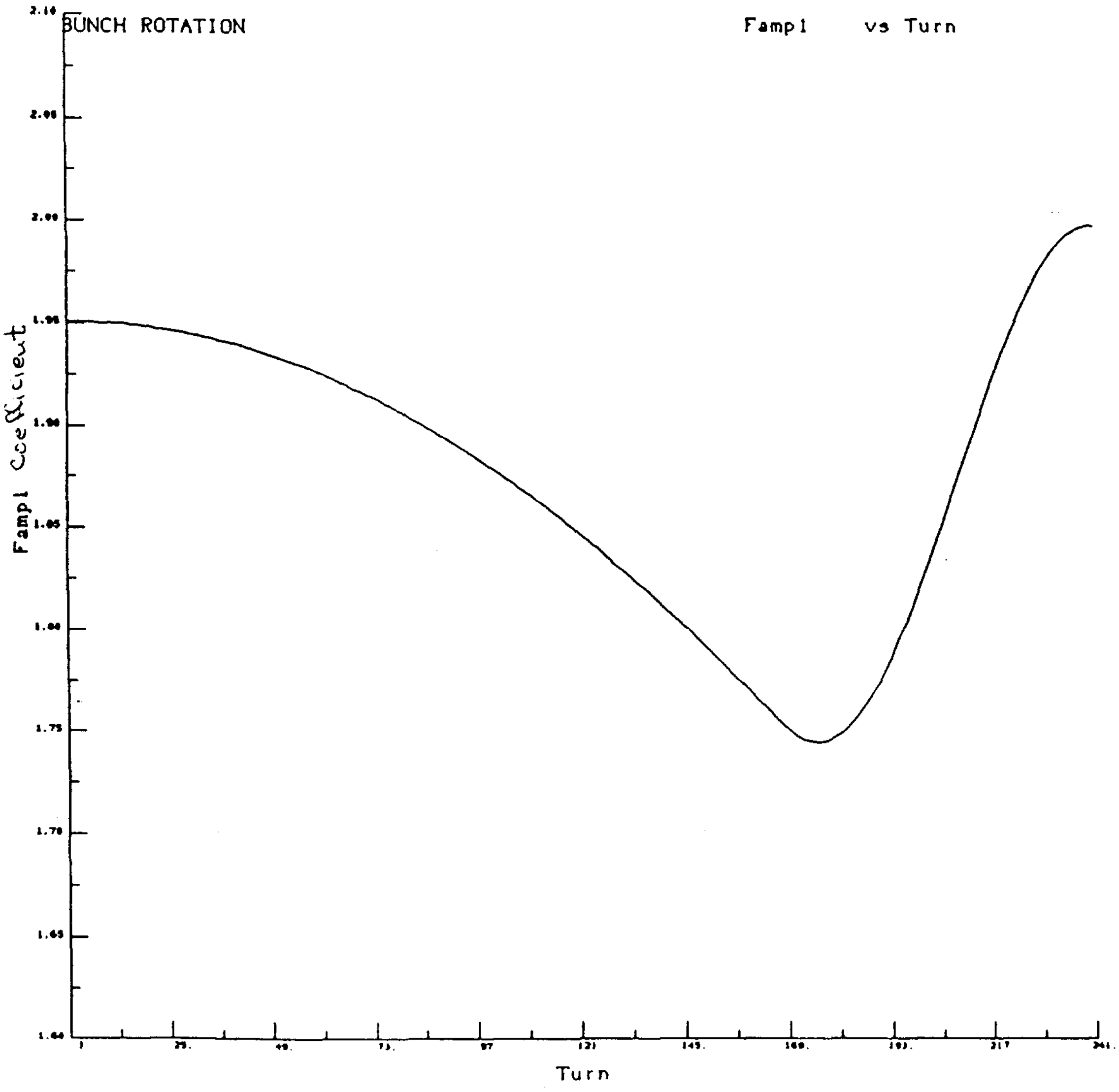


Figure 5. Variation of Fourier coefficient of dc beam current during shearing and rotation.

Because of the simplicity and evident advantages of this scheme it would seem imperative that it be tried as soon as possible.