Fermilab

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MULTITURN INJECTION INTO THE MAIN RING

Lee C. Teng

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The general principle for a scheme to inject more than one turn into the main ring was discussed in FN-104. Now that the parameters of the single-turn injection system as operated are well established one can give a more precise design of the modifications required for multiturn injection. In this scheme, the turns are stacked in the horizontal betatron-space. With the presently available useful horizontal aperture it is doubtful that more than 2 turns can be stacked. But, of course, a factor of 2 increase in intensity is already a big step forward.

A more ambitious approach would be to stack in the momentum-space in the manner of a storage ring. The available momentum aperture of the main ring would allow a stacking of more than 10 turns. This, however, involves the addition of a number of major components such as the shuttered injection kicker and the stacking rf system. In addition one has to abandon the present high-efficiency synchronous capture and suffer the rather lossy processes of debunching and rebunching. Moreover it is questionable that the 8-GeV beam can be stored in the main ring for ~10 sec without major loss.

Thus, a two-turn stacking in the horizontal betatron-space presents a simple and attractive first step.

A. Kickers and septum

For horizontal stacking the beam must be kicked horizontally.

We need two horizontal kickers placed 180° horizontal betatron phase apart with the 90° midpoint somewhere in the injection long straight. With the present operating tune of $\nu_x = 19.4$ such two locations are stations F46 and A12. As shown in Fig. 1 a kick of -0.5 mrad (negative means "to the right" or "inward") at F46 (k_1) and a kick of -0.85 mrad at A12 (k_2) will produce an inward local orbit bump with x going from -34.5 mm (A) to -42.0 mm (B) in the long straight.

The beam should be brought to be travelling along AB at B by the septum. For the present geometry it is simplest to bring the beam down vertically by a Lambertson septum. At A the present injection line is horizontal and at $y \cong 0.4$ m above the MR orbit. Hence it should be bent downward $-\frac{0.4\text{ m}}{50\text{ m}} = -8$ mrad using MV60. This requires a Lambertson septum with $B\ell = 2.37$ kGm (say, $B \sim 7$ kG, $\ell \sim \frac{1}{3}$ m) to straighten the beam out at B.

The emittance of the booster beam is ~ 1π mm-mrad. This gives a beam size of ±11 mm horizontal and ±7 mm vertical at B. The cross-sectional geometry of the beams and the Lambertson septum at B is shown in Fig. 2.

B. Modification of the transport line

The present transport presumably matches the beam optics and dispersion properly. So no modification is required for optics and dispersion. Only slight adjustment in geometry is needed. The present injection beam travels exactly above the MR orbit in the long straight. For two-turn injection it should travel along AB. This is simply done by adjusting the dog-leg formed by MH-40,41 and MH-50. As shown exaggerated in Fig. 3 the bend angle of MH-40,41 should be reduced by $\frac{34.5\text{ mm}}{38.727\text{ m}} = 0.89$ mrad from 104.84 mrad (left) to 103.95 mrad (left) and the bend angle of MH-50 should be reduced by -(0.89-0.15) = -0.74 mrad from -24.34 mrad (right) to -23.60 mrad (right).

Quadrupoles MQ-44, 45, 46, 50, 51 downstream of MH-40,41 must be displaced slightly in the horizontal plane. MV-60 is turned down to a field of B = 1.555 kG to give a $B\ell$ = 1.555 kG x 1.524 m = 2.37 kGm for the 8 mrad downward bend. MV-61 and MP-70 are replaced by the Lambertson septum at the end of the long straight (B).

In practice, of course, all dipoles are fine-adjusted by observing the beam positions.

C. Mode of operation

The first turn of 13 booster pulses is injected using only k_2 in the usual manner. The 14th booster pulse should be extracted from the booster at the proper time so that it arrives at the MR exactly alongside a booster pulse (say No. 1) already circulating in the MR. At the same time kickers k_1 and k_2 should be fired so that pulse No. 1 is kicked by k_1 to x = - 18 mm to nudge against the septum and alongside pulse No. 14 just on the other side of the septum. This takes a kick angle of $\theta_{k_1} = \frac{-18}{42} \times 0.5 = -0.214$ mrad. Both pulses 1 and 14 arriving at k_2 should be kicked by k_2 so that the average position of the two pulses sits on the central orbit. This requires a kick angle of $\theta_{k_2} = -\frac{30}{42} \times 0.85 = -0.607$ mrad. Altogether the required kick angles are

	k_1	k_2
1st turn	0	-0.85 mrad
2nd turn	-0.214 mrad	-0.607 mrad .

Of course the turn-on and turn-off of the kickers must be precisely timed so that only pulses No. 1 and No. 14 are affected. For k_2, two sections (1 m long per section) of the present kicker can be souped up to kick the 8 GeV beam by 0.85 mrad. One section is adequate for k_1.

We described a procedure in which pulse 14 is stacked with pulse 1, pulse 15 with pulse 2, etc. It is obvious that we can equally well stack pulse 2 with pulse 1, pulse 4 with pulse 3, etc. If the booster beam can be extracted in halves, we can even stack the second half of a pulse with its first half. The advantage of this half-pulse stacking scheme will be discussed below, but to extract the booster beam in halves will introduce the problem of "cogging" and involve a great deal more effort.

D. Phase space dilution and other considerations

The most efficient two-turn filling of the phase space is accomplished by properly mismatching the injected beam as shown in Fig. 4a. The resulting phase space area is 2.6 times that of each turn. This is possible only if the second turn is injected immediately after the first and before the coherence of oscillation of the first turn is lost. In our case this is possible only with the half-pulse stacking scheme.

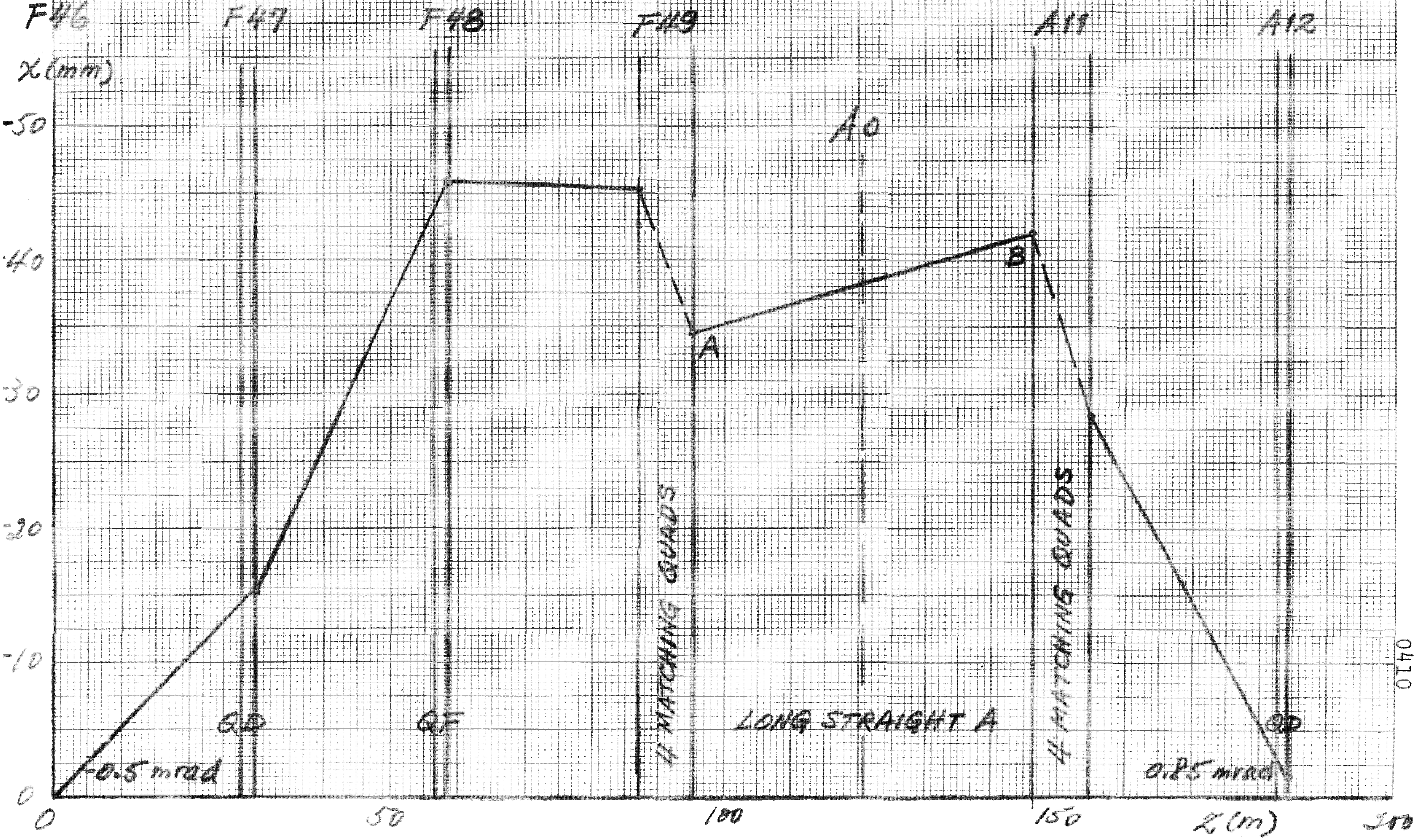
With matched injection the phase areas look like that in Fig. 4c. The resulting area is 4 times that of each turn, namely about 4π mm-mrad. The resulting area can be reduced slightly by mismatching the second turn as shown in Fig. 4b, but the improvement is relatively minor.

All the modifications and additional components are simple and straightforward. The only slightly tricky part is the timing of the turn-on and off of the kickers.

One important question to be answered is whether the MR has a large enough good field aperture to contain the 4π mm-mrad two-turn beam. Experiments to answer this question should be carried out. But the modified geometry should be better even for single-turn injection. It eliminates the troublesome MV-61 and MP-70 and replaces them by the very much simpler Lambertson septum.

Another consideration is the availability of space at F46 and A12. Both ministraights are now occupied by trim dipoles, position monitors, and extraction orbit-position bump magnets. Whether space can be made available for the kickers should be studied.

FIGURE 1 LOCAL ORBIT-BUMP PRODUCED BY KICKERS



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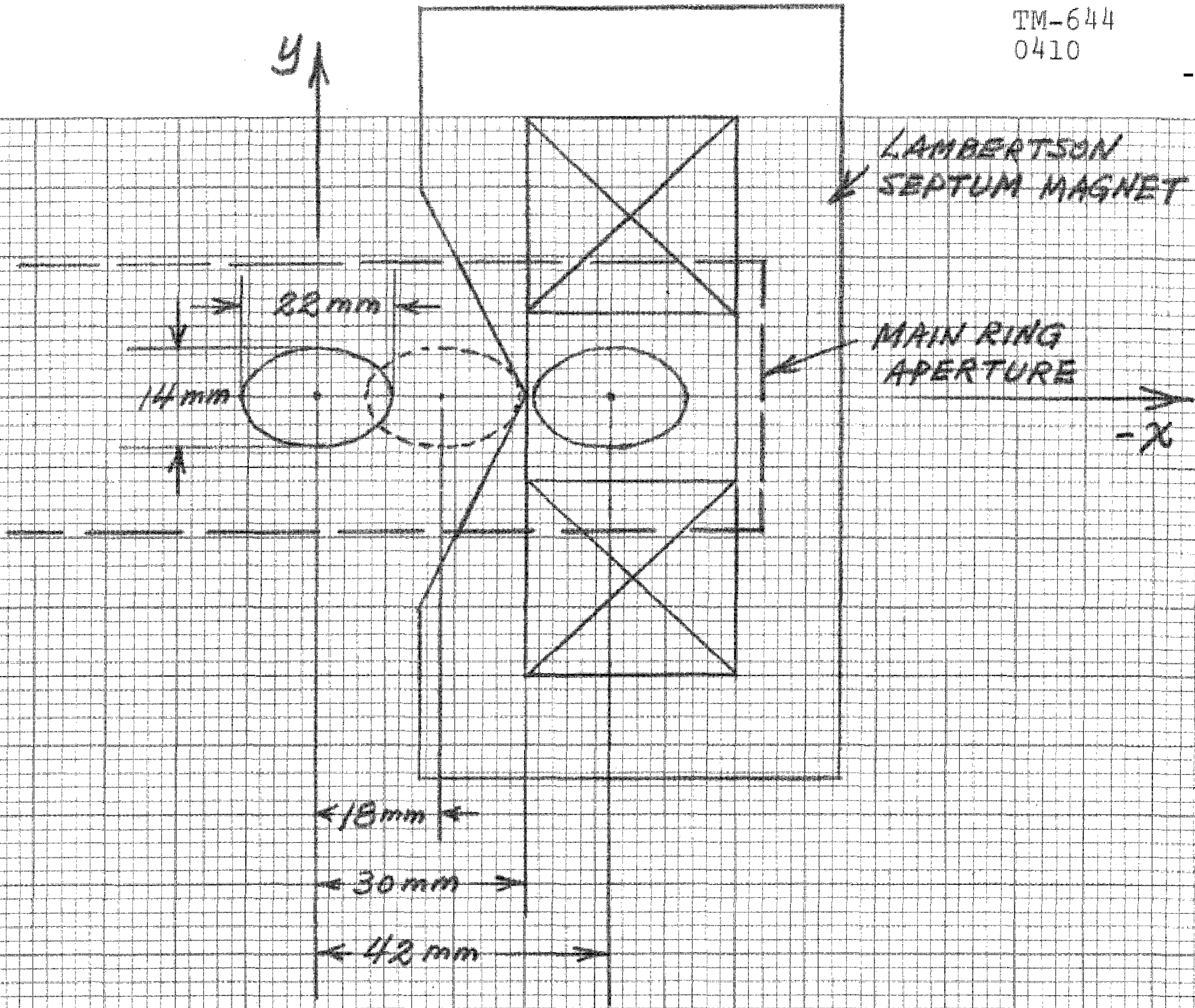


FIGURE 2 CROSS-SECTION AT END OF LONG STRAIGHT

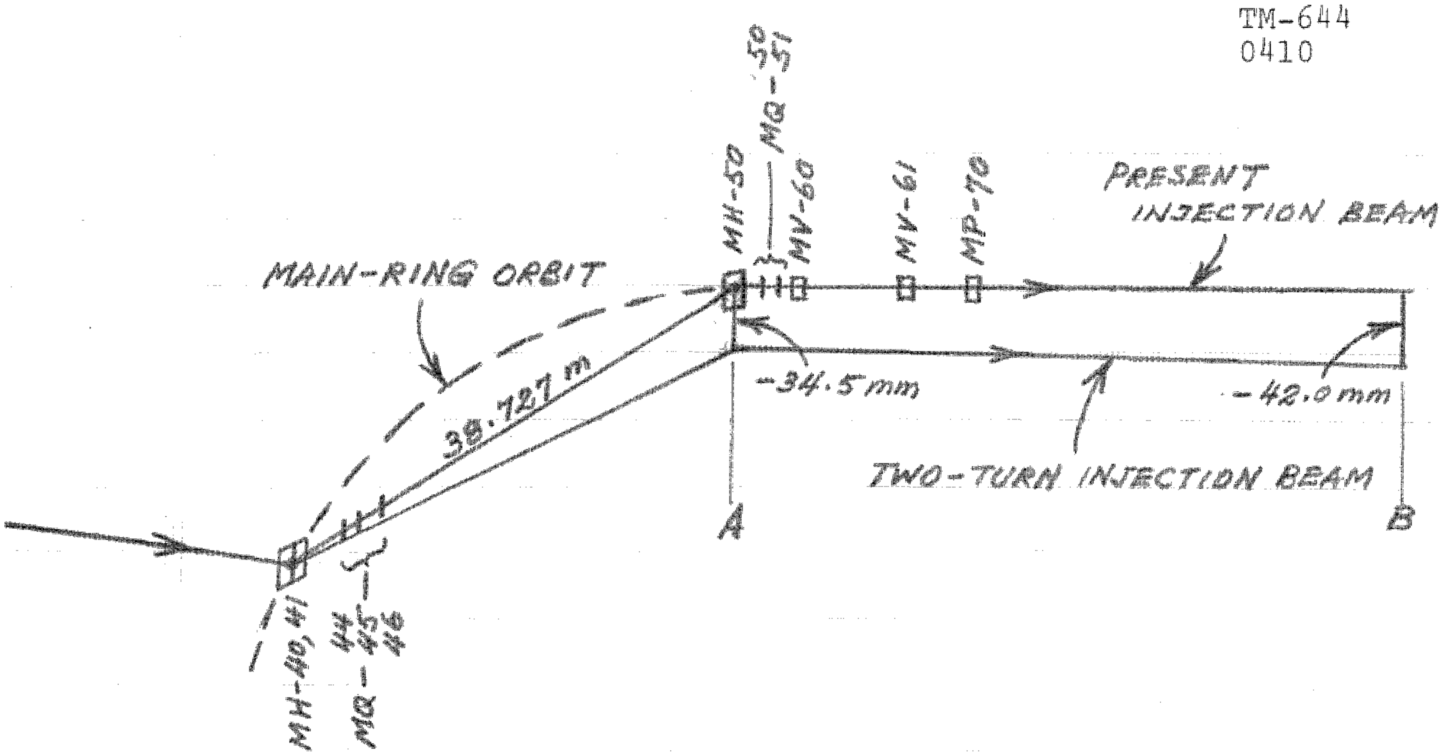
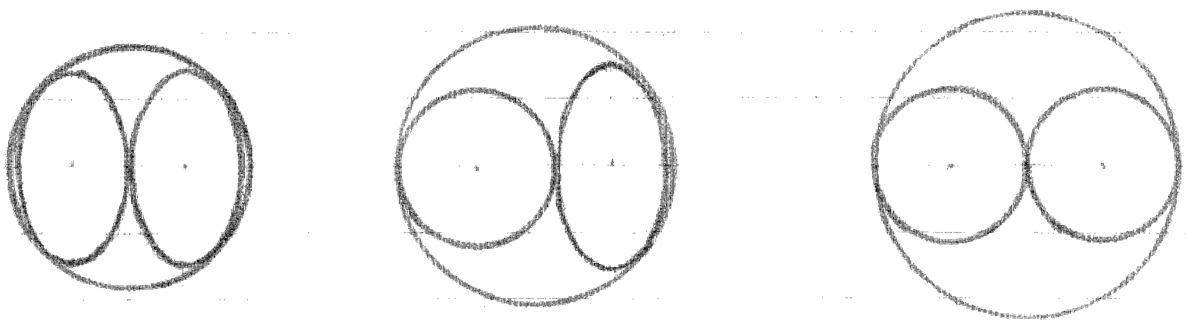


FIGURE 3 MODIFICATION OF INJECTION BEAM
(NO SCALE)



a b c

FIGURE 4 TWO-TURN PHASE-SPACE FILLING