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A POSSIBLE EXPLANATION OF THE MISSING BUNCHES IN THE BOOSTER

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Summary

In this paper we describe a model that might explain the missing bunches effect in the booster.[1] The model is based on the following two assumptions:

(a) phase and amplitude fluctuations among the 16 rf cavities make the voltage program during the acceleration cycle uncertain. The voltage might be lower than the design value by 5% or more around transition; and

(b) the 84 bunches have different momentum spread because of the fast momentum spread modulation within the 3 μs linac pulse.

The first assumption permits the rf bucket area to be smaller than the design value. The second assumption allows adequate rf buckets for bunches with smaller momentum spread, but not for bunches with larger momentum spread.

The result is that a bunch crossing transition is affected by a particle loss which depends on the size of the bunch.

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The Model

The longitudinal phase motion in the NAL booster has been studied previously using a multiparticle program.[2] Such an approach enables us to study nonlinear phase motion in detail in regions where the motion is nonadiabatic. We apply this program to investigate our model as outlined below.

At injection, we assume the 200-MeV linac beam to have a specified momentum spread and neglect the 200 MHz bunching. The beam phase space is uniformly populated with 100 particles in each strip of 0.2×10^{-3} in $\frac{\Delta p}{p}$ up to a total width of $\pm 1.6 \times 10^{-3}$ in $\frac{\Delta p}{p}$. We, then, perform a 120-turn ($\cong$ 355 μsec) "adiabatic" rf trapping with a final cavity voltage of 100 kV. The final rf bucket is about 70% filled for the design value of initial momentum spread, i.e., $\pm 0.8 \times 10^{-3}$. The accelerating cycle in the booster lasts 33.333 msec with a final beam energy of 8 BeV. The voltage program for the acceleration in the adiabatic region was calculated by Snowdon[3] based on a constant bucket filling factor of 0.7. This is shown in Fig. 1. In the neighborhood of transition where the motion is nonadiabatic, the voltage program can only be determined through cut-and-try scheme. The cavity voltage program corresponding to curve A in Fig. 1 is generally considered adequate for a beam with an initial momentum spread of $\pm 0.8 \times 10^{-3}$ as reported in Ref. 2.

In order to study the effects on the phase motion due to insufficient rf power at transition, we lower the peak voltage

of A by 2.5%, 5% and 7.5% as indicated by curves B, C and D, respectively. We carried out calculations of the phase motion of the multiparticle system also for these three voltage programs. In all cases a reasonable assumption is made that the energy gain per turn is independent of the voltage program and known a-priori.

Results for beam bunches of different initial momentum spreads following various voltage programs are shown in Fig. 2. Particle losses are shown at three different times in the neighborhood of transition. Time t_1 is approximately at the beginning of the nonadiabatic region (~2.0 ms before transition). Any particle loss before or at this time is due to insufficient rf buckets. Time t_2 is at transition and time t_3 is just after the nonadiabatic region. In some cases, there are particle losses between t_1 and t_2 despite the fact that the synchrotron oscillation frequency is approaching zero rapidly in this region. The beam loss between transition and time t_3 is mainly due to the mismatch of the beam to the rf bucket. This mismatch is caused by the presence of nonlinear rf forces and a second order momentum spread effect. For all the cases studied, there is no particle loss after t_3.

Conclusions

By inspecting the results in Fig. 2, we can make two kinds of suggestions:

(a) Try to make all the 84 bunches even, i.e., with the same momentum spread. This means the beam from the linac has

to be improved. In this case, if the voltage on the booster cavities fluctuates, all bunches suffer the same amount of particle loss when the peak of the voltage program changes from the design. In order to reduce the loss, then, the linac beam must have a very small momentum spread (see Fig. 2).

(b) Eliminate the fluctuations among the rf cavities and keep under control the voltage program. A seventeenth cavity might be quite useful to provide more power. As we can see from the lowest curve of Fig. 2, if the momentum spread of the linac beam is less than $\pm 1.0 \times 10^{-3}$, the bunches with different size will not suffer particle loss.

References

1. A. G. Ruggiero, "Missing Bunches in the Booster," Exp-6, March 10, 1972.

2. W. W. Lee, "Effects of Nonlinearities on the Phase Motion in the NAL Booster," TM-333, December 1, 1971.

3. S. C. Snowdon, "Booster Constant Bucket Area Regime with Space Charge," TM-304, May, 1971.

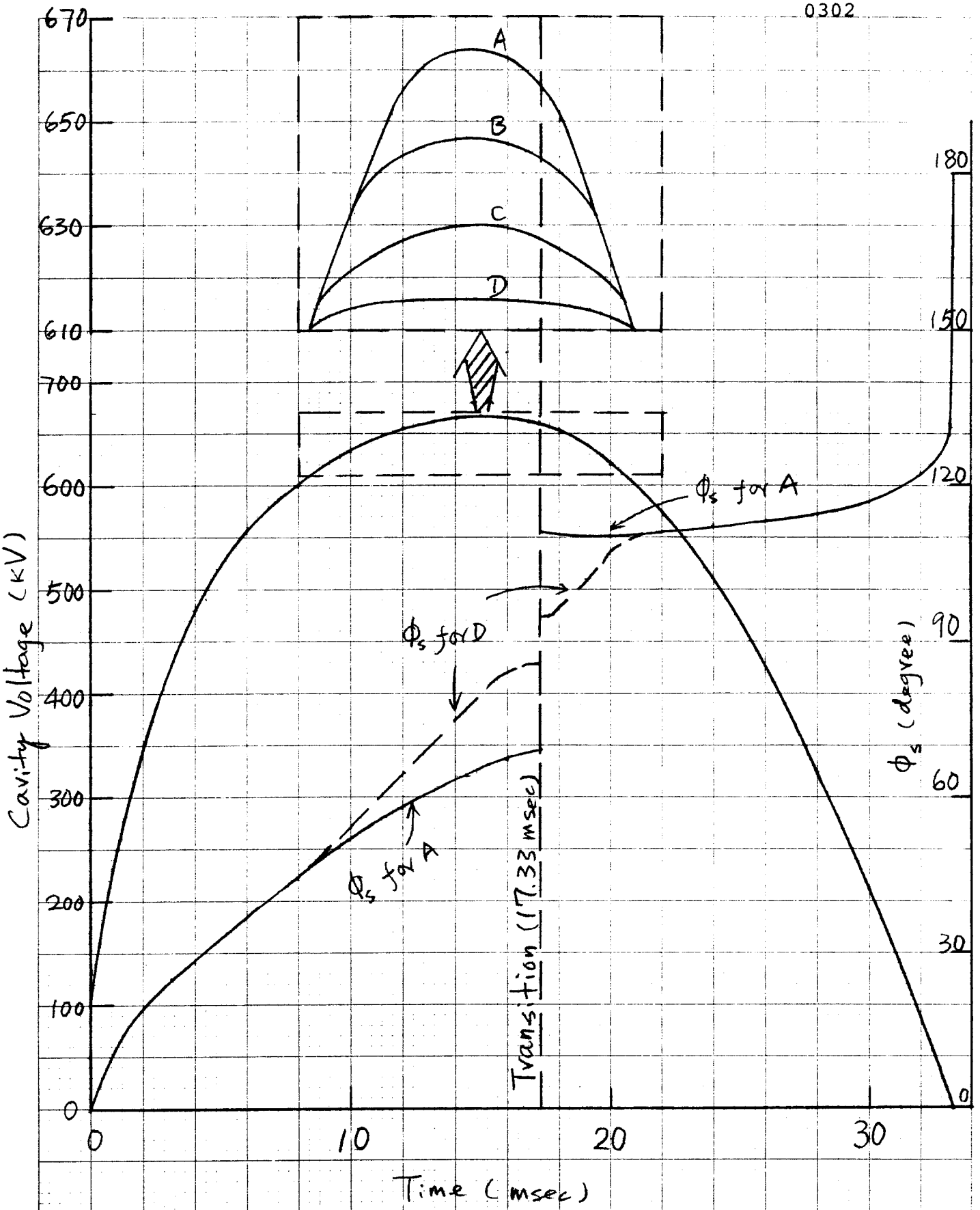

Fig. 1 Voltages Programs for the Acceleration

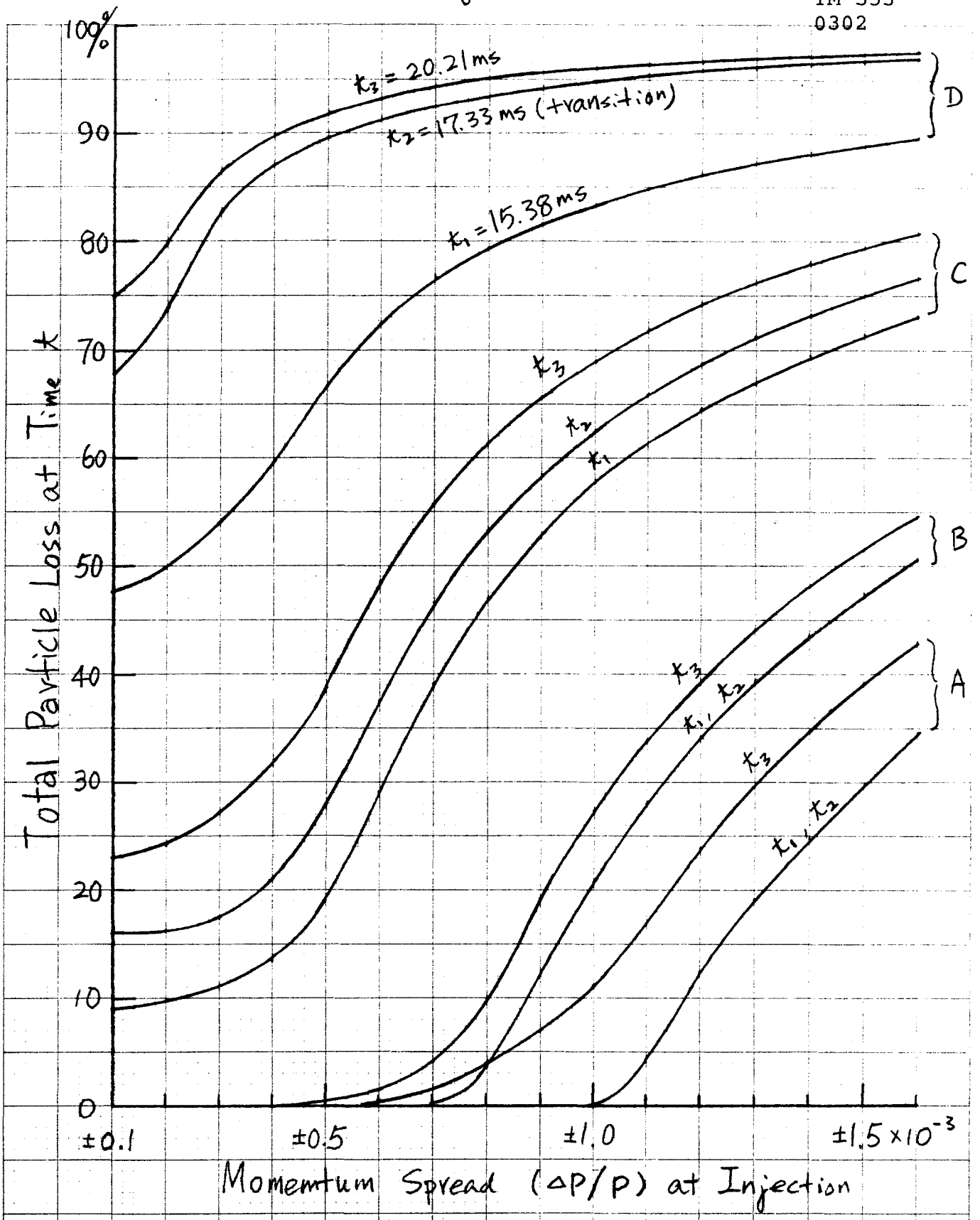

Fig. 2 Total Particle Loss for Various Voltage Programs In the Neighborhood of Transition