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RF Capture at Low B

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Subject RF Capture at Low $\dot{B}$

OBSERVATIONS AND CONCLUSION

Purpose: To study rf capture at $\dot{B} \approx 2.5$ kG/sec or about one-half the normal value of 4.9 kG/sec. In particular to try and repeat the high capture efficiency, i.e., ≈ 84% between #1 and #3 CBM obtained in October 1979 during a 1.5 GeV run. At that time two Acme supplies were used to power the main magnet and injection $\dot{B}$ was about 2.5 kG/sec. See Photo 1.

Procedure: The injection front porch was retuned to give maximum $\dot{B}$ for about 35 msec followed by a dip to half this value or ≈2.5 kG/sec for 40 msec, than a ramp back to maximum and finally a switch over to the main bank. Photo 2. The 60~ in the photo is due to ground loops but the ripple at 720 ~ is real and did result in some peaker jitter. The calibration is that the D-3 back leg signal is .19 volts at 2.5 kG/sec.

In order to reduce the effects of the rf cavity impedance, four stations were shorted with large capacitors across the gaps. Initially the injected intensity was limited to $1.3^{+} \times 10^{13}$, i.e., the value present on 10/18/79. After a preliminary adjustment of the rf parameters, the multipole corrections were tuned for maximum intensity. Then the rf capture was optimized as best as possible. The results are shown in Photo 3 where the inverted rf amplitude sum signal at .5 volt/div. and the F-20 current X FMR at .2V/div. appear at a sweep speed of 200 μsec/div. These are the scope settings for Photos 4 and 5 also.

Next the injected beam was increased to $1.8^{+} \times 10^{13}$ with no change; Photo 4. Then input was further increased to $\approx 2 \times 10^{13}$ and the rf sum was reduced slightly and the slope of the rise decreased; Photo 5. Finally the multipoles were retuned as well as the injection parameters. The latter brought the injected intensity to $>2.3 \times 10^{13}$. Photo 6 shows the raw L-15 current X FMR signal for these conditions with the rf as in Photo 5. This photo, at 1 msec/div., 1 volt/div. ($\approx .6 \times 10^{13}$/volt) should be compared to Photo 7 which shows the normalized L-15 X FMR at 1 volt/div. ($\approx .336 \times 10^{13}$/volt) and the rf sum at .5 V/div., both at 1 ms/div. The conditions were regular $\dot{B} = 4.9$ kG/sec during May '83 with $2.3^{+} \times 10^{13}$ injected.

Observations and Conclusions: It should be noted that toward the end of this run it was discovered that the 3 CBM timing was more than 3 msec from 1 CBM so the relative intensities measured in Photos 3-5 were on the pessimistic side. For this reason, Photo 6 was taken to give a better indication of the overall loss pattern for the final set of parameters. As can be seen from Photo 3 it was not possible to reproduce the smooth bunching during capture that was obtained in Photo 2. The ratio of 3 CBM to 1 CBM was ≅71% as compared to 84% for the October '79 photo. As noted above this is an underestimate. In Photo 4 the ratio is 65% while in 5 it is 58%. Now in Photo 6, if we measure at 3 msec after injection, the ratio is 67% corresponding to 1.6×10^{13} at that time. However one finds in Photo 7, at the same distance from injection, a ratio of 66%. Here, of course, the acceleration rate is twice that for the other photos.

The loss at 4 msec from injection in Photo 6 is presumably not related to the rf capture process. Although it is not shown, the rf sum signal is essentially constant during the 10 msec period seen here in contrast to the large variations present in Photo 7. We should also note that the amplitude of the sum signal in Photo 2 is ≈1.7 volts while that of Photo 3 is ≈1.1 volt. In Photo 7, at normal $\dot{B}$ it is ≈1.7 volts initially, which should be compared with ≈ a constant 2 volts obtained from a 6/27/77 photo. The latter was made during a one week period of 10^{13} operation with ≈ the same $\dot{B}$ but of course not H^- injection.

Now Photo 2 shows essentially ideal adiabatic capture with little evidence of bunch shape oscillations or filamentation. Photos 3-5 are less than ideal due to the presence of bunch shape oscillations. However, the peak to peak density variations for 3 and 5 are less than 10% and thus would result in, at most, a 5% increase in space change effects. Although the true 3 CBM to 1 CBM ratio is not known for Photo 3, it can be argued that it was probably less than that of Photo 2 for the following reasons. The space charge tune shift was greater and the necessary corrections to reduce its effect were not as well optimized since only a brief period was devoted to this process. Certainly the initial horizontal density was greater due to the increased brightness of the H^- beam and the mode of injection. Secondly, as noted above, the rf sum signal was only 1.1 volts, about 91 kV vs. 1.7 volts or 141 kV, for the October 1979 case. Hence the bucket area was smaller by about 35% so that the bunching factor is greater while the beam size due to synchrotron oscillations is less.

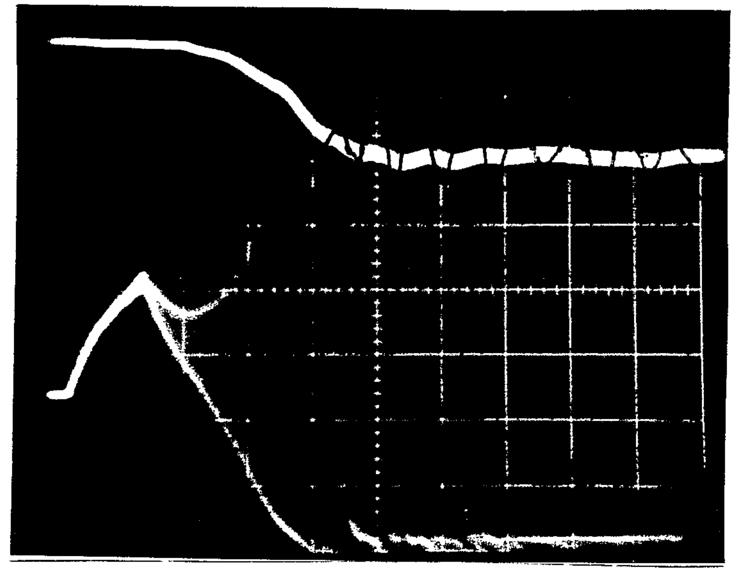
Now the smaller bucket size is a direct result of the smaller linac momentum spread (see Study Reports 144 & 147) about 7 X $10^{-4}\Delta E/E$ or 0.8 MeV. In both cases the final bucket area is at least 50% greater than the 90% linac phase space area. Generally there is a range of final rf amplitude of the order of ±10% over which the 3 CBM reading changes very little. At lower voltage one does not have sufficient bucket area while at higher voltages more aperture is needed for synchroton oscillations. Also at higher voltages, if essentially all the available beam is already in the bucket, one only increases the peak density and hence enhances the space charge tune shifts.

We also note that even with four rf stations "shorted out" it was not possible to obtain the very gradual bunching during early capture shown in Photo 2 even though the slope of the rf voltage program was set at 1/3 to 1/4 the value used on 10/18/79. The reason for this is most likely due to the reduced linac momentum spread. Without the rf drive on, there was very strong self-bunching of the beam at f_{rf} due to the cavity impedance. One should mention that although ten stations were probably used in October 1979 one normally had three tuned off resonances with the rf frequency during the capture process. Hence the difference in impedance between the two cases was probably not very large.

Finally we remark that at reduced $\dot{B}$ the beam spends more time at low energy where space charge effects are more pronounced. Although the 1 CBM read 1.37×10^{13} and the 3 CBM 1.15×10^{12} in Photo 2, the final 1.5 GeV intensity was $< 9 \times 10^{12}$. In the past it was found that with lower $\dot{B}$ and normal acceleration, one never succeeded in obtaining a final intensity greater than that achieved with the maximum (4.7 - 4.9 kG/sec) available from the flat top bank. Any increase in initial capture was never sufficient to overcome losses due to other processes.

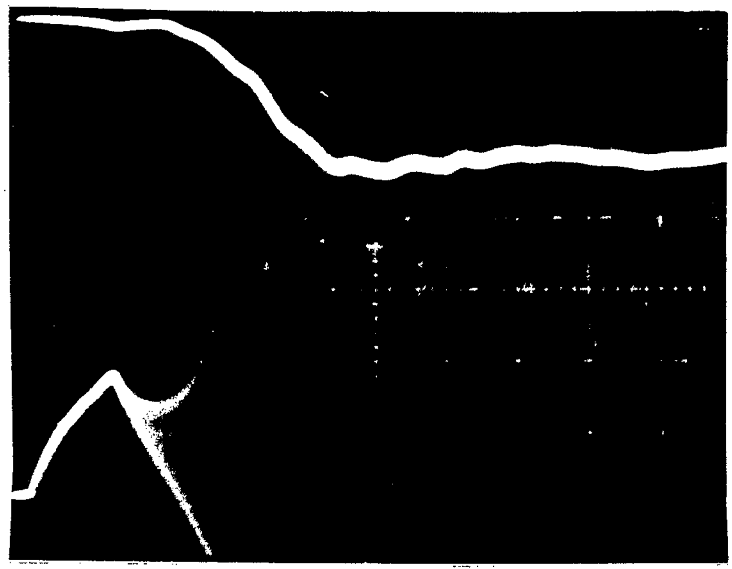
In conclusion then, lower $\dot{B}$ at injection will not improve the overall intensity with the present conditions. In particular the smaller momentum spread means less rf voltage required for capture but a greater tendency to self-bunch. Hence unless the cavity impedance seen by the beam can be reduced one cannot obtain optimum bunching. Also one would have to inject such as to fill the entire horizontal acceptance and thus reduce the space charge tune shifts before considering this option. In addition, more work on identifying stop bands and compensating for them would be required.

1

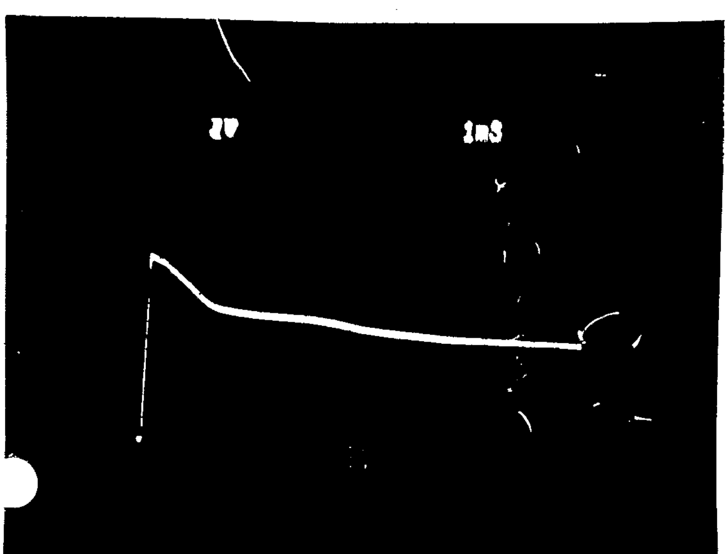


5

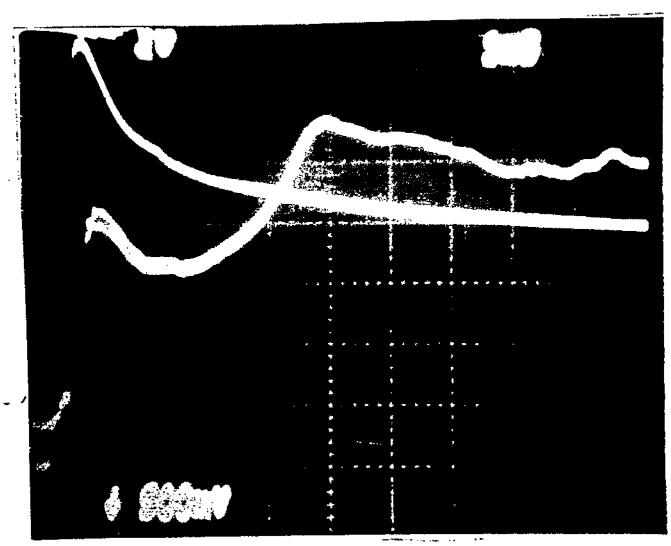
3 4



4 5



6



7

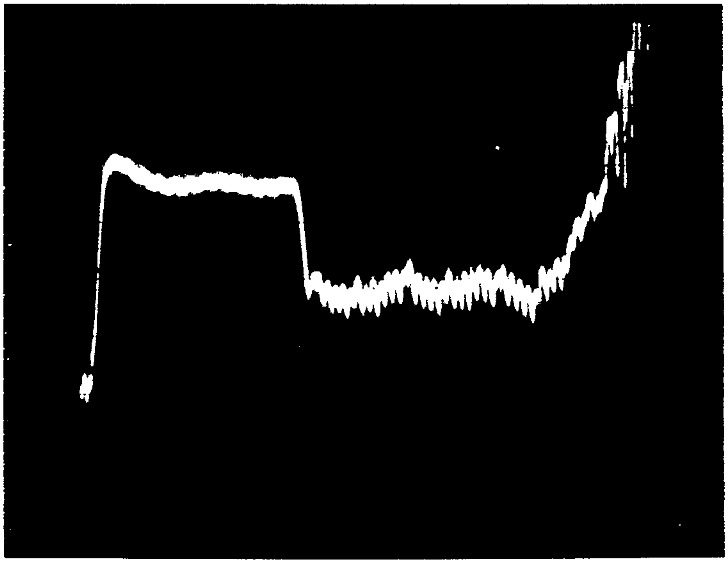


Photo 2
10 Msec/div ; .1V/div ; t_0 trigger