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HIGH-INTENSITY PHENOMENA AT THE BEVATRON

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ABSTRACT

Present maximum beam intensity at full energy is 2.3×10^{12} protons per pulse; this is reached with about 10-mA injector current. Greater injector current is available, but does not yield an increase in accelerated beam. Amplitude of the initially captured beam reaches a limit of 8×10^{12} protons. At this intensity, one observes a spontaneous bunching of the coasting beam before rf is applied. This bunching occurs at about the predicted longitudinal space charge limit for growth of perturbations in the coasting beam. At high intensity, the accelerated beam bunches contain more fine structure; also, beam losses during acceleration are greater than at lower beam amplitude. Studies directed toward increasing the intensity are in progress.

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With the completion of the new 20-MeV injection system, the beam amplitude of the Bevatron has been increased to a level at which one may expect space-charge and beam-loading effects to be detectable. The present performance will be described with particular reference to intensity-dependent effects.

The dependence of beam amplitude upon injected current is shown in Fig. 1. The upper curve gives the beam captured and accelerated through the first millisecond. The lower curve is the amplitude accelerated to full energy. It is evident that the fraction of beam lost during acceleration is greatest at high intensity. This loss, at any beam level, appears as a smooth attenuation during the first 50 msec of acceleration, up to 70 MeV, after which there is no further loss. It is of interest that the beam amplitude at full energy is limited at about 2.4×10^{12} protons per pulse independent of an increase in intensity at the start of acceleration. Capture efficiency at low intensity is about 20%, a reasonable capture for the Bevatron with no rf pre-bunching. The overall captured-beam amplitude is nonlinear above 4×10^{12} protons, although not so dramatically limited as the lower curve.

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Present measurements are insufficient to determine the sources of these nonlinearities of Fig. 1; nevertheless, it may be of interest to discuss some of the effects that have been considered.

The conventional transverse and longitudinal space-charge limits have been calculated. The intensity that would shift the betatron frequency to the nearest resonance is about 1.8×10^{13} protons in a bunched accelerating beam. Very few observations pertaining to transverse instabilities have been made. Longitudinal instability to small perturbations in a smooth injected beam with an energy spread of 1.2% should occur at an intensity of 5.4×10^{13} protons.[1] A bunching factor of four would make this number 1.3×10^{13} protons in an accelerating beam.

Spontaneous bunching of the injected beam has been observed in the Bevatron and is a function of intensity and of energy spread.[2] This irregular longitudinal disturbance which appears during the injection period may become as large as ±20% modulation of the average azimuthal intensity. Figure 2 shows this modulation as a function of the circulating-beam amplitude. Energy spread of the beam, $\Delta E/E$, was varied by means of a debuncher following the injector linac. Normal operation with no debunching gives the curve for 1.4% energy spread. At a spread of $< 0.4\%$, the effect arises at an intensity which is smaller by a factor of about 20. The shift expected from a dependence on ΔE^2 would be a factor greater than 12. Here the uncertainty in the measurement of the smaller energy spread prevents a more quantitative comparison. A reversal of the debuncher to increase ΔE shifts the instabilities beyond the maximum current available from the injector. For reference, the instability limit for each value of $\Delta E/E$ is noted in Fig. 2. The incidence of bunching below these limits is not unreasonable if we consider the uncertainties

in the calculations and the possibilities for disturbances arising from interactions with various structures electrically exposed to the beam. For Fig. 2, the amplitude of the circulating beam was assumed proportional to the injected current. If the amplitude were less in the presence of strong disturbances, this would remove the apparent fall-off of the relative modulation.

Observation of capture and acceleration in the presence of the longitudinal disturbances suggests that no losses arise from these effects except at high intensity, where the associated increase in energy spread can be sufficient to carry particles out of the aperture or outside the rf bucket.

In an attempt to change conditions at the start of acceleration, the rf was turned on at low amplitude during injection to provide pre-bunching of the beam. Accelerating voltage at 20% of normal amplitude was applied with a short frequency sweep, then increased to full voltage at the end of injection. This resulted in an increase of 15% in the captured beam. At high intensity, we could attain 9×10^{12} protons captured, but found no increase in the final beam of 2.4×10^{12} protons.

It has been observed that the bunch density modulation arising from motion in synchrotron phase space occurs at a 15% greater frequency at high intensity. A calculation of the effect of longitudinal space-charge fields yields only 3% increase from this cause alone. An analysis of possible beam-loading effects in the accelerating rf has not been completed.

Experiments are in progress to determine the nature of the loss during acceleration, and to increase the beam intensity.

REFERENCES

1. C. E. Nielsen, A. M. Sessler, and K. R. Symon, in Proceedings of the International Conference on High-Energy Accelerators and Instrumentation, CERN, 1959 (CERN, Geneva, 1959), p. 239.

2. M. Q. Barton and C. E. Nielsen, Proceedings of the International Conference on High-Energy Accelerators, Sept. 6-12, 1961, Brookhaven National Laboratory (U. S. Government Printing Office, Washington, D. C., 1961), p. 163.

FIGURE LEGENDS

Fig. 1. Amplitude of accelerated beam versus injected current. The dashed curve gives the amplitude of the captured beam. The solid curve is the intensity at full energy.

Fig. 2. Spontaneous azimuthal modulation of the circulating beam at the end of the injection period. The curve at the right applies to injection with 1.4% energy spread; at the left, injection at < 0.4% spread.

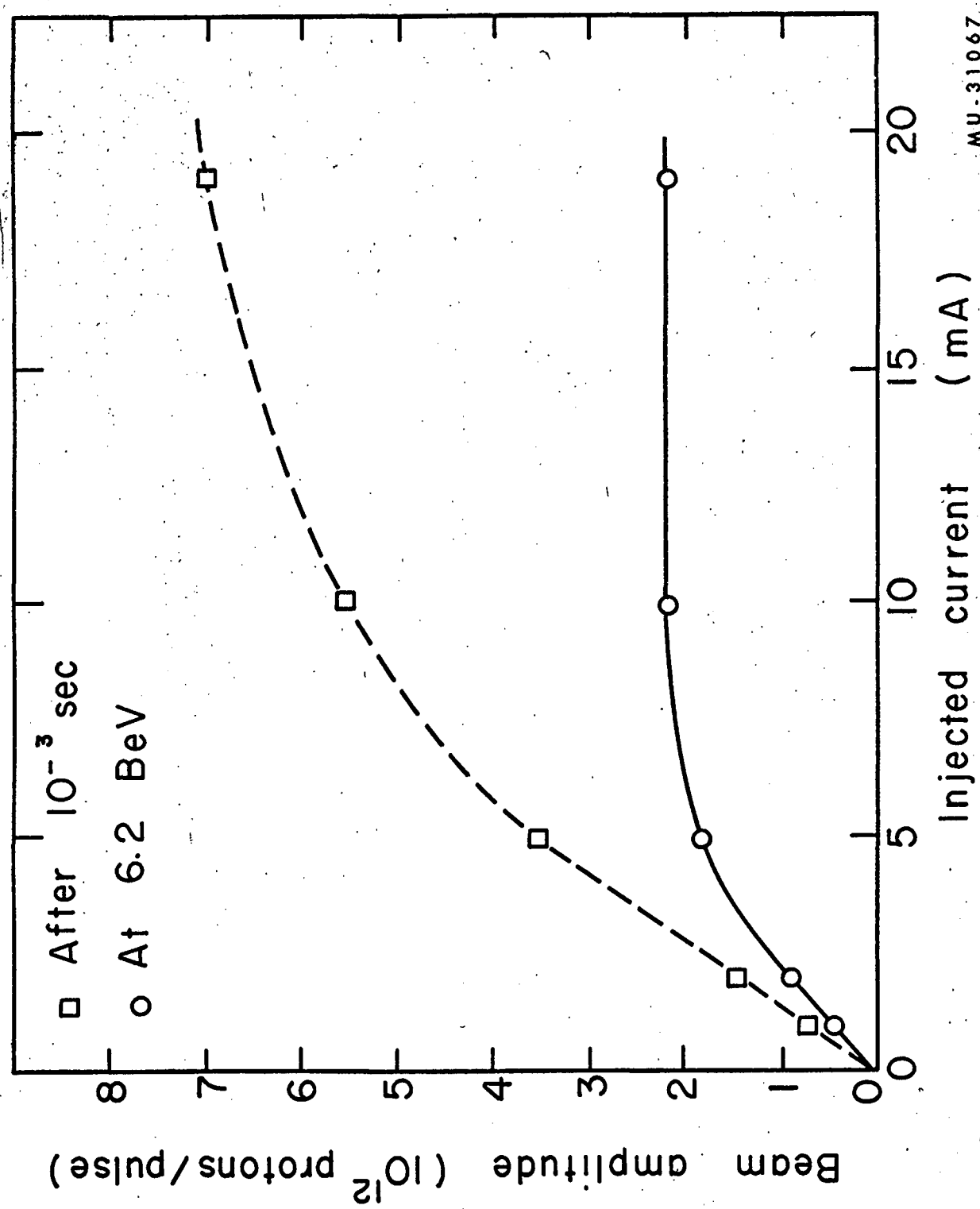

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Fig. 1

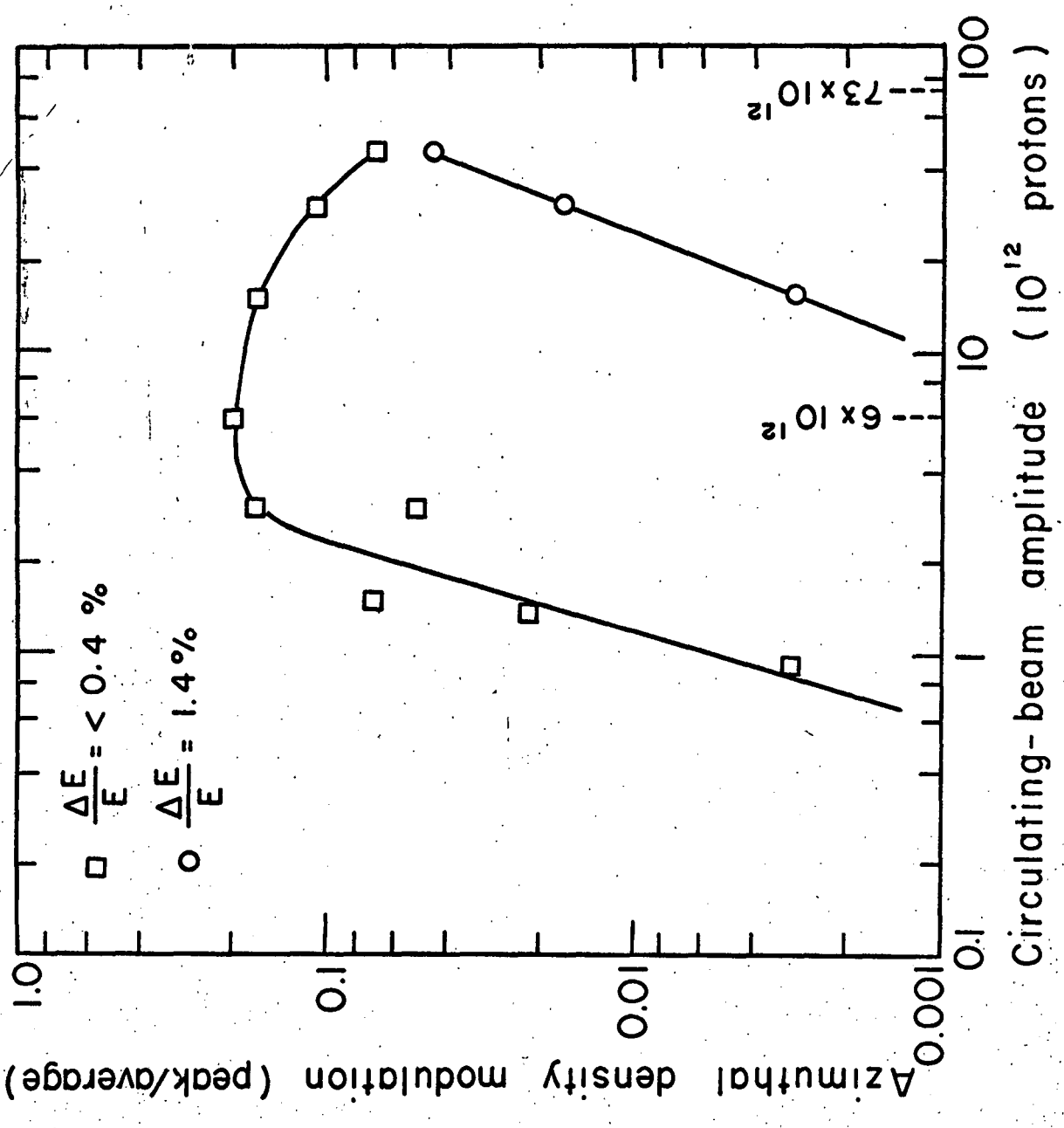

Fig. 2

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