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Space Charge Effects in the Low Energy Booster

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The effects of space charge on the beam dimensions were studied using a simulation program.[1] This program uses the actual lattice of the LEB; the space charge forces are entered as kicks at the beginning and exit of each element. The beam is assumed to have a gaussian distribution with rms dimensions σ_x and σ_y which change with time. The growth of σ_x and σ_y is determined by tracking a sample of 16 particles through the actual lattice and in the presence of the space charge forces. This program has been tested by applying it to three operating accelerators. For these three operating accelerators, the program found space charge limits which were about a factor of 2 higher than the measured results.

Studies were done for a beam having $N_b = 1 \times 10^{10}$ protons/bunch at 60 MeV. When the beam is injected as a round beam with a normalized, 1–σ emittance $\epsilon_n = 0.15\ \pi$ mm–mrad, the beam dimensions were found to grow by 43% due to space charge, or to a final emittance $\epsilon_n = 0.31$. Since the program has been found to underestimate the growth, one might introduce a safety factor of 2 in the beam growth which would give a final emittance of $\epsilon_n = 0.52$. For these results, the energy spread in the beam was $\Delta p/p = \pm 2 \times 10^{-4}$.

If the beam is injected as a round beam with ϵ_n larger than $\epsilon_n = 0.15$, then the beam dimensions were found to grow to a final emittance larger than the $\epsilon_n = 0.31$ found for $\epsilon_n = 0.15$ at injection. The primary effect of the space charge appears to be to couple the horizontal and vertical betatron motions. The beam growth can be reduced by moving away from the coupling resonance $\nu_x = \nu_y$.

The space charge ν–shift was computed for the actual lattice using the actual β_x, β_y and X_p of the lattice. For the final emittance of $\epsilon_n = 0.31$, $\Delta\nu_x = \Delta\nu_y = -0.70$ was found for $N_b = 1 \times 10^{10}$ protons/bunch.

When the beam intensity is increased to $N_b = 5 \times 10^{10}$ protons/bunch, the beam was found to grow from the injected $\epsilon_n = 0.15$ mm–mrad to a final $\epsilon_n = 0.60$ mm–mrad. A safety factor of 2 in the beam growth, would increase the final emittance to $\epsilon_n = 2.4$ mm–mrad. The space charge ν–shift for the final emittance of $\epsilon_n = 0.6$ mm–mrad was found to be $\Delta\nu_x = -1.6$, $\Delta\nu_y = -1.8$.

[1] G. Parzen, Space Charge Effects in Proton Synchrotrons, Nucl. Inst. and Methods **A 281** (1989) p. 413–425.

ν–Dependence of the Space Charge Limit

The LEB may not be intended to operate close to its space charge limit which is about $N_b = 50 \times 10^{10}$ protons/bunch. The following study of the dependence of the space charge limit on the choice of the ν–values may be interesting but not too relevant for the proposed performance of the LEB.

The space charge limit is plotted versus ν_x in Fig. 1. For each $\nu_x, \nu_y = \nu_x - 0.1$. The 1/4 intrinsic resonances, and the 1/6 and 1/8 intrinsic resonances corresponding to the periodicity of 54 are shown by dashed lines. The 1/4 resonance shows up clearly at $\nu = 13.5$. In addition there are two resonance like peaks and valleys at $\nu \simeq 8$ and $\nu \simeq 19$. The closeness of the 1/6 and 1/8 resonances makes it difficult to distinguish between these two resonances, and one could attribute the resonances like results near $\nu \sim 8$ and $\nu \sim 19$ as due to the combined effect of the 1/6 and 1/8 resonances.

The aperture here was arbitrarily assumed to be ± 20 mm, both horizontally and vertically. The normalized 1–σ injection emittances were $\epsilon_x = \epsilon_y = 0.15$ mm–mrad.

One may note that the proposed operating ν–values $\nu_x = 16.85, \nu_y = 16.75$, shown as a large dot on the figure, is not an optimum choice for obtaining the largest space charge limit. Also for this lattice, the $\nu = 19$ peak is close to the 1/3 resonance at $\nu = 18$ which may be excited by chromaticity correcting sextupoles. The $\nu = 13$ peak may correspond to a transition energy which is on the low side.

LEB Synchrotron – Space Charge Limit versus ν_x

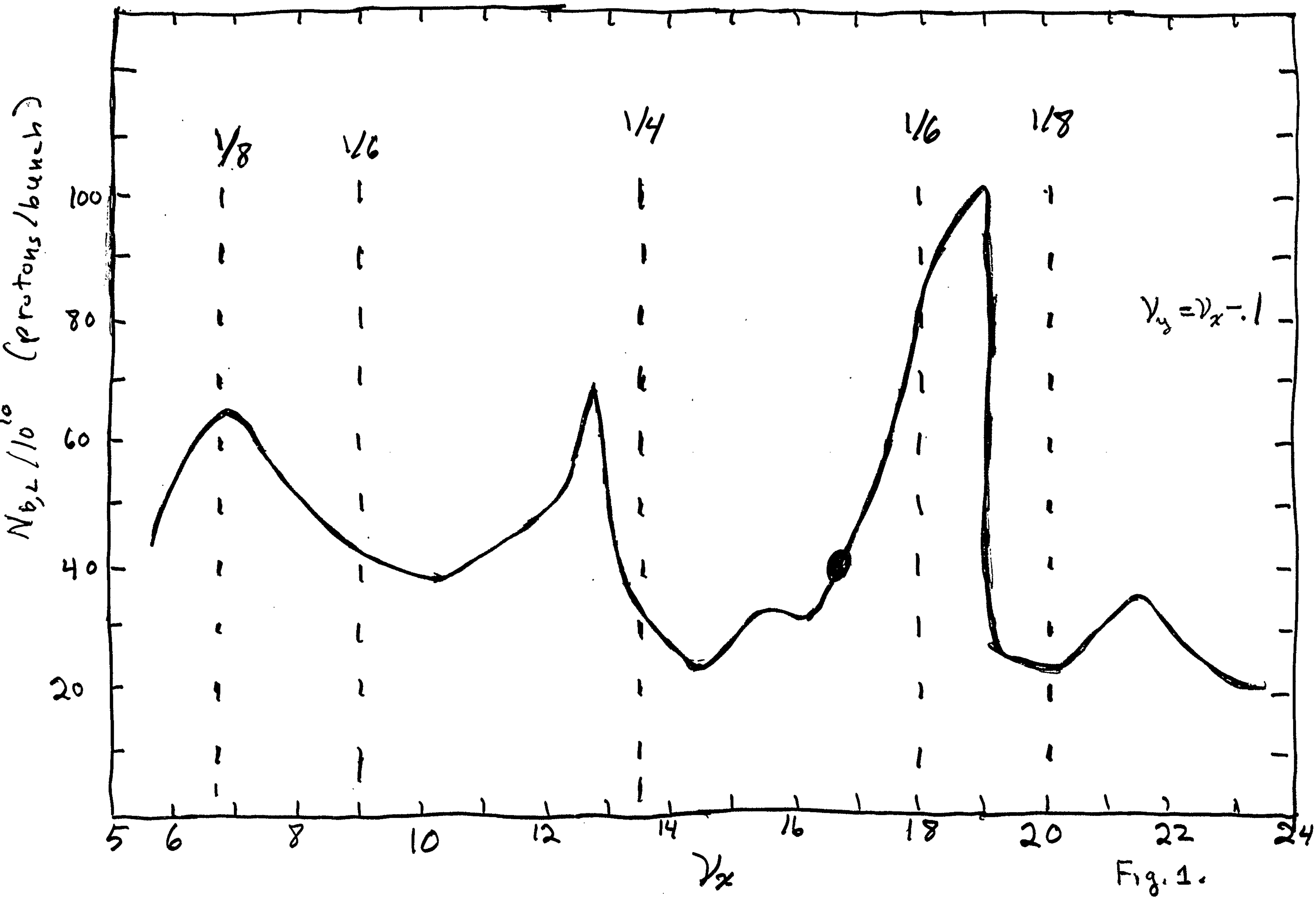

Fig. 1.