LINAC BEAM COLLIDING WITH A STORED BEAM REVISITED*

Recd

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In Ref. 1, a system was suggested to collide an accelerator beam, such as a linac electron beam, with the stored positron beam in a storage ring, and a simple theory of the performance of the system was worked out in terms of the beam parameters of the linac and the storage ring. In cases where the available accelerator can deliver beam energies greater than those which can be stored in the ring, a higher center-of-mass energy can be attained with this system than with the storage ring alone. This is the situation we now find ourselves in at SLAC with the linac capable of supplying beams of about twice the energy of those we can store in PEP and with developments in progress to raise the linac energy still more. The center-of-mass energy, E_{cm} , is given

$$E_{cm} = 2\sqrt{E_S E_L} \quad , \quad (1)$$

where E_S is the energy of the stored beam and E_L that of the linac beam, so we can reach $E_{cm} = 42.4$ GeV with the 30 GeV linac beam, and we could reach $E_{cm} = 54.8$ GeV with a 50 GeV linac beam, assuming in both cases that the PEP beam was stored at 15 GeV, a somewhat arbitrary choice, but a reasonable one, to achieve the high stored current we would need.

The analysis of Ref. 1 treated the disruption of the stored beam by the linac beam and led to the conclusion that using higher and higher

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linac beam currents becomes eventually profitless, because the stored beam is blown up transversely in proportion to the linac current so that the luminosity saturates, and, moreover, the stored beam grows too large for the vacuum chamber. That regime is entered when the linac-beam-pulse population reaches a value

$$N_c = \frac{2\gamma \sigma_r^{*2}}{r_e \beta^* \sqrt{f\tau \ln(4/3)}} \quad , \quad (2)$$

where γ is the stored-beam energy, σ_r^* is the natural r.m.s. radius of the stored beam at the interaction point, r_e is the classical electron radius, β^* is the interaction-region value of the betatron function in the storage ring, f is the repetition frequency of the linac and τ is the transverse radiation damping time. It is assumed that the stored beam is round at the interaction point, that $\beta_x^* = \beta_y^* = \beta^*$, and that the incoming linac beam spot is matched to the equilibrium size of the stored beam.

Equation (2) takes a particularly simple form when it is expressed in terms of the natural transverse emittance of the stored beam which we shall define without the sometimes-used factor of π .

$$\epsilon = \frac{\sigma_r^{*2}}{\beta^*} \quad , \quad (3)$$

in terms of which

$$N_c = \frac{2\gamma\epsilon}{r_e \sqrt{f\tau \ln(4/3)}} \quad . \quad (4)$$

Now, we cannot plan on repetition rates above 180 pulses per second at the highest linac energies, and τ is 8.2 milliseconds at 15 GeV. The smaller we can make ϵ , the lower N_c . If the linac can reach N_c or more

particles per pulse, the attainable luminosity is almost independent of ϵ ; if not, the luminosity varies inversely with ϵ ; so we shall always want the smallest value of ϵ we can get.* One of the smallest values yet studied is achieved with a tune of $\nu_x = 36.75$.² Using this value and assuming full horizontal-vertical coupling, we should be able to get

$$\epsilon = 1.2 \times 10^{-8} \text{ meter radians}$$

which would give

$$N_c = 3.8 \times 10^{11} .$$

Since the efficacy of this scheme depends on using a very small β^* , we must produce these electrons in one S-band bunch in the linac, and since the prospects at the moment suggest that one-eighth this value will be hard to achieve, we can assume for the moment that we must work well below the saturated luminosity.

That assumption simplifies things. We can forget the complexities of beam disruption and write the luminosity simply and straightforwardly.

$$L = \frac{f N_S N_L}{4\pi \sigma_r^{*2}} = \frac{f N_S N_L}{4\pi \beta^* \epsilon} . \quad (5)$$

This is the formula, and there is nothing tricky about it. N_S is the total number of stored particles, all concentrated in a single storage-ring bunch.

If we suppose we can store $N_S = 5 \times 10^{12}$ positrons in PEP with $\beta^* = 0.01$ m and strike them with $N_L = 5 \times 10^{10}$ per pulse from the linac,

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* This fact may argue for storing beams at lower energies than 15 GeV, but we shall disregard that possibility now.

we can get

$$L = 3 \times 10^{30} \text{ cm}^{-2} \text{ sec}^{-1}$$

This is optimistic on all fronts, but it might be possible. The stored direct current corresponding to $N_S = 5 \times 10^{12}$ is 110 milliamperes, all the rf power will allow. If we achieved half that current in the bunch, 55 milliamperes, and $\beta_x^* = \beta_y^* = 0.1$ meter, we could get

$$L = 1.5 \times 10^{29} \text{ cm}^{-2} \text{ sec}^{-1}$$

at a center-of-mass energy of 42 GeV. Those beta values are not outlandish. Martin Lee has produced a configuration with $\beta_x^* = \beta_y^* = 0.25$ meter just by using the touch-panel in the PEP control room.

We can do better than this. In the foregoing calculations, we have assumed that the two beams were round and of the same size. To make the stored beam round, we used full horizontal-vertical coupling. That is probably the optimum arrangement in the case that the linac beam is strong enough to disrupt the stored beam, but we found that we were not in that regime. Therefore, we could gain luminosity by making both beams denser. This we can do by reducing the coupling, letting the stored beam take a flat shape and matching the round linac beam's diameter to the height of the stored beam. In this case, it is probably safe to estimate the maximum useable linac beam by means of Eq. (4) using the smaller of the two emittances, the vertical one. We chose a value of

$$\epsilon_y = 1.6 \times 10^{-9} \text{ meter radian} \quad (6)$$

which corresponds to a coupling, $K = (\epsilon_y/\epsilon_x)^{1/2} = 0.27$. This gives for the critical linac bunch population

$$N_c = 5.0 \times 10^{10} \quad , \quad (7)$$

equivalent to that sought for the single pass collider. Now the luminosity for the case at hand is given by the formula

$$L = \frac{f N_s N_c}{2^{3/2} \pi \sigma_y^* \sqrt{\sigma_x^{*2} + \sigma_y^{*2}}} \approx \frac{f N_s N_c}{2^{3/2} \pi \sigma_y^* \sigma_x^*} .$$

In terms of the storage ring emittances, this equation takes the form

$$L = \frac{f N_s N_c}{2^{3/2} \pi \beta^* \sqrt{\epsilon_x \epsilon_y}} . \quad (8)$$

If we use in this formula the natural emittances of the PEP beam, we shall overestimate the luminosity, because we shall be ignoring beam disruption. However, an estimate of the effects of disruption indicates that it should reduce the luminosity by only about 20%, so we shall neglect it here and use Eq. (8) with the natural emittances. One of these is given in Eq. (6), and the other is for the same coupling

$$\epsilon_x = 2.2 \times 10^{-8} \text{ meter radian} \quad (9)$$

Then, taking again $N_s = 5 \times 10^{12}$ and $\beta^* = 0.01 \text{ m}$, we get

$$L = 0.9 \times 10^{31} \text{ cm}^{-2} \text{ sec}^{-1}$$

and for $N_s = 2.5 \times 10^{12}$ and $\beta^* = 0.1 \text{ m}$

$$L = 0.44 \times 10^{30} \text{ cm}^{-2} \text{ sec}^{-1} .$$

Whether we shall want to pursue this technique in the future to reach center-of-mass energies beyond the grasp of PEP (without major enhancements) depends on the attractions of physics at these energies. It cannot be represented as easy, but on the other hand, should luminosities in the vicinity of $10^{30} \text{ cm}^{-2} \text{ sec}^{-1}$ prove attractive, there seems to be a good chance of reaching them.

REFERENCES

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2. R. Helm, private communication.

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