LETTERE ALLA REDAZIONE

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A Possible Apparatus for Electron Clashing-Beam Experiments (*).

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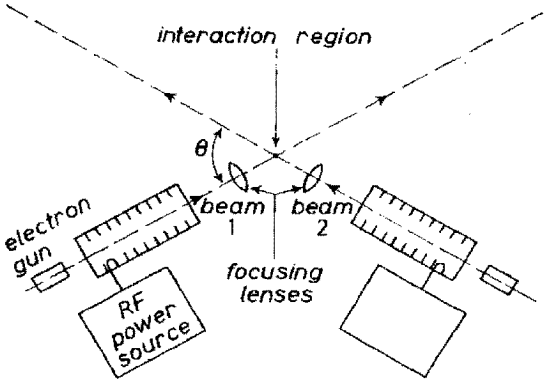
While the storage ring technique for performing clashing-beam experiments (1) is very elegant in concept it seems worth-while at the present juncture to investigate other methods which, while less elegant or superficially more complex may prove more tractable.

In order to be useful for clashing-beam work an acceleration device must produce beams of small cross-section or beams of high enough quality that they may be focused to a small spot in the interaction region or regions. Such beams are well known to be produced by linear radio-frequency accelerators. Figure 1 depicts a rudimentary type of arrangement for performing a clashing beam experiment with standard traveling wave linacs. For purposes of illustration let us consider two linacs having energy gains of 500 MeV each and producing continuous beam currents of 50 to 100 milliampere. (As we shall see currents of this order would be necessary to obtain useful interaction rates at this energy.) Under these conditions the rf power necessary to establish the accelerating field in the guides would be of the order of 100 megawatt in a standard design while an additional 25 to 50 megawatt would be carried away by each beam. Although in principle it may be possible to produce and handle this large power the sheer brutishness of the scheme robs it of all appeal.



θ = small crossing angle

Fig. 1.

With some modification we may be able to retain the basic advantages of the linear device while avoiding the

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(1) See for instance G. K. O'Neill: *Phys. Rev.*, **102**, 1418 (1956).

economic consequence of this particular arrangement. First, by the introduction of superconducting accelerator sections one may avoid the high power necessary to establish the accelerating field. With this technique one might hope to achieve an energy gain of about 11 MeV per meter for a rf power investment of about 12 watt per meter at an operating frequency of about 1000 megacycles per second (2). One is still faced with the problem of the power wasted in the beam. By the use of an artifice this problem may also be solved. Consider the arrangement shown in Fig. 2. The accelerator sections are now placed coaxially with the electron guns placed to one side to avoid damage by the incoming beam from the opposite accelerator. Further let us assume that the accelerators have exactly the same energy gain and the same beam current, operate in the standing wave mode at the same frequency and are phase-locked together. The distance between conjugate points in the opposite accelerator sections must be an integral number of wavelengths at the operating frequency.

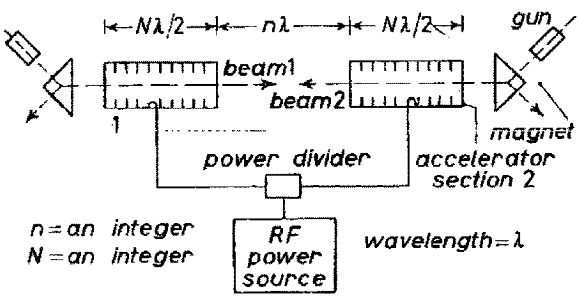

Fig. 2.

We see that under these conditions it can be arranged that electrons leaving accelerator 1 arrive at accelerator 2 at just the right phase to be decelerated in accelerator 2, thus giving back their energy to the field. The same holds for electrons in beam 2 entering accelerator 1. Another way to describe the situation is to say that the two currents cancel in the steady state. In this case the energy stored in the beams is supplied only once, during the transient period while the beams are being turned on.

One difficulty with such a device is that the two beam currents must be made equal very precisely. For example at 500 MeV, 100 mA and constant r.f. power, the currents must be kept equal to about one part in ten thousand to maintain the energy constant to one per cent even when the accelerators are heavily overcoupled to the generator. While this problem might be solved by the use of sophisticated electronic feedback circuitry there appears to be another configuration which, if designed properly, ought to make the currents track well and has the added attraction of eliminating one of the accelerator sections. A schematic drawing of this arrangement is given in Fig. 3. In this configuration the beam is turned back upon itself and re-enters the accelerator where it gives back its energy to the accelerating field provided that the path length through the magnet system has been correctly chosen. As shown the magnet system would work only for monoenergetic particles. In practice the magnet system would have to be somewhat more complex to accommodate the energy spread in the beam.

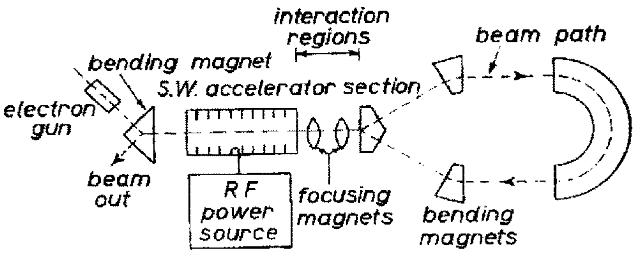

Fig. 3.

The interaction rate that we might

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(2) H. A. Schwettman, P. B. Wilson, J. M. Pierce and W. M. Fairbank: *The Applications of Superconductivity to Electron Linear Accelerators*, in *Advances in Cryogenic Engineering*, vol. **10** (1964).

expect to achieve by this means may be estimated with the aid of the following formula:

$$R = \frac{i^2 D}{\bar{A} e^2 f} \sigma \tag{1}$$

where

R = interaction rate for a process of cross-section σ per unit time per interaction region;

i = beam current;

e = electronic charge;

f = frequency of excitation of the accelerator;

D = duty factor = 1 for continuous operation (³);

$\bar{A}$ = average cross-sectional area of the beams in the interaction region.

The figure of merit for the device, called the luminosity is the coefficient of σ in (1).

$$\frac{i^2 D}{\bar{A} e^2 f}.$$

To give a typical value, the design luminosity for the 3 to 4 GeV electron-positon storage ring proposed by Stanford University (⁴) is $3 \cdot 10^{30}\ \text{cm}^{-2}\,\text{s}^{-1}$. We can, of course, only estimate the luminosity for the scheme outlined here. The uncertain factor is $\bar{A}$, the average cross-sectional area of the beam where they interpenetrate. If we use the known beam quality of an existing linear accelerator we can, using Liouville's theorem (⁵), estimate how small a spot we might hope to obtain at the focus of a well built lens system. Owing to the finite length of the beam bunches the effective area of the beam will be somewhat larger than that at the focus. For a representative beam quality, W, defined as the product of the beam radius and divergence half-angle at the exit of the accelerator, we use that of the Mark III linac at Stanford University (⁶).

$$W \simeq 0.9 \cdot 10^{-4}\ \text{radian centimeter}.$$

Using a lens system chosen to minimize $\bar{A}$ approximately we have

$$\bar{A} \simeq 2 \cdot 10^{-4}\ \text{cm}^2$$

Setting the luminosity equal to $3 \cdot 10^{30}\ \text{cm}^{-2}\,\text{s}^{-1}$ we obtain a required beam current of

$$i \simeq 120\ \text{milliampere}$$

which seems a reasonable operating current for a high quality injection and bunching system at the present state of the art.

We should note that one expects to have an enhancement of the beam quality and energy spread in the case of a continuously running accelerator at low frequency (²) because of the absence of transient effects and the larger aperture. How much is to be gained is unknown.

Table I presents a list of approximate parameters for the acceleration section of superconducting linear machines for 0.5 and 3 GeV.

At the lower energy one could probably do useful experiments with a luminosity somewhat less than $3 \cdot 10^{30}$ as the cross-sections rise rapidly with falling

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(³) Owing to the current dependence of the rates it might be possible to use pulsed high current operation of a conventional type of accelerating structure at the lower energies. The currents probably would have to be kept below one ampere because of space charge effects in the bunching section.

(⁴) Proposal for a High-Energy Electron-Positron Colliding Beam Storage Ring at the Stanford Linear Accelerator Center, Stanford University (March 1964).

(⁵) See for instance LIVINGSTON and BLEWETT: *Particle Accelerators* (New York, 1962), p. 117.

(⁶) P. B. WILSON: private communication.

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TABLE I.

Beam energy (GeV)	0.5	3
Length (m)	47	275
Beam current (A)	0.120	0.120
Luminosity ($cm^{-2}\,s^{-1}$)	$3\cdot 10^{30}$	$3\cdot 10^{30}$
RF power to establish accelerating field in absence of beam (kW), (1000 MHz operation)	.55	3.3
Refrigerator power (MW)	0.92	5.5
Synchrotron radiation loss in magnets (kW)	—	14 (30 m) bending radius)

energy. The electron-electron elastic scattering cross-section, for instance, depends upon the inverse square of the energy so that a beam current of 20 mA might suffice for this experiment at 0.5 GeV.

There are some other features of the linear device. First, the interaction regions are well defined, the beam bunch lengths being on the order of one centimeter at 1000 MHz and one percent energy spread. Second, since the field-free region between the accelerator and the magnet system may be quite long one might run several experiments simultaneously without interference or run many units of identical analysing apparatus concurrently thereby reducing the required luminosity. Another advantage of the long field-free region is that charged particles scattered at small angles can be observed easily. Thirdly, the residual gas pressure in the interaction regions can easily be kept quite low as there will be no synchrotron radiation there to drive off gas from the vacuum vessel walls (4). If the vacuum in the magnet section suffers from the soft radiation it should be easy to apply differential pumping.

The energy recovery technique might also be useful in experiments other than clashing beam type. For instance a low-density target such as liquid hydrogen might be placed in the return leg of the magnet system. There, reactions of very small cross-section might be observed by the use of a large continuous beam.

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