REPORT ON THE PERFORMANCE OF THE SUPERCONDUCTING INJECTOR
FOR THE STANFORD LINEAR ACCELERATOR

E. Jones, M. S. McAshan and L. R. Suelzle
High Energy Physics Laboratory
Stanford University
Stanford, California

Abstract

This report describes some recent experiments performed with a prototype of the injector section eventually to be used in conjunction with the superconducting linear accelerator at Stanford University.

Introduction

This paper reports the preliminary results obtained with the fully operational superconducting prototype capture section which is to serve as the injector for the Stanford 500 ft linac. The only difference between the capture section in its present form and the final capture section is that the superconducting material in the present accelerating structure is lead (plated onto copper) and not the more amenable niobium. Otherwise the prototype has all the control and feedback systems stabilizing both amplitudes and phases in two entirely separate superconducting cavity structures; one of these being the accelerating and capture sections and, the other, a transverse deflection cavity (a prototype RF separator) which is used for beam diagnostics.

In addition, another feedback loop locks the frequency source onto the accelerating and capture structure. This section of n/2 resonant structure is arranged so that its corresponding traveling wave has phase velocities equal to 0.93 of the velocity of light. This velocity, along with the low accelerating fields of about 1 MeV/ft, was chosen so that on injecting into the capture section a beam of 80 keV electrons having a phase width of nominally 20°, the emergent beam should have the appropriate characteristics: a) Some tens of µAs bunched to about 1° in phase width, b) Mean energy of a few MeV, and c) Momentum spread of 2 to 3% of the final momentum.

The following is a brief description of the prototype and its operation, along with the results of a brief preliminary survey of the main characteristics of the beam emergent from the capture section.

Apparatus

Figure 1 is a block diagram illustrating the layout of the experiment. Electrons of 80 keV (≈ 10 eV) are emitted from the gun, and the transverse phase space is manipulated by means of lenses and apertures to yield an emittance of π × 0.5 mm mrad, at the entrance to the capture section. The electrons are injected in longitudinal bunches of about 20° phase width. The bunching is obtained by chopping the initially dc beam with the TM210 deflecting cavity and "chopper" aperture.

Bunched beams of this sort with up to 20 µA average current have been captured and accelerated. Furthermore, by simply turning off the chopper cavity so that the maximum available dc beam of 220 µA was injected, we were able to capture and accelerate up to 40 nA of beam. This capture efficiency matches the theoretical values. No instabilities in beam spot size were observed even at this level of beam current.

The rest of the system, shown in Fig. 1, "downstream" of the accelerating section is the beam analyzing arrangement, and will be described below.

Figure 2 is a diagrammatic representation of the RF feedback and stabilization systems. It has been described in detail elsewhere and is shown here for the sake of completeness and as an aid to understanding some of the results of the RF measurements given below.

Results

The accelerating structure contains field probes for examining and controlling the field level. A typical oscilloscope trace of the field is given in Fig. 3 (top) along with that of the power fed in from the klystron (bottom trace). In the bottom trace, it is seen that the klystron power comes on at the maximum level initially, until the desired field level is reached; at which point the power is turned down until the level is just sufficient to maintain the desired field in the presence of the residual wall losses (in this particular case the unloaded quality factor Q₀ was about 10⁵ and the coupling factor β ≈ 6).

After some delay, the bottom trace shows an increased power level once more just at the instant when a beam of about 40 µA is being captured and accelerated. It is seen that the feed-
back system is well able to handle such step-function increases in current without observable perturbations in the field level. In fact, Fig. 4 illustrates a situation where the feedback loop is opened so there is no regulation of the field level in the accelerating structure. The field probe signal given in Fig. 1 has been amplified many times, so that one large division on the graticule represents 6 parts in $10^3$ of the actual level of about 1 MeV/ft. In one oscilloscope trace is shown the field in the accelerator reaching a peak value and then decreasing in level as a function of time. For the second trace an electron beam of approximately 10 $\mu$A was injected at a time corresponding to 2.5 cm on the horizontal graticule. The beam loading causes the field level to fall rapidly to where the display amplifier saturates. It is seen that beam loading is significant and that the operation of such an accelerating section without regulation is not to be contemplated.

Figure 5 illustrates the same situation as above, i.e., a field probe signal with about 10 $\mu$A injected, each graticule division of 1.2 $\times$ $10^{-3}$ of 1 MeV/ft, but this time with all feedback loops closed. The regulated situation is therefore such that the field levels in the beam loaded situation do not change during injection by an observable ($= 10^{-4}$) amount except for an initial small transient of the order of 2 parts in $10^5$.

The beam spot size was examined by means of sapphire screens and was found to be of the order of 1 mm diameter and was always stable when the feedback loops were closed. Furthermore, the diameter was qualitatively independent of the accelerated beam current within the range 1 to 20 $\mu$A. Quantitative measurements are planned for the near future.

Figure 6 shows a plot of the spectrum obtained by means of dispersing the beam in a double focusing magnet. It is seen that most of the beam is contained within 2% of the mean energy (1.3 MeV kinetic).

Finally, Fig. 7 is a photograph of the spot as seen on a sapphire screen during a very preliminary measurement of the phase spread of the captured and accelerated beam. This measurement is carried out by means of the prototype superconducting RF separator cavity. This is nothing more than a single $T_{020}$ cavity mounted off axis, such that the beam passes through a region of maximum deflecting magnetic field. The phase of the RF amplitude on the "separator" is adjusted with respect to that of the accelerator such that the center particle in the accelerated bunch receives zero net deflection. Particles on either side of the center are then deflected either upward or downward, so that the larger the bunch, the greater is the spreading of the beam in the transverse direction. The transverse spread is then a measure of the bunch width. It may be calibrated in degrees of phase width by simply changing the phase difference between "separator" and accelerator.

In Fig. 7, the brightest "flat" spot is the undeflected beam with "separator" off. The fainter, elongated spot is the result of applying "separator" power and deflecting the beam. The two pictures were taken on the same Polaroid frame by simply displacing the camera horizontally by hand and, in doing so, losing the symmetry of the picture. In practice the deflected or "spread out" spot is symmetrically disposed about the undeflected position.

This very preliminary result indicates that the phase width of the bunch is about $2^\circ$ or less.

Conclusion

The preliminary survey of beam characteristics given above seems to indicate that the prototype superconducting accelerating and deflecting systems perform adequately and gives added confidence in the final success of the Stanford 500 ft superconducting linear accelerator.

References

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Fig. 1 Block diagram of injector, capture and accelerating, and deflecting system, including layout of diagnostic aids.

Fig. 2 Block diagram of RF system.
Fig. 3 Oscilloscope traces of field-probe signal (top) and klystron input power (bottom).

Fig. 4 Oscilloscope traces of amplified field-probe signal; unregulated and beam loaded. Each large graticule division is equivalent to 6 parts in $10^3$ of the actual field level of about 1 MeV/ft.

Fig. 5 Oscilloscope trace of amplified field-probe signal; regulated and beam loaded. Each large graticule division is equivalent to 1.2 parts in $10^3$ of the 1 MeV/ft field.

Fig. 6 Momentum spectrum of a typical accelerated beam. Mean momentum corresponding to a kinetic energy of about 1.3 MeV.

Fig. 7 Photograph of undeflected ("bright and flat") and deflected ("diffuse and elongated") beam spot as seen on TV monitor viewing a sapphire screen.