October 23, 1963

BEVATRON INJECTOR LINAC II

E. L. Hubbard
Lawrence Radiation Laboratory

I have some data on the new injector that should be of interest to those working on the design of new linacs. Most of the information that will be presented was obtained from R. W. Allison, E. C. Hartwig, R. M. Richter and D. W. Hartsough.

The basic design of the linac cavity is similar to cavities of the 50 MeV injectors for the Brookhaven AGS and the Argonne ZGS. However, the output energy is only 19.2 MeV, and beam is injected from the Cockcroft-Walton at 485 keV, instead of 750 keV as on the other machines. The lower injection energy requires the addition of four more drift tubes on the low energy end.

Drift Tube Magnets

The dc quadrupole magnets are connected in the NNSS configuration with injection at the center of a polarity group. The magnetic field gradients vary according to the usual $1/\beta$ rule except for the first two magnets which are operated at half the field gradients specified by the $1/\beta$ rule.

RF System

In contrast to the Argonne machine, where the rf power is supplied by a single amplifier, the Bevatron injector is driven by 10 self-excited oscillators and a pre-exciter. The tube used in the oscillators is the Eimac 3W10,000. The peak rf power delivered to the cavity is about 1.5 MW. This amounts to 150 kW per oscillator which is well below the maximum power that one of the oscillators is capable of delivering. In case of trouble in one oscillator, the cavity can be driven satisfactorily with the other nine. Further insurance of reliable operation is provided by keeping a spare oscillator ready to go at all times. The spare can be installed and put into operation in less than an hour. The average life of the 3W10,000 tubes on the old Bevatron injector was 10,000 hours. The new machine has not been running long enough to obtain data on the tube life. Since the stored energy in the cavity is only 60 J, it is not considered necessary to protect the tubes with an rf crowbar.

Cockcroft-Walton Beam

The pre-injector easily produces 100 mA of total beam at the ground end. With careful tuning as much as 120 mA has been obtained. About 60% of the beam particles are protons. The emittance areas of the Cockcroft-Walton beam are 87π mm-mrad. in the horizontal plane and 95π mm-mrad. in the vertical plane. Solenoid magnets are used for focussing between the pre-injector and the linac cavity.

GLUCKSTERN: Is all of the 100 mA within these emittance values?

HUBBARD: About 95%.

GLUCKSTERN: Does that distinguish protons from H_2^+?

HUBBARD: No, they don't separate H_2^+ from protons except when they want to make a measurement to find out how many of them really are protons. The injector beam goes straight into the linac with no analysis at all. There is another thing that is a bit unusual. There are no quadrupoles between the Cockcroft-Walton and the linac so that all the focussing is done by solenoids. Then the first two quadrupoles in the linac have half the magnetic field strength that one would usually use in that position.

Linac Acceptance

Preliminary measurements of the radial acceptance of the linac yielded the following values:

192 π mm-mrad. (vertical plane)

151 π mm-mrad. (horizontal plane).

Although these numbers are larger than the emittance values quoted for the pre-injector, the matching is not perfect, and apparently about 10% of the beam injected into the linac is outside the acceptance phase space area, as shown in Fig. 1.

The design value of the synchronous phase angle is 26°. The measured value is 29°. The measured value of the phase acceptance is 59° (full width at half maximum), and with the buncher the energy acceptance is 9 keV. The buncher has a single gap and increases the beam out of the linac by a factor of 2.7.

NAGLE: Do you find a distribution of particles within the phase bunch?

HUBBARD: Yes. This corresponds to the fish diagram where

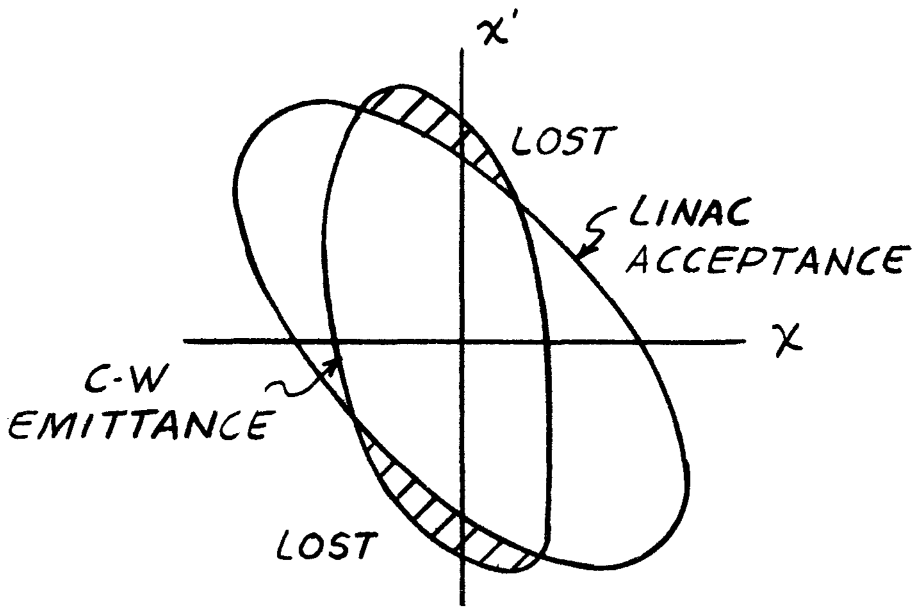

FIG 1
EMITTANCE MATCHING INTO LINAC

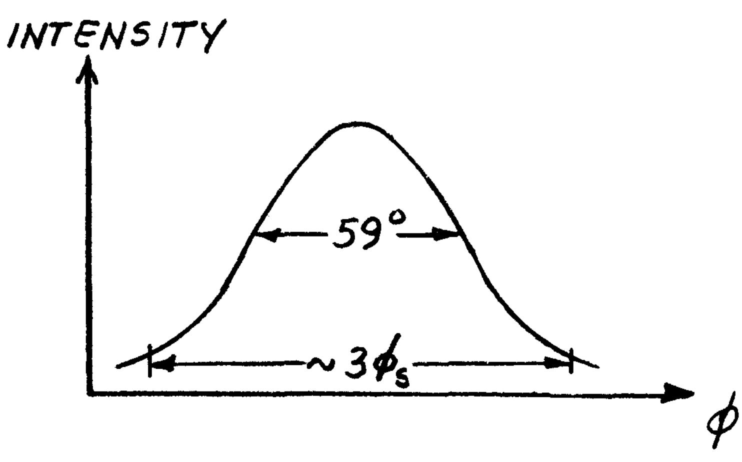

FIG. 2
PHASE ACCEPTANCE INTO LINAC

a lot of particles are found in the middle and not so many on the "tail".

KNOWLES: If Allison's measurement (in Fig. 2) is one of intensity versus phase, does this actually say what the phase acceptance was? Is this a product of what beam is available and the acceptance, or is it the acceptance itself?

HUBBARD: It depends on what you mean by the acceptance. It is said that the full width of the fish is about three times the synchronous phase. The number that I've quoted is actually less than this (it is full width at half maximum), but as you can see, $3\varphi_s$ corresponds to the extreme limits on such a curve as in Fig. 2

VAN STEENBERGEN: The beam structure is developed by the buncher and you have to shift the timing of the rf with respect to a particular beam phase and then measure the output intensity, and it will depend on input intensity, as well as on acceptance.

HUBBARD: You can also look at the rf structure of the beam on a sampling scope. We have used this technique at the Hilac.

Linac Output Beam

After careful tuning, beam currents as high as 28 mA have been obtained at 19.2 MeV. This is considerably more current than can be used at present, and typical operation is in the 5 to 10 mA range.

Measurements of the radial emittance gave the following values for the areas enclosed by the contours in phase space where the intensity is 6% lower than at the center of the ellipse:

15 mA	15.1 π mm-mrad.	(horizontal)
	13.0 π mm-mrad.	(vertical)
24 mA	17.5 π mm-mrad.	(horizontal)
	15.7 π mm-mrad.	(vertical)

An interesting point is that there is only a small increase in the emittance when the beam is increased from 15 to 24 mA. If the emittance of approximately 90 π mm-mrad. at 485 keV is scaled to 19 MeV by multiplying by the ratio of the momenta, the value obtained is 14 π mm-mrad.

POLK: How does this match up with the Cockcroft-Walton currents? You quoted 120 mA maximum, of which H^+ is 60%, say 70 mA of protons. Did you ever put that in to see what you'd get out?

HUBBARD: The 28 mA linac output goes with the maximum Cockcroft-Walton output of 120 mA total.

POLK: Then out of an input 70 mA of protons, you get out about 30 mA.

HUBBARD: This matches fairly well with the acceptance figures; there isn't any sizeable discrepancy.

The energy spread in the 19 MeV beam as it comes out of the linac is 136 keV. The energy spread can be reduced with a debuncher. However, since no improvement in the Bevatron beam results, the debuncher is normally not used.

GLUCKSTERN: What phase width does this correspond to? Do you know how much phase damping has occurred?

HUBBARD: No.

LIVDAHL: Is this with the buncher?

HUBBARD: I believe it is with the buncher, because they very seldom run without it.

LIVDAHL: You may have seen the reports from the Nimrod injector, of variation of the energy spread with rf level in the tank both with or without the buncher. Without the buncher they observed two peaks in their energy spectrum. There's a peak below and a peak above the mean energy. With the buncher they have a second peak. Have you been able to observe this?

HUBBARD: Not to my knowledge.

KNOWLES: May I comment on that? I have talked to Allison, and he has observed double and triple peaks with the buncher, and the sizes of the satellite peaks are quite substantial - perhaps 15% of the main peak. Those were obtained by momentum analysis: if my recollection is correct, the lower peak was 70% of mean momentum which means something like half energy.

HUBBARD: Certainly the experience both at Yale and at Berkeley on the heavy ion machines is that, if the tank flatness isn't right, it is very easy to observe satellite peaks. Of course, the farther the ions are out on the phase spread, the easier it is for them to drop out of phase to make satellite peaks. It would seem that putting a buncher in would reduce these peaks.

PERRY: The peaks observed on Nimrod are only 300 keV apart, not at partial energy. We have observed a half energy beam from our linac when things weren't working right.

HUBBARD: The 300 keV is only a drift tube or two, isn't it?

PERRY: Half of one drift tube.

Bevatron Beam

The highest full energy beam obtained to date in the Bevatron is 3.2×10^{12} particles/pulse. This value was obtained with 11 mA injected from the linac. One millisecond after turning on the Bevatron rf, the beam was 10^{13} particles/sec. Full energy beams of 2×10^{12} particles/pulse can now be obtained routinely.

Injector Reliability

During the past few months the Bevatron was in operation 84% of the scheduled operating time. It was off during 3% of the scheduled operating time because of failures of the injector equipment.

Some of the causes of injector failures are:

(1) Droop in the inflector voltage caused by beam hitting the plates.

(2) Failure of capacitors in the pulse line that supplies the plate voltage to the rf oscillators.

(3) Sparking in the 120 kV voltage supply for the ion source lens.

(4) Ion source filaments burning out.

They use the same capacitors at the Bevatron that we used to use on the Hilac. We have a new capacitor on the Hilac that has extended foil construction and we have not yet lost one of these, so this can probably be corrected.