THE NIMROD INJECTOR

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A description of the injector for the Nimrod accelerator follows by considering the preinjector, linear accelerator and initial operating performance.

Preinjector

The high voltage generator for the preaccelerator is a SAMES machine with output specifications of 650 kv and 4 ma dc with a combined dc and pulse stability of 3 kv. Dc stabilization is applied to the exciter of the generator and pulse stabilization to the ground side of the .025μf storage capacitor. The system allows a pulse rating of 200 ma, 2 msec pulse, at 2 pps.

Various troubles have arisen with this equipment and the final 650 kv rated generator has yet to be delivered. Up till now various standard 600 kv sets have been used.

The preinjector column is a steerable cantilevered structure with a rf ion source and electrostatic focusing electrodes. The ion source, which is based on the CERN design, has been progressively modified. The rf coupling is now well matched to the source and the excitation coil operates in a pressurized enclosure at 30 psi to prevent sparking to the ion source pot. It is now possible to feed 15 kw rf power into the discharge and this gives adequate ion density. Cleanliness of the source has had to be improved by using only pyrex and metal in its construction. At this stage the source has been good for 30 ma, for a pulse length of 200 μsec, at 2 pps, with a life of 200 hrs. Future requirements are up to 100 ma for 1.5 to 2 msecs. Attention is now being paid to the cathode shield and cathode canal geometry. There is strong evidence that the plasma boundary is not located at the top of the cathode shield. One source with a modified geometry has given 70 ma at a pulse length of 600 μsecs with a lifetime of somewhat more than 10 hours. Cathode breakdowns were still present with this source but they were no longer disastrous.

The column performance with long high current pulses is causing some concern because of abnormal x ray levels. Also, some modification to the electrostatic focusing elements, in particular increased apertures, seems to be necessary.

As a backup a duoplasmatron source is being developed and also some design work is being done on a new preinjector column having a very short accelerating gap.

Linac

Final assembly of the linac was completed July 1, 1961 and the first 15 Mev beam produced on August 1. It is an Alvarez type structure; 13.5 m long with 49 drift tubes and an operating frequency of 115 Mc/s. Construction is of braced copper sheet, with a separate vacuum vessel. Dc quadrupole magnet focusing is used in the ++- mode. With a measured Q factor of 80,000 (70% of the theoretical value) the power requirement is 800 kw for operation with a synchronous phase angle of 30°.

The power source is a Siemens RS1041. This tube was designed for 30 Mc/s, although the makers have operated it up to 70 Mc/s. This tube is capable of 1.9 Mw output at 30 kv plate voltage with a gain of 14 at 115 Mc/s. The tube has operated satisfactorily at 115 Mc/s although there is some doubt as to whether it is giving its rated efficiency. The tube circuit is somewhat unconventional in that the anode is directly coupled to the linac feed loop via a two stage coaxial $\lambda/4$ transformer. The loop and coaxial line operate in air with the vacuum window, of glass reinforced epoxy resin, situated above the loop, such that the loop lies below flush with the cavity wall. Mechanical improvements to this circuit have consumed several months of operating time, in particular the anode blocking capacitor has had to be modified several times.

With the multipactor problem in mind this tube was designed to be driven from a multistage drive chain, but provision was made for trying an oscillator system with feedback derived from a second loop coupled to the linac. The machine is in fact now operating with a self oscillator system, the feedback drive being taken to the last stage of the drive chain. This has the obvious advantage of eliminating the need to tune against frequency shifts and reactive beam loading effects and of reducing the number of rf stages.

An interesting recent development is a system for stabilizing the rf field level in the linac during a pulse. A signal from the linac is rectified and compared with a reference voltage, the difference signal is amplified and fed to the grid of a triode, in parallel with the driver tube. These two tubes share a common resistor in their high voltage feed line so that the driver can be anode modulated. This system has proved to be very effective and has reduced the effect of beam loading to negligible proportions. This is shown in Figs. 1 and 2, where in Fig. 1 the top trace shows the final amplifier cathode current and the bottom trace the tank rf pulse. This was taken with rf pulse stabilization. In Fig. 2 these pulses are magnified. Here the top trace gives the tank rf pulse and the bottom trace the cathode current. This illustrates the stabilization of the rf pulse against beam loading.

For the first seven months of linac operation severe multipactoring was encountered. The multipactor rate was rarely better than 20% of all pulses at a repetition rate of 1 pulse per 8 secs and the multipactor rate increased sharply with increased repetition rate. The rate of rise of rf drive to the final amplifier was sharpened but with no improvement. The machine was also operated for long periods at various repetition rates and different conditions without producing any conditioning. Finally the drift tube faces were coated with a thin layer of carbon black which has eliminated the multipactoring but has introduced a sparking problem.

The buncher and debuncher cavities and the achromatic inflector elements (four sectoral magnets and an electrostatic element) are all on site but are awaiting testing and installation. In addition quadrupole triplets, beam steering magnets, beam measuring toroids and four jaw defining apertures have all been in use for some time.

Beam Operation

15 Mev beams have been available under reasonably reliable conditions since about April of this year. However, operational time is limited by the need for access to the injector hall for installation work and because of the radiation hazard. The greater part of the operational time is being devoted to machine physics experiments. To facilitate this some of the equipment is not in its final state, notably the low energy end beam matching system. Typical operation beam currents are 26 ma from the preinjector, 20 ma at the linac input and 3.5 ma accelerated current. Corresponding maximum figures are 60 ma, 44 ma and 10 ma, all at 200 μsec pulse length.

Measurements with a 20 ma preinjector beam have shown that 90% of this beam lies within an emittance of 2.5cm-mrad. This is to be compared with the computed linac acceptance of about 15 cm-mrad. The proton percentage is approximately 70%. A preinjector beam phase space boundary with density distribution is given in Fig. 3.

It has not been possible so far to measure the linac input radial acceptance, due to the difficulty of producing probe beams of large and known divergence. However, the acceptance limits of paraxial probe beams have given a displacement acceptance equal to the radius of the first drift tube bore in the initially focusing plane, and 60% of this radius in the initially defocusing plane. This is thought to give a reasonable indication that there are no serious quadrupole misalignments.

Beam emittance from the linac has been measured using a calibrated deflector magnet followed by a fixed aperture and an adjustable aperture. This system has the advantage that measurements can be made on beams that are blowing up rapidly on leaving the linac. Emittances as high as 6cm-mrad have been measured, which represents a radial phase space blow up of a factor of 11 in the linac. It is hoped to improve this when the low energy beam matching system is in use. To investigate this problem further, an emittance defining system at the linac input, consisting of two apertures and two quadrupole triplets is being devised.

One of the inflector magnets has been borrowed for momentum analysis of the 15 Mev beam. This is a 50°, 70 cm radius element, which if used with 1 mm wide slits is capable of an energy resolution of about 40 kev. This made it possible to identify from the momentum spectra the number of phase oscillations in the linac, from which it should be possible to determine tank flatness. These results are indicated in Fig. 4 giving the momentum spectrum of the 15 Mev beam output for various tilts of tank "flatness". The same figure shows also the computed spectrum. This can be compared with the computed phase acceptance of the linac given in Fig. 5. The results show that the momentum spread is in good agreement with the computed figures.

It is hoped to have a 115 Mc/s rf deflector in operation soon with which it is planned to investigate the phase spread of the momentum analysed beam. Results from this should give useful information from which the optimum drift distance before debunching can be determined.

Discussion

R. P. Featherstone (Minnesota): How long is the preinjector column?

N. D. West (Rutherford): Approximately five feet.

J. P. Blewett (BNL): Why was the Siemens triode used, rather than the grounded grid triode which was developed for this purpose?

N. D. West (Rutherford): The grounded grid triode was designed for 200 Mc/s.

J. P. Blewett (BNL): I am aware of this. The next question is then why was the linac not designed for 200 Mc/s?

N. D. West (Rutherford): Plotting curves of frequency versus required quadrupole fields indicated that for higher frequencies more quadrupole strength is required, in connection with defocusing because of the rf fields. At that time no dc quadrupoles were developed for a 200 Mc/s machine. Pulsing the quadrupoles seemed unrealistic because of the required pulse length of two millisec. In connection with this the linac frequency was chosen as 115 Mc/s resulting in more favorable requirements for quadrupole focusing.

G. K. Green (BNL): Using the linac tank as a self oscillator, how do you start the excitation. Does it start itself or do you trigger somewhere in the drive chain?

N. D. West (Rutherford): It starts itself.

L. Smith (LRL): Did you draw any conclusions from the experience with the carbon black to stop multipactoring.

N. D. West (Rutherford): At the end of this year we intend to devote some more time to this problem. It is troublesome, also because it increases the x ray level in the machine, possibly also producing rf power losses because of electron loading.

J. P. Blewett (BNL): At what field levels does the multipactoring start?

N. D. West (Rutherford): It varies, but I should say anything from perhaps 1/1000 of the final field level to perhaps 1/20 of the final field level. That is when it cuts in.

R. Perry (Argonne): Is the copper used in the drift tubes oxygen free?

N. D. West (Rutherford): No, it is not. Although it is true that oxide inclusions in copper raise the secondary emission coefficient, it is already high for pure copper. At present we are engaged in studies of secondary emission coeffients for various materials. It has been observed that thin layers of pump oil are "cracked" under operational conditions giving rise to thin carbon layers which may prevent multipactoring.

G. W. Wheeler (Yale): Our experience with Hilac with respect to the importance of fast rise time for the drive signal indicated that the time relation between the application of rf drive and plate power to the final stage was very important. There was only a very narrow range of timing which would permit us to break through the multipactoring levels.

N. D. West (Rutherford): We have in fact paid a lot of attention to this particular aspect. We ran the machine under all sorts of conditions, before applying the carbon black to the drift tubes, and could find no point at which it would drive through the multipactoring levels.

M. V. Hoover (RCA): One more comment on this multipactoring. Have you observed a swing voltage on the valve during the time multipactoring is going on? In other words, are you putting full plate voltage on the valves and is the rf swing voltage developing on the tube, ignoring the cavity? You have two cavities here that are coupled and one normally is more interested in the accelerating vessel, than in the tube cavity. I was curious to know whether, when multipactoring is going on, the tube is trying to generate power, and if it possibly could be a coupling problem.

N. D. West (Rutherford): Well, I think I take your point. It seems worthwhile to consider this further.

A. van Steenbergen (BNL): Referring to the phase space diagram of the preinjector beam, you observed a low intensity side lobe, which you thought to be due to molecular ions in the beam. What prompted this assumption?

N. D. West (Rutherford): With the pepperpot method for the emittance measurement we used a magnetic field and observed a relative shift in brightness of the two spots.

J. P. Blewett (BNL): When do you expect to inject into the synchrotron?

N. D. West (Rutherford): Supposedly during August of next year.

E. D. Courant (BNL): Would you be able to do injection studies without synchrotron acceleration?

N. D. West (Rutherford): One octant will be evacuated first to accommodate injection studies.

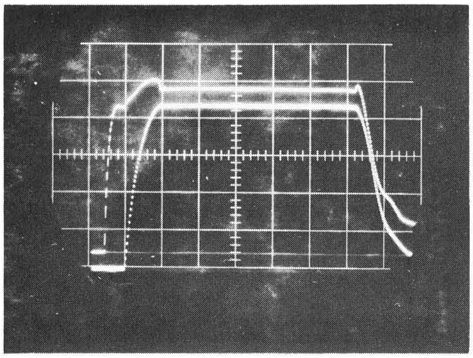

Fig. 1

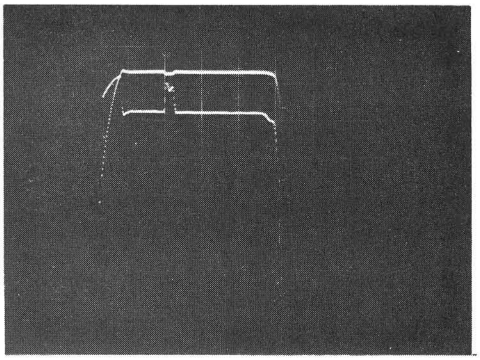

Fig. 2

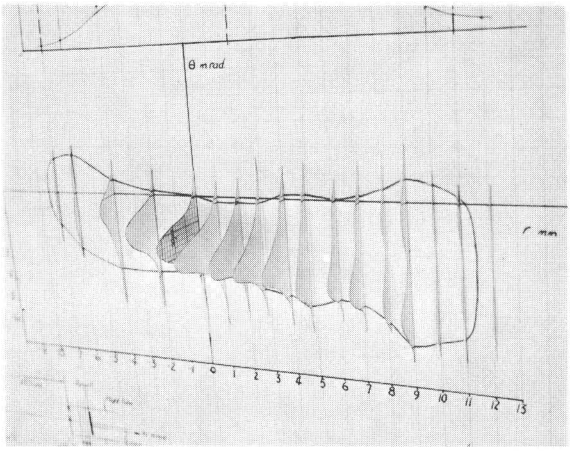

Fig. 3

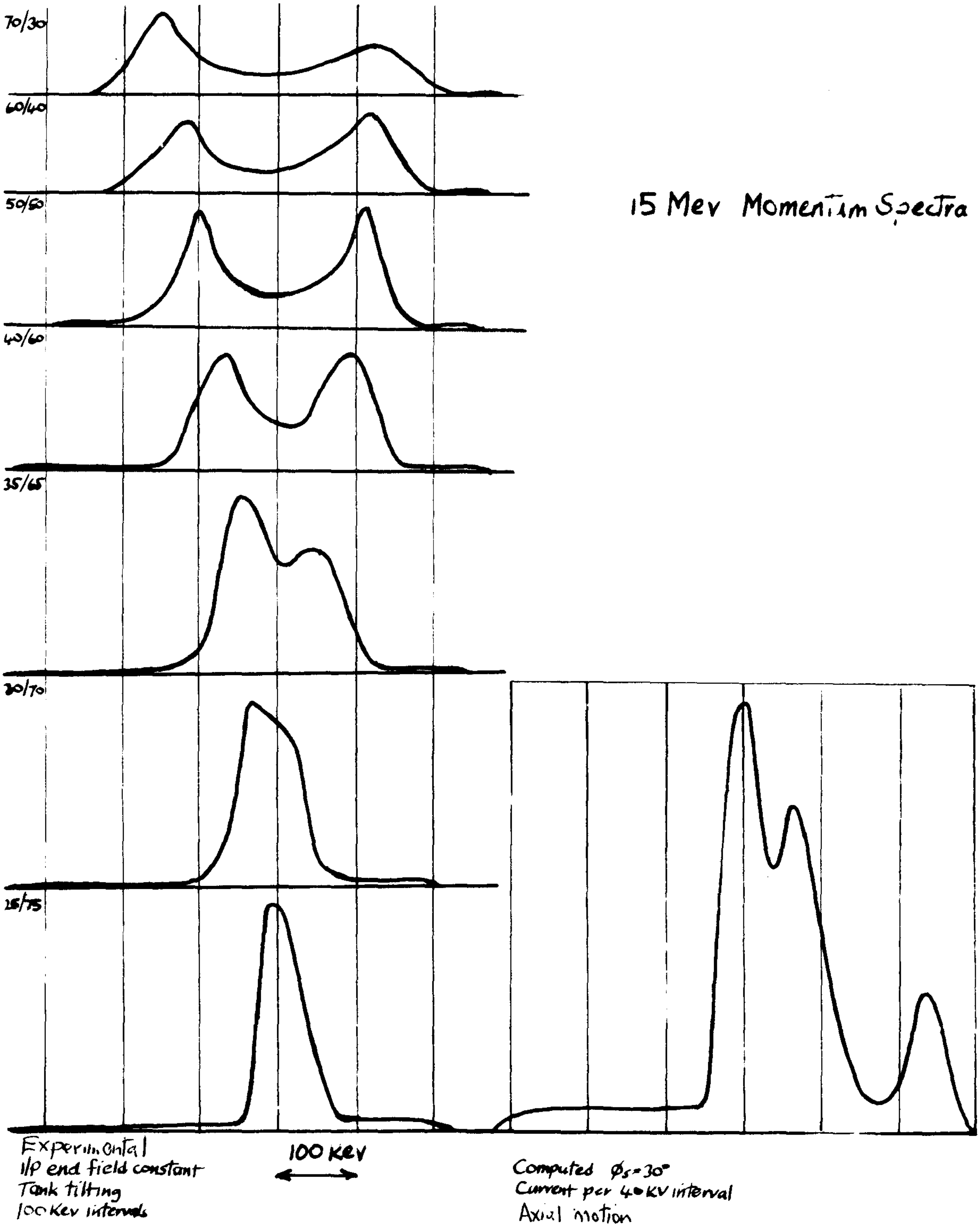
70/30
60/40
50/50
40/60
35/65
30/70
25/75
15 Mev Momentum Spectra
Experimental
I/P end field constant
Tank tilting
100 Kev intervals
100 KeV
Computed $\phi_s = 30°$
Current per 40 KV interval
Axial motion

Fig. 4

Axial Phase Acceptance

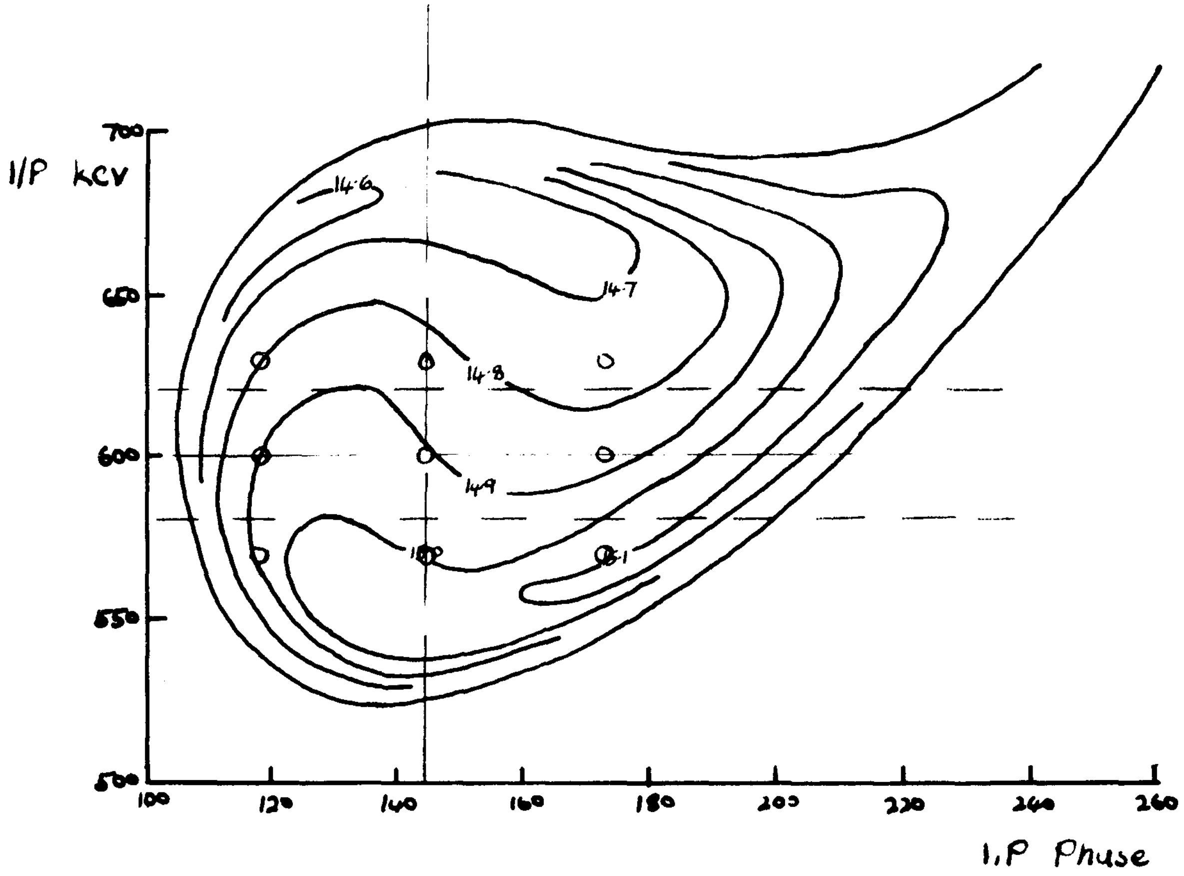

Fig. 5

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