

Linac Conference

A brief report of some of the topics covered at the sixth proton linear accelerator conference held at Brookhaven, USA, on 20-24 May. The Editor would like to thank C.S. Taylor for helping in the preparation of this report.

The accelerator builders who think straight met at Brookhaven National Laboratory for the latest of their series of bi-annual conferences. Major features of the conference were the reports on the work that has gone into linac structures over the past two years; increased understanding of space charge effects, which are beginning to trouble many people now that very intense beams can be accelerated; 'factory-type' accelerators; and finally a feeling, rather than any specific pointers, that superconductivity will soon be coming into its own in the design of linacs.

Factory-type accelerators

W.B. Lewis from Chalk River, Canada, opened the conference with a talk on future factory-type accelerators. He concentrated particularly on the Chalk River proposal for an Intense Neutron Generator (ING) — see CERN COURIER vol. 7 page 200. To recall the main parameters: it would be a 1 GeV proton linear accelerator producing 65 mA continuous. This could be used as the basis of a meson factory and also, by firing the beam into a liquid lead-bismuth target, could produce 10^{16} neutrons/cm²/s. A long term aim is to find a way of producing neutrons other than by nuclear fission at a competitive cost.

Other accelerators which come under the heading of 'factory-type' are the cyclotrons of Zurich and British Columbia (see page 136) which were of course not covered at this conference, and the Los Alamos Meson Physics Facility (LAMPF).

LAMPF

Since LAMPF is the most formidable proton linear accelerator at present under construction, and was the subject of several papers at the conference, it is worth describing the machine in some detail.

It is designed for a peak proton energy of 800 MeV, with an average beam current of 1 mA. The duty-factor (the percentage of time that the machine is producing beam) is 6 to 12%. These are the parameters which qualify the machine for the title of 'meson factory'. The energy is sufficiently high for copious production of muons and pions; the average current is high (ten thousand times the intensity of any existing accelerator at that energy)

and the duty-factor is way above the usual 0.1% for a linac.

To achieve these parameters, a lot of new thinking has had to go into the design which has evolved as follows:

The input will be from an expanded duoplasmatron ion source and a short accelerating gap giving 750 keV (as used on the CERN PS, see vol. 6, page 88). Then come four tanks which are of the Alvarez type (but probably with some modifications to the structure — see the section on Linac Structures below), operating at 201.25 MHz and taking the beam energy to 100 MeV.

For energies much above 100 MeV, the Alvarez structure becomes inefficient and LAMPF therefore changes to the waveguide type where the particles are swept along, as it were, on the crest of a radio-frequency wave. In the Alvarez structure, particles are accelerated by r.f. fields between drift tubes and are hidden inside the drift tubes when the fields are decelerating. The fields between the drift tubes are in phase — all pointing the same way at the same time — and this is known as the zero mode of operation. Power is propagated along a waveguide accelerator more efficiently if the $\pi/2$ mode is used. Here a series of cavities have fields which are, at one point in time, successively accelerating, zero, decelerating and zero (the decelerating fields swing to accelerating as the particles reach them). The zero field cavities, however, waste half the accelerating length of the linac and the Los Alamos people have moved them out to the side as shown in the figures. The waveguide section of LAMPF is therefore known as 'side coupled' operating in the $\pi/2$ mode. It operates at 805 MHz and has 90 tanks taking the protons from 100 to 800 MeV.

The total length of the accelerator is 850 m and the average r.f. power consumption at 6% duty cycle is 3 MW. Construction of the accelerator began early this year and is scheduled for completion in 1972. The cost estimate is \$55 million.

Los Alamos have been working on several electron models prior to finalizing the LAMPF design and their latest, which came into operation last December, is a 20 m linac capable of energies from 20 to 35 MeV using side-coupled cavities. It is

working successfully with high intensity and a 6% duty cycle and is also being used to study the extent to which computer control of the accelerator can be reliably achieved.

MTA

Before leaving the factory-type accelerators it is interesting to recall what was achieved some sixteen years ago with the 'Materials Testing Accelerator' at Livermore, USA. This monster of a machine has been largely dismissed as a failure since it did not achieve its aim, originally promoted by E.O. Lawrence, of using intense deuteron beams to produce weapons quality plutonium from 'depleted' uranium. It was made economically unsound by the dramatic fall in cost of natural uranium and the project was abandoned in the mid 50s. Nevertheless, the MTA design team, though their project did not succeed and though their aim was far removed from that of present-day accelerators, made contributions to accelerator technology which underlie many of the recent developments.

Construction of the MTA was completed in January 1952. It was a linear accelerator with a single huge vacuum vessel that you could drive a truck into. It measured about 28 m long by 19 m in diameter. The drift tubes weighed up to 30 tons each and were so large you could crawl through the bore ... and face an unhealthy drop if you fell out. (That compares with present drift tubes bores of a few centimetres.)

The required deuteron beam intensity was never achieved and the machine suffered from fierce sparking problems. But the list of achievements is considerable. MTA had the first expanded duoplasmatron type ion source — this type has only recently come into vogue on the high energy accelerators leading to very high linac currents on the CERN PS, for example. The team developed vacuum techniques so far as to reach a pressure of 10^{-7} torr in their huge tank — in 1952 so high a vacuum had only been achieved on a laboratory scale. A similar feat was to put 9 MW of r.f. power into the tank. Even their breakdown troubles proved useful since they sparked off the work at Berkeley which resulted in the famous

In Figure 3, an artist has extracted the main features of LAMPF — Los Alamos Meson Physics Facility — an 800 MeV proton linear accelerator.

Figure 1 shows the structure of a waveguide accelerator which operates in the $\pi/2$ mode. By moving the zero cavities (cavities with no field in them) out to the side, the alternate cavities actually seen by the beam have their fields in opposing directions as shown.

Figure 2 is of a portion of a waveguide accelerator with 'side-coupled' cavities (the boxes sticking out above and below the accelerator pipe) such as will be used for the higher energy portion (above 100 MeV) of LAMPF. (Photos Los Alamos)

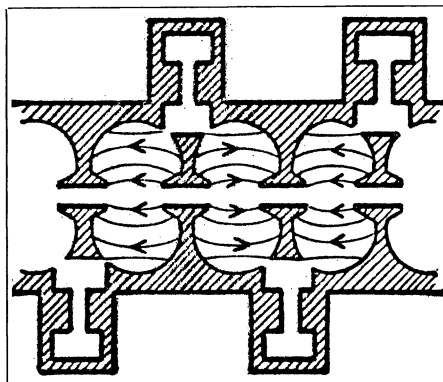


Figure 1

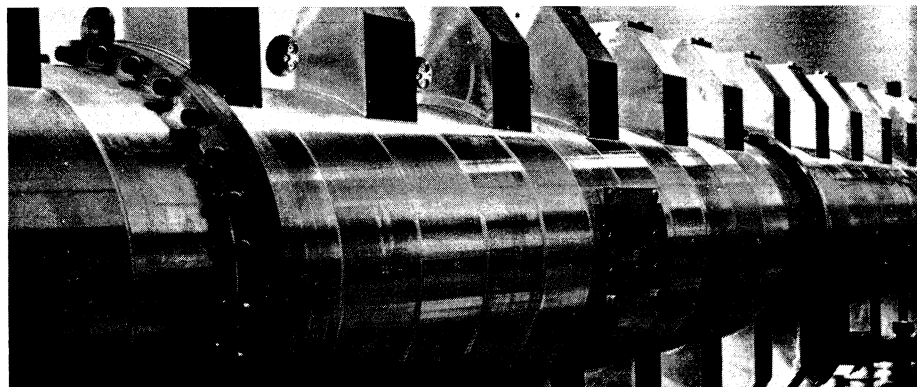


Figure 2

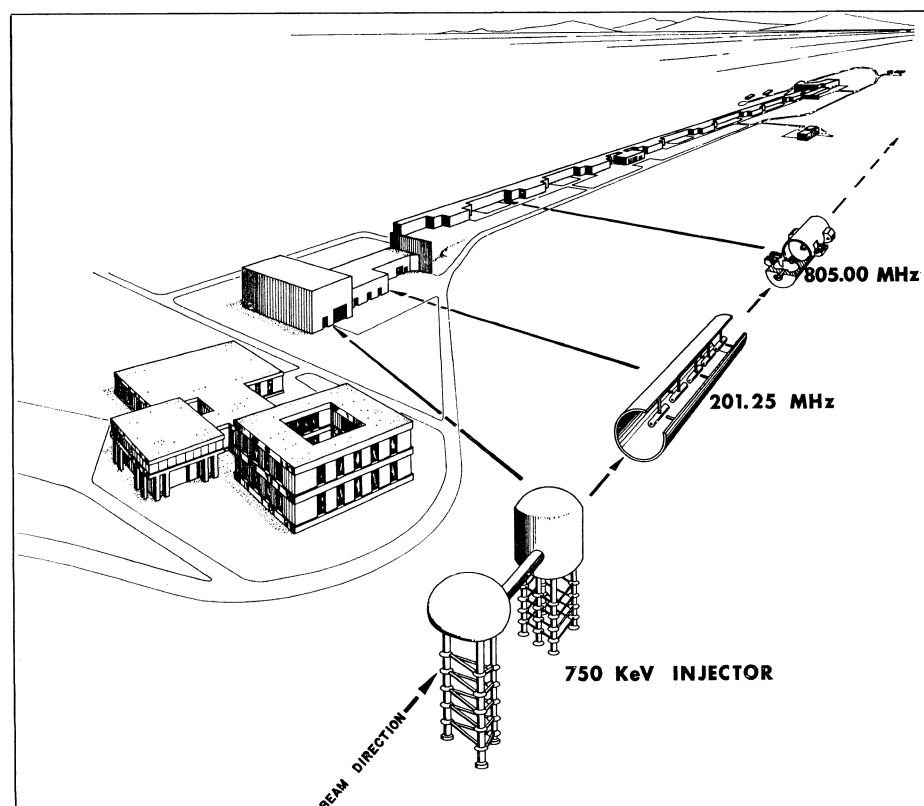


Figure 3

Kilpatrick criteria on breakdown. Problems of beam loading, beam control and focusing were mastered and a proton beam intensity of $1/4$ A was reached in part of the accelerator. This still stands as the world record in proton linac intensity.

Finally, a sequence of events has linked MTA to CERN in a most roundabout way. The MTA team initiated the use of copper-clad steel for their linac and produced tons of it. When MTA was dismantled, some went to build the new Bevatron injector, some to build the Yale HILAC (Heavy Ion Linear Accelerator), and some to build the Manchester HILAC. Some surplus from Manchester found its way to the Rutherford Laboratory, and from Rutherford some came to CERN to build the 3 MeV linac model which has just been completed.

Linac Structures

This topic is one which has been intensively investigated over the past two years, chiefly at Los Alamos, at Brookhaven and at CERN, and a very intriguing position has now been reached. The interest of Los Alamos is obvious from the description of their project above. Brookhaven's concern is in relation to the 200 MeV linac which is part of the improvement programme at the Alternating Gradient Synchrotron. (Weston also have an interest here since, for the 200 GeV project, they hope to take over the Brookhaven design in its essentials.) At CERN, a good deal of consolidating work has been done with model structures (see the photo on page 100 of the last issue) and G. Dome gave a comprehensive paper on the theory of compensated structures.

This work has been prompted by the need to cope with the heavier beam loading that will be experienced with the more intense beams that linacs are now called upon to produce, and to improve on the efficiency of the Alvarez structure for higher energies. The aim is to modify the simple Alvarez structure by making the drift tube supports (or by introducing other posts) in such a way as to change the r.f. characteristics of the linac tank. This can increase the coupling between the separate cells of the linac. The velocity at which power is propagated along the structure is improved and the various modes in which the tanks can resonate are pushed

The linear accelerator at Serpukhov. There are three tanks, seen in the photograph with their vacuum lids removed, taking the proton beam to an energy of 100 MeV. On 15 February, an intensity of 100 mA at full energy was reached, an outstanding achievement for a linac of such high energy.

(Photo Serpukhov)

further apart giving higher stability to the r.f. fields. It also reduces the mechanical tolerances involved in constructing the linac.

A considerable variety of structures have been put forward involving drift tube supports of different thicknesses and orientations. Los Alamos are proposing a 'post-coupled' structure which has a single drift tube support and a post projecting from the side of the tank in the plane of the drift tube, though not actually connected to it. Brookhaven are proposing four drift tube supports at right angles (they need

spring-loaded connections so that they can be detached when it is necessary to get into the tank).

A great deal has been learned about the properties of such structures, but as a sobering thought it should be noted that, with long structures of the simplest uncompensated type, a beam of 100 mA has recently been taken to 100 MeV on the Serpukhov linac. A question linac designers have to ask themselves before going on to the final hardware is, 'Is your structure really necessary?'

Space charge effects

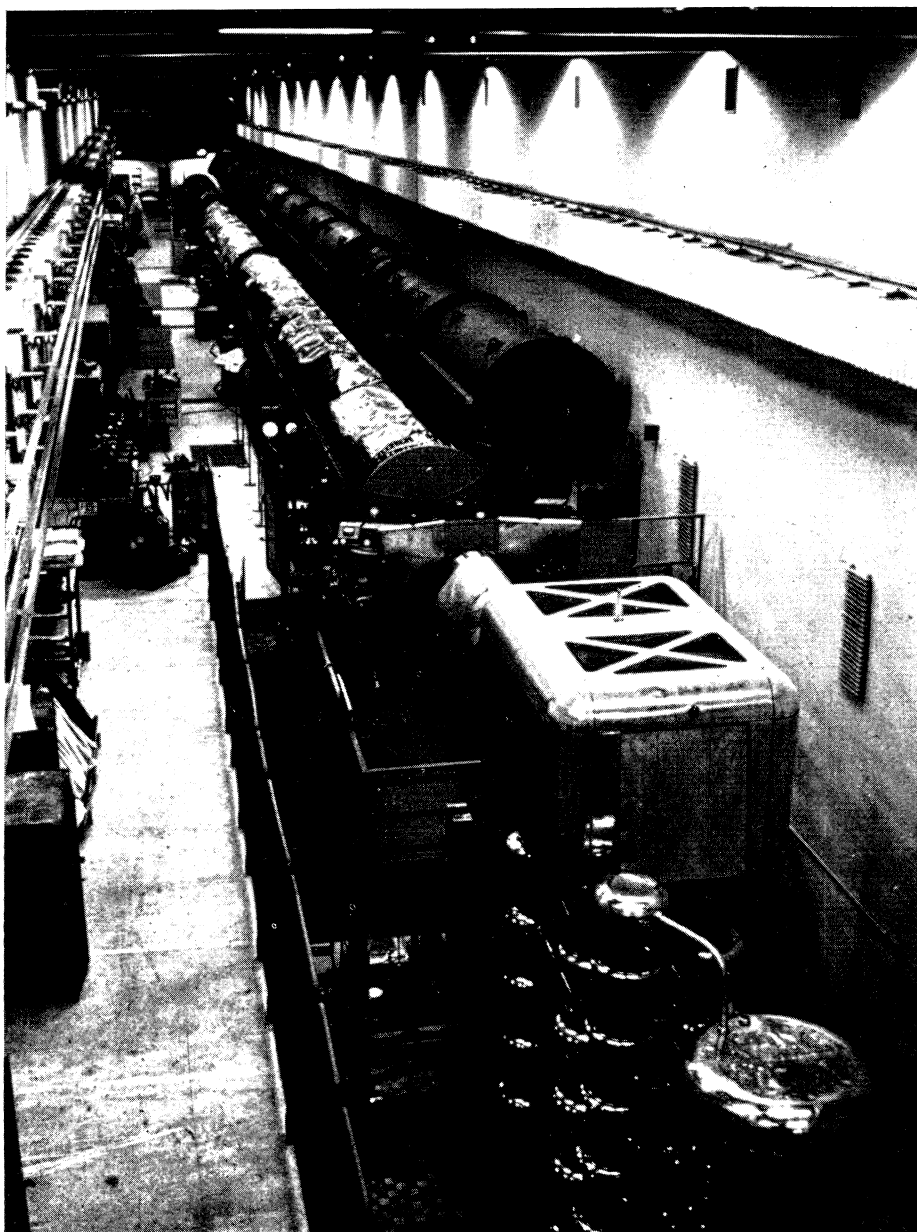
Another problem which has raised its head with the advent of high intensity beams is that of space charge. It also has received a lot of attention since the last linac conference. The session on space charge opened with a review, by P. Lapostolle from CERN, of bunching problems in the presence of space charge.

Mrs. R. Chasman from Brookhaven has carried out a thorough investigation, developing a computer programme which adds the effect of space charge to the normal six dimensional approach to beam dynamics in a linac. She traces, for example, a 100 mA beam through a linac structure and computes the effect on a single proton of the proximity of all the other positive charges in the beam. Beam 'blow-up' (loosely speaking — increase in the cross-section of the beam and the angles that the protons travel with respect to the axis of the beam) due to transverse-transverse coupling and to transverse-longitudinal coupling could be identified, and it emerges that the 'blow-up' is not affected very much by the linac parameters, implying that the beam behaviour is dominated by the space charge effect.

Other topics

J.M. Lefebvre from Saclay reported on the progress of the new linac which is to replace the existing 3.6 MeV Van de Graaff as injector for the 3 GeV proton synchrotron 'Saturne'. He was able to announce that, in the middle of May, the linac had accelerated a proton beam (1mA) to the design energy of 19 MeV for the first time. It will be coupled to Saturne in about six months' time and will considerably improve the performance of the machine.

A new-comer to the agenda of a linac conference was the Electron Ring Accelerator (discussed in full in CERN COURIER, vol. 8, page 28). A.M. Sessler gave a paper concentrating on the difficulties which might confound the high hopes for this exciting new accelerating principle. Development of ERAs is under way at Berkeley, USA, and Dubna, USSR, and Sessler remarked that, by the time of the next conference, 'we should know whether to talk of a new era or of an old error'.



CERN/PI 09.3.68

An aerial photograph taken some months ago of the Alternating Gradient Synchrotron at Brookhaven National Laboratory. Coming from the wheel-shape of the machine can be seen the path cut through the woods for the 200 MeV linac which is to be constructed as part of the AGS improvement programme. Construction of the building to house the linac has now started. (Photo Brookhaven)

The 750 kV accelerating column of the new 19 MeV linac at Saclay. In a very neat design the Saclay team have incorporated the duoplasmatron ion source, short accelerating gap and the Cockcroft-Walton set producing the high voltage, all in one unit which is enclosed in a tank filled with a carbon-dioxide/nitrogen mixture under pressure to reduce sparking problems. (Photo Saclay)

Some of the work on, or in connection with, the CERN PS linac was covered by C.S. Taylor and D.J. Warner. The progress report on the performance of the linac concentrated particularly on the success of the expanded duoplasmatron ion source and high gradient column which has led to currents up to a maximum of 130 mA being accelerated to 50 MeV.

Mention was made of an unexplained observation on the PS linac beam when it was accelerated to 10 MeV and then allowed to drift over 24 metres. Unexpected beam blow-up occurred but the effect did not repeat itself when the same test was done with higher energy beams. Further investigation will be carried out during the present PS shutdown.

The heaviest beam loss in linacs usually occurs at low energies and some thinking is being given at CERN to increasing the energy of pre-injectors to above 1 MeV. Also, to understand better what is happening particularly at the low-energy end of a linac, a 3 MeV model linac (mentioned above) has been built for experiments.

Another development reported was the coupling of the emittance measurement equipment on the PS linac to the IBM 1800 computer in the Main Control Room. A typewriter can print out the phase-space area and the current distribution inside it.

Finally, we report a contentious conclusion reached by A. Pearson from Chalk River who discussed the philosophy of computer control. This subject is growing in importance in the accelerator world. In the USSR, work on a 'cybernetic' accelerator where the computer is an integral part of the machine operation has advanced to the stage where a 1 GeV model has been built. Los Alamos are planning extensive computer control of LAMPF and other Laboratories are sampling the possibilities (e.g. injection at Berkeley, ejected beam at Rutherford...)

Pearson brought the twelve years experience of computer control of reactors into the discussion and stated that, in his opinion, it is never easier to make changes to the software of a computer programme than to go down to the machine and make changes to the hardware. This opinion was questioned by other speakers but has certainly provided food for thought.

