THE BROOKHAVEN 200 MeV LINAC INJECTOR CONSTRUCTION PROGRESS REPORT*

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Introduction

This paper presents some of the highlights of the present status of the construction of the new 200 MeV linac injector for the Brookhaven Alternating Gradient Synchrotron (AGS).[1] Details on parameters and specifications are not discussed here. The following table shows only some numbers of interest as regards the physical design of the machine.

Peak current: 100 mA (with possibility of going to 200 mA)
Beam pulse length: 200 μs
Beam repetition rate: 10 pps (duty cycle 0.2%)
Operating frequency: 201.25 Mc/s
Rf pulse length: 400 μs (duty cycle 0.4%)
Peak excitation power: 23 MW (92 kW avg.)
Peak beam power at 100 mA: 20 MW (80 kW avg.)
Total length of cavities: 450 ft. (9 cavities)
Total length of accelerator: 500 ft.

Brookhaven National Laboratory was funded in December 1966 to carry out the AGS Conversion Program, part of which consists in the construction of the 200 MeV linac. At this time Title II design is 70% completed and fabrication of major components has begun. It is scheduled to have the first 10 MeV section assembled for low level field measurement in March, 1969 and to have it assembled ready for power test is September of that year. The eight successive cavities will follow-up sequentially and it is planned to have the first 200 MeV beam in early 1971.

Building Construction

Figure 1 is a simplified drawing of a cross section of the accelerator building. Although linacs supposedly are clean machines with little or no beam loss resulting in radiation, experience indicates that there are still inherent risks of losing the beam accidentally. Also, as the peak current is increased manyfold one has to accept the fact that some loss will occur. Based on these two factors, it was decided that we should have the accelerator structure built in a separate tunnel and have the radiation shielding sized for a 1% continuous beam loss or the loss of a complete pulse treated as a point source with however the resultant reaction spectrum mostly directed forward. The shielding thickness is 3-feet of concrete and 11-feet of compacted Brookhaven sand, this is equivalent to 11-feet of concrete. Subsequent studies and measurements done at CERN indicate that these numbers are conservative.

The accelerator structure is supported on 50-feet H beam piles (two per pile cap) sunk in the sand, rock appears only at 1600-feet. Brookhaven has had a great deal of experience with this type of support and although not necessarily stable it has proved reliable and predictable. After the major settlements have taken place we can expect pile cap movement of ± .015" over long periods providing no major disturbances are introduced by, let's say, adding shielding.

The two story equipment building provides room for all power equipment and mechanical services for the accelerator. This scheme eliminates the need for trenches which would have disturbed the soil, thus increasing the settlement problem. Figure 2 shows this same building actually taking shape.

Construction on the linac buildings started in January of this year and is scheduled for completion on June 1, 1969.

Injector

The preinjector consists of a 750-kV Cockcroft-Walton generator and high voltage terminal, housing the ion source. The proton beam will be accelerated down a "short" (high gradient) column, a number of which are being developed at different laboratories, including Brookhaven.[2] The beam is then matched and bunched before entering the first 10-MeV accelerating cavity.

The Cockcroft-Walton generator is presently being fabricated and should be delivered this fall. In the meantime a short column prototype is being tested[3] and the same will be installed on the 50 MeV linac in September for evaluation while the final column gets built.

Accelerating Structure

The linear accelerator consists of nine separate cavities totaling 450-feet in length. Figures 3 and 4 show the conceptual design of the cavity, which is completed. Each cavity, averaging approximately 55-feet in length, is designed in three separate 18-20 feet long sections bolted end to end. Each section is a flanged cylinder made from a single sheet of copper clad steel whose thicknesses are 0.150" of copper and .750 inches of steel. An order for the cavities was placed in early April and the first section is scheduled to be delivered in January, 1969.

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The cavity supports, vacuum system using sputtering ion pumps, cooling system are all in the design stage and will be completed during the summer.

The accelerator cavities require a total of 277 drift tubes, varying in length from 1.9 inches in the first cell to 17.9 inches in the last cell and each containing a focusing quadrupole magnet. The drift tube design has only one vertical structural stem carrying all services to the drift tube body. This concept is carried all the way to the low energy end where the first stem measures one inch in diameter. Figure 5 shows a typical one-stem drift tube. The stem support system is a simple plate providing flexibility in the X, Z, coordinate and rotation about the Y axis. It is locked in the aligned position. The alignment is performed with the help of an accurate fixture fitting on top of the tank. The vertical adjustment is achieved first by proper shimming. The primary vacuum seal is a Viton "O" ring evacuated on both sides; the bellow permits access to the inner seal. The stems are made of precipitation hardened stainless steel with electroformed OFHC copper 0.005" thick on the surface. The stem has four drilled holes; two for the water passages, one for the magnet leads and one for the rough vacuum.

The drift tube body is a brazed assembly except that the final joints, after assembling the quadrupole, are made by welding using the electron beam technique in vacuum. This process, first used at Argonne and then perfected at CERN and Saclay, is ideally suited for this type of fabrication and does away with low temperature soldering materials which have proved troublesome in the past. Our experience to date with the process is good although one has to watch the metallurgy of welds when welding dissimilar materials such as copper to stainless steel which can form a very brittle alloy in the weld interface which cracks under thermal stress.

The drift tubes in cavities 2 have three stems and in #3 - 9 have four stems.[4,5] These drift tubes, with a single support stem, have the other (dummy) stems removable. These dummy stems consist of rigid water cooled stubs protruding into the cavities and are connected to bosses brazed on the drift tube by sleeves which allow for any reasonable misalignment. The electrical contact on the sleeve is done using spring rings fitted in grooves. Figure 6 shows the development of the brazing technique for the bosses which are fitted on the drift tube diameter by mating the surfaces and brazing with alloy, contained in the tube above, which flows into the joint at the proper brazing temperature. This scheme has proved very reliable and allows one to carefully tailor the amount of brazing material at the joint area to be brazed. This is a necessity if one wants to avoid any excessive runs of brazing material on the drift tube surfaces.

At this time, production of drift tubes has been initiated, the fabrication process scheduled to last for about 18-months. At the same time, the focusing quadrupoles for the drift tubes are also being produced partly here and partly by industry.

The focusing quadrupoles in the drift tubes are pulsed because of the low duty cycle and the high gradients required in the low energy part of the linac. The following parameters are typical of the system:

Quadrupole Number	1	50	250
Gradient, kG/cm	10.0	2.0	0.5
Pole Tip Radius, cm	1.1	1.7	2.2
Magnet length, cm	2.5	10	15
NI (ampere-turns)	5000	1600	1000
Power Dissipated, Watts avg.	120	20	10
Mode of Operation, pulsed	2800 μs, 10 pps		

The pulsed mode of operation requires the use of a laminated core magnet, and the very tight quarters, limited by the drift tube boundaries, make it difficult to achieve very high gradients. Several designs have been tested [6] [7] and the most promising is a split magnet with a simple pole geometry as shown in Fig. 7. The four double-layer windings are assembled on the split laminated core and then the quadrupole is tightly fitted in a steel ring. The entire quadrupole assembly is then potted in epoxy and mounted in the drift tube in its proper position, its magnetic center and axes coinciding with those of the drift tube.

The magnets are energized by pulse-forming networks. A pair of series-connected magnets is a component of each network, as shown in Fig. 8 in simplified form.

The two sections of the network begin to deliver power at different times, determined by external trigger pulses. During the time between linac pulses, the two capacitors are recharged from an external supply to the level corresponding to the gradients requirement of the pair of quads within that network.

The pulse width is nominally 2.8 ms, and the flatness of the 200 microsecond top varies from .1% to .3% of height, depending on how far into saturation the pair of magnets is operated. Preliminary work with a shunt regulator has enabled us to maintain a flatness of .1% through a wider range of gradients than has been achieved with the unaided PFN, and an added advantage of improved long-term stability is to be expected. Figure 9 shows a typical pulse for a current of 200 amperes.

As mentioned earlier, each drift tube in the accelerator contains a focusing quadrupole. In addition, however, each cavity will have four quadrupoles which will include a superimposed dipole moment for beam steering. These magnets are located in pairs at the high energy end of each cavity about one beam oscillation apart and permit steering in both x and y coordinates.

The alignment scheme for the linac cavities and drift tubes will make use of an optical laser and photosensitive targets. Tests made to date indicate that the system is very practical and flexible. It allows the use of a fixed reference target and the use of intercepting collimators on the parts to be aligned, these collimators are interesting as they can be made cheaply and can be made to fit in any restricted area. These, however, reduce the resolution on the laser target by a factor of 2 to 3.

Rf Systems

The rf systems for the linac will power the accelerator structure at 201.25 Mc/sec and be capable of maintaining the correct accelerating gradient in each cavity during the loading caused by injection of a 100 mA beam. This requires the delivered rf power to double during the pulse. Each cavity requires about 5 MW of power for a 100 mA beam.

All rf systems are identical[8] and consist of (1) 5 MW power amplifier, (2) plate power supply, (3) capacitor bank and crowbar, (4) charge control amplifier, (5) 350 kW driver amplifier, and (6) modulator. A common oscillator-amplifier feeds all nine systems at a 10 watt power level.

The 5 MW rf output amplifier uses an RCA 7835 in a Continental Electronics coaxial cavity. Tests to date on this unit have been carried out successfully to 6 MW for over 200 hours[9] and procurement on these units has been initiated.

The capacitor bank of 40 μF at 60 kV limits the modulator plate voltage droop to less than 10% during the 300 ampere plate output pulse. The associated crowbar system uses a National Electronics type NL-1039 EHV ignitron as a shorting device. Over-all crowbar firing delays of 1.1 to 1.3 microseconds are obtained with the prototype systems. A major problem has been the availability of a good crowbar resistor which will last more than a few hundred pulses. This problem has been solved. Initial development with the use of glowbar (silicone carbide) resistors failed miserably at the interface between the carbide and the conductor by thermal stresses. Now we are using a filament resistance suspended in an asbestos weave with very good power dissipation. Figure 10 shows a partial prototype of the capacitor bank and crowbar resistance. Production on these units will be started when the cabinets are available.

Isolation between the power substation and the capacitor bank is provided by a series vacuum tube. This triode and its associated circuitry form the Charge Control Amplifier (CCA), which provides constant charging current to the capacitor over the full interpulse period. The CCA by its fast switching capability provides good regulation of the capacitor bank voltage and also allows fast isolation of the main power supply in the event of a crowbar.

Figure 11 shows a typical rf subsystem module. In this case the modulator uses three Machlett type ML-8618 magnetically focused triodes as output tubes. The high efficiency, low drive requirements of this type tube are desirable for the fast analog modulation control required to correct for the 100% change in loading of the accelerator cavity during beam injection. The modulator ON-OFF command is telemetered to the floating deck with a solid state infrared optical system. The analog level control information is directly coupled to the deck through a high voltage dc amplifier. The low level (10 volt) command signal from an operational amplifier is amplified in a solid state linear amplifier to a level (300 volt) sufficient to drive the main high-voltage amplifier to a maximum output of 40 kV. A bootstrapped cathode follower stage (4CW10, 000A) is used to supply the grid current, mainly reactive, of the three parallelled output tubes. Response time of one microsecond for an output voltage of 40 kV have been obtained.

Figure 12 shows the 350 kW driver amplifier which provides the grid power for the 5 MW amplifier. The associated electronics and screen modulator are also contained in a modular cabinet and have been developed to be powered at the 10 watt level mentioned earlier. The driver amplifiers are in the process of being delivered and procurement for all rf subsystems modules has been initiated.

The 5 MW peak power from the final power amplifiers is transmitted to the accelerator cavities through a 12-inch diameter coaxial transmission line. These are made of aluminum tubing with rexolite disc supports. All transmission line components are made of the same materials and designed to be pressurized. Presently we are doing final matching of component impedances prio to releasing purchase orders.

Conclusions

At this time, although Title III construction of the accelerator has begun, work is still continuing in the areas of structures development and beam dynamics. Also the detail design of the control system and beam monitoring and analyzing systems have been initiated and are subject to a major effort on our part.

Notwithstanding unforseeable future constraints, the plans for completion of the project in 1971 are being carried out according to schedule and budget estimates.

Acknowledgements

The author acknowledges the help of G. W. Wheeler, Director of the project, and of the whole linac group who is making this undertaking possible.

References

1. "Alternating-Gradient Synchrotron Conversion Program, Scope of Phase I," Brookhaven National Laboratory Report BNL 9500, September, 1965.
2. J. Huguenin et al., "The New 500 keV Single-Gap Preinjector Tube for the CERN Proton Synchrotron Linac," Proc. 1966 Linear Accelerator Conference, Los Alamos (CFSTI, Springfield, Virginia), ibid., p. 355.
3. Th. Sluyter and V. Kovarik "Large Brightness Beams up to 200 mA in a 750 kV High Gradient Preinjector," p. 275, 6th International Conference on High Energy Accelerators, Cambridge, 1967.
4. S. Giordano and J. P. Hannwacker, "Measurement on a Multistem Drift Tube Structure," ibid., p. 88.
5. S. Giordano and J. P. Hannwacker, "Studies of Multistem Drift Tube Accelerator Structures," to be published in Proc. 1967, ibid., U. S. National Particle Accelerator Conference.
6. A. N. Otis and R. Damm, "Drift Tube Quadrupoles," ibid.
7. G. T. Danby and J. W. Jackson, "Theory, Design and Measurement of the BNL Narrow Quadrupole," ibid.
8. J. F. Sheehan and R. L. Witkover, "The RF System for the AGS 200 MeV Linac," Proc. 1966 Linear Accelerator Conference, Los Alamos, (CFSTI, Springfield, Virginia) p. 457, ibid.
9. J. T. Keane and A. J. McNerney, "Experimental Results on the RCA 7835, and Initial Operating Parameters of the FTH," ibid., p. 183.

DISCUSSION

(P. Grand)

HUBBARD, NAL: Do you plan to withdraw the dummy stems from the structure when you work inside the tank and are there demountable joints at the drift tubes then?

GRAND, BNL: Yes. We have no choice, the dummy stem construction is a problem and a real sticky one. It's very nice to improve structures electrically but some one has to pay for it. To keep within practical tolerances, we cannot expect the tank to be perfect as far as roundness or location of all holes go. The specification on the tank manufacturing is ± 1/4 inch for roundness and straightness and +.100, -0 inches for the inner circumference, which is meaningful electrically. This is as close as we can obtain in practice. Also, the drift tubes need not necessarily be at the center of the tank when they are assembled. So if we couple all the possible errors, we have to allow 3/4 inch adjustment for relative radial location and ± 1/8 inch adjustment for the transverse and longitudinal errors. This is the problem and therefore a universal joint is needed to take up these errors. One design, that was tried, employed a spherical seat in the tank wall and a spring finger type contact at the drift-tube but this system applied a loading to the drift tube which disturbed its alignment. This design was discarded and a new design which uses a horizontal stem consisting of a universal joint and a cover sleeve has been developed. The main support stem is used to align the drift tube. While the drift tube is still under observation, with the alignment equipment, the side stem is fitted and locked in position. The cover sleeve then covers the ball joints. The two remaining stems are simple projections from the cavity wall and are jointed to the drift tube by a cover sleeve. The side stem containing the ball joints are cooled, the remaining dummy stems are not. Coiled spring rings are used to make the rf joints. Whenever anyone has to go into the tanks we have to, at least, take out the bottom stem; we have no choice. The remaining dummy stems can stay until the point is reached, at which the man is required to work, then all but the main support stem can be removed.

FEATHERSTONE, CERN: When entering the tank to work, will all work be done from one end of the tank or will the tank be split at intervals as it is in the present BNL design.

GRAND, BNL: No, the tanks will not be split at any point in the length once fabricated. All work will be done from one end or the other of each 55 ft. cavity.

POLK, BNL: It should be mentioned that we have never taken the present BNL linac apart and the same gaskets and spring rings that were installed approximately 10 years ago are still in use.

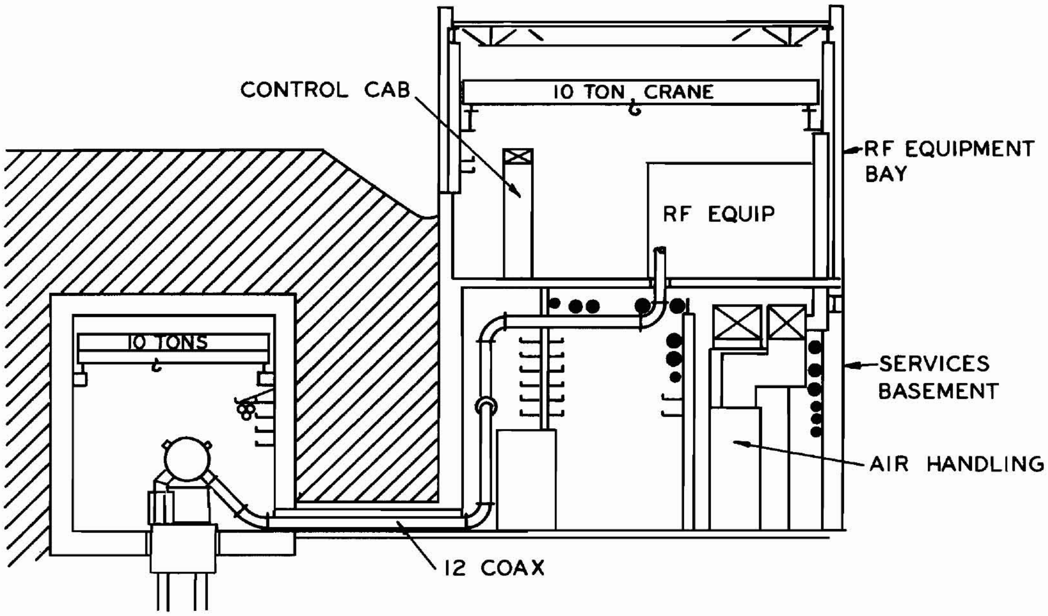

Figure 1) Linac building cross section

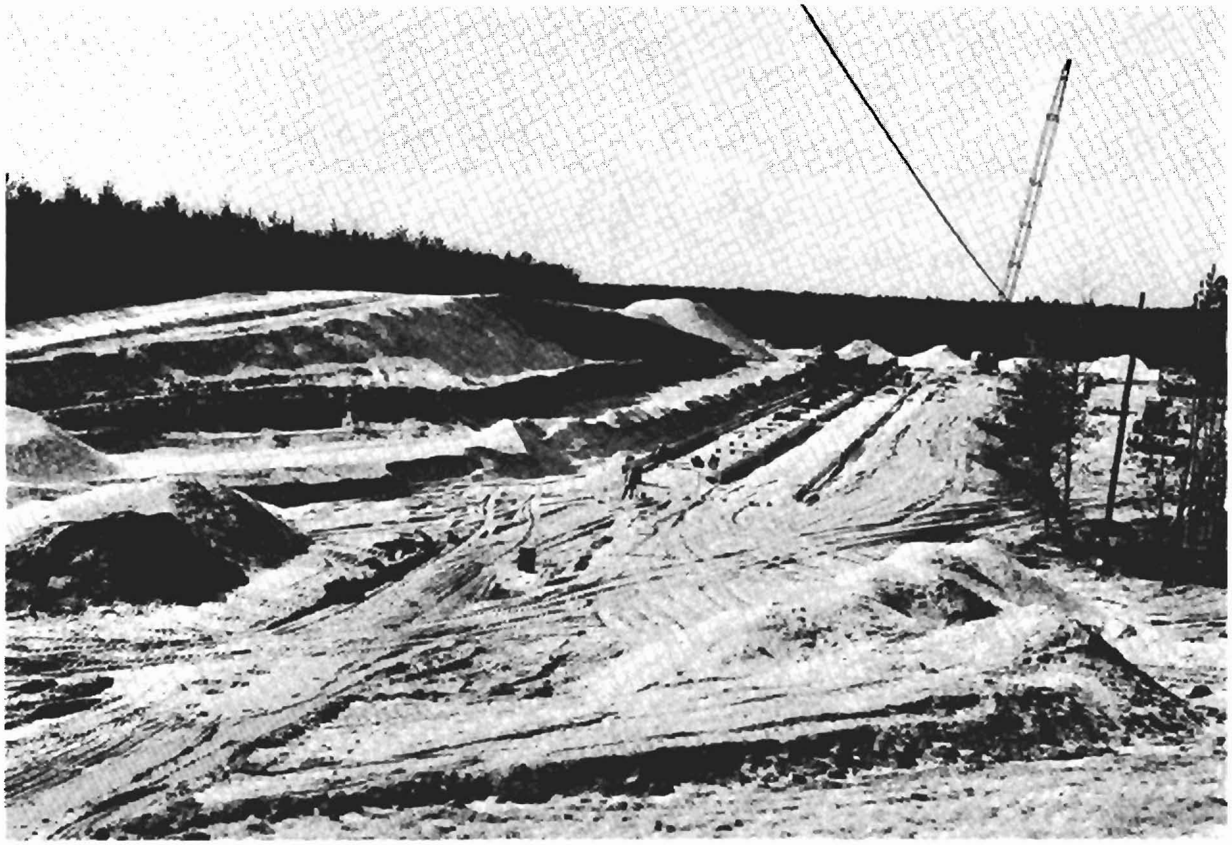

Figure 2) Linac building site development

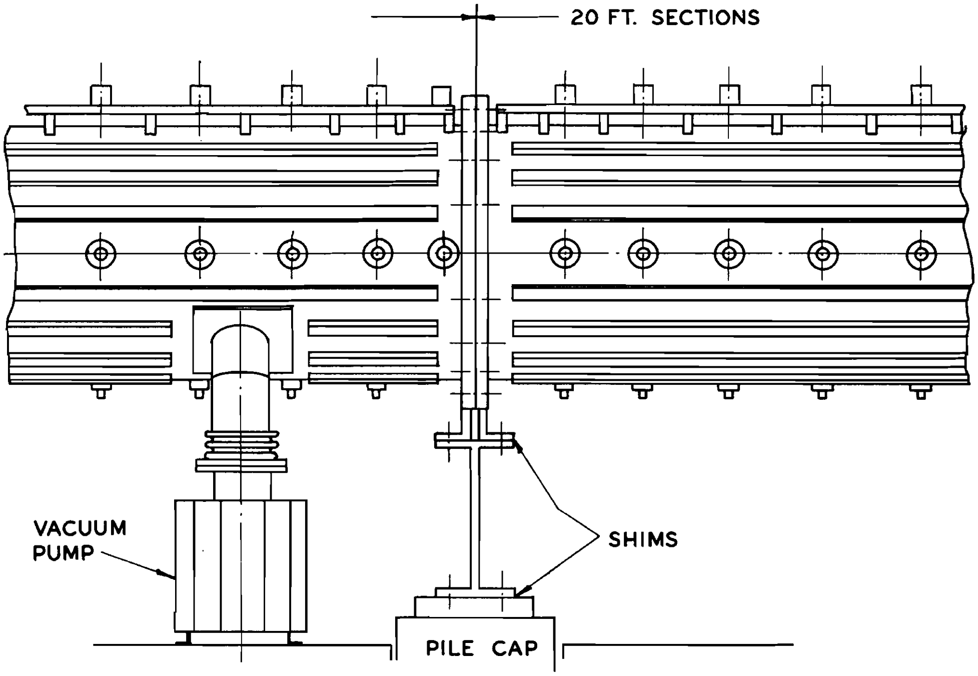

Figure 3) Linac tank support

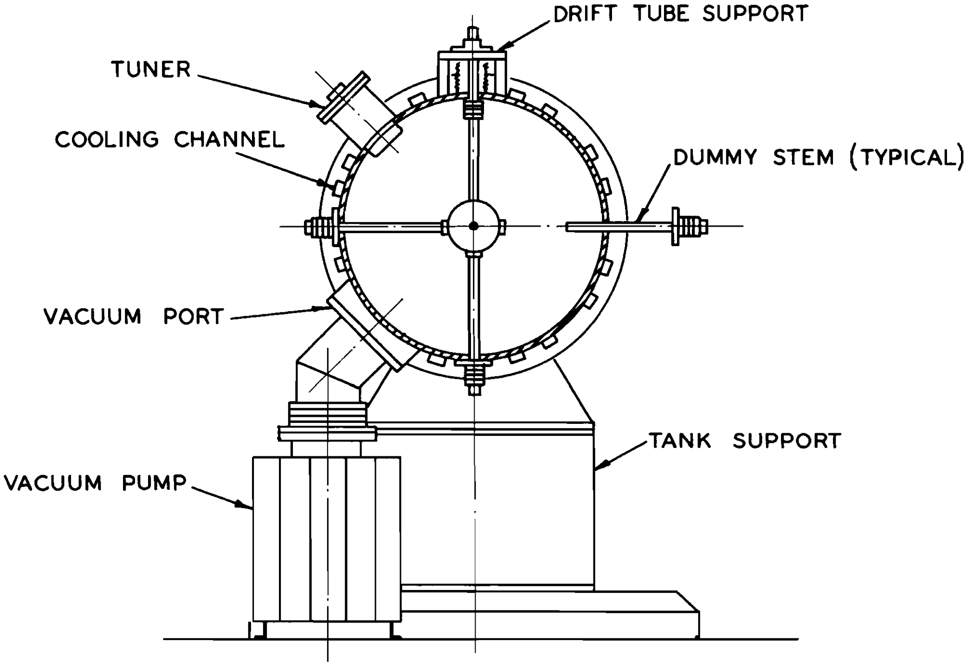

Figure 4) Linac tank cross section

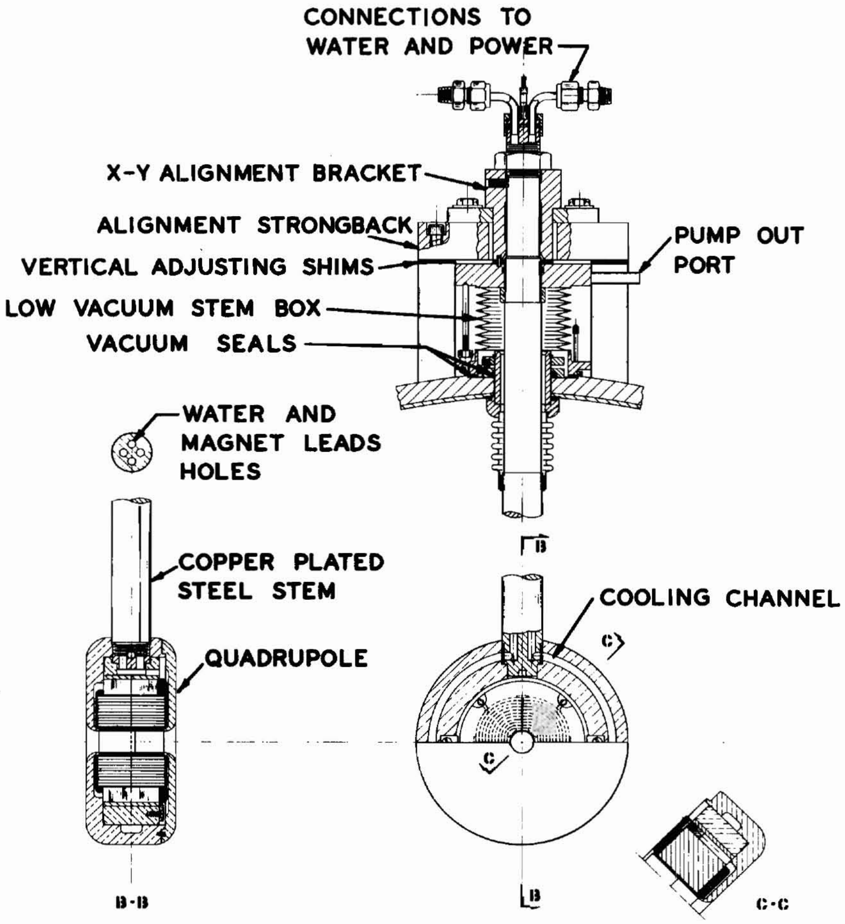

Figure 5) Drift Tube

Figure 6) Drift tube brazing prototype

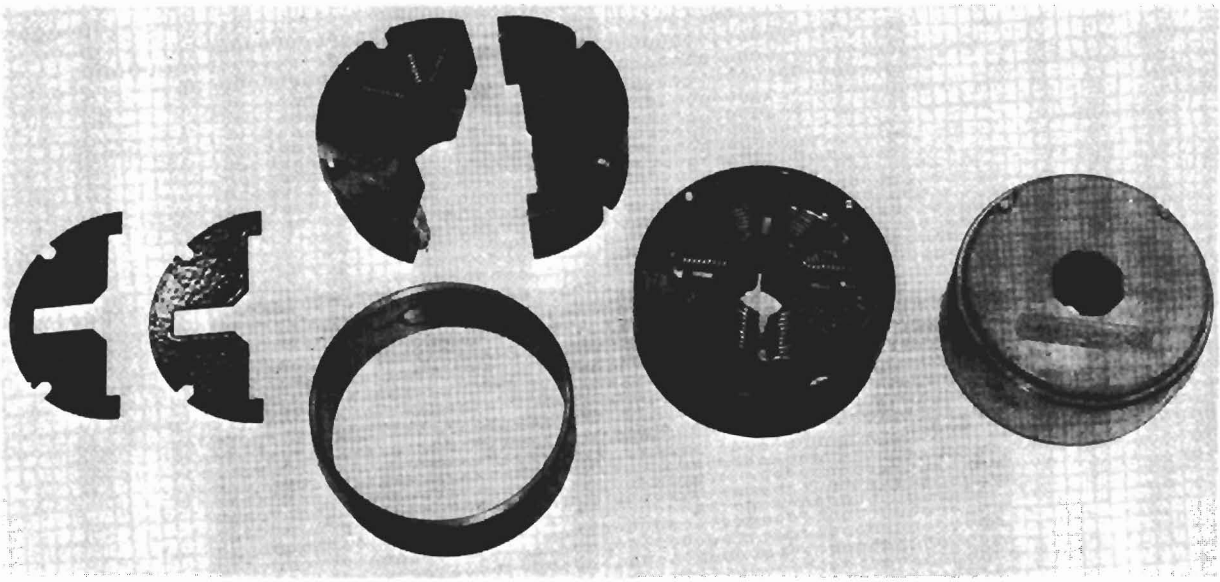

Figure 7) Quadrupole

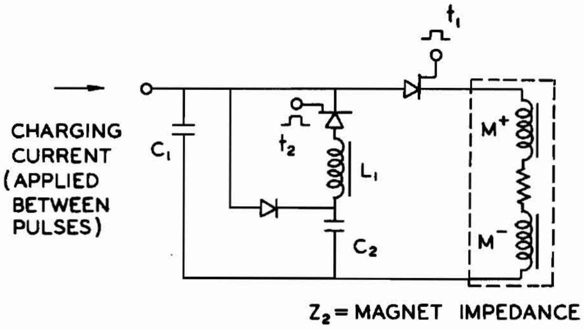

Figure 8) Quadrupole pulsing network

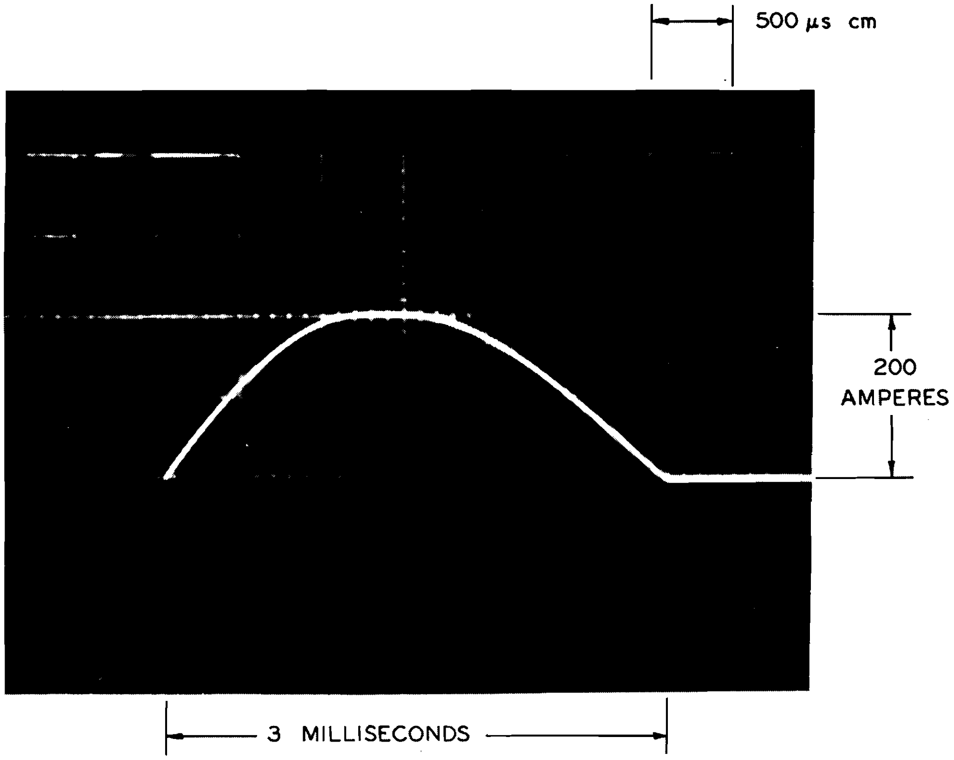

Figure 9) Quadrupole pulse

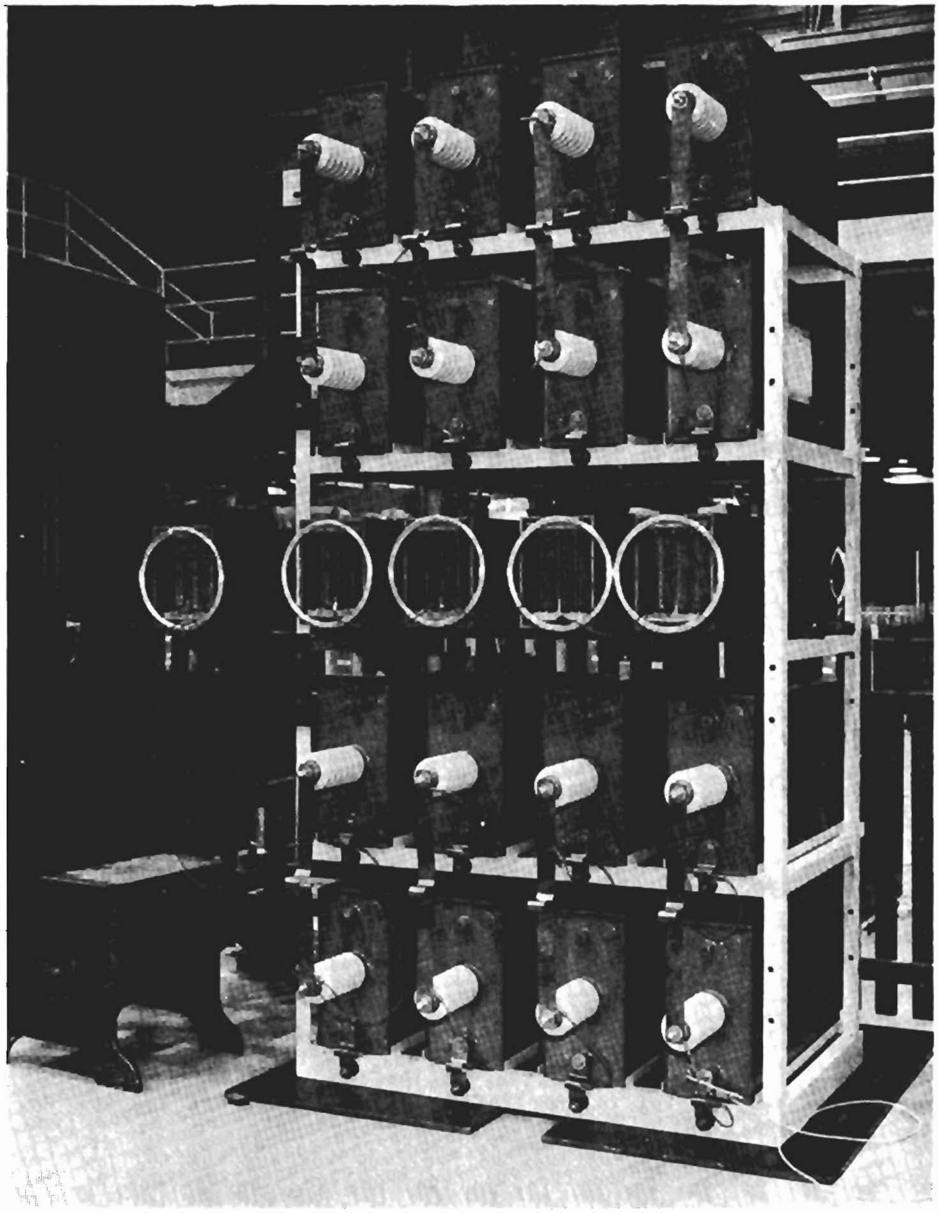

Figure 10) Capacitor bank prototype

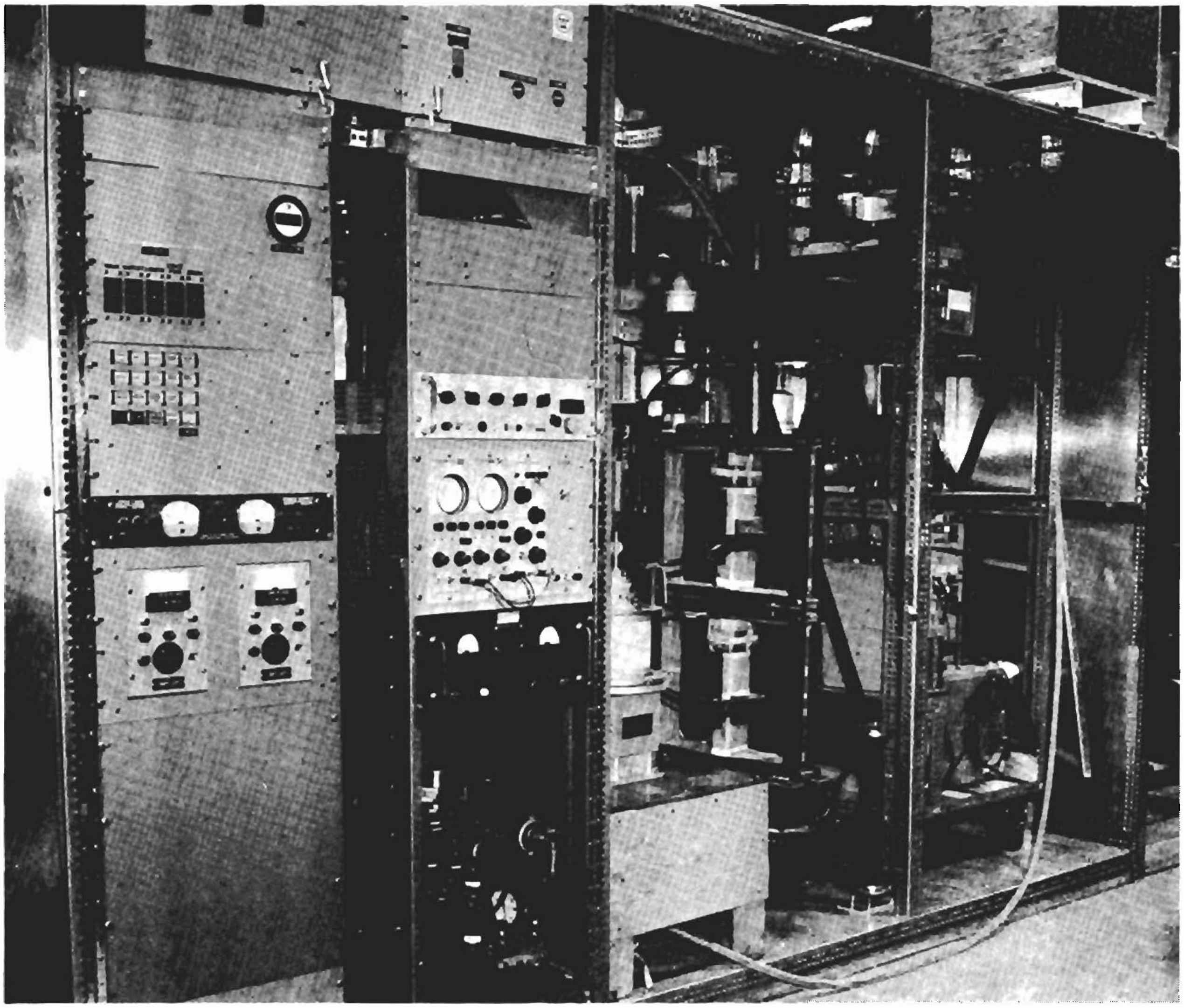

Figure 11) Rf subsystem (modulator)

Figure 12) 350 kw driver amplifier