THE OPERATION OF THE FIRST SECTION OF THE 200 MEV LINEAR ACCELERATOR FOR THE 200 GEV SYNCHROTRON

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1. Introduction

An early design of decision the National Accelerator Laboratory 200 BeV synchrotron project[1] was to use a 200 MeV linear accelerator injector. It was further decided to adopt a design similar to the new 200 MeV injector for the AGS at Brookhaven National Laboratory[2] in an effort to reduce both design effort and fabrication time. The design parameters for the 200 MeV linear accelerator are summarized in Table I.

Table I

DESIGN LINEAR-ACCELERATOR PERFORMANCE PARAMETERS

Output energy	200 · 30 MeV
Output energy spread, before debuncher	$\pm$600 keV
Output energy spread, after debuncher	$\pm$300 keV
Peak beam current	75 mA
Beam pulse length	100μsec
Pulse repetition rate	15 pps
Emittance at 200 MeV	0.5π to 1.0 π mrad-cm
RF frequency	201.25 MHz
RF pulse length	400 μsec

* Operated by Universities Research Association; Inc. under contract with the United States Atomic Energy Commission

RF duty factor	0.5%
Peak rf excitation power	22 MW
Average rf excitation power	110 kW
Total peak rf power at 75 mA	37 MW
Number of accelerating cavities	9
Number of unit cells	286
Total length (including drift spaces between cavities)	144.8 m (475.0 ft.)

In May of 1968 the Atomic Energy Commission authorized the Laboratory to proceed with the fabrication of the preaccelerator and first accelerating section of the linac as a prototype to test design decisions and to carry out the development work needed to insure the rapid integration of all of the subsequent systems into a working unit

By December 1968 it became apparent that the 750 keV power supply for the preacceleretor was going to be the component which could delay the start-up of the prototype system. The Argonne National Laboratory loaned to NAL a 600 keV test set which was modified for use as an 800 keV power supply. This supply was installed in the Linac Research Building at Batavia, Illinois, and by mid-April of 1969 the first proton beam was accelerated from the column. On April 24, 1969 the first 750 keV beam emittance measurements were made using the online computer and display system. (See Figure 4). In May and June the installation of the accelerating cavity was completed and on the 26th of June the first protons were accelerated to 10 MeV.

A buncher has not yet been installed ahead of the 10 MeV section nor is the last triplet yet in place. Without these units the accelerated beam current from the linac has been limited to 30 mA, with 180 mA from the pre-accelerator. Preliminary emittance measurements of this beam have been made but energy analysis has not yet been attempted.

2. Preaccelerator and Beam Transport

The ion source is a duoplasmatron with a plasma expansion cup 1 cm. in diameter. A drawing of the source and column is shown in Figure 1. Testing of the source on a test stand gave beam currents up to 300 mA at an accelerating voltage of 80 kV. Measurement of the source emittance by use of a slit plate gave an approximate value of 7π cm mr at a current of 250 mA. Measurement on an earlier source of similar design but with a grided extractor the MURA laboratory[3] gave an emittance value one-third as large for currents just under 200 mA.

The accelerating column is 30 cm long and is designed with a convergent Pierce field. There are seven accelerating gaps following an extraction gap, with all electrodes fabricated of titanium. The exterior of the vacuum envelope for the accelerating column is insulated by sulphur hexafluoride at a pressure of two atmospheres in a fiber glass and epoxy pressure vessel. A photograph of the accelerating column in its operating position is shown in Fig. 2.

The design parameters of the preaccelerator are given in Table II.

Table II

DESIGN PREACCELERATOR PERFORMANCE PARAMETERS

Voltage	750 kV
Voltage stability	$\pm 0.05\%$
Ion-beam current	220—300 mA
Beam pulse length	30—100 usec
Pulse repetition rate	15 pps
Beam emittance (90% of total beam)	5π mrad-cm

To date the maximum beam current accelerated to 750 keV is approximately 180 mA. Pending development of a plasma expansion cup with a larger diameter, the extraction gap is being operated as an enlarged plasma expansion cup.

The 3 meter long beam transport system shown in Fig. 3 utilizes three focusing triplets and a single cavity buncher. Beam diagnostic equipment in the transport line includes 5 beam current toroids, two beam position monitors, and horizontal and vertical emittance probes at two locations. A crossed-field mass separator, not yet installed, will deflect the molecular ion beam in advance of the first emittance measuring device.

A schematic diagram of the emitance equipment and associated data acquisition system is shown in Fig. 4. The probe consists of a narrow (0.075 mm) slit, a 10 cm drift space and a segmented current pickup plate which has 20 segments on 0.2 mm centers. An individual segment thus corresponds to two milliradians angular divergence. Under program control, the computer positions the slit and steps it across the beam. At each slit position, analog signals, proportional to the amount of current incident on each segment, are amplified, sampled and held at a pre-selected time, digitized and fed into the computer. Immediately following the beam scan, the computer calculates the phase space area and fraction of beam contained within this area, for pre-selected intensity thresholds.

Input parameters for the program and the results of the calculations are transmitted between the operator and the computer via an alpha numeric display scope. Graphic representation of the results of the measurement are presented in two dimensional and isometric form on the alpha numeric and the analog storage scopes, respectively.

An example is shown in Fig. 5. One sees that the two mass components of the beam appears with different focal properties (protons focused, molecular ions diverging), after passage through the first triplet.

With this system, the beam emittance in one dimension may be measured, calculated and displayed. The beam is interrupted for only a few seconds while the data are being acquired. An additional 20 seconds are required to perform the calculations and to present the graphic display on the storage scope.

3. 10 MeV Section

The design parameters for the first accelerating section of the 200 MeV linac are summarized in Table III.

Table III

DESIGN PARAMETERS OF THE 10.3 MEV SECTION

Proton energy in (MeV)	0.75
Proton energy out (MeV)	10.42
Cavity length (m)	74.4
Cavity diameter (cm)	94
Drift tube diameter (cm)	18
Bore hole diameter (cm)	2.0 –2.5
Drift tube corner radius (cm)	2.0
Bore hole corner radius (cm)	0.5
Cell length (cm)	6.04—21.8
Gap length (cm)	1.3—6.7
G/L	0.21—0.31
Axial transit time factor	0.64—0.81
Effective shunt impedance (Mo/m)	27.0—47.97
Number of unit cells	56
Number of full drift tubes	55
Average axail field (MV/m)	1.50—2.31
Average gap field (MV/m)	7.62—7.45
Peak surface field (MV/m)	8.9—10.2
Cavity excitation power (MW)	0.63
Synchronous phase angle, $\varnothing_s$—32°	

The 10 MeV accelerating cavity is made of copper-clad steel and is pumped by three 1200 liter/sec ion pumps. The cavity normally operates at a pressure of 2×10^{-7} torr. The cavity is temperature controlled by water flowing in cooling channels which are welded to the steel structure. The accelerating section is shown in Figure 6 as it is installed in the Linac Research Building.

The drift tubes are fabricated according to dimensions calculated by the MESSY-MESH program[4] and are dimensionally identical to the

Brookhaven drifi tubes. The drift tube quadrupoles are pulsed and the quadrupole and drift tube assembly are cooled by the same temperature controlled water system as is the tank. The drift tubes are electron-beam welded units with a single stem 3.17 cm. in diameter.

The loaded Q of the linac tank is 60,000, 89% of the calculated theoretical value with no corrections for openings such as pump out ports and pick up loops.

The 10 MeV section was designed to have a large tilt in the electric-field gradient which is achieved by tuning the lower energy end at a calculated frequency above the operating frequency and the high-energy end below the operating frequency by the same amount. The rf fields were measured using perturbation techniques[5] with the on-line computer. Figure 7 is a plot of the normalized gap fields along the tank as they were finally adjusted.

The rf system characteristics are described in Table V.

Table IV

RF SYSTEM CHARACTERISTICS

Pulse length	400 usec
Repetition rate	15 pps
Peak power capacity	5 MW
Power amplifier tube type	RCA 7835
Modulator tube type	Westinghouse 23185
Modulator power rating	10 MW
Driver peak power rating	300 kW
Driver tube type	RCA 4616

The rf system was connected to the accelerating cavity on June 19, 1969, and within 14 hours field gradients 30% above the design gradient had been achieved. There was a small amount of multipactoring encountered in the initial excitation of the cavity and a very small amount of tank sparking. The X radiation level around the cavity reached as much as 2000 mR per hour at the tank ends but quickly decreased to much lower levels as the cavity was conditioned. At design gradient no X-rays are detected outside of the tank after one month of operation.

Figure 8 shows the waveforms of the linac cavity voltage and reflected power in the transmission line under conditions where the amplitude servo loop is open or closed.

Since the required excitation power for the first accelerating section is less than 1 MW it has been necessary to carry out all of the high power testing of the power amplifier system into a resistive calorimetric load. The power amplifier has delivered into this load its full rated power at the design duty cycle.

The control system for the 10 MeV accelerator is developed around a 16 bit control computer, a TV display scope with alpha numeric and graphic capability, storage scope and a complete complement of computer peripherals. Primary emphasis for this system has been directed toward data acquisition and control of equipment useful in beam diagnostic and machine research experiments. The turn-on turn-off control and monitoring have not yet been implemented. The computer assembles information from the various machine components as commanded by programs stored in the memory and prepares displays of the assembled information for the operator. The control of the various parameters of the accelerator can be carried out from the TV display by a control knob, a light pen, a key board or from punch cards. Typical parameter displays are illustrated in Figure 9. Any variable may bo adjusted through the control system so that displays are presented of the variation of beam intensity as the variable is changed.

A beam transport and diagnostic area is presently being set up at the end of the 10 MeV linac. This system includes two beam toroids, a beam position monitor, a quadrupole doublet, horizontal and veritical emittance measuring equipment, and a momentum analysis system consisting of an object slit, a spectrometer magnet and two segmented horizontal beam profile monitors. The first profile monitor measures width of the beam entering the magnet; the second monitor is located at the horizontal focus beyond the magnet. Data from the second monitor are fed into the computer and analyzed to provide an on-line measurement and display of the momentum spread of the beam. The 10 MeV emittance measuring equipment, appropriately modified to compensate for the higher energy, is essentially the same as the 750 keV system described previously.

4. Status and Schedule of 200 MeV Accelerator

The schedule of the 200 MeV linac has been accelerated as much as possible to allow some time for investigation of the behavior of the multiple cavity system. The building to house the linac was started in December 1968. Figure 10 is a protograph of the building taken in early August 1969. The building will be completed by January 1, 1970, and installation of the first section will begin immediately.

The major long delivery items for the other eight sections have been ordered. Completion of installation of all equipment is planned for December 1970.

A diagnostig area is planned between the end of the 200 MeV linac and the entrance to the Booster synchrotron tunnel where equipment will be provided to analyze beam characteristics at various times during the beam pulse as well as variations from pulse to pulse.

5. Acknowledgements

The linac section staff has divided the responsibility for mechanical systems as follows: M. L. Palmer, drift tubes; J. O'Meara, accelerating cavities and vacuum systems; G. Lee, preaccelerator and beam transport; F. Krzich, water systems; J. D. Hogan, alignment systems and technician supervision.

Electrical engineering responsibility was divided as follows: R. A. Winje, rf systems; R. P. Featherstone, electronic systems and computer software; A. Donaldson, timing systems; E. W. Aderson, computer hardware; N. J. Lau, computer hardware and software; R. Goodwin, computer software; and C. Mendenhall, rf equipment and technician supervision.

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2. Staff, AGS Conversion Division, Brookhaven Accelerator Department Alternating-Gradient Synchrotron Conversion Program, BNL—9500 (1965); G. W. Wheeler, Progress report on the AGS Conversion Project; Proceedings of the VI International Conference on High Energy Accelerators, Cambridge, Massachusetts, CEA 1—2000, p. 414 (1967)

3. **J. A. Fasalo, C. D. Curtis and G. M. Lee,** Duoplasmatron Source Performance at MURA. Proceedings of 1966 Linear Accelerator Conference, Los Alamos, New Mexico, 1966, LA 3609, p. 371

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5. **C. W. Owen, C. A. Radmer and D. E. Young,** RF Perturbation Measurements in Long Linac Cavities, Proceedings of the 1966 Linear Accelerator Conference, Los Alamos, New Mexico, 1966, LA 3609, pp. 140—145

ДИСКУССИЯ

Мурин: Почему отказались от системы multistem в пользу структуры со штырьевыми элементами связи post couplers,

Livdahl: We chose the post couplers system for the following reasons:

1. The mechanical simplicity of the post couplers.
2. The post couplers are variable, tunable devices which we prefer.

Невяжский: Наблюдался ли мультипакторный разряд между трубками дрейфа и регулировочными стержнями?

Ливдаль: Нет, не наблюдался. Однако имело место искрение, не нарушающее серьезно поверхности трубок дрейфа.

Ильевский: В каких местах поверхности трубок дрейфа обнаружены следы искрения?

Ливдаль: На торцевых поверхностнях первых девяти трубок.

Безногих: Каков диаметр регулировочных стержней?

Ливдаль: Три см. Минимальное расстояние между стержнями и трубками дрейфа также равно 3 см.

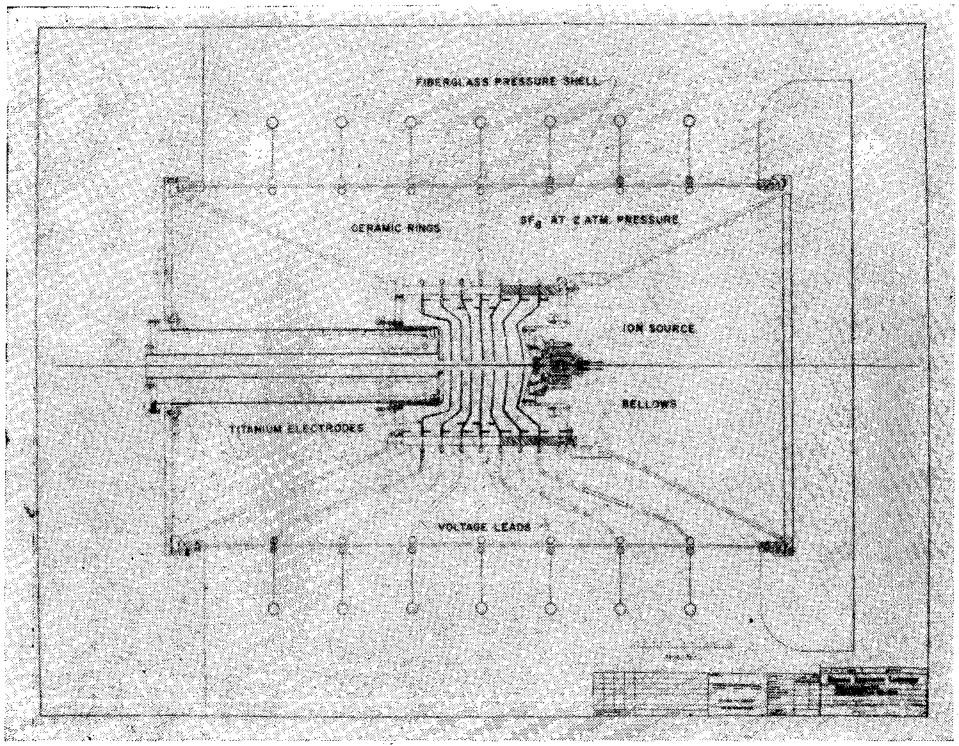

Fig. 1. Accelerating column.

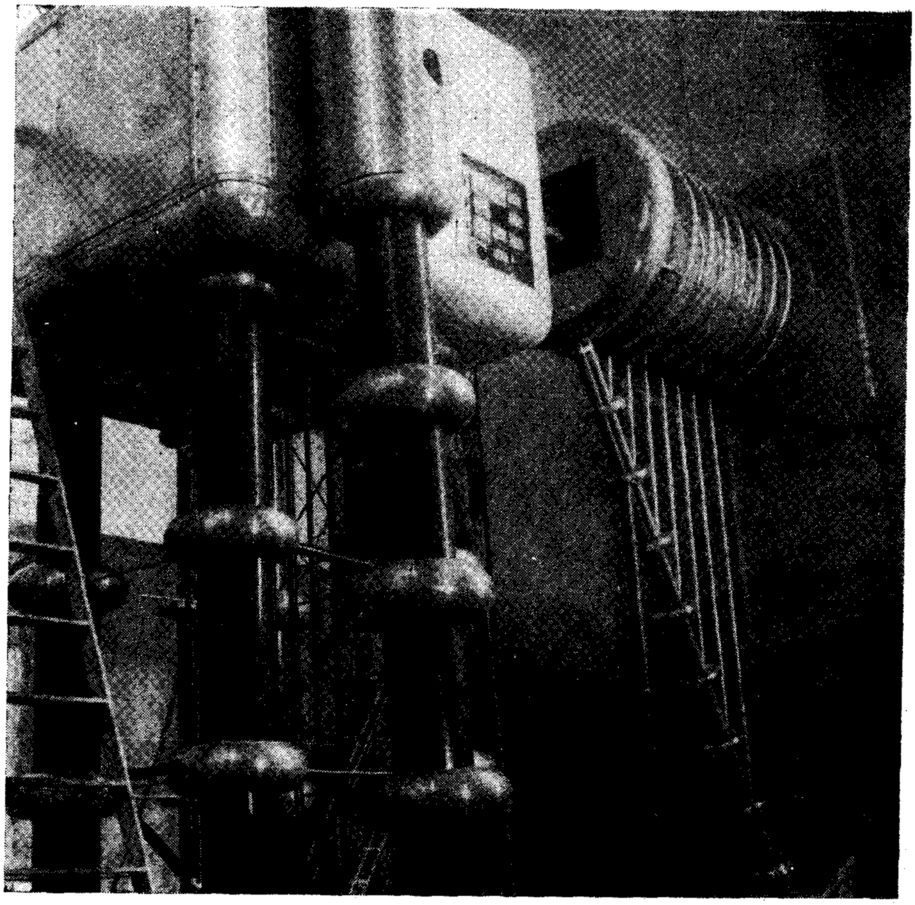

Fig. 2. Accelerating column installed in linac research building.

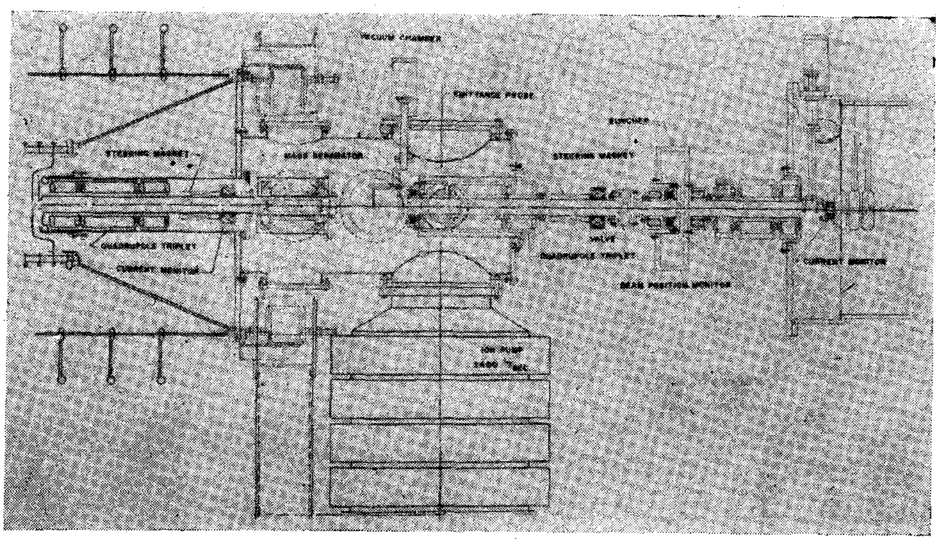

Fig 3 750 keV beam transport.

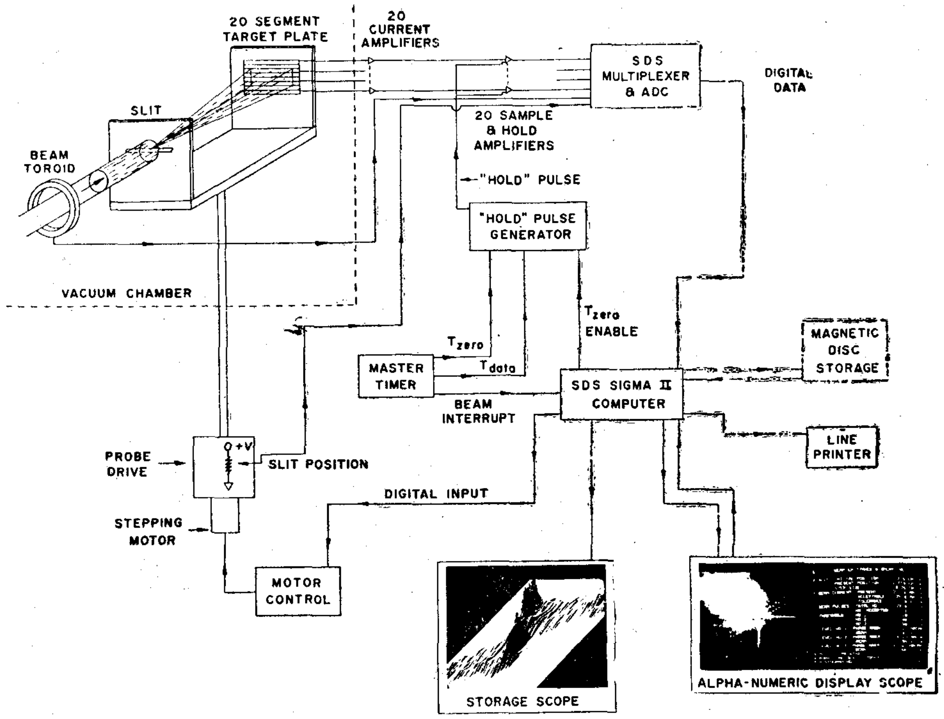

Fig 4. Emittance measuring equipment

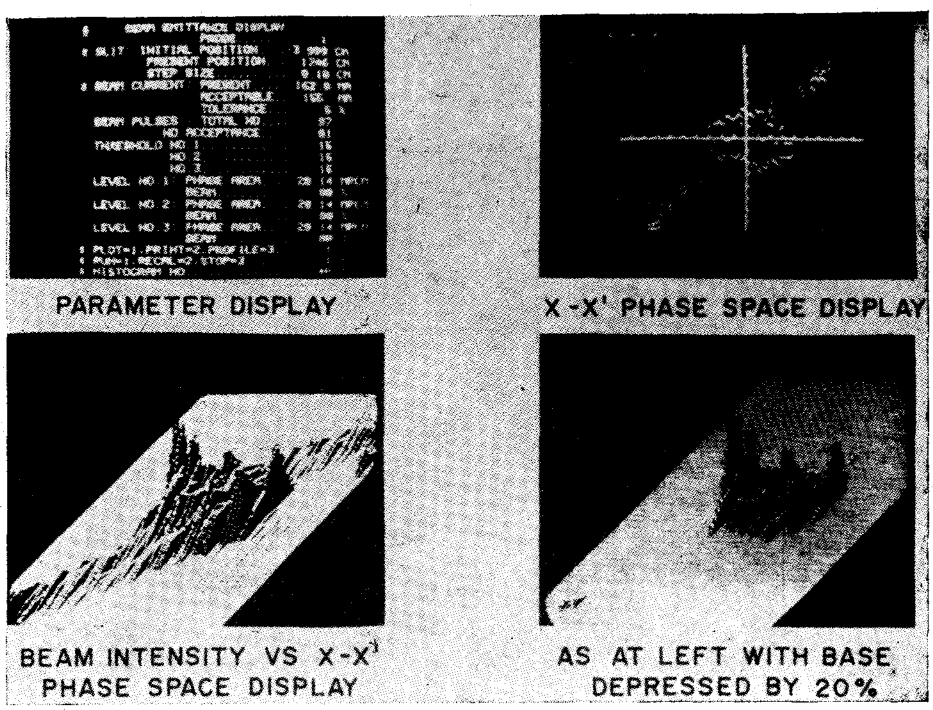

Fig. 5. 750 MeV emittance measurment displays

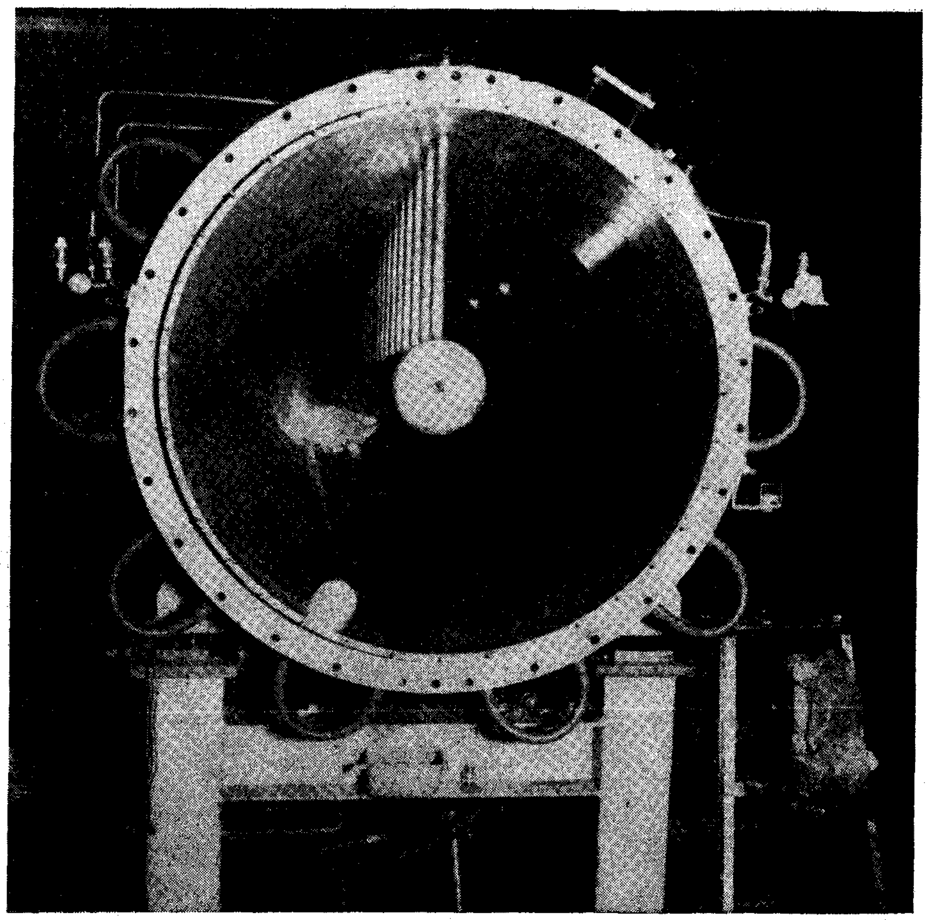

Fig. 6. 10 MeV linac cavity installed in linac research huilding.

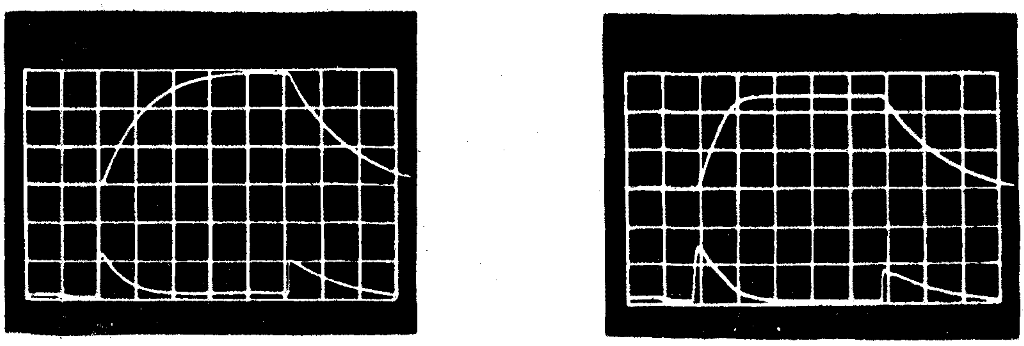

Fig. 7. Linac RF waveforms.

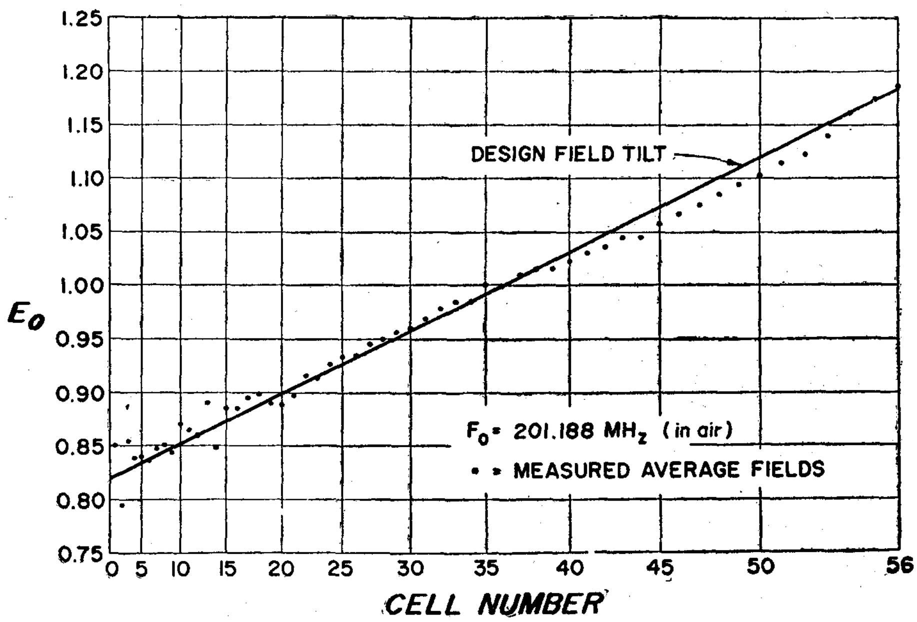

Fig 8. Comparison of measured and design fields in 10 MeV cavity.

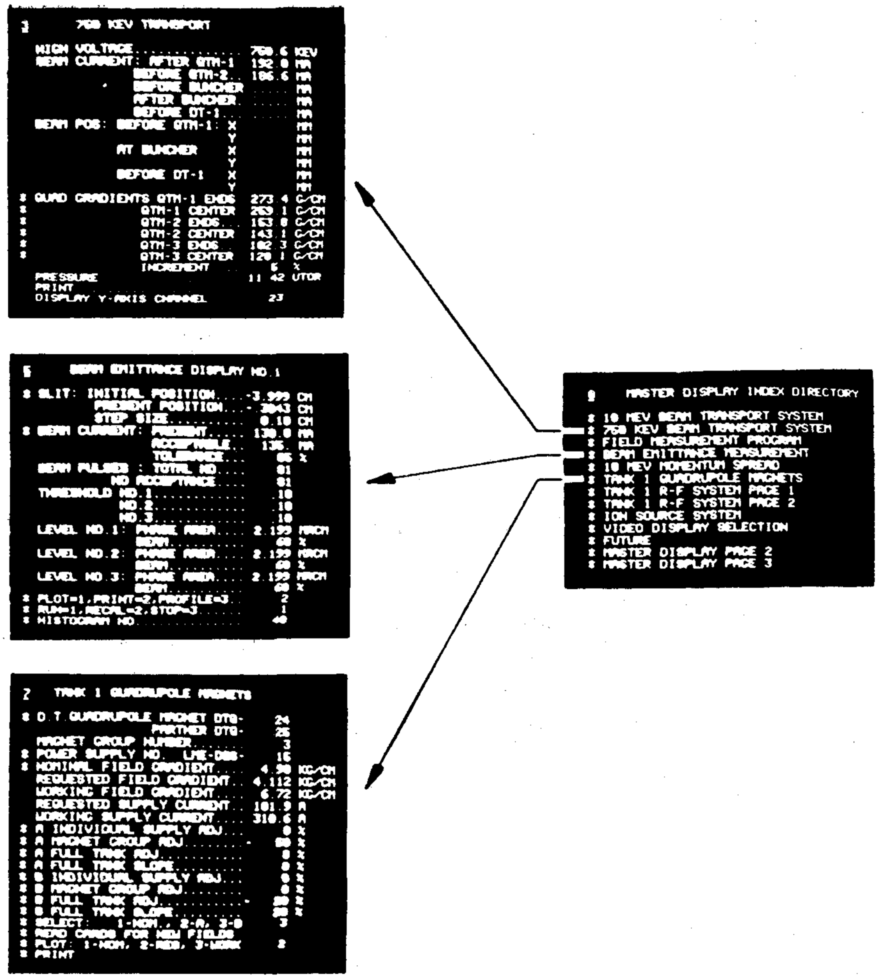

Fig. 9. Control system parameter displays.

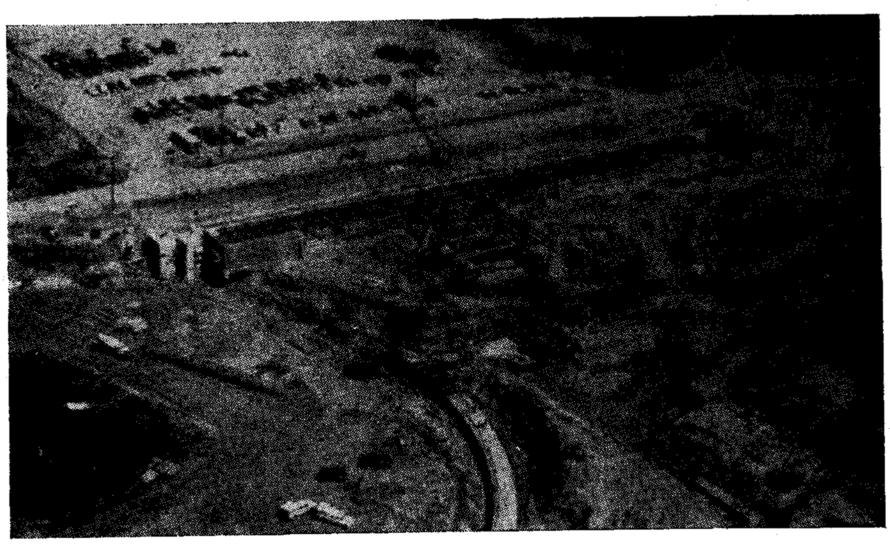

Fig 10. 200 MeV linac building, aug. 1,1969.