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Quarterly Status Report on the
Medium-Energy Physics Program
for the Period Ending January 31, 1967

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I. SUMMARY

Accelerator Structures

201.25 MHz

The 4-ft Alvarez accelerator tank has been operated at > 220 kW peak power and 5% duty factor (DF). The peak power input produced field gradients slightly greater than the design gradient of 2.4 MeV/m. Following rf conditioning, hydrogen purging and warm water bakeout, the base pressure, without rf power, is $\sim 4 \times 10^{-8}$ torr. At half power, the pressure stabilizes at 2×10^{-6} torr. The x-ray level at full power does not appear to be excessive. Experience thus far indicates that the basic design criteria incorporated in this model are satisfactory. Calculations and experiments are being pursued relevant to the design and fabrication of the quadrupole magnets and power supplies.

805 MHz

Model L, a 1-m, 5-cell, $\beta = 1$ side-coupled accelerator tank has operated successfully at 150 kW peak power, 1.5% DF, and 25 mA peak current. There is no evidence for beam-induced difficulties, such as sparking or window breakdown. This model will be taken to higher average beam powers.

Model K, a 61-cell, $\beta = 0.65$ side-coupled tank, consisting of five separate sections, has been successfully brazed, assembled, mounted, and aligned in the Mockup Building. The separate sections will be driven through a resonant bridge coupler which has been fabricated. The cooling system has been installed in preparation for operation of this model.

Although beam dynamics calculations of the longitudinal and radial motion of electrons in a standing wave linac cavity are being continued, the basic design has been completed and fabrication has started on the components of the 60-ft electron prototype accelerator. Die fabrication and forgings are being done at

LASL. The contract has been placed for machining clamshells and main cells.

RF Power Sources

201.25-MHz Systems

The first 3-MW, 7835 cavity which will serve as the main amplifier in the Alvarez section has been completed by Continental Electronics. Delivery of the cavity is expected shortly. All components necessary for testing this amplifier, including filament supply, modulator, condenser bank, cooling system, water load, fault protection devices, and driver amplifier are all in readiness. The driver amplifier is already being used to power the 4-ft Alvarez model at 5% DF and at peak powers up to 200 kW.

805-MHz Systems

Difficulties at the RCA plant continue to plague the Coaxitron development program. Two of the newly designed tubes failed at RCA--one during processing and the other during 6% DF testing. The second failure may have been due to inadequate window cooling.

In contrast, the Coaxitron at LASL continues to function well, although it is not being operated at full power and duty factor. It has been used to drive Model L through a waveguide run of ~ 200 ft. The long waveguide presented no operational difficulties.

The Litton program to construct a 12%-DF, $1\frac{1}{4}$ -MW klystron for test and evaluation appears to be on schedule. The tube should arrive at LASL in March. An Amplitron of similar characteristics is promised by Raytheon for delivery in April.

Extensive tests with two 100-kW Amplitrons in series produced inconclusive results on the stability and control characteristics of this tube. Reasonably stable operation into a resonant load was demonstrated, but at reduced gain.

The 8618 high-power modulators which have had a good history of operation have, following design changes at the factory, shown excessive failure rates. This program will be backed up by developing modulators around other available tubes.

Accelerator Control and Instrumentation

During the past quarter a considerable effort was devoted to development of software and interface hardware for testing the computer control concepts on prototype modules. The software activities were facilitated by the completion of a simulator program whereby the MANIAC is used to assemble and run SEL-810 programs.

The SEL-810A prototype control computer has been delivered. Many of the computer programs were checked out before the computer was shipped from the vendor's plant. This served the dual purpose of permitting the debugging of both the vendor's computer and LASL-constructed programs for its utilization.

Prototype models of the computer interface equipment and the module remote control equipment have been fabricated and are ready for installation and testing.

A remote control system for operation of all elements of Model L, the 4-ft electron accelerator, has been completed.

The problem of x-radiation monitoring is being studied anew as increasingly stronger sources of radiation are being brought into operation from 805- and 201.25-MHz structures. A number of monitoring systems have been evaluated for use in the high-intensity pulsed radiation fields which will comprise one of the major hazards.

Accelerator Physics

Specifications for the Cockcroft-Walton injector have been developed for the purpose of soliciting bids for a prototype unit. A prototype

ion source and high-gradient column for operation at 200 kV are in process of fabrication.

The beam characteristics in the low-energy part of the linac have a profound effect on the overall beam dynamics. Programs have therefore been developed for computing the effect of space charge forces on the motion of particles in the transport and buncher system following the injector, and also in the Alvarez section.

Analog experiments indicate that by adding small dipole fields to the quadrupole magnets the magnets may be used for steering and beam alignment.

Project Scheduling and Facilities Planning

Foundation studies on Mesita de Los Alamos are nearing completion. Thus far it appears that there will be no unusual requirements on the foundations to maintain alignment of the accelerator and of equipment in the experimental area.

Design of the site and utilities (except electric power) has been completed and bids for this package have been received.

Title II engineering is more than 85% complete for the injector and Alvarez structure buildings. Design criteria have been established for the laboratory-office building, to assist the A-E selection and negotiation panel. Another panel has been appointed to formalize the criteria to be used in soliciting and evaluating proposals for supplying LAMPF with electrical power.

Designs have been completed and construction has started on the electron prototype accelerator building. The ground has been prepared and most of the shielding is in place.

II. ACCELERATOR STRUCTURES

Introduction

Model K, a 61-cell, side-coupled tank with optimized shunt impedance, has been constructed and installed in the Mockup Building; tuning of the tank is under way. A bridge coupler is being constructed for this cavity.

Model M, a 6-cell, graded-phase-velocity electron accelerator, designed as an injector for the Electron Prototype Accelerator (EPA), is undergoing brazing; completion is scheduled for the next quarter. No difficulties have been encountered in extending the side-coupled accelerator principle from periodic systems to this tapered-phase-velocity system.

Beam dynamics calculations are under way for the EPA, to investigate the longitudinal and radial motion of electrons in a standing-wave linac cavity system. The longitudinal motion study has led to a final design with optimized spacings between cavities along the beam line. The 100-cell section of EPA will be split into four 25-cell tanks bridged with bridge couplers. The 25-cell tanks will have identical cells cut for a particle velocity equal to that of light; any particle slip will be adjusted by properly choosing the distance between tanks. Mechanical design of the EPA is being continued.

Model L, a 1-m long, 5-cell, side-coupled accelerator tank with $v_p = c$, has been run successfully at low power (150 kW peak, 1.5% DF) with a high-current (25 mA) electron beam. No evidence of beam-induced sparking or window breakdown has been observed in these preliminary tests.

The 4-ft Alvarez accelerator tank has been run at > 220 kW peak power and at 5% DF, corresponding to field gradients slightly greater than the design gradient of $E_0 = 2.4$ MeV/m. Studies of temperature stability, frequency stability, x-radiation from the tank, and component performance are under way.

The drift tube quadrupole magnet design program is being continued. A computer program has been written to help design the magnets, and studies have been completed to investigate the effects of the proximity of the up- and downstream magnets on the fields of the quads.

The LALA computer program has been used to investigate the variation of shunt impedance with beam aperture. In the low-energy portion of the 805-MHz accelerator a gain of as much as 40% in shunt impedance is available if the aperture is reduced from 3.8 to 1.8 cm.

805-MHz Accelerator Studies

Model K (61-cell, $\beta = 0.65$ side-coupled tank)

Assembly: The Model K accelerator tank, consisting of five separate sections, has been successfully furnace-brazed, assembled, and mounted on its support structure in the Mockup Building. Prior to assembly, each tank section was joined to its vacuum manifold by heliarc welding the pumping nozzles as shown in Fig. 1. The Model K tank partially assembled, with Model F tank in the background, is shown in Fig. 2. Each tank section was joined to the next at the mechanical rf joint which functions both as a rf electrical connection and a metal-to-metal vacuum seal. All four joints were vacuum-tight after assembly. Alignment of the tank sections was performed using an optical tooling jig transit and a self-centering target holder shown in Fig. 3. Once the first tank section was positioned on the line of sight, the knife-edge joint functioned as a pilot for the next tank section. Each tank section's free end was positioned with the target device placed in the center bore hole.

The alignment mounts provide restraint to keep the tank on line and at the same time allow for longitudinal tank movement due to thermal expansion.

Fig. 1. Tank section of Model K joined to vacuum manifold.

Fig. 2. Model K tank partially assembled. (Model F tank in background.)

Fig. 3. Self-centering target holder.

Bridge Coupler: All parts for the resonant bridge coupler for Model K have been fabricated. The coupler is now ready for assembly by furnace-brazing.

Cooling System: Plumbing, pumps, controls, etc., for cooling Model K have been installed as designed. The equipment is ready to be tied into this model after the cooling tubes are attached, upon completion of the tuning process presently under way.

Tuning: Initial tuneup procedures are being continued for Model K. A least-squares fit to the mode spectrum data indicates that the coupling cells are ~ 804.95 MHz whereas the $\pi/2$ mode is at 804.8 MHz. A leeway of ~ 200 kHz was allowed on the accelerating cells for tuning so that the $\pi/2$ mode can be made 805.000 MHz at operating temperature under vacuum. The coupling cell frequency is satisfactory.

The coupling iris is being enlarged to match Model K to the waveguide power feed. The drift tubes of the center cell, in which the coupling iris is cut, have been hand-machined

with a specially made tool to compensate for detuning caused by the iris.

The voltage standing wave ratio (VSWR) at the input to Model K has been reduced to 1.4:1, undercoupled. The ceramic vacuum window which will cover the iris is expected to increase the coupling slightly; as soon as the window is installed, the matching will be finished.

A preliminary tuning run has been made to correct for differences in cell frequency remaining from the prebrazing tuning. Each cell in sections A, B, D, and E was tuned to minimize the field in the preceding coupling cell. A bead pull indicates a peak-to-peak unflatness of $\sim 3\%$ for Model K.

Model M

Tuning: The prebrazing tuning of Model M (a 6-cell graduated β model) has been completed. The waveguide coupling iris has been cut in cell No. 4 and the cell retuned to compensate for the detuning effect of the iris. The iris was cut to a diameter of $3\frac{1}{8}$ in. to minimize the amount of cutting of the iris and retuning of cell No. 4 which must be done after brazing.

Initially, provision was made for varying the cell-to-cell coupling constants to permit flattening the field levels. This proved to be unnecessary as the model is nearly flat--using equal peak field amplitudes in each cell as a flatness criterion--and the coupling slots in each cell are identical.

Solenoid Magnets: The design of solenoid magnets for Model M has been started. The Zia Co. will wind one coil for testing; if the coil performs as expected, three more coils will be wound and installed on Model M.

Dynamics: The WATUSI program, which investigates the acceleration of particles through various field configurations without considering radial motion (equivalent to assuming on-axis

particles), has been used to predict the behavior of Model M at various average field levels (E_0) from 1.0 - 2.0 MeV/m. Optimum performance was obtained at 1.65 MeV/m, but 1.5 MeV/m (the design value on the basis of an assumed field shape not quite the same as for the real cells) is satisfactory. Some 40% of a continuous stream of incoming electrons at 100 keV are captured in a bunch with $\pm 15\%$ energy spread at output (from 1.0 to 1.3 MeV). A comparison with the particle dynamics program, LINDY, gives good agreement for on-axis particles. The LINDY program, which has been used to investigate the radial motion in the Model M fields, uses the field output from LALA and numerically integrates the motion of a particle through the cavity. For a continuous stream of electrons 0.5 cm off axis, LINDY indicates some 30% will be bunched and will emerge without hitting the drift-tube wall.

Electron Prototype Accelerator

Dynamics: The WATUSI program has also been used to determine the length of the bridge coupling cells for the EPA. To simplify the construction of the EPA it is desirable to have all cells designed for $\beta = 1$ (18.62 cm long). Since the incoming electrons (from Model M) have an energy of ~ 1.3 MeV, corresponding to a β of 0.96, the bridge coupler lengths and the Model M to EPA phase difference must be optimized. By optimizing these factors for an average field gradient E_0 of 1.5 MeV/m, good efficiency of operation is possible over a range of 1.0 to 2.0 MeV/m gradients for the EPA by simply adjusting the phase of Model M relative to the EPA through a $\pm 30^\circ$ range from the optimum at 1.5 MeV/m.

Fabrication: The contract for machining the clamshells and segments for the EPA has been placed. This order calls for machining 210 clamshells and 80 segments from LASL-furnished forgings. To date, 40 of the clamshell forgings have been produced at LASL. The forging dies for the segments are presently being fabricated

in LASL shops. The forgings for the EPA Model are being made at LASL on the 5000-T Lake Erie press.

Cooling: Detailed design of the cooling water system from the existing support building to the EPA cavity cooling supply and return headers is under way.

Support and Alignment: Initial design of the nonmagnetic support structure and alignment mounts for the EPA tanks has begun. Final design of the EPA bridge couplers will depend upon results from the Model K bridge coupler installation.

Model L

The setting up of Model L in the iron shield house has been completed. Preliminary runs showed the beam position monitoring quadrants to have inadequate cooling; in one of these runs a beam of ~ 1 mA peak current at ~ 3 MeV was reached before the quadrant failed. An improved model quadrant has now been designed, fabricated, and installed; with it, an unaccelerated pulse of ± 75 mA peak has been focused through the beam-defining apertures onto a Faraday cup at the output of Model L. Approximately half the current leaving the gun reaches the Faraday cup; the remainder is lost mainly at the first beam-defining aperture. Operation has been limited to low-power rf levels. However, a 25-mA beam has been accelerated to ~ 1 MeV for 250- μ sec pulses and at 1.5% DF with no indication of window or cavity sparking.

Alvarez Accelerator Studies

201.25-MHz High-Power Tank

The 4-ft model 201.25-MHz tank has been operated, with all components installed, to full design rf power level at 5% DF. A concrete shield wall has been built for operator protection from the x-radiation emitted by the tank at high

excitation. Thus far, few difficulties have been experienced with the vacuum and mechanical aspects of the model.

Radio-frequency runs, hydrogen purging, and a 110°F "bakeout" with warm water have reduced the pressure to 3.8×10^{-8} torr. At one-half power, the pressure holds at $\sim 2 \times 10^{-6}$ torr.

The water cart has provided adequate cooling for the power level reached. A fairly short cycle $\pm 0.25^\circ\text{F}$ temperature fluctuation occurs, but some of this is due to variations in the mixing water temperature and pressure. Thermocouples have been installed in individual circuits to be used with flow measurements for determining heat loads of the various components.

The drift tube installation was made using a phosphor bronze bellows, soft-soldered to an all-copper seal contact flange. This section was copperplated after soldering. An indium O-ring provides the vacuum seal. Bellows of OFHC copper have been received for use on future seal contact flange designs, so that brazing and welding techniques can replace soft-soldering and plating.

Investigation of sparking across the ceramic window in the drive loop showed a poor contact between the coax line connector and the center conductor of the loop. Correction of this condition has eliminated sparking at the present operational level. Development of the all-metal seal system to eliminate elastomers in the loop has been continued. The copper-plated steel plug was unsuccessful due to a dimensional error made during machining. A second plug is now being plated.

The tuning slug operation has been satisfactory. Tuning range varies greatly, depending on the cavity configuration. The range of the slug in an empty cylinder, i. e., with no drift tubes, is 226.8 kHz. With drift tubes and the slug centered on the drift tube, the range is 138.6 kHz. With the slug centered on the gap

between drift tube and half drift tubes, the range is 105.5 kHz.

During power runs, there was indication of field breakdown and multipactoring within the cavity. Upon letup to atmosphere, only two obvious breakdown or multipactoring areas were discovered. The face of a copper plug in an unused part was discolored and "tracked." Also, a maroon-colored coating was found on the monitor loops. An x-ray powder diffraction photograph showed the coating to consist of three detectable crystalline phases: Cu_2O , Cu (metal), and CuO .

A Pyrex window was installed so that further breakdown might be detected. During a subsequent rf run, no sparking or flashing was observed.

For the field strengths and power levels reached so far, all designs appear satisfactory. No discoloration due to arcing was discovered at any of the rf contacts.

Quadrupole Magnet Design

A computer code, QADFLX, was written which, given gradient, quadrupole magnet geometry and adjacent magnet spacing, determines (and plots) the flux density in the pole tip and yoke. This code used equations developed at Berkeley by E. L. Hubbard, in which he was able to predict flux densities in the poles within 10% of measured values. The equations were extended to include the necessary radii on the pole and yoke edges.

This code should prove to be extremely valuable in optimizing the quadrupole cross sections in the 144 drift tube quadrupole magnets throughout the accelerator. The basic linac design dictates the pole radius and yoke diameter in each of the four tanks. The quadrupole magnet groups previously established¹ were incorporated in this program. Utilizing the grouping criteria, the quadrupole cross section was altered in order to match the flux densities

in the pole tip, pole base, and yoke. The resulting design will operate at maximum flux densities of 12.7 kG in the first magnets of tank No. 1 and < 2 kG in tanks Nos. 3 and 4. Other gains worthy of mention are weight reduction in the magnet iron of up to 6% compared with earlier designs, and correspondingly shorter coils.

Properties of the quadrupole doublet designs proposed for the 805-MHz section were investigated along with designs presently in use by other establishments in order to obtain a feeling for the various geometries.

Quadrupole Magnet Measurements

Field surveys were conducted on three early-generation (3-turn) quadrupole magnets spaced to model the conditions induced by the adjacent magnets in the magnets in tank No. 1. Numerous surveys of the center quadrupole were made with a Hall-type gaussmeter probe accurately positioned by X, Y, and Z slides and motor driven along the scanned axis. An X-Y recorder was used to plot the flux density vs axial position. Axial scans with the probe positioned 1 cm off-axis were made at various currents, and radial scans at various axial stations revealed a very linear field distribution. The field measurements showed that even these early-generation magnets are capable of delivering 130% of the required quadrupole strength based on the present linac design.

Another program was designed to investigate the effect of quadrupole magnet spacing on the axial field distribution. Traces were made with gaps of 3, 3.5, 4, 5, and 6 cm between magnets. From these data the gradient in the quadrupole magnet design equation can be replaced by an empirical term that more accurately describes the gradient distribution than does the rectangular approximation frequently assumed for analytical purposes. Currents predicted by the modified equation to achieve a given quad strength are within 6% of measured values.

A low-energy, four-turn quadrupole magnet and a high-energy, three-turn magnet have been fabricated. The coils have been wound with available copper tubing, installed, and are ready for preliminary field measurements.

The coil-coating program has proceeded as well as can be expected using copper refrigerator tubing. The OFHC conductor is scheduled for delivery early in March. Porcelainized coil samples potted in cement and coils covered with woven glass fiber tubing have been prepared but have not yet been evaluated for bond strength and susceptibility to hydrogen-firing.

Computer Studies

Radial Motion of Electrons in Model M

The radial defocusing to be expected in Model M without a focusing solenoid is being studied, by means of the LINDY code. Unfortunately, as the code is set up, it is necessary to use electromagnetic fields as computed by the LALA code, and only a few particles may be studied per computer run. Consequently, the calculations are slow. Procedures are being developed which are faster and which permit the incorporation of data from experimental measurements of the spatial variation of the fields.

The WATUSI code indicates that about one-third of the injection phase space is susceptible to capture and bunching. Thus far, the LINDY code shows that about three-fourths of the electrons bunched are not lost radially in passing through Model M.

Long Waveguide Tank with Multiple Drives

The computed shunt impedance of many waveguide sections coupled together to form a long tank with multiple drives shows an increased sensitivity to tuning errors in the coupling cells relative to the waveguide sections operated independently. For a few sections taken together, the sensitivity to tuning errors in the

coupling cells is so low that the degradation is not important. For as many sections as would be required in an 800-MeV proton accelerator, this sensitivity to tuning errors in coupling cells is likely to be prohibitively high. It has been found that imposing the constraint that the average main cell frequency error and the average coupling cell frequency error both be zero does not eliminate the sensitivity to coupling cell frequency errors. Sample calculations and details of the method of calculation and use of the computer code have been presented in a technical memorandum.²

Determination of Cavity Parameters from Mode Spectra Data

Methods have been worked out for calculating individual cell frequencies and near-neighbor coupling constants from mode spectra data for chains of two or three main cells (three or five cells total). The procedures are based on analysis of the circuit analog.³ It appears that the methods should be used with caution, however, since the results are very sensitive to errors in the measured data.

Alvarez Linac with Multistem Drift Tubes

The mode frequency separation to be expected in an Alvarez linac with multistem drift tubes has been studied using the circuit analog for a chain of coupled cavities. In the circuit analog view, the cells of the Alvarez structure were represented by main cell resonators with coupling cell resonators in between. The latter represented the effect of resonating the space between the drift tubes and the cavity walls. The coupling cell frequency was lower than that of the zero mode, and thus gave rise to a passband below the normal operating mode. The normal zero mode of the Alvarez structure was then analogous to the $\pi/2$ mode of a biperiodic waveguide structure as far as mode separation is concerned. The use of multiple stems may be contrived to

reduce the stop band between the normal zero mode and the lower passband.

Calculations were made with a narrow stop band and with the coupling cell frequencies tilted to represent nonuniform geometry of the drift tubes. The main effect of the tilt was to excite the odd-numbered modes which are suppressed by driving the Alvarez tank in the center. The effect became greater for modes higher than the zero mode. With such a passband below, the normal zero mode exhibits the insensitivity to coupling cell frequencies of the $\pi/2$ mode of a biperiodic structure.

LALA Studies

The six cells of Model M were investigated with the use of the LALA program. Drift tube lengths were adjusted to give 805 MHz. Experimental data on cells with the LALA-designed drift tube lengths confirmed that the actual resonant frequency was 805 ± 1 MHz, before the coupling slots were cut. The effect of the coupling slots was to drop the resonant frequency of the cavities ~ 10 MHz.

Another problem was to optimize the shunt impedance for a cavity of $\beta = 0.45$ by varying the beam hole size r_H (see Fig. 4) from 0.9 to 1.905 cm for various cavity radii r_{max} . Although construction of the family of curves is still in progress, the curve shown in Fig. 5 indicates an increase of 42% in shunt impedance may be available if this change is feasible.

An investigation was made of the shunt impedance as a function of r_2 (see Fig. 4) for $1 \leq r_2 \leq 4$ cm. There was little change in the shunt impedance within this range of r_2 values.

Present problems in progress include optimization of the shunt impedance as a function of r_H , θ , r_1 , and r_{max} .

Fig. 4. Quarter cross section of a shaped linac cavity.

Various auxiliary computer programs were written to eliminate much of the preliminary hand calculations and manual card punching called for previously. Preliminary setup time has been reduced 60% by using these programs.

Instrumentation and Related Equipment

Beam Current Monitors

A beam current monitor made by winding a coil of 450 turns on a tape-wound torus of 2-mil supermalloy has a measured sensitivity of 8 mV/mA with 10% droop into a 5-k Ω resistor during a 500- μ sec pulse.

A modified "White Cathode Follower" was built with an output impedance of 5 Ω which gave a voltage gain of about 0.90 into a 50- Ω load to permit driving a long cable with the beam current pulse. A housing for this torus is being fabricated.

Fig. 5. Shunt impedance of linac cavity vs r_H . ($r_{max} = 13.9$ cm)

Beam Position Monitors

A study is being made of various beam position monitors. Methods used at other accelerator facilities are being compared as to sensitivity, accuracy, convenience, stability of calibration, and cost.

Of particular interest is the SLAC system to extract integrated position information using resonant cavities, diode detectors, 4-arm bridges, and d-c logarithmic amplifiers. Also under consideration is a real-time sampling system to provide instantaneous position information over a 60-dB range of beam currents using resonant cavities, heterodyne detectors, and a logarithmic IF amplifier.

RF Amplifier

The 3-tube 805-MHz rf amplifier has been completed and is ready for mounting with a power supply for experimental use. The 3-dB bandwidth is ~ 5 MHz at 805 MHz. The amplifier has a 30-dB gain at

805 MHz and at 820 MHz, the upper frequency limit. At the practical lower frequency limit of 700 MHz the gain is 39 dB. The tuned circuits have twice the bypass capacitance at the ground end as the first version of this amplifier, which tuned from 750 to 805 MHz. The increased capacitance has moved the tuning range of the present amplifier to a somewhat lower frequency than expected. The improvement in mechanical stability is significant, and tuning is not noticeably affected by bumping or shaking the chassis.

Regulated Power Supply for Quadrupoles

Construction on the 15-V, 1500 A-dc regulated power supply has been completed and a number of tests were made. With the supply connected to a 0.0144- Ω load, the maximum output current was 900 A (13 V across load). This was with a 3-V drop across the regulating transistors which proved necessary for acceptable filtering of the 360-cps ripple of the power supply.

The supply successfully delivered 1500 A to a 0.0023- Ω load (3.5 V across load). Since the effective voltage drop through the supply at 900 A is 3.8 V, and the fact that at least 3 V across the regulator transistors is needed for acceptable filtering of the output current (see waveshapes in Fig. 6), the maximum output voltage at 1500 A will be ~ 11 V. Transient spikes at a frequency of 360 cps are seen in the figure. At 1500-A output current, peak value of these spikes is about 60 mV on a dc level of 3.5 V. With improvement of the high-frequency response of the control circuit, the amplitude of these spikes should be lower.

References

1. E. D. Bush, Jr. and D. R. Copenhagen, "Grouping Criteria for 201.25 MHz Linac Drift Tube Quadrupoles," Internal Tech Memo MP-3/EDB/DRC-1, 8/11/66.

Fig. 6. Wave forms of 15-V, 1500-A, dc regulated power supply.

2. G. R. Swain, "Degradation of Long Tank Performance with Tuning Errors--Summary of Calculated Results," Internal Tech Memo MP-3/GRS-5, 12/2/66.
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III. RF POWER SOURCES

Introduction

The cascade arrangement of two Amplitrons was studied experimentally; the results were often confused by the tendency of the second tube to oscillate. However, reasonably stable operation into a resonant load was demonstrated. Following this work, the second tube was dismantled at Raytheon and it was found that, in the course of brazing, the cathode had been severely poisoned and the anode cooling was so ineffectual that the surface of the anode structure had melted. Under these conditions, it is surprising that the tube was operational.

Hot-testing of the 1.25-MW klystron is scheduled to start at Litton in Feb. 1967.

Two of the redesigned Coaxitrons failed at RCA; one during processing and the other during 6% -DF testing.

Three methods of crossing the high-voltage interface in the modulators have demonstrated response times of order $1 \mu\text{sec}$. The 8618 tubes used as the modulating element have suddenly shown an excessive failure rate; development of modulators using alternative tubes has been started.

The 200-MHz intermediate power amplifier (IPA) has been used to drive the 4-ft Alvarez model at power levels approaching 200 kW. The cavity assembly for the final power amplifier (the 7835) was completed at Continental Electronics and will be shipped to LASL in February.

RF Control Studies

Overall System Design

A program was initiated to prepare the Amplitron test stand in the Mockup Building for automatic operation by the central control computer. The steps necessary for turning on and off the stand were listed in detail from the water, air, and high-voltage yard systems

through turn-on of the klystron IPA, modulator, crowbar test, and full rf operation. All interlock checks were included. This listing will provide the basis for writing a supervisory control program. In performing this function, the computer will receive and process a great deal of binary interlock data, as well as some analog data concerning such things as proper high-voltage dc levels.

In addition, the capability of monitoring and sampling analog signals during the pulse is being reviewed, with the goal of allowing the control computer to automatically cycle the stand through its operating range, gather amplifier data, and process and display the results.

RF Frequency and Phase Control Studies

Development work has been concentrated on a transistor-varactor version of a multiplier chain. Preliminary studies of varactors indicated that tripling utilized most advantageously the efficiency of a varactor without serious compromise in stability and purity of output. Also, tripling to 201.250 MHz made it possible to use a starting frequency of 2.484567 MHz which is near enough to the 2.5 MHz commonly used in the better crystal-controlled commercial frequency standards so that adjustment of the required standard is not a problem. Based on these considerations, a multiplier chain has been completed which uses 5-W transistor drivers into varactors acting as triplers. Thus, the fundamental frequency of 2.484567 MHz from the crystal standard is multiplied to 201.250 in four stages. The derivation of 805 MHz will call for a quadrupler or two doublers from the 201.250 output; however, power transistors currently available become so inefficient and unpredictable above a few hundred MHz that it now appears more practical to use two 201.250 drivers, one followed by a varactor doubler and the other by a varactor quadrupler, to derive 402.500 and 805-MHz frequencies. These last two stages

are currently under development. Preliminary studies of the solid-state multiplier chains indicate that they will be inferior to the tube versions insofar as stability and purity of signal are concerned.

As indicated in the previous quarterly report (LA-3624-MS), there were unwanted components in the driver output spectrum for the 201.25-MHz IPA. Therefore, a new tunable driver with a 25-W output and 35-dB gain was designed and built. It has sufficient gain so that it can be driven by a conventional signal generator (5-mW or less output) and is tunable from 170 to 280 MHz which will cover the extremes of frequency that may be required in experiments on tank structures.

Amplitude Control

An investigation has been initiated of closed-loop rf drive modulation for amplitude control of klystrons. Integrated circuit control amplifiers are being used in conjunction with a PIN-diode rf modulator. The integrator-gate generator has received particular attention, in order to understand better the diode-matching problems and the effects of transients generated in the diode portion of the gate.

805-MHz Power Amplifiers

Coaxitron Program

Operation: The Coaxitron has been used to drive Model L as an electron accelerator. The waveguide run between the two components is about 200 ft; although this is rather long, no operational difficulties have been experienced.

Theoretical Program: Analysis with the LALA code of a series of Coaxitron cavity configurations, ranging from a bench-test cavity to the final RCA design (idealized for cylindrical and axial symmetry), mentioned in the preceding report, has been completed and the field distributions and resonant frequencies

have been determined. Although the absolute frequencies computed cannot be expected in the working tube (which is not axially symmetrical), the relative trend is of interest. The final design resonates at 817 MHz, according to LALA. The bench-test cavity, machined to match the final RCA design including departure from axial symmetry, is found to resonate at 850 MHz. This frequency was independent of whether the cavity was excited at the center of the grid-anode space or at various peripheral points. Thus, both the LALA computation and the test cavity indicate that the final cavity design may be resonant somewhat above 805 MHz.

Another computer code, COAX, was then applied in an attempt to predict the efficiency of the Coaxitron cavity. This requires, unfortunately, a large number of assumptions. First, the plate voltage-plate current characteristics of the tube received and tested last summer were assumed to hold for the new tube. Furthermore, the field distributions given by LALA are normalized and must be quantified or scaled in terms of an expected rf plate voltage swing. A simple Class C amplifier calculation, assuming 120° conduction angle and 40% efficiency, indicated an rf swing of $\sim 75\%$ of the dc anode voltage. This was used to scale the LALA magnetic field numbers. The information was put in the COAX code and the efficiencies were calculated for a wide range of dc anode voltages. The results are plotted in Fig. 7, which also shows the frequencies determined by LALA for several iterations.

The efficiencies follow remarkably well the trend of the curve measured in 1965.¹ The difference is even less than shown if allowance is made for 10-15 kW of circulating current dissipation in the cavity walls, a factor not accounted for by LALA in the Coaxitron application. It should be noted, however, that the LALA efficiencies are at 815 MHz whereas those of the published curve are at 805 MHz.

Fig. 7. LALA frequencies and efficiency computations for the Coaxitron.

The indication is that a properly tuned Coaxitron should develop efficiencies near 45% at full power. This is substantiated by the test results on the Rieke diagrams in the last quarterly report, where it was shown that efficiencies of 42-48% may be possible with optimum matching from the active region through the output sections to the load.

Test Stand Modifications: The drawings for the new Coaxitrons (15191B) have been reviewed and appropriate mounting hardware is being procured. A new filament power supply was completed, tested, and installed. A new screen room was also installed.

Procurement: The first of the 15191B Coaxitrons was tested at RCA and a window failure occurred at the several-hundred-kW, 6%-DF level. This may have been caused by

insufficient window cooling. The second 15191B was inadvertently let down to air by an accident with the filament supply during processing.

Klystron Program

1.25-MW Test Stand Construction: The capacitor bank is complete and high-voltage switches and cables are being installed. The modulator is complete and has been given preliminary high-pot and pulse performance tests. An overhead crane has been installed for assembling the klystron, magnet, and modulator. The water system connections are essentially complete.

Theoretical Program: Because of the similarity between the linac 805-MHz cavities and the cavities on Litton's 1.25-MW klystron design, the LALA code is being used to determine the fundamental klystron cavity characteristics, namely, resonant frequency (without beam loading), field distributions, Q , and ZT^2 .

Procurement: Brazing of the subassemblies of the first 1.25-MW klystron has been started. The first tube should go to exhaust shortly and the performance tests should commence during February.

Amplitron Program

Performance of 100-kW Amplitron No. 2:

Prior to extensive testing of Amplitrons in series, Amplitron No. 2 was run alone. Unfortunately, the performance was unsatisfactory, as shown by the spectral analyses in Fig. 8 made with a Hewlett-Packard 851B/8551B spectrum analyzer. The spectra are qualitatively correct, but the relative pip heights should be interpreted with care because no effort was made to sweep slowly enough to scan each frequency adequately.

Fig. 8. Top: Spectral analysis of input signal to Amplitron No. 2 (drive level 16 kW). Bottom: Spectral analysis of output of Amplitron No. 2 into resistive load (Amplitron current 2A). Total sweep = 300 MHz in 50 sec; rf duty cycle = 3% with 250 μ sec pulses at 120 pps.

The input from the driver klystron is seen to be quite pure. The Amplitron output, however, shows a large component near 670 MHz, and other spurious outputs near 705, 740, 780, 815, and 850 MHz. The 670-MHz response is at the π -mode of this particular tube; this unwanted excitation is the root of the problem. On many traces, the 670-MHz response was within a few decibels of the 805-MHz response, making impossible a meaningful interpretation of operating data.

Experimentation with the input damping cavity and shunting bars to distort the magnetic field proved successful in obtaining a satisfactory spectrum at some points of the operating range, as shown in Fig. 9. As was found with Amplitron No. 1, however, these measures resulted in lower gain and reduced operating

Fig. 9. Satisfactory spectrum from Amplitron No. 2 after modifications (drive level 60.3 kW, Amplitron current 3A).

range. In the experiments with the Amplitrons in series, Amplitron No. 2 was run with its own input damping cavity and magnetic shunts. Its output was, in general, unsatisfactory in spectral content. Moreover, as will be shown, the phases of mismatches in the system can combine to excite the π -mode preferentially.

After completion of the experiments with the series arrangement, Amplitron No. 2 was returned to the vendor for analysis. The tube was cut open and it was observed that there had been severe overheating in the active region. Melting and pitting of the anode vane surfaces had occurred, with heavy copperplating of about two-thirds of the cathode surface, and solder flow at the joints in the cathode structure. This overheating was a result of an accident during construction of the tube when a furnace malfunction resulted in a prolonged over-temperature heat. The anode did not appear to be damaged at that time. However, the anode vanes in this tube had Monel inserts to eliminate contact between the cooling water and the copper vane. During the overheat, most of the solder joining the Monel to the copper diffused out through the grain boundaries in the vane. The resulting poor contact greatly reduced the heat-transfer efficiency.

Fig. 10. Power output and efficiency of two Amplitrons in series as functions of load impedance at 805 MHz. (Driver power 69.5 kW; sum of Amplitron currents = 16.8 A, near upper current mode boundary.)

Performance of Amplitrons in Series: In most of the work described below, the two 100-kW Amplitrons were arranged as series rf amplifiers. Both or either of the cathodes were driven by the same modulator. Amplitron No. 1 was fitted with an electromagnet, which was left on even when this tube sat idle in the circuit with no voltage on it. Amplitron No. 2 was used with its permanent magnet and shunts as described above. The field provided by the electromagnet was adjusted so that both tubes reached the upper mode boundary at the same voltage.

1. General characteristics.

The performance of a series amplifier driving a reactive load was investigated using the technique described in the preceding quarterly report. The results are shown in Fig. 10. It is of interest to note that the area where the π -mode oscillation is particularly troublesome lies very

near the center of the chart representing load impedance at 805 MHz; the impedance presented at 670 MHz is obviously quite different. Insertion of the Raytheon waveguide bandpass filter was not successful in spoiling the Q of the 670-MHz oscillation. By suitably adjusting the phase of a nearly matched 805-MHz load, reasonably satisfactory operation can be obtained; this was done for the operating data below.

2. Operating characteristics.

Figures 11 through 16 show the response of the Amplitrons in series to operating parameter changes. In general, the behavior is entirely analogous to that of a single Amplitron and the design approach for the 1.25-MW tube appears workable if the problems with spurious outputs and excitation of other modes are solved.

3. Operation into a resonant load.

With a waveguide run between the Amplitrons and a resonant load (Model F), performance was erratic and unstable. The Raytheon waveguide bandpass filter and a waveguide E-H tuner were inserted. The filter did not appear to be effective, but manipulation of the tuner allowed performance to be obtained as predicted by the Rieke diagram of Fig. 10. That is, reasonably stable operation was possible on one side of the matched position (or resonance), while severe breakup occurred on the other side. No quantitative data were taken.

4. Parallel dc operation of Amplitrons and driver.

Since the 100-kW klystron driver and the Amplitrons run at nearly the same dc voltage, all three were driven in parallel from the same modulator. This would result in considerable system simplification. The operation was quite satisfactory, as shown in Figs. 17 and 18.

The phase shift across the operating range is greater but within the dynamic range of a control system. It may be possible to compensate for some of this increase by driving

Fig. 11. Typical anode voltage vs total current characteristic for two Amplifrons in series.

Fig. 12. Typical gain vs total current characteristic for two Amplifrons in series. (The spurious mode-spoiling measures necessary with both of these tubes are detrimental to gain.)

Fig. 13. RF power output vs rf power input characteristics at constant dc power supplied by the modulator.

Fig. 14. Typical efficiencies obtained for two Amplitrons in series.

Fig. 15. RF power output vs rf power input characteristics at constant dc voltage. (Shows feasibility of using drive modulation to control power output of the amplifier when compensating for beam loading, as an alternate approach to programming the modulator voltage.)

Fig. 16. Change in phase across two Amplitrons in series as a function of the total current. (Slope of curves is the important information; relative levels at different rf power levels are not meaningful.)

Fig. 17. Typical operating characteristics of a series rf, parallel dc arrangement of a klystron driver and two Amplitron amplifiers.

Fig. 18. Phase shift characteristic for a series rf, parallel dc arrangement of a klystron driver and two Amplitron amplifiers. (Zero levels are arbitrary for each curve.)

the modulating anode of the driver klystron with a signal proportional to Amplitron current. In a preliminary experiment, the collector and the body of the klystron were connected together and grounded. A ± 3 -kV power supply was connected between the modulating anode and ground. Figure 19 shows the phase shift obtained at different points in the Amplitron's operating range. The effect of this amount of mod-anode swing on output power appears secondary.

Theoretical Program: Testing of the Amplitron has revealed significant amounts of rf energy appearing as spurious oscillations at

frequencies other than 805 MHz. This leads to the conclusion that the inherent broadband characteristics of the tube as presently designed are not entirely satisfactory in the linac application. An attempt is being made to analyze crossed-field power tubes in order to understand better how their frequency band may be narrowed.

The fundamental criteria which form the basis of magnetron (and Amplitron) design were reviewed and organized in a technical memo.² The equations of motion were then programmed into a hybrid (analog-digital) computer. The program is formulated around a hypothetical tube design which has the electron beam circulating through narrow-band input and output cavities. The analog computer was chosen because of its speed and its versatility as an engineering tool.

The computer is programmed to trace the electron trajectories in cylindrical coordinates, time-scaled by a factor of 10^{10} . The electrons

Fig. 19. Modulating anode phase shift characteristic of the 100-kW klystron driving Amplitron No. 1 (with electromagnet) as a function of Amplitron current.

can be started with any initial conditions of radius and radial or angular rates within the amplitude scaling limitations of the program. Besides computing the nonlinear equations of motion, the program performs two additional functions: (1) it computes the sum of kinetic and potential energy as a check on conservation of energy, and (2) it simulates the presence of input and output gaps through which the electron passes repeatedly in its orbital circuit (producing the "reentrant" nature of the device). At the input gap a small amount of rf energy is added which alters the orbital motion of the electrons, causing them to bunch as they progress around the tube. As these bunches pass the output gap, larger amounts of energy are removed by excitation of the output cavity. The electrons then debunch and again pass the input gap after completing their circuit. If net energy is removed from the tube, it will manifest itself as a migration of the electrons toward the anode. They will thus give up their potential energy to the rf field at the output gap while maintaining essentially constant kinetic energy, the latter appearing as heat at the anode.

The purpose of the computer study is to determine, for sample cathode and anode radii, the optimum spacing of the input and output gaps and whether the electrons will, on the average, be captured by the anode, and how fast. To achieve this, electrons will be injected into the input gap with circular orbits but shifted in time relative to the rf field at the input gap. Their motion through the gaps for several revolutions around the cathode will then be plotted for different gap spacings and field intensities to obtain an indication of the power gain of the device.

The program thus far has been applied primarily to understanding the nature of electron trajectories in crossed fields. Specifically, the distinction between "cyclotron" and "Larmor" frequencies and their relation to circular frequency has become clearer. A linear model of the reentrant tube concept, programmed as a separate problem, has been tested by stopping

the computer when the electrons reach the input and output gaps and changing the initial conditions to simulate changes in kinetic energy and then allowing the computation to proceed. The results indicate a general movement of the electrons toward the anode for the injection times considered. At present, an automatic means of achieving these changes in energy is being completed using a hybrid computer which will allow the problem to run continuously. More conclusive results are expected when a large number of electrons can be followed for several circuits through the tube.

Procurement: The first 1.25-MW Amplitron is scheduled for testing during April. Partial assembly of the tube has been made and the electrical design is complete.

201.25-MHz Power Amplifier

Intermediate Power Amplifier

The IPA has been used for power tests of the 4-ft Alvarez model at 5% DF and peak powers as high as 200 kW. The impedance mismatch of the cavity during fill time caused some difficulty with low-frequency oscillations in the amplifier system, but this has now been corrected. Some sparking in the transmission line has occurred near the vacuum window at the tank.

3-MW Final Power Amplifier

Fabrication of the 7835 cavity for the 3-MW 201.25-MHz main amplifier in the Alvarez section of the LAMPF accelerator has been completed by Continental Electronics of Dallas. The plant was visited to obtain familiarity with cavity assembly and disassembly procedures; delivery of the cavity is expected shortly. Virtually all of the in-house preparatory work has been completed. The 72-kJ energy storage bank with its associated crowbar circuitry has been installed. The hard-tube modulator used in the original Amplitron test stand has been modified by the addition of a second Machlett 8618 in parallel with the first to permit a 200-A pulse capability. The 4-V,

7000-A filament supply previously used in the Coaxitron test stand was relocated to the 200-MHz area and a 12-phase, 2.5-V, 3500-A filament supply was fabricated and installed in the Coaxitron stand. A water system fully compatible with a 3-MW, 6% DF operational level was installed. The output of the IPA currently being used to power the 4-ft Alvarez model will be rerouted and used as a driver source. Fault protection logic has been constructed and tested. This circuitry is enclosed in standard Nuclear Instrument Module (NIM) bins and is similar to previous instrumentation, with two important exceptions: (1) integral fault summing and (2) the main monostable gate "on input" is insensitive to high-frequency noise.

Floating Deck Modulator Development

A new 8618 modulator was completed during November 1966 and high-voltage (HV) testing was begun with the new light-pipe assembly crossing the HV interface.

Considerable ringing, 20 kV peak-to-peak for 40-kV dc level, was observed on the leading edge of the pulse. An investigation of the video load showed that it had considerable inductance ($\sim 325 \mu\text{H}$) and that the inductance was inherent in the load design. The load was rebuilt using Globar resistors and now provides a reasonable match at the frequencies of interest. The new load has an impedance of 50Ω with an average dissipation of 10 kW.

After replacing the load, rise-time measurements were begun with each of the interface crossing schemes. The following complete modulator rise times were observed at 100-A output pulse:

	<u>Rise Time</u>	<u>Bandwidth</u>
Light pipe	650 nsec	400 kHz
Pulse transformer	1.5 μsec	160 kHz
RF link	800 nsec	315 kHz

Separate frequency-transfer functions (Bode plots) have been run for the pulse transformer

and the light-pipe interface units. The 3-dB point for the light-pipe is 1.8 MHz and for the pulse transformer it is 950 kHz.

A new series of modulators using the EIMAC 4CW100,000D tetrode are under way. The new modulators will be smaller than previous models. The use of this new modulator tube has been prompted by the failure of eight of the Machlett 8618s in the past four months.

Miscellaneous RF Components

Some experiments call for substantially more signal power at 805 MHz than is available from a signal generator. To meet this need, a compact booster was designed using Nuvistors in a two-stage amplifier. This device has a gain of 27-30 dB with a power output up to 3W. It is therefore capable of boosting the few-mW output of a conventional signal generator to a watt or more. Four of these amplifiers have been completed.

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IV. ACCELERATOR CONTROL AND INSTRUMENTATION

Introduction

The major effort has been directed towards implementation and checkout of the computer system and the control system hardware. A major milestone occurred with the delivery of the SEL-810A control computer on January 21, 1967. Sufficient progress was made in the development of the programs for the computer system so that many of these were checked out on the computer before it was shipped from the vendor's plant. Hence, the computer can be put into operation as soon as acceptance tests have been passed.

Development and checkout of a prototype of the computer interface equipment has progressed to the point where it is now ready for installation. The module remote control equipment is also ready for installation.

Considerable effort went into development and installation of a remote control system for the Model L experimental accelerator. The digital control system for the electron gun was checked out and is now operating satisfactorily along with the other instrumentation and control circuits required for this accelerator.

Development of the instrumentation and remote controls for the Amplitron test stand is progressing. Many of the operational units have required some degree of modification in order to place the test stand under computer control. These modifications as well as the wiring to the module interface unit are about 50% completed.

The master timing system for operation of Model L and the various test stands have been installed and used with a manual control panel. The communications system has been in use for most of the period and is working satisfactorily although the desirability of some modifications has become evident.

Since both Model L and the Alvarez test stand generate a considerable amount of radiation, much effort has gone into providing monitoring for personnel safety and installing various monitoring systems for evaluation in the high-intensity pulsed radiation fields.

Work has been continued on the development and installation of various control and monitoring units in the Central Control Room. Seven racks of equipment have been nearly filled with panels and chassis for the computer control system and for Model L. The Model L equipment is completely hooked up and checked out and installation of the balance of the control equipment is about 50% complete.

Data Acquisition and Control System

Control Computer

Systems Engineering Laboratories, Inc. (SEL), the company building the computer system for the LAMPF Mockup control system, completed integration of all components, except the display scope, in late November 1966. Since no further work on the system was scheduled for two weeks, SEL allowed four LASL programmers to check out programs and look for errors and interactions in the hardware. Despite extensive testing, only three minor errors were detected and were quickly corrected. No interactions were observed and no equipment failures were experienced. These results indicated that a major portion of the system was ready for delivery. However, because the scope unit was behind schedule, the factory acceptance test was slipped two weeks to Jan. 16, 1967.

Prior to the preliminary program checkout, an ordering for the priority interrupt levels was transmitted to SEL for inclusion in the system assembly. Also, a second interface unit and associated input/output (I/O) cable were deleted from the computer order because analyses of programs for the Line Printer showed that it was more economical of core storage to run the

printer from the standard I/O Channel rather than from the Block Transfer Channel.

On Jan. 16 and 17, the computer system (except for the scope unit) passed a factory acceptance test. During the first phase of the test, SEL ran a diagnostic program for each portion of the computer (memory, arithmetic unit, etc.) and for each peripheral unit. The second phase of the test consisted of the successful execution of Octocat, a LASL-written program to be described later.

The computer was delivered on Jan. 21. Installation was begun Jan. 23 under direction of the SEL project engineer. By Jan. 24, all units except the disk had passed a repeat of the factory acceptance test. Acceptance of the disk has been suspended pending a final adjustment by the SEL disk specialist. The scope unit is scheduled for shipping during the week of Feb. 6, 1967.

Arrangements have been made for an SEL instructor to spend a week at LASL giving an intensive course on maintaining the SEL-810A.

Programming

Several of the major systems programs were brought to an advanced stage of development by LASL personnel during the visit to SEL. The Executive and Disk Driver programs performed together to swap several programs from the disk to core and execute them in an orderly manner with other programs already executing in core. These two programs form the heart of the operating system.

The Initialize program provides a way of linking all application programs together into an overall system program. The first version of this important program was checked out and a more sophisticated version is nearing completion.

One of the programs used as a factory acceptance test (Octopus) drives all the electromechanical I/O devices asynchronously

at full speed via interrupts. This program was run earlier at SEL and a more comprehensive version (Octocat) with full checking capabilities was run for the acceptance test.

The software associated with the display system continues under development. The various packages are being written in a modular form so that the system can be brought from one level of sophistication to the next with only minor revisions being required at each transition. A level-1 system is now ready for checkout; level-2 (approximately the Scope Driver) is nearing completion.

The Computer Interface Unit (CIU) Driver, which schedules the operation of the CIU, has been completed, assembled, and documented. This version does not contain the command-data priority feature planned for the final version because it would unduly complicate checkout. Only two sections of software logic need be inserted to provide the priority option and they have been flow-diagrammed and coded. This program, like the scope programs, cannot be checked out until the hardware is available.

The application programs needed to handle operator requests from the console have been defined in detail and several of the programs have already been written.

The serious drawback of the simulator program for the MANIAC, namely its slow execution of assembly programs, has been removed by a special assembly program written for the IBM-7094. The card image of the object paper tape produced on the SEL-810A Assembly Program can be obtained and this can be read into the MANIAC for simulation.

Prototype Computer Interface Unit

The CIU provides the digital logic to decode the instructions from the computer and transmit them to the appropriate accelerator module. The CIU also receives and temporarily stores the data requested from the modules

Fig. 20. Module Data Acquisition and Control System.

prior to transfer into the computer. The CIU wiring and chassis fabrication have been completed. A computer simulator board to simulate semi-statically all command and data signals produced by the computer for the CIU, was designed and wired for the LAMPF digital simulator system. The checkout of the CIU with the simulator board was approximately 50% completed.

The computer interface cable driver-terminator printed circuit boards were completed, the chassis was wired, and the completed chassis was bench-checked. Integration of the CIU system with the computer will start as soon as the computer acceptance tests are completed.

Prototype Remote Information and Control Equipment (RICE)

The RICE contains the digital logic which performs command and data instructions under the control of the CIU. An expandable input/output system (RICE I/O) collects data and performs commands under the control of the RICE. The RICE I/O system is connected to the data and command instrumentation in the module through the Module Interface Unit (MIU). The data collected are transmitted to the CIU by

the RICE unit, whereupon the computer is signaled to collect the data from the CIU. The video control coaxial multiplexer unit (VCU) is also controlled through the RICE unit. Figure 20 is a simplified block diagram of the system.

The RICE unit is a synchronous digital machine consisting of a function detector, address register and decoder, instruction register, binary comparator, pulse output register, and control logic; 63 data channels and 63 command channels can be handled. It should be noted, however, that a binary channel (either data or command) consists of 10 data sources or sinks.

Communication between the RICE and CIU is serial utilizing a minimum number of cables (approximately five). This represents a considerable saving in cable because the CIU resides in the Central Control Room while the RICE units are at module, distributed along the $\frac{1}{2}$ mile of accelerator. Communication between the RICE and I/O chassis is in parallel using a common command and data bus system.

Three functions are recognized by the RICE: command (CMD), data take (DTK), and video channel select for the VCU (VDO).

A CMD function can be either a binary output, e.g., close a relay, etc., or an analog command, position a potentiometer to establish an analog set point, etc. Binary commands are performed on a 10-bit word basis, i.e., each bit of the 10-bit instruction word is simultaneously applied to its respective output. The binary commands control devices which vary greatly in the time required to actuate or release. To accommodate this time variation, a binary comparator examines the state of each device being controlled in relation to the state requested and holds the command until a match is achieved, whereupon the command is released. Analog commands are accomplished by driving pulse motors clockwise or counterclockwise. A pulse command is executed by transferring the count requested into a pulse counter. The control logic allows the number of pulses requested to be routed to the addressed channel on either the clockwise or counterclockwise line. The RICE identifies the type of command channel (pulse or binary) by a signal returned from the addressed channel in the RICE I/O. After identification, the proper action pertinent to that type of channel is initiated. While a CMD is in execution, a signal (Command Busy) is transmitted to the CIU to notify the computer that a command is in execution.

A DTK may be a request for data from either an analog or binary channel. The channel identifies itself as described above, the data are transferred to the data register and are transmitted to the CIU.

The command and data sections of the RICE and RICE I/O are independent of each other to the extent that a DTK or VDO may be performed while a CMD is in execution. This feature is desirable because of the long execution time expected of some CMD channels. An interrupt feature exists in the unit; a CMD under execution will be aborted, and a new CMD entered should it be received from the CIU. A DTK or VDO will be aborted if a new instruction is received while the previous instruction is in execution.

Parity is checked on all transmissions to and from the CIU. An error causes a termination of any CMD or DTK in process, generates a computer interrupt, and inhibits the remaining portion of the word (if any) from entering the unit. The same action is taken should an undefined function code occur.

The initial bit in an instruction from the CIU is checked for presence. Should it not appear, the rest of the instruction is inhibited from entering the unit. These error-checking features are necessary to prevent the RICE unit from losing synchronism with the control words in the event that noise obscures the timing and control signals. In addition, the computer can reset the unit should synchronism be lost.

Three RICE and RICE I/O units have been designed and fabricated for the mockup program. One set has undergone individual bench tests and is now undergoing tests as an integrated unit.

RICE Input/Output Chassis

The RICE I/O chassis provides the interface logic for the instrumentation and control signals between the RICE and MIU. It also provides the required channel adaption and expansion flexibility to enable the RICE to be used in a wide variety of control and instrumentation applications. The I/O chassis handles: Binary Inputs and Outputs (switch or relay closures and indications) arranged in groups of 10 signals to channel; Pulse Outputs which increment stepping motors; and Analog Input Signals which are converted to digital values by an integral A/D converter for the RICE to relay to the control computer.

The signals are handled by five types of printed circuit cards. The chassis is modular and repetitive in design so that it can be made as large or as small as the particular application requires. In addition, this chassis can operate with any number and combination of the channels

given above up to a total of 63 Input channels. Control signals to and from the RICE consist of Channel Addresses and Input/Output Enables and Response signals.

The MIU (see below) conditions the Binary Input signals to compatible logic levels and the Analog Input signals to a zero to +10 voltage range.

The Binary Output signals can be made to be either momentary or latching by a wire jumper on the Binary Output PC card. This permits relays to be pulled in and electrically latched by the I/O chassis if so desired.

The RICE I/O chassis also contains a compact, low-cost Analog-to-Digital (A/D) Converter to translate analog signals into digital values. The Analog signal selected by the Analog Multiplexer (see Fig. 20) is sampled and held for conversion by a Sample and Hold circuit. The sample time (relative to the rf pulse) is under control of the RICE and is specified by the computer program. This feature allows data to be sampled and converted at any time during or outside the beam pulse. The sample duration is set at 20 μ sec which is determined by the response of the sampling amplifiers. The conversion speed is 10 μ sec/bit so that the total conversion period is on the order of 125 μ sec.

The A/D converter has some special features which enable the RICE to interrupt a conversion in process in the event that the RICE receives a request for data from the CIU of greater priority than the data which are in the process of conversion. The digital data from the A/D converter are transferred into the RICE in the same manner as the Binary Input channels, via a common data bus.

The chassis checkout is 80% complete and operational tests with the RICE are in progress.

Module Interface Unit

As described above, the MIU provides the conversion between the digital commands from

the CIU-RICE system and the module equipment and provides for level conditioning of the data from the module instrumentation. All necessary printed circuit cards for the first MIU have been designed and are on hand or on order, except for Analog Data cards. Analog Data channels are not yet well defined but the design of a general-purpose card is 50 % complete.

The MIU requires five card cages which have been assembled. Three have been wired and installed in the Amplitron test stand in the Mockup Building. Wiring lists for the RICE to MIU to rack terminals are complete except for the Analog Data channels. This interchassis wiring is being installed.

Injector System

Model L Electron Source Control

The control system for the Model L electron gun was completed and checked out, and is now operating. This system consists of a panel in the Control Room, a control unit in the high voltage head (which is about 200 ft from the Control Room), transmission cables, and a set of light links. The light links are used to cross the high-voltage interface between ground and the head. The system was designed to provide remote control of the electron gun and to test out the light link system.

A block diagram of the system is shown in Fig. 21. The function of the system is to provide control of the following: (1) Pulser power supply ac ON/OFF. (2) Pulser power supply high voltage ON/OFF. (3) Polarity switching. (4) Output voltage. (5) Pulser output.

The system also collects and transmits data on the following: (1) Pulser power supply output voltage. (2) Pulser power supply current, i.e., the sum of beam, electron-gun grid, and pulse control tube electrode currents. (3) Status of various commands.

Fig. 21. Model L Control System.

The control chassis contains the switches required to issue the commands listed above, a numerical readout for the data, and the digital logic for generating and transmitting timing pulses and instructions. The logic circuits in the head control unit decode these instructions and perform the function requested. Four coax lines are used with four light links to carry timing pulses and commands to the head and to transmit data back.

Three function codes are used at the present time; they are described in the following four paragraphs.

Binary Data Take (BDTK): A register in the head control unit stores information concerning the status of the pulser power supply ac power ON/OFF, high voltage ON/OFF, and output polarity. This register also contains information on the status of a remote/local switch in the head and whether the A/D converter is reading current or voltage. The bits from this register are put on the data line, in sequence, by the timing pulses when a BDTK is called for. The control panel in the control room receives the string of pulses on the data line, places them in a register, and decodes the register to light the appropriate indicators.

Analog Data Take (ADTK): A "convert" pulse into the A/D converter in the control unit causes the converter to read the input signal, convert it to a 10-bit binary word, and store the word in an output register. An ADTK reads the bits onto the data line in sequence starting with the most significant bit. The information is received in the control panel, converted to the proper format, and presented to the operator as a numerical readout of either the voltage or current.

Command (CMND): Each controlled element in the head has a specific bit position assigned to it in the data portion of the command word. A register in the control console contains information concerning the various switch positions on the panel. A CMND function reads this register in the proper sequence and transmits the string of pulses to the control unit in the head where the word is stored in a command register. The word is decoded and the control relays actuated as called for.

The voltage output of the pulser power supply is determined by a 3-gang potentiometer which is in turn controlled by a stepping motor. If the "increment" switch on the console is

actuated, a bit is set in the CMND word. Each time the CMND is sent out, the motor will step up one step (as long as this bit is present). If the switch is moved to the "decrement" position, the motor will step down one step each time the CMND is issued. Since the CMND is issued about 10 times/sec, the apparent change in voltage is quite smooth.

The electron-gun pulser itself is driven by the Master Pulser through one of the light links. The pulser can handle pulse widths which vary from $\sim 2 \mu\text{sec}$ to $600 \mu\text{sec}$ at 120 pps. Peak amplitude (without exceeding the pulser tube specifications) is 800 V with rise and fall times of about $1 \mu\text{sec}$.

All control and pulser signals (except the head power control) are transmitted to the head through a set of four "light links." Each link consists of an infrared transmitter and receiver separated by $\sim 7 \text{ ft}$. No difficulty has been experienced with focusing or alignment of the beams or crosstalk between the beams. Figures 22 and 23 show the high-voltage and ground terminations of the light links used on the Model L electron gun system.

Model L High-Voltage Supply

The high-voltage system which had been in use on the first electron model experiment was moved to the Mockup Building and a new output shield adapter was designed for the high-voltage tank so that RG-19 cable could carry the high voltage to the Model L electron gun.

In the new location and with an extra 100 ft of control cable, excessive noise and hum pickup made precise measurement of the high voltage impossible. The control cable system was modified and the null indicator system redesigned and rebuilt. The measuring precision was now found to be better than 50 V out of 150,000 V. Random swings of $\pm 2000 \text{ V}$ at 100,000-V output were observed and these

were traced by the use of multiple recording to small transients in the 115 V ac line. An electronic 5-kVA line regulator was subsequently installed which reduced the high-voltage transients to $< \pm 100 \text{ V}$.

RF Module Control

201.25-MHz Modules

The cable tray layout design for the 201.25-MHz test stand has been completed and the installation of the cable tray is about 50% complete. The pulse motor and motor driver circuitry for the test stand high-voltage power supply has been received. The motor driver circuitry is being checked out and soon all components will be assembled into the power supply controls. The design and implementation of remote controls for this test stand has been postponed until about mid-1967.

805-MHz Modules

An appreciable effort has been spent this quarter preparing the Amplatron test stand to be controlled remotely by the on-line computer system. Devices within the stand which were manually controlled are being modified to be handled by the computer system. A precise test stand, turn-on, run, and turn-off procedure has now been written. This is being used as a guide in the development of the required instrumentation for the Amplatron test stand. An extensive schedule for the wiring of all channels within the module to the MIU has been prepared. The actual installation of the wiring is about 50% complete.

Modifications to the existing high-voltage power supply are under way. These modifications will allow the klystron or the Amplatron test stand to be powered from this supply. Remote control of the power supply by the computer system for either test stand will be provided.

A design has been worked out for the use of thermistors for sensing water flow. This

Fig. 22. High-voltage terminations of light link on electron gun.

Fig. 23. Ground termination of light link on electron gun.

design promises to lead to an economical, reliable, and fail-safe flow indicator and alarm. Development of the flow switch is being pursued.

Accelerator Module Control

All parts are on hand for assembling a prototype quadrupole magnet high-temperature alarm circuit. The circuit uses a thermistor which is to be soldered to the magnet tubing and has the property that, if the thermistor leads are either open or shorted, an alarm will be given.

Auxiliary Operational Systems

Timing

Development of the master pulser system to provide timing pulses for operation of the various test stands and experimental accelerators in the mockup program has been continued. Two pulser units and a manual controller have been completed and the three units installed in the Control Room for use with the Model L. In December 1966, the units were removed and the computer interface circuitry modified to match the requirements of the SEL-810A computer. This modification has been checked out on the bench and the units are being reinstalled. The completed system is designed to provide the timing gates shown in Fig. 24; however, all three gates are not being used at the present time.

A block diagram of Master Pulser No. 1 is shown in Fig. 25. Master Pulser No. 2 functions in the same way as No. 1 but provides only the 3T4 signal. (The interval between reference points is designated by the numbers associated with the beginning and ending reference points; thus, 3T4 is the interval between T_3 and T_4 .)

The pulsers are synchronized to the 60-Hz line by a (voltage) zero crossing detector which provides the input signal to the pulse repetition rate counter. The

repetition rate may be changed by means of a selector switch on the front panel; the pulse rates available are 7.5, 15, 30, 60, and 120 pulses/sec.

The T_0 signal is used to synchronize the computer operation to the machine and initiate the gate generating sequences. The T_1 commences counting the input clock pulses. As soon as the interval count (determined by the patchboard wiring) is complete, the 1T4 gate output switches from 0 to ~ 10 V and the T_2 counter starts. At the completion of the interval (determined by a preset count obtained from the T_2 buffer) the 2T4 gate output goes high, the T_3 counter is started, and the preset count is transferred from the buffer to the counter. (The readout of the buffer is nondestructive.)

Three counts before the completion of the 3T4 interval, the 3T4 output is switched to zero. At the completion of the count, outputs 2T4 and 1T4 are switched to zero; the T_4 count is preset, and the master pulser is ready for the initiation of a new sequence by the next T_0 pulse. The three-count delay shuts the beam off before the RF is turned off.

The computer controls the output gate durations by addressing the buffers and entering the required count (interval). The 0T1 interval is not under computer control but can be changed by making a wire change on a printed circuit board in the chassis. The T_4 buffer has an additional storage element or register which is used to inhibit the pulser outputs. If this bit is set, the pulser continues to run through the sequence starting with each T_0 pulse, but the output gates are "closed" and no signals are transmitted. This bit may be set either by the computer or by a switch on the control console.

Fast Shutdown and RF Permissive Systems

The rf permissive system is for the purpose of inhibiting the injection of the beam

Fig. 24. System timing signals.

Fig. 25. Block diagram of Master Pulser.

until all rf systems are correct in phase and amplitude. Should the rf not remain within tolerance during the beam pulse, the permissive system will inhibit the beam injection for the remainder of that pulse and cause a computer interrupt. The computer can then diagnose the trouble.

The fast shutdown system will also prevent beam injection and initiate a computer interrupt. The fast shutdown is activated at all times whereas the rf permissive system is active only during beam.

These systems have been designed and a prototype built in each case. Final design for fabrication has been started. The systems will be used and tested in the electron prototype experiment.

Operational Support Systems

Communications

The interphone and public address system for the mockup program is about 90% complete. This system has operated satisfactorily for the past two months. The interphone system operates from a dc voltage supply and no amplification is used. About seven headsets can be plugged into any one of five channels before the audio signal level is greatly reduced. Because headsets are usually left plugged in at the various interphone communication panels, a panel off-switch has become necessary. This modification will be implemented as time permits. In the Central Control Room, a small audio amplifier monitors the interphone guard channel. During peak communication times, it has become desirable to have another amplifier similar to the guard amplifier which could be switched to any one of the other interphone channels. This has not yet been implemented.

Radiation Safety Systems

Model L: Crude estimates indicate that the radiation level in the Iron House could exceed peak values of 10^6 R and average values in excess of 10^5 R during full-power operation of Model L. Therefore, an area monitor capable of fail-safe operation in this environment and a means of testing it were sought. An interim check of VAMP, an area monitor manufactured by Victoreen, indicated that its operation would be fail-safe. However, in the pulsed radiation field during preliminary operation of Model L, the VAMP reading leveled off at 30 mR/h. Investigation showed that VAMP employs a Geiger counter followed by a pulse-counting system. The Geiger counter has a dead time of about 135 μ sec which allows for an average of 4 counts/rf pulse. Therefore, monitors employing scintillator-photodiode combinations or ion chambers are being considered for this application. A Nuclear Measurement Corp. unit which employs a scintillator-photodiode as a sensor, has been installed and is being evaluated.

Two plastic scintillator-diode units have been obtained for evaluation. Their principal use will be to assess the peak value of the x-rays as these units are known to maintain good linearity to fields in excess of 10^6 R.

To measure the average level of the radiation field, a pressurized argon ion chamber, complete with electrometer-cathode follower, was installed near the Faraday cup on Model L. A 200-ft cable carried the energy and signals between the readout panel in the Central Control Room (CCR) and the Iron House. A special readout and control panel was built for this purpose and installed in CCR. This same panel can be used to monitor remotely the area monitor or any of five ion chambers.

The ion chambers were placed along the ceiling of the Iron House so that radiation from the electron gun, beam transport system, Model L tank, and the spectrometer can be monitored remotely.

The readout panel electrometer-to-cable (200 ft to coax) time constant was estimated to be as long as 6 days. A new circuit configuration was designed employing feedback so that the effective electrometer input impedance is greatly decreased, thereby reducing the maximum time constant to about 6 msec.

A variety of coax cables were installed between CCR and Model L to permit evaluation of their performance in a radiation field. This work will have to await full operation of Model L.

Alvarez Mockup: A measure of the radiation fields near the short Alvarez tank showed the field intensity to vary as the fifth power of rf power input, approaching an intensity of 1 R/h at 1 m from the tank at rated rf power input. The field intensity was found to vary inversely with the distance from the tank, indicating the source of x-rays is effectively quite large. Multipactoring apparently is not involved; the dependence of the radiation level on power input showed no threshold characteristics and was everywhere a continuous function of the power. Also, the radiation level did not change with tank "cleanup" nor with operating time.¹

From these measurements it is evident that a considerable level of x-radiation will be present during normal operation of the Alvarez portion of the linac. Consequently, appropriate revisions will have to be made to the design of the radiation safety system.

TV Systems

A need for closed-circuit television systems has developed in the mockup program because of the high radiation levels from Model L and the expected radiation from the Electron

Prototype Accelerator (EPA). A surplus Motorola surveillance-type, closed-circuit TV (CCTV) system was installed in the Model L area so that beam spot size, meters, etc., can be monitored from CCR. In addition, a second CCTV, a Vicon Insul-8 system, was obtained on a long-term loan. This system was serviced and 300 ft of cable ordered so that it can be installed for use with Model L and later with the EPA. Three CCTV systems will be required in EPL and so an additional system will have to be obtained.

In order to determine which type of TV systems will be specified for LAMPF, reviews of the qualifications and plans for the scheduling of demonstrations of several commercially available systems are under way.

A start has been made on an applications study employing a TV system to assess injector beam quality for the ion source program and to permit feeding data on the beam into the computer for on-line presentation of emittance diagrams.

Video System

The video system is designed to select remotely and route pulse signals to the CCR for presentation of waveforms on a Tektronix RM-565 dual-beam oscilloscope. The system possesses a dual signal switching capability: (1) manual patching, in which any two of 15 video signals at a module may be selected for routing to the CCR by means of a manual patchboard; and (2) automatic patching, in which any two of the 15 may be selected by means of the control computer through the CIU and RICE. When the control console operator decides to select a video signal for viewing, a set of console channel selection switches are actuated which then interrupts the computer and causes a subroutine to command the RICE unit to select the required channel through the associated Module Video Control Unit (VCU). The signals from the module of interest are then selected for viewing by the Console VCU and Video Patch

Panel. The signals may be either both manual, both automatic, or one manual and the other automatic, as selected at the CCR console operator's option.

The Module VCU receives parallel address and control signals from the RICE to actuate the channel selection logic. The selection logic output drives relay driver circuits which pull in the appropriate relay in a coaxial video switching relay matrix. Four video buffer amplifiers in the module VCU are used to isolate the selected signals from the cable runs to the CCR. The amplifiers have a frequency response of dc to 1 MHz and a gain of two. The source impedance of the amplifier may be optionally set to the characteristic impedance of the coaxial cable to minimize reflections.

The CCR patch panel contains a coaxial video signal switching matrix for computer-controlled selection of the signals from the modules. The matrix switch drive is derived from logic which utilizes logic signals from the console channel selection switches and the CIU in a manner similar to that employed by the Module VCU. Both the shield and center conductor of the matrix switch are switched so that when a signal is not selected the cable is completely disconnected and terminated. This provision will permit ground isolation of signals from unselected modules. A pulse transformer or dc isolator will be employed to provide ground isolation of video signals between the modules and module to CCR.

For the mockup program, two Module Video Control Units, one CCR Video Patch Panel, and one Control Room Video Control unit have been built. The Control Room Video patch panel can accommodate signals from four modules.

Centralized Control

Design and fabrication of the control console for the Mockup facility is essentially complete. Checkout is 50% complete.

The console hardware has been modified to include the following features. A lamp flasher was added to the module selector switch. If an alarm condition is detected by the computer in any module (four modules in the Mockup), a bit is set in a register in the status panel. This causes the light in the module selector push button switch associated with that module to flash at a 3 pps rate. When the operator presses the switch, the light shifts to a steady output mode. Three "slewing" controls were also added. The operator dials the module and channel number desired on one set of controls. The set point of that channel may then be raised (or lowered) at a predetermined rate by actuating a 3-position, spring-return toggle switch associated with the particular set of module and channel selector switches. These controls function through the computer.

Miscellaneous

Channel Engineering

To aid the final design of the MIU, an up-to-date channel listing has been prepared. From this, channel implementation details were recorded and work schedules provided. Channel implementation from the Amplitron test stand to the MIU is about 50% complete. Test stand modifications are under way (see 805-MHz Modules).

Wiring and Terminations

The overall Wire and Termination Schedule and the corresponding inter-area wiring and terminations required for the Model L were completed. This required a total of approximately 175 cables and 1700 terminations. All chassis in the CCR racks for Model L were installed and appropriately terminated.

A Kingsley KTE-6 wire and tube-marking machine was ordered to facilitate labeling all inter-area control cables to be used in connection with the mockup program.

Wiring schedules from all devices within the Amplatron test stand to the MIU, from the MIU to the RICE, from the RICE to the CIU, and from the CIU to the computer and control console is about 90% complete. The actual installation of the wiring is about 60% complete. A large amount of effort is being spent in this area at this time.

A review was made of the experience to date in applying the Wire and Terminations Designation Scheme. The revisions have been compiled from agreement reached by interested personnel. Subsequently, a survey was made of desirable accounting jobs that a computer can do employing this system; these were written up as a set of Programmers' Tasks. Preliminary work has begun on a computer program to handle the Wire and Terminations Schedules with provisions for updating the schedule and for making certain checks on the interconnections.

Special Equipment

A logic simulator has been fabricated and checked out. It consists of logic gates, flip-flops, multivibrators, drivers, gated pulse generators, and lamps wired to a programmable pinboard receptacle. The pinboards are simple to wire and are used to test designs or implement a logic machine for testing other digital equipment. An additional asset is that logic hardware is not tied up on equipment for which the simulator may be substituted.

Reference

1. For description of measurements, see "Radiation from Mockup Cavities," Tech Memo, MP-1-1104.

V. ACCELERATOR PHYSICS

Introduction

Programs for computing the effect of the space-charge forces on the motion of particles in the beam have been developed and applied to calculations of particle motion in early portions of the linac, namely, the beam transport system, the buncher, and the Alvarez section.

Experiments with analog models of the Cockcroft-Walton have led to the development of a satisfactory voltage stabilization circuit.

Analog experiments indicate that the beam transport quadrupole magnets can be used for fine steering and beam alignment. This is achieved by adding a small dipole field.

Particle Dynamics Studies

Alvarez Linac

Space-charge forces in the particle beam will reduce the frequencies of oscillation of the beam particles in both the transverse and longitudinal directions. Although these effects will be small for a 20-mA beam, the high duty factor of the accelerator means small percentage losses in beam are serious, and so attention must be given to effects of this magnitude.

Several procedures have been developed for evaluating the effects of the space-charge forces for buncher and beam transport studies. These techniques are described below under the subheading Double Drift Buncher. Of these, the Many Rings Averaged (MRA) procedure is best for evaluating space-charge effects in the linac proper.

During the past quarter, the basic features of the MRA calculation have been put in the PARMILA dynamics program. Preliminary results confirm that the effects are being properly evaluated. Further study is needed of the space-charge effects on the quality of the beam from the Alvarez linac.

A - ROOM FOR VALVES, BEAM CURRENT AND POSITION MONITORS, ADJUSTABLE APERTURES STEERING AND FOCUSING MAGNETS, ALIGNMENT MONUMENTS, VACUUM PUMPS.

Fig. 26. Layout of region between 201.25-MHz and 805-MHz linacs.

The Alvarez drift tube supports are copper stems located at the midplane of the drift tube, and oriented normal to the electric field. The perturbation to the resonant frequency of the cavity by these stems can be calculated from a knowledge of the electric and magnetic fields in the vicinity of the stem. Information on the electric and magnetic field distributions in linac geometries are available from field calculational programs such as MESSYMESH and LALA. A formula was derived and a computer subroutine was written to evaluate the frequency perturbation of metallic stems in fields as calculated by MUKA's MESSYMESH program. This subroutine will be used at MURA to evaluate the stem perturbation as well as the power dissipated on the stems for a large number of linac geometries. In a few cases, the calculated perturbations will be compared with measured perturbations. This information will then be used to refine the design of the Alvarez linac tank.

It is desirable to reshape the longitudinal phase space of the beam coming from the Alvarez linac before it is sent into the 805-MHz linac. A better match to the latter will result by reducing the phase width of the beam coming from the

Alvarez linac, at the expense of increasing the energy width. This can be accomplished by a combination of a drift space, an accelerating cavity, and another drift space, as shown in Fig. 26. The name "bucket rotator" is suggestive of the manipulations performed by this system on the longitudinal phase space.

In order to specify the length of the drift spaces and the excitation of the cavity, it is necessary to make some assumptions about the shape of the longitudinal phase space of the beam coming from the Alvarez linac, and the desired shape of this phase space at the end of the bucket rotator system. Suppose that the beam at the entrance to this system occupies the region of phase space within the ellipse

$$\frac{\phi^2}{A^2} + \frac{W^2}{B^2} = 1,$$

where ϕ and W are the displacements of the phase and energy coordinates from the synchronous values. It is reasonable to demand that the phase space at the end of the system should lie within the ellipse

$$\frac{\varphi^2}{(A/R)^2} + \frac{W^2}{(RB)^2} = 1,$$

where R denotes the ratio of the energy width at the end of the system (RB) to the energy width at the entrance to the system (B).

Let D be the drift distance to the cavity, E the peak energy gain in the cavity, and S the length of the entire system. The transformations performed by this system on the $(\frac{\varphi}{W})$ vector can be written as the product of three 2 x 2 matrices, namely

$$P = \begin{pmatrix} 1 & H \\ 0 & 1 \end{pmatrix} \begin{pmatrix} 1 & 0 \\ G & 1 \end{pmatrix} \begin{pmatrix} 1 & F \\ 0 & 1 \end{pmatrix} = \begin{pmatrix} 1 + GH & F + H + FGH \\ G & 1 + FG \end{pmatrix}$$

where

$$F = - \frac{360}{\lambda \beta^3 \gamma^3 W_0} D = - 9.675 D \frac{\text{degrees}}{\text{MeV}}$$

$$G = \frac{\pi}{180} E = 0.01745 E \frac{\text{MeV}}{\text{degree}}$$

$$H = - 9.675 (S-D) \frac{\text{degrees}}{\text{MeV}}$$

for 100 MeV protons, for D and S in meters, and for E in MeV.

At the present state of the accelerator design, it is of interest to determine S. The bucket rotator system suggested here was evaluated for S equal to 4, 5, 6, and 8 m. For each S there is a range of systems which can be obtained by varying D and E.

The present parameters of the 200-MHz and 800-MHz linacs yield a B/A of 0.016 and suggest that an R of 1.4 would be desirable. It is essential that a range of values near the foregoing may be accommodated. On the basis of this and other criteria, the systems corresponding to S = 5 m proved superior to both shorter and longer systems.

Figure 27 shows the results of an analysis of the systems for S = 5 m. Values B/A and R corresponding to any combination of D and E can be read directly from the graph. Similarly, values of D and E corresponding to particular values of B/A and R can be obtained.

A small error in the phase of the rf voltage in the cavity will induce a small acceleration on the beam in addition to the desired rotation of the longitudinal phase space. The main effect of this acceleration will be to shift the

Fig. 27. Analysis of Bucket Rotator System for S = 5 meters.

phase of the beam arriving at the 805-MHz linac. The shift in phase $\Delta\phi_p$ of the beam caused by an error in phase $\Delta\phi_c$ of the cavity is

$$\frac{\Delta\phi_p}{\Delta\phi_c} = -0.168 E (S - D)$$

for 100 MeV protons, where $S - D$ is in meters and E is in MeV. The values of this ratio are indicated by dashed lines on the figure.

Experimental Area

Shielding

Shielding computations using the Oak Ridge 05R and NTC codes have been discontinued temporarily, and essentially the entire computational effort is being devoted to implementing the use of the DTF IV codes. The discrepancy between the results obtained from the 05R and NTC codes in the energy region in which their function overlaps (~ 50 -70 MeV) has been explained in terms of the manner by which the two codes treat elastic scattering. The results from the two codes represent extremes in neutron transmission through a shield and an average is probably the best dose prediction. The input data for the DTF IV codes are being prepared.

Studies have been made of the thermalization of fast neutrons in thick shields. It is thought that some of the wide variation in the literature values for dose attenuation lengths of incident high-energy neutrons is due to the improper treatment of thermalization within the shield. In this respect, the most critical component of a shield is hydrogen. The use of the DTF IV transport codes will permit a detailed study of the importance of hydrogen content in shields.

Targets

For the proposed beam specifications of LAMPF, it has been demonstrated that targets can be made which have the necessary heat transfer characteristics. However, the

mechanical problems related to the pulsed nature of the beam and to radiation damage have not been evaluated. The LAMPF electron mockup will be used to study the thermal cycling problem, and an estimate of the effect of radiation damage may also be possible.

A program has been started to manufacture targets for the electron mockup. Various materials including beryllium, beryllium oxide, graphite, and copper will be used as targets in the preliminary studies. An increasing emphasis will be placed on target development in order to complete designs compatible with the restrictive environment of the LAMPF target area.

Injector Program

Cockcroft-Walton Model

Further tests with the C-W model have been performed, especially to investigate the stabilization circuit. A satisfactory stabilized C-W model was developed, and the basic circuit is shown in Fig. 28. The values in the model are essentially the same as those that could be used in a 750-kV full-scale unit. Each diode in the model is bypassed by a 30- μ f capacitor, C_S , to simulate the storage capacity of the full-scale condenser stacks.

An electronic switch simulates an ion source by applying a 16-M Ω load to the C-W power supply at 120 cps rate, each pulse lasting 500 μ sec. The lower trace in Fig. 29 shows the voltage form at the test point, which is proportional to the output voltage. The scale represents a 0.3% change in voltage/cm (large scale division). The C-W model was operated at 5 kHz; thus, the 10-kHz ripple represents $\sim \pm 0.03\%$ of the output voltage. The upper trace shows the square-wave pulse used to operate the electronic switch and to provide a simulated feedback voltage. There are four important features of the voltage pulse, without

Fig. 28. C-W model circuit used to investigate stabilization schemes.

Fig. 29. Upper trace: output of square wave generator.
Lower trace and sketch: C-W voltage output wave form, with individual regions of interest.

any simulated feedback. These are indicated by the expanded drawing of the pulse in the lower part of Fig. 29. The ripple has been omitted for clarity.

In region 1, immediately after the pulse load is applied, the voltage drops rapidly due to the time constant $\frac{1}{4}(R_L C_D)$ of the compensated measuring stack and the load. In region 2, a voltage division between R_S and R_L has been established, and the discharge rate is primarily determined by the time constant, $\frac{1}{4}(R_S + R_L)C$, minus the average charging rate of the rectifiers during the pulse. In region 3 the pulse load has been removed and the voltage rises rapidly. The rise time is limited by the capacity of the switch and the load resistor, as well as by the time constant of the compensated voltage divider. The slow rise in region 4 reflects the recharging of the supply capacitors, C , by the rectifying stacks. It is important to note that the voltage has not quite reached a steady state prior to the following pulse, but it is still rising. In this case, where the repetition rate is high, the C-W does not have time to recharge itself completely between pulses.

The C-W can be recharged completely between pulses by modulating the 5 kHz feed to the rectifying stacks during the pulse, as shown in Fig. 30. (Note that the time scale in this photograph is twice that of the other photographs.) Thus, the increased feed during the pulse can be made to balance the load drain during the pulse, and the capacitors will then maintain practically a constant charge. The resulting waveform is shown in Fig. 31. In this case, the modulation was slightly too large, as indicated by the rising voltage during region 2 and by the decreasing voltage, barely perceptible, in region 4. To eliminate the steep fall in region 1 and the steep rise in region 3, the stack voltage must be raised an appropriate amount to establish the proper voltage division between R_L and R_S when the load is applied. The circuit which does this is popularly called the "bouncer." With the proper mixture of bouncer output and modulation, the output voltage can be made constant. Figure 32 shows a proper setting of parameters to reduce the variations to $\pm 0.03\%$ before, during, and after the pulse.

An accurate voltage reference supply and a differential amplifier would have to be added to close the feedback loop. Extrapolating the model results to a full-size C-W generator, the modulation needed would be 5%, and the bouncer would be required to lift the rectifying stacks 25 kV during the pulse. In the model, it was found necessary to have an electrostatic shield between the primary and the secondary of the rectifying stack driving transformer to eliminate a common-mode 5-kHz ripple from appearing at the output voltage. This would seem to be necessary for the full-scale C-W.

Fig. 30. Modulated 5-kHz stack driving voltage.

Fig. 31. C-W output waveform with modulated drive feeding the rectifying stack.

Fig. 32. C-W output voltage waveform with both modulated feed and bouncer feedback.

Ion Source Test Stand

Various circuits, involving the use of the test stand, were made operational during this report period, as follows:

1. The 240-kV high-voltage power supply for the partial accelerating column and the 60-kV high-voltage power supply for the accelerating column pulsed extractor were both tested without external loads. Both units operated satisfactorily.

2. A hydrogen-flow automatic regulation system was tested using a dummy ion source. At 0.2-torr pressure the system maintained a pressure variation of < 0.015 torr, which is adequate for early operation of the ion source.

3. The vacuum system -- forepump, cold trap, 1000-liter ion pump, and various pressure gauges -- was operated satisfactorily and has maintained a pressure of $\sim 10^{-8}$ torr.

The ion source and ion-source manifold have been vacuum leak-tested and are now being assembled to the test stand vacuum system. The test stand will soon be ready for preliminary tests. The most important of these tests include: (a) Hydrogen-flow pumping speed with the model A ion source. (b) Filament insertion into ion source and subsequent filament actuation. (c) Cooling characteristics of the ion source for high duty factor.

Beam Transport-Emittance

It is necessary to know the effective transverse emittance of the beam from the preaccelerator transport system. A study of the effects of aberrations from types of lenses on beam emittance has been under way, and some of the results are reported here. For convenience, effective beam emittance is defined as the area, divided by π , of the smallest parallelogram in phase space which will enclose the entire beam. Consider a zero-effective emittance beam whose

trajectories are parallel and are incident upon a lens or lens system. The angle α that the trajectories make with the axis on leaving an ideal lens will be $\alpha \sim x/f$, where f is the focal length of the lens and x the trajectory displacement from the center of the beam at the lens. In a lens with aberrations, the angle α will deviate from the ideal by $\Delta\alpha = -x\Delta f/f^2$, where Δf is a measure of the lens aberration. The increase in effective emittance can now be defined as

$$\frac{\Delta\epsilon_x}{\epsilon_x} \sim \frac{X_m (p_x)_m}{f^2} = \frac{2X_m^2 (\Delta f)_m}{f^2},$$

where X_m is the maximum beam radius, $(p_x)_m$ is the maximum transverse momentum in normalized units of radians, and $(\Delta f)_m$ is the maximum focal length deviation. A similar expression exists for $\Delta\epsilon_y$. This expression is used to estimate the increase in effective emittance due to the various types of lenses.

The calculations for a magnetic lens are rather complicated because of the numerous types of aberrations. However, calculations have been carried out considering only the dominant factors, and the results are given below. In each case the geometric parameters were adjusted to the requirements of the transport system and also to minimize the effective emittance.

<u>Lens Type</u>	<u>Effective Emittance (cm-mrad)</u>
Solenoid	0.5
45° Bending magnet	0.1
Quadrupole triplets	0.2

Quadrupole triplets have the additional advantages over the solenoid lens that their power requirements are about an order of magnitude smaller, their cost is less, and their weight is less. Knowing the emittance increase, from both the accelerating column and the nongridDED double drift buncher, the total effective emittance of the beam at the linac can be estimated.

Elements	Effective Emittance (cm-mrad)
1 - Accelerating column	1.0
4 - Quadrupole triplets	0.8
2 - 45° Bending magnets	0.2
1 - Double drift buncher	1.0
Total transport system	3.0

Other beam transport elements, such as the steering magnets and beam diagnostic equipment, have a negligible effect on the total beam effective emittance. It is not clear that the effective emittance of the various elements should be simply added to get the total, but it does give a conservative answer with which to work.

Beam-Transport -- Steering

Investigations are under way on a method for using quadrupole magnets to effect a small amount of beam steering--a method which has been used successfully in steering Van de Graaff beams. Basic advantages of the system are: (1) a separate steering power supply is eliminated and (2) no additional space would be required. However, there is a disadvantage in that the steering field is not uniform over the entire beam area and, consequently, some aberration is introduced.

The method consists of shunting various pairs of quadrupole excitation coils as indicated in Fig. 33 so as to produce a small imbalance in the excitation of the quadrupole. This unbalanced excitation will result in the superposition of a transverse dipole steering field on the quadrupole focusing field.

Studies were therefore made of the spatial variation of this steering field in the central region of the quadrupole magnet by using an electrostatic analog. Electrostatic field plots were made for an ideal quadrupole lens (hyperbolic pole faces) with a dipole excitation as shown in Fig. 34, where the applied voltage was normalized to a unit voltage. The electrostatic potential distribution was determined, and the variation of the steering field E_x along the x and y axes in the central region of the quadrupole lens ($x, y < R/2$), was measured and was found to vary as:

$$(E_x)_{y=0} = -E_0(1 - 0.8 x^2/R^2), \quad x < R/2, \text{ and}$$

$$(E_x)_{x=0} = -E_0(1 + 0.8 y^2/R^2), \quad y < R/2.$$

Fig. 33. Two methods of producing dipole steering in quadrupole steering.

Fig. 34. Electrostatic equipotential plots of dipole steering field of a quadrupole magnet.

An approximate solution to Laplace's equation, using the hyperbolic pole faces as a boundary condition, is

$$\phi(x,y) = E_0 x - \frac{\pi E_0}{12R^2} (x^3 - 3xy^2),$$

from which the field strength is

$$\vec{E}(x,y) \approx -E_0 \left[\left(1 - \frac{\pi(x^2 - y^2)}{4R^2} \right) \hat{x} + \frac{\pi xy}{2R^2} \hat{y} \right],$$

which agrees with experiment.

Assuming a beam diameter (2ρ) of 1 cm, and a 5-cm diam bore for the quadrupole, the effective emittance added to the beam by the nonuniformity of the steering field may be estimated. Since $(\rho/R) = 1/5$ implies a variation of no more than $\pm 3\%$ in the steering field for an

axial beam, the phase-space area will be increased by

$$\Delta\xi = (\rho\Delta\rho')/\pi \approx (1)(0.06)/\pi \approx$$

$$0.3 \text{ cm-mrad/deg of deflection,}$$

where ξ is the effective emittance. This effective emittance will scale linearly with the deflection angle and will vary as $(\rho/R)^2$. The use of unbalanced quadrupoles would appear to afford a simple, easily implemented method of effecting a small amount of beam steering without introducing a significant emittance. This method will be evaluated with a quadrupole magnet on the prototype electron accelerator.

Double Drift Buncher

In the last quarter's report brief mention was made of four computer programs designed to study the effects of space charge on the beam dynamics and on the optimum geometrical and electrical parameters of the double drift buncher. In general, the results of these four programs were consistent; however, the detailed results had some disturbing features. A fifth program evolved using a somewhat different approach, which circumvented the shortcomings of the four previous ones. This program, called MRA, includes the effects of a solenoidal lens, but does not allow the use of a quadrupole lens.

In MRA the r - z space of a beam of particles is covered with a rectangular mesh. At any given time, the number of particles contained within a given rectangular box is considered to act as a ring of charge located at the centroid of that box. The r and z components of the space-charge electric fields are then computed at the mesh points. The electric field felt by each particle is obtained by a linear interpolation consistent with the particle's position with respect to the mesh points. The program computes the positions

of the particles as the beam goes through one or two bunchers and an ideal focusing lens. The rectangular mesh covers a section of the beam which is one wavelength of the first buncher frequency in length. The beam is assumed to be periodic in the z direction and the effects of neighboring sections is taken into account when computing the electric fields at the mesh points.

Figures 35a through 35h were produced by MRA for a typical case. These figures show the condition of the bunch at various times. In this particular case the beam current was 20 mA, the initial radius was 0.7 cm, and the effective voltages on the two buncher cavities were $V_1 = 20$ kV and $V_2 = -13$ kV. The first buncher cavity operates at a frequency of 200 MHz whereas the second operates at 400 MHz. The positions of the buncher cavities and focusing lens are shown at the top of each figure. The tiny rectangle represents the position of the beam bunch. In the middle of each figure is shown the distribution of the rings in r - z space. The distributions in the longitudinal and transverse phase spaces are shown at the lower left and lower right, respectively. The uniformly charged beam entered the first buncher at a waist and with zero emittances in both the longitudinal and transverse phase spaces. As well as bunching the beam, the buncher cavities have focusing and defocusing effects on different parts of the beam, producing a spread in the transverse phase space. In Fig. 35h approximately 88% of the particles in the section have been bunched to lie within a phase angle of $\pm 30^\circ$. The transverse emittance of the beam has been increased ~ 1 cm-mrad.

Ignoring space-charge effects, it is possible to obtain a set of optimum parameters for a buncher system; that is, a set of buncher voltages and drift distances that will cause the largest percentage of particles to be bunched within a specified phase angle. The three curves in Fig. 36 show the maximum percentage

of particles (not including space-charge) that could be expected to be bunched within a range of phase angles for three different types of buncher systems: (1) a double drift buncher (top curve), in which there are two buncher cavities separated by a drift distance and the second cavity, operating at twice the frequency of the first; (2) a harmonic buncher (middle curve), in which there is no drift distance between the cavities; and (3) a simple buncher (bottom curve), in which there is only one cavity.

It is of interest to compare these curves with some points obtained by MRA for three different currents. In all cases the initial radius of the beam was 0.7 cm, the voltage of the first buncher was 20 kV, and the final bunched beam radius was required to be 0.7 cm. The MRA program was searched for optimum parameters to maximize the percentage of particles within a given phase spread. These points are indicated on Figs. 37, 38, and 39. In general, the points can be brought closer to the zero-current curve by increasing the first cavity buncher voltage. In practice, however, this will be limited by the acceptance of the linac.

Some general observations can be made in regard to the design of the double drift buncher. Higher buncher voltages reduce space-charge effects but increase the spread in the transverse phase space, unless grids are placed on the buncher cavities to remove the focusing-defocusing effects. To obtain optimum bunching with a double drift buncher as the current increases, the distance between the two buncher cavities must be decreased and the magnitude of the second buncher voltage must also be decreased.

Figs. 35a-d; for details see text (p. 47).

Figs. 35e-h; for details see text (p. 47).

Fig. 36. Maximum percentage of particles that can be bunched within a phase of $\pm \Delta \phi$ for three different bunches (space charge neglected).

Fig. 37. Comparison of space-charge effects on maximum percentage of particles bunched within a phase of $\pm \Delta \phi$ using double drift buncher (20 kV on first cavity).

Fig. 38. Similar to Fig. 37 but with harmonic buncher.

Fig. 39. Similar to Fig. 37 but with single cavity buncher (20 kV on cavity).

VI. PROJECT SCHEDULING AND FACILITIES PLANNING

Introduction

IBM PERT Cost II scheduling of LAMPF has progressed to completion of a manpower leveling program and 60% completion of the Work Breakdown Structures. This work is initially directed toward development of a Preliminary Program Management Network.

In support of the R&D program, facility activities were concerned with early completion of additions and modifications to existing buildings and construction of the new Electron Prototype Laboratory (EPL).

Site and building engineering for LAMPF now ranges from preliminary planning to construction bid opening. Foundation studies have been very encouraging with increased soil loading now in progress. Design has been completed for site preparation work, and bids will be opened shortly. Title II engineering is about 87% complete for the Injector and 201, 25-MHz Accelerator Buildings; alternative layouts are being evaluated for the Central Control and 805-MHz Accelerator Buildings. For the Laboratory-Office Building, the criteria have been updated to assist the A-E Selection and Negotiation Panel. Another panel has been appointed and is engaged in formalizing the criteria to be used in soliciting and evaluating proposals for supplying LAMPF electrical power.

Scheduling Activities

As stated in the preceding report, the scope of LAMPF PERT will include (1) the collection of criteria for site and buildings, (2) the design of the site and buildings, (3) an A-E construction monitoring system, (4) accelerator design and procurement, (5) component testing, and (6) accelerator installation and checkout. No attempt will be made to apply PERT to the accelerator R&D program. Informal training

sessions with the technical groups on the philosophy and general operation of PERT have been continued.

At present the LAMPF Work Breakdown Structure appears to be about 60% complete. Specifically, about 90% of all objectives at Level 3 have been defined and in some cases the definition of Level 5 objectives has been started.

The experimental "manpower leveling" program mentioned previously has now been completed. Plots of man-months vs months were obtained both on an incremental and cumulative basis. The incremental plot indicates the number of people required during any month, if the associated plan is to be accomplished on schedule. The cumulative plot indicates the total number of man-months expended to date for any month. Although the plots are obtainable only on a network and/or subnet basis, a Manpower Loading Report is obtainable which breaks down the total number of people into the numbers of people by skills vs time. Current plans call for application of manpower leveling only to accelerator design, procurement, installation, and checkout.

A decision has been made to develop first a Preliminary Program Management Network and then to expand it, through more detailed planning, into the Master Network. By this approach it is felt that any major scheduling problems that may have been overlooked in the past will be discovered sooner. Minor scheduling problems will be taken care of later when detailed planning is carried out. With the aid of the computer, the Master Network will then be skeletonized back into the Management Summary Network(s).

Facility Activities for the R&D Program

Numerous facility service modifications have been essentially completed. In the Physics Building these included electrical control or power, process cooling water, a capacitor room, and hoisting equipment installations to accommodate

the 7835 amplifier, 4-ft Alvarez model, and magnet laboratory. In the Mockup I Building all provisions for the 1.25-MW klystron tests are in progress, an rf screen enclosure has been assembled, tested, and accepted, and a power supply for the ion source laboratory has been installed. Waveguide runs have been completed between the Mockup I Building, the Iron House, and the Physics Building.

Much activity has been associated with the new EPL described previously. Immediately after authorization of construction by Albuquerque Operations Office (ALO), the site preparation work was completed. Atlas missile counterweights totaling 2469 tons were delivered to the site and stacked for the floor and side walls of the accelerator radiation enclosure. For the prefabricated metal building, specifications were issued, bids received and reviewed, and a contract awarded, for delivery on Feb. 15, 1967. A used transformer for this facility was located and is presently being rebuilt. Final design has been completed and approved for the building foundation and the floor construction.

LAMPF Site and Building Activities

Geologic and Foundation Studies

The quantitative determination of soil load-bearing properties continued, with favorable results. Negligible creep was experienced with normal building loads on the Mesita de Los Alamos surface tuff. To determine the maximum acceptable limit, the loading has now been doubled and measurements are in progress of elastic deformation, creep, and rebound as a function of time. These tests will be performed again at the building foundation elevations when Phase I of the site grading work is completed.

Site Roads, Grading, and Utility Work

During this period a proposal was made to implement the legislation passed by the 89th Congress, and the AEC Division of Research approved the proposal for a FY-1967 site preparation package. In accordance with this plan, Giffels & Rossetti assembled Title II drawings and specifications for the access road, a portion of the main site road, site grading, the domestic water and gas lines to the site, and a portion of the site gas and water distribution lines. This material was reviewed, corrected, and approved. Advance notification to prospective bidders was given on Dec. 19, 1966, and the final plans and specifications were released on Jan. 9, 1967. This Phase I of the site work has apparently been received with some interest since to date 27 contractors have purchased the documents. The bids for this package were due to be opened on Feb. 2, 1967.

Design of Injector and 201.25-MHz Accelerator Buildings

The difficulties encountered during the previous period in regard to 100-MeV facility mechanical system design were resolved. A preliminary issue of drawings was approved as amended and constitutes about 87% of the Title II engineering for this portion of the accelerator buildings. Completion of the design work on these structures will be deferred until a firm construction date can be selected.

Design of Central Control and 805-MHz Accelerator Buildings

As previously reported, updated requirements from the accelerator R&D program suggested the possibility of major building cost savings in the 805-MHz sectors. The modified criteria have been relayed to G&R and several

alternative schematics were prepared by that firm. The general features of these layouts are currently being reviewed. Acceptable alternatives will be returned to the A-E for further preliminary engineering and relative cost estimates.

Laboratory-Office Building Design

Criteria for the LAMPF Laboratory-Office Building were subjected to an additional detailed review and were subsequently reissued in updated form. For this portion of the project, an A-E Selection and Negotiation Panel was appointed by ALO, and requests for proposals were issued on Dec. 20, 1966. The Panel convened on Jan. 23, 1967 to consider the 11 responses that had been received. Official announcement of the A-E selection and contract negotiation will probably be made in Feb. 1967.

Supply of Electric Power

On Dec. 20, 1966, a panel was appointed to formalize LAMPF electric power criteria and to evaluate proposals for the supply of power. The membership is composed of representatives from AEC Headquarters Construction Division, ALO, Los Alamos Area Office, and technical advisors from LASL. Several informal meetings have been held in preparation for a draft of the project requirements.

VII. PUBLICATIONS

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