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LOS ALAMOS SCIENTIFIC LABORATORY
of the
University of California
LOS ALAMOS • NEW MEXICO

Quarterly Status Report on the
Medium-Energy Physics Program
for the Period Ending April 30, 1968

UNITED STATES
ATOMIC ENERGY COMMISSION
CONTRACT W-7405-ENG. 36

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LA-3419-MS

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Printed in the United States of America. Available from
Clearinghouse for Federal Scientific and Technical Information
National Bureau of Standards, U. S. Department of Commerce
Springfield, Virginia 22151

Price: Printed Copy \$3.00; Microfiche \$0.65

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Report written: May 1968

Report distributed: June 3, 1968

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I. SUMMARY

Accelerator Structures

The design goals of the Electron Prototype Accelerator (EPA) have been met during this quarter; that is, an average current of 1 mA, an energy greater than 20 MeV, and a duty factor (DF) of 6%. Beam spot size and energy distribution are consistent with expected performance.

The parameters for the side-coupled accelerator tanks for LAMPF have been set and design of the tanks for LAMPF has been started. The choice of cavity diameter effectively places the TM_{110} transverse mode band well away from any multiple of 201.25 MHz, while staying near optimum shunt impedance.

Extensive investigation of the post-coupled drift tube accelerator has been completed. The performance of this system has been exceptionally good, and Tanks 2, 3, and 4 of the LAMPF drift tube linac will utilize this field-stabilizing scheme.

Design of the LAMPF drift tube linac tanks is well under way. Some trouble with the drift tube stem-to-body braze joint has been encountered and a new joint system is under test.

RF Power Systems

An experimental study of the operating characteristics of the first Litton klystron, under conditions of reduced beam current and increased beam voltage, has led to an operating point with increased efficiency and stability at significant power levels. These effects are important and desirable.

A complex set of experiments was started which should elucidate some of the interactions between the rf amplifier, the accelerator, and the accelerated beam. The data are being collected through the controls computer and will provide another test of the computer system.

Testing and refinement of the 201.25-MHz rf system continue. The blocking capacitor in the 7835 amplifier cavity remains a source of trouble at high average powers. Stable, linear control of the 7835 modulator is now possible with a bandwidth of 200 kHz.

Design and procurement of many of the components for the Experimental Test Laboratory (ETL) test stands have been started.

Development of frequency sources and low-level amplitude modulators is being continued.

Accelerator Control and Instrumentation

Trial operation of various portions of the EPA under computer control has received considerable attention. This effort has involved both development and debugging of the necessary computer programs and the checkout of the controls for various devices as they were installed on the accelerator. Other activities include design studies and tests on numerous circuits and subsystems involved in the final design of the LAMPF control system.

The package of programs for the turn-on, run-up, and beam-steering for EPA are now about 95% complete. This package includes programs for preparing the preaccelerator (Model M) for rf, turning on the Model M rf power amplifier, setting the timing gates, and running up the power to the operating point. In parallel with this, other programs prepare the rest of the accelerator for beam, turn on the main 1.25-MW klystron, and condition the electron injector for high voltage. Upon completion of these preliminary programs, the electron gun is turned on and the computer begins a search for the beam. Programs have been developed to maximize the beam through the first two current monitors.

The installation and checkout of special data channels and the correction of various faults in the EPA control equipment have continued throughout most of the period. Toward the end of the quarter, however, as the many problems encountered were resolved, the system began to approach a level of reliability more in keeping with its design. Valuable experience is leading to modifications in many areas as final prototype designs are developed.

Accelerator Physics

A computer study has been carried out on the energy and phase dependence of the radial

emittance at the transition between drift tube and waveguide linacs.

Preliminary tests on a rotating wheel beam scanner were conducted in the EPA, and the performance was generally encouraging. A beam collimator (scraper) was successfully tested on the EPA.

A superconducting quadrupole doublet has been designed and is being built for test and evaluation as a general purpose doublet for the experimental area. Life tests of the duoplasmatron ion source were continued with very encouraging results. In particular, the problem of cathode life, originally thought to be serious for high DF operation, appears to have been solved.

The 192-keV accelerating column has been assembled and tested for vacuum leaks, for insulating gas pressure capability, and for high-voltage breakdown properties. The results are generally satisfactory and the column is being readied for installation in the ion source test stand.

Experimental Area

The main effort on design of the experimental area has been focussed on the high-resolution proton spectrometer area, the stopped muon and fast pion channels, and the design of shielding and radiation safety aspects. The latter consideration was propelled into highest priority by the scheduled visit of the AEC Advisory Panel on Accelerator Radiation Safety. This panel met at LASL on April 26 and heard numerous presentations about LASL plans and the bases for them. In preparation for this meeting, a document was prepared outlining the procedures LASL proposed to adopt for insuring radiological safety in the maintenance and operation of the accelerator. These procedures have been approved by the panel.

Construction

LAMPF PERT has now progressed to a single integrated project network. Two new subnets were added and interface logic has been approved. The results are being applied to a review of project planning and scheduling.

Construction has been started and is now 7% complete on the ETL Building, and a construction contract has been awarded for the Injector and 201.25-MHz Sector Building. Bids will be opened at the beginning of the next period for the second phase of site utility work. Redesign of the 115-kV Substation and the continued Title I design of the 805-MHz Accelerator Building are in progress.

Publications

"Two-Degree-of-Freedom Control Moment Gyro for High-Accuracy Attitude Control," J. Spacecraft Rockets, 5, No. 1, 74 (1968).

"Physics with Meson Factories," Proc. Intern. Conf. on High Energy Physics and Nuclear Structure, Rehoveth, Israel, Feb. 1967. North-Holland, 1967, p. 447.

"Polarized Protons as Nuclear Probes," Science, 157, 1127 (1967).

"Why Meson Factories?" Phys. Teacher, 5, 145 (1967).

"Computer Design of the UHF Power Amplifier Tubes," Gmelin, 1967 AED-CONF. 67-082-040.

"Calculation of Neutron Polarizations Using a Local Optical Potential with Average Parameters," LA-3788.

II. ACCELERATOR STRUCTURES

Introduction

During this quarter the design goals of the Electron Prototype Accelerator (EPA) have been met, i. e., an average current of 1 mA, an energy > 20 MeV, and a duty factor (DF) of 6%. Beam spot size and energy distribution are consistent with expected performance.

The parameters for the side-coupled accelerator tanks for the LAMPF have been set and design of the tanks for LAMPF has started. The choice of cavity diameter effectively places the TM_{110} transverse mode band well away from any multiple of 201.25 MHz while also staying near optimum shunt impedance.

Extensive investigation of the post-coupled drift tube accelerator has been completed. The performance of this system has been exceptionally good and Tanks 2, 3, and 4 of the LAMPF drift tube linac will utilize this field-stabilizing scheme.

Design of the LAMPF drift tube linac tanks is well under way. Some trouble with the drift tube stem-to-body braze joint has been encountered and a new joint system is under test.

Side-Coupled Accelerator Studies

Model N

Model N (5-cell side-coupled accelerator tank, $\beta_s = 0.35$) was received from the brazers and given its final tuning. The measured Q is 17,800. The shunt impedance (ZT^2) is 31 M Ω /m. The main-cell-to-coupling-cell coupling constant is 0.053 and the main-cell-to-main-cell coupling constant is -0.0008.

Passbands of higher order were noted at 1485-1585 MHz and 1720-1960 MHz. By comparison with data from the single-cell test program, the former was tentatively identified as TM_{110} modes; the latter passband was not identified.

Model K

The TM_{110} passband for Model K was found at 1305 to 1367 MHz.

Model L

A passband at 1240-1261 MHz in Model L (5-cell, $\beta = 1$ cavity) has been tentatively identified as the TM_{110} by comparison with the single-cell test program data.

Electron Prototype Accelerator Operation

Essentially full current operation of EPA has been achieved. With 500 kW rf dissipation in the main tanks giving slightly more than 20 MeV energy, a peak current of 18 mA with a 480- μ sec pulse at 120 pps was possible; this gave just over 1 mA average current. The current was limited by waveguide arcing at higher peak beam currents; the cause for this arcing will be investigated.

Magnetic spectrometer measurements at low current gave a peak energy of 20.2 MeV for 500-kW tank excitation. The energy spectrum had a peak with 1% FWHM, and a considerable tail; about half the current was in the upper 2% of the peak region. The energy of the beam should be independent of current since the phase and amplitude of the rf are servo controlled.

A foil of 0.0003-in. Ta was placed in the beam to get an idea of the beam size. Beam heating caused the foil to glow and the light was observed by a TV system. The hot spot was $\frac{1}{4}$ - $\frac{3}{8}$ in. in diameter with a beam of 8-mA peak for a pulse length of 300 μ sec and a pulse rate of 120 pps.

Beam Position Monitor

During this quarter, one unit of the beam position monitor system was tested on the EPA, at the output of Model M, the first section of the side-coupled structure. The sensitivity to beam current was as expected. The beam position was monitored for a peak current of a few mA, using the quadrupoles to steer the beam.

The position outputs followed the beam as it was moved up and down and left and right. No x-to-y coupling was observed. A centered beam coincided approximately with maximum transmitted current.

The indicated position showed no dependence on beam current over the range from 1-20 mA. No noise (nonbeam-induced signals) was

Fig. 1. Tests of EPA cooling system.

noted even though the 1.25-MW klystron was operating into the EPA tanks during the tests.

A complete set of mixers for the position monitors that are electrically identical with the prototype are being assembled, and the remaining two analog channels are being calibrated. Work is beginning on a 200-MHz mixer for the position monitors of LAMPF.

Electron Prototype Accelerator Mechanical Engineering

All target components for EPA have been installed and vacuum-tight conditions have been maintained. Minor problems have been experienced with the target vacuum system, most of which are electrical in nature. There has been frequent malfunctioning of the Geissler spark gap, which quite often has been traced to the power supply. There have been some outages of the turbomolecular pump power; a faulty breaker has been discovered which may have been responsible. When these outages occur, the turbo-pump remains under vacuum, but not running; this results in oil being pulled through the shaft seals, adversely affecting the ultimate vacuum which can be reached. Despite these problems, a pressure in the lower 10^{-5} torr range has been achieved.

The pressure in the EPA accelerating structure is being maintained at $\sim 2.5 \times 10^{-8}$ torr without rf power. The outgas rate has been measured at 1.2×10^{-11} torr liter/sec/cm².

The Model M, EPA tank, and collimator cooling systems are in operation. Eight of the thermistor flow switches have been installed in these systems. Initial operation of the flow switches has been satisfactory, although there is a few seconds delay in the tripping action. The operation of these switches will be monitored during the next few months to evaluate their reliability.

Tests were conducted to evaluate the effectiveness of the EPA cooling system, and several unexpected conditions were observed (Fig. 1). Tanks 1 and 2 received less rf power than Tanks 3 and 4. Due to this unequal power distribution, Tanks 1 and 2 ran about 4°F cooler than Tanks 3 and 4 at 8% DF. An imbalance of power was expected from the bead pull data, for Tank 2 has a large error in several cells which lowers its average field over the fields in Tanks 3 and 4. But the effect is more pronounced than expected, and the temperature shift may be increasing the imbalance. All of these measurements are complicated by the extremely poor thermal transmission properties of the aluminum-loaded epoxy which is used to fasten the cooling passages onto the tanks. With properly brazed or soldered joints the temperature change in the water required to maintain resonance will be much less. The result that the temperature control system can track resonance with this poor thermal joint gives added confidence in the system proposed for LAMPF.

805-MHz Side-Coupled Structures

A prototype tuning slug is being fabricated for the 805-MHz side-coupled linac bridge couplers. This tuning slug will be assembled by welding and furnace brazing to provide an all-metal vacuum envelope.

Bids and quotations are being obtained for final machine components. An effort is being made to utilize stainless steel investment castings, where possible, to reduce machining time required for a finished part.

A mockup of an 805-MHz vacuum manifold was made to determine if space was available for a field-welded vacuum joint. The joint was

successfully welded under a tank section positioned 6 ft above the floor. The space allowed will be the minimum encountered in the 805-MHz linac.

Equipment Test Laboratory

An order for two large furnaces, five bases, five retorts, and miscellaneous controls to be used in the fabrication of LAMPF was placed with delivery expected about Oct. 1968. The design of the furnace evacuation system was completed. This system will evacuate any one of the five retorts from 1 atm to 50 μ in < 15 min. Two gas purifiers, each with an output of 600 ft³/h, have been ordered with delivery expected in October. These purifiers will be used during brazing operations to maintain high-quality H₂ and Ar at all times. The design of the brazing furnace gas system is essentially complete pending final coordination with the furnace supplier.

Post-Coupled Linac Tanks

Drift Tube Accelerator Studies

The post-coupled drift tube linac structure developed during the past year will be used in Tanks 2, 3, and 4 of the drift tube linac portion of the LAMPF accelerator. These tanks cover the energy range from 5-100 MeV. All studies to date show the structure to be highly satisfactory.

A recent study demonstrated excellent performance of the structure in the low-energy portion of the energy range. For this purpose, a 26-cell drift tube model was built, utilizing a piece of the aluminum pipe 8 ft 9 in. long and 14 in. diam, loaded with 25 full drift tubes and two half drift tubes. The model resonates at 517 MHz and the cell geometries vary from 5 MeV at one end to 30 MeV at the other end.

Some important properties of the field distributions in the 26-cell linac model both with and without post couplers are seen in Fig. 2. The six traces show how the resonant frequency of the structure changes as a small metallic bead is pulled along the axis of the tank. The frequency drops as the bead enters a region of high electric fields and returns to the "base line" when the bead is in the hole of the drift tube. The height of the spikes

Fig. 2. Field distribution in 26-cell drift tube linac model.

so produced is proportional to the square of the field at the center of the gap.

The center trace in the upper and lower rows represent a nominally flat field distribution in the 26-cell model. The longer spikes on the left end of the trace than on the right are due to the continuous change from a 5-MeV geometry on the left end to a 30-MeV geometry on the right.

The standard test for field stability in these structures is based on an observation of changes in field distribution in response to end-cell tuning errors. The upper left and upper right traces show marked changes in the field distribution of the 26-cell model in response to the 5-MHz end-cell perturbations without post couplers. The lower left and lower right traces reveal the exceptional stability of the field distributions in the structure with post couplers in response to the same perturbations.

Eccentric tabs on the post couplers will be used to provide fine control of the field distributions within the structure. The performance of these tabs has now been demonstrated on the 26-cell model (5-30 MeV) and the 35-cell model (40-100 MeV). Even though the tabs provide some control of the fields, they do not jeopardize the field stability gained by use of the post couplers. For a given orientation of the eccentric tabs, the resulting field pattern exhibits excellent field stability properties against tuning errors and power losses.

A power model of the post coupler was installed in the 4-ft drift tube linac model. The model was excited to full power with no evidence of electrical breakdown. The 4-ft linac model

has one full drift tube and two half drift tubes, and as such will accommodate only one post coupler. After a considerable effort to adjust the single post according to the procedure used on other models, it was realized that a two-cell model coupled with one post does not perform quite like an N-cell model coupled with $N - 1$ posts, where $N \geq 3$. Therefore, in the power tests it could not be demonstrated that the post was properly tuned. In the absence of this information, power tests were made for a range of settings of the post coupler in a cell of the same energy in the 40-100 MeV 35-cell model. No electrical breakdown was observed. Since post excitations are not critically dependent on post tuning, these power tests are considered to be conclusive.

It has been suggested that fields associated with excited post couplers might have a detrimental effect on the dynamics of the particles traversing the structure. A considerable effort has been made to measure such fields in the 35-cell model. Before describing this effort, the point should be made that the post-coupled linac structure is operated in the so-called $\pi/2$ mode, which has the property that the post couplers are unexcited in the lossless case with no tuning errors. In this idealized situation, the perturbations to the accelerating field due to the unexcited post couplers are quite small, as a result of their small size and favorable orientation.

In the practical case with losses and tuning errors, the post couplers are expected to have some small excitations. An indication of their relative excitations can be deduced from measurements of the magnetic field along the wall of the structure. These fields were measured by observing perturbations on the resonant frequency of the structure as a metallic slug was pulled along the outer wall. The data revealed the way in which the post-coupler excitations depend on tuning errors and losses, and are in complete agreement with the predictions of the coupled resonator analysis.

Such evidence of post-coupler excitation is not sufficient, however, to evaluate the effect of these excitations on the dynamics of the particles traversing the structure. For this purpose, it is necessary to search for perturbations to the normal

accelerating fields near the axis of the linac produced by the excited post couplers. It has been possible to detect some transverse fields on the axis of the linac by observing perturbations on the resonant frequency of the structure as a transversely oriented needle is rotated about the axis of the linac.

It was necessary to resort to very large tuning errors in order to produce measurable transverse fields on the axis of the linac. These fields are due to post-coupler excitations which have been shown to depend on tuning errors and power losses as predicted by the coupled resonator analysis. Tuning errors in an actual linac will certainly be two or three orders of magnitude smaller than in these measurements. The largest field measured, when reduced by a factor of 100, would produce a transverse impulse on a beam particle that is very small compared to the radial impulse received by the average particle on crossing the gap. The quadrupole focusing system can easily counteract transverse fields of such magnitudes.

Drift Tube Linac Resonance Control

Study has been continued of the temperature control system to maintain resonance in the 4-ft drift tube linac model. Information and experience with this system are aiding in the design of resonance control systems for the full-size drift tube linac.

Controllers for the copper circuit and tank-wall cooling water circuits of the 4-ft model have been constructed so that the effects of various pulse rates and various combinations of state variables could be investigated. Digital simulation studies have provided insight in the matters of choosing only the relevant state variables and of optimizing the performance of a given configuration. The copper circuit controller incorporates a new sample and hold circuit for rf phase information. In order to accommodate occasional large errors without creating large overshoots, the system incorporates circuits to prevent the temperature rate of change with time from exceeding a preset value.

In a test these controllers maintained resonance within $\pm 10^\circ$ in phase continuously for 2.5 h, which is adequate. Three different rf power levels were used. The amplifier that supplied power was operated without amplitude feedback control. If amplitude feedback control had been used, indications were that resonance would have been maintained to $\pm 5^\circ$.

The delay in sensing a change in water temperature in the copper cooling system is one of the limiting factors in the speed of response for the system. Ways to reduce this delay are being investigated.

A small amount of cross-coupling between the two cooling water systems (one for tank shell and one for drift tubes) has been detected. Variation in water supply pressure with demand and electrical crosstalk have been investigated as possible mechanisms for creating cross-coupling and appear to have little or no effect. It is thus likely that the coupling is the result of thermal conduction paths within the 4-ft model. The coupling is small enough that no significant control problems from it are expected.

Tests were run on the 4-ft drift tube linac model to determine any effect on the resonant frequency caused by water pressure changes in the tank wall cooling water jacket. With the tank open to atmospheric pressure and with the tank closed and under a vacuum, a change of +76 Hz per psi increase in cooling water jacket pressure was observed. This test was run from 0-30 psi above ambient atmospheric pressure.

The difference in the tank resonant frequency between the conditions of the tank at atmospheric pressure and the tank under a vacuum was ~ 10 kHz. Most of this shift is due to the decrease in the dielectric constant in the evacuated region of the tank, mechanical strains accounting for < 1 kHz of the shift.

In an effort to demonstrate that the tank wall cooling water pressure might be used as a very fine frequency control, a servo motor-driven air regulator was connected to the tank wall cooling water jacket and its servo motor amplifier-driver unit fed with a signal proportional to the phase

difference between the drive of the tank and the fields in the cavity. With the tank driven at 50 kW peak power and 6% DF (3 kW input power) this control system held the phase error signal to $\pm 1^\circ$ for 5 min. At the end of this time the pressure in the tank wall cooling water jacket was up to 30 psi. Since it was not desirable to pressurize the cooling water jacket above 30 psi, the signal to this control system was removed; at this time the phase error climbed steadily to a full-scale reading ($\sim 7^\circ$ phase) in 15 sec. The sensitivity of this method of control is quite good, considering that calculation indicates a Δf of 35 Hz will cause a 1° phase change. A 0-30 psi change in tank wall cooling water jacket pressure on this 4-ft model is equivalent to a temperature change between 1 and 2° F.

A limited effort has been made to investigate control schemes which would reduce noise levels or reduce the effect of amplifier drift. A controller was built that eliminates the integrating action of the valve motor and incorporates an integrator at the head end of the control circuitry; it operated satisfactorily over a limited range of error. In this scheme, the valve motor is made to run only as there are changes in the output voltage of the controller. Operation is then immune to dc drifts in all the amplifiers preceding the output stage, except for the one integrator stage. No differentiating circuits are needed. It was necessary, however, to insure that the controller did not drift into saturation, since the output of a saturated amplifier is constant and this might falsely indicate a no-error condition.

Four-Foot Power Model (201 MHz)

New field monitor loops for the 201.25-MHz tanks have been designed, incorporating a ceramic well which allows changing or transferring loops without disturbing the vacuum. New loops have been made and the ceramic wells are being fabricated and brazed at LASL. These units will be tested in the 4-ft power model.

There were problems with the springs which provide sliding contact on the tuning slug. Both beryllium-copper and phosphor bronze

Fig. 3. Pole piece of magnet in grinding fixture.

springs of various wire diameters and spacing diameters have been tried, but they melted during high-power runs. At the present time, a silver-plated spring is being used but it has not been subjected to high power for a long period of time. Zirconium-copper wire has been ordered for evaluation. This material has a conductivity $\sim 80\%$ that of copper, which is 3-4 times higher than the conductivity of phosphor bronze and beryllium-copper.

A tuning slug design using a stepping motor is essentially complete and will be tested in the 4-ft power model.

A second generation drive loop for the 4-ft power model has been installed, matched to the cavity, and tested at full field strength. Full power tests will be conducted in the near future.

A feasibility model post coupler has been constructed and installed in the 4-ft power model. Full field tests have been conducted with no evidence of arcing. A prototype post coupler which will allow positioning under vacuum has been designed and is $\sim 90\%$ complete.

Drift Tube Development

One of the prototype drift tubes was assembled, complete with quadrupole magnet, but many problems were encountered. The quadrupole magnet and coil were assembled, potted, and subjected to a hydrogen brazing atmosphere prior to assembly within the drift tube body halves. The

initial body braze failed to reach the required temperature, resulting in a leak in the body and the bore tube. Another heat corrected the body leak but failed to repair the bore tube. Two subsequent heats were run without success and it appeared that the alloy failed to reach brazing temperature. It was decided to run the stem-to-body braze in spite of the bore tube leak. This mechanical joint was extremely tight and the stem failed to seat, resulting in a leak. The stem-to-body joint is very complicated because of the limited space within the drift tube. In an effort to simplify this braze, a split yoke has been designed to permit the coil leads to pass through the yoke rather than around the ends as in the previous design. The coil appeared to present the major problem; however, a coil was wound and inserted in a prototype yoke proving its feasibility. An iron yoke is being fabricated that will be used to investigate the quality of the resulting magnetic field. The new design offers several desirable mechanical features in addition to being somewhat easier to fabricate. The split yoke does not change the existing magnet pole design.

Quadrupole magnets of each of the six designs in the drift tube linac have been fabricated, including the associated coil winding forms, annealing forms, and potting forms. These units will be assembled and used for field surveys. All of the essential tooling for the quadrupole magnets is complete and the resulting poles have been ground to within ± 0.0002 in. of the theoretical dimensions. Figure 3 shows a pole in the fixture on a Brown and Sharpe No. 3 Universal Grinding Machine.

A potting material developed at LASL appears to be far superior to any cement commercially available. It is a calcium aluminate with an alumina binder. This material casts well around the coil with minimum cracking and exhibits no apparent reaction in the hydrogen brazing atmosphere.

All components for the gaussmeter positioning device have been fabricated and received and some of the assembly work is complete. Installation and wiring of the electric wafers and associated drive equipment is in progress.

The rotating-coil instrumentation is nearing completion. A preliminary survey of one of the quadrupole magnets indicated a low-frequency oscillation in the amplitude of the output signal. It is believed that this perturbation is caused by the driving motor and further studies are under way to eliminate same.

Drift Tube Linac Structures

Good progress has been made in the final design of the drift tube linac tanks, heads, plates, and mounts and many of the drawings are essentially complete. A mockup of the first group of quads for Tank 1 has been built and will provide detailed design information for quad electrical and water cooling system components, as well as structural supports. A drift tube positioning apparatus for the tank has been designed and the fabrication drawings are now being made. The design of the adjustable alignment mounts, mount ways, and support structure for Tank 1 has been completed and detail drawings of these mounts were made. The necessary hardware has been ordered for the construction of a prototype of the mounts.

The water flow tests are now complete for the drift tubes in all four tanks. Flow test models were used that incorporated identical stem and body water passages to the final drift tube designs. Water pressure drop equations were written based on constants derived from the experimental data and included in the drift tube heating subroutine of PARMILA. The drift tube end caps and body cross sections are identical in the last three tanks. Only the drift tube lengths and stem diameters are different. This uniformity of design will reduce tooling and production costs.

A prototype has been fabricated of the final design of the differential screw assembly which moves the drift tube plates of Tank 1 to tilt the fields. This assembly was installed in the simulated head and cycled 570 times. Although the performance of the mechanism was quite satisfactory, several slight modifications are being made.

Computer Studies

Theory of Sensitivity to Tuning Errors

It has been found that the results of the tuning error analysis for a biperiodic multiply-coupled chain of resonators can be simplified for certain cases of interest. The effect of a tuning error in any particular resonator on the field level in any particular resonator may now be calculated in a straightforward manner for resonator chains in which nearest-neighbor coupling dominates and which are operated in the $\pi/2$ mode. The results give insight in regard to tuning procedures and field stability for both side-coupled cavity linacs and resonant-post drift tube linacs.

III. RF POWER SOURCES

Introduction

An experimental study of the operating characteristics of the first Litton klystron, under conditions of reduced mean current and increased beam voltage, has led to an operating point with increased efficiency and stability at significant power levels. These effects are important and desirable.

A complex set of experiments was started which should elucidate some of the interactions between the rf amplifier, the accelerator, and the accelerated beam. The data are being collected through the controls computer and will provide another test of the computer system.

Testing and refinement of the 201.25-MHz rf system are being continued. The blocking capacitor in the 7835 amplifier cavity remains a source of trouble at high average powers. Stable, linear control of the 7835 modulator is now possible with a bandwidth of 200 kHz.

Design and procurement of many of the components for the Experimental Test Laboratory (ETL) Building test stands have been started.

Development of frequency sources and low-level amplitude modulators is being continued.

RF Control Studies

Overall System Design

Study of hardware and procedure standardization has been continued. Drafting standards are nearing final form. Construction work is proceeding on the 201.25-MHz status panel.

Frequency and Phase Reference Studies

The prototype hybrid multiplier chains (see LA-3838) now have 4250 h of continuous service without failure or deterioration. A second generation multiplier of similar design, but with mechanical improvements and higher quality components, is under construction. The first unit, a 6.249-201.250 MHz chain, was completed and tests show it to be superior to the prototypes in that it has better multiplier efficiency and tuning is less critical.

Power into the 805-MHz drive line for the Electron Prototype Accelerator (EPA) and Mockup Building frequency reference was increased from 100 to 350 W by installation of a 350-W amplifier. This addition completes the power amplifier complement for the EPA rf drive line. Plans for the ETL contemplate using the same amplifier complement; hence reliability, signal purity, and phase coherence of these amplifiers is of interest. Reliability is excellent. The high-power amplifier now has 1340 h of service and the lower power stages have accumulated nearly 1900 h. The amplifier chain is turned on Monday mornings and runs 24 h a day until Friday night when it is turned off for the weekend. To date no retuning has been required, and after turn-on, the amplifiers come up to normal power in about 10 min.

Phase coherence was checked and found to be very good. Phase disturbance contributed by the amplifiers is less than that measured on the multipliers, but is concentrated in the frequency range above 750 kHz, whereas phase disturbance from the multipliers appears below 750 kHz so that the two are not cumulative. Signal-to-noise measurements at the output of the amplifiers show at least 105 dB for the frequency range above 20 kHz. Measurements below 20 kHz have been unsatisfactory because it is very difficult under present conditions to isolate the amplifiers from extraneous sources of noise, especially the noise fed into the amplifier shield cabinets and the screen room on power lines and rf transmission lines.

Experience on klystron operation with amplitude and phase control indicates that more gain and power output will be required of the interface amplifiers. They were, therefore, redesigned as a compact unit incorporating two cascaded stages using the Machlett 8534 planar triode. This amplifier has a gain of 23 dB and a power output capability of 25 W. Two views are shown in Figs. 4 and 5; the in-line arrangement should be noted. The first stage uses a $\lambda/4$ cavity capacity coupled to the second stage which uses a $\lambda/2$ cavity link coupled to the output circuit. A 201.25-MHz two-stage version of the interface amplifier, shown in Fig. 6, has similar gain and power output. Since there is a possibility that higher power output might be necessary at 201.25

Fig. 4. 805-MHz interface amplifier assembly.

Fig. 5. Amplifier disassembled, showing in-line arrangement.

Fig. 6. 201.25-MHz two-stage interface amplifier assembled and one section disassembled.

MHz, a three-stage version was built which had over 30 dB gain and a maximum output capability of 75 W.

Until recently, the klystrons were amplitude controlled by applying a control signal to a PIN diode modulator in the rf drive to the interface amplifiers. This was satisfactory as an amplitude control, but introduced substantial phase shift. As much as 45° change was measured between cutoff and maximum transmission, with several degrees variation over the area of amplitude correction. As part of the hardware simplification and packaging program, it was found that the interface amplifier power output could be controlled by varying cathode voltage in the second stage, with the added advantage that no phase shift could be detected from cutoff to full-power output.

In order to control the cathode voltage with a low power source, an NPN transistor was used in a common emitter configuration with the rf amplifier cathode connected to the transistor collector. The transistor used (2N1711) has a current gain of ~ 100 so that 1 mA of base current was enough to drive the rf amplifier cathode current up to the 100 mA required for full rf output. As the circuit is designed, a 2.5-V pulse is sufficient. In addition to the on-off response to pulse input, linear control of power output can be accomplished by varying the pulse amplitude. These amplifiers have been tested in the amplitude control loop on the 1.25-MW klystron test stand. Modulation bandwidth has yet to be measured, but their performance appears to be as good as that obtained with the PIN diode modulator. The advantages of this new approach are (1) the simplification resulting from combining the interface amplifier and the amplitude modulator, and (2) removal of controller drive turns the rf drive off instead of full on as with the PIN diode modulator.

RF Phase and Amplitude Control Studies

The major activity for this quarter was to gather data on the klystron systems as they interact with the EPA cavities, namely, the 100-kW klystron driving Model M, and the 1.25-MW klystron driving the EPA tanks. There are many parameter variation studies necessary as the

foundation for further control design. Most of these measurements must be made quickly and continuously, with later analysis, because the high-Q nature of the system makes it difficult to achieve steady-state conditions at each desired data point. To facilitate gathering of this information, it was decided to use the control computer mockup system, thus allowing the system tests to serve two purposes. Thirteen analog data channels were set up and calibrated for each klystron stand: time, frequency, rf output (forward and reflected power), cavity phase angle, reflection coefficient phase angle, average and peak cavity field, mod-anode voltage, klystron cathode current, cooling water demand, cooling water error, and copper temperature error (the latter three from the resonance control system). The 1.25-MW klystron test stand also has data channels for dc high voltage, rf drive, and collector current.

A substantial amount of programming was done to allow data storage and semiautomatic sequencing of the proposed experiments. A data storage program stores up to 672 points from each channel; initial runs have utilized storage of a set of points every 3 sec. This test requires all of the computer's time under the present program, mainly because of disk accesses--data can be collected about once every 5 sec at best. A future program will place this special data collection task outside the executive program, and will thus increase the speed. Another program calculates VSWR on-line from the forward and reflected power data.

The first experiments were designed to study the interaction of klystron and cavity as the cavity goes through resonance. Cavity resonance was controlled by varying the cooling water temperature or, separately, by varying the rf frequency. Since the computer can change the water controller set point, a program was written to cycle the cavity automatically through resonance by incrementally changing the water temperature, watching VSWR until it reaches a given limit, reversing the water temperature demand until VSWR passed through a minimum and back to the limit, and so on.

These experiments were run on the 100-kW klystron Model M system using all combinations of the following conditions:

1. Resonance control by water temperature or frequency.
2. Beam off or on.
3. RF amplitude loop closed with rf information fed to water controller.
4. RF amplitude loop open with and without rf information to water controller.

The same experiments will be run on the 1.25-MW klystron EPA tank system.

The raw data are available from the computer on paper tape. Programs were written which convert the paper tape to cards or magnetic tape in the CDC-6600 format, perform scaling or calibration curve-fitting to put the data in proper units, and plot the data files against time or against each other with the 4020 plotter. These programs have now evolved to a very useful and simple format which will be an important tool in the testing programs.

Analysis of the Model M data has begun, but it will have second priority until the experiments on EPA have been accomplished.

A new stripline 805-MHz phase bridge (hybrid ring model) was completed and checked. Performance was not as good as expected. The completed model had 24-32 dB of isolation, depending on which port was examined, rather than the expected 40-60 dB.

Upgrading of some of the EPA apparatus was accomplished. New amplitude control cards were built for both klystrons' control circuits. The card for the 100-kW klystron circuit has been installed and tested. This card eliminated one previous fault in the design, a zener which changed operating levels because of insufficient current. New temperature measuring instruments for the Model M and EPA water tanks were acquired and installed.

The set-point potentiometer in the 100-kW klystron amplitude controller was motorized for startup by the computer. This plus the ability to reset the protective logic remotely after faults

(see below) enables the computer to turn on the Model M system remotely under program control. This startup has been demonstrated successfully. The program runs up rf power until (1) a VSWR fault (usually caused by Model M sparking until the vacuum cleans up) or other fault occurs, or (2) until calculated VSWR from forward and reflected power data reaches a set limit. It then stops, resets the fault protection logic, or waits until VSWR is safe, and then proceeds toward the demanded power level.

Logic and Protective Circuitry

The EPA logic was interfaced with the computer so that VSWR faults can be detected and the logic reset under program control. The computer reset will clear all fault indications except for arcs, which remain in the nonclearable category.

An improved optical solid-state arc detector was designed and installed on the EPA klystron. The electronics are completely insensitive to the largest expected noise signals and more sensitive to light than previous models. The circuitry is also less complex and has an improved mechanical design.

A new VSWR detector was designed, built, and tested on the 201.25-MHz totem-pole output. This circuit detects voltage ratios rather than absolute value of reflected power. It has the advantage of being simple for a ratio detector, although it may prove to be overly sensitive to noise. It must, of necessity, be sensitive to differential signals on the order of 10 mV. Tracking is good enough for this application; as an example, if the unit is set to trip at a VSWR of 1.5 at full power, it will trip at a VSWR of 1.7 at 10% of full power. This unit will be incorporated in all future fault protection logic if it proves successful.

Preliminary design is complete on the crowbar for the 805-MHz klystrons in the ETL Building. The modified Sherwood Spark Gap was tested on the 90-kV supply in the Mockup Building and found to require less holding current than the commercial unit. Future low-impedance supplies may make multiple firing of this spark gap unnecessary, and thus reduce the cost and complexity of the trigger logic.

The 7835 crowbar was improved by replacement of the krytron with a Silicon Control Rectifier. Krytron life was averaging only 3 months. An improved version of some of the electronics was bench-checked satisfactorily.

A successful grid-clamp circuit was tested. It may not be needed, however, since the ITT 7560 triodes exhibit no latchup problem due to secondary grid emission. The anode-grid arcs that sometimes are initiated by faults are still a problem; the experience with gaseous gaps to protect the clamp circuit has been unsatisfactory.

805-MHz Power Amplifiers

1.25-MW Klystron Program

Klystron S/N-1 has now been run in excess of 600 h and performance is satisfactory. Operation since the last report was primarily to provide power for the EPA and for certain experiments to see if klystron efficiency could be improved by modulator circuit modifications. These experiments and their results are described below.

In consideration of new modulator circuits, the light-pipe interface crossing has been dropped. This approach required too much gain on the high-voltage deck and was susceptible to noise. A new circuit has been proposed which is essentially a triggered blocking oscillator. This circuit has the advantage that the pulse feedback transformer need not hold off voltage and the trigger transformer, which must withstand the entire voltage, is required to pass a very low energy pulse; therefore, it is much smaller than the present interface transformer. A full-scale alternate modulator deck is under construction using this approach.

Considerable time and effort was spent in refining the instrumentation for the test stand. In particular, new mod-anode voltage divider and cathode and collector current viewing systems of considerably improved accuracy have been installed.

The 3-dB isolator which was mentioned in the last report has been removed from the waveguide between the klystron and accelerator. Operation without the isolator is entirely satisfactory.

Fig. 7. Schematic of klystron test stand showing definition of mod-anode resistor.

From a critical examination of the beam parameters of the first 1.25-MW klystron, it was concluded that the conversion efficiency of the device could be increased by decreasing the beam current thereby reducing space-charge effects. The modulating anode connection could be moved from one end of a resistor to an intermediate tap; by doing this, the mod-anode voltage (for a fixed cathode voltage) could be varied, thus reducing the beam current. The resistance between the tap being used and the original connection is called the mod-anode resistor (Fig. 7). An experiment was performed in which the efficiency was measured as a function of the cathode voltage; the results are shown in Fig. 8. The value of the mod-anode resistor is the parameter, and the microperveance, based on the cathode voltage, is indicated beside each curve. These curves show that the conversion efficiency is improved significantly by decreasing the beam current. The output rf power is reduced as the resistor is made larger, but most of this loss can be regained by operating at a higher voltage. Thus, 1 MW of output power can be achieved at 84 kV with a 25-kΩ mod-anode resistor. A 35-kΩ resistor was also used, but the 1-MW output power could not be reached, although the efficiency was slightly higher.

Another significant improvement in the operation of the klystron is that the adjustment of the focusing field for stable operation is not critical when the 25-kΩ resistor is used. In addition, the tube can be driven from low levels to past saturation

Fig. 8. Efficiency vs cathode voltage with mod-anode resistance as parameter (3% DF).

tion or over a wide range of input power. Because of the more stable operation, the klystron is now usually operated with the 25-kΩ mod-anode resistor. This value of the resistance lowers the saturation gain by ~ 1 dB, but the gain is still ~ 56 dB.

A theoretical analysis of the klystron was initiated. This analysis is based on a large-signal computer program which is being written. A few of the subroutines have been coded.

Experimental Crossed-Field Amplifier Program

The experimental crossed-field amplifier (CFA) was assembled during this quarter, and testing was started. The device has a total of eight vacuum seals which include the ion pump, waveguide windows, and cathode assembly. The system was plagued by leaks, which arose from a variety of causes, e. g., from the creeping of soft metal seals (some solder seals were used) to leaks through the grain boundaries in the cast copper vacuum chamber at the bottom of several bolt holes. The CFA was then installed in the drive line of the 100-kW klystron and connected to a water load. RF power was delivered by the klystron which was tuned to the predetermined resonant frequencies of the CFA slow-wave structure, namely, 715, 830, and 860 MHz. About 90 kW was transmitted through the CFA to the water load at 830 MHz. The tube was thus conditioned, and outgassing continued for several hours at up to 6% DF.

Top trace: RF anode current, ~ 2.2 -A peak.
 Bottom trace: RF voltage delivered to water load, ~ 10 dB gain over klystron level.
 Time scale: $50 \mu\text{sec/cm}$.
 DC voltage 22 kV
 Power Generated: 40-kW peak (estimated)
 Frequency: 712 MHz

Fig. 9. RF power generated by Experimental Crossed-field Amplifier.

The next step was to pulse the tube with short dc voltage pulses to determine its operating characteristics. Space charge made it uncertain how well the CFA would operate at its design resonances and how well the cold cathode would produce current at these points. The first phase of testing, therefore, was to operate the CFA over the frequency range of 700-900 MHz. It was found that the tube produced an amplified rf signal at its three resonant frequencies, with ~ 40 -kW peak power generated at 712 MHz and lesser amounts at 826 MHz (~ 10 kW) and 855 MHz (~ 20 kW). The rf output pulses obtained at 712 MHz are shown in Fig. 9. Since the output at 712 MHz was the largest, the klystron was retuned to this frequency with the intent of letting the tube operate for several hours and thus better condition the cathode. It was found, however, that the output level initially achieved (40 kW) could not now be attained and, although the tube operated with a reasonably wide dynamic range, its output was disappointingly small.

The cathode emission capability of the klystron had fallen under suspicion earlier and so the second phase of testing was begun, namely, to

experiment with the cathode. The vacuum was broken and the cathode removed. It was found to be heavily coated with what appeared to be copper from the anode. The regions near the end caps were quite blue and dark longitudinal streaks were seen at the centers of each anode side resonator. The cathode will be cleaned and reinstalled to determine if emission is improved. A similar cathode is being machined to a smaller diameter (4.8 cm vs 6.0 cm, originally) since there is some evidence that the rf fields are too strong in the 1.5 cm anode-cathode gap. A smaller cathode may allow more effective formation of the space-charge spokes although it may also change the resonant frequencies at which the tube will operate.

201.25-MHz Amplifier Program

Testing of the 201.25-MHz rf system has progressed well, marred only by the loss of an RCA 7835 triode due to component failure in the 201.25-MHz amplifier cavity. This failure was caused by a piece of rf finger stock which broke off the tube cathode connector and fell across the grid-cathode ceramic seal; the finger stock thus shorted the rf drive and the resulting arc destroyed the vacuum integrity of the tube. An improved cathode connector was designed and is presently in use; a protective ring was also placed in the amplifier to shield the grid-cathode seal. Other improvements were also made in the amplifier. A new machined aluminum output cavity was installed and appears to be operating very well. It uses an improved manufacturing technique in which it is much easier to hold close mechanical tolerances. A new ceramic output cavity pressure window was designed and is being built; a new input cavity center conductor with water cooling coils is also under construction. These last two items are necessary due to excessive heat generated in the amplifier during high average power operation.

A new Teflon blocker was received from Continental Electronics and placed in service. It lasted only 55 min, however, before corona between two layers of Teflon destroyed the dielectric. Continental is presently working on an

improved version of this same blocker which should alleviate the corona problem. A blocker of LASL design is being fabricated for test.

The first prototype of the 14-in. coaxial transmission line was built and will soon be installed. This large line size will allow operation at high average and peak powers without line pressurization.

Improvements were made in the remainder of the 201.25-MHz rf system. The use of stepped grid bias supplies in the Intermediate Power Amplifier(IPA) was eliminated and a PIN diode rf modulator is now being used to pulse the system. The protective logic for the IPA was improved with the addition of a VSWR detector which replaces the old reflected power level detector.

During this period, a contract was let for the fabrication of several prototype units, including most of the small power supplies and subunits for the 201.25-MHz IPA. An essentially complete prototype IPA is expected to be in operation in about 2 months.

201.25-MHz Modulator Program

Encouraging progress has been made on the 201.25-MHz amplifier modulator. A pair of ITT 7560's were placed in service, and appear to have none of the grid emission characteristics of the Machlett 7482 PV tubes used earlier. The ITT tubes have a grid coating which eliminates the negative grid current characteristic and allows simplification of the modulator circuit. There is now no need for a grid clamp or the elaborate grid swamping which was necessary with the Machlett tubes. The method of crossing the high-voltage interface was greatly improved with the elimination of the 30-MHz rf interface system and the use of a pulse transformer video driver unit. Linear control of the modulator is now possible up to a 200-kHz rate, with none of the problems of instability which were noted when previous modulators were run out of saturation.

Construction of an alternate modulator system utilizing a pair of EIMAC 4CW250,000 tubes is under way and it should be ready for evaluation in the next quarter. This system is

potentially simpler than the one now in use and would be a desirable approach if tests show it to operate satisfactorily.

Included in the outside chassis construction contract mentioned above is a prototype modulator for the 201.25-MHz IPA using a single EIMAC 4CW100,000D. This unit should be completed and placed in service within the next two months.

High-Voltage Power Supplies

Bids on three high-voltage power supplies for the ETL Building were received in February. Cost of the voltage regulator and vacuum breaker was about as estimated, but for the 600-kVA transformer/rectifier units it was 2-3 times that estimated.

A study of cost reduction methods was initiated and the problem was discussed with all vendors who had submitted bids on the supplies. These discussions indicated that the optimum method of getting cost down was to use more than one klystron load per power supply. This would reduce the number of vacuum breakers needed and reduce the cost of voltage regulators and transformer/rectifier units on a per module basis. Insulation in transformers is much more expensive than kVA. Therefore, by holding the voltage constant and making the kVA three or more times that originally planned, cost per kVA is decreased substantially. This specification was released for bids along with requests for budgetary quotes on 15 1800-kVA units and seven 4200-kVA units. Specifications were rewritten for the vacuum breakers and voltage regulators reflecting the higher kVA's and new quantities. When these bids are received, the question of using either three or seven klystron loads per power supply in the accelerator can be evaluated and a power supply for the ETL Building can be procured.

An order was placed with General Electric for 100 1.38- μ F capacitors at 45 kV. These capacitors will be arranged in a series-parallel configuration to make three capacitor banks for the ETL Building, each bank being rated at a nominal capacitance of 11 μ F and 90 kV working voltage.

Directional Coupler Studies

Some inconsistencies in power measurements at load VSWR's > 1.5 using directional couplers in waveguides led to an investigation of the accuracy of available couplers under various conditions of power and standing-wave ratios.

An experiment in which the position (phase) of a constant amplitude voltage standing wave was shifted using an E-H tuner in conjunction with a water load revealed different outputs from the incident and reflected ports depending on the relative position of the voltage maximum and the coupling port. The effect is very pronounced on all the commercial waveguide couplers (loop-type) on hand, and on a Bethe hole coupler constructed at LASL; it is present to a lesser extent in the resistive-terminated and $\lambda/4$ loop couplers for $3\frac{1}{8}$ -in. coaxial line. These results indicate that couplers which sample a short length of a transmission system compared to $\lambda_g/4$ have only limited ability to separate the forward and reflected components of the power flow. A two-probe coupler was developed with probe spacing $\lambda_g/4$ and an external $5\lambda/4$ coaxial phasing section between probes so as to take an averaged sample of voltage over the standing wave in the waveguide. This coupler was adjusted to a coupling ratio of -50 dB and demonstrated a true directivity of at least 20 dB to high VSWR's. Further investigation of distributed, multiple port couplers is planned.

IV. ACCELERATOR CONTROL AND INSTRUMENTATION

Introduction

Trial operation of various portions of the Electron Prototype Accelerator (EPA) under computer control received prime attention this quarter. This effort has involved both development and debugging of the necessary computer programs and the checkout of the controls for various devices as they were installed on the accelerator. Other activities include design studies and tests on numerous circuits and subsystems involved in the final design of the LAMPF control system.

The package of programs for the turn-on, run-up, and beam steering for EPA is now about 95% complete. It includes programs for preparing the preaccelerator (Model M) for rf, turning on the Model M rf power amplifier, setting the timing gates, and running up the power to the operating point. In parallel with this, other programs prepare the rest of the accelerator for beam, turn on the main 1.25-MW klystron, and condition the electron injector for high voltage. Upon completion of these preliminary programs, the electron gun is turned on and the computer begins a search for the beam. Programs have been developed to maximize the beam through the first two current monitors.

The installation and checkout of special data channels and the correction of various faults in the EPA control equipment have been continued throughout most of the period. Toward the end of the quarter, however, as the problems with components and wiring errors were resolved, the system began to approach a level of reliability more in keeping with its design. Valuable experience has been obtained from all of the systems in the Mockup Program, and this is leading to modifications in many areas as final prototype designs are developed.

In parallel with the effort on EPA, final design studies were initiated on several of the major accelerator control systems.

Fig. 10. Turn-on sequence for EPA.

EPA Computer Control System

Control Computer

The computer maintenance program established during the previous quarter has continued to be beneficial in the form of increased availability. The program is predicated on a 5-day work week for two technicians with one day reserved for computer maintenance. Experience so far indicates that most unscheduled maintenance items occurring during the week can be tolerated until the scheduled maintenance day.

The most troublesome units have been the teletypes and the disk. Since the teletypes received abnormally high use, it proved advantageous to place them under a separate maintenance contract. The service provided by the contractor improved markedly during the past month. The disk failures appear to be due to underrated components in the access drive motor circuitry. Substitution of components with higher ratings has alleviated the difficulty but not completely resolved it. In addition to these maintenance problems, three design faults in the display scope were discovered and corrected.

Work was started on a digital clock and calendar which the computer can read. This piece of hardware is needed for the new resident program system discussed later. Specifications call for a 30-stage counter having a minimum resolution of 8 msec, corresponding to the 120 pps repetition rate of the accelerator. Completion of this unit will depend on receipt of components.

Programming

A major effort went into the development of programs to allow the computer to turn on the EPA, steer a low-intensity beam through the first two current monitors, and then shut down the facility. This effort is 95% complete, the remaining 5% being associated with refinements suggested by operating experience. The major programs and their interlocking relationship are shown in Fig. 10 and are discussed below.

Preparing Model M for rf involves checking the temperature controller, turning on certain water pumps and checking their flow, turning on the tank heater, and checking the tank vacuum. The turn-on sequence for the Model M Intermediate Power Amplifier (IPA) requires turning on a water

pump and the filament, checking the air and water flow, and then, after a 10-min delay to allow the filament to warm up, checking a trio of interlocks. Concurrently with these actions, the rf pulse length from the master pulser is set to 500 μ sec and pulsing is initiated. Upon completion of these three programs, the computer turns on the high voltage to the IPA and starts to run up the rf power. Since this causes heating of the Model M cavity, the computer must monitor the copper temperature and pause in the run-up if it gets too high. Moreover, the computer has to watch for faults in the protection circuitry caused by sparking. Upon detection of a spark, the fault circuit is reset and if 10 sec pass without a fault, the run-up is continued.

Running in parallel with the foregoing programs are others which prepare the target area for beam, set the beam line magnets to their nominal polarities and currents, warm up the EPA cavities, prepare the 1.25-MW klystron for high voltage, and condition the electron injector for high voltage. This last program is followed by another to run up the current to the electron gun filament. Completion of all these programs brings in the beam run-up program which is followed by the beam steering program.

The computer begins the search for the beam by setting to zero the currents through two magnets which steer in the horizontal and vertical directions. Then the currents are adjusted to move the beam along an expanding square spiral until the beam current measured in the nearest current monitor reaches a threshold value. The program then goes into an optimization procedure which works alternately with the horizontal and vertical magnets to maximize the beam current through the current monitor. The optimization algorithm is especially tolerant of noisy signals and variations in beam profiles. Upon completion of the steering operation, the facility can be shut down with the operator having the option to leave various major subsystems operational.

All of the sequencing programs were written in a control language tailored to the task. The language statements are understood by an interpreter program as if the accelerator and

control computer were a giant programmable machine with its own instruction repertoire. This pseudo-machine has multiprocessing capabilities so that as many as 10 programs can be in operation concurrently. The language is being elaborated as needed to meet new program requirements.

A second major effort went into programs to facilitate an experiment with both the 100-kW and 1.25-MW klystrons. The exercise involved controlling the water temperature in either the Model M cavity or the EPA tanks so that the associated klystron could be operated into a nonresonant load on either side of resonance. The control program was written in the new language. A supplementary program to calculate and display the VSWR from both cavities was added to the system. A program to record data from up to 16 channels at 1-sec intervals for as long as 10 h was completed. A program was written to plot portions of the data as a Smith chart. The major data reduction load was shifted to the CDC-6600 in order to take advantage of the SC 4020 plotter in the Central Computing Facility.

Most of the displays currently available on the system are updated once per second. It became apparent, however, that an operator who was adjusting a channel would want the setting updated more often. To remedy this situation the slewing and the line display programs were modified so that any channel being slewed would be updated four times per second. Initial user response was quite favorable. An update rate of 10/second was obviously too fast. The program which displays beam current and position information was also rewritten for an update rate of 4/sec. In addition, the form of the graph was altered to display the digital values of the current ordinates. A photograph of the display is given in Fig. 11.

The schematic of the vacuum system for EPA was simplified and made available to the operator on the display scope; Fig. 12 indicates the result. The states of the vacuum control power and of the local/remote switch are shown together with the state of each vacuum valve and, where available, the actual vacuum reading. The state of each valve under computer control can be changed by selecting it with the light pen.

Fig. 11. Beam current monitor display.

The problem of scaling raw data collected by the data scan program so that they can be displayed in engineering units was given attention. Linear scaling is now available but several channels have sine-wave or log-log characteristics. It appears that these calibration curves may be represented by second- or third-order polynomials, but since hand calculations are too tedious, a program was written to aid in further evaluations. If the representation proves adequate, this program will be used to process calibration data to produce and store the coefficients of the polynomial.

Experience accumulated from several months of operations showed that simplifications could be made in the programs which handled transmissions to the display scope and the Computer Interface Unit (CIU). In particular, it is not necessary to queue requests for these devices. By rewriting the driver programs to eliminate queuing as well as sharing of the block transfer channel, it was possible to reduce the size of the programs and free an additional 8% of the core memory for application programs.

Work has been continued on the new resident system being prepared on a second disk pack so as not to conflict with the present system. Recent tests showed that the added features built into the new Executive program do not degrade the performance of the system and that the increased

Fig. 12. EPA vacuum display.

efficiencies permitted in the application programs will enhance the overall performance of the package.

EPA Control Equipment

After 15 months of service, the prototype CIU suffered its second failure. The logic power supply had to be replaced and, possibly as a result of the power supply failure, two logic modules were found to be faulty and were replaced. The fault required ~ 4 h to find and correct. Most of this time was needed to replace the logic power supply. Based on hours in actual service, the CIU has been available ~99.92% of the time.

Three complete modules (RICE and I/O) have been operational this past quarter in the mockup program. In this time, 14 troubles have occurred in the equipment, of which five have been design or fabrication errors and nine were component failures. Since two of the modules have recently become operational, some of these failures can be attributed to early component mortality.

Installation and checkout of the Module Interface Unit (MIU) in EPA is complete except for modifications and additions required to implement fully computer control of the accelerator. Typical of the new channels are the vacuum pulse

detector for the electron injector, and the VSWR fault detector and the rf power control for Model M.

The beam-steering and focus-control systems and the vacuum-control chassis have functioned satisfactorily, with only one maintenance call for a defective switch. The Geissler circuit has given trouble in that it is not quite as sensitive as desired and it occasionally trips on noise. A larger electrode system has been made and will be tested to see if it will cure the problems.

Injector System

In preparation for designing the controls for Injector A and the transport area, an effort is being made to determine the various instrumentation and control requirements for both the Injector Control Room (ICR) and the Central Control Room (CCR). Various systems are being identified and preliminary device and channel lists have been generated for the Head of Injector A, transport area A, and transport area D. These lists are under continual revision and expansion as the system requirements become more clearly defined. The ICR and its rack layout were reviewed and the resulting modifications were included with the Title II drawings for the injector building.

The initial logic design of the Manual Head-Controller (MHC), formerly called the CIU Simulator, was completed. The MHC converts the manual "Head" control signals from ICR into a computer-compatible format for transmission via light links to the "Head" RICE for execution. It also converts the returning computer-formatted data from the "Head" RICE into suitable forms for display in ICR. The MHC was designed to issue 23 commands and to receive 33 data channels. It includes automatic data scan and update logic and a priority command system. The logic and memory for the MHC will require two logic chassis. Key portions of the logic are currently being breadboarded and checked.

Accelerator Module Control

201.25-MHz Modules

Some work on the drift-tube accelerator controls was accomplished this quarter. Preliminary functional schematic drawings of the water systems were completed and similar drawings for the vacuum system are being generated. A final version of these drawings should be available in the near future.

Title II drawings for the drift-tube building were reviewed. Numerous changes in the control circuits on the cooling water systems were required to make them compatible with the computer. The original time schedule calling for detailed circuits to be ready to contract for chassis fabrication by the end of the summer still seems realistic.

805-MHz Modules

Detailed discussions are being held regarding operational requirements. At this time, the vacuum system is fairly well defined. Hardware interlock criteria relating to the operation of ion pumps, the vacuum isolation valves, and the run-permissive system have been generated. Computer control and readout requirements for the vacuum system have been specified in the form of device and channel lists.

Generation of criteria for the water temperature control system for the rf tanks is progressing. The system control and instrumentation requirements are defined for the tank system but as yet are undefined for any beam scraper or magnet cooling system. The criteria for the beam steering system are straightforward and have been enumerated.

A natural result of these discussions will be a "best guess" of the number of wires required and the number of channels needed in the RICE and analog data system. Preliminary estimates of the number of racks and their cooling requirements have been submitted for inclusion in the Title I

drawings of the 805-MHz cluster buildings. Considerable time has been spent in laying out conduits and cable trays between the beam channel and service aisle but the final design is not yet firm.

Ion Source Test Stand

Work has been resumed on computer control of the ion source test stand. Design was begun on a rack of instruments to control the existing stand by local and computer control. This will be module No. 4 of the Mockup computer control system. Analog command modules will be fabricated to control the palladium leak heater, filament power, focus magnet, beam pulser, and the extractor power supply. Approximately a dozen each of various binary and analog data channels will be required.

Interface Equipment

Remote Information and Control Equipment (RICE)

Fabrication and bench test of the fourth prototype RICE unit was completed. It was constructed with diode-transistor logic (DTL) and was assembled by Data Technology, Inc., using their TLS construction technique. This is a mechanical packaging scheme designed to permit convenient computerized layout and wiring. The unit will be compared with conventional printed circuit board construction with regard to cost and maintainability.

Circuits of DTL logic for the RICE I/O were designed and laid out for the ion source RICE. These circuits are ground-isolated and less noise-sensitive than previous designs. Moreover, they incorporate some of the functions of the former MIU hardware, thereby reducing the amount of wiring, reducing the number of different types of circuits, and simplifying the module control and data hardware. The I/O circuits were tested with some of the control modules under development.

The I/O chassis for these circuits was fabricated and is ready for testing with the Data Tech RICE. The chassis is designed to handle 96 channels of binary data, 30 analog commands, 24

binary commands, and 10 channels of video switching onto four outputs. System tests of the RICE I/O and control hardware for the ion source test stand will be performed with the computer over a set of cables running to the laboratory area.

Analog Data Subsystem

An analog data system based on commercial hardware is being investigated. The subsystem will provide differential input with ± 100 -mV to ± 10 -V full-scale capability. A sample and hold may be incorporated in any channel requiring that type of signal conditioning. The resolution of the conversion equipment will be 11 bits plus sign.

A prototype subsystem is under bench-test at present. The final selection of one of two basic methods will be made in the near future and will be installed for operational test in the ion source test stand.

Local Controls

Design and evaluation of a modular packaging scheme for the local controls and the analog data system are being continued. A number of different module designs were constructed and discussed with interested individuals. In order to evaluate the modular concept under operating conditions, the water system control chassis in EPA will be replaced by an equivalent bin of the binary command modules. Bids were received for fabrication of these modules; Eberline and Associates, Inc., of Santa Fe was low with a bid of \$75 per module, which is realistic for fabricating only eight modules. The necessary changes in EPA wiring for this test have already been scheduled. In addition to this test, the modules will be used in the local controls of the ion source test stand.

A test rack was built for testing the completed modules. In a reliability run, one of the binary command modules was exercised $\sim 500,000$ cycles without a failure. The design of a standard analog command module is in progress and the first practical use of these modules will be in the ion source test stand.

Fig. 13. Simplified schematic of data transmission system.

Data Transmission Link

The redesigned communications link between the RICE Interface Unit (RIU) and the RICE was wired and checked out. A simplified diagram of the system is shown in Fig. 13. The breadboard version operated at pulse repetition rates of 250-450 kHz. (The range allowed was designed to be quite narrow.) Component values were changed to permit operation at 130-240 kHz. The following characteristics were observed during testing of the breadboard model:

1. The timing duty factor produced satisfactory coding and decoding.
2. Operation was satisfactory for signal amplitude in the range of 10-40 V peak-to-peak. (The power supply feeding the line driver was varied from ~ 5-20 V to make these measurements.)
3. The receiver integrates the incoming signal for ~ 50% of each half-cycle. Adjustment of the integration time constant and the phase shift detector was not critical.
4. Injection of a common mode signal approximately equal to the data signal had no effect on the decoding. A common mode square wave tuned through the signal frequency had no effect.

Apparently some of the circuits incorporated into the breadboard model to increase reliability and stability are not required. These circuits are being removed from a second-generation system now under design.

RICE Mark II

A version of the RICE which will operate with the new transmission system has been designed.

It will be constructed from a standard line of logic modules and will have incorporated in it the new generation line driver and receiver. A delay in the receipt of logic modules has held up the wiring.

Auxiliary Operational Systems

Fast Protect System

The fast protect system is hardware which can rapidly inhibit the beam in the event of an abnormality which may cause a beam spill. The system is based on one chassis per sector. Bench-test of a two-module prototype system has been completed. Installation and checkout of the hardware in the Mockup Program is in process.

Timing Systems

A rough draft of an "EPA Timing System Manual" was completed. It includes input and output requirements, theory of operation, detailed circuit descriptions, and interconnection tables.

A rough draft of the LAMPF timing system was completed and preparations are being made for a system design review.

Radiological Safety

All of the rack-mounted equipment having to do with measurements of the environment in and outside EPA has been moved to a set of racks located near the health physics monitor's desk. In this location it will now be possible for the people concerned to have access to these instruments during accelerator operation. A mobile pair of racks was obtained from GSA Excess Property for this purpose. Their mobility allows access to the shield door located behind them.

Abbreviated descriptions of the Rad-Safe system used at EPA, together with detector development work being done, and an outline of plans for LAMPF were presented to the Advisory Panel on Accelerator Radiation Safety which convened at Los Alamos on April 26.

During the past quarter a completely new document dealing with Radiological Safety Procedures was prepared, reviewed, and approved by the required offices in LASL and the AEC. The

new procedures cover the Radiological Safety Organization and Procedures for current operations and were designed to facilitate the transition toward operation of the LAMPF. These procedures supplement the established LASL Radiological Safety Procedures and were prepared with the close cooperation of the Laboratory Health Division.

Personnel Safety System

A preliminary design study of the LAMPF Personnel Safety System has been completed. It covers the basic requirements for personnel control and warning systems throughout the accelerator areas.

The primary function of the Personnel Safety System is to protect personnel against possible accidental exposure to machine radiations, residual radioactivity, and high voltages. This involves the control of personnel access into potentially hazardous areas and the prevention of accelerator operation when personnel have entered a restricted or unsafe area. The system must also ensure that areas to which access has been permitted are properly cleared of personnel before beam turn-on.

Basically, six general categories of circuits or systems are considered to come under the Personnel Safety System. They are:

1. Warning lights for equipment and machine status. Throughout LAMPF, red lights are to be used for high voltage, amber lights for rf power, and magenta lights for radiation hazards and accelerator operation.
2. Warning systems for beam turn-on. These include taped announcements, warning horns, and light dimming.
3. Hardware interlocks for personnel access doors and control barriers.
4. Remotely actuated key banks at critical access points to enable the accelerator operator to control access to potentially hazardous areas.
5. Emergency stop stations at appropriate locations throughout the facility.
6. Interlock reset stations at selected points in each area to ensure that each area is properly cleared.

The general philosophy to be used in designing the various safety systems is that they must be fail-safe and that parallel redundant circuits are to be used throughout.

Three interlock systems are involved in the Personnel Safety System: the Run Permissive System, the Fast Protect System, and the Personnel Control Logic System. The Run Permissive Interlock Chain is a hard-wired interlock system involving both personnel protective interlocks and machine protective interlocks. It prevents beam turn-on unless all systems are "go." The Fast Protect System provides the fast shutdown (within 10 μ sec) of the beam in case of a fault or beam spill during the beam-on time. It also prevents beam turn-on in case of a fault in an rf system at the start of a pulse or failure of an interlock circuit. The Personnel Control Logic System provides the interlocking function which requires an area to be cleared properly and the local circuits reset if an access door to the area has been opened.

The Radiation Safety System, which involves both personnel monitoring and machine protective systems, is treated as a separate system for LAMPF although it is involved closely with personnel control and protection.

In addition to complete redundant hardware interlock and warning systems, LASL Health Physics and designated Operating Personnel will be used in surveillance and personnel control. These personnel are to be given sufficient responsibility and authority to permit them to exercise adequate control for the protection of all persons on the site. They will monitor operations, control personnel access to and working time in radioactive areas, and assist in general personnel control. Prior to beam turn-on, Health Physics personnel will assist the operating staff in clearing areas.

Through the evaluation of various systems that have been installed on the EPA and the systems that are in use at other accelerator installations, sufficient design information has been obtained so that the preliminary details of a reliable personnel safety system can now be developed.

Operational Support Systems

TV System

Two camera systems were evaluated for the task of reproducing the graphic and alpha-numeric displays on the data display scope in the Central Control Room (CCR). The performance of one camera, having a horizontal resolution of 800 line pairs per line, was not adequate. The second camera, having a horizontal resolution of 1100 line pairs per line, was found to be just adequate. The results are consistent with theory except that theory also predicted an 1100-line vertical resolution. Both cameras tested had only 525 lines vertical resolution.

Video System

The Module VCU's used with RICE's No. 2 and No. 3 in EPA were modified to improve the video response. Buffer amplifiers were installed which have a 10-90% rise and fall time of 100 nsec and a 10-V bipolar output capability. The amplifier outputs are short-circuit proof.

The console VCU was modified by installing a differential-input bipole-output buffer amplifier.

The whole video system is currently under review.

Central Control

A continuing effort has been made in both the EPA-CCR and in the LAMPF-CCR. The physical layout of the LAMPF-CCR has been provisionally agreed upon and liaison with LAMPF Engineering continued throughout the quarter. Several equipment and console designs have been roughed out; however, the design will hinge upon experience gained in operation of EPA and upon the evaluation of the additional prototype equipment slated for EPA-CCR. A special operator keyboard has been ordered for evaluation and installation in EPA-CCR. The necessary interface has been fabricated and checked in preparation for the keyboard. The addition of a small alphanumeric display scope is under study.

Miscellaneous

Channel Engineering

A channel identification scheme which lists all the necessary control and instrumentation channels for a given area was implemented. This system is also being used to identify devices along the beam line which are associated with the various channels. To date, channel and device lists have been generated for Injector A and the transport area and for module No. 5 in the 805-MHz section.

Wiring and Terminations

The first usable computer outputs of the LAMPF wire and termination schedule became available this quarter. The program, designed for trouble-shooting after initial installation, was used to produce "rack books" and these were located appropriately in EPA. As new devices are added and modifications are made to EPA, the information is added to the card deck and an updated rack book is produced. EPA wiring information is presently contained on ~ 5000 computer cards.

A second program is nearly operational. This program will produce wiring lists from the same input cards as the previous program, but the output is designed so that it can be used directly by the installers.

The 201.25-MHz test stand wiring has been coded on computer cards. This exercise led to a meeting in which a number of agreements were reached concerning the methods of naming devices and racks.

Wiring in the target area of EPA is in a period of constant change. The addition of thermistors and beam profile monitoring equipment required the complete rescheduling of wires in the area of the target plus the addition of 90 more wires and a new junction box in the target area. The removal of radiation and environmental equipment from the EPA control racks has also made a few more wires available in the beam channel for other uses.

Arc Modulator

An arc modulator with SCR's as the switching elements was breadboarded and tested with satisfactory results. A second version is being fabricated and will be tested in the ion source test stand. The breadboard model exhibited the following characteristics:

1. Pulse widths varying from 1 μ sec to 6 msec were handled satisfactorily by the modulator. Power supply limitations restricted the tests to a low duty factor.
2. A 10- μ sec, 200-V spike was added to the leading edge. This will not be present in the second model, but it can be added at a later date if required.
3. Delay plus rise time was 0.6 μ sec; storage and fall time was ~ 1.2 μ sec. About half of the turn-off time appeared to be due to circuit inductance.
4. A 10- Ω noninductive resistor simulated the load. Load voltages up to 250-V peak were tested, and no load less than 10 Ω was used. The current handling capability of the SCR is load-dependent. At 120 pulses/sec the current capability should be around 200 A at a pulse width of 100 μ sec to 70 A at a 1-msec pulse width.

Water Flow and Indication

The water flow indicator chassis has been partially wired into the interlock system in EPA. Although the first eight flow switches appear to be operating satisfactorily, they are marginal in accuracy because they are sensitive to fluctuations of the EPA 28-V dc power system. They have not been tested in EPA for over-temperature actuation but they have been calibrated in the laboratory for both low-flow and over-temperature actuation. The remaining five flow switches are in the target area and are awaiting the development by another LASL group of a suitable thermistor glass-to-metal seal which can withstand the radiation in the target area. One has been developed and at the present time is undergoing tests in the Water Boiler reactor.

Standards Committee

Standards were set covering meters, time-delay relays, racks, bins and bin modules, knobs, and panel indicator light colors. A standard for device designation and one for logic symbols were included in the Standards Book which was distributed to all LAMPF designers. Copies of the LAMPF Standards Book were also sent to interested parties at LASL and at other AEC accelerator installations. Most of the items selected as standard are being placed in LASL stock.

V. ACCELERATOR PHYSICS

Introduction

A computer study has been made of the energy and phase dependence of the radial emittance at the transition between drift tube and waveguide linacs.

Preliminary tests on a rotating wheel beam scanner were conducted in the Electron Prototype Accelerator (EPA). Performance was generally encouraging. A beam collimator (scraper) was successfully tested on the EPA.

A superconducting quadrupole doublet has been designed and is being built for test and evaluation as a general-purpose doublet for the experimental area. Life tests of the duoplasmatron ion source were continued with very encouraging results. In particular, the problem of cathode life, originally thought to be serious for high duty factor operation, appears to have been solved.

The 192-keV accelerating column has been assembled and tested for vacuum leaks, for insulating gas pressure capability, and for high-voltage-breakdown properties. The results are generally satisfactory and the column is almost ready for installation in the ion source test stand.

Beam Dynamics Studies

Waveguide Linac

In the interest of minimum beam loss in the waveguide linac, the emittance of the beam as it enters the linac should be matched to the admittance of the linac. By matching is meant that the emittance and admittance ellipses have the same shape and orientation, so that the emittance ellipses fit comfortably within the admittance ellipses.

The x - x' and y - y' admittance ellipses have previously been calculated for particles that enter the linac at the correct energy and phase. For different initial energies and phases, the transverse admittances are likely to be quite different because of the strong phase dependence of the rf defocusing. If these differing transverse admittances are known, then it may be possible to

select the "best" shape and orientation for the 100-MeV beam emittance so that the transverse admittance is the largest for a large spread in initial energy and phase.

The computer code LINAC was used to determine the transverse acceptances for particles having several initial phases and energies. The parameters of an ellipse were fitted to each transverse admittance using the method of least squares. The equation for an ellipse in the x - x' plane can be written as

$$\gamma_x X^2 + 2 \alpha_x X X' + \beta_x (x')^2 = E_x / \pi,$$

where $\alpha_x = (\beta_x \gamma_x - 1)^{1/2}$, E_x is the area of the ellipse, $(\beta_x E_x / \pi)^{1/2}$ is the maximum x -extent, and $(\gamma_x E_x / \pi)^{1/2}$ is the maximum x' -extent. Table 1 gives the parameters for the different admittance ellipses as a function of initial phase and energy.

Beam Diagnostics

Rotating Wheel Beam Scanner

The rotating wheel beam scanner was assembled and preliminary tests have been carried out on the EPA at full beam power. A picture of the scanner is shown in Fig. 14. In general, the device functioned as expected. The signals were observed with low noise background and the general features of the beam profile could be seen. Mechanical difficulties were encountered, however, with the rotating-wheel assembly which precluded precise scanning of the electron beam. The outer edge of the rotating wheel scraped at several points on the inside of the scanner housing and the mounting used for the synchronous motor was not sufficiently rigid. These difficulties resulted in a nonuniform rotary motion of the wheel so that proper phasing of the tungsten pins with the electron beam was not obtained. Modifications to the unit to correct these difficulties are now almost complete.

In the tests, the observed maximum pulse amplitudes, corresponding to the situation where a tungsten pin intercepts the full diameter of a beam pulse, were 0.1 V across a 1000- Ω load for a 14-mA peak electron current impinging

Table 1. Parameters of Admittance Ellipse at 100 MeV.

ϕ_0 (°)	W_0 (MeV)	β_x (cm/mrad)	γ_x (mrad/cm)	E_x/π (mrad-cm)	β_y (cm/mrad)	γ_y (mrad/cm)	E_y/π (mrad-cm)
-60	100	.493	3.40	4.26	.776	6.36	4.09
-50	100	.354	3.60	4.61	.610	5.12	4.62
-40	100	.330	3.50	4.80	.602	5.05	4.65
-30	100	.310	3.59	4.52	.501	4.19	4.60
-20	100	.249	4.46	4.34	.408	4.17	4.32
-10	100	.229	5.03	4.13	.374	4.90	4.14
0	100	.269	4.87	3.91	.415	4.89	3.93
10	100	.300	4.02	3.93	.483	4.43	4.09
20	100	.214	4.85	3.70	.346	3.85	3.49
36.788	99.0	.382	4.10	3.84	.558	6.12	3.90
36.788	99.2	.295	3.85	4.45	.518	4.37	4.30
36.788	99.4	.348	3.79	3.95	.612	4.93	4.15
36.788	99.6	.321	3.61	4.39	.560	4.62	4.45
36.788	99.8	.320	3.64	4.71	.565	4.66	4.58
36.788	100.0	.330	3.41	4.67	.560	4.59	4.72
36.788	100.2	.343	3.26	4.55	.579	4.49	4.55
36.788	100.4	.366	3.03	4.46	.609	4.43	4.35
36.788	100.6	.372	2.85	3.97	.629	4.08	3.98
36.788	100.8	.378	2.77	3.60	.608	3.73	3.50
36.788	101.0	.468	2.46	3.74	.705	4.37	3.69

Fig. 14. Rotating-wheel beam scanner.

Fig. 15. Beam profile monitor electrode arrangement.

on the tungsten pin. The background noise level was < 1 mV.

A control panel for the beam scanner has been designed, built, and tested and will be installed when the mechanical modifications to the scanner unit are completed. More detailed study of the operation of the device will then be carried out.

Beam Profile Monitor

A beam profile monitor modeled on one used at ANL has been installed on the EPA. The beam passes between two grids (Fig. 15) which accelerate electrons and ions created by ionization of the residual gas. Ions collected on the -10 kV electrode create secondary electrons, which are then accelerated to the +10 kV cathode-ray tube face electrode. Remote observation of the screen is made by a sensitive-image orthicon. Patterns observed to date appear to be caused by: (a) high ambient radiation illuminating the entire CRT face, and (b) collection of low-energy electrons created by scattering of the beam by the vacuum chamber walls. Attempts are being made to eliminate this background by shielding and by electric and magnetic electron traps.

Since the linac current will be only $1/300$ of a ZGS (ANL) ring current and since the linac vacuum may be better, a more sensitive system may be required. Local gas pressure may be increased by admitting gas or by evaporating a self-pumping solid. A copper oven has been made which creates a 10^{-8} g/cm² vapor, 0.02-eV thick at 500 MeV. By having this thin "target" at a 45° angle to the beam, a true profile could be observed.

Beam Scraper

The beam scraper for the final collimation of the EPA beam has been received. Flow tests and mechanical inspection tests were carried out and the beam scraper has been installed on the EPA. No difficulties have been experienced in the operation of this unit at full beam power of the EPA, although no tests have yet been made to determine the beam power actually being intercepted by the scraper.

Superconducting Quadrupole Development

Because superconducting magnet systems have small operating costs and are capable of extremely high fields, it may prove economical to use superconducting rather than conventional magnets in some portions of the LAMPF experimental area beam transport systems. Superconducting magnets of various configurations have been designed at LASL and at other laboratories; however, no superconducting quadrupoles have been constructed here which meet the field symmetry and alignment requirements of a beam transport magnet.

A superconducting quadrupole doublet has been designed at LASL, and the parameters are listed below. The field gradient, 3 kG/cm, is somewhat higher than will be required for the LAMPF experimental area.

Free magnet bore	6 in. diam
Field gradient	3 kG/cm
Effective length	> 12 in.
Doublet focal length for 800-MeV protons	~ 60 cm
Optical alignment capability	± 0.010 in.
Dipole correction	± 0.020 in.

Two different types of superconducting wire will be used. The first is a single, large strand of superconductor in a copper substrate; the second is a recently developed multiple-strand wire consisting of a matrix of 49 small strands of superconductor in a copper substrate. The multiple strand wire is expected to have superior performance characteristics, but it is more expensive. This wire has been ordered and is expected to arrive about May 15. Rough machining of the coil forms has begun and will be completed by May 23. Final machining will be done on a 3-axis milling machine. The magnets will be wound in quadrants. Each quadrant will be tested at cryogenic temperatures before final assembly. The doublet will be installed in the Mockup Building, where wire orbit, rotating coil measurements, and field-mapping tests will be conducted.

Injector Program

Cockcroft-Walton (C-W) Power Supply

The circuit diagram for the control unit of the C-W power supply was received from Haefely

& Co. After considerable study, modifications to these circuits were made so that the unit could be operated in one of three modes: (a) from Injector Control Room (ICR), (b) from Haefely's control unit (READY), and (c) from the Computer Control Room (CCR). Transfer of control from one mode to another will be made without disruption of service. The most expeditious manner to effect such a transfer is made by make-before-break relay contacts.

To provide control to the computer of turn-on and turn-off functions and reset capabilities, separate relays in each control circuit are required. Haefely & Co. have been advised of these modifications, and control relays, compatible with computer interfacing, have been forwarded to them for inclusion in their control unit.

A set of construction drawings for the Faraday cage for the first high-intensity C-W injector has been completed. A rough draft of the specifications is being corrected, and it is anticipated that the bid for the fabrication of the Faraday cage can be let in the near future. The erection of the cage in the injector building is part of the contract and should be completed with the building.

Ion Source Test Stand

In anticipation of converting the present ion source test stand, which is limited to 30-kV extraction, to the 200-kV test facility, the ion source life tests have been terminated. These tests indicate the presently designed ion source is adequate for 6% duty factor operation in the LAMPF accelerator. For 12% DF, the present design may require some modifications, as indicated by some of the results described below. Further research and development of the ion source will continue on the 200-kV test stand to obtain the optimum operating parameters for extracting a beam which has a uniform radial current density, a programmable current intensity as a function of time, a maximum H^+ to H_2^+ ratio, and a low emittance.

The life tests were run under the following approximate conditions: 50 mA of current with 25 kV of extraction voltage applied, a normalized

emittance (emittance area $\cdot \sqrt{\beta/\pi}$) of 0.045 cm-mrad, a H^+/H_2^+ ratio of unity, and a hydrogen-pumping throughput of 2 cm³-atm/min. The final results of the ion source life tests are listed here:

6% DF	1289 h arc on (16 A)
	300 h extractor voltage on
12% DF	170 h arc on (22 A)
	170 h extractor voltage on.

In the following paragraphs individual components of the ion source are evaluated on the basis of their performance during these life tests.

Vacuum Pump: The VacIon pump has been in operation for over 3549 h with the original titanium plates still in use. Hydrogen has been pumped at 2 cm³-atm/min for 1846 h.

Cathodes: Cathodes were originally thought to be a problem in ion source maintenance. One cathode, however, was in continuous use for 3500 h heater-on time, 1290 h arc-on time at 6% DF and 16-A arc current, and 300 h with 25-kV extraction. The cathode was kept hot continuously with 25-A heater current except for brief intervals when the vacuum system was opened for changes. An interesting point is that the ion source will continue to pulse at rated values even with the cathode heater off. An ultraclean vacuum system is apparently unnecessary for long cathode life. Glass, stainless steel, mild steel, copper, silver solder, and brass are present in the system. Viton O-rings are used with generous applications of silicon grease, and vinyl acetate, Loctite, and Apiezon seals have been used.

Magnet Coils: Two failures have occurred involving breaks in the winding of the magnet coil. Improved methods of sealing against water leaks by soft soldering the metal jacket around the coil winding, providing a pressure-release vent, and using flexible leads to the coil are now being used successfully.

Cooling-Water System: An independent closed-loop water cooling system using a small pump has operated satisfactorily. Heat is dissipated by convection cooling from the surface of a water storage reservoir. In the final design

Fig. 16. Ion source insulating ring.

Fig. 17. Photomicrograph of iron whisker growth.

the cooling reservoir will be replaced by a radiator.

Ion-Source Insulating Ring: During the life tests, a metallic conducting coating (copper) formed on the insulating ring (region A, Fig. 16). Fortunately, a nonconducting region remained where the insulating ring was in the shadow of a centering shoulder. Future design will provide

Fig. 18. Photograph of anode aperture after 12% DF life test.

Fig. 19. The 200-kV partial accelerating column.

more complete shielding. The source of this conducting coating of copper is believed to be the region around the nose of the intermediate electrode (region B, Fig. 16).

Palladium Hydrogen Leak: A General Electric (commercial) palladium leak has been used to control the hydrogen flow into the ion source. The hydrogen flow has been manually controlled

during the life tests by controlling the temperature of the palladium leak. An automatic regulating system was tried but critical damping of the feedback loop could not be achieved. An advanced design will be tried soon.

Intermediate Electrode: A profuse growth of iron whiskers (Fig. 17) was found in the copper joint around the removable nose piece after the life tests (region C, Fig. 16). Although no abnormal behavior of the ion source was noted during the life test, some other whiskers either migrated to or grew on the copper face of the anode near the end of the intermediate electrode (region D, Fig. 16). The individual whiskers were in the centers of a discolored patch of copper, giving the impression that some discharges had occurred in these regions. A spectroscopic analysis of the whiskers showed their composition to be 99% Fe, 0.1-1.0% Cu, 100-1000 ppm of Ni and Mn, and lesser amounts of Al, Zn, Si, Ca, Ba, and Sr. It is gratifying to know that Ni from the cathode or Ti from the ion pumps do not constitute a significant portion of these whiskers.

Plasma Aperture: In the region of 6-12% DF, the plasma aperture (region E, Fig. 16) appears to be the only component of the ion source which must be operating close to the limits at which failure will occur. This marginal situation is associated with the use of soft iron for the thin plasma aperture system used to insure a near field-free region in the expansion cup. The iron septum is 0.005-in. thick with a layer of copper of the same thickness joined to it by silver solder. The diameter of the aperture was 0.040-in. After the 6% DF test was complete, an examination of the aperture showed little damage. After the 12% DF test, the aperture showed some melting with a resulting globular structure (Fig. 18). Further design improvements will be necessary for 12% DF operation.

Pulser: The transistor pulser unit has worked fairly well, occasionally failing when a transistor burnt out. These failures have occurred when the transistors were operated outside their normal range, either by intent or by

transient currents caused by high-voltage breakdown of the 25-kV extractor. Protecting zeners and fuses has eliminated most of these failures.

In a test to determine the H^+/H_2^+ current ratio, a magnetic field was applied across the beam to separate the ions. The split beam was incident on a fluorescent quartz plate for photographic study and scanned across a wire for an electrical measurement. Both methods contain several doubtful corrections to convert image response to real current, but both indicate that the H^+/H_2^+ ratio is ~ 1 . More accurate measurements using thermocouples will be made on the 200-kV test stand. The same data, taken to determine the H^+/H_2^+ ratio, have been used to obtain an electrical measurement of the angular spread of the beam at the axis. This spread, extrapolated to the entire beam, corresponds to a normalized emittance of 0.06 cm-mrad as compared to 0.045 cm-mrad measured optically.

Accelerating Column

The 200-kV partial accelerating column (Fig. 19) was completely assembled and was tested for vacuum leaks, for SF₆ high-pressure capability, and for high-voltage breakdown characteristics. These tests proved the column to be satisfactory and it can now be installed as part of the 200-kV test stand.

The inner electrodes of the column were aligned coaxially within ± 0.002 -in. using an acrylic rod penetrating the central aperture of each electrode. Shims were used in fastening the electrodes to the inner column to provide the proper axial spacing for the Pierce geometry. Since the ceramic rings used in the inner column were undersized, the design voltage of the column was reduced from 200 kV to 192 kV to maintain the desired potential gradient. The extracted current will therefore be the same, 50 mA. The design potential on the electrodes shown in Figs. 18 and 20 of the preceding quarterly report (LA-3884-MS) are as follows:

Anode	0	3rd electrode	-96 kV
1st electrode	-24 kV	Shield	-144 kV
2nd electrode	-48 kV	4th electrode	-192 kV

The assembly of the column proceeded with little difficulty. The acrylic cylinder for containing

the SF₆ insulating gas was first positioned around the accelerating column. The middle corona rings, barely visible in the photograph, which slide just inside the acrylic cylinder were then attached by aluminum pins which pass through the acrylic wall and secure the outer corona rings. These pins were a source of many high-pressure leaks. Conducting spokes of aluminum were then inserted between the middle corona rings and the small corona rings mounted on the titanium washers of the inner column. The compression bellows was then installed on the top of the column and the top flange bolted on to complete the mechanical assembly.

The required electrode potentials are achieved by removable bleeder resistors which draw 1 mA total current with 200 kV across the column. The terminations at each end of the resistors serve as protective spark gaps for the column. The larger spark gaps at the base of the column were originally set to hold off 29 kV; the rest of the gaps were set for 60 kV in a uniform field. The second set of gaps was set for 60 kV although the potential across them is only 24 kV; the first electrode may be pulsed in the future to supply extremely short pulses of current in the μ sec range, putting 48 kV momentarily across these resistors.

The acrylic high-pressure jacket was tested to 34 psig. The gas pressure has been limited subsequently to 20 psig and will be reduced further to a minimum value determined by voltage breakdown tests. High-pressure leaks were sealed with RTV Silastic, Krylon, and glyptal.

The ultimate pressure reached in the polycarbonate-bonded inner column was 1×10^{-8} torr with a 500 liter/sec ion pump; however, leaks at the end of the test stand, previously sealed with RTV Silastic and glyptal, opened up under mechanical stressing. It is believed that these leaks are a result of the rebonding technique, which did not supply an adequate amount of polycarbonate adhesive at the region of rebonding. As the Silastic provides an adequate seal for testing purposes, attempts to rebond these flanges properly will be done at a later date. The pressure inside the column, with 20 psig of SF₆ in the outer jacket,

was 2×10^{-7} torr, which is sufficiently low for high-voltage testing.

The electrical tests conducted on the partial column involved applying a negative high voltage to the upper flange by means of a cable, barely visible in the photograph. On the first test, the partial column went to 160 kV, limited by corona discharge in air at the highest bleeder resistor terminal. To correct this, a larger corona ring of $1\frac{1}{2}$ -in. diam tubing was installed at the top of the resistor stack, as shown in Fig. 19. On subsequent tests, the design voltage of 192 kV was reached. Only a very few gas bursts were indicated on the vacuum gauge in raising the voltage to this level. Essentially no voltage conditioning was required. This is probably due to use of highly polished titanium electrodes and conservative high-gradient design inside the column. There was no indication of voltage limitation inside the inner column or inside the SF₆ high-pressure jacket. Higher voltages are at present limited by corona in air at the lowest 50-kV resistor terminal. Larger corona rings will be installed at all the 50-kV resistor terminals to achieve slightly higher voltages.

200-kV Test Stand

The high-voltage test dome (Fig. 20) to house the beam transport and diagnostic equipment to be used with the 200-kV test stand has been completed and is ready for installation. All quadrupole lenses and power supplies have been obtained and final testing is in progress. The alignment carriages to be used with the rail support system have been designed, and the unit for the smaller quadrupole lens has been built and tested. The two larger carriages are now being fabricated. The only remaining work on this test dome is the final detailing and fabrication of the required beam tube hardware and test chamber. Work is now in progress on these items.

A 200-kV resistor divider has been designed for accurate measurement of the dc potential applied to the test stand. A capacitor divider will be used to monitor the potential during application of the pulsed load.

Fig. 20. High-voltage test dome.

Fig. 22. Dismantled Faraday cup and emittance measuring device.

Fig. 21. H^+/H_2^+ beam analyzer.

An H^+/H_2^+ analyzer, shown in Fig. 21, has been designed for the 200-kV column exit. A sample of the beam at a desired radius is obtained by means of a plate (1) with holes along a radius and a rotatable cover plate (2) with matching holes along a spiral. The sample travels along a 6-in. region (3) where crossed electric and magnetic fields can be adjusted to allow either ion to go undeflected to an insulated copper wire (4) acting as a heat sink. A thermocouple connected to the heat sink allows a calorimetric determination of the currents.

A Faraday cup and emittance measuring device for use at the exit aperture of the 200-kV partial column has been designed and fabricated. The dismantled unit is shown in Fig. 22. The proton beam is intercepted by a copper plate containing an array of 0.010-in. diam apertures, each located at the bottom of a $\frac{1}{16}$ -in. diam hole. The image formed by this array is viewed on a quartz plate some $2\frac{3}{4}$ -in. beyond the array. The image can be photographed through a window at the downstream end of the assembly. The entire emittance measuring device is located within a

Faraday cage complete with two bar magnets attached to suppress secondary electron emission. The assembly is water cooled in such a manner that a simple calorimetric check of the cup current can be made by observing the temperature rise of a known flow of cooling water.

The success of the partial accelerating column to withstand the design voltage has initiated the conversion of the ion source test stand to a 200-kV test stand. The partial column will be assembled to the present ion source test stand after the minimum required SF_6 insulating gas pressure has been determined.

Injector Control

Detailed descriptions of each control circuit of the injector systems are being written. From these descriptions, complete wiring schedules can be produced and registered in the computer memory. Such descriptions will eventually lead to the compilation of an Injector Control Manual, which will be a complete record of all control circuit schematics, including related interlock circuits, operational procedures, maintenance schedules, and other pertinent information. The data recorded into the computer memory will be a registry of the work to be done in accelerator wiring of the injector building.

Polarized Ion Source

One of the basic considerations in the design of a polarized ion source for LAMPF is the determination of the required vacuum system that is suitable for use in the limited space of the Cockcroft-Walton injector dome. A study of various types of vacuum systems has been carried out, and a testing program for evaluating pumping systems for a polarized ion source has been initiated. Discussions have been held of the polarized ion source programs now in progress at ORNL and LRL.

In the conventional atomic beam source, two basic designs have been used. One, such as the Saclay source, employs a small aperture nozzle at the exit of the dissociator, whereas the other type, such as the Harwell source, uses a relatively large multicapillary collimator on the

dissociator. The nozzle systems require 10 to 20 times more pumping capacity than the multicapillary collimator systems but only give a factor of two or three improvement in extracted ion current. Most of the gas load must be pumped at the dissociator, and existing sources have used large mercury or oil diffusion pumps and blower pumps to handle the large throughput.

The space available in a Cockcroft-Walton injector dome will limit the size of such a vacuum system; moreover, the possibility of oil or mercury contamination makes the use of a cleaner vacuum system desirable. It appears that either cryogenic or titanium sublimation pumping could be used to obtain a clean compact pumping system. In order to study the operation of these pumping systems, a test stand will be built and an evaluation program carried out. A new laboratory area is now being prepared for this test stand.

A prototype cryogenic pump has been designed and will be tested. Titanium sublimation pumps that appear suitable for this application are commercially available and will be considered.

In the metastable polarized ion source, the vacuum problems are primarily concerned with the pumping of cesium and argon gas as well as of hydrogen. Oil diffusion pumps have been used on existing sources, but other pumping systems will be examined.

At the present time the best choice for a polarized ion source for a Cockcroft-Walton injector dome appears to be the conventional atomic beam source using a multicapillary collimator, but the final decision must wait until the capabilities of various pumping systems have been evaluated.

VI. EXPERIMENTAL AREA

Introduction

During the past quarter, the design of the experimental area has been focussed on the high-resolution proton spectrometer area, the stopped muon and fast pion channels, and the design of shielding and radiation safety aspects. The latter consideration was given the highest priority by the scheduled visit of the AEC Advisory Panel on Accelerator Radiation Safety. This panel met at LASL on April 26 and heard numerous presentations about LASL plans and the bases for them. In preparation for this meeting, a document was prepared outlining the procedures LASL proposes to adopt for insuring radiological safety in the maintenance and operation of the accelerator. These procedures have been approved by the panel (see p. 25).

Facility Planning

Updating has been started of the design criteria for the experimental area buildings and their related utility systems. It is now anticipated that as the result of a concerted effort this spring and summer, the basic criteria can be completed in preparation for the start of design work early in the fall.

Estimates of facility and service requirements for planned experiments have been continued and the estimates are being incorporated in the design resolution proton spectrometer which will be included in the proton experimental area. Preliminary plans have been completed for the low-energy neutron facilities and they are being reviewed. As the main beam transport and the secondary magnet systems become further defined, cooling water requirements and power loads are being compiled.

Investigations of possible magnet systems for the beam switchyard are under way. The system designs will provide further information for the design of the beam channel structures and the orientation of the several experimental areas.

Studies of remote-handling requirements and systems are being continued. A proposal has

been prepared to combine the Merrimac service facility and the shielded area for the equipment to handle the exhaust air and cooling water for the target cells. The facility can be located adjacent to the west end of Experimental Area A. The new location may simplify the Merrimac roadway system and provide more effective use of remote equipment space.

Early studies of the proposed building structure for Beam Area A indicate that a roof system can be made that will support two 30-ton bridge cranes in the area without column systems near the beam channel. A box-type girder supported at each end of the facility appears to be a fairly economical solution to the problem of column interference.

It is now proposed to locate the LAMPF control building near the experimental end of the accelerator. Preliminary layouts have been made combining this with the experimental area support space. The planned location of this facility is near the end of the accelerator to the southwest of Area A. The combined facility, now called the Operations Building, will be connected to the last rf cluster building and to Experimental Area A by covered walk and cable ways.

Shielding

A version of the DTF code usable with anisotropic neutron sources has been employed to calculate the transverse shielding of LAMPF. The DTF code is a discrete ordinates transport code which obtains solutions to the time-independent Boltzmann equation. The one-dimensional calculation has been performed in a cylindrical geometry using Legendre coefficients up through P_8 to describe anisotropic processes.

Input data are in the form of "multigroup-multitable" cross section sets and a source term. The Los Alamos Monte Carlo cascade code is used to generate cross sections above 50 MeV. From 14 MeV to thermal energies, the LRL-LASL tape library of cross sections is used. Between 14 MeV and 50 MeV the cross sections are obtained by linear interpolation. Elastic or diffraction scattering above 50 MeV is not considered. The source term is derived from a first-order correction to

the neutrons produced from a linear 800-MeV proton beam spill of 2 nA/m along the accelerator structure. Evaporation neutrons are included. The first-order correction is a "single scattering" computation to account for attenuation by the accelerator structure. Oxygen and aluminum are considered as the absorbing media above 14 MeV. Below 14 MeV, hydrogen, from 3% by weight of water, is included. The calculation was performed for 25 energy groups at 48 radial points.

The dimensions used in the calculation do not correspond exactly to the LAMPF configuration because of the cylindrical symmetry assumed, but the results can be interpreted with confidence to give usable dose rate estimates. The estimated neutron dose rate at 800 MeV outside the accelerator shield is 0.075 mrem/h from the assumed spill. The dose attenuation length is 76.9 cm or 127 g/cm². The calculated dose rates are conservative enough to allow for leakage from duct and waveguide penetrations.

A similar calculation performed at 100 MeV with an assumed spill of 250 nA/m indicates a neutron dose rate of 0.36 mrem/h in the rf equipment room. Additional calculations will be made for the experimental area.

Targets

Installation of the target water system is almost complete. Under test, an imperfection was discovered in the pump end casting. Discussions are in progress with the vendor to get the pump repaired.

Flow monitors of the thermistor-bridge type have proved to be unsatisfactory for the target water system. It will be necessary to use turbine-type flow meters with remote readout.

Remote Handling

The changing of main beam targets is expected to be frequent and predictable. The desire to perform this operation as rapidly as possible has led to the design of a plug-in type of targeting mechanism. In concept, the relatively simple device consists of a 9-ft long, 6-in. diam, 1000-lb shield plug which has a machined taper on the lower end for alignment, a smooth exterior

surface on the upper end for a squeezed-gasket vacuum seal, and two holes through its length in which two water pipes slide. A bracket rigidly connects the lower ends of the water pipes. A target array, that may contain numerous targets in a variety of arrangements, is clamped to the bracket thereby making up the array cooling connections. The upper ends of the water pipes are clamped in a block which is on an elevating mechanism attached to the shield plug. The water pipes slide up and down through the shield plug providing vertical positioning for the targets. Metal bellows provide the vacuum seal between the water pipes and the shield plug. Horizontal alignment is provided by the taper on the bottom of the shield plug and by pre-aligning the individual target arrays during fabrication. The possible location of shafts or push rods within the straight water pipes could provide a means for actuating flip targets, rotating wheel targets, or remotely aligning the targets in the horizontal plane.

The target mechanism is located at the vertical crack in the shield doors and extends upward about 1½ ft into the 7½-ft deep door keyway. The keyway shield blocks would be contoured to provide clearance for the mechanism and its lines. The target system is compatible with the Merrimac maintenance system. A few inches of vertical clearance exist between the top of the mechanism and the underside of the manipulator trolley rails when the Merrimac box is in its working position.

For routine target changes, a door keyway block would be removed, exposing the top of the target mechanism 6 ft below. An operator standing on the top of the door would disconnect the drive motor, position indicators and water lines, and release the pressure on the vacuum seal gasket, with long tools if necessary. A bottom-entry cask would be lowered into the keyway and the mechanism drawn up into it. The cask and mechanism would be transported to the hot cell and positioned over an open roof plug. The mechanism could then be lowered into the hot cell for changing the target array. A shutter may be required to cover the open target mechanism hole to reduce area radiation levels.

To service the Merrimac support area, the southern half of the Beam Area A crane and wall system would be extended west about 40 ft. Within the support area would be located the Merrimac maintenance area (grease pit) and below it the mockup area, the hot cell complex, and the air and water systems for the target cells. The hot cell complex would consist of a target cell the same size as the hot cell to be compatible with Merrimac. The floor of this cell would be movable, to expose the contaminated portions of the air and water systems for manipulation from within the hot cell. One wall of the hot cell would contain holes for the storage of radioactive targets and other items.

Primary and Secondary Beam Transport

A pion beam transport and spectrometer are being designed for use in high-resolution pion scattering experiments. The overall resolution will be good enough to resolve elastically scattered pions from those which inelastically excite a target nucleus to a low-lying level, e.g., 1 MeV above the ground state. The overall momentum resolution must be 1% or less. Thus the beam transport must have a high ratio of dispersion to magnification at the location of the momentum-defining slits, be of zero dispersion and, preferably, achromatic between production target and scattering target, and present a large solid angle to the production target.

The beam transport as it now stands includes four identical, uniform field magnets, with pole tip rotation angles chosen to give double focusing. Each magnet deflects particles through 90° , has a 1-m central ray radius of curvature, 16.68 kG field (for 500 MeV/c) and pole tips rotated to 26.6° both at entrance and exit. It is designed to transport $\Delta p/p = \pm 1\%$.

In order to make use of the small vertical extent of the beam, the first bend is downward, the second is in the opposite sense back to horizontal, the third is in the same sense as the second, bending toward the particles upward, and the last bend is in the same sense as the first, directing the momentum-analyzed particles horizontally again at the original beam height. This array of magnets

is symmetric about its midplane and automatically has zero dispersion at the final focus. At the midplane focus, the dispersion is 8 cm/percent, and the magnification is unity. The overall length of the transport is 22 m. It is not achromatic.

The dispersion of the second half of the transport system is large enough so that protons can be removed from the π^+ beam by placing an appropriately chosen absorber at the midplane and a set of slits at the exit. The absorber method will not serve to remove electrons from the π beams.

The next design steps to be taken are:

- (a) to add lenses to render the transport achromatic, and (b) to choose an optimum radius of curvature for the spectrometer.

Cost estimates based on the design parameters established thus far have been made for the stopped muon channel, and for the 500- and 300-MeV pion channels. The total costs are nearly the same as those of previous estimates. The breakdown reveals that substantial cost savings might be realized if a more economical way of energizing the magnets were used than that of conventional dc power busses.

Preliminary parameters have been established for stopped muon channels as follows:

Channel Length:	~ 9.5 m
Design momentum:	100-200 MeV/c
Configuration:	adapter doublet - 10 in. quadrupoles, two bending magnets 350
	focusing channel - 8-in. quadrupoles (one 10-in. quadrupole placed between the bending magnets)

The CERN code used in the channel calculations provides only for wedge-type and parallel-face $n = 0$ bending magnets. It is under these restrictions that the above configuration provides a maximum muon flux for minimum spacing between the two bending magnets.

An arbitrary pole-rotation feature is being added to the CERN B56/57 code. This will permit the investigation, thus far neglected, of a two-bend channel with pole-face rotation similar

to conventional beam transport, i. e., nondecaying charged particle transport with a symmetry plane in the center between the two bends. Such a design provides substantial drift spaces between the bending magnets, which would be desirable for mechanical reasons. The latter configuration may also provide a better beam as input into a superconducting solenoid.

VII. LAMPF SCHEDULING AND FACILITY CONSTRUCTION

Introduction

LAMPF PERT has now progressed to a single integrated project network. Two new subnets were added and interface logic has been approved. The results are being applied to a review of project planning and scheduling.

Construction has been started and is now 7% complete on the Equipment Test Laboratory Building (ETLB), and a construction contract has been awarded for the Injector and 201.25-MHz Sector Building. Bids will be opened at the outset of the next period for the second phase of site utility work. Redesign of the 115-kV Substation and the continued Title I design of the 805-MHz Accelerator Building are in progress.

Accelerator Scheduling

During this period the application of PERT to LAMPF design and construction progressed significantly. The individual technical group networks have been joined together into a single project schedule. Much effort was involved in achieving this integrated network. The difficulties reported previously in summarization of milestones were removed. The logic of interfacing between technical groups was made more rigorous. Added to the schedule was a funding network which constitutes the initiating activities for all other branches. A final checkout network was constructed and added which brings the component activities together into an operational accelerator facility. The printouts from this integrated network are presently being employed in planning reviews.

LAMPF Site and Building Activities

Equipment Test Laboratory Building

The J. R. Brennand Construction Co. received a notice to proceed with construction of the ETLB on Feb. 2, 1968. Heavy snows at the outset of this 240-day contract impeded progress somewhat. Nevertheless, the foundations, grade beams, and under-floor electrical and mechanical services have now been placed so that the project

completion, compared with the scheduled 11%, is 7%, and erection of steel is ready to start.

Accelerator Building Activities

Advance notice of construction for the Injector and 201.25-MHz Sector Building was issued on Feb. 12, 1968. The Title II plans and specifications for this portion of the project were received from Giffels & Rossetti, Inc. on Feb. 26. Formal review was held on Mar. 6-7, and the resultant comments were transmitted to the A-E during conferences in Detroit on Mar. 8-14. Distribution of the plans and specifications to the prospective bidders was made on Mar. 18. On Apr. 25 the George Rutherford Co. of Albuquerque, N. M., submitted a low bid of \$2,114,000, compared with the A-E estimate of \$2,415,100. The preconstruction conference with this firm is scheduled for the beginning week of the next period.

As previously reported, new architectural and mechanical alternatives for the 805-MHz Accelerator Buildings had been developed; they were reviewed during this period. Conceptual layouts have been received from the A-E and are being reviewed and improved prior to detail design. This new work differs from previous studies in that the 805-MHz rf power sources are clustered together into seven discrete buildings, mechanical services for the accelerator structure are located in equipment rooms at Beam Channel elevation, and the control facility has been relocated to a site much closer to the Experimental Area. This package of construction is scheduled for issuance to prospective bidders in the fall of 1968.

Utility Work

The second phase of site utility work will consist of facility water storage tank, fire pump house, sewage lagoons, and extensions of the site water, sewage, and gas piping systems. Full completion of Title II engineering for this package was held in abeyance until FY 68 funding had been clarified. Advance notice for this phase

was then issued on Mar. 22, and bid documents were issued on April 9. Bid opening had been scheduled for April 25; however, a delay by the Department of Labor in issuance of Davis-Bacon wage rates caused postponement to May 2, 1968.

Restrictions on obligational authority necessitated cancellation of bids for construction of the 115-kV Substation, as previously reported. Rebidding was scheduled to follow immediately after the Injector and 201.25-MHz Building bid opening. In the interim, however, authorization was given for the AEC to construct a new Eastern Technical Area Terminal Station at LASL. Although the original LAMPF substation could well have been incorporated into the new system, it appeared prudent to specialize the design. Uhl & Lopez Engineering is therefore working on revisions to the Title II plans and specifications with completion scheduled for early in the next reporting period.