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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 January 31, 1968

UNITED STATES
ATOMIC ENERGY COMMISSION
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LOS ALAMOS SCIENTIFIC LABORATORY
of the
University of California
LOS ALAMOS • NEW MEXICO

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Quarterly Status Report on the
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I. SUMMARY

Accelerator Structures

Side-Coupled Structure -- 805 MHz

The focus of attention during the last quarter has been the electron prototype accelerator (EPA). This 60-ft, 100-cell accelerator was successfully brazed, assembled, and aligned. In the accompanying table design parameters are compared with present achievements. Experience thus far indicates that there will be no difficulty in attaining design specifications. It is apparent, therefore, that the basic concepts involved in the side-coupled cavity system and in the resonance coupler are sound. Moreover, no deleterious transverse modes have shown up.

<u>Design Parameters</u>		<u>Experience to Date</u>
Peak current (mA)	17	17
Energy at peak current (MeV)	20	> 20
Pulse length (μ sec)	500	200
Pulse repetition rate (pps)	120	120
Duty factor (%)	6	6
Shunt impedance ($M\Omega/m$)	40	not determined.

Drift Tube Structure -- 201.25 MHz

Significant success has been achieved in efforts to develop a closed-loop cooling system for the 4-ft model. This problem is not simple for the expected heat loads, and additional work will need to be done before a reliable system with adequate control is accomplished. Final design work on the drift tube and quadrupole assemblies for the first tank has been started.

RF Power Systems

201.25 MHz

The 7835 amplifier and cavity system has been operated at full peak power and 6% duty factor (DF). The results are generally very encouraging although there is much additional work to be done on controls systems (especially fault location) and the hard tube modulators. There appears little doubt, however, that the basic concepts underlying the design of the power source for the drift tube

portion of the accelerator are sound in principle and technically feasible.

805 MHz

A major effort was devoted to the installation of klystron power for the EPA. A 100-kW klystron was used for the graded- β section of the accelerator and a 1.25-MW klystron for the remaining sections. Closed-loop phase and amplitude control was used on both rf sources and operation was successful even under conditions of heavy beam loading. It now remains to refine the control system and to develop an industrial manufacturing capability for the 1.25-MW klystron tubes.

The second Litton klystron has been accepted. It is a definite improvement over the first, although the efficiency is a few percent lower than anticipated.

Progress has been good on the development of a stable frequency multiplier chain to be used in the reference drive line. The 805-MHz amplifiers for this drive line are also in a satisfactory state of development.

Accelerator Control and Instrumentation

The main efforts in the realm of controls and instrumentation were focussed on the EPA, and with a very satisfactory outcome. The work involved fabrication, installation, and checkout of systems to control the electron gun and preaccelerator, temperature of water for cooling accelerating structures, focussing and steering magnets, target water, beam dump, and a spectrometer magnet, as well as various beam and radiation monitoring devices. All systems operated essentially according to design and EPA commenced operation after only a few hours of tuneup and alignment.

A major effort will now be directed toward bringing EPA under computer control. This exercise should reveal any faults in the basic control philosophy and any shortcomings in the technology that will apply to control problems.

Accelerator Physics

Computations have been continued on the dynamics of particles in both the drift tube and waveguide portions of the accelerator. The routines for including the effects of space charge have now been incorporated into the drift tube linac computation program.

The high-intensity ion source has demonstrated in an extended test (90 h) its ability to run at 50 mA and 6% DF. No deterioration of electrodes or other operational problems were encountered. The emittance was satisfactory for use with LAMPF. This represents an important milestone in the development of a high-quality, high-DF injector for LAMPF. Lifetime testing is being continued.

An accelerating column for 200-keV operation has been fabricated and is undergoing initial tests. Plans for conversion of the ion source test stand for 200-keV operation are complete, and the components are being procured.

Experimental Area

Several basic decisions have been made which require the updating of the design criteria for the experimental area. The two beam channels will each be designed for full 800 MeV, 1 mA proton beam transport capability. The deflector or switchyard will be located after the last 805-MHz section of the accelerator. Space will be provided at the switchyard for initial beam diagnostics equipment.

The previous general cost estimates for the experimental area buildings and equipment have been reviewed. To allow for possible revisions due to the changing situation in physics and to new ideas for experiments, a number of combinations of buildings and equipment with their respective cost estimates have been drawn up and evaluated. A flexible overall plan has been selected to keep pace with criteria changes, particularly for the design of buildings and their built-in utility systems.

Studies of proposed experiments have been continued to develop buildings and services

that will most effectively meet the varied requirements. Preliminary layouts and facility cost estimates have been started for proposed low-energy neutron experiments and for a high-resolution proton spectrometer area.

Calculations of subgrade deformations resulting from heavy shielding loads are being continued and tests are being prepared to determine the deformation characteristics of the broken and compacted subgrade material. Investigations of building structures and crane systems are being made to explore the possibility of removing the support columns in the experimental areas and of effectively increasing the overhead crane coverage.

Calculations are in progress on optimization of primary beam transport through the experimental area and on the stopped muon channel.

Scheduling, Facilities Planning, and Construction

Site and building activities have been added to LAMPF PERT and the rf power system schedule is being updated. An experimental network has been constructed which has already proved valuable for the improvement of project programming.

Construction activities have made less progress than previously scheduled because of allotment limitations. Site preparation has now been completed, construction is about to start on the Equipment Test Laboratory Building, and Title II engineering is almost completed for the Injector-Drift Tube Accelerator Building.

A new PERT scheduling network which will reflect the present funding situation is currently being prepared.

Publication

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

II. ACCELERATOR STRUCTURES

Introduction

During this quarter the Electron Prototype Accelerator (EPA) has been successfully brought into operation and many of the design goals have been achieved. The design parameters for EPA are:

Electron energy - 20 MeV at design current
- 30 MeV unloaded

Current - 17 mA peak

Pulse length - 500 μ sec.

Duty factor - 6%

Shunt impedance - 40 M Ω /m

The accelerator has been operated at the following conditions:

Electron energy - $\sim$ 24 MeV at 550 kW Cu dissipation.

Peak current accelerated - $\sim$ 17 mA at
200 μ sec pulse.

Average current accelerated - 600 μ A ($\sim$ 10
mA at 500 μ sec pulse,
120 pps).

Repetition rate - 120 pps.

Max. DF - 6%.

The peak current is slowly being increased and nothing has arisen which would indicate that the design goals will not be reached soon. No indication of transverse beam blowup has been observed to date. There has been no trouble with the long accelerator tank, and this would indicate that the design for LAMPF is sound. Final design of the accelerator tanks is under way.

The drift tube accelerator design has been continued and current plans are to complete the final design for Tank 1 in the coming quarter. Experimentation with the closed loop cooling system on the 4-ft Alvarez model has yielded satisfactory results. The 4-ft tank has been held on resonance at full power using information from the phase of the incident fields and the fields excited in the tank to adjust the water temperature set points. An improved water temperature control system is under construction.

Fig. 1. Observed and calculated tilts for Model K center section.

Side-Coupled Accelerator Studies

Model K Center Section

The 12-cell center section of Model K, which was removed from Model K and replaced by a bridge coupler assembly, has proved useful in verifying predictions of the coupled resonator theory.

Elementary perturbation analysis of the coupled resonator model predicts that

$$\% \text{ tilt} = 100 \cdot \frac{n \Delta_O \Delta_S / 2}{2 + n \Delta_O \Delta_S / 2},$$

where $\Delta_O = 4 \Delta \omega_O / K \omega_O$, the relative perturbation of the end cell frequencies, and $\Delta_S = 4 \Delta \omega_S / K \omega_S$, the relative stopband. Figure 1 shows experimental data for the Model K center section compared to the coupled resonator model predictions. Agreement between theory and experiment is considered to be quite good in view of the difficulty in making all the coupling cell frequencies identical for each given stopband.

Two passbands of higher order modes have been observed in the center section of Model K. One passband extends from 1735 to 1770 MHz, the other from 1874 to 1899 MHz. No clear identification of these modes has been made at this time, although neither passband seems to be associated with a deflecting mode.

Electron Prototype Accelerator

The installation of the 12 EPA tank sections, the three bridge couplers, cooling systems, and vacuum pumps has been completed and aligned and the tank has been tuned and flattened. After leak-testing, a system pressure of 4×10^{-8} torr was obtained prior to rf power application. It is significant that all furnace-brazed joints, welded joints, and mechanical rf joints are vacuum-tight since similar fabrication techniques and methods are planned for the 805-MHz portion of LAMPF accelerating structures. Figure 2 is a view of the tank array prior to installation of the beam line equipment and ion pumps.

Two experimental quadrupole doublets have been installed, one under the first bridge coupler and the other at the end of the last tank. These doublets were aligned with special offset target fixtures using a tooling laser.

Final tuning of the EPA has been accomplished. The bridge coupler post tuners were used to minimize the power flow phase shift across the bridge couplers. The bridging cell frequency was lowered to 805 MHz, as determined by minimizing the coupling cell fields, by capacitively loading the bridging cavities with posts $1\frac{1}{2}$ in. long.

The coupling iris was opened to maximum available size, giving a VSWR of 1.2:1 overcoupled, while the power flow phase shift was kept zero.

The square of the EPA accelerating field vs cell number is shown in Fig. 3.

The source of tilt in the second EPA tank has been identified as gross tuning errors of three cells in that tank. The errors have been corrected and the tank flattened experimentally to verify identification of the source of the tilt. Permanent removal of the tuning errors was not undertaken.

Greater care will be taken in prebrazing tuning to prevent recurrence of this problem.

The measured Q of EPA is 25,100 by the transmission technique. This is 84% of the theoretical Q and is in accord with experience with other brazed side-coupled structures.

The EPA was tested Dec. 21, 1967. It produced a 1-mA peak current beam having a 30- μ sec duration at a pulse rate of 120 pps. The current was measured by collecting the beam in an insulated aluminum block after it emerged from a thin window on the end of the last tank. Beam energy was measured by penetration and darkening of a stack of glass microscope slides as shown in Fig. 4. Beam energies of ~ 16 MeV were observed with 300 kW of rf power in the main accelerator tanks and 24 MeV with 550 kW of rf power. The accelerated current was kept at a low level because cooling had not been installed on the beam scrapers positioned along the machine. After this preliminary checkout, the accelerator was shut down to facilitate installation of the target area components and interlock systems. Some of this equipment during installation is shown in Fig. 5.

All components in the target area are evacuated by a trapped turbomolecular pump system whereas the rest of the accelerator is evacuated with ion pumps. Two fast-acting valves have been employed for rapid isolation of the accelerating tanks and the target area vacuum system from the rest of the target area equipment in the event of cooling water influx due to target or beam-stop failure. These valves are triggered by a rise in pressure and are interlocked so that the beam cannot be initiated if they are closed or if the actuating air pressure is insufficient to assure fast operation.

The tube forest beam stop has been successfully furnace brazed and welded vacuum-tight. The 80 tubes, having a wall thickness of 0.005 in., were brazed simultaneously (160 joints) to the tube sheets. This subassembly was then welded to the two header block assemblies and subsequently pressure-tested at 115 psi. The

Fig. 2. EPA tank array.

Fig. 3. Square of accelerating field vs cell number in EPA.

Fig. 4. Darkening of microscope slides for measurement of EPA beam energy.

beam stop operates within a vacuum and may be lowered into the beam path or retracted as desired. Figure 6 is a view of the beam stop components after brazing and prior to final assembly.

During the last week in Jan. 1968, the accelerator was again tested, with the beam scraper and target deionized cooling water system

Fig. 5. Equipment for installation in EPA.

Fig. 6. Beam stop components before final assembly.

operative. The tube forest was used as a beam dump in these tests. Accelerated currents of 10-mA peak, 6% duty factor (DF), and 18-mA peak, 2.5% DF were recorded, with 500-kW peak copper dissipation in each case, corresponding to ~ 22 MeV beam energy. No troubles were encountered with the EPA accelerator system.

Higher current operation was precluded by (1) a high neutron flux outside the shielded enclosure, (2) a firing of the "geissler" over vacuum interlock in the target area by radiation background rather than by pressure rise, and (3) an intermittent sparking in the preaccelerator, Model M. Steps are being taken to resolve these problems and full operation should be resumed shortly.

Drift Tube Accelerator Studies

Drift Tube and Quadrupole Magnet Design

The 10-cell drift tube alignment model is complete and has been installed on the existing stand in preparation for future alignment studies.

Drift tube flow test models have been constructed in order to study various cooling configurations and develop pressure drop equations for inclusion in the drift tube cooling subroutine of PARMILA. The expression for the drift tubes in Tank 1 is complete and the flow model for Tanks 2, 3, and 4 is being assembled.

All prebraze machining is complete on the three Tank 1 pilot model drift tubes. The body forgings still exhibit small surface blisters when hydrogen-fired in the forged state, but appear to be blister-free after firing in the rough-machined condition. Subsequent machining failed to reveal any apparent laps or voids. Upon completion of brazing, leak checking, and final machining, the final braze assembly can be made. The three quadrupole magnets for these drift tubes are complete and the coils have been wound in preparation for installation on the poles.

The positioning fixture for the Hall Effect probe has been designed and some of the special components have been ordered.

The rotating coil magnet measuring device is being assembled. All components are on hand; the rotating parts have been dynamically balanced and are ready for coil winding and mounting.

201.25-MHz Drift Tube Linac

Design of Tank No. 1, the intertank spacer, and all associated equipment is well under way and final drawings are being made. An order

has been placed for the 13 copper-clad steel plates required for tank shell material.

Alignment

A new autocollimating tooling laser complete with power supply and readout electronics has been received. This unit will be used in alignment studies of the 201-MHz drift tubes.

A prototype laser alignment target to fit the 3.0-cm diam bore drift tubes has been completed. Preliminary tests indicate this target will function satisfactorily as a displacement target and as an autocollimating target. Further tests of this target will be performed on the 10-stem drift tube alignment model. Design and fabrication has begun on a 1.5-cm diam laser target to fit bores of the low-energy 201-MHz drift tubes.

III. RF POWER SOURCES

Introduction

The 201.25-MHz power amplifier has been tested for a significant number of hours at average power levels in excess of the requirement at 6% beam duty factor (DF). These levels are equivalent to 75% of the average power required for 12% beam DF. Following these tests, a complete inspection of the 7835 cavity was made and all components appeared to be in satisfactory condition. These results are encouraging.

The rf power for the Electron Prototype Accelerator (EPA) operation was supplied from a 100-kW klystron and 1.25-MW klystron. Closed-loop phase and amplitude control was used on both units. The operation was substantially as expected and represents an experimental verification of the validity of the approach to phase and amplitude control of the rf power for a heavily beam-loaded accelerator.

The second Litton klystron has been accepted. It displays none of the deficiencies of the first tube. Its conversion efficiency is higher (38%), but still below the specified value of 40%.

The problem of floating deck modulators for the 201.25-MHz amplifiers is unresolved, but progress is being made. The present dual 7482PV-triode unit can now be operated in the unsaturated region without oscillation.

Progress on conventional control problems is being made at a satisfactory rate. A method of rapid location of system faults for the 201.25-MHz systems is well along in development. Extended runs (~2000 h) of the hybrid multiplier chain have been made without interruption.

Satisfactory 805-MHz amplifiers for the reference drive line have been developed covering the power range from 1 to 100 W; a 350-W unit is essentially complete.

A revised magnet system on the first Amplitron has resulted in conversion efficiencies in excess of 75% at a power output of 1.4 MW.

RF Control Studies

Overall System Design

The effort to put the R&D test stand experience into practical maintenance and troubleshooting policies for the accelerator rf systems was continued. The (unfinished) experimental status panel for a 201.25-MHz module shown in Fig. 7, as an example, is intended to allow a module operator to locate the specific area of an rf-subsystem failure in the shortest possible time after his dispatch to the module by the central operator. This unit will incorporate prototype hardware in the sensing circuitry.

The study of possible areas for system simplification and standardization of hardware, circuits, procedures, etc., has been continued. This effort has been expanded to consider how final engineering design and procurement procedures should be structured to facilitate surveillance and recording of these activities.

Frequency and Phase Reference Studies

The hybrid-multiplier chain using tubes and varactors, described in LA-3838-MS (p. 13), has been in continuous service since early Oct. 1967 and has now accumulated well over 2000 h of operation. There have been no interruptions from any cause, but one unit had to be retuned because of low output. Periodic examination of signal output with the spectrum analyzer shows no deterioration of signals. Since mid-Oct. 1967, this source has been used for most of the klystron evaluation tests, Amplitron, and EPA experiments. The actual frequency reference used up to this time is a composite crystal oscillator designed to provide ± 50 kHz at the 805-MHz operating frequency, so that the output of the power amplifiers could be matched to the resonant frequency of the accelerator tanks. This reference has a long-time frequency stability of about 3 in 10^7 and a short-time stability of about 5 in 10^8 when operated in an unregulated temperature and input power environment.

Installation of the 805-MHz drive line in the Mockup Building and the EPA Building was completed in Dec. 1967, with 14-dB couplers at

Fig. 7. Experimental 201.25-MHz rf module status panel.

Fig. 11. LASL experimental PIN-diode rf modulator.

Fig. 8. 805-MHz 50-W cavity amplifier.

Fig. 9. 805-MHz cavity amplifier disassembled to show venting tube modifications and output coupling.

Fig. 10. 805-MHz interface preamplifier.

five test locations. The next project in connection with the drive line will be the development of a temperature-control system to hold the drive-line temperature constant in order to prevent phase shift between successive couplers due to expansion and contraction with heat changes.

Work has been directed toward the development of the power amplifiers to excite the 805-MHz drive line, and the interface amplifiers required between the phase and amplitude control devices and the klystrons. The drive line amplifiers are now essentially complete. Two low-level preamplifiers and the 100-W driver have been in service since Dec. 15, 1967. The 350-W stage is being tested and will soon go into regular service as the final drive line amplifier.

A slight change in tube choice has been adopted since the last report. As originally planned, the power amplifier string was to be driven directly by the 1-W output of the multipliers. Subsequently, a buffer amplifier was included in the last stage of the multiplier chain which delivers 4 W, thus easing the gain per stage demanded of the power amplifiers. The present amplifier chain uses a Machlett 8534 preamp operating at ~ 30 -W output, followed by an RCA 8226 driver operating at ~ 100 -W output driving an RCA 7650 at 350- to 400-W output. In this arrangement, all stages are running conservatively so that continuous trouble-free operation can be expected.

All three power-amplifier stages have independent input and output cavities. This arrangement was chosen over the reentrant cavity because it simplifies tuning and coupling arrangements and provides better isolation between input and output

circuits. Such a system takes more space but, in this application, space is not a factor insofar as the drive line amplifiers are concerned. The 8534 preamplifier is shown in Figs. 8 and 9. In Fig. 8 the amplifier is seen assembled with the anode structure at the right side. The picture shows the plastic air manifold which directs cooling air over and into the anode structure. Air then passes through the anode tuning slug, over the tube, through the ground plane and out through ports in the grid/cathode tuning structure. Figure 9 is a disassembled view showing the venting arrangement inside the cavities. In general, this same design is followed in the succeeding stages.

The interface amplifier calls for two stages, since at least 15 dB of power gain will be required at this point. The first stage has been completed and is depicted in Fig. 10. This amplifier uses a type 6442 pencil triode with a π -matched, grounded-grid input, and a half-wave coaxial anode circuit. The next stage will use the RCA 5893 pencil triode in a similar arrangement, to give a final output of ~ 7 W. If more power is needed, the Machlett 8534 can be used as the second stage in the same circuit arrangement.

RF Phase and Amplitude Control Studies

During operation of the EPA, the fields in both the Model M buncher tank and the EPA itself were controlled in phase and amplitude simultaneously using the linear phase and amplitude control systems on the 100-kW and 1.25 MW klystron amplifiers. Amplitude control is accomplished by modulating the rf drive to the klystrons with a PIN-diode rf modulator. Phase control using a varactor phase shifter was referenced to the stable 805-MHz drive line discussed in the preceding section. At present, both controllers employ integral and proportional terms in their control equations. Setup is straightforward and control bandwidths of 150-200 kHz are achievable with no degrading interaction between the phase and amplitude systems. The phase difference between the Model M and EPA fields are readily adjusted for optimum electron beam transmission by shifting the reference phase of the Model M phase control loop with a motorized mechanical phase shifter.

These results are an experimental verification of the validity of the approach to phase and amplitude control of the rf power for a heavily beam-loaded accelerator. At the present time, (a) a careful and complete definition of the rf control problem has been made, (b) the necessary equipment and hardware to furnish and control the rf output have been assembled, and (c) the entire system has operated as a controlled unit demonstrating the approach to first order. Detailed design of the control system can now begin. A start has been made on a detailed analysis of the dynamic behavior of the entire system and the in-circuit behavior of each subsystem, taking into account the exact effects of such heretofore neglected properties as time delays, saturation, limits of dynamic range, etc.

To aid in the understanding of the experimental data, an improved model is being developed using LASL's hybrid computer system. This model will include the time delay and nonlinear effects mentioned above. Continuing studies are being made on the application of nonlinear techniques to phase and amplitude control. Dual-mode systems which show promise of combining the best characteristics of linear and nonlinear systems are also being investigated. The goal of these studies is to determine the optimum responses available within the constraints of the proposed hardware and physical layout of the system.

A significant effort was made in the area of resonance control of EPA. An improved controller was designed, which operates as follows: The resonant frequency of the accelerator structure depends on its dimensions, which in turn depend on the amount of cooling or heating applied. At a steady-state rf input condition, a resonance controller must be able to hold the dimensions very closely. This was done by optimizing the response of a feedback system which keeps the temperature of the tank cooling water very constant--within $\pm \frac{1}{4}^{\circ}\text{F}$.

The system, however, is unaware of the operating conditions needed at another point in the operating regime, such as at higher or lower rf input. A linear relation exists in the steady state between the rf power input to the tank and the

required cooling water temperature to keep the tank on resonance. This information was used in a feedforward control loop to change the demand on the cooling water loop. The result is a system which can immediately apply a water temperature correction when the rf power input changes, before an error in resonance occurs, and also maintain resonance at steady state within close tolerances.

Since resonance is thus controlled only indirectly, and since the feedforward equation was only for steady state, there is some deviation from resonance during transients. At present, in order to keep the VSWR presented to the rf amplifier to a safe limit, a change from zero to full rf power must be made in two steps--from zero to half power, and then from half to full power; the whole process takes about 5 min. It is possible to reduce the transient effects by dynamic compensation of the feedforward loop, or by other methods. These will be investigated as time permits.

An rf modulator using PIN diodes has been designed and tested for use as an amplitude controller. This device is useful as a modulator or switch at 800 MHz, and as a switch at 200 MHz. The LASL version, shown in Fig. 11, replaces a commercial unit at less than 30% of the cost. (The commercial unit was not suitable for 200-MHz applications.)

A study has been initiated on ways of improving the packaging of the phase and amplitude control system components in the accelerator tunnel.

Logic and Protective Circuitry

The permissive logic system which checks closed-loop operation of the phase and amplitude control systems before the beam is permitted is being designed, and some parts have been ordered. The phase error and amplitude error comparators have been designed, constructed, and tested, with satisfactory results.

Work is being continued to simplify and improve general fast-pulse logic circuitry. Fairchild linear integrated circuits are being used

extensively and several new standard level detectors, AND-gates, etc., have been developed. These circuits will be used on the next generation of fault-protection logic.

805-MHz Power Amplifiers

1.25-MW Klystron Program

The present klystron has now been run in excess of 470 h. This operation has been primarily to furnish power for the EPA. The klystron is operating into the accelerator through ~ 240 ft of WR975 waveguide. Calculations show that, through this length of guide, the detuned short position of the accelerator, as seen by the tube, shifts ~ 45 electrical degrees between zero and full power due to electrical losses which cause thermal expansion of the guide. So far this phase shift has caused no harm, but the implications for the main accelerator installation are being examined.

Various modulator circuit alternatives are being investigated before final design of the klystron modulator prototype. One possibility is the use of a "light pipe" rather than a pulse transformer to cross the high-voltage interface. This change may reduce size and possibly cost, at some increase in system complexity. A comparative study was made of the protection given to the klystron modulator by fast high-voltage fuses, the primary circuit breaker, and crowbars. The conclusion was that the only effective protection against high-voltage faults was through the use of a crowbar.

Litton Industries has recently completed the second klystron under the present contract. Preliminary acceptance tests were conducted at the vendor's plant where it was shown that the tube meets all specifications except beam efficiency, which was 38% instead of the specified 40%. This second tube is superior to the first in that there were no discernible discontinuities or jumps in power output as the output was varied from zero to the full 1.25 MW. This klystron was run slightly more than 2 h at the full 12% DF or 150-kW average power output.

A new 3-dB isolator with improved magnetic field shaping and cooling was constructed for use

Fig. 12. Amplitron performance with new electromagnets.

between the 1.25-MW klystron and the EPA accelerator structure as a safety measure. This unit has given no trouble during EPA operation at peak powers to 0.8 MW and average powers to 40 kW.

Amplitron Program

The QKS1493 S/N 1 tube, the first of the two-stage Amplitrons, was reinstalled in the test stand following vacuum failure of the second tube (QKS1493 S/N 2). The former was operated to determine the effect of the new electromagnet system which had been redesigned to give a more uniform magnetic field. The tests immediately indicated that the tube would operate with considerably lower dc anode voltage than had been required with the same magnetic field intensity used in previous tests. At similar output power levels, anode voltages in the 46- to 47-kV range had been common before whereas 39-40 kV were now typical. Associated with this decreased voltage is an increased efficiency (55-65% as opposed to 40-50% previously for 30-A magnet currents).

The efficiency increase is predictable on theoretical grounds, and theory furthermore indicates that both efficiency and power should increase as the magnetic field is made larger. That this indeed happens is shown in Fig. 12, plotted from data taken over the entire dynamic range between upper and lower mode instability boundaries at various magnetic field levels. Associated with the higher magnetic fields are relatively higher operating voltages, but because the whole level of operating voltage is lowered by the new magnet system, even the highest magnetic fields attempted did not require an anode voltage above 44.5 kV. The drop-off in efficiency is partly attributable to saturation in the magnet system.

By redrawing the average efficiency curve in terms of magnetic field intensity, the curve is straightened out as seen in Fig. 12. Also shown is the average gain measured as a function of magnet current. The most impressive result was obtained at a magnet current of 50 A for which a peak power of 1.41 MW at a power gain of 13.1 dB was obtained at a conversion efficiency of 79%. The conversion efficiency takes into account the fact that the klystron drive power is transmitted through the Amplitron and also appears in the load. The DF was 2%.

Spurious output of the tube is about the same as before, with signals at 750, 950, and 1050 MHz. In conclusion it is apparent that the performance of the Amplitron is very sensitive to the distortions and intensity of the magnetic field and that the use of uniform fields is beneficial to obtaining high power output, high gain, and high circuit efficiency.

Crossed-Field Amplifier Research

The experimental Crossed-Field Amplifier (CFA) is nearing completion. Cold-probe tests of an aluminum cavity had indicated proper resonant characteristics. The cavity has been modified to include waveguide transition sections. These sections will be in vacuum and will deliver rf energy directly to the No. 1 side cavity in the anode structure and extract it from the No. 7 side

cavity. The transition sections are merely tapered waveguide of full width WR975, and so no cut-off problems will be present.

Cold-probe tests indicated proper resonance in the 800- to 820-MHz range; consequently, fabrication of the copper vacuum chamber with the tapered waveguide sections was carried out. This chamber has been the subject of numerous difficulties involving the welding of the stainless steel vacuum-seal rings. It is presently nearly complete although still plagued with leaks at the welded seams. The copper anode has been completed and the cathode is partly assembled. The field-shaping steel inserts are installed on the cathode. Attachment of the tungsten end caps and platinum plating for cold-cathode emission will complete the cathode. The 50,000-A-t electromagnet is being assembled and the coil is being wound with heavily shellacked rectangular wire which should give better heat transfer characteristics than the present Amplitron electromagnet.

201.25-MHz Amplifier Program

Operation of the 201.25-MHz rf chain during this report period has generally been highly satisfactory. Few difficulties have been encountered, and these have been easily corrected.

The most significant trouble experienced with the rf chain was arcing across the dielectric of the newly-designed Teflon upper blocker in the 7835 amplifier. Upon examination it was found that the arcing in the Teflon blocker had not been destructive; the dielectric had not broken down, and arc tracks were only across the surface of the dielectric. The arc tracks were cleaned off and the blocker was returned to service and has since operated satisfactorily. Continental Electronics engineers are presently working on a design for a Teflon-dielectric blocker with an increased surface breakdown path.

Detuning of the 7835 input cavity was experienced and found to be caused by a leaking water connection in the grid-cooling water course. This leakage was due to a design fault in connecting a plastic water hose to a metal tube. An improved connector has corrected this trouble.

On Dec. 18-19, 1967, the 7835 amplifier was used for the first time to excite the 4-ft Alvarez cavity. Because of the excessive radiation produced, operation was restricted to 260-kW power at 14.4% DF into the cavity. The entire rf chain was stable when operating into this resonant load.

The prototype 200-MHz crowbar design was completed with some minor exceptions involving changes to standardized parts. Mechanical fabrication is essentially complete; voltage hold-off tests using the Ohm-Weve resistor on the 201.25-MHz power supply have been satisfactory. The electrical design combines the pulse width and amplitude circuits on one printed circuit card; electrical checkout is awaiting delivery of some components.

In late Jan. 1968, a high-power life test of the entire 200-MHz rf chain was begun. Operation was mostly at the 2.6- to 3.25-MW power level and 8.4% DF, sometimes reduced to 6% DF to allow simultaneous operation of the 800-MHz klystron test stand without overloading the local substation. The test had to be terminated after 48 h due to a failure of the modulator. The higher average powers in this run completely fulfill the power requirements for 6% beam DF and represent 75% of the power required for 12% beam DF. After the conclusion of the test the 7835 amplifier was disassembled for inspection of its components. No evidence of incipient failure was found and the condition of all amplifier components was good. The only problem observed was a few arc tracks of the type previously found on the surface of the dielectric of the Teflon blocker. In particular it should be noted that there was no burning of any of the finger stock on any of the sliding rf contacts in the amplifier.

Modulation of the rf envelope with a PIN-diode modulator at the 200-mW power level was successful. This scheme simplifies the overall circuitry of the totem-pole amplifier by eliminating two bias keyers. Construction of an rf driver amplifier for use with the PIN-diode modulator is nearing completion.

Work has begun on a mechanical prototype of the 4616 (totem-pole) screen modulator.

Floating Deck Modulator Development

Evaluation and development of the hard-tube modulator for the 7835 amplifier has been continued. The modulator utilizes two Machlett 7482PV triodes, driven by an Eimac 4C100,000D tetrode. Operation in both the linear and saturated modes has usually, although not always, been satisfactory.

A problem of frequent failure of the 7482PV grid bias supply was eliminated by revised circuitry and improved components. Grid emission in the 7482PV tubes causes them to fail to cut off following a fault, thus causing a long overcurrent pulse which in turn initiates operation of the crowbar circuit. This effect is predictable from the published tube characteristics. Since crowbars entail an undesirable loss of time with each fault, considerable effort was made to overcome the problem. A satisfactory grid-clamping circuit employing a Krytron was developed which drives the triodes into the cut-off region in the event of a fault.

It was found, however, that there is a degradation of the 7482PV voltage standoff capability with increased average dissipation. Thus, under some operating conditions, the tubes arc from anode to grid. This places the entire 30-kV capacitor bank directly across the grid-clamp circuit, destroying it. Special gaseous spark gaps are on order which should protect the clamp circuit from these arcs.

Two ITT 7560 tubes are to be used to replace the 7482PV's in the present modulator. These tubes are reputed to have no grid emission in the normal operating range and it is felt that this will alleviate many of the problems.

During an extended run of the 200-MHz rf amplifier chain a failure was experienced in the modulator rf-interface transformer and in the interface demodulator. The interface demodulator utilizes four Eimac Y490 diodes which have been subject to frequent failure. Investigation has revealed that the LASL specifications for these tubes were not correctly interpreted by the manufacturer. The tubes are incapable of satisfactory operation in their present state of development,

being deficient in both peak current and in long-pulse capabilities. The manufacturer is investigating the problem and suggests that an improved cathode design might remedy it.

Two encouraging experiments were conducted with the 7482PV modulator. In one, output current to the 7835 amplifier was varied by a step function, and in the other it was varied by a sine function at up to a 50-kHz rate; the modulator operated in the unsaturated mode in both cases. The results demonstrate the feasibility of the design concept of controlling rf power output level with a small control signal to the modulator.

Development of an alternate modulator utilizing 4CW250,000 tetrodes is well under way.

Preparations are being made for the installation of a 4CW100,000D modulator to plate-modulate the final (4616) stage of the totem-pole amplifier. Mechanical design of this modulator is being reviewed for construction of a prototype.

Work is being done on improved high-voltage interface units. Two versions with Hewlett-Packard 50-kV light pipes were designed and tested--a linear unit for use on the 201.25-MHz modulator, and a switch unit, compensated for changes in oil temperature, for the 805-MHz klystron modulator. The output of the latter is at low level, suitable for driving an amplifier on the deck.

A simpler and more rugged interface system using a wide-band current transformer is being investigated. This circuit would be potentially much less sensitive to noise than a light-pipe circuit. It would be a linear-control unit suitable for use on the 7835 anode modulator.

High-Voltage Power Supplies

Final specifications for the high-voltage power supplies were completed. The supplies were broken into three packages for procurement, and separate specifications were written for the vacuum breakers, voltage regulators, and the transformer-rectifier units. This division of the power supply system came after a series of meetings with prospective vendors. After evaluation of the situation, it was concluded that a package

approach for an entire power supply was not economically feasible. It was decided, however, that the rectifier stacks and high-voltage transformer should be specified as a package and contained in the same tank.

Specifications for three power supplies for the Equipment Test Laboratory Building have been released for bids. Bids are to be opened the first week in February.

Design of the high-voltage capacitor banks is in progress. Tentative specifications for the capacitors were written and submitted to selected vendors for comment. These comments are now being reviewed.

It would seem that substantial savings may be achieved by using 45-kV capacitors in the 90-kV bank arranged in a series-parallel configuration. The same capacitor, i. e., 1.38 μ F at 45 kV, could then be used in all capacitor banks. This is attractive from the standpoint of procurement as well as of stocking of spare parts.

IV. ACCELERATOR CONTROL AND INSTRUMENTATION

Introduction

The major effort of the Control and Instrumentation group was centered on the fabrication, installation, and checkout of the control systems for the Electron Prototype Accelerator (EPA). In addition, based on the experience gained to date from the Mockup and EPA programs, design modification studies were conducted on numerous other systems.

The control computer system performed well and permitted the development of new control and display programs, automatic turn-on sequences, and special data acquisition and display programs. Based on the experience gained with the programming system, various faults and limitations were analyzed and ideas for improving the system were studied. Development of a new control language progressed to the point where the first version could be tested successfully. The initial package of sequencing programs for the turn-on of EPA is about 80% complete.

The computer interface equipment for EPA was installed and final checkout essentially completed. As the local controls for EPA were made operational the circuits were checked out and operated through the computer. As circuit deficiencies were corrected the interface equipment was found to operate reliably, although full scale operation of the accelerator has not been attempted as yet.

Interface hardware design development has been continued with the major change being a shift to diode-transistor logic (DTL) for decreased noise. Units are under fabrication for test in the operation of the Ion Source Test Stand. A revised data transmission system between the computer and the module control units has been devised. The new system provides a decreased noise level, self-clocking, and somewhat simpler logic design. These modifications do not represent a basic change in the system but only in its detail design.

The bulk of the EPA control and data acquisition system was completed sufficiently for initial operation of the accelerator during the

latter part of Dec. 1967. The total system was about 95% complete at the end of this quarter. Certain devices and signal sources have not yet been installed, and so some data are not available to the computer.

Data Acquisition and Control System

Control Computer

The computer system achieved its best maintenance record during the last quarter. The display scope and line printer both suffered from a transistor failure and the console teletype had to be sent in for its 2500-h overhaul; it had logged a total of 4500 h. The rest of the equipment performed reliably. A schedule of weekly maintenance was instituted and a limited number of crucial spare parts are being stocked.

Programming

To aid with maintenance, a series of 16 diagnostic programs were written and added to the system. Each program exercises one of the computer peripherals or one of the interface units in all its modes of operation. The testing is performed while the device is on-line to the accelerator. In this way it should be possible to make on-line repairs to devices such as the console and the teletype which have their functions duplicated by other units. These programs will be elaborated and augmented as better diagnostics are devised.

The vocabulary of keywords recognized by either teletype was expanded so that all the functions available on the operator's console are duplicated in the teletype. This is just another step toward implementing the philosophy of reliability through redundancy. In addition, a set of keywords was added which allows the operator to program the time delays associated with the Master Pulsar.

Several new display programs were added to the system. The Channel Index program, which provides the operator with a dictionary of all data and command channels, was expanded to include all the channels in the two new EPA modules. A catalog of all the video channels is now available from the Video Index display program.

The data-scanning program which goes along with the Beamplot program was completed. Beamplot presents three graphs to the operator: one each for x-displacement, y-displacement, and intensity. The intensity is automatically scaled for maximum sensitivity.

An automatic sequencing feature was added to the Vary program which permits the operator to obtain on-line the steady-state transfer characteristic of any operating parameter in the facility. A Recorder program was written to provide the capability for longer term monitoring (8-24 h). After the operator specifies a channel and the frequency of sampling, the computer records on the disk a data point for each time interval. The operator can display the data file at a later time in a variety of formats. Only the file display program remains to be finished.

An automated turn-on sequence for the Klystron Test Stand was written and executed successfully. It was cast in the framework of the generalized sequencing program developed last quarter. The same sequence has also been written but not tested in a new control language. The first version of an interpreter program which processes the language statements has been tested successfully. This program will be expanded gradually until it can handle the full language. All further sequencing and operating programs will be written in the control language. Four out of the five sequencing programs for EPA have already been written. An assembly program to convert the language statements to machine programs is in the final stages of checkout.

An alternative approach to automatic sequencing has been developed in the form of a Copy program. This program can memorize a sequence by monitoring and recording the requests an operator makes through the console. The complete sequence can be played back any time later at the option of the operator. The Copy program is complete; the Playback program is in the final stages of checkout, and the auxiliary editing programs are partially written.

Sufficient experience has been gained with the present programming system to expose its faults and limitations. Some of the difficulties are

inherent in the computer system because of the small memory (8000 words) and the slow disk (~100 msec average access time). Other problems arise because of the structure of the Executive program and the way application programs have to be written. The various ideas for improving the system have crystallized into a specification for a new resident system which should be smaller, faster, and more convenient for the application programmer to use. The first steps toward implementing the new system have been taken in order to gain a better understanding of the consequences of some of the design decisions. The new system will gradually be built up over the next few months on a second disk pack so that it can be tested without disturbing the present system.

Documentation of the present system received considerable attention. The latest source and object language tapes for each program were placed in a box which was labeled with the program number and name. These boxes were filed numerically on shelves for convenient access. The data recorded on various sectors of the disk were filed in a similar fashion. At the same time an up-to-date listing of each program was filed numerically in a group of binders. Another set of books was organized to hold flow diagrams and other information associated with each program. In this way each programmer has ready access to complete documentation for all the programs in the system. The first draft of an operator's manual for the prototype control system was completed. It will be reviewed after thorough testing by a number of people.

Computer Interface Unit (CIU)

The prototype CIU has performed without any failures. The experience gained to date suggests that the present design is sound but that a number of modifications are necessary to make it more compatible with the overall control system design. For example, the console Video Control Unit (VCU) logic should be integrated into the CIU rather than leaving it as a separate chassis. The CIU can also be simplified by combining the data-take, data-collect, and data-store opera-

tions into a single instruction. These modifications are so extensive, when coupled with the decision to build all equipment from diode-transistor logic (DTL), rather than the present resistor-transistor logic (RTL), for decreased noise, that a new prototype of CIU must be designed. The chassis will carry the designation RIU, for RICE-Computer Interface Unit. The RIU design is ~40% complete.

Remote Information and Control Equipment (RICE)

Two RICE and RICE Input/Output systems for EPA have been fabricated, bench-checked, and system-checked with the computer and CIU. These units were installed in EPA and channel checkout is nearing completion.

The major difficulty so far has been with the analog data channels. The sample and hold and multiplexer will not hold a $\pm \frac{1}{2}$ least significant bit (LSB) accuracy over an extended period of time. For this reason, consideration is being given to a commercial low-level analog data acquisition system. An "inquiry specification" was prepared and submitted to a number of manufacturers of data amplifiers, multiplexers, and A/D converters. The response was quite good and the results were enlightening. The manufacturers pointed out where the specifications were too tight in their standard approaches to solving the problem and in the resultant cost estimates. The latter varied from about \$9000 to \$25,000 per module. Consequently, the specifications will be rewritten and some of the desirable but nonessential features will be sacrificed to allow the manufacturers a different, less costly solution to the problem.

The construction of a fourth RICE is nearing completion. This unit is being fabricated from DTL using the "mother-board" technique. Vendors using this type of construction indicate a considerable cost saving over the conventional printed circuit board construction. The RICE will be used to instrument the Ion Source Test Stand. It will provide the opportunity to test the effects of lower noise of DTL logic, to check for acceptability of the "mother-board" construction

technique, and to compare the cost of mother-board versus printed circuit board construction.

Remote Information and Control Equipment Input/Output (RICE I/O)

Circuitry for the fourth RICE I/O was designed and laid out in printed circuit form. This unit will be joined to the fourth RICE and used on the Ion Source Test Stand. Part of the design task involved translating the circuitry from RTL to DTL logic. The rest of the effort was directed toward absorbing some of the MIU and VCU functions into the RICE chassis, thereby simplifying the module control equipment and reducing its cost. For example, previous designs of the RICE I/O - MIU circuitry for a binary command channel consisted of five cards of three types with 20 interconnecting wires. The new design uses five cards of one type and eliminates the interconnecting wires. Comparable simplifications were made in the other types of channels. The whole RICE I/O redesign was made less subject to noise by incorporation of better ground isolation.

Head Control System for EPA

Installation and dynamic checkout of the computer Head Control Unit was completed. Several noise problems were encountered at first but these were corrected with noise suppression diodes and filters. The unit now appears to work well.

Data Transmission System

The signal transmission system between the module and Central Control Room (CCR) was redesigned to decrease the noise level. The signals transmitted between the RICE and the RIU were revised and fixed with respect to format, word length, and bit rate. The proposed system reduces noise effects by: (a) combining timing and data in a single line, (b) limiting the duration of the allowable input interval to $\sim 120\%$ of the expected word length, (c) requiring a specific "count" or number of timing pulses in the interval, (d) acknowledging legitimate instructions, and (e) requiring a specified input wave shape. A

prototype is being constructed to verify the design and to determine the tolerances of the signal.

RF Module Control

805-MHz Modules

The Klystron Test Stand was wired for computer operation and the system was exercised periodically by the computer. The system includes 18 binary data channels, 2 binary command channels, 1 pulse channel, and 5 analog channels. These channels were incorporated in module 1 of the computer control system along with those for the Amplatron Test Stand.

Accelerator Module Control

201.25-MHz Modules

Work was started to determine the detailed control functions required for the drift tube linac. It is anticipated that rack layouts and block diagrams of all systems will be completed by the end of the next quarter and that detailed chassis drawings will be ready so that construction of chassis can start by late summer.

EPA Modules

Much effort has gone into the control system for the EPA. This required fabrication, checkout, and installation of about 40 different control chassis, and modifications to several others. Included in this number were chassis to control steering magnets, focusing magnets, a spectrometer magnet, vacuum, temperature, target water, the beam dump, and various water flows. Each chassis underwent a complete wiring and functional checkout in the laboratory prior to installation into the EPA control racks. This checkout found and corrected errors in the individual chassis and, although time-consuming, proved to be a valuable operation. As the control chassis for each system was installed in the control racks, the system operation was checked out and made to work properly.

The bulk of the EPA systems installation was completed by Dec. 21, 1967, and this facilitated the initial operation of the accelerator. For 3 weeks thereafter, system installation and

checkout continued until the accelerator went into operation again on Jan. 24, 1968. At that time the control system was about 95% complete. The work remaining consists of systems that are not directly involved with the operation of the accelerator. For example, there are a few areas where instrumentation for the computer is incomplete, principally analog channels associated with the water flow and temperature monitoring.

One of the EPA control systems that requires special mention is the temperature control of the accelerator structures. An analysis was performed which defined the major time constants and gain terms for the system. This led to a control scheme that is not too different from the one initially proposed but which is much better understood. The EPA system controls the tank temperature (maintains resonance) for increasing rf input power but lacks the heating capacity to compensate for decreases in the rf input, nor can it control against rapid on-off changes in the rf. Nevertheless, the system in EPA is operating satisfactorily and work will continue to improve the performance in other areas of the control operation.

Auxiliary Operational Systems

Four-Foot Drift Tube Linac Model

Temperature Control: Analysis of the thermal behavior of the 4-ft drift tube linac model is being continued with the ultimate goal of designing the temperature control system for the full-size drift tube linac. The theoretical relations for heat transfer and storage have been used to obtain equations relating the temperature and heat flow in various parts of the 4-ft model to the rf power input, cooling water temperature, flow rate, etc. These equations were modeled in a LASL analog computer facility in order to study their behavior as a group and to determine what sort of information was valuable to use for control purposes.

A program of experiments is also under way with the object of checking the validity of the theoretical model. In the drift tube part of the model, the transport time delay is a few seconds and the thermal response lag of the metal with

respect to the water has a coefficient of ~ 1 sec. Both results agree with the predicted values. The tank wall temperature is related to the wall cooling water temperature by a simple lag in the first approximation. The measured and predicted value of the coefficient for this lag was $1\frac{1}{2}$ min. The measured response also indicated that a pure time delay of $\frac{1}{2}$ min was present. Probably part, but not all, of this delay may be attributed to transport time.

Various control circuits are being evaluated; this helps in evaluation of the control limitations of the copper and wall cooling systems on the 4-ft model. A modification of the existing controller (designed when copper and wall cooling were one water system) permitted variable amounts of error and error rate information to be used in controlling the drift tube temperature. When adjusted to give an approximate critically damped response, the arrangement succeeded in keeping the tank near enough to exact resonance to permit operation in the presence of slow variations in rf power level and cooling water supply. The performance of the system with this controller was found to be limited by the maximum pulse rate that could be produced by the valve motor-driver circuit. Another limitation at low rf power levels was the slow rate at which the system heated up with the valve completely closed.

A new set of controllers has been designed and built. They have provision for using both error and error rate information; the maximum valve motor speed can be varied, so that this limitation can be investigated. These controllers have not yet been tried with rf power on. In the absence of rf power, control to within $\pm \frac{1}{8}^{\circ}\text{F}$ has been achieved, both on the copper system and the wall cooling system.

Modifications which would decrease the noise level and make the system more immune to dc amplifier drift are under study.

Pinhole Camera: Several pinhole pictures of the prototype 201.25-MHz tank have been taken with an x-ray pinhole camera to determine sources of x-ray emission. The outline of the end of the

drift tube and part of the support stem were seen but with a high level of background radiation. Additional shielding has been incorporated and more pictures will be taken.

Electron Prototype Accelerator

Timing System: The master timing system for the EPA was completed, checked out, and installed. It included a manual (local) master pulser located in the control racks near the EPA and a computer-controlled master pulser located in the CCR. The timing system has been used for EPA runs under local control only, but it appears to operate as required under both local and computer control.

Fast Protect System: "Fast Protect" is the name given to a hardware system which can very rapidly inhibit injection of beam into the linac in the event of an abnormality which may cause beam spill. The system is based on one chassis per cluster. Fast protect inputs from the modules comprising the cluster will be gathered at the cluster fast protect chassis where they will be interfaced with the fast protect line. It is contemplated that the timing system will also be distributed by the same chassis hardware. Two prototype versions of the design are being fabricated for testing on the EPA.

Beam Position Monitor: All the switching electronic circuits for multiplexing the EPA beam position monitors have been built and tested. The analog signal processing circuitry is being constructed. The prototype works satisfactorily. The gated clamp and fast store-and-hold circuitry have been combined into one circuit considerably simpler and more easily adjusted than the separate circuits.

Logarithmic intermediate frequency (IF) amplifiers have been built with a 60-dB dynamic range and an output of 0.2 V/dB. The units are calibrated by means of an electronically stepped attenuator which has an 80-dB range in 5-dB steps. The log amp output is adjusted to give a uniform staircase output over a 60-dB range with the input stepped in 5-dB jumps from the electronic attenuator.

Problems with the switching mixer have been solved by the use of HPA 2301 hot carrier diodes as the mixer diode. Preliminary measurements indicate that a conversion loss of from 8-10 dB can be expected when attenuation of the mixer in the off state is on the order of 40 dB. The performance of the mixers is quite satisfactory and within the originally proposed specifications. Production of the mixers for the EPA beam position monitor system is in progress. Work on the fast store-and-hold circuit has led to the development of a system which can store in 300 nsec and hold for a $1/e$ time of 50 sec.

Beam Scanner: Fabrication of the component parts of the rotating wheel beam scanner is now complete except for the outer housing; assembly will start when the housing is complete. The offset bellows type of rotary feedthrough originally planned for use in this device has been replaced with a feedthrough unit with a solid shaft rotating in elastomer seals because of the torsional oscillations experienced with the bellows type of feedthrough.

Beam Scraper: Fabrication difficulties have delayed delivery of the beam scraper until early Feb. 1968. This scraper will limit the beam to the 1.5-cm diam and is capable of withstanding full beam impingement.

Operational Support Systems

Communications

The basic communications system throughout the Mockup facility includes a paging system and an interphone system which interconnect all areas for communication purposes. The system was expanded to cover additional locations involved in the operation and maintenance of the EPA. Five interphone outlets were installed at convenient points along the EPA walls, three at the control racks, one at the Klystron Test Stand, one at the computer console, and one in the large screen room in the Mockup Building. The outlet in the screen room was specially fabricated so as to contain the public address speaker also and in such a manner as to preserve the shielding integrity of the shield room. Measurements

made to date show that no interference leakage was introduced. To conserve rack space, a thin "C" frame mount was developed for the interphone outlets so that they could be mounted in the rack walls.

Work with this communication system has been satisfactory but a number of desirable modifications have become apparent; they will be incorporated in the final system design.

Rad-Safe Systems

201.25-MHz Test Stand: Five ion-chamber type area monitors were located in access and passage areas associated with the 4-ft drift tube model. Alarms were installed at each monitor. The radiation levels at the monitors are read out on a panel near the control racks.

Correlation of radiation level and operating power has been difficult in the past because of variations in rf power and frequency. This problem was virtually eliminated by recording power level and radiation level on the same chart with a two-pen recorder.

The Test Stand was run at high power for a period of several hours to get a gamma-ray pin-hole camera picture of the x-ray sources within the accelerator tank. Unfortunately, the back side of this camera was not well shielded and the resulting pictures were heavily overexposed by back-scatter radiation. The camera has been rebuilt for use during the next high-power run.

Electron Prototype Accelerator: Three ion-chamber area monitors were installed around EPA-- near the electron gun, near the power-input bridge-coupler, and near the target end. The gun and bridge coupler monitors were equipped with local alarms. The alarms are interlocked with the shield door so that they do not operate when the door is closed. The principal purpose of the ion chamber near the target is to monitor for residual activity following accelerator operation. For this purpose the alarm associated with it is to be mounted at the control racks.

A monitor system was installed to monitor beam-spill radiation at each "beam scraper" and

beyond the target. These have proved useful as auxiliary guides for steering the beam. Their sensitivity, at least for low-beam transmission, far exceeds that of the beam-current monitors.

TV Systems

The high radiation fluxes that the television cameras may be exposed to strongly suggest the use of all vacuum-tube cameras with lenses fabricated of the so-called "radiation-protected" glasses. For zoom lenses, however, the increased price for a "radiation-protected" zoom lens (about \$1000) justifies an attempt to rejuvenate radiation-browned lenses. This approach was explored with two very brown zoom lenses obtained from the Nevada test operations. They were disassembled and the lens elements held at a temperature of 450°F for 5 days. The browning was completely removed and lens performance appears to be normal.

Two monitors obtained through the Government Services Administration were re-conditioned and mounted in the EPA control racks. A cable system was installed so that two camera systems can be used simultaneously anywhere within the EPL. One of the monitors can also be switched to a camera in the CCR, this camera will view the data on the display scope.

Video System

The basic design of the Video System has been revised so that the VCU will function as a sector device rather than as a module device as had been planned. Thus, one RICE in a cluster will have the additional task of controlling 60 channels of video signals gathered from the modules in that cluster. The performance of this RICE will not be degraded either in channel capacity or speed because video channels are distinct from data or command channels, the execution of a video instruction is fast, and the video signal switching instruction occurs only as a manually commanded instruction. Another advantage of the cluster VCU is a reduction in bulk of circuitry in the video system. A disadvantage is the increased performance required in the signal conditioning as a result of the

greater distance from the signal sources to the VCU.

The cable drivers in the video system are being improved. A relatively inexpensive, bipolar 5-MHz driver is required. A discrete component amplifier developed at LASL appears to fill the requirement. The amplifier is being modified and packaged for application as a video cable driver in the VCU system.

Centralized Control

Injector Control

Conceptual design of the manual injector control console was begun. Initially, the console will contain controls for one ion source, one Cockcroft-Walton high-voltage supply, and the beam transport and diagnostics system. Provisions are being made for controls for additional ion sources and other subsystems but these will not be determined finally until a later date.

The manual console will contain the "primary" controls and data displays needed for injector checkout and operation. "Secondary" controls and data (i. e., those not pertinent to normal injector operation and those normally set to one condition and left in that state) will be housed in racks behind the control console. The control console will be a low-profile style such that the operator can view the "secondary" controls and data without leaving the console.

Ground-level control will be functionally similar to that of any module along the accelerator, except that the primary controls of all injector modules will be condensed onto the control console, permitting the entire injector system to be controlled as a unit. Controls and data from the "heads" require a somewhat different approach in that all must be digitized for transmission to and through the head RICE's via the light links (because of the 750-kV potential of the heads). Thus, these signals should be transformed into formats compatible with the computer control system for which the transmission is being designed. This will be accomplished with a "CIU simulator." Data in the heads will then be scanned automatically by the manual console and selected

data channels will be displayed continuously or upon request, and in a preselected form (e. g., decimal, meter, on-off, etc.). Issuance of a command interrupts the normal data scan long enough for the command to be executed. Thus, commands can be issued to the head at any time; the data are continually updated, and the controls and data display for the head are similar, from the operator's standpoint, to those from ground level.

Since both the computer and manual console communicate with the heads via the light links and head RICE's, the computer and manual console must either be tied together to prevent crosstalk and confusion on the transmission lines or they must exercise mutually exclusive control; that is, one and only one may be in control of any given head at any given time. This latter approach is being taken initially because it is simpler and less expensive without sacrificing any of the system's capabilities. Design work on the manual console is being continued.

Miscellaneous

Wiring and Terminations

The computer program, written to the specifications of the prototype Wiring and Termination Designation System, was checked out and found to work satisfactorily. Application to the EPA wiring, however, showed that two revisions were required, one to describe "jumpers" going to other "paths" and the other to describe paths having discontinuities. Although these conditions are not expected to arise in LAMPF, they should be anticipated. Therefore the computer program was revised to include these provisions. The programming difficulties encountered have now been solved and the program is in final checkout.

In the meantime, maintenance of correct wire records for EPA without an operating computer program has been a very serious problem. The wire records are complete, however, having been kept on IBM cards in the format required for the computer program. The wire lists which are in use are simple lists of the IBM data cards.

Fig. 13. EPA Master Interlock Logic

EPA Interlock System

The interlock system for pulsing the electron gun is illustrated functionally in Fig. 13. The system is designed to provide maximum flexibility in operating the various subsystems in EPA consistent with the requirements for personnel safety. An example of this is seen in the first line which indicates that having either the shielded access door or the gun vacuum valve closed will permit activation of the remaining portion of the interlock chain. The interlock system is based on the fact that no harmful radiation was measured, either from Model M or from the main tanks, with only rf present in the cavities; therefore, the rf need not be turned off to allow personnel access to the accelerator enclosure (Iron House) provided that no electrons are available from the source.

The interlock chain begins with the series Scram, or emergency OFF, switches. There are 10 of these switches located inside the Iron House and all of them must be closed before any of the systems can be operated. They are provided to allow personnel inside the house to shut down the machine operation on an emergency basis.

The branch of the interlock chain through the main header water flow interlock permits three subsystems to be activated independently--the Model M and its 100-kW Intermediate Power Amplifier (IPA), the main tanks and the Klystron Test Stand, and finally the target area. The branch through the electron gun vacuum interlock permits

conditioning the "head" for high voltage and, if the shielding door is closed, allows the gun filament to be energized. The door cannot be closed, however, until the master key is removed from the personnel key bank and this is not possible until all six keys are in place. Thus, persons working inside the Iron House keep in their possession one of the personnel keys and only return it to the key bank upon completion of their activities.

The head high-voltage ready, gun filament ready, Model M ready, main tanks ready, and beam line interlocks all form a logical "AND" function. The final input to this gate requires the door be closed, the sounding of a horn, and a 30-sec delay during which time anyone inside the Iron House would have time to hit a Scram button.

Arc Modulator

Two versions of an arc modulator for the Ion Source Test Stand were designed; one using a high-power transistor as the switch element, the other a high-speed Silicon Controlled Rectifier (SCR).

A breadboard model of the transistorized version was made on the bench and operated up to 250 V with a peak current of 25 A at pulse widths up to 2 msec (low DF). Rise and fall times of 250 nsec were observed along with a storage time of 1.2-3.0 μ sec (depending on the drive amplitude). No turn-on delay was observed. Circuitry was included in the bench model to place a spike on the leading edge of the pulse. Operation with a 150-V pulse and a 250-V, 15- μ sec (base width) spike was checked out. The spike amplitude and base width were easily varied. The transistor characteristics limit the amplitude to 300 V and current to 30 A with the drive circuit used.

The SCR version promises higher voltage operation with faster turn-off. Parts are on hand but the bench model has not been built.

RICE Exerciser (REX)

Preliminary design of a REX has been completed. This unit will simulate the outputs of the RIU to the RICE for bench-checking the

RICE and transmission system. The unit will also function as the manual control unit for the injector head although this will require some additional circuitry.

Standards

A LAMPF Standards Committee was organized to evaluate and to standardize where desirable on electronic components, practices, and circuits. To date the committee has standardized on connectors, several relays, indicator lights, and terminal strips. Meter and rack specifications will be standardized soon, and control circuits have been discussed. A "Standards Book" is in preparation and will be distributed to all LAMPF designers.

V. ACCELERATOR PHYSICS

Introduction

Computations have been continued on the dynamics of particles in both the drift tube and waveguide portions of the accelerator. The routines for including the effects of space charge have now been incorporated into the drift tube linac computation program.

Fabrication of the 750-kV Cockcroft-Walton is continuing at the Haefely Co.

The high-intensity ion source has demonstrated in an extended test (90 h) its ability to run at 50 mA and 6% DF. There was no deterioration of electrodes and no operational problems were encountered. The emittance was satisfactory for use with LAMPF. This represents an important milestone in the development of a high-quality, high-DF injector for LAMPF. Lifetime testing is under way.

An accelerating column for 200-keV operation has been fabricated and is undergoing initial tests. Plans for conversion of the Ion Source Test Stand for 200-keV operation are complete, and the components are being procured.

Several types of beam scanners are being developed. One, a rotating wheel scanner, is now undergoing initial testing. Another, which derives from an Argonne (ANL) design, will measure the ionization of gas atoms by the beam.

Beam Dynamics Studies

Drift Tube Linac

Until recently the PARMILA program evaluated only single-particle dynamics, ignoring the forces due to other particles in the beam. A recent modification provides a means of including these effects. If a random collection of particles is assumed to be a reasonable description of the charge distribution in the beam, the effects of this charge distribution can now be evaluated by a SCHEFF (space charge effects) subroutine. At present two such routines are in use.

SCHEFF I, which assumes circular symmetry, sets up a table of forces that is used to

Fig. 14. Computation times for SCHEFF I and II.

find the forces on individual particles by interpolation. It is a relatively fast routine, the computation time being linearly proportional to the number of particles used in the simulated beam.

SCHEFF II calculates the forces on each particle due to every other particle, point by point. This is a much more realistic approach and assumes no symmetry. It is, however, a lengthy calculation proportional to the square of the number of particles (see Fig. 14).

Dynamics calculations using both of these routines were found to be in very good agreement. They were compared on the basis of forces on individual particles as well as the trajectories of particles and bunch size and shape as transformed through an accelerating tank. On the basis of these comparisons it was concluded that the more efficient SCHEFF I routine may be used with confidence in particle dynamics calculations involving space charge.

Fig. 15. Rotating wheel beam scanner.

Beam Diagnostics

Rotating Wheel Beam Scanner

A rotating wheel beam scanner to be used as a beam profile monitor on the Electron Prototype Accelerator (EPA) has been fabricated and is now being assembled (Fig. 15). This scanner consists basically of a 12-in. diam stainless steel wheel which has tungsten pins attached to its periphery. The wheel will rotate about an axis parallel to the electron beam at a speed of 2 rps and will be synchronized to the 120 cps repetition rate of the electron pulses. The wheel is mounted in a suitable vacuum housing and is positioned so that the tungsten pins will intercept various regions of the electron beam as the wheel rotates. The current pulses intercepted by these pins constitute the output signal and will be displayed on an oscilloscope.

There are two groups of pins in this wheel. The first group consists of 15 pins which project radially from the wheel at specified angular positions. This group provides the horizontal or x-scan of the beam. The other group consists of 15 pins uniformly spaced in angle, but they are bent so as to be tangential to the wheel at varying distances from it. This group will provide the vertical or y-scan of the beam. The angular and vertical spacings of the pins have been chosen to permit electron beams up to 1.5 cm to be scanned.

The tungsten pins are 0.020-in. diam; this is essentially the spatial resolution for the vertical scan since the motion of the scanning pin is then perpendicular to the direction being scanned. In the horizontal scan, however, the pins will move about 0.040-in. during a 500- μ sec beam pulse so that the spatial resolution for this scan is only 0.060-in. The pins will intercept about 1/1000 of the beam power which will subsequently be radiated to the outer housing.

The rotary motion of the wheel is provided by a synchronous motor with an appropriate gear reduction. This motion is then fed into the vacuum system by means of a rotary feedthrough unit. In the original design an offset bellows unit was to be used, but difficulties with torsional oscillations have made it necessary to employ a unit with a solid shaft rotating in elastomer seals. The phase of the wheel can be synchronized to that of the electron pulses by simply rotating the motor. It is also possible to derive a synchronized pulse from the wheel by means of a photodetector viewing the light transmitted through a slit in the wheel.

In summary, the scanner will provide oscilloscope presentation of the x and y beam profiles of a high-power electron beam with a spatial resolution of the order of 1 mm for beam diameters up to 1.5 cm. The scanner will be used as a beam diagnostic tool in conjunction with targeting studies to be carried out on the EPA.

Injector Program

Cockcroft-Walton (C-W) Power Supply

Detailed construction drawings of the equipment dome for the C-W high voltage power supply have been received from Haefely & Co. Modifications to these drawings were made to insure low-velocity air cooling of the electronic equipment and ion pumps and to supply sufficient air for the proper operation of the heat exchanger for the ion source. Other changes were specified so that the equipment dome will be compatible with the attachment of the accelerating column. The access door was widened to 2 $\frac{1}{2}$ -ft to allow for sufficient clearance to replace ion pumps and other bulky equipment.

Ion Source Test Stand

The high-intensity ion source has operated for a total of 90 h at a rated current of ~ 50 mA, a pulse length of 500 μ sec, and a pulse-repetition rate of 120 cps. Periodic inspection of the ion source, particularly the plasma aperture of the extraction cup, showed no apparent deleterious effects. The best normalized emittance (emittance area $\times \gamma\beta/\pi$) obtained was ≤ 0.03 cm-mrad. Unfortunately, this value represents the limit of resolution available for measuring emittance with the present geometry. Extrapolated to 750 keV, the emittance obtainable is less than 1 cm-mrad. Thus it would appear that the ion source depicted in Fig. 16, meets the high DF and low emittance specifications for proper operation in LAMPF.

The unique features of this ion source are illustrated in Fig. 17, which shows the region of major interest. The insert shows that the plasma aperture of the expansion cup is fabricated of a brazed sandwich of copper, for adequate cooling, and iron for reducing the magnetic field in the cup. To bring the current up to the specified level, a new anode structure was installed to provide the undercut lip. In this way, cooling of the plasma near the expansion cup walls will not reduce the effective extraction area. (The effect is illustrated in Fig. 21 of the preceding Quarterly Status Report (LA-3828-MS)). At the same time the opening of the extractor electrode was enlarged to 2 cm. With these changes, and 25 kV across the 2.54-cm extraction gap, the required 50 mA of ion current is now easily obtainable from what is probably a reasonably flat plasma surface of 1.4-cm diam. These currents were confirmed by a calorimetric check.

The behavior of the ion source beam is consistent with the view that a divergence of the beam, which is extracted normally from a plane plasma surface, occurs between the lip of the expansion cup and the Pierce extraction electrode due to the lens action of the latter. Adjustments to counteract this beam divergence, by increasing the extraction voltage, produces a concave plasma surface with a resultant reduction of the potential gradient near the plasma boundary and consequently

Fig. 16. High-DF ion source with multichannel cooling fields.

Fig. 17. Details of ion source.

a reduced current. A true Pierce field configuration can be achieved in the region of the extractor gap only if additional downstream electrodes are provided. This will be the case with the partial accelerating column.

A noticeable increase in the noise level of the extracted current, which is normally of the order of 4%, was noted when the beam grazed

the extraction aperture. A possible explanation for this could be that a sheath of electrons knocked off the extractor by the edge of the proton beam travels back along the edge of the beam and reduces the effects of space charge. The beam will then converge because of the focusing action of the $4/3$ power potential gradient of the Pierce geometry and the proton beam will miss the extraction electrode and shut off the supply of electrons. The beam now expands because of space charge, again striking the extractor, and the cycle is repeated. Calculations of the particle transit times involved indicate that a frequency of 14 MHz should be expected. Such a frequency is dominant in the noise and has the proper response to variations of the extractor voltage. There are, however, other prominent frequencies, notably at about 2 MHz, which are not accounted for by this simple model.

Since fuses have been installed in the arc pulser circuit at both its dc input and its pulsed output and a copper backing has been brazed to the soft iron of the plasma aperture, enlargement of this aperture has not occurred, although many transistor failures during the first part of the report period had caused the pulser circuit to fail. Without fuses, and without a brazed aperture, this type of failure had previously resulted in a 100% DF voltage being applied to the ion source with consequent melting and enlargement of the plasma aperture. A test of the brazed aperture with 100% DF has not been attempted to date.

The ion source arc has been pulsed for the equivalent of 363 h at 6% DF. The present cathode has been kept at a normal operating temperature for 2568 h. The original set of titanium plates is still in use in the ion pump after the equivalent of 905 h of ion source operation. As mentioned previously, the full current at 6% DF has been extracted for 90 h. A typical set of parameters for obtaining a good emittance 50-mA beam with the required 25 kV across the 2.54-cm extraction gap is the following:

Arc chamber pressure	250 μ gauge
Arc voltage	130 V
Arc current	16 A
Magnet current	0.5 A

For small variations around these values, beam current is directly proportional to arc current; the arc impedance decreases with hydrogen pressure and is relatively insensitive to magnet current; and the noise in the beam is much smaller for higher pressures and is smaller for higher magnet current.

From a visual observation of the beam size and intensity at the extractor aperture as a function of very short pulse lengths, the time-history of the plasma formation in the ion source can be inferred. A beam does not appear for 12 μ sec after the arc voltage has been applied. This is interpreted as the plasma buildup time in the arc chamber. At first visual observation the beam is of very small diameter, about the size of the plasma aperture. As the current increases with time, the diameter of the beam grows until the expansion cup is filled and a plasma surface of 1.4-cm diam has been established. Filling of the expansion cup takes about 4 μ sec. Thus a stable plasma surface does not appear for ~ 16 μ sec after the arc voltage has been applied. The buildup time of the plasma boundary at the anode is consistent with the transit time of the protons from the plasma aperture to the stable plasma surface (1 cm).

In future tests the beam current density profile will be studied as a function of radius and of bias voltage on the expansion cup. At present, the optimum parameters for good emittance give a beam which appears to be slightly hollow, i. e., the beam density is greatest near its edge. The effects of parametric variations on the ratio of H^+ to H_2^+ ions will also be of interest.

Accelerating Column

An accelerating tube section, consisting of a titanium washer bonded with polycarbonate between two 15-in. diam alumina rings, has been tested and used to develop fabrication procedures. The bonds were found to be leak-tight by a mass spectrometer. Cleaning and masking techniques were developed to define sharply the bead-blasted area of the ceramic up to the metal interface without destroying the 2- μ in. finish on the titanium inside and outside of the section. The

high outgas rate observed on initial pump down is attributed to the cleaning solvent, since polycarbonate is reported to have a low outgas rate. This high outgas rate was not observed on subsequent pump downs.

Fabrication of the titanium electrodes and the partial column for 200-kV testing has been completed. These units and the bellows for compressive loading of the column are seen in Fig. 18. The exploded view of the electrodes shows their relative position inside the partial column. Pump-out holes in the conical sections are staggered to reduce direct line electron backstreaming. After the first heating, the partial column was leak-tight at all bonds except for the one at the bottom flange. There was evidence that the 600-lb loading during bonding caused the oven floor to sag, bowing the bottom flange sufficiently to cause the leaks. The column was later reheated with measures taken to avoid this problem, and it was found to be leak-tight at all bonds.

Spark-gap tests have been conducted on annular-shaped aluminum electrodes which will be attached to the ends of each partial column bleeder resistor. Tests simulating the energy of discharge in the partial column show that aluminum should suffice as the spark-gap material. No pitting, only surface discoloration, was observed. The approximate gap separation has been determined with an insulator simulating the resistor. Final gap separation will be determined under more uniform gradient conditions with a new resistor.

The resistors will be attached to the outer corona rings (not shown) which will be positioned concentrically outside the acrylic cylinder in Fig. 19. There will be six equally spaced strings of resistors, all parallel to the axis of the column. The corona rings will be supported by, and connected electrically through, the threaded inserts in the acrylic cylinder to the titanium washers of the partial column. To prevent breakdown, the acrylic cylinder will contain SF_6 at 1-2 atm.

Fig. 18. Titanium electrodes and bellows from partial column.

Fig. 19. Partial column in high-pressure acrylic cylinder jacket.

Fig. 20. Schematic of 200-kV Test Stand beam transport.

200-kV Test Stand

The Ion Source Test Stand will be converted to a 200-kV Test Stand with the addition of the partial column. A high-voltage dome to house the beam transport and diagnostic equipment to be used on this stand has been designed and partially fabricated. A schematic diagram of the layout of the test equipment is shown in Fig. 20. Provision has been made to test both the triplet and the quadrupole lens systems for matching the divergent beam from the 200-kV accelerating column to specified beam conditions. The outer housing of this dome and the rail system to be used for supporting and aligning the quadrupole lenses are completed. The inner framework and the insulating support legs are now being fabricated. The two smaller quadrupole lenses and their power supplies have been obtained and tested; the two larger ones and their power supplies are due shortly. Most of the remaining beam transport hardware has been procured while the necessary diagnostic equipment is either on order or is being designed.

Polarized Ion Source

There are two basic types of polarized ion sources that can be used to produce a polarized proton beam for LAMPF, namely, the conventional source and the metastable atom source. The conventional source produces polarization by using an inhomogeneous magnetic field to separate spatially the two electronic spin components of the ground state of atomic hydrogen. The proton polarization can then be enhanced by rf-induced transitions between the hyperfine states. The metastable source polarization is effected by selective quenching of certain of the hyperfine levels of a metastable state of atomic hydrogen. These two types of sources have comparable, but small, efficiencies for producing polarized protons, and consequently the peak beam currents that can be expected at present are only several microamperes. A summary of the two systems is contained in an internal report, MP-4/RRS-1. Studies are being continued on the relative merits of these two sources before a choice is made.

An important problem associated with the operation of the polarized ion source for LAMPF is

that of having a suitable polarization analyzer to monitor the proton beam. The elastic scattering of 750-keV protons has been considered, but the polarizations produced are small and difficult to measure accurately. In recent work,¹ however, a suitable polarization analyzer has been found in the ${}^7\text{Li}(p,\alpha){}^4\text{He}$ reaction. Preliminary results indicate that an analyzing power of the order of 50% can be expected for 720-keV protons.

Beam Diagnostics

A proposed emittance scanner operates by analyzing the scan lines of a TV camera viewing a scintillator which has been struck by a proton beam after passing through a slotted plate. Tests were made on two scintillators, quartz and loaded glass (Nuclear Enterprises NE901), to determine durability, linearity, and efficiency. For 30-kV photons, no decrease in light output was noticed after 10 mA/cm² for 1 h at a 6% DF. The NE901 appeared to saturate at around 10 mA/cm², whereas the quartz did not. Absolute efficiency (photon W/beam W) was about 10⁻⁶ for quartz and 3 x 10⁻⁶ for NE901. The low light intensity requires a very sensitive TV camera. In addition, good resolution is required to observe details of the emittance. Tests have been made with a Bendix BX7, 875-line scan image orthicon system having the required sensitivity. Although emittance patterns were picked up and observed visually, noise in the video made an analysis of the scan line signal impossible. To improve the signal-to-noise ratio, some sort of averaging technique must be used. An averaging device which analyzes vertical scan lines (Colorado Video-302) will be tested. With this device, or a similar one, the required bandwidth of the TV system would be effectively reduced by an order of magnitude.

Injector Control Room Layout

The injector control room design has been changed because of removal of the satellite computer originally planned for this area. Most controls will be of the raise/lower type for reasons of console space and simple transfer of controls to computer. Graphic control and display for the vacuum system, beam transport, and beam diag-

Fig. 21. Injector control room layout.

nostics appears useful. The control console will have beam transport, TV monitoring, and diagnostics in the center, high-intensity injector controls on one side, and polarized injector controls on the other. Nine low-height racks would be required as shown in Fig. 21.

Reference

1. Private communication from Louis Brown, Carnegie Inst. of Washington, D. C.

VI. EXPERIMENTAL AREA

Introduction

Several basic decisions have been made which require the updating of the design criteria for the Experimental Area. The two beam channels will each be designed for full 800-MeV, 1-mA proton beam transport capability. The deflector or switchyard will be located after the last 805-MHz section of the accelerator. Space will be provided at the switchyard for initial beam diagnostics equipment.

The previous general cost estimates for the experimental area buildings and equipment have been reviewed. To allow for possible revisions due to the changing situation in nuclear physics and to new ideas for experiments, a number of combinations of buildings and equipment with their respective cost estimates have been drawn up and evaluated. A flexible overall plan has been selected to keep pace with criteria changes, particularly for the design of buildings and their built-in utility systems.

Studies of proposed experiments have been continued to develop buildings and services that will most effectively meet the varied requirements. Preliminary layouts and facility cost estimates have been started for proposed low-energy neutron experiments and for a high-resolution proton spectrometer area.

Calculations of subgrade deformations resulting from heavy shielding loads are being continued and tests are being prepared to determine the deformation characteristics of the broken and compacted subgrade material. Investigations of building structures and crane systems are being made to explore the possibility of removing the support columns in the experimental areas and of effectively increasing the overhead crane coverage.

Calculations are in progress on optimization of primary beam transport through the experimental area and on the stopped muon channel.

Shielding

A new version of the one-dimensional transport codes, called GA-DTF, is now being

used. The author of GA-DTF has written an addition to the code which will permit the use of anisotropic source term for neutron production mentioned in LA-3828-MS. (p. 38). After the incorporation of the GA-DTF addition, the code will be run using as input, to describe the transport process, the cross sections derived from the Cascade Code and the LASL tape library of neutron data.

A report of the transport calculations will be prepared for a review by the AEC's Advisory Panel on Accelerator Radiation Safety. In addition, the report will contain a discussion of all of the radiation-related health and safety problems that exist for LAMPF.

Targets

Some minor changes were made in the design of the electron prototype accelerator (EPA) target water system. The changes involved the relocation of several pipes to permit easier access to the beam-analyzing spectrometer and other target area components. All essential components of the system are on hand and installation should begin shortly.

Six targets of graphite or beryllium oxide are ready for testing. (In general, the dynamic diagnostics of target performance will be restricted to heat dissipation phenomena.) An attempt will be made to view some of the targets through Lucite mountings. The success of the last venture is in doubt because of the possibility of charge rupture of the Lucite.

Remote Handling

The Merrimac remote manipulation system has been subjected to continuing review for system compatibility, optimization, and cost reduction. The primary area of improvement has occurred in the moving of the 200-ton shielded room. Present concepts are based upon the use of hydraulic cylinders mounted in the vertical corners of the room to provide the lifting requirement. The extension of these cylinders pushed the room up vertically out of the target cell. The room rises between two rather large "I" beams. When sufficient elevation has occurred, so that the

bottom of the room is well clear of the shielding, lugs are driven horizontally outward from within the roof of the room. The room is then allowed to settle, transferring its weight through the lugs to the "I" beams. The stilt-like cylinder rods are then retracted and the shield doors closed beneath the room.

The two "I" beams are tied together and equipped with steerable powered wheels. The wheel assemblies will be the dual-wheeled main gear from excess military aircraft, the B47-B Stratojet being the presently favored model.

Details have evolved of a possible method for supporting and rolling the shielding doors. Confirmation of this design must await the results of an experiment to determine the load-carrying capacity of commercial roller assemblies. This experiment will also reveal the quality of plate necessary for methods and forces required to open the doors. The experiment is awaiting the delivery of items from vendors.

Primary and Secondary Beam Transport

A nominal effort has been devoted to designing proton beam transport systems from accelerator through the targets into the beam dump of Beam Area A. Because of the substantial magnet apertures involved, the transport through the targets and to the dump requires a systematic exploration of a variety of possibilities, such as transport by sets of doublets, triplets, and waist-waist transport. In the course of this work, it had become evident that a simple first-order code, producing graphs from which design parameters can be read for the various configurations (in principle similar to that which has been obtained with analog computers), would be helpful. Program TUIMAGE was written to produce the graphs, and the designs are explored in more detail by the use of the TRANSPORT code. The graphs produced by TUIMAGE show the converging conditions for object-image transport through one intermediate image in each of the two orthogonal planes in the drift space between two magnet systems that are symmetrical to each other; the magnet systems consist of doublets or triplets.

The new LASL version (CDC-6600) of J. Fronteau's (CERN) design code for pion and muon transport has been used for some preliminary data explorations and comparison of results with those obtained independently by others. One problem undertaken was that of a straight alternating-gradient muon channel computed by S. Ohnuma, Yale, with his code. A set of computations has been carried out with the parameters of the Chicago muon channel. The channel presently under construction at the Space Radiation Laboratory at Newport News is also being investigated.

The design of quadrupoles with straight pole faces (Danby type) for secondary beam channels has been pursued. A preliminary layout of the meson channel quads, including the intra-quad connections, has been made. Quotations have been obtained for tensile specimens for the intended exposure to fast and thermal neutron fluxes. A preliminary design has been made up and a quotation received for the bimetallic (stainless steel to aluminum) connection between the coolant lines and the quadrupole conductors.

Utilization of LAMPF

A group of experimental physicists interested in proton and pion experiments met at LASL Jan. 15 and 16, 1968. This group included

H. Palevsky, BNL
R. Rau, BNL
J. Friedes, BNL
H. Wegner, BNL
E. Gross, ORNL
A. Zucker, ORNL
P. Gugelot, VARC
K. Brown, Varian
N. Hintz, University of Minnesota
H. Holmgren, University of Maryland
L. McIntyre, University of Arizona
G. Phillips, Rice University
R. Sheline, University of Florida,

in addition to LASL representatives.

A large part of the discussion revolved around the desirability of developing a high-resolution spectrometer facility (HRS) for protons, although a number of those present indicated an even greater interest in such a facility for pions. Need for the latter facility has been anticipated and presents no new problems.

The HRS as now visualized, however, involves a drastic and costly change in the configuration of one of the experimental areas as well as new (and probably expensive) main beam transport. In addition, serious background problems may be encountered in the detectors, as well as induced radioactivity problems in the spectrometer. These matters are now under consideration. If the purely technical questions submit to reasonable solution, a decision will be made whether accommodation of the HRS should be incorporated in building plans at the expense of some other capability. This decision will naturally be heavily influenced by consideration of cost, of the probability that capital equipment funds can eventually be found for the spectrometer and, particularly, of the stated desires of the potential users of LAMPF.

VII. LAMPF SCHEDULING AND FACILITY CONSTRUCTION

Introduction

Site and building activities have been added to LAMPF PERT and the rf power system schedule is being updated. An experimental network has been constructed which has already proved valuable for the improvement of project programming.

Construction activities progressed very much less than scheduled because of funding limitations. Site preparation has now been completed, construction is about to start on the Equipment Test Laboratory Building (ETLB), and Title II engineering is almost completed for the Injector-Drift Tube Accelerator Building.

Accelerator Scheduling

The application of PERT to LAMPF design and construction has been continued with one major addition and one major modification, neither of which has produced a change in project completion date.

A small subnet for site and buildings was added to the network, which increases the number of subnets from seven to eight. The new subnet, BLDG, consists of two 36 x 54 in. drawings and ~ 250 data cards. Manpower information was not included. Although the subnet is small, its addition is considered to be of major importance since the interrelationship of the accelerator and the site and building construction has now been established and the effects of schedule changes can now be more readily and more accurately determined.

RFPS, the subnet for rf power systems, is being completely reconstructed to gain more detail and to show that the systems will be built on a sector rather than an equipment basis as previously assumed. The number of RFPS diagrams is not expected to change; however, it is anticipated that the number of data cards will increase from ~ 630 to 950.

The difficulties encountered (LA-3828-MS, p. 42) in the summarization of milestone events have not as yet been eliminated. Verification of

the apparent solution has been delayed by the current reconstruction of RFPS, since the computer program requires that all subnets must be integrated before the network can be processed.

A new small network, XNET, has been constructed which will assist in the improvement of LAMPF PERT programming. It provides a hypothetical network which is amenable to experimentation during periods (such as described above) when the project network is inoperative because of modifications. In its initial application, XNET has already contributed to: (a) a more comprehensible method for subnet interfacing, (b) an improved summary report diagramming technique, (c) improvement in Level I management summary network production, (d) a method of adding manpower at a summary level, (e) a method of correcting for vacations, holidays, and sick leave in manpower considerations, and (f) a better understanding of the cost provisions of the PERT program.

LAMPF Site and Building Activities

Site Preparation Work

As a consequence of minor field changes, the site preparation contract was extended 14 days. At the end of that period, on Nov. 28, 1967, a final inspection was made and the work was accepted for beneficial use. The Burn Construction Co. subsequently remedied the few remaining deficiencies, cleaned up the construction area, and thus completed in an entirely satisfactory manner this portion of the project.

Accelerator Building Design

The modified criteria previously described for the Injector and Drift Tube accelerator buildings were completed and forwarded to the A-E. The completed Title II drawings, specifications, and supporting documents are scheduled for review near the beginning of the next report period.

At the close of this period, work was resumed on some new architectural and mechanical alternatives for the 805-MHz accelerator buildings.

Equipment Test Laboratory Building

The ETLB construction contract award to the J. R. Brennand Construction Co. was withheld until the Jan. 12, 1968 relaxation of the construction freeze and allotment of some FY 68 funds. A preconstruction conference was held on Jan. 25, at which time it was agreed that the 240-day construction period would be initiated near Feb. 1.

Laboratory-Office Building

Funds were not authorized to permit construction of the Laboratory-Office Building. All bidders were notified of the cancellation and refunds were issued. A request for A-E contract modification has been processed which will permit rebidding at a later date when construction funds become available.

Utility Work

It had been planned that the second phase of site utility work would consist of the facility water storage tank, fire pumphouse, sewage lagoons, additions to the site water, sewage, and gas piping systems, and a small amount of electrical distribution. Title II engineering and issuance of the Advance Notice were accomplished in the preceding period. A new determination of a feasible scope for this phase and the subsequent distribution of bid documents have been deferred until a relative magnitude can be established between Injector-Alvarez building costs and the amount of FY 68 funding.

Even though critically long-term procurements dictated otherwise, restrictions on obligational authority have necessitated deferment of 115-kV substation construction. As a consequence, the bids have been cancelled and a contract modification is being processed so that Uhl & Lopez Engineering may have this portion of the project rebid at a later date.

An evaluation was made during this period of the joint proposal, reported previously, by New Mexico Public Service Co. and the

Bureau of Reclamation for supply of LAMPF electric power and associated 115-kV lines. The AEC selection panel and their technical advisors unanimously found the proposal to be unacceptable in its initial form. A compilation of the objections was transmitted, and further negotiations await a response from the proposers.