LOS ALAMOS MESON FACTORY: PRESENT STATUS AND FUTURE PLANS*

Invited Paper

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Abstract

This paper describes briefly the present status and future plans of the work at Los Alamos Scientific Laboratory on a meson factory project. At the time of writing, some 40 scientists and engineers are engaged in research and development activities for this project. The primary emphasis at present is on the linear accelerator which will generate the proton beam for meson production; in the future, this emphasis will shift to research activities connected with the use of the accelerator as a tool of experimental physics. More detailed descriptions of this work can be found in the quarterly progress reports (LA-3419-MS and following reports). The first section of the paper contains a general description of the accelerator; the following sections give somewhat more detailed descriptions of particular research and development activities.

I. Description of the Accelerator

The accelerator will be a proton linac with a maximum energy of 800 MeV and a design average current of 1 mA. The macroscopic duty factor of the machine for initial operation will be 6%; later the duty factor will be extended to 12%. The output energy of the machine will be continuously variable between 100 MeV and 800 MeV with typical energy spreads being 0.4% (full widths at half maximum) and typical emittances being 1 cm-mrad.

The injector building will have space for three high-voltage terminals powered by Cockcroft Walton units. Initially, two units will be installed; one will be used for a high-intensity ion source and the other for a polarized ion source. The injection energy is to be 750 keV. The 750-keV proton beam will be bunched in a single-stage buncher; a double drift buncher may be added at a later date.

The first four sections of the accelerator are of the conventional Alvarez design operating at a frequency of 201.25 MHz. These sections will accelerate the protons to an energy of 100 MeV. The first Alvarez tank is quite short so that its electrical gradient may be precisely adjusted; experience on other accelerators has shown that this will be a valuable feature. The first Alvarez tank requires a driving power of 350 kW and produces protons of 5 MeV. The three succeeding Alvarez tanks accelerate the protons to 40, 70, and 100 MeV respectively; they each require a peak driving power of 3 MW. The total length of the Alvarez portion of the machine will be ~200 ft.

The remainder of the accelerator uses a newly developed π/2 mode standing wave structure operating at 805 MHz. This structure is composed of accelerating cells operating in their fundamental TM_{010} mode; these cells are resonantly coupled by off-axis coupling cells. A single accelerator tank contains from 27 to 101 accelerating cells and the length of a particular tank is mainly determined by the required distance between the quadrupole doublets used for radial focusing. The phase velocity of this part of the machine is stepped, i.e., it is constant in any tank but changes from tank to tank to match the increasing velocity of the protons. This portion of the accelerator requires 45 MW of peak power. The power amplifiers will be rated at 1 MW and each amplifier will drive from one to four accelerator tanks depending on its location along the accelerator. The total length of the 805-MHz portion of the accelerator is ~2400 ft.

The Alvarez portion of the accelerator and its associated rf equipment will be placed in a common building with the Alvarez structure separated from the rf equipment by a suitable shielding wall. The remainder of the accelerator will be housed in an underground beam corridor running ~25 ft below grade; the associated rf equipment is housed in an equipment aisle located on grade. Such an arrangement is well suited to the contour of the site and provides the needed increase in shielding along the accelerator as the beam energy increases. The selected site is of ample size to permit any reasonable future expansion of the experimental area or of accelerator length.

II. Accelerator Structures

The low energy portion of the linac will use the Alvarez type of structure. The drift tube shapes are essentially combinations of spherical and cylindrical surfaces; drift-tube dimensions are calculated using the MESSYMESH code originally developed at MURA. All cooling paths are being designed for the eventual 12% duty factor operation. A four-foot section of Alvarez tank is now under construction; this will be used to test the cooling and electrical properties of drift tubes, tuners, and drive loops.

A variety of structures has been investigated for use in the high energy portion of the machine with the most promising being a side-coupled structure developed at Los Alamos and operating in the π/2 mode. In this structure, the coupling takes place through resonant cells placed on the outer diameter of the accelerating cells. The coupling from the accelerating cell to the side cell is through small (several cm) apertures. The size of the cells is adjusted so that the π/2 mode occurs at the desired frequency of 805 MHz. In this mode, energy is stored mainly in the accelerating cells; the coupling cells

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store only that small amount necessary for the real power flow along the structure.

Such a side-coupled structure has two important advantages: (1) the desired mode is in the center of the pass band and (2) the cavity shape may be adjusted to maximize the acceleration efficiency without appreciably affecting other characteristics. The main consequence of (1) is a relatively large group velocity leading to excellent electrical stability of the structure and maximum mode spacing; for example, these structures do not require accurate tuning to obtain a uniform accelerating field along a tank, thus, the individual cell frequency tolerances are relatively loose (typically ± 500 kc), and the proper field distribution is maintained under heavy beam loading. To make optimum use of (2), a mesh-type computer code (LALA) has been developed at LASL which can calculate field distributions and losses in cylindrically symmetric cavities with arbitrary boundary shapes. Geometries with excellent shunt impedance have been discovered.

Several accelerator sections of the side-coupled type have been built and their properties measured. Their shunt impedances are within 15% of the calculated value. An average shunt impedance of 35 MΩ/m (including the square of the transit time factor) is expected for the entire accelerator between 100 MeV and 800 MeV using the cavity shapes optimized with the LALA code. For comparison a resonant π-mode iris loaded waveguide with 5% bandwidth would have an average shunt impedance of 5-10 MΩ/m and much poorer electrical stability properties.

A short section of the side-coupled structure has been driven to several times design power and no tendency for prolonged sparking was observed; full-length sections will be power tested within the next few months.

III. The RF System

The 201.25-MHz rf system will be composed of three 3-MW peak power units and one 350-kW peak power unit; the 350-kW unit will be identical to the intermediate power amplifier stages of the 3-MW units. A prototype 3-MW unit is now under construction and should be operational in the first quarter of 1967. The intermediate power amplifier for this prototype should be operational during the summer of 1966 and will initially be used to test short sections of the accelerator. The tube lineup is 7651, 7651, 4616, 7835; the drive requirement is 8 W. A minimum efficiency of 50% is expected in the 7835 stage. The 7835 cavity is being constructed and is similar to the cavities now in use at ANL and BNL; its design is being modified for operation at duty factors up to 12%. The complete prototype amplifier shall be used to verify the amplifier design and for testing of accelerator components.

The 805-MHz rf system will be composed of 45 amplifiers each capable of delivering 1.25 MW peak power; to increase reliability and tube life, each unit is derated to 1 MW for accelerator operation. The system receiving the most attention to date is an RCA 1.25 MW coaxitron driven by a 100-kW klystron. The coaxitron (an integral cavity triode) is a special design for this purpose; the klystron is a standard UHF TV klystron (4KM70LH) slightly modified for pulse service. An rf system of this type has been in operation at LASL for approximately one year and has been extensively used for tube testing, accelerator structure testing, and experiments on phase control. This system exhibits tractable control characteristics, reasonable efficiency (coaxitron anode efficiency 35 to 40%), and is not unduly complicated. The mechanical design of the coaxitron must be improved before it performs satisfactorily at the requisite duty factor; however, no fundamental design problems have been encountered. As alternative approaches for the 805-MHz systems, Amplitrons and klystrons are receiving serious attention. The Amplitron is attractive when its plate efficiency is considered (typically 70%) but its control characteristics for standing-wave accelerator service are unknown. A 100-kW peak power Amplitron has been constructed and will soon be on test at LASL. Also, it is planned that a 1.25-MW klystron will be constructed and tested in early 1967.

The allowable tolerances on amplitude and phase are ± 1% and ± 1° respectively. This degree of accuracy places severe but realizable demands on the fast rf control systems; the situation is further complicated by the variable beam loading which may be as high as 30%. The present control scheme uses closed-loop control on the amplitude and phase of each rf unit. The phase comparison will be based on a highly stabilized master driveline and all phase corrections will be done at low level using slow (mechanical) and fast (varactor) phase shifters. Experimental and theoretical studies of the rf control system have verified that this scheme is practical.

IV. Controls Computer

The use of an on-line digital computer for control purposes is naturally suggested by the complexity and repetitive nature of this accelerator. Budgetary studies have shown that such a system is no more costly than a conventional manual control system; and, in principle, a computer control system should lead to more reliable operation of the machine. It is apparent that, if the computer system is to work satisfactorily, it must be considered a part of the accelerator design from the beginning. To implement the use of a computer for control purposes, we are leasing a small computer from Computer Control Co., Inc. This computer will be installed in the fall of 1966 and will be used to control prototype rf and accelerator systems. This early use of a controls computer will insure that interface problems are satisfactorily solved before acquisition of major system components. Further it permits an early start on the problem of real time programming for control purposes.

This small computer will have an 8,000-word core memory and disc file bulk storage system with two 128,000-word discs (16-bit words). The main display is on a high-speed CRT with its own 1000-word core memory; this display will permit the operator to monitor selectively the crucial aspects of machine operation at will. A logging typewriter will also present information. Commands are given to the computer via an input-output typewriter and paper tape system. A 23-level priority interrupt system is available.

V. Beam Dynamics Calculations

Calculations of particle trajectories through the machine have resulted in tolerance values for placement of machine components, and amplitude and phase of the rf field. Typical values are:

Phase of the rf field	± 1°
Amplitude of the rf field	± 1%
Drift tube quadrupole transverse displacement	± 0.004 in.
Drift tube quadrupole rotation about transverse axis	± 1°
Drift tube quadrupole rotation about beam axis	± ½°
Drift tube quadrupole current	± 1%
Doublet quadrupoles internal displacement	± 0.002 in.

While some of these tolerances are tight, they may all be satisfied with existing techniques.

The present emphasis in the dynamics calculations is on a determination of the optimum design of the Alvarez portion of the machine so as to minimize the phase width of the beam bunch at 100 MeV. This is important because the phase bucket width (measured in time) in the 805-MHz portion of the machine is 1/4 the width of the phase bucket in the Alvarez portion of the machine. Typical calculated values of emittance will match into the waveguide portion satisfactorily but improvements in match are desirable. Some improvement in matching can also be obtained by programming the rate of acceleration in the first few tanks of the 805-MHz portion of the machine. These studies are being carried out using the Parmila program developed at MURA and the code LINAC developed at LASL.

VI. Ion Source Development

A study of low emittance ion sources is being carried on in cooperation with the Brookhaven National Laboratory. Measurements on a reduced aperture ion source have been made and show an emittance of 10 cm-mrad at 55 mA and 35 keV for the significant portion of the emittance diagram. The extrapolated value at 750 keV is less than 2 cm-mrad which is much smaller than the acceptance of the presently designed linac. An ion source test stand facility is now under construction at Los Alamos; this will be used to continue these studies at 12% duty factor.

VII. Shielding Studies

Extensive shielding and activation calculations have been made using codes developed at LASL and codes from Oak Ridge. The design criteria established has been that, within two hours after accelerator shutdown, the beam channel can be occupied for 100 min without receiving more than 100 mrem. To achieve this, no more than 2 nA/m average beam spill is allowable along the machine. The shielding is designed for this beam loss and a dose rate in the main equipment aisle of 2.5 mrem/hr. This beam loss rate can be achieved with reasonable tolerances on the accelerator components. The amount of shielding is sufficiently thick so that, even if the entire beam were lost at one point at full energy for one minute, the dose in the equipment aisle would be 3 rem--complete loss of beam for this length of time is extremely improbable.

VIII. Building and Site Planning

The major architectural engineering contract for this facility has been awarded to Giffels and Rossetti, Inc. Work is now in progress on the general site layout, utility distribution systems and on the building housing the ion sources and the low-energy portion of the machine.

DISCUSSION

ALEKSEYEV (through an interpreter): Could you tell us something about the cost estimates for this project?

HAGERMAN: The cost estimates for this project were very seriously studied, I believe, in the summer of 1964. The total construction cost of the project is estimated at $55,000,000. This includes both the escalation and contingency figures.