ACCELERATOR PERFORMANCE DEMONSTRATION FACILITY IN LOS ALAMOS*

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ABSTRACT

The Accelerator Performance Demonstration Facility is proposed as a prototype of the first 40-MeV of an accelerator that is useful for Accelerator-Driven Transmutation Technologies. The facility will be used to gain operational experience and to demonstrate reliability, availability, and maintainability of components and system. In this paper, the conceptual design of the facility will be presented. The R&D programs to develop high-current proton sources and a high-energy RFQ will also be introduced.

INTRODUCTION

During recent years, high-power proton accelerators have been proposed as drivers for the spallation neutron sources for various applications. These applications include the transmutation of waste, production of tritium, and the disposition of weapon plutonium, collectively referred to as the Accelerator-Driven Transmutation Technologies (ADTT) [1]. They require a CW proton accelerator, nominally at 1 GeV with a current up to 200 mA and with high reliability and availability.

An accelerator useful for ADTT application has been proposed for the Accelerator Production of Tritium (APT) Project. The APT-accelerator design [2], although well received in various design reviews, is technically challenging and is a large extrapolation in terms of beam power from any existing proton accelerator. To date, the highest average-power proton accelerator is the Los Alamos Meson Physics Facility (LAMPF) at 1 MW. There are no operation data on machines at a power level of hundreds of megawatts like the APT accelerator. The accelerator's reliability and availability need to be demonstrated.

Los Alamos National Laboratory has proposed to build the Accelerator Performance Demonstration Facility (APDF), which is the front-end prototype of the first 40-MeV of the APT accelerator. The goal is to gain experience operating a high-current CW accelerator. The facility will evaluate the engineering and operational aspects of the design as well as the reliability, availability, and maintainability of the components and system. APDF will also develop funnel technology and will establish beam performance and benchmark simulations.

The conceptual design of APDF has been completed and documentation is being prepared. Because of limitation of space, this paper describes the conceptual design briefly with minimum figures. More detailed description can be found in Ref. 3.

DESCRIPTION

Figure 1 shows a schematic of the APDF accelerator. It consists of two identical 20-MeV, 350-MHz linacs, each generating a CW proton beam of 100 mA. Each of these 20-MeV linacs has an ECR ion source, a low-energy beam transport (LEBT), a radio-frequency quadrupole (RFQ) accelerator, a drift-tube linac (DTL), and a matching section between the RFQ and the DTL. The two beams are combined (funneled) together at 20 MeV and further accelerated to 40 MeV in a 700-MHz bridge-coupled drift-tube linac (BCDTL).
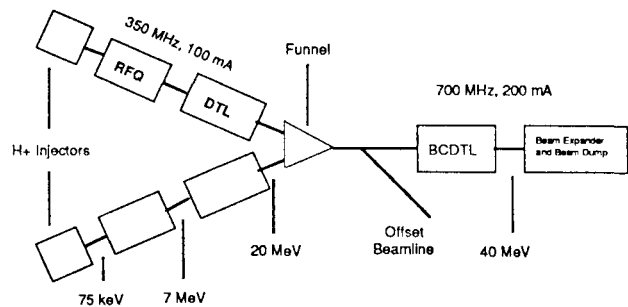

Figure 1:   A schematic of the APDF

The APDF accelerator has been designed without discontinuities in the transverse and longitudinal focusing. This design enables acceleration of beams from zero to full current using the same tune and without any beam loss. This current-independent feature simplifies the accelerator startup and increases system tolerance to beam fluctuations. The APDF design incorporates numerous beam diagnostics to assure the beam is matched to the accelerator throughout the system.

APDF INJECTOR

Each APDF Injector consists of an ECR source and a low-energy beam transport (LEBT). The source is designed to operate at 75 keV and to provide more than 110 mA at the RFQ input. The design normalized rms emittance is less than 0.02 π-cm-mr with a beam fluctuation of less than 1% at 1-MHz bandwidth. For beam commissioning and reliable beam turnon, the CW ion source will have pulsing capability. The LEBT is instrumented with non-interceptive beam diagnostics. Two solenoids in the LEBT will be used to provide the proper match needed for the RFQ. The system has been designed with automatic-fault recovery, variable-current operation, and beam interrupt systems.

The design of the APDF Injector has been completed and a prototype built. An experimental program to study the reliability and stability of this injector is now in progress. [4].

RFQ

The APDF RFQ is an 8-m long RFQ accelerating the beam to 7 MeV and is the longest RFQ ever proposed [5]. The high energy of the RFQ is chosen for two reasons. First, the transverse focusing strength of the RFQ is better matched to the DTL at higher energy allowing for a current-independent accelerator design. Second, the longitudinal $\beta\lambda$ is longer at higher energy allowing more space in the RFQ-DTL matching section for diagnostics and the use of electromagnetic quadrupoles.

Because of the high multiplicity of modes and their spacing in a long RFQ, it will be difficult to tune and to obtain the required field uniformity. This issue is being addressed by coupling four 2-m long RFQs to form the needed 8-m. The concept of resonantly coupled RFQ has been recently verified with a full-scale cold model [6]. A field uniformity better than 2% with a dipole component less than 2% has been obtained. The mode spectra for the quadrupole and dipole modes show mode separation of better than 2 MHz around the operating mode. The cold model is currently used to investigate the possibility of waveguide coupling to the RFQ. If successful, the complication in using multiple coupling loops can be eliminated.

Building a long RFQ can be expensive and time consuming using the conventional method of electroforming. A Fabrication Development Program [7] to investigate fabrication of RFQs using hydrogen-furnace brazing as a joining technique has recently been successfully completed. Under this program, it was demonstrated that the required alignment tolerances, vacuum integrity, and structural properties could be achieved and the performance, cost, and schedule can be reliably predicted.

RFQ-DTL MATCHING SECTION

The RFQ-DTL matching section matches the beam between the RFQ and DTL. The DTL quadrupole gradients and accelerating gradients are chosen to match the RFQ output focusing strength. The matching section is designed to have a focusing lattice that is an extension of the DTL and RFQ focusing lattice to achieve a current-independent design [8]. The matching section has been equipped with diagnostic to monitor the current, centroid position, and profile of the beam to insure that the optimum beam characteristics exist at the RFQ output.

DRIFT-TUBE LINAC (DTL)

The DTL design is in an advanced design stage [2]. There are three DTL modules on each leg of the funnel. Each tank is designed to be driven by an 1-MW klystron station. The drift tubes are girder mounted for ease of alignment and repair. They have knife-edged RF seals and flex-membranes with the tank wall for CW operation. The drift tubes contain radiation-hardened EMQ's for reliability and adjustability.

As with all CW room-temperature accelerator systems, temperature control and thus resonant-frequency control of the module is critical and difficult. A constant-flow system is used with the DTLs with the maximum temperature differential kept to less than 10°C. Thermal stress analysis has been completed showing no serious problem expected.

FUNNEL

The funnel is used to merge two beams at 20 MeV. This scheme halves the beam intensity at low energies where space charge forces are strongest and most detrimental to beam quality. The funnel also serves to match the beams emerging from each DTL section to the BCDTL. An extensive effort was required to design the funnel with all the required elements, including bunchers, quadrupoles, and diagnostics, within the severely constrained physical envelope. Beam diagnostics is crucial to characterize the beam throughout the funnel and maintain the beam emittance in this extremely critical region.

There are two special rf cavities in the funnel. They are the two-beam buncher and the deflector cavity. With two beams going through these cavities, their electromagnetic field distributions do not have axial symmetry. Both cavities have high thermal losses and significant cooling is required to keep them in tune. Detailed calculation was performed with 3-D codes because of the lack of axial symmetry. MAFIA codes have been used to calculate the electromagnetic fields and the thermal loads. These load data are then transferred to an engineering code, ABAQUS, to calculate the thermal distribution and stresses. Results show that the cooling designs in these cavities are adequate [10].

BRIDGE COUPLED DRIFT-TUBE LINAC (BCDTL)

BCDTL [2] is the type of accelerating structure chosen to accelerate the beam from 20 to 40 MeV. Seven-$\beta\lambda$ long drift-tube tanks are bridge-coupled together over intervening 5-$\beta\lambda$ gaps that carry the quad doublets. With no quadrupoles in the drift tube, the BCDTL structures are relatively easy to build. The bores of the drift tubes can be increased to 4-cm diameter. The alignment of the drift tubes is no longer particularly critical. The drift-tube can be hard-socketed to the tank wall to provide good rf seal.

Recently, a new structure, Coupled-Cavity Drift-Tube Linac (CCDTL), has been proposed. This type of structure is expected to be much less sensitive to tuning errors than BCDTL structure. It is presently under study and cold-model test is being planned [11].

RF SYSTEM

There will be four basic types of rf-power modules. First, each RFQ will be powered by a module that has two 350-MHz

1.1-MW klystrons. Second, each DTL tank will be powered by a module that has one 350-MHz 1.1-MW klystron. Third, the BCDTL tank will be powered by modules that has one 700-MHz 1.1 MW klystron. These modules, because of restriction on available electric power on site, will be pulsed at 6% duty factor. Fourth, the buncher cavities will be powered by modules that have 700-MHz, 50-kW klystrodes.

The rf-field stability will be maintained with feedback and feedforward control. With the accelerator heavily beam loaded, beam current fluctuation is a major disturbance to the rf fields. In the APDF rf control system, the beam current fluctuation will be detected early upstream and fed to rf generator downstream to anticipate the current induced rf fields. This "feedforward" control is possible because the beam bunches are nonrelativistic. In addition, the feedforward control will have automatic gain control such that operator intervention will be minimized [12].

To maintain a regular periodicity of the focusing lattice for current independence, the rf power needed for accelerator module varies. Subsequently, the klystron efficiency is reduced because it is not operated in maximum design power. Simulation and experiments [13] have been carried out to understand klystron efficiency at reduced power under various operation conditions. Results show that lowering output power by decreasing both the beam voltage and beam current while maintaining a constant beam impedance has the least impact on efficiency. The next desirable way is to reduce the output power by only reducing the beam current and maintaining the same voltage. This way has the advantage of having one operating voltage for all klystrons. Both of the above methods compare favorably to decreasing output power by lowering drive power.

BEAM DIAGNOSTICS

The beam turnon and commissioning procedures have a great impact on accelerator design, particularly the placement of diagnostics. A beam turnon procedure, modeled after the procedure presently employed at LAMPF, has been proposed. To minimize the hazard of equipment damage, the beam will be operated initially at low duty factor and low current and will then be increased gradually to the design operating condition. The diagnostics [14] required are:
– radiation monitors and current monitors to detect unexpected beam spill for equipment protection.
– microstrip probes and steerers to keep beam on axis
– current monitor to measure beam transmission through the RFQ.
– beam energy monitored using phase-scan and time-of-flight method and adjusted by amplitudes and phases of rf cavities
– transverse tune monitored by measuring beam profiles with beam profile monitors and adjusted with quadrupoles
– longitudinal beam width monitored by measuring higher harmonic signals in microstrip probes and adjusted by changing buncher amplitudes
– beam emittance measured at offset beamline

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