OVERVIEW OF THE APT ACCELERATOR DESIGN*

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Abstract

The accelerator for the Accelerator Production of Tritium (APT) Project is a 100-mA continuous-wave (cw) proton linac with an output energy of 1030 or 1700 MeV, depending on the tritium-production capacity that is needed. A high-energy beam transport (HEBT) system conveys the beam to a raster expander, which provides a large-area rectangular power distribution at a target/blanket assembly. Spallation neutrons generated by the beam in the target/blanket are absorbed in Helium-3 to produce tritium. The APT linac has an integrated normal-conducting (NC)/ superconducting (SC) design; the machine architecture, beam dynamics, performance issues, and the supporting engineering-development-and-demonstration program have been discussed elsewhere [1, 2, 3]. The NC linac consists of a 75-keV injector, a 6.7-MeV, 350-MHz radiofrequency quadrupole (RFQ), a 96-MeV, 700-MHz coupled-cavity drift-tube linac (CCDTL), and a 700-MHz coupled-cavity linac (CCL), with an output energy of 211 MeV. This system is followed by a SC linac that employs 700-MHz elliptical-type niobium 5-cell cavities to accelerate the beam to the final energy. The SC linac is built in two sections, using cavities optimised at β = 0.64 and 0.82. Each section is made up of cryomodules containing two, three, or four five-cell cavities, driven by 1-MW, 700-MHz klystrons. An overview of the current linac design is presented.

1 INTRODUCTION

Figure 1 shows the architecture of the APT plant. The APT linac begins with a normal-conducting low energy (LE) linac, which generates the cw proton beam in a 75-KeV injector and continues the acceleration through a RFQ, a CCDTL, and a CCL to 211 MeV. This is followed by a superconducting high energy (HE) linac that accelerates the beam to full energy. The HE linac is divided into two sections. The first is a medium-β section that has 102 five-cell niobium cavities optimized for β = 0.64. At the end of this section, the proton beam energy is 471 MeV. The second is a high-β section that has five-cell niobium cavities optimized for β = 0.82. To attain an output energy of 1030 MeV, 140 cavities are needed; an additional 140 cavities are required to reach 1700 MeV. As shown in Figure 1, the HEBT configuration changes depending on the output energy of the accelerator. The HEBT transports the beam and then expands it to a large-area footprint at the target/blanket or conveys it to a 2% power tuning beam stop.

2 ACCELERATOR DESIGN

The following sections describe the design of the various stages of the APT Linac.

2.1 Normal-Conducting Low Energy Linac

The LE linac consists of the injector, a 350-MHz RFQ, a 700-MHz CCDTL, and a 700-MHz CCL.

2.1.2 Injector

The 2.8-m long injector[4] has a radio frequency (RF)-driven ion source that produces a 110-mA cw proton beam at 75 keV. A low energy beam transport that has two solenoid magnets matches the proton beam into the acceptance of the RFQ.

2.1.2 Radio Frequency Quadrupole

The RFQ[5] is an eight-meter long structure built of four resonantly coupled segments tuned for 350 MHz. The RFQ accepts the 75-keV, 110-mA beam from the injector and produces a 6.7-MeV, 100-mA beam. It is driven by three 1.2-MW klystrons.

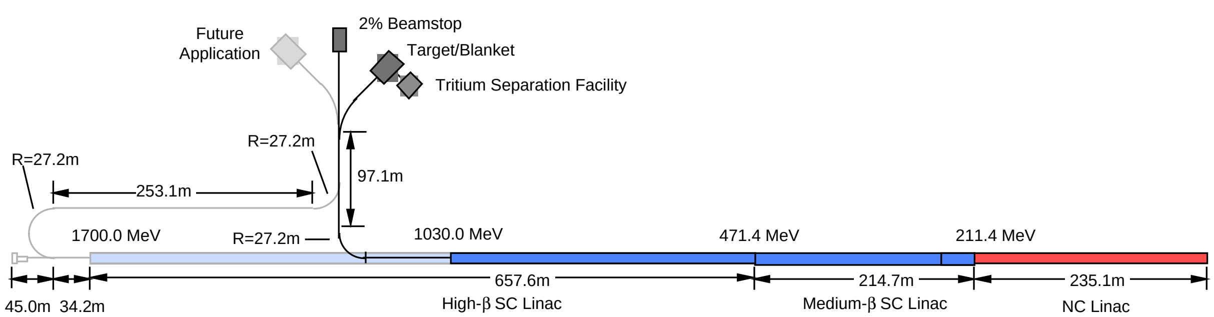

Figure 1: Architecture for APT plant.

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2.1.3 Coupled Cavity Drift Tube Linac

A 700-MHz CCDTL[6] accepts the 100-mA beam from the RFQ and accelerates it to 96 MeV. The CCDTL cavities are grouped into six resonant structures called supermodules that span a length of 112.8 m. The first supermodule consists of a series of side-coupled 2-gap drift tube linac (DTL) cavities with the quadrupole magnets of the FODO lattice located between them. The focusing lattice begins with a period of 8-βλ to match the beam from the RFQ and transitions to 9-βλ at 9 MeV to provide additional space for the quadrupole magnets and beam diagnostics. Module two is made up of DTL cavities with two drift tubes, forming a series of three-gap cavities connected by coupling cells. Modules 3 to 6 consist of two-cavity, two-gap segments. To maintain strong transverse focusing, the quadrupole magnets[7] in the FODO lattice continue with the same 9-βλ periodicity. The first module is energised by a single 1-MW klystron. The other five supermodules are energised by up to five klystrons.

2.1.4 Coupled Cavity Linac

The CCL is composed of five supermodules spanning a length of 110.4 m. Each is made up of a string of seven-cell segments side-coupled to form a single resonant structure energised by up to seven 1-MW klystrons. The singlet 9-βλ FODO lattice is continued throughout the CCL.

2.2 Superconducting High Energy Linac

The superconducting cavities of the HE linac are contained in cryomodules that provide the thermal insulation and connection to the cryogenics system to maintain the cavities at their operating temperature of 2.15 K. The FODO lattice of the LE linac transitions to a doublet lattice in the HE linac. The normal-conducting quadrupole magnets[8] are located in the warm regions between the cryomodules. To improve the match from the LE linac, the first six cryomodules in the medium-β section contain two cavities each, providing a relatively short 4.877-m focusing period. The remaining 30 cryomodules in the medium-β section contain three cavities each, with a longer 6.181-m focusing period. Each cryomodule in the medium-β section is powered by a single 1-MW klystron. Each cavity is fed by a pair of RF power couplers, so that the RF power from each klystron is divided by four or six, with up to 210 kW per coupler.

The high-β section is a series of four-cavity cryo-modules with the room temperature quadrupole magnets in the warm regions between the cryomodules continuing the doublet lattice with a period of 8.540 m. The quantity of cryomodules in this section is determined by the ultimate proton beam energy needed to achieve the production requirements of the APT plant. This can range from 35 cryomodules at 1030 MeV to 77 at 1700 MeV. Each high-β cryomodule is powered by two 700- MHz klystrons. The power is divided equally between two cavities, and again by two to feed the two power couplers on each cavity. Figure 2 depicts the tunnel in the medium-β section of the high energy linac, showing the RF power splitting to the three-cavity cryomodules and the quadrupole doublets between the cryomodules.

Figure 2: HE linac tunnel section.

2.3 High Energy Beam Transport

The doublet lattice of the HE linac is continued along the transport line of the HEBT. A beam stop capable of handling 2% of the beam power is located at the end of the beam transport line. It is used during commissioning, start up, and tuning of the accelerator. A 45° bend in the switchyard directs the beam from this beam stop to the target/blanket assembly. The beam is expanded onto the target by a beam raster system[9], which sweeps the beam uniformly over the 19-cm wide by 190-cm high tungsten target.

2.4 RF Power Systems

Three 1.2-MW, 350-MHz klystrons are used to energise the RFQ. Only two are required to accelerate the beam in the RFQ; the third is a spare so that the linac can continue to operate if one of the 350-MHz RF power systems fails. The power from each klystron is split by four, feeding twelve iris couplers in the RFQ cavity.

The supermodules in the LE linac and the superconducting cavities in the HE linac are powered by 1-MW, 700-MHz klystrons. There are 52 klystrons in the LE linac, 36 klystrons in the medium-β section of the HE linac, and up to 154 klystrons in the high-β section of the HE linac.

The architecture of the APT linac is configured so that the failure of an RF power system does not result in the loss of production of tritium while it is being repaired.[10] The supermodules in the LE linac, except for the first supermodule of the CCDTL, are fed by one more klystron than is required to accelerate the beam. Should one of the RF systems that feed these supermodules fail, it is isolated from the supermodule and the RF power output from the remaining operating klystrons is increased to compensate for the RF power lost from the failed klystron. The first supermodule is fed by a single klystron, with a standby unit that can be switched in, if necessary. The RF power systems for the HE linac will normally be operated at a reduced power level, so that if one fails, the affected cavity is detuned and the power from adjacent RF systems is increased to make up for the failed system. The RF power systems in the medium-β section normally operate at 91% of their rated power and 95% in the high-β section. Figure 3 shows a portion of the klystron gallery and tunnel with layouts for the RFQ, the start of the CCDTL, and a two-cavity cryomodule.

2.5 *Cryogenic System*

The cryogenic system supplies helium cooling to maintain the niobium cavities at 2.15 K. It will provide approximately 15 kW of refrigeration at 2.15 K for the superconducting RF cavities and approximately 50 kW of refrigeration between 5 K and 30 K for the thermal intercepts on the RF power couplers and thermal shields in the cryomodules and the cryo-distribution system. There is a cryogenic distribution line containing two sets of supply and return lines that runs the length of the HE linac. Sets of four U-tube transfer lines connect each cryomodule to this distribution line. The distribution line is supplied by a cryogenics plant where multiple, semi-independent helium refrigerators provide the closed-loop helium cooling. Each refrigerator contains a 4-K coldbox using gas-bearing turbine expanders, a 2-K coldbox with cold compressors to generate the sub-atmospheric conditions within the cryomodule, warm helium compressors for gas compression, liquid and gas storage, and appropriate instrumentation and controls.

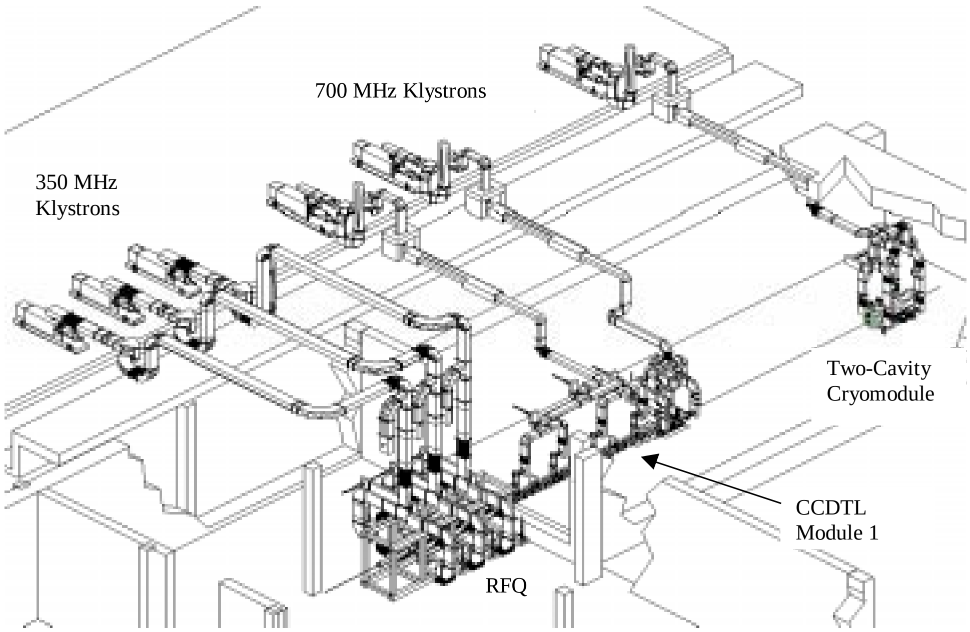

Figure 3: Portion of klystron gallery and tunnel showing various RF layouts along linac.

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