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AN OVERVIEW OF THE LOW ENERGY
DEMONSTRATION ACCELERATOR (LEDA)
PROJECT RF (RADIO FREQUENCY) SYSTEMS

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AN OVERVIEW OF THE LOW ENERGY DEMONSTRATION ACCELERATOR (LEDA) PROJECT RF SYSTEMS*

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Abstract

Successful operation of the Accelerator Production of Tritium (APT) plant will require that accelerator downtime be kept to an absolute minimum. Over 230 separate 1 MW RF systems are expected to be used in the APT plant, making the efficiency and reliability of these systems two of the most critical factors in plant operation. The Low Energy Demonstration Accelerator (LEDA) being constructed at Los Alamos National Laboratory will serve as the prototype for APT. The design of the RF systems used in LEDA has been driven by the need for high efficiency and extremely high system reliability. We present details of the high voltage power supply and transmitter systems as well as detailed descriptions of the waveguide layout between the klystrons and the accelerating cavities. The first stage of LEDA operations will use four 1.2 MW klystrons to test the RFQ and supply power to one test stand. The RFQ will serve as a power combiner for multiple RF systems. We present some of the unique challenges expected in the use of this concept.

1 INTRODUCTION

The purpose of the LEDA accelerator is twofold. The LEDA accelerator shall validate and demonstrate the front end design of the APT accelerator and shall also serve as a test bed for different accelerator component designs that are competing for use in the APT plant. Each major high-power RF sub-system is described, proceeding from the unit substation which supplies power to the accelerator up to the accelerating cavities.

2 HIGH VOLTAGE POWER SUPPLIES

The high voltage power supply sub-systems convert the AC line voltage from the unit-substation to DC voltages of up to 95 kV which are supplied to the klystrons through the transmitter sub-system. Each power supply must be capable of delivering 2 MW (21 A at 95 kV) to a 350 MHz klystron to produce 1.2 MW of RF power. Power supplies using two different topologies are currently being built for use in LEDA. The design of the power supplies purchased for LEDA has been dictated by the operational requirements of the final APT plant. The plant driven requirements on reliability, cost of operation and cost and time to repair are quite stringent given that over 230 power supplies will be used in the APT plant.

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2.1 SCR Controlled Center Tapped Power Supply

SCR controlled power supplies are being built by Maxwell Laboratories for use in the LEDA accelerator. These supplies utilize an SCR bridge which regulates the current through the center tapped transformer primaries to control the secondary output voltage as shown in Fig. 1. Center point control allows the output voltage filter inductance to be placed across the SCR bridge on the low voltage side of the transformer. This placement offers several advantages. The reduction in the filter inductor operating voltage gives increased reliability and reduces cost. The lower voltage also allows an SCR to be placed across the inductor to short out and dissipate the energy stored in the filter inductor in the event of a klystron arc.

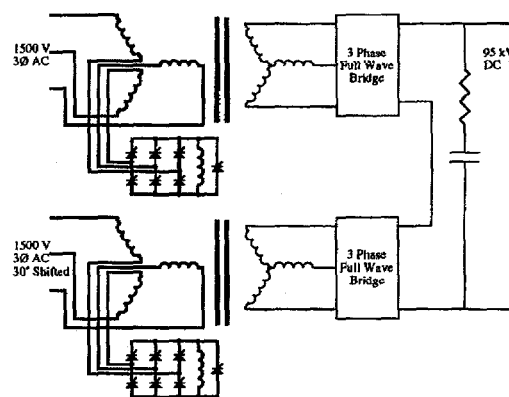


Figure: 1 Secondary voltage is controlled by SCR bridges located in the centers of the transformer primaries.

Two sources of 1500 V, 3-phase power are supplied by the unit-substation. Figure 1 illustrates how one set of 3 phase power is offset by 30° with respect to the other set to produce 12-pulse rectification from two 6-pulse rectifiers whose outputs are wired in series.

The SCR controller and transformer/rectifier sub-units shown in Fig. 1 are located outside the main accelerator building adjacent to the unit-substation. The third sub-unit of the power supply contains the ripple voltage filter capacitor and crowbar circuits. This sub-unit is located inside the accelerator building and adjacent to the klystron. In the event of a klystron arc, the crowbar circuit protects the klystron from stored energy in the filter capacitor and in the power supply cables and from any power supply follow-through energy which enters the tube before the SCRs shut off the current.

2.2 IGBT Controlled SSM Style Power Supply

The second power supply type being built for LEDA is the Insulated Gate Bipolar Transistor (IGBT) controlled Solid State Modulator (SSM) style power supply made by Continental Electronics. The power supply design is based on the Solid State Modulators that are currently produced for AM radio service. Figure 2 shows how these supplies utilize 96 separate rectifying modules wired in series to produce high voltage. The relative phase differences between the sets of 3-phase secondaries on each of the four transformers are arranged to achieve 24-pulse rectification at the output.

A schematic of a single module is illustrated in Fig. 3. Each module contains a full wave, 3 phase rectifying bridge which produces 1.1 kV DC across a small filter capacitor. An IGBT is used to switch the filter capacitor across the output terminals of the module. A diode allows current produced by other modules to pass when the IGBT is turned off.

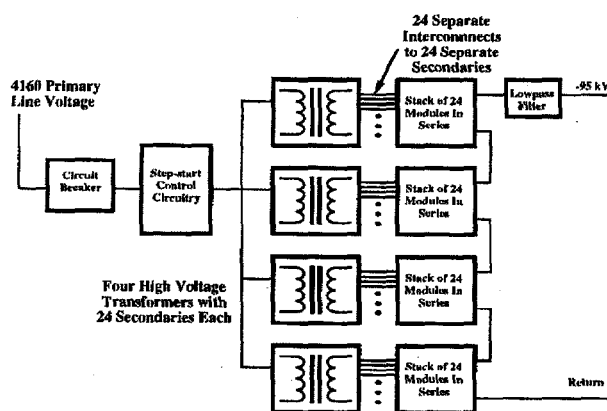


Figure: 2 The secondaries of the HV transformers are arranged to produce 24 pulse rectification.

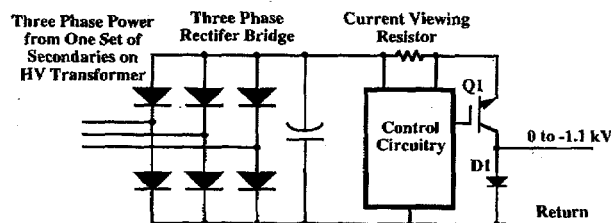


Figure: 3 Each module contains a 3-phase, full wave rectifying bridge.

The IGBT controlled SSM Power Supply has several strengths, the most important being that the fast response of the IGBTs allows the supply to turn off quickly enough to limit the energy in a klystron arc without the use of a crowbar circuit. The elimination of the crowbar circuit reduces power supply cost and increases reliability. A sophisticated diagnostic system allows graceful degradation of the power supply output capability by disabling a failed module or modules and compensating with the remaining modules. The supply also offers an extremely high efficiency (>97%) and

power factor (>0.98). These will be critical factors in the operating costs of the APT plant.

3 TRANSMITTERS

The transmitter provides support functions for the klystron. These functions include: klystron magnet power, a solid-state RF drive amplifier and klystron interlocks. The transmitter also includes a cathode referenced voltage source that provides variable high voltage to the modulating anode of the klystron. The modulating anode voltage is derived from and referenced to the cathode voltage as shown in Fig. 4 in order to reduce the tendency for cathode voltage ripple to cause ripple on the RF output of the klystron. Ripple on the klystron RF output power can complicate accelerator phase control issues [1].

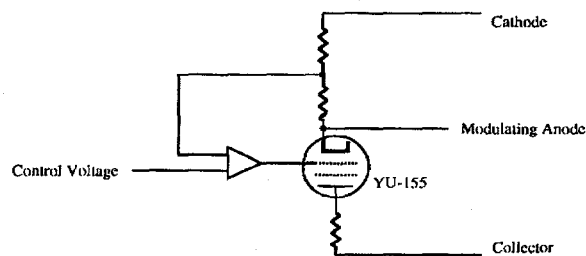


Figure: 4 The modulating anode voltage is derived from the cathode voltage to eliminate the affect of power supply voltage ripple on the klystron current.

4 KLYSTRON AMPLIFIERS

The RFQ is driven by 350 MHz klystrons made by BEV Ltd. Figure 5 shows how these klystrons employ a coaxial RF window to transition from the tube to WR2300 waveguide. The klystron RF windows are similar to the RF windows used at the accelerator [2]. The klystron collector is rated to absorb the full 2 MW of klystron beam power. A full power collector was chosen to allow the RF output power to be shut off quickly (by removing the RF drive) without causing a massive disruption in the amount of electrical power used by the accelerator. The use of a full power collector was motivated by the fact that discontinuities in the power drawn by the accelerator will be a major challenge in the successful operation of the APT plant with the rest of the regional power grid.



Figure: 5 Each 350 MHz klystron is capable of producing 1.2 MW of RF power.

5 CIRCULATORS

350 MHz Y-junction circulators shown in Fig. 6 have been built by AFT for the LEDA project. These circulators are rated to operate into a full-reflection standing wave with the worst-case phase for the circulator while 1.3 MW of RF power is being transmitted by the klystron.

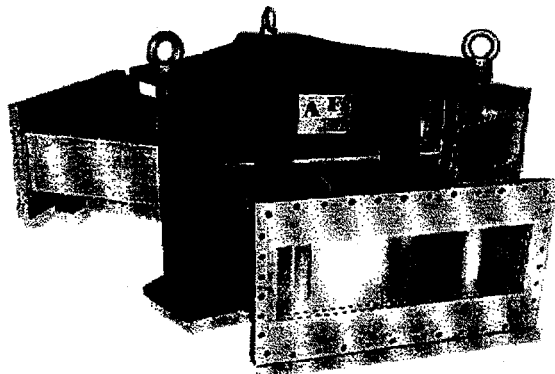


Figure: 6 350 MHz circulators protect each klystron from reflected RF power.

6 WAVEGUIDE RUNS

Three separate WR2300 waveguide runs are used to transport the RF power produced by three 350 MHz klystrons on the mezzanine to the twelve RF windows on the RFQ located in the adjacent tunnel [2].

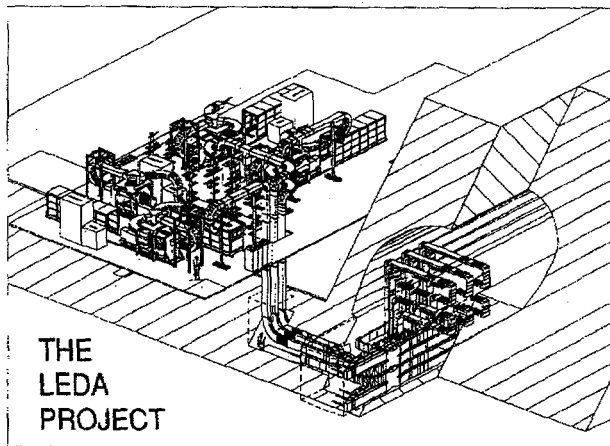


Figure: 7 Three separate WR2300 waveguide runs deliver RF power to the RFQ located in the beam tunnel.

Each waveguide run consists of 64.6 m of WR2300 waveguide as shown in Fig. 7. The three waveguide run lengths have been equalized as much as possible in order to reduce the demands on the three-probe phase shifters and Low Level RF control systems as the waveguide expands and contracts with temperature [1].

7 HIGH-POWER RF WINDOWS

The RF power produced by the klystrons is divided into four equal parts to minimize the stress on the vacuum RF windows at the RFQ [2]. The RFQ portion of the accelerator requires 1.96 MW of RF power, but 3 MW of RF power must be available to implement the supermodule concept as described in Section 9. Half-height WR2300 waveguide is used for the last 22 m of the waveguide run to minimize the space occupied by waveguide. The RFQ portion of the accelerator achieves an RF power per accelerator length of 245 kW / meter.

8 ACCELERATING CAVITIES

An RFQ and various CCDTL configurations will be used throughout the LEDA program. The CCDTL sections will be driven by 700 MHz RF systems which are very similar to the 350 MHz RF systems and will be fully described in a later paper. The first LEDA configuration is shown in Fig. 8. It will test the injector and RFQ and accelerates 100 mA to 6.7 MeV.

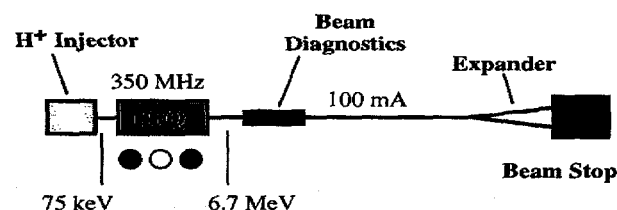


Figure: 8 The initial configuration of the LEDA accelerator will consist of the injector and the RFQ.

9 SUPERMODULE OPERATION

The RFQ portion of the accelerator achieves high reliability through the use of the supermodule concept [3]. In this concept, the RFQ is used as a power combiner for 3 RF systems. Each of these systems is capable of producing 1.2 MW of RF power. If one RF system fails, the accelerator is shut down briefly. The other two RF systems are brought to full power and the accelerator resumes operation. This capability is indicated in Fig. 8 where the three circles below the RFQ represent the three RF systems and filled circles represent the minimum number of RF systems that are required to operate.

REFERENCES

- [1] A. Regan, *et. al.*: "APT LLRF Control System Model Results", to be presented at this conference.
- [2] K. Cummings, *et. al.*: "Experimental Evaluation Of 350 MHz RF Accelerator Windows For The Low Energy Demonstration Accelerator", to be presented at this conference.
- [3] D. Rees, *et. al.*: "Design of 250-MW CW RF System for APT", to be presented at this conference.