A 700 MHz, 1 MW CW RF SYSTEM FOR A FEL 100 MA RF PHOTOINJECTOR*

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Abstract

This paper describes a 700 MHz, 1 Megawatt continuous wave (CW), high efficiency klystron RF system utilized for a Free Electron Laser (FEL) high-brightness electron photoinjector (PI) [1,2]. The E2V klystron is a mod-anode tube that operates with a beam voltage of 95 kV. This klystron, operating with a 66% efficiency, requires ~96 watts of input power to produce 1007 kW output. This output drives the 3rd cell of a 2 cell, π-mode cavity. Coupling is via a ridge-loaded tapered waveguide section and "dog-bone" iris. This paper will present the design of the RF, RF transport, coupling, and monitoring/protection systems that are required to support CW operations of the 100 mA cesiated, semi-porous SiC photoinjector.

RF SYSTEM

The RF system, providing 1 Megawatt of CW power to the normal-conducting RF (NCRF) photoinjector is a modification of a 700 MHz Low Energy Demonstration Accelerator (LEDA) test stand. The LEDA RF systems [3,4], which were prototypes for the full Accelerator for Production of Tritium (APT) project, have been demonstrated to provide high efficiency and reliability. This LEDA RF equipment, located at Los Alamos National Laboratory (LANL), was previously operated as a test stand for the individual components as well as a test of the overall CW RF system. This existing 700 MHz test stand is being connected to the 100 mA normal conducting RF photoinjector to deliver up to 1 Megawatt of continuous wave RF power. For the LEDA 700 MHz RF test stand system to be adapted for the FEL photoinjector tests, several modifications were performed and tested. A complete system checkout of individual components, subsystems, interlocks, diagnostics, as well as the overall system operation into a dummy load, were required. The components of the RF system are described here in more detail.

700 MHz Klystron

The 700 MHz klystron has a nominal output power of 1.0 MW CW at a minimum DC-to-RF conversion efficiency of 65%[5]. The maximum beam voltage is 95 kV and nominal beam current is 17 A (21 A Max.). The klystron was designed with a modulating anode and a large collector designed to dissipate the full CW beam. The 700 MHz klystron in the K0 test stand was developed by English Electric Valve (EEV). This klystron vendor is now known as E2V. This klystron has demonstrated that it operated at the vendor's test stand and at full power into a 1.2:1 VSWR mismatch on the LEDA test stand. A table showing the klystron requirements is shown in Table 1:

Table 1: 700 MHz Klystron Requirements

Cathode Voltage	95 kV (Max.)
Beam Current	21 A (Max.)
Output Power	1.0 MW (Nominal)
Test Power	1.1 MW
Gain	40 dB (Min.)
Efficiency	65 % (Min.)
1 dB Bandwidth	+/- .7 MHz
Collector Dissipation	Full Beam Power
VSWR Tolerance	1.2:1 (Max. at any phase)
Modulating Anode	Yes

High Voltage Power Supply (HVPS)

The RF system's high voltage power supply is a Silicon Controlled Rectifier (SCR) controlled power supply built by Maxwell Laboratories for use in the LEDA accelerator [6]. LEDA has four of these fully operational power supplies. Three of these power supplies are used with the 350 MHz,1.2 Megawatt CW RF systems that delivered RF power to the LEDA Radio Frequency Quadrupole (RFQ). The fourth Maxwell power supply, a subsystem of K0, now supplies a 700 MHz, 1 Megawatt CW klystron.

The high-voltage power supply's subsystems convert the AC line voltage from the unit-substation to DC voltages up to 95 kV. Through the transmitter subsystem, the high voltage power supply can deliver 95 kV, 21A (2 MW) to a 700 MHz klystron to produce 1 Megawatt of RF power.

LEDA used two different topologies of power supplies. In addition to the Maxwell SCR controlled power supplies, two Insulated Gate Bipolar Transistor (IGBT) controlled Solid State Modulator (SSM) power supplies, built by Continental Electronics, were delivered and operated at LANL. These two IGBT power supplies were used on 700 MHz test stand RF systems, which were two. Because both types of high voltage power supply demonstrated efficient and reliable performance with the LEDA 700 MHz CW klystrons, either HVPS topology could be used on K0 RF System for the FEL NCRF photoinjector testing.

Operational experience showed that reliability of the Maxwell Laboratories SCR controlled power supply and the Continental Electronics IGBT controlled power supplies were equivalent. Both power supplies had their

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advantages and disadvantages when compared to one another. However, since there was no strong reason to replace the Maxwell SCR controlled HVPS with the Continental Electronics IGBT controlled HVPS, the K0 700 MHz RF system remained operating with the preexisting Maxwell SCR controlled HVPS.

The Maxwell SCR controlled power supply has three subsystems: SCR Controller Cabinet, Transformer/Rectifier (TR) Tank, and the Crowbar/Filter Cabinet as shown in Figure 1. The HVPS utilizes an SCR bridge which regulates the current through the center tapped transformer primaries to control the secondary output voltage. Center point control allows the output voltage filter inductance to be placed across the SCR bridge on the low voltage side of the transformer, which reduces the filter inductor operating voltage. An SCR placed across the inductor is used to dissipate the energy stored within the filter inductor in the event of a klystron arc.

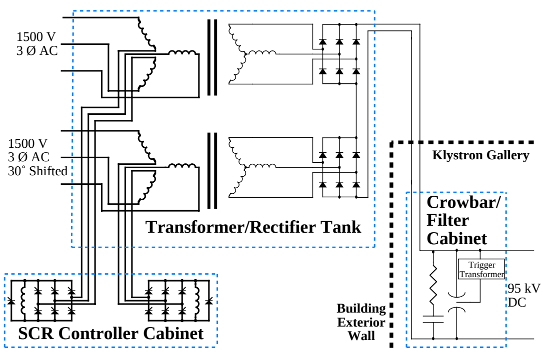

Figure: 1: Schematic of the Maxwell High Voltage Power Supply.

Two sources of 1500 V, 3-phase power are supplied by the unit-substation. 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 TR and SCR controller sub-units are separate from the klystron, while the Crowbar/Filter sub-unit is located in the klystron gallery near the klystron. In the event of a klystron arc, the crowbar circuit protects the klystron from stored energy in the filter capacitor and from any power supply follow-though energy.

Transmitter

The transmitter provides support functions for the klystron. These functions include user interface, klystron magnet power, a solid-state RF drive amplifier, and klystron interlocks. The transmitter also includes a filament transformer and a cathode referenced voltage source that provides variable high voltage to the modulating anode of the klystron. The transmitter [3] was originally built by Continental Electronics for LEDA. It served the K0 test stand when it had a 350 MHz klystron and was modified slightly when K0 was converted to a 700 MHz test stand.

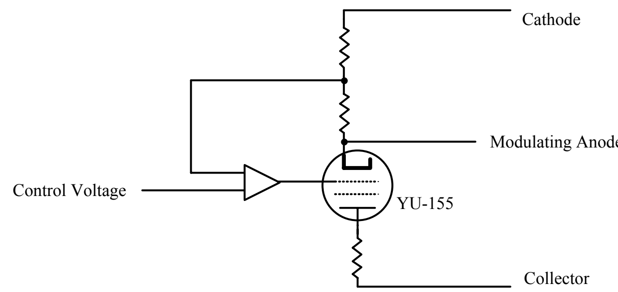

Figure: 2: Schematic of the Continental Electronics Modulating Anode voltage divider that reduces the effect of power supply ripple on the klystron current.

The modulating anode voltage and cathode voltage circuit is shown in Figure 2. The modulating anode voltage is derived from and referenced to the cathode voltage to reduce the effect of the power supply ripple on the beam current and the RF output of the klystron.

RF Transport

Originally the 700 MHz test stand was in a local testing area which was adjacent, but separate, from the LEDA accelerator tunnel. The entire 700 MHz test stand was located in the klystron gallery of the LEDA building. The LEDA tunnel, which previously housed the LEDA accelerator, now contains the FEL photoinjector test bed. With the LEDA WR2300 and WR1500 waveguide removed, a single WR1500 waveguide run was routed through the waveguide basement, down and up vertical shafts, and through a tunnel floor penetration opening and into the LEDA accelerator tunnel. The power is split by a 3 dB short slot hybrid and delivered to the experiment through two equal phase matched waveguides. The interface between the RF transport system and the photoinjector vacuum structure is made through two water-cooled 700 MHz RF windows, one on each waveguide run. These windows [7] are L band alumina disks assembled in WR1500 waveguide. These windows were designed at Lawrence Berkeley National Laboratory (LBNL) and were based on the PEP-II window design. They were built as a LBNL/LANL collaboration and tested high-power tested at LANL on the 700 MHz window lifetime test stand for over 300 hours at 700 kW CW [8].

Coupling

Within the vacuum envelope, the RF power drives the 3rd cell of a 2 cell, π-mode cavity [9]. The RF windows are connected to a pair of ridge-loaded tapered waveguide sections with "dog-bone" style of irises for optimal coupling. These coupling irises are comprised of long narrow slots with two circular holes at the ends. The design of these irises came from LEDA RFQ and SNS high-power RF couplers.

Shown in Figure 3 is a schematic of the 2 cell RF cavity with the two symmetrically placed ridge-loaded tapered waveguides attached. The WR1500 flanges on the ridge-loaded waveguides are the interface for the RF system which will be delivering 1 MW of RF power at 700 MHz.

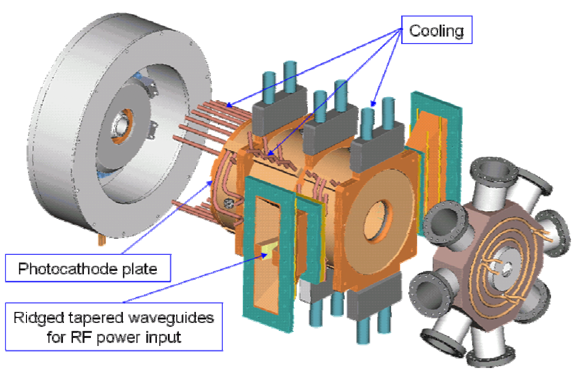

Figure 3. Schematic (from D. C. Nguyen, *et. al.* [8]) of the 2 cell RF cavity (center) with the two symmetrically placed ridge-loaded tapered waveguides attached.

Monitoring/Protection System

Several RF system parameters are monitored for personnel and equipment safety. In addition to the standard interlock and monitoring capability through the available RF system, numerous interlocks and monitoring was provided. All 4 ports of the 3 dB hybrid splitter were fitted with Dual Directional Couplers (DDC) to measure the forward and reflected power levels. In addition, RF samples at the cavity are monitored. A circuit will be used to protect the cavity from arcs by utilizing the RF samples at the cavity input and at the cavity itself.

To monitor RF power in both the forward and reverse direction. The cooling circuit for the NCRF photoinjector has a flow meter with an interlock to take the transmitter to the Standby state if the cooling flow falls below a certain level. Forward and reflected RF power at the 3 dB hybrid load will be monitored and interlocked. This protects the load as well as the cavity against mismatches or failures.

Fiber optic arc detection will be provided on both the atmospheric and vacuum pressure sides of the 700 MHz RF windows. Additional fiber optic arc detection was added to the RF load on the 4th port of the 3 dB hybrid. Vacuum levels will be monitored at each RF window and interlocked to inhibit RF when limits are reached. All RF power, vacuum levels, temperatures, are monitored and archived by EPICS software.

REFERENCES

[1] S.S. Kurennoy, *et. al.*: "Normal Conducting High Current RF Photoinjector for High-Power CW FEL," PAC'05.

[2] A.M.M. Todd, *et. al.*: "State-of-the-Art Electron Guns and Injector Designs for Energy Recovery Linacs (ERL)," PAC'05.

[3] J. Bradley III, *et. al.*: "An Overview of the Low Energy Demonstration Accelerator (LEDA) RF Systems," PAC'97.

[4] D. Rees, *et. al.*: "Design and Test Results of the Low Energy Demonstration Accelerator (LEDA) Project RF Systems," PAC'97.

[5] D. Rees, *et. al.*: "Accelerator Production of Tritium 700 MHz and 350 MHz Klystron Test Results," LINAC'98

[6] J. Bradley III, *et. al.*: "Operational Experience with Two Types of 2 MW HVDC Power Supplies on LEDA," PAC'99.

[7] R.A. Rimmer, *et. al.*: "A High-Power L-Band RF Window," PAC'01.

[8] K.A. Cummings, "700 MHz RF Window Lifetime Testing," Accelerator Production of Tritium Technical Report, Accelerator ED&D Program, LA-UR-02-4090, July 2002.

[9] D.C. Nguyen, *et. al.*: "Overview of the 100 mA Average-Current RF Photoinjector," PAC'05.