TESTING OF THE SSC DTL AND CCL KLYSTRON MODULATORS

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Abstract

Two line type modulators have been designed, manufactured, and successfully tested for providing pulsed high voltage for the klystron tubes which would have provided rf power for the SSC Drift Tube Linac (DTL) and Coupled Cavity Linac (CCL). The DTL provides 125 kV, 60 A, 105 µs output pulses at rep-rates up to 10 Hz while the CCL generates 215 kV, 230 A, 75 µs pulses at the same rep-rates. Other important specifications include a pulse flat top ripple of less than ±0.25% and a pulse to pulse peak voltage amplitude variation of less than ±0.2%. Detailed acceptance tests were performed on the modulator. These tests can be grouped into three categories: subsystem testing, system testing into a dummy (resistive) load, and system testing into a klystron load (with no rf applied). Subsystem tests involve interlock and control signal verification and analog signal calibration of the more than 150 modulator control signals for the various modulator subsystems. System testing of the modulators into a dummy load verifies system integration and acceptable output pulse characteristics during ac high line and low line conditions. The last series of tests with the modulator operating into the klystron load includes a 100 hour continuous run of the modulator and verifies all required output pulse parameters, including pulse rise time, flat-top width, flat-top ripple, peak-to-peak amplitude variation, jitter, and rep-rate. Details of the testing results for both modulators are presented in the paper.

Introduction

The Superconducting Supercollider (SSC) CCL and DTL modulators are thyratron switched PFN modulators for providing voltage pulses for the klystrons used on the coupled cavity and drift tube linacs respectively. The pulse parameters for the two modulators are given in Table 1.[1]

Table 1

Parameter	CCL Modulator	DTL Modulator
Output Voltage	215 kV	125 kV
Output Current	230 A	60 A
Pulse Width	75 µs	105 µs
Pulse Top	60 µs	90 µs
Pulse Flatness	<0.5% p-p	<0.5% p-p
Pulse to Pulse Amplitude Variations	<0.2%	<0.2%
Peak Power	46 MW	8 MW
Average Power	34 kW	8 kW
Repetition Rate	10 Hz	10 Hz

Ten CCL modulators plus one spare and four DTL modulators plus one spare were to be used for the SSC modulator. For maintenance purposes, the modulator and klystron assembly could be removed from the linac and a spare modulator and klystron would be put in its place. In addition to verifying the modulator performance for acceptance testing, the modulators performance parameters and subsystem parameters had to be carefully measured and recorded in order to minimize the setup time required to reinstall a new modulator and bring the linac back up to operation.

The SSC modulators have several features which differentiates them from other modulators. The SSC CCL and DTL modulators have an extensive control system of over 150 control signals to and from the modulator for monitoring the modulator and fault protection of the modulator and modulator subsystems. The SSC modulators are charged with multiple commercially available switching power supplies operating in parallel as opposed to resonant charging. The supplies operated as required when operating into a resistive load, but when operating into a klystron, the PFN charging path through the pulse transformer had to be bypassed with a high voltage diode. Performance of the original thyratron in the DTL was inadequate due to quenching of the tube during long pulse mode of operation, requiring a larger tube to be used in the modulator. Photographs of a finished DTL and CCL modulators are shown in Figures 1 and 2 respectively.

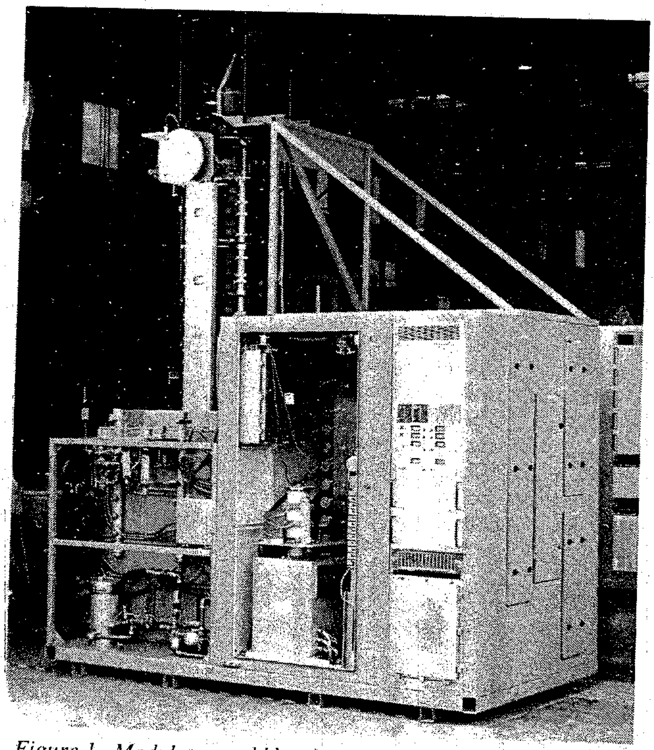

Figure 1. Modulator and klystron for the SSC drift tube linac.

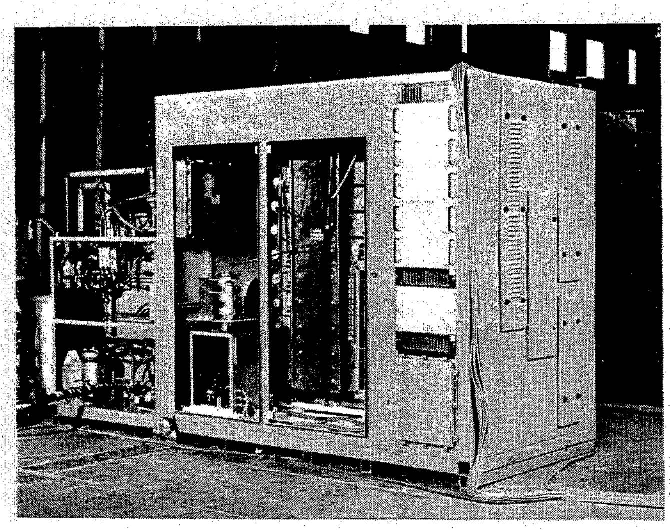

Figure 2. Modulator and klystron for the SSC coupled cavity linac.

Subsystem Test

The modulators are only operational from the remote computer controls. No manual control panels were allowed to be incorporated into the modulator design. The extensive control and monitoring functions of the computer controls prevented the modulator from operating until all subsystems and their respective control lines were tested and calibrated. The subsystems were broken up into the following: klystron filament supply, modulator (circuit breakers, cooling interlocks, dump sticks, door access panels, AC power interlocks), thyratron filament supply, ion pump supply, klystron magnetics, HV power supplies (CCDS switching supplies), thyratron grid driver (negative bias, auxiliary discharge, and trigger generator), and PFN (end of line clipper and pulse transformer bias supply). Where applicable, the following tests were performed on each of the above subsystems. The accuracy of the output setpoint and analog readback was measured and calibrated to the actual output (in most cases better than 1% accuracy). The limit setpoint trip level and the setpoint readback accuracy were all individually tested and calibrated, also to better than 1% accuracy in most cases. The regulation of the power supplies were tested and measured at high, low, and nominal line. The proper inhibit and shutdown action for each fault was simulated and verified. The performance of all digital inputs and outputs were tested and verified.

System Test Dummy Load

Once the individual subsystems had been tested and calibrated, the modulator was operated and pulsed into a resistive dummy load. The PFN was tuned to the dummy load and the modulator pulse parameters were verified. Once the pulse parameters were verified the modulator was run continuously into the dummy load at full power for three hours.

While testing into the dummy load, the thyratron in the DTL modulator began to quit conducting or quench while discharging the PFN. Quenching of a thyratron when conducting in a long pulse mode is not unusual and was considered in the initial design. When selecting the initial F-307 and F-331 thyratrons for the DTL and CCL, discussions were held with the manufacturer on the long pulse mode of operation. Both tubes were designed with internal structures which have apertures to allow neutral gas to flow from the cathode region (reservoir) to the anode region during conduction. The apertures are intended to prevent "gas pumping" and ion bombardment of the cathode late in the long conduction process. The F-307 tube was replaced by the F-331 tube used in the CCL. Since the thyratron subsystems (heater and reservoir supplies, grid drivers, and bias circuits) for the DTL and CCL were nearly identical (designed to be a standard unit), swapping of the tubes did not have a major impact on the thyratron subsystem other than a change of tube.

System Test Klystron Load

After completion of the dummy load burn in, the klystron and lead shield were assembled on the pulse transformer tank. All klystron auxiliaries (ion pumps(s), magnet(s), and heater) were connected to the klystron. For dummy load test these items were operated into dummy loads. The PFN was tuned for the klystron load and the modulator pulse parameters were verified.

To maintain the output pulse-to-pulse variation to less than 0.2%, the PFN is charged with a parallel arrangement of Maxwell CCDS switching power supplies. The CCDS supplies allow the PFN to be charged directly, eliminating the need for resonant charging components. The CCDS supplies have very little stored energy since there is no filter bank thus minimizing the possibility of damage to the klystron in the event of a klystron arc. Other advantages of the CCDS supplies are reduced power supply volume, efficiency greater than 90%, regulation better than 0.1%, and excellent reliability. By operating the supplies in parallel, the system is inherently redundant and the loss of a supply does not prevent operation. The SSC modulators were designed so that the modulators could continue to operate at full repetition rate and full klystron voltage in the event that one supply failed.

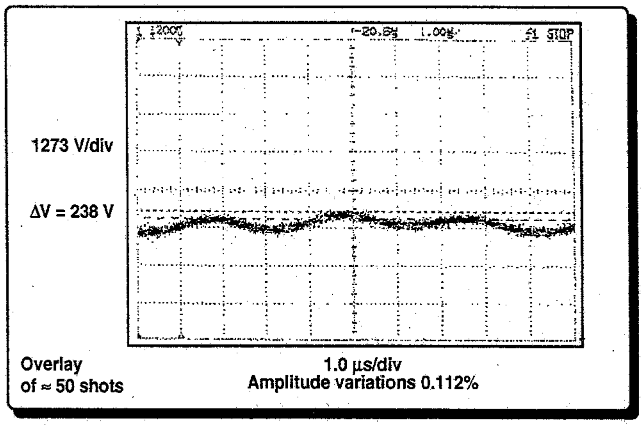

Figure 3. Output voltage pulse to pulse amplitude fluctuations were maintained to <0.112%.

The supplies perform as a constant current supply, thus charging the PFN linearly. The supplies are designed to charge the PFN up to the preset voltage and maintain that voltage until the thyratron fires. The supplies sense the discharge and delay the recharging of the PFN for a preset time (delay after discharge) to allow the thyratron to recover. The PFN charging waveform is shown in Figure 4.

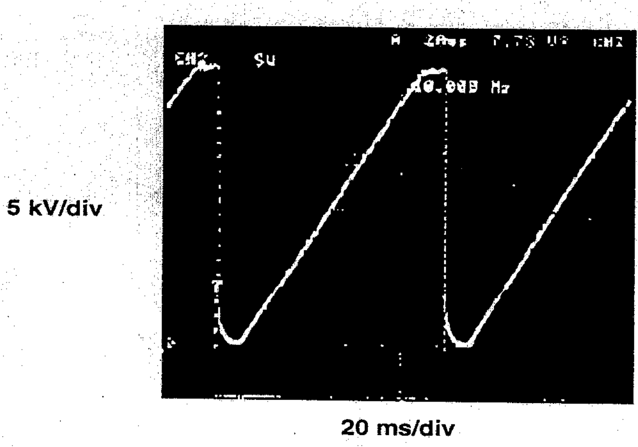

Figure 4. The constant current charging of the PFN results in a linear charging waveform .

When beginning to test the modulators into the klystrons, an additional diode had to be installed into the system in order to allow the PFN charging current to bypass the pulse transformer. When charging the PFN the charging current through the pulse transformer flows in the opposite direction of the pulse current. The output current of the switching power supplies is made up of high frequency current pulses. When these high frequency pulses pass through the pulse transformer, a large reverse voltage appears on the klystron (secondary of pulse transformer) since the reverse biased klystron appears as a very large impedance. The resulting reverse voltage resulted in internal arcing in the klystron. To prevent the internal arcing, the charging current was diverted by a diode inserted into the charging circuit as shown in Figure 5, thus diverting the charging current from the pulse transformer. This diode will see the full PFN voltage when the thyratron fires and must be able to hold off the 35 kV PFN charge voltage. The diode must also conduct the charging current delivered (1 amp average DTL and 2.5 amp average CCL) by the supplies.

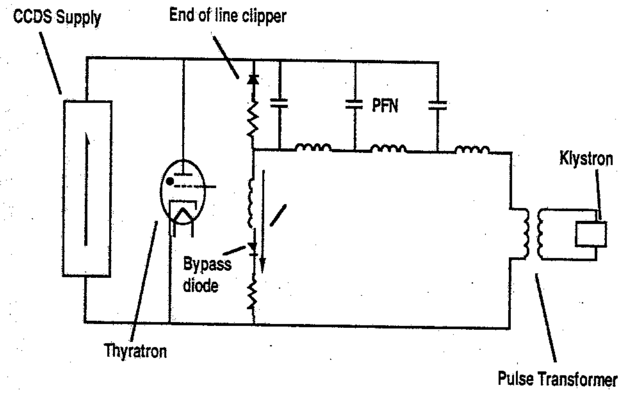

Figure 5. Bypass diode inserted to divert PFN charging current from pulse transformer.

The output voltage pulse width, pulse top, and pulse flatness, were met by tuning the PFN. The output voltage waveform for the DTL and CCL into the klystron are shown in Figures 6 and 7 respectively.

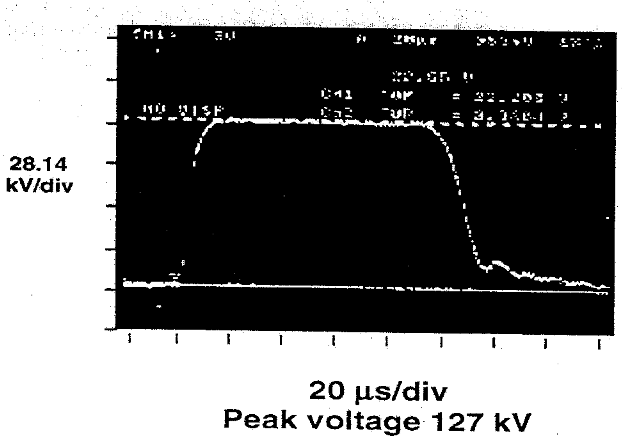

Figure 6. Output voltage for the DTL was measured at 127 kV into the klystron.

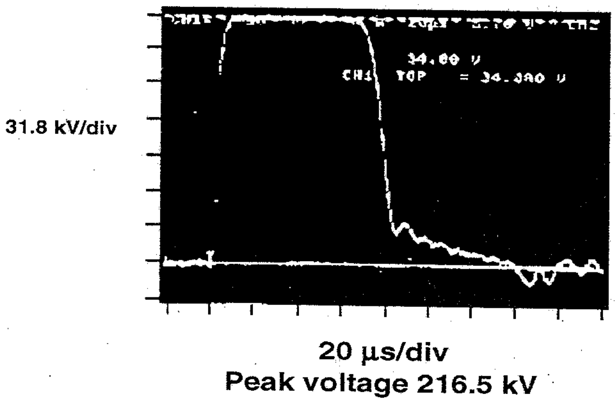

Figure 7. Output voltage for the CCL was measured at 216.5 kV into the klystron.

Once the pulse parameters were verified the modulator was run continuously into the dummy load at full power for one hundred hours. During the hundred hour run, the output voltage, output current, magnet current(s), ion pump current(s), klystron filament voltage and current, and klystron water inlet and outlet temperature was recorded every fifteen minutes.

Conclusion

The computer control system monitored over 150 I/O channels to provide detailed information on all subsystems and provided immediate identification of a fault condition. The long term, continuous operation of multiple parallel Maxwell CCDS switching power supplies was demonstrated for charging a PFN to highly regulated (0.112%) voltages. Quenching of the original DTL thyratron occurred as a result of long pulse operation, requiring a larger tube. The high impedance of a negative biased klystron required a bypass diode to be inserted into charging circuit to bypass the pulse transformer when charging with the CCDS supplies. Acceptance testing of both CCL and DTL modulators was successfully completed. Two (each) CCL and DTL modulators were fully tested and accepted. The remaining nine of eleven CCL modulators and three of five DTL modulators were in various stages of fabrication (up to 96% complete) when the program was terminated by Congress.

References

1 B.L. Thomas et al. "Thyratron Modulators for the Superconducting Supercollider Drift Tube and Coupled Cavity Linacs" Pulsed Power Conference, Albuquerque, N.M. (1993)