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FREE-ELECTRON LASER

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HIGH-POWER RF-PULSED MODULATORS FOR THE LOS ALAMOS FREE-ELECTRON LASER*

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In the rf-driven free-electron laser (FEL) at the Los Alamos National Laboratory, there are two pulsed-power rf modulators as sources for two tandem, side-coupled 20-MeV linear accelerators. The rf power used to control the cavity fields is supplied by two 5.5-MW modulating anode klystrons operating at a center frequency of 1300.2 MHz. The modulation of the 125 kV klystron is achieved by using a triode switch tube that provides a pulse width up to 300 μ s and a pulse repetition rate up to 10 Hz.

This paper describes the present configuration of these two duplicate systems and presents plans for meeting the requirements of future rf FEL experiments at Los Alamos.

1. Introduction

The basic rf modulator design has been previously described by Tallerico, et al. [1]. However, our system's critical design constraints are a 125-kV operating voltage and an energy deposition of less than 10 J during a crowbar; thus, many design changes have been made.

The klystron and modulator system are shown in fig. 1. These assemblies are permanent fixtures and there are no readily available spares; therefore, reliability of the installed system is a third critical design factor.

2. Electrical design

The present design schematic is shown in fig. 2. The ML-8495 triode switches the modulating anode potential from approximately -12 kV to the cathode potential

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of -125 kV. The zener diode self-bias circuit for the switch tube has been increased to -600 V from -450 V to completely reduce the probability of any cathode leakage current. However, this necessitates a high grid drive power. Because it is necessary for the klystrons to be totally off during the intrapulse period, a cathode bias circuit has been added. This intrapulse off period is accomplished by adding -1 kV to the modulating anode potential. The circuit is realized by utilizing one of the secondary taps off the klystron filament supply transformer and adding this voltage to the high side of the modulating anode voltage divider (ohm weave) during the intrapulse period. By using shielded cable externally to the tank for the modulating anode's capacitive divider voltage measurements, we found that the accuracy was significantly increased for this diagnostic. Previously, shielded cable was used only internally in the tank. A $19\text{-k}\Omega$, 52-W resistor was added in series with the modulating anode's voltage divider tap to protect the modulating anode from high power dissipation, thereby creating outgassing of molecules and subsequent internal high-voltage breakdown. Two modulating anode's current transformers are used to both monitor and trigger the crowbar should this current rise above a preset level. Several other current transformers are placed strategically around the modulator tank and are used to trigger the crowbar system. The action of this crowbar system is completely described in another paper at this conference [2]. A neon light bulb was added across the filament supply secondary as a personnel safety feature. A light notifies personnel that although the -125-kV high voltage may be off, the cathode bias circuitry is still on and caution is advised. This method is more simple than the nuisance of interlocking this circuitry. In fig. 3, a water detector schematic is depicted. It works on the principle that water in the oil will short out the base-collector junction, turn the transistor on, and send current to a relay interlock, which will turn off the high-voltage power supply. The water detector was recently added to the modulator tanks after a klystron was severely damaged because of water intrusion that was not discovered soon enough.

Because the klystrons we use are sensitive to deposited energy, careful computer analysis was done to ensure that our rf system protects these tubes. The maximum sustained energy cannot be more than 10 J. Fig. 4 describes the model used for this analysis. The results obtained were that the rf system can provide up to 76.05 kJ. The crowbar takes $2\text{ }\mu\text{s}$ to react; therefore, the modulator tank must be able to withstand the full energy dissipated during this time. Thus, a $19\text{-}\Omega$ carborundum resistor was added in series with the cathode high-voltage lead. Fig. 5 shows the current profile in one of the klystrons during an arc. The arc begins at $6\text{ }\mu\text{s}$; at $8\text{ }\mu\text{s}$ the crowbar system is activated. Also, an energy detection monitor was appended to the rf modulator tanks. This monitor operates by sensing

the forward current in the coax cable for the high voltage and then integrates this current waveform. This integrated current multiplied by the klystron assumed voltage drop during an arc (100 V) reveals the total energy dissipated in the microwave tubes. Typically, we see about 1 J discharged into the klystron.

3. Mechanical design

The complete modulator tank is 137.2 x 256.5 cm and contains 1100 gallons of transformer oil. An oil pump is placed on the side of each tank to circulate the oil through the pump's filtration system. This circulating action also keeps the temperature of the oil evenly distributed throughout the tank because the 1000-W heater is mounted on the lid of the modulator. The oil pump has an external timer that is programmed to circulate oil at night when the modulators are not in use because the filtration pump tends to introduce air into the oil. The ML-8495 switch tube has its own oil pump to flow oil around its anode while we are operating. To facilitate ease of repairing modulator components, four hydraulic jacks have been installed underneath the component deck. The older and smaller modulator tanks were plagued with arcing problems. The problems were solved by enlarging the tanks to their present size and by canting both the pulse transformer and the switch tube/filament transformer at a 45° angle with respect to the side walls of the tank, thereby, maximizing the space between the high-voltage winding and side wall. In addition to this, the phenolic-impregnated cloth end walls of each transformer was replaced with 2.54 cm Lexan plates.

The complete modulator tanks weigh about 15 000 lb each.

4. Conclusions

Because the above alterations were made to the original LAMPF modulator tanks, the assemblies have achieved their required electrical and reliability goals[1]. There have been no accelerator downtimes caused by modulator malfunctions during the past two calendar years. Future plans call for operating both modulator tanks at 135 kV. The tanks were recently tested at this voltage and no problems were discovered. The higher voltage is for two 6.5-MW klystrons that will be used in future high-current FEL experiments.

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References

- [1] P. J. Tallerico, R. L. Cady, and J. D. Doss, "Design and Performance of the LAMPF 1 1/4-MW Klystron Modulator," IEEE Conf Record 11th Modulator Symp., New York, New York, September 18-19, 1973, 55 (1973).
- [2] J. O. Hornkohl and M. L. Lynch, "Development of High-Energy Crowbar for the Los Alamos Free-Electron Laser," Ninth Int. Free Electron Conf., Williamsburg, Virginia, 14-18 September 1987, to be published.

Figure Captions

Fig. 1. Modulator tank assemblies.

Fig. 2. Electrical schematic of modulator tanks.

Fig. 3. Water detector electrical schematic.

Fig. 4. Computer model of RF system.

Fig. 5. Simulated discharge current in a klystron during an arc and subsequent crowbar.

$$R8 = 24 \exp(-t/2.3 \text{ uSec})$$

S1, CROWBAR SWITCH.

S2, KLYSTRON ARC.

R9, KLYSTRON A BEAM IMPEDANCE.

R10, KLYSTRON B BEAM IMPEDANCE.

Current (A)