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Conf-930411--184

A 2-Megawatt Load for Testing High Voltage DC Power Supplies*

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Abstract

A high power water-cooled resistive load, capable of dissipating 2 Megawatts at 95 kilovolts is being designed and built. The load utilizes wirewound resistor elements suspended inside insulating tubing contained within a pressure vessel which is supplied a continuous flow of deionized water for coolant. A sub-system of the load is composed of non-inductive resistor elements in an oil tank. Power tests conducted on various resistor types indicate that dissipation levels as high as 22 times the rated dissipation in air can be achieved when the resistors are placed in a turbulent water flow of at least 15 gallons per minute. Using this data, the load was designed using 100 resistor elements in a series arrangement. A single-wall 316 stainless steel pressure vessel with flanged torispherical heads is built to contain the resistor assembly and deionized water. The resistors are suspended within G-11 tubing which span the cylindrical length of the vessel. These tubes are supported by G-10 baffles which also increase convection from the tubes by promoting turbulence within the surrounding water.

I. INTRODUCTION

A resistive load capable of dissipating 2 megawatts at 95 kilovolts DC is required by Argonne National Laboratory to test klystron power supplies used in the Advanced Photon Source. The overall design of the test load is intended to simulate the load seen by the power supply during normal klystron operation. In this way, power supply maintenance and testing can be performed without risk of damage to the klystrons.

The operating parameters of the load are dictated by the TH2089A klystron power supply requirements. A resistive load is required for each power supply sub-system, as given in Table 1.

The beam power dissipation of 1900 kilowatts is the most difficult design specification to meet, due to the high voltage and power dissipation levels. The mod-anode and filament loads, although relatively low in power dissipation, have specific design requirements due to the high voltages involved. The focus magnet load is considered optional at this time, as its design requirements are much simplified due to the fact that the operating voltages are much lower.

A block diagram of the entire load system is shown in Figure 1. The beam load consists of wirewound resistor elements enclosed in a stainless steel pressure vessel which is supplied a continuous flow of deionized water for cooling. Due to its size, the pressure vessel is located in a fixed location inside the RF/Extraction building at the Advanced Photon Source, in close proximity to all five klystron power supplies.

The mod-anode and filament loads are contained in an oil tank which can be moved to each individual power supply location within reach of the power supply output cables. Mating connectors on the oil tank allow easy connection of the load to the power supply. The pressure vessel is connected to the power supply through the oil tank by a 350-foot coaxial high-voltage cable. All operator controls and instrumentation are mounted on the oil tank assembly.

A safety interlock system is utilized to insure personnel safety and prevent equipment damage in the event of a malfunction in the load. The pressure vessel is interlocked to prevent overloads due to over-temperature, over-pressure, or insufficient deionized water flow. An internal arc detector is utilized to detect arcing of internal components. The oil tank is interlocked to prevent over-temperature operation and access to high voltages. All of these interlock circuits are connected in a normally-closed series arrangement and are used to shut down and/or prevent turn-on of the power supply under test should a malfunction occur in the test load system.

Table 1
TH2089A Power Requirements [1, 2]

Parameter	Voltage/Current	Power Level	Equivalent Resistive Load	Duty
Beam power	10 to 95 kV DC @ 20 amps max.	1900 kW max.	4750 ohms	cont.
Mod-anode	5 to 85 kV DC @ 10 mA max.	850 watts	8.5 megohm	cont.
Filament	25 vac @ 25 amps	625 watts	1 ohm	cont./int.
Focus Magnet Coils	300 V DC @ 24 amps	7200 watts	25 ohms (x2)	cont./int.

* Work supported by U.S. Department of Energy, Office of Basic Energy Sciences, under Contract W-31-109-ENG-38.

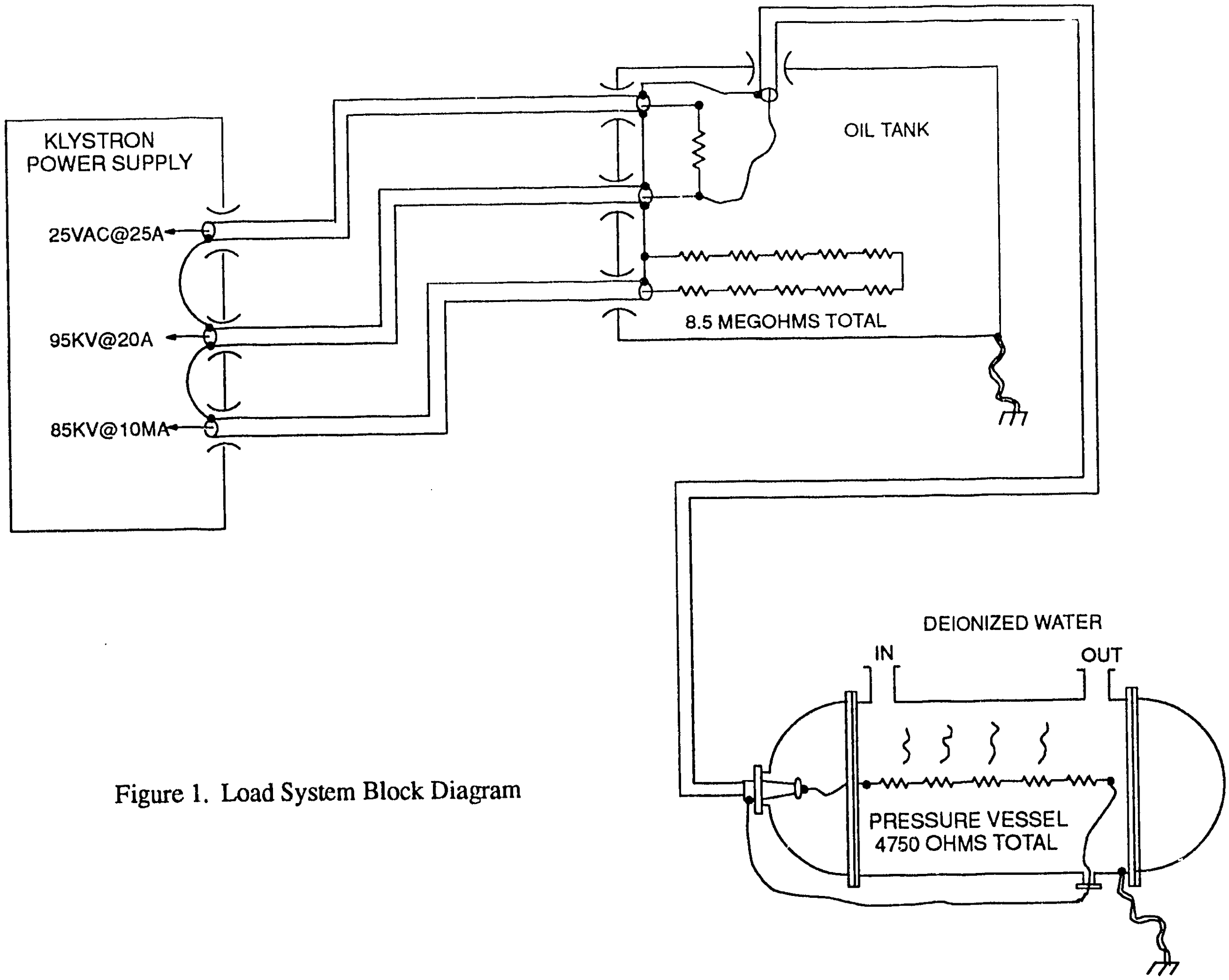

Figure 1. Load System Block Diagram

II. DESIGN OVERVIEW

The pressure vessel contains the resistor network for the beam power supply load. The selection of a resistor best suited for this application was made after extensive power testing of sample units. Compatibility with the deionized water system was also a determining factor in resistor selection, which limited metals in contact with the water to copper and stainless steel.

A test chamber was built to determine the power dissipation capacity of resistor designs when cooled by a turbulent deionized water flow (see Figure 2). The chamber consists of a 5-inch ID clear Plexiglass pipe, 36 inches long, connected to a supply/return system of deionized water. The resistor under test is suspended inside the tube, in the water stream, and supplied electric power through watertight feedthrough bushings. Inlet and outlet water temperatures were monitored to verify power input to the test system.

Electric power was supplied to the test resistor from a 0–560 volt AC/60 Hz source (variable autotransformer) capable of 40 kilowatts maximum power output. Design and cost constraints restricted the choice of resistor types to molded composition (tubular) and wirewound designs, with both types capable of dissipating approximately one kilowatt in free air.

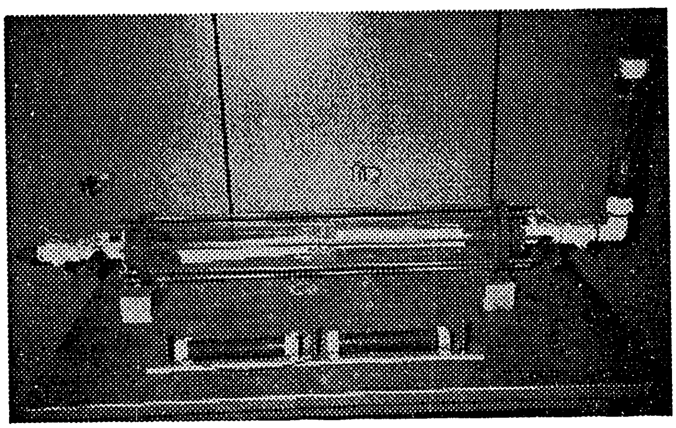

Figure 2. Test Chamber

Power dissipation tests were carried out using a resistor of each variety. The results of the tests are given in Table 2.

The composition resistor failed at a power input level of 18.92 kilowatts and a water flow of 15 gallons per minute. Water temperature data was not accurate because the resistor failed before temperature data could be taken. Observation of the resistor during the test revealed steam production on the interior surfaces of the resistor, beginning at 11 kilowatts input. At 18 kilowatts input, :am production was intense, resulting in hot spots being created on the resistor due to cavitation of the cooling water on the resistor surface. After approximately 45 seconds of operation at 18.9 kilowatts, the resistor failed due to a crack in the resistor body.

Tests of the wirewound resistor indicated that it was capable of dissipating at least 22 kilowatts of power with no distress, at water flow rates between 7.5 and 15 gallons per minute. No active steam production was noted, and an inspection of the resistor after the tests revealed no physical damage.

Results of the power tests revealed that the wirewound resistor design was capable of dissipating at least 22 times its rated dissipation in air when cooled by a turbulent deionized water flow of at least 7.5 gallons per minute. Using this data, the beam load was designed using 100 series-connected resistors of equal resistance value, with each dissipating 20 kilowatts at full power input, and a combined dissipation of 2000 kilowatts. The water flow through the pressure vessel should be maintained between 250 and 500 gallons per minute, resulting in acceptable cooling water temperature rise.

The oil tank contains the mod-anode and filament power supply load resistors, and has a volume of approximately 25 cubic feet. It will contain all of the resistors and approximately 175 gallons of dielectric insulating oil. Due to the relatively low combined power dissipation level of the two loads (1475 watts) and the intermittent nature of their operation, natural convection cooling of the oil tank will be utilized.

III. ELECTRICAL DETAILS

The beam load consists of 100 wirewound resistors connected in series. Each resistor has a cold resistance value of 43.2 ohms, and a free-air dissipation rating of 1000 watts. The resulting total load resistance, assuming a 12% increase in resistance at full power input due to the positive temperature coefficient of the resistor material, will be approximately 4750 ohms.

The mod-anode load consists of ten non-inductive resistors connected in series. Each resistor has a resistance value of 850k-ohms and a free-air dissipation rating of 300 watts. The resulting total resistance is 8.5 megohms. The filament load is a one-ohm wirewound resistor with a free-air dissipation rating of 1000 watts. Both types are suitable for use in oil.

IV. MECHANICAL DETAILS

The pressure vessel, fabricated from 304 stainless steel, will be stamped and manufactured in accordance with section VIII of the ASME Boiler and Pressure Vessel Code. Two support pads will be used to distribute the total weight load of 35,000 pounds. Torispherical flanged heads and Viton o-rings will be used to seal the vessel and welding will be performed in accordance with ASME Code, Section IX. The maximum external pressure for the vessel will be 30 psi.

The operating pressure for the vessel will be 85 psig, with a MAWP of 110 psig. The relieving pressure (set pressure + overpressure + atmospheric pressure) will be 135 psia. Two ASME-stamped relief valves will be used to relieve pressure on the vessel. A hydrostatic relief valve, with a set-pressure of 103 psig, will have a rated capacity of 75 gpm. The steam relief valve, with a set-pressure of 110 psig, will have a rated capacity of 18,100 pounds/hour.

Based on a deionized water inlet temperature of 90 degrees F and 25 degrees F temperature rise through the vessel, the operating temperature will be 115 degrees F. The maximum temperature for the vessel is 350 degrees F, and is based on the saturation temperature of steam at 135 psia.

V. SUMMARY

We have outlined in detail the specifications and design of a high-power resistive load to be used in testing klystron power supplies at Argonne National Laboratory. The load simulates the loading conditions of the TH2089A klystron. This allows testing and maintenance of the klystron power supplies without risk of damage to the klystron tubes. Utilization aspects of the load were presented along with design details related to personnel safety and equipment protection.

VI. ACKNOWLEDGEMENTS

We thank J. F. Bridges and H. Frischholz for discussions which produced vital input to this project, and to C. Verdico, E. Wallace, and D. Meyer for their efforts in building prototype materials and the test stand.

VII. REFERENCES

[1] Thomson TH2089A Klystron Amplifier Operating Manual, UTH 2089, November, 1986.

[2] Technical Specification for Amplifier Tube Power Supply System, Document No. 3104010202–00001, Argonne National Laboratory.

Table 2
Resistor Dissipation Test Data

Type	Flow	Water Temp, °C In	Water Temp, °C Out	Voltage AC, RMS	Current Amps	Power E•I	Power Water ΔT
Wire 13-ohm	15 gpm	24.05	29.38	552	39.8	21.97 kW	21 kW
	7.5 gpm	24.33	34.27	552	39.8	21.97 kW	20 kW
Comp. 10-ohm	15 gpm	29.33	30.66	435	43.5	18.93 kW	——

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