DESIGN AND CONSTRUCTION OF A 1-MW, 352-MHZ RF TEST LOAD

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Abstract

A 1-MW, 352-MHz rf load was built at Argonne National Laboratory for performance testing the klystrons used as final amplifiers at the Advanced Photon Source (APS). The load utilizes four CERN-type 300-kilowatt coaxial water loads which are fed from a single WR2300 waveguide using a four-way power splitter consisting of a WR2300 hybrid-T junction and two WR2300 waveguide-to-dual-6-1/8" coaxial transitions. The load system is cooled using deionized water at a nominal flow rate of 160 GPM. The entire load system is mounted on a wheeled carriage which allows for rapid relocation to specific areas of the APS klystron gallery. The metering and interlock system will be described. The load has logged approximately 250 hours of use and has demonstrated accuracy in flow and temperature measurement sufficient to allow calorimetric rf power measurement.

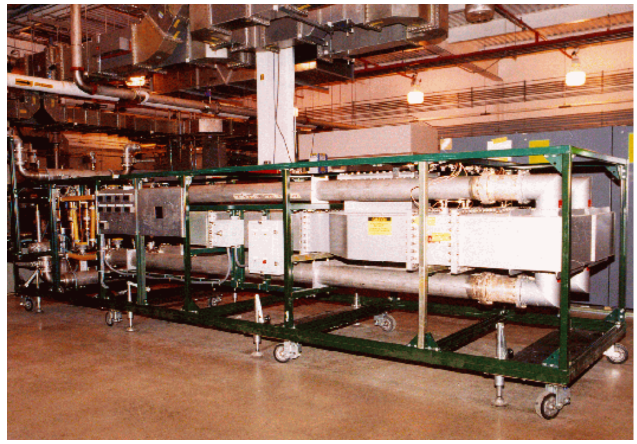

Figure 1: Side view of the rf load.

1 CAPABILITY REQUIREMENTS

A high-power rf test load capable of dissipating 1.2 MW at 352 MHz was built for full-power testing of the APS 352-MHz klystrons. The test load was designed with features which shorten required set-up time, thereby reducing rf system downtime when klystron testing or troubleshooting is necessary. The load system is a one-piece design with outside dimensions that allow for mobility to specific areas of the APS klystron gallery where the klystron rf output flanges are accessible. The existing APS deionized water system is used as a coolant source and features hose connections that provide rapid connections to the water supply and return lines at various locations in the building. The load has an interlock system which can protect each of the coaxial water loads individually against insufficient water flow and excessive return water temperature, and excessive voltage standing wave ratio (VSWR) on the H-plane outputs of the hybrid-T junction. The interlock system provides a dry contact for control of the high-voltage power supply (HVPS) used during klystron testing and rapid PIN-diode rf source switching to inhibit the rf drive to the klystron in the event a high-VSWR condition exists at either output of the hybrid-T junction.

2 DESIGN DETAILS

The rf power circuit of the load forms a four-way power divider, with the input power dissipated in four individual water-cooled rf loads (see Figure 1). A hybrid-T junction [1] was chosen as the first power divider in order to keep the overall width of the load system under 60 inches. The rf power input to the load is a standard WR2300 waveguide flange that terminates at the input of a WR2300 H-plane hybrid-T junction at either the H-plane or E-plane port, depending on orientation to the rf system output flange. Each of the two H-plane outputs of the junction are fed through WR2300 waveguide directional couplers to WR2300-to-dual-6-1/8" coaxial transitions. The orthogonal port of the hybrid-T junction is terminated with a shorting plate or a 50-ohm matched load to dissipate reject power due to load phase imbalance. Each 6-1/8" coaxial transition output is terminated with a 6-1/8" coaxial input water load.

The individual water loads were designed and manufactured at CERN. Each load consists of a coaxial line, made from stainless-steel components, shorted at one end with a plate that also provides for water inlet and outlet connections. Each load is capable of a maximum rf power dissipation of 300 kW, with a maximum outlet water temperature of 60°C. The water circuits of the load consist of 4" hose fittings which terminate into supply and return manifolds (see Figure 2). Four individual parallel water circuits, one for each coaxial rf load, complete the path between the supply and return water manifolds. The water circuit to each individual load includes flow throttling valves on both the inlet and outlet lines plus temperature and flow measurement devices. The outlet water flow for each load is measured using an electronic flowmeter and is also passed through a direct-reading float-type flowmeter for independent confirmation of the electronic flow measurement. Outlet water temperature of each load is measured using platinum RTD thermistors. Thermometer wells are provided on each load outlet line to allow use of standard mercury thermometers for independent confirmation of the electronic temperature measurement. The inlet

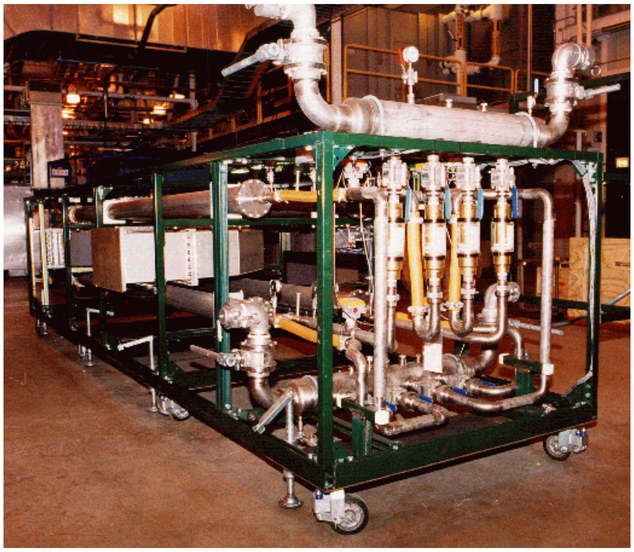

Figure 2: The rf load water system.

water temperature is measured using an RTD thermistor mounted in the inlet water manifold.

The load interlock systems protect against cooling water temperature and flow problems, and excessive VSWR conditions. The water interlock uses the programmable alarm-setpoint form-C dry contacts internal to each flow and temperature measurement meter to configure a series interlock circuit which provides a form-C dry contact for control of the HVPS supplying beam power to the klystron under test. If an under-flow or over-temperature condition exists on any of the individual coaxial water loads in the rf load system, the HVPS will be immediately shut down, removing beam power from the klystron under test. VSWR protection for the load system is provided by using the reflected-power outputs of the WR2300 directional couplers at each H-plane output of the hybrid-T junction. Each of these outputs is peak-detected and used to trigger the DC input of a PIN-diode fast rf switch controller, which removes the rf drive from the klystron in the event a high VSWR is detected at the input of either coaxial transition. Both interlock systems latch in the tripped state and require a manual operator reset to clear.

The load assembly is constructed on a unistrut frame equipped with wheels for easy mobility within the APS klystron gallery. The load carriage is also equipped with leveling jacks around the frame perimeter to assist in waveguide flange alignment when mating to the fixed rf output flange of the klystron under test.

3 PERFORMANCE MEASUREMENTS

The 1-MW rf test load system has logged approximately 250 hours of use to date during power-testing of klystrons and other high-power rf transmission components at the APS facility. It has demonstrated adequate stability in both impedance and power handling characteristics to be an effective load at the 1-MW power input level. However, during initial high-power tests of the load system, the power division between the four individual coaxial loads would occasionally become unbalanced at intermediate power levels. This resulted in one or two of the coaxial loads reaching their individual maximum power handling capability prematurely, thereby limiting the total dissipation of the load system to well under 1 MW. This power imbalance phenomenon was random in nature and suddenly occurred at various input power levels between 600 and 900 kW.

Thermal effects were the suspected cause of this power imbalance. As the rf impedance of the individual rf loads varied with water temperature (see Figure 3), a power imbalance between the loads began to appear. The impedance differential on the outputs of the hybrid-T junction further promoted imbalance of the system, and the phenomenon avalanched into greater power imbalance. Thermal expansion of the waveguide-to-coaxial transition components may have been responsible for the initial power imbalance. This original subtle difference then increased to greater power differential as the individual load temperatures change. During continued investigation of this phenomenon, it was noted that the power balance improved and remained much more stable if the inlet water temperature to the load system was raised from 25°C to approximately 30.5°C, and fans were positioned to cool the external surfaces of the waveguide coaxial transitions. With these changes, the load system became stable and power balance between the four coaxial loads remained close enough to allow 1-MW operation.

The rf input impedance of the load system varied with water temperature and provided a better match as the total power dissipation rose (see Figure 3). The best VSWR performance observed was 1.18:1 at a power input level of 928.1 kW. This VSWR is only marginally sufficient for direct-terminating load on the APS klystrons and, at lower power input levels, the load system match would exceed the maximum VSWR specification for the APS klystrons.

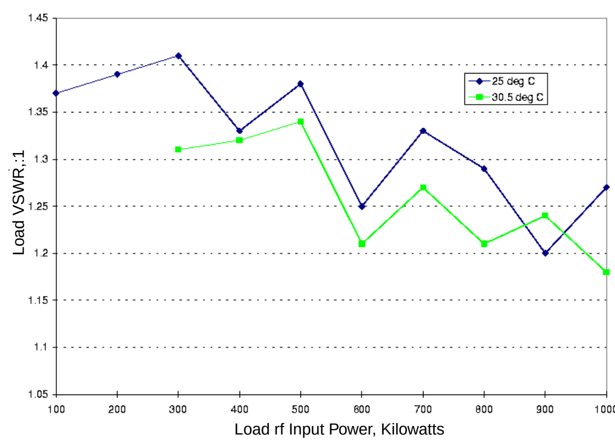

Figure 3: Load VSWR vs. water temperature.

Therefore, this load must be used in conjunction with a 1-MW Y-junction circulator when testing klystrons. The 3-dB return-loss bandwidth of the load system was measured under "cold" conditions and found to be approximately 3 MHz, exceeding the 1-dB power bandwidth of the klystrons.

The calorimetric power data with 1 MW of output power is shown in Table 1; the close power balance between the individual coaxial loads is apparent. The klystron output power was measured using a power meter on a WR2300 directional coupler immediately after the klystron output flange. Assuming waveguide and circulator transmission power losses of 15.5 kW and 40.1 kW, respectively, the calorimetric power calculation of the load power is within 2 percent of the total klystron rf output power, an accuracy sufficient to verify electronic power measurement data.

4 CONCLUSION

The 1-MW rf load system has proven to be adequate for high-power testing of the APS klystrons and rf transmission components. Future improvements to the load system include an on-board computer to perform real-time calorimetric calculations of the power dissipation for each coaxial load directly from the water flow and temperature data and to provide remote status readout capability over an RS232 data link. Permanent fans will also be installed on the load system to enhance the cooling of the coaxial transition components.

5 ACKNOWLEDGMENTS

The authors would like to thank Eugene Swetin and Andy Kelly of the APS Mechanical Engineering Group for their assistance in the design and assembly of the water system and support structure of the load. Work is supported by the U.S. Department of Energy, Office of Basic Energy Sciences, under Contract No. W-31-109-ENG-38.

6 REFERENCE

[1] R. E. Collin, *Foundations for Microwave Engineering*, McGraw-Hill, pp. 435-437, 1992.

Table 1: Calorimetric Power Data at 1 MW rf Input Power

	Load 1	**Load 2**	**Load 3**	**Load 4**
Flow Rate	40 gpm	40 gpm	40 gpm	40 gpm
Supply Temp, °C	30.6	30.6	30.6	30.6
Return Temp, °C	52.2	52.8	52.4	52.6
Water Power, kW	228.09	234.43	230.20	232.32

Total water heat = 925.04 kW

Estimated total waveguide transmission losses = 15.5 kW

Estimated circulator rf transmission losses = 41.0 kW

TOTAL rf power = 981.54 kW