TEST STAND FOR CONDITIONING HIGH POWER TETRODES AT TRIUMF *

N. V. Avreline†, V. Zvyagintsev, D. Gregoire, K. Piletskiy, TRIUMF, Vancouver, B.C., Canada

Abstract

A major part of the 520 MeV Cyclotron’s RF system is the high-power RF amplifier. The amplifier is based on eight 4CW250,000B tetrodes. A new high-power tetrode or a high-power tetrode that underwent refurbishing could trip the RF system through inner sparks. The likelihood of those sparks should be reduced prior to applying nominal power to the new and refurbished tetrodes. This could be achieved by RF conditioning of these tetrodes on a test stand. The test stand represents a 150 kW RF amplifier loaded by a dummy load. The amplifier is built using common grid schematics. The test stand’s output stage incorporates the 4CW250,000B tetrode that is under test. This paper describes the mechanical and electrical designs of the test stand, procedures of testing and conditioning for 4CW250,000B tetrodes, and the results of test stand’s commissioning.

INTRODUCTION

To reduce downtime of the 520 MeV Cyclotron at TRIUMF, the RF group is addressing RF system trips caused by sparks in the transmission line, in the cavity resonator or in vacuum RF tubes [1]. To mitigate internal sparking in vacuum RF tubes, a test stand has been designed and built.

The test stand has been built by retrofitting a 100 kW RF amplifier previously used in a mass-separator at TRIUMF. This RF amplifier originally operated with 50 kW and 100 kW vacuum tubes. During the retrofit, the output power of the original RF amplifier was increased to 150 kW. Also, the original RF amplifier has been equipped with a hoist mechanism for lifting and installation of RF tubes and LabView™ instruments to control forward power, reflected power and amplifier gain. Those modifications allowed the test stand to test 4CW250,000B tetrode RF tubes.

Furthermore, the existing filament power supply has been replaced with a DC power supply. Water cooling has been expanded to provide cooling for screen and grid in addition to the existing water cooling for anode and cathode. The blocking capacitor has been redesigned to tolerate higher voltage and to support larger RF tubes. Finally, the design of the new ramping circuit for the anode amplifier allowed to ramp voltage up to 20 kV instead of 15 kV in original configuration. The test stand uses a PLC to control all ramping stages and interlocks.

MAKEUP OF THE TEST STAND

The test stand is composed of three cabinets as is illustrated in Fig. 1. The first cabinet is the control cabinet that houses the PLC, the RF Driver, power supplies for the RF Driver, screen, and BIAS. The second cabinet is the RF amplifier cabinet that also contains the filament power supply. The third cabinet contains the 20 kV anode power supply. The schematic of high-power RF amplifier based on the high-power tetrode under test is presented in Fig. 2.

DESIGN OF OUTPUT POWER CAVITY

The 250 kW vacuum RF tube that is under test operates in C-class; output circuit represents quarter wavelength resonator loaded by output capacitance of this tube under test.

To determine resonance frequency and its Q-factor, an Eigenmode simulation in ANSYS HFSS of the output resonant circuit was performed, where the output capacitance \(C_{out} = 124 \text{ pF}\) of vacuum tube was modelled as two coaxial copper cylinders. The contribution of the blocking capacitor \(C_{blk} = 3.79 \text{ nF}\) to the overall results is only 1.7%. Therefore, for coarse estimation, it wasn’t included in the model. The resulting distribution of the electrical component of the RF field is shown in Fig. 3 and the simulation determined that \(f_0 = 23.41 \text{ MHz}\) and \(Q_0 = 13400\).

The blocking capacitor has been redesigned from original configuration and the new one has four layers of 5 mil Kapton instead of three layers in the original capacitor. The new capacitor withstood a high potential (HiPot) test of 29 kV.

Hoisting System for Tube Installation

As the weight of the 4CW250,000B tetrode is 45 kg, a lifting system is required to properly and safely install this tube. Therefore, the test stand uses two cable hoist mechanisms to lift this tube into place and also comes with a rail cart to move the tube into the output compartment of the RF cabinet (the second cabinet in Fig. 1). Fig. 4, a-c shows steps of tube installation:

1. The tube is brought on the a cart to the front of the test stand’s RF cabinet. The first hoist mechanism is attached to the tube and the tube is lifted from the cart.
2. The tube is installed onto the rail cart that would move the tube into the RF cabinet and the first hoist mechanism is detached. The tube is moved inside the cabinet.
3. The second hoist mechanism is attached to lift the tube from the cart. The rail cart is removed and the tube is inserted into the socket inside the RF cabinet.

Copper Cover for the Tube

The RF tube uses a steel cooling water jacket with polyethylene water supply hoses. An additional copper cover for tube was designed, manufactured and installed (see Fig. 4. d) to protect the water supply hoses from RF power,
to increase the stability of RF connections, and to avoid RF losses in the steel water jacket. A bal seal was used to ensure a good RF connection between the blocking capacitor and the copper cover.

**POWER GAIN CALCULATION BASED ON MEASURED DATA**

The output circuit represents a quarter wavelength cavity resonator loaded by the output capacitance \( C_{out} \) of the tetrode. This resonator could be equivalently represented by a parallel resonance circuit. The active load of the tube \( R_L \) of this equivalent circuit could be calculated by formula:

\[
R_L = Q_L \frac{1}{\frac{1}{2\pi f_0 C_{out}}}
\]

where \( Q_L \) is the loaded quality factor. Finally, we also have the following formula to calculate gain [2]:

\[
K_p = \mu_{ts} \frac{R_L}{R_L + R_i}
\]

where \( \mu_{ts} \) is tube gain, \( R_i = \frac{\mu_{ts}}{S_{ts}} \) is plate resistance, and \( S_{ts} \) is transconductance. The values of \( \mu_{ts} = 300 \), \( S_{ts} = 23.3 \, \text{mA/V} \).
Figure 4: Installation of the tube in the test stand (a-c) and the tube’s copper jacket (d).

\[ C_{\text{out}} = 124 \, \text{pF} \] were obtained from the characteristics presented in the tube’s datasheet. Then \( f_0 = 20.07 \, \text{MHz} \) and \( Q_L = 83 \) were obtained from measurements. Therefore, we get \( R_i = 12.8 \, \text{k}\Omega \), \( R_L = 5.3 \, \text{k}\Omega \) and \( K_p = 88 \).

**INPUT CIRCUIT OF THE HIGH-POWER RF AMPLIFIER**

The test stand uses Pi-network matching circuit, composed of two adjustable vacuum capacitors C6 (480 pF) and C10 (337 pF) and of the inductor L5 (180 nH). To prevent reflections in the line that give rise to undesired modes of operation, the transmission line has an electrical length that is an integer multiple of half wave lengths.

**INTERLOCKS AND PLC**

The interlock system of the test stand is based on a MicroLogix 1000 PLC. It provides the start and stop sequences for test stand, reset operation, interlocks for water, air flow, doors, and for the ground stick. The PLC also indicates the statuses of the filament power supply (PS), BIAS PS, anode PS, screen PS, shows overloaded PSs for BIAS, anode, screen and “RF Driver only” status. Finally, the PLC provides a time delay after filament ramping.

**ANODE DC HIGH VOLTAGE CONDITIONING**

In addition to RF conditioning of vacuum tubes, the test stand could also be used for DC high voltage conditioning of tubes, as recommended by the manufacturer [3]. New tubes following filament conditioning sometimes lose potential of holding full range of high voltage in the anode. To recover electrical strength of such tubes, the test stand with HiPot tester is used for high voltage conditioning (see Fig. 5). Figure 6 shows that after two months of conditioning rate of improvement diminishes.

**CONCLUSIONS**

DC commissioning of the test stand was performed with 15.5 kV anode voltage which was enough to obtain 80 kW RF power for 4CW250,000B tetrode. In the near future, we plan to complete RF commissioning and upgrade the anode power supply’s ramping circuit to allow to RF test and to RF condition vacuum tube with anode voltage up to 20 kV.

**REFERENCES**

