DEVELOPMENT OF 100 KW RF AMPLIFIER FOR SUPERCONDUCTING CYCLOTRON AT VECC

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Abstract

High power rf amplifiers (3 nos.) have been developed at our centre for feeding power to three nos. of coaxial rf cavities of the k500 Superconducting Cyclotron. Each of this amplifier can supply output power of 100 kW (max.) at 50 ohm impedance within the frequency range of 9 MHz to 27 MHz. The amplifier, based on Eimac 4CW 150,000E water-cooled tetrode, is tuned by moving the sliding short of the coaxial cavity within the said frequency range[1]. An inductive coupling loop is inserted along one side of the coaxial cavity through the sliding short and is matching the output impedance of 50 ohm. The four identical Bridge-T networks in the grid of the final amplifier are driven with equal power levels of up to 150 watts. The amplifier is operated in Class-AB mode with power gain of 22 dB. Anode Power supply of 20 KV@7.5A, Screen Power supply of 1.5 KV@1A, Grid Power supply of -500V, and Filament power supply of 15.5V@215A are applied to the terminals of the aforesaid tetrode. A PC-based stepper motor controlled sliding short movement system have been developed. The movement of the 3 transmitter cavities for tuning at different frequencies can be done from a computer located in the main RF control room through LAN. This system has been used for movement of the sliding shorts of the 3 transmitter cavities for different measurements including Q, shunt impedances etc at different resonating frequency at different length of the cavity. Limit switches are connected at the cavity for upper limit and lower limit. These limits are decided according to required cavity length at 9MHz (lowest freq) and 27 MHz (highest freq).The frequency response of the input circuit of the amplifier has been measured using Vector Network Analyzer.

POWER AMPLIFIER

The high power rf amplifier (Cross-sectional view as shown in Fig.1.) is based on Eimac 4CW 150,000E water-cooled tetrode[2] and the output tank circuit of the amplifier consists of a λ/4 type variable length coaxial cavity. The short-circuited coaxial cavity is tuned by the precise movement (minimum 50 μm corresponding to tuning accuracy of 19.35 Hz at the lowest frequency and 1.135 kHz at the highest frequency) of the sliding short within the operating frequency range of 9 MHz to 27 MHz under unloaded condition.

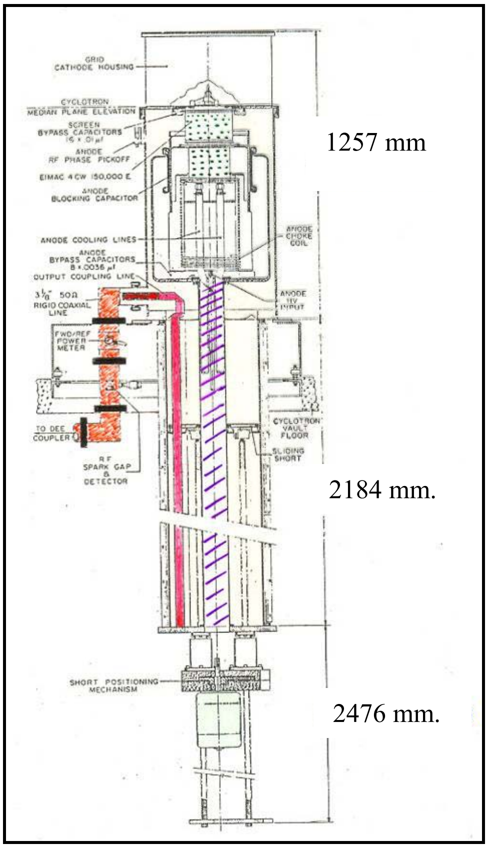

Figure 1: Cross-sectional view of high power rf amplifier.

The coaxial line is made of hexagonal outer conductor (with each side of hexagon 201.65±0.05 mm.) and circular inner conductor (with outer diameter 58.42±0.05 mm.). The sliding short plate is electrically connected to the outer and inner conductor of coaxial line by Be-Cu contact finger (as shown in Fig.2.) with sliver-graphite (99%Ag +1%C) contact ball at the tip. The sliding short contact must operate below the copper softening temperature (~460^{o}k), since the softening could lead to fusion welding. The inner and outer conductors are aligned concentric preferably within ±0.25 mm., because large asymmetry may give rise to uneven stress on the contact finger. The contact resistance is of the order of 0.7mΩ per finger.

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Figure 2: Sliding short contact fingers for amplifier

An inductive coupling loop is inserted along one side of the cavity (through the sliding short) at 1/5th voltage point to reflect nearly constant impedance at the anode of the tetrode. But as the length of the loop is comparable to operating wavelength, this assumption is not valid. So, by loop area trade-off it is kept in required range. Anode shell heavily loads the tank circuit, thus reducing the cavity length and shifting the cavity higher order modes beyond 66 MHz. The output rf power (~ 100 kW max) is taken out at 50Ω impedance through this inductive loop, which is matching the high cavity impedance to 50Ω.

The four identical Bridge-T networks (see Fig.3) in the grid of the final amplifier are driven with equal power levels of up to 150 watts each. VSWR of the input circuit of the amplifier has been measured using VNA (See Fig.4.) and obtained max of 1.14 at 18.18 MHz.

Figure 3: Input circuit (assembled) for amplifier

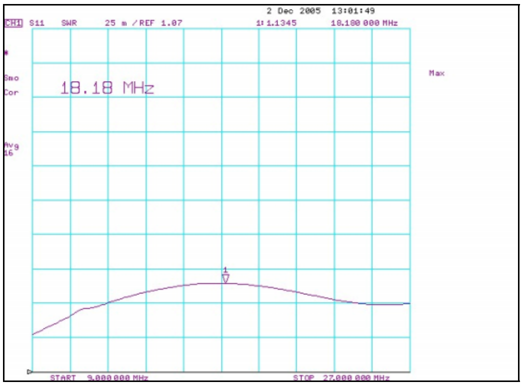

Figure 4: VNA measurement of input VSWR

The precise movement of the sliding short is accomplished by a PC-based Stepper motor controlled system (as shown in Fig.5.), that can be operated locally or from RF Control Room through LAN.

Figure 5: Stepper motor assembly with amplifier sliding short.

Limit switches (as shown in Fig.6.) are connected with the cavity for upper limit and lower limit of the movement. These limits are decided according to the required cavity length at 9 MHz (lowest freq) and 27 MHz (highest freq).

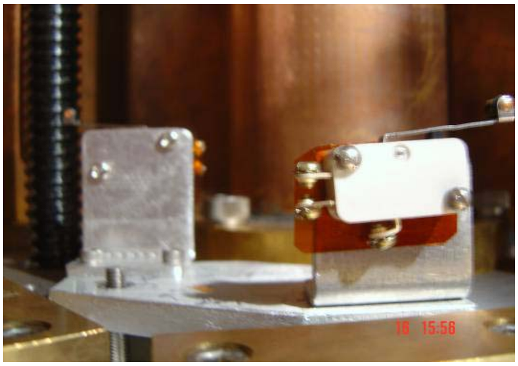

Figure 6: Limit switches assembly of the cavity

The anode of the tetrode is coupled to the cavity by a cylindrical Blocking capacitor (~ 3000 pF) as shown in Fig.7 & 8.

Figure 7: Anode Blocking Capacitor.

DC power supply (20kV@22.5A for 3 amplifier anodes) is fed to the anode through RF Choke (100 µH) and High Voltage Filter capacitors (3600 pF x 8 Nos. , 30 kV) as shown in Fig.9.

Figure 8: Tetrode assembled with anode blocking capacitor.

Figure 9: Assembly of RF Choke & HV Filter capacitors.

DC Power supply (1.5 KV@1A) is also made and fed to screen terminal. Screen by-pass capacitor (10000pF x 16 nos., 2.5kV) assembly is shown in Fig.10.

Figure 10: Assembly of Screen by-pass capacitors.

The measured unloaded Q of the cavity varies from 4300 to 1800 (as shown in Fig.11) and the measured loaded shunt impedance values vary from 5kΩ to 1kΩ for 9 MHz to 27 MHz as shown in Fig.12. Only for low frequency near 9 MHz presence of higher order modes is found[3]. But the values are significantly small. At 9 MHz, next higher order mode is found near 66 MHz with shunt impedance of 1.5k and at 10 MHz, next higher order mode is found near 81 MHz with shunt impedance of 1k.

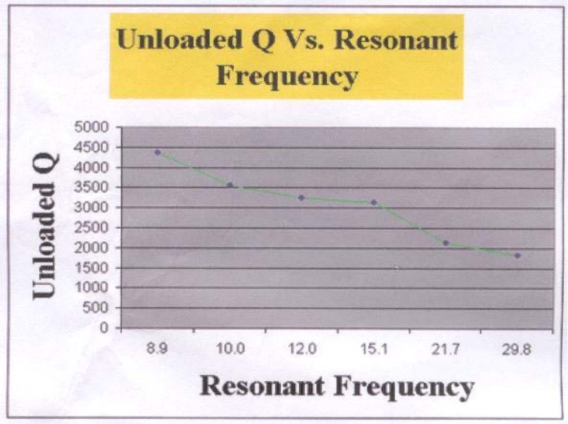

Figure 11: Unloaded Q vs. resonant frequency.

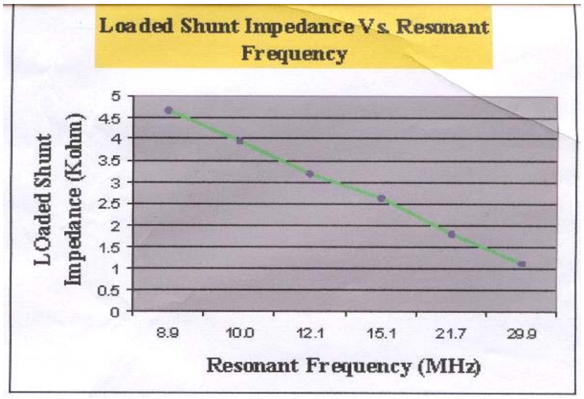

Figure 12: Loaded Shunt Impedance vs. resonant frequency.

CONCLUSION

Three nos. of 100 kW rf power amplifiers have been installed in the vault area of k500 Superconducting cyclotron building. The cold rf measurements of the amplifier cavity has been successfully carried out using Vector Network analyser (VNA). The warm rf measurements with dummy load are yet to be performed as cable laying are in progress and will be completed soon. The tetrode has been leak tested with 17 gpm of LCW flow at 80 PSI before assembly.

REFERENCES

[1] S. Som et. All, "An overview of the RF system of k500 Superconducting Cyclotron at VECC", InPac-2005, C-139.

[2] S. Paul et. All, "Overview of control and power electronics of k500 RF system". InPac-2005, C-141.

[3] S. Som et. All, "Present status of radiofrequency system of superconducting cyclotron at VECC", InPac-2006.