COMMISSIONING EXPERIENCE OF THE RF SYSTEM OF K500 SUPERCONDUCTING CYCLOTRON AT VECC

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Abstract

Radio frequency system of Superconducting cyclotron at VECC, Kolkata, has been developed to achieve accelerating voltage of 100 kV max. With frequency, amplitude and phase stability of 0.1 ppm, 100 ppm and ±0.5o respectively in the frequency range of 9 – 27 MHz. Each of the three half-wave coaxial cavity is fed with rf power (80kW max.) from each of the three high power final rf amplifiers based on Eimac 4CW150,000E tetrodes. Initially, the whole three-phase RF system has been tuned for operation with RF power to the cavities at 19.1994 MHz and thereafter commissioned the cyclotron with neon 3+ beam at external radius at 14.0 MHz. In this paper, we present brief description of the rf system and behaviour observed during initial conditioning of the cavities with rf power and the way to get out of multipacting zone together with discussion on our operational experience. We have so far achieved dee voltage up to 57 kV at 14 MHz with 20 kW of RF power fed at each of the three dees and achieved vacuum level of 4.5 x 10-7 mbar inside the beam chamber. We also present discussion on the problems and failures of some RF components during commissioning stage and rectifications done to solve the same.

INTRODUCTION

The Radiofrequency system of k500 Superconducting Cyclotron including the development of high power rf amplifiers, design aspects of rf cavities and their coarse frequency tuning mechanism, low-level electronic controls like three-phase signal generation, phase detection, amplitude regulation, phase regulation etc. of the complete rf system and Programmable logic controller based interlocks for the safety of the rf system and personnel, have been thoroughly described in various status and review papers presented in a number of conferences [1-8]. In the following sections, we will discuss the commissioning experience of the rf system gained so far, some major problems we faced and finally the solutions or rectification we decided to incorporate in the system for better reliability.

RF AMPLIFIERS

Three high power rf amplifiers (each having 80kW output at 50 Ohm) for feeding power to the three main rf cavities have been installed at the vault of Superconducting cyclotron building (as shown in Fig.1) and are driven by solid-state wideband amplifiers in the specified frequency range.

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Fig.1. High power rf amplifiers installed at SCC Vault

Each of the high power rf amplifiers consists of Eimac 4CW 150,000E water-cooled tetrode as active device and with individual cavity tuneable by moving the sliding short, similar to that used for the main dee resonator cavity. The four identical Bridge-T network in the grid of the final amplifier are driven with equal power levels of up to 300 watts. PLC-based interlock system for all parameters like all water interlocks for main cavities, amplifier cavities and tetrodes, interlocks for DC power supplies related to RF amplifiers, airflow interlocks for dee-stem alumina window cooling, coupler alumina cooling and amplifier internal cooling etc. was in operation before putting on the rf system. DC power supplies for the tetrode – 3 nos. of Filament P/S (15.5V/215A), 3 nos. of Control Grid P/S (–400V to –200V), one no. of Anode P/S (20kV/22.5A) with fast crowbar protection for 3 amplifiers and 3 nos. of Screen Grid P/S (1.5kV/0.5A) were tested and installed. Amplifier cavity was tuned (with VNA connected at Anode pick-up port) by moving the position of its sliding short with the help of a PC-based stepper motor controlled drive system with positional accuracy better than 20μm.

PROBLEMS IN AMPLIFIERS

We encountered a problem in high power RF Amplifier-B after few months of operation with RF. Under DC condition with 2.5A anode current, suddenly we observed RF power appeared in the power meter. It seems the amplifier is oscillating and observed the oscillation at 1.083GHz on a 6 GHz Spectrum Analyzer. As this kind of high frequency oscillation can appear only from the tetrode itself, we replaced that particular tetrode with a new one and the problem got solved.

In one occasion, we found in one amplifier that as soon as screen grid power supply is put on, it trips. On close observation it was found that control-grid current is much higher than the usual operating value (bleeder current).

Finally it was detected that the grid terminal of the tetrode socket (Eimac SK-2011A) is electrically short with ground due to it's insulation breakdown. In another occasion, for the same initial observation, the control-grid terminal of the tetrode was detected electrically short with the ground under hot condition. However, in cold condition the shorting problem disappears. In the above two cases, the socket and the tetrode were replaced with new ones respectively.

MAIN RF CAVITIES

Before, energizing the cavity, we properly tuned the main RF cavity (two quarter-wave one-end short-circuited coaxial transmission line sections making half-wave resonant cavity of around 12 m length) first with the movement of two sliding shorts of two λ/4 sections for coarse frequency and the loaded Q of the cavity is measured (as shown in Fig.2) using Vector Network Analyzer (VNA).

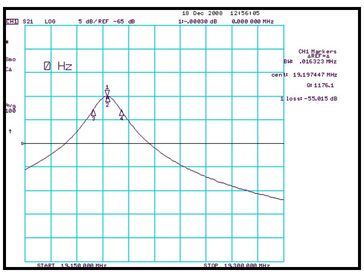

Fig.2.Measurement of main cavity parameters using VNA

It is to be noted that the position of the two sliding shorts (up and down) of one half-wave coaxial cavity is almost same, thus confirming the system symmetry good enough to use geometrical symmetry for positioning the sliding short. Three cavities, however, have slightly different parameters due to different dee capacitances. This is a consequence of the resonant extraction mechanism that requires different dee radial extensions.

The precise movement of sliding short is accomplished by the same mechanism as adopted in case of amplifier cavity. Then PC-PLC-based hydraulic drive system [9], which is developed at VECC for the movement of coupling capacitor (coupler) and trimmer capacitor, is operated to move the coupler upward or downward for matching (as shown in Fig.3) the high shunt impedance of the cavity close to 50Ω, which is the output impedance of the high power RF amplifier. Finally, Trimmer capacitor is also operated for fine tuning.

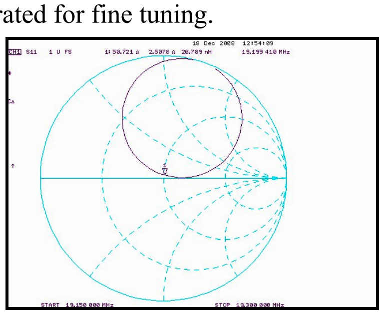

Fig.3. Measurement of impedance at the input coupler

LOW-LEVEL ELECTRONICS

The closed loop amplitude control is done by Dee Voltage regulator (DVR) unit. DVR is based on AD834JN RF Modulator [10] that modulates the RF drive signal according to the error signal between highly stable dc reference (REF01) and the feedback sample obtained from Dee pick-up signal.

Any deviation of sample phase from the reference phase is detected by the phase detector that produces dc error signal, which, in turn, controls online I&Q phase modulator and lock the phase to its reference within $\pm 0.5^{o}$. Phase detectors, based on double balanced mixer, have been fabricated using MCL-RPD-1 having response of 8mV/degree in +8dBm saturated mode.

CAVITY CONDITIONING

With vacuum level inside the cavity having $1.0\text{x}10^{-6}$ mbar and magnetic field off, we started feeding RF power in the cavity at 19.2 MHz and immediately observed pressure increasing rapidly. When RF drive is put off, vacuum level improved very fast and came back to the original level. This indicates that the phenomena of multipacting occurred in the virgin cavity with a lot of trapped gases and they were getting ionized under the low power rf field. After some time we increased the power level to around 1kW and kept on feeding RF power to the cavity in pulsating mode for about 3 hours and thus finally we could overcome the multipacting zone and achieved steady RF field inside the cavity. Vacuum interlock was set at $5.0\text{x}10^{-6}$ mbar.

It is to be noted that to cross the multipacting level, pulsed input rf power of around 2kW is preferred in order to reduce the conditioning time. After few days of round-the-clock operation, we could achieve Dee voltage up to 45kV at 19.2 MHz, with forward input rf power of 20kW into the cavity measured with RF power meter of make-Bird Electronic Corp.,USA. The amplitude of the dee voltage is measured by dee-pick-up signal, once calibrated by Vector Network Analyzer according to the shunt impedance of the cavity.

COUPLER & DEE-STEM ALUMINA INSULATOR PROBLEMS

During first RF power test, we had one coupler failure. After initial conditioning of the cavities, when around 17 kW of RF power was fed to the cavity-C, suddenly pressure burst occurred with vacuum interlock operated and RF tripped. The vacuum level was not restored at all. Finally, it was identified that the ceramic (alumina) to copper brazing inside the coupler (as shown in Fig.4) has been damaged. The obvious mechanism of destruction is persistent arcing on the air side of alumina. However, the other two identical couplers for cavity-A & B are working fine each with 20 kW of RF power at 14 MHz till date. Probably, there was a manufacturing defect existing in that particular coupler. We have now incorporated reflected power interlock, which eventually withdraws RF power if the reflected power exceeds the set limit (100W).

We had encountered dee-stem alumina insulator damages few times for different cavities. The dee-stem upper and lower cavity with alumina insulators is shown in Fig.5, The alumina window got cracked twice for upper cavity-C, once each for lower cavity-B and C and upper cavity-B. The photo of cracked alumina for cavity-C is shown in Fig.6. We are analysing the causes of alumina failures. Probably, the local multipacting is taking place near the alumina (vacuum side). We are also thinking of thin coating of titanium on the alumina surface to minimize possible multipacting effect.

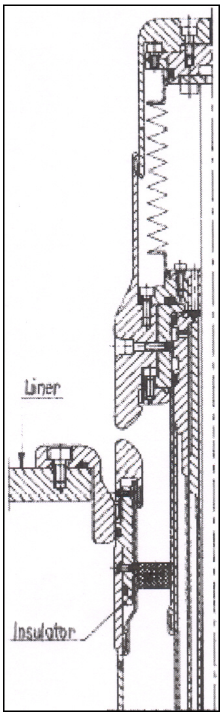

Fig.4.

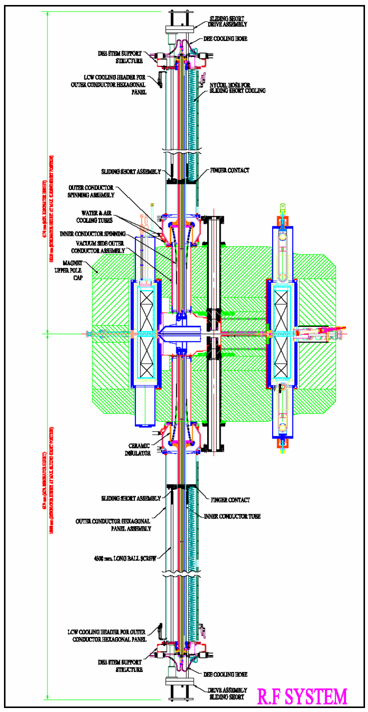

Fig.5.

Fig.4. Assembly of RF Power Coupler

Fig.5. Assembly of one cavity with dee-stem insulators

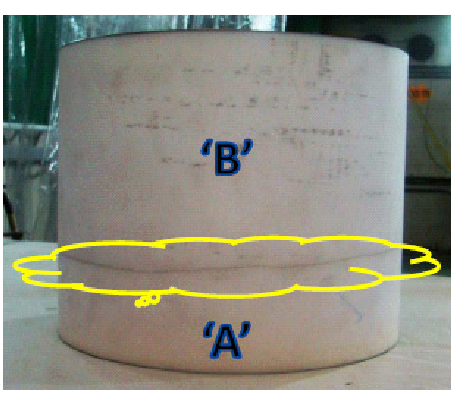

Fig.6. Cracked alumina insulator for cavity-C

CONCLUSION

Despite the problem in one coupler and few dee-stem alumina insulators, the general behaviour of the overall radio-frequency system during high power tests has been very satisfactory. The performance of major rf components were very well and reliable. The damaged coupler and dee-stem alumina insulators have been replaced by new ones and performed satisfactorily, without any further failure at 14 MHz RF frequency, with power level up to 20 kW. We have already obtained accelerated neon 3+ internal beam (40 nA) at the extraction radius with RF frequency 14 MHz from the k500 Superconducting Cyclotron successfully on 14^{th} August, 2009. After that machine was shut down for installation of external beam lines, deflector etc. and now again the same neon3+ beam tuning is in progress and hoping to get the external beam very soon.

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