LINE-TYPE MODULATOR DEVELOPMENT FOR MULTI-BEAM KLYSTRON IN 10 MEV INDUSTRIAL ELECTRON LINAC

Abhijit Tillu*, Shiv Chandan, Kavita Dixit, Vivek Yadav, Ramchandra Chavan, K.C.Mittal & D.P.Chakravarthy, APPD, BARC
S.Y.Kulkarni & Amol Bhagwat, MED,SAMEER.

Abstract

At Electron Beam Centre, India, a 10MeV industrial electron linac has been designed, developed, commissioned and is regularly operating at ~3 kW beam power. The Linac is driven by a 6 MW (peak) and 25 kW (avg) multi beam klystron (Toriy KIU147A) at 2856 MHz. It is rated for maximum 55 kV, 300 A, 10µsec pulse at 400pps. The paper describes the step by step development of the klystron modulator including the testing of the klystron modulator on the resistive load, impedance matching issues with klystron load, the first-pulse problem & finally long term operation of the klystron modulator. The paper also describes the problems faced after prolonged operation, as with respect to HV arcing inside the klystron, and hence replacement of klystron followed by PFN tuning and testing at full peak power.

INTRODUCTION

BARC and SAMEER are jointly developing a 10MeV, 10kW Industrial Electron Linac based Irradiation facility at Electron Beam Centre, India. The RF source, designed and developed by SAMEER, consists of a line-type pulse modulator powering the TORIY-make klystron (KIU-147A) that generates 6 MW (peak)/25 kW (avg.) power output at 2856MHz. The klystron output is given to the linac through the RF plumb line consisting of directional couplers, circulator with matched load, bends with arc detectors and RF window.

KLYSTRON MODULATOR

The klystron modulator is a conventional line type modulator. The 10 stage PFN has a total capacitance of 400nF. The PFN charging choke has an inductance of ~0.57H, The PFN is charged to ~26kV in 1.5msec. On triggering the thyratron the pfn discharges its energy in the load in a time duration of 10µsec. The 1:4 HV pulse transformer steps up the voltage to a maximum of 52kV. After successful testing of the modulator on a resistive load, at full peak power, the modulator was integrated with the klystron. The modulator was tested at a pulse repetition frequency of 40 Hz and full rated peak power (Vdc = 13.6 kV) on a resistive load of 180Ω. The fig 1 shows the output waveform. The 180Ω load consists of 5 nos. of 36 Ω non-inductive resistors in series. The waveform was recorded across the lower 2 resistors. The testing was done at 40 pps, because of limitation on the power dissipation capacity of the Resistive Load.

----

*abhijittillu@rediffmail.com

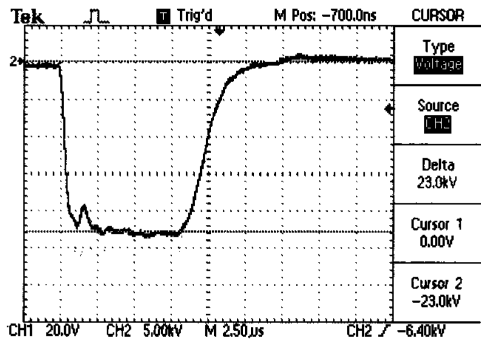

Fig.1: Output of modulator across resistive load

The conventional line type modulator is designed to power a 180Ω load. The pfn is designed to have a characteristic impedance of ~12.5Ω. There is a slight negative mismatch between the pfn and the load (as seen by the primary). .After successfully testing the system on resistive load, the klystron was connected to the modulator. The klystron filament was conditioned for 24 hours by slowly increasing the filament power till 700 W. The RF input of the klystron was terminated in 50Ω and the klystron pulsed voltage was slowly increased at a low PRF of ~ 5 pps. The HVDC was slowly increased from minimum using the 3*Φ* autotransformer. The waveform of Fig.2 shows the voltage developed across the primary of the Pulse transformer at low charging voltage as observed with a HV voltage probe (Tektronix P6015). The staircase pattern observed indicates severe positive mismatch. As the voltage was increased beyond ~1.75kV DC, the thyratron went into continuous conduction

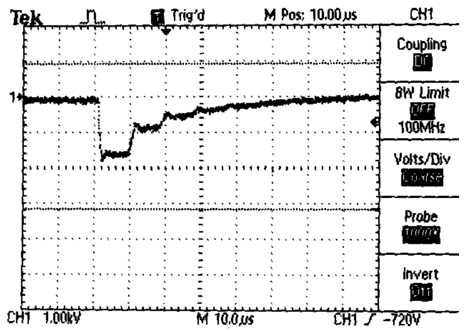

fig2: Severe positive mismatch at very low pulse voltages.

V-I CHARACTERIZATION OF KLYSTRON

The problem of thyratron going in continuous conduction at low HVDC was eliminated by connecting a 25Ω resistance in parallel to the primary of klystron pulse transformer and the klystron VI characteristics for the klystron were plotted. During the above measurements the problem of thyratron continuous conduction at lower HVDC was solved at the cost of severe negative mismatch at higher HVDC, i.e. for a klystron primary voltage of 8 kV, HVDC of ~9.5kV was required..

Table1: VI Characteristics of the klystron

V_{kly} (kV)	I_{kly}(A)	Z_{kly} (Ω)	$Z_{pri}=Z_{kly}/16$ (Ω)
28	80	350.0	21.87
32	102	313.7	19.61
40	139	287.7	17.98
44	166	265.1	16.56
46	176	261.3	16.33
48	184	260.8	16.30
50	194	257.7	16.10
52	204	254.9	15.93

The results in Table 1 show that there is a deviation from the manufacturer's specifications, with the klystron showing a lower perveance and thus, presenting a higher impedance. Hence, it was necessary to redesign the PFN for an impedance of ~16 Ω. Because of ~ 25% reduction in current, maximum peak RF power of 4.6 MW was obtained from the klystron at 50 kV (instead of 6MW).

FIRST PULSE PROBLEM

When the modulator is off, pfn capacitors and the storage capacitor are both at zero potential. The instant the HV contactor is switched on, both the storage capacitor and the pfn capacitor start charging towards the V_{dc} and hence it was observed that $V_{pfn} = V_{dc}$, instead of $2V_{dc}$, as expected for resonant charging. Hence, when the thyratron is triggered, the voltage developed across the klystron is almost half the nominal operating voltage, as the impedance offered by the klystron at that voltage is greater than the nominal operating impedance. This causes positive mismatch for the first pulse. This may lead to thyratron going into continuous conduction, especially in high duty cycle modulators, where the charging inductance cannot be high and is limited by the PRF. In the present case, PFN was initially tuned to have characteristic impedance of ~ 16 Ω. Since the first pulse across the klystron is of ~28kV, the klystron offers an impedance of ~ 350 Ω, resulting in reflected impedance of ~21 Ω as seen by the primary. This caused positive mismatch and hence thyratron going into continuous conduction, and tripping the system.

The pfn was hence tuned to have a slightly higher characteristic impedance of ~18 Ω, thus mitigating the problem, at a cost of slightly larger negative mismatch at operating voltage.

BACK-SWING REDUCTION

For any reverse voltage across the klystron, the klystron offers infinite impedance. Hence at the end of the pulse when the thyratron has commuted, large back-swing appears across the klystron, if is there is no designed path for the HV Pulse transformer magnetizing current to decay. This is shown in Fig.3.

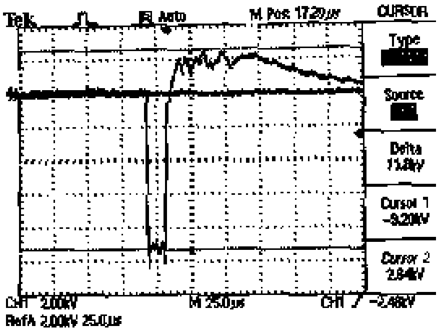

Fig 3: Back-swing at the end of the pulse

The measurement is taken across the primary of the HV pulse transformer. As can be seen, for a primary pulse voltage of 9.2 kV, there is a back swing of ~ 2.5 kV. To overcome this problem, a resistor diode series combination (Tail Clipper) is connected across the pulse transformer primary, such that the Pulse transformer magnetizing current decays through this resistor. With the tail clipper in place, the back-swing was reduced to less than 1.0 kV at 11 kV peak voltage

KLYSTRON REPLACEMENT

After ~ 4 years of operation, electrical arcing was seen inside the klystron, when in operation at 2.6 MW Peak (RF) and 410 Hz. This arcing resulted in ringing on the klystron current and total reflection of PFN voltage. There was no change in the V-I characteristics of the klystron or the filament. However at higher voltages (beyond 25kV), arcing was observed after a few good pulses. The Klystron was replaced by spare klystron of the same make and the V-I characteristics were confirmed using the same procedure mentioned above. Unlike earlier case, the V-I characteristics matched the manufacturer's specifications. hence the pfn was re-tuned to ~14 Ω. The klystron was tested on a water load up to 5.3 MW peak power. Maximum klystron current was 235 A at a voltage of 50 kV.

CONCLUSION

The klystron modulator is operating successfully at ~42kV, 176A, 10µsec, 3.2MW (Peak RF), 300Hz . The modulator has been tested for 24 hours continuous operation at the above stated parameters. It has been operated at 400pps and3.5MW (RF) for more than 4 hours on many occasions.

REEFRENCES

1. A.R.Tillu, et. al., "Commissioning of the RF system of 10MeV Industrial RF Linac", InPAC 2006 pp339-340
2. Glasoe & Lebacqz, "Pulse Generators" McGraw Hill, New York 1948