DEVELOPMENT OF S-BAND RF POWER SOURCE FOR 10MEV INDUSTRIAL LINAC

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Abstract

A 10 MeV RF Electron Linac has been indigenously designed, developed, commissioned and is being operated regularly at beam power of 3kW for industrial applications. The pulsed S-band bi-periodic standing-wave structure Linac is driven by a 6 MW (peak), 25 kW (average) klystron at 2856 MHz. The klystron-based system has been tested on matched water load and then integrated with the linac. RF conditioning of the structure has been carried out at 4 MW (pk), 16 kW (avg), without electron beam. Beam trials have been successfully accomplished up to a beam power of 3 kW (avg). This paper summarizes the development and testing of the RF source, both on matched load and linac load. The problems faced and the solutions successfully implemented are described. RF conditioning and results of linac operation up to a beam power of 5 kW are also presented.

INTRODUCTION

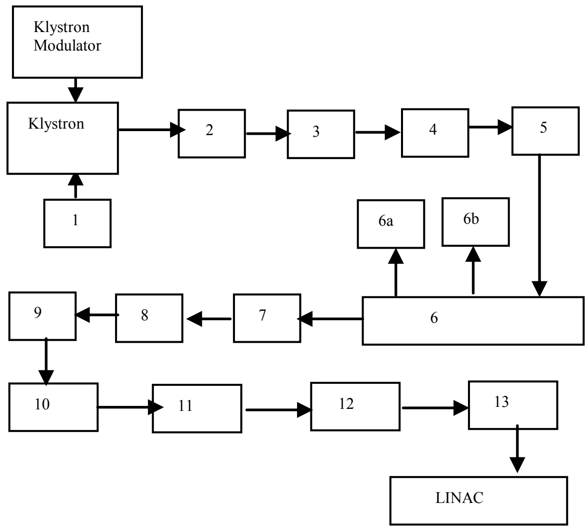
A 10MeV RF Industrial Electron LINAC [1] is in operation at EBC, Kharghar. This LINAC uses a Toriy (KIU-147A) make Klystron with duty cycle of 0.4% (i.e. 10µsec, 400Hz). The RF source consists of a line type pulse modulator powering the klystron. Microwave components like directional couplers, circulator with matched load, bends with arc detectors and RF window are used for transmission of microwave power from Klystron to LINAC. Pulsed driver amplifier of 110W was used to give low RF power to Klystron input cavity.

KLYSTRON TESTING ON WATER LOAD

Klystron was first tested on water load. For power measurement, a loop type directional coupler with forward & reverse coupling of 55 dB and directivity of 25dB was used. Klystron modulator was tuned to impedance of 16Ω. Klystron was first operated in the diode mode and its VI characteristics were measured. Beam perveance of 21µPerveance was measured. Klystron was tested up to peak forward power of 5.5MW at 50kV, 235A. Reflected power was less than 1%. All these tests were done at PRF of 50Hz.

KLYSTRON TESTING ON LINAC LOAD

The schematic for testing the RF source on LINAC is shown in Fig1: For testing the Klystron on LINAC load, water load at circulator port 2 was disconnected and a second directional coupler (DDC-2) with forward coupling of 66.1dB, reverse coupling of 70.9dB and directivity of 30dB was used & a flexible waveguide were connected in the waveguide line. To isolate the vacuum in the LINAC & pressure in the waveguide line, RF window was connected between DDC-2 & LINAC. Waveguide line was pressurized with 2 bar SF6.



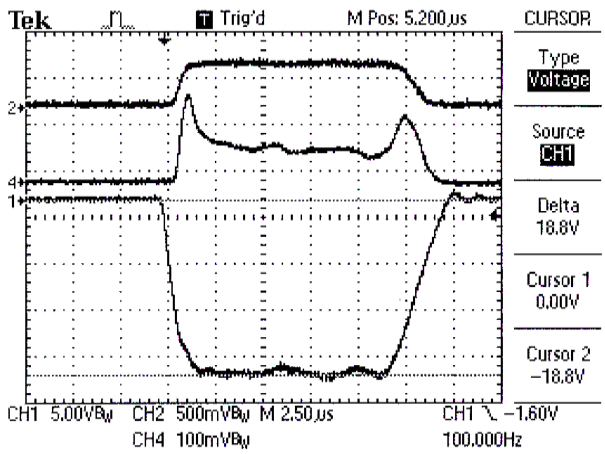
(1) Driver Amplifier (2) Flexible waveguide-1 (3) DDC-1(4) E bend-1 with arc detector (5) H bend-1 (6) 4-port Circulator with (6a & 6b) water loads (7) H bend-2 (8) E bend-2 with arc detector (9) Flexible waveguide-2 (10) DDC-2 (11) Straight waveguide section (12) Flexible waveguide-3 (13) RF Window.

Figure 1. Schematic of RF source

RF Conditioning of LINAC Cavity

Initially frequent arcing was observed at RF peak powers as low as 0.5MW. The arcing was accompanied with heavy out-gassing in the linac region, and total power reflection. On sustained arcing, the ARC detector (at linac side) would trip the modulator at such low peak powers. The vacuum level in the linac would deteriorate to 10^{-05} mbar range. Subsequently frequent arcing reduced after the RF conditioning of cavity. RF conditioning of cavity was done at variable PRF (minimum 10 Hz to a maximum of 400 Hz) at each peak power level of 500kW to 4MW in steps of 100kW. This took ~250 hours. During the RF conditioning of the linac cavity, a vacuum of 3.0×10^{-7} mbar was maintained throughout the complete linac system. Vacuum in the cavity & Reflected power signals were monitored to do the RF conditioning of linac

Cavity. The value of reflected power was minimized by tuning the frequency at the driver amplifier input within the range of 2856MHz ±500kHz. The reflected power was <10% of the forward power for all the forward power levels. The klystron current pulse and envelope of forward and reflected powers is as shown in Fig2.



Ch1: Klystron current $I_{kly}=V_{ch1}*10=188A$.

Ch2: Forward power envelope corresponding to 3.5MW.

Ch4: Reflected power envelope corresponding to ~200kW.

Fig2: 3.5MW peak, 3.5kW avg. power testing of klystron on LINAC

BEAM RESULTS

After conditioning the LINAC cavity with RF power, electron beam was injected into the LINAC cavity from 70kV, 1A pulsed Electron Gun. E-Gun Filament heating was kept at ~250W dc heating. Synchronous trigger pulses were given to driver amplifier, klystron modulator & E-Gun Modulator with delays ≤1µsec. Electron beam was accelerated in the presence of pulsed RF electromagnetic field in the cavity.

Experiments were done to check the effect of various linac parameters on output beam current. Beam current increase is ~25% with increase in RF power from 1.5MW to 3MW. Beam current increase is ~50% with increase in E-Gun injection voltage from 25kV to 50kV.Beam current increase is ~65% with increase in Gun Filament power from 200W to 250W. With PRF increase from 50Hz to 250Hz, Beam current increases by 30%.

Beam energy was measured using depth-dose technique by measuring charge collected on two Aluminium plates (top 12 mm & bottom 25mm). The experiment was done at fixed parameters of 5Hz, E-Gun injection voltage of 50kV and RF power from 2MW to 4MW at various beam currents. The experimental result matches with the theoretical calculations. Dependence of Beam energy on beam current & RF power (Theoretical analysis) is shown in Fig. 3.

LINAC was operated for ≥5hours at each beam power of 1kW to 4kW without any breakdown. System was also operated successfully for 24hours at 3kW beam power. Now, system is routinely being operated at 3kW for various Industrial and R&D experiments.

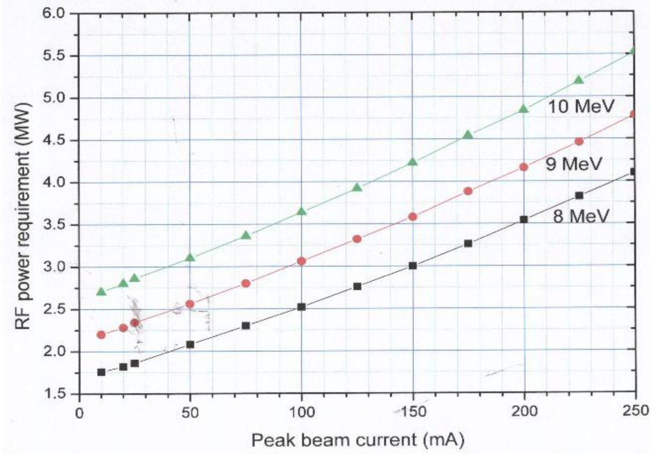


Fig. 3: Beam Energy Relation with Beam current & RF Power

TECHNOLOGICAL CHALLENGES

For operating the LINAC at beam power >2kW, many technological challenges were encountered. Different electronics placed in the LINAC radiation area like Arc detector connected at E-Bend, Vacuum gauges, temperature sensors and power meter sensors were either getting falsely actuated or got damaged in the presence of beam (>2kW). These components were then placed in power supply operating room.

Breakdown in RF window is observed at 3MW Klystron peak power due to improper RF contact and reflected power>25%. A new RF conducting copper gasket was designed, developed and connected with RF window.

Due to improper cooling pipe contact at LINAC central 5 cavities, frequency detuning was up to 750 kHz which is tuned by changing the klystron driver operating frequency. This detuning is restricting the long term beam power operation for >5kW, which is being tackled by improving the cooling pipe contact and installing a water chiller plant that will be operated at 30 ± 2^0C.

HIGH BEAM POWER RESULTS

With increase in E-Gun injection voltage up to 67kV, output beam current of 165mA was measured. LINAC System was operated at maximum beam parameters of 10MeV, 5.6kW for ~1hour.

CONCLUSION

The RF source was successfully tested up to 4MW peak & 16kW average power with LINAC as load, without any beam loading. Reliable beam operation at 3kW is routinely done.

REFERENCES

[1] K.C. Mittal, “Accelerators at Electron Beam Centre, Kharghar,” Proc. InPAC 2006, page 98-101.