DESIGN & OPERATIONAL EXPERIENCE & TESTING OF 50kW/120kHz OSCILLATOR FOR 3MeV, 30kW DC ACCELERATOR

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Abstract

A 3MeV, 30kW dc industrial electron beam Accelerator is being developed at EBC, Kharghar, Navi Mumbai. The 3MV dc is generated by parallel coupled voltage multiplier operating at 120 kHz. This requires an input voltage of 150kV-0-150kV at 120 kHz. This is achieved by 50kW/120kHz power oscillator in conjunction with a tuned air-core step-up transformer. Input primary voltage of 6kV-0-6kV at 120 kHz is generated by an oscillator using BW1121J2 water cooled triodes in push-pull Colpitts configuration. The tank circuit for the oscillator is formed by the secondary winding inductance of the step-up transformer and capacitance formed by RF feeder electrodes of the voltage multiplier column. Grid feedback for the oscillator is derived by arranging a set of electrodes in the feeder assembly in a capacitive divider configuration. The oscillator is operated in class-C mode with grid leak bias for better efficiency which also has the advantages of self-adjustment with varying load conditions. High power test has been conducted in a simulated test set-up on dummy load up to 30kW. Subsequently, the power oscillator has been tested with HV multiplier at 1MeV level satisfactorily. This paper describes the design, test results and operational experiences of the oscillator.

DESIGN FEATURES

The electrical schematic of the power oscillator is shown in the Fig.1. Oscillator is based on the water cooled triode tubes BW1121J2 (10kV, 6.5A dc) in push-pull Colpitts configuration operating in class-C mode for better efficiency. It has the following advantages of: (i) self adjustment with varying loads by grid-leak bias, (ii) immunity to high voltage surges, (iii) natural elimination of even harmonics, (iv) higher voltage output and hence ease of matching with RF transformer. The main challenge in the design and development of power oscillator involves the selection of the device (Triode tube), EMI shielding, HV insulation and power delivery of 50 kW to the load. In general the cabinet shielding is last thing for the design of the RF system but in our oscillator, the EMI shielding, cabinet selection, orientation of the component inside the cabinet, cable entry for power inlet/outlet have been considered in the design itself. The cabinet is made of the zinc coated steel of 3 mm thickness. The two sets of 800mm (w) x 800mm (d) x 2000mm (h) have been bayed together. The cable entry/outlet, aperture cut-out for fan and filters unit and LCW water inlet/outlet has been made in the cabinet manufacturing stage. The cabinet is having the shielding effectiveness of 80dB for E-field & 30dB for H-field at 120 kHz. The triode & associated circuit components like Filament transformer, RF chokes, blocking capacitors, grid-leak resistor and cooling water column coils are enclosed inside the cabinet whereas the tank circuit is located inside the accelerator tank in the accelerator cell area. EMC fan & filter unit has been provided in the cabinet for 3kW heat dissipated. Plate RF chokes (10mH, 10kV, 10A, 200Q) and grid RF chokes (10mH, 1kV, 1A, 200Q) have been designed and fabricated using Litz wire to minimize the eddy current losses. The distributed capacitances in the RF chokes were minimized by sectionalized winding and perforated insulators. This enabled to keep the self-resonance frequency >500 kHz. EMI filters are provided in the 230V ac power line to minimize RFI. LCW at a flow rate of 15LPM serves to cool the plates of triodes. Spiraled nylon braided PVC pipe with 1kV/m has been chosen to isolate 10kV dc plate voltage from ground. Electronic interlocks have been incorporated for protection of the system and operators safety. Output energy of the accelerator can be adjusted by varying the DC input voltage to the oscillator. In order to maintain the shielding effectiveness of the cabinet, visual display for various oscillator parameters are displayed on a separate local control cabinet. The photograph of oscillator assembly is shown in Fig.2.

The RF power transformer is located in a pressure vessel containing the SF_6 gas at 6 kg/cm^2 pressure for high voltage insulation & better heat removal. The single layer toroidal air core winding scheme has been adopted for transformer design. The Q factor the transformer is inversely proportional to the AC resistance, which is function of skin effect, proximity effect & distributed capacitance of winding. Considering this, Litz wire made of AWG-40 gauge copper wires rated for 50A at 120 kHz & spaced single layer winding are adopted. Winding dimensions of 1.5m OD, 0.6m ID & winding diameter of 0.45m have been arrived for achieving the minimum AC resistance. The calculated Q factor for this 5mH inductance is ~2000 at 120 kHz, which minimized the I^2R losses to about 6kW. The photograph of RF transformer is shown in Fig.3. The power handling capability for various cables for different frequencies has been done. The RG218 coaxial cable is being used for connection between oscillator to RF transformer.

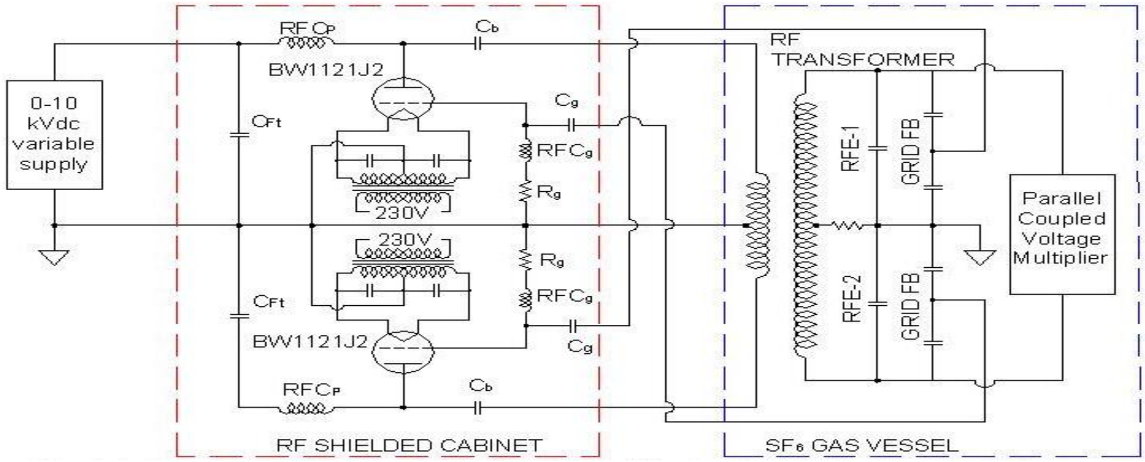

Fig.1. Schematic circuit diagram of 50 kW, 120kHz Push-Pull Power Oscillator

Fig.2 Assembly view of 50kW/120kHz push-pull oscillator

TEST SETUP AND RESULTS

The performance of oscillator was evaluated in two stages. First, a Hartley based tank circuit comprising of 110µH tank inductor &. 15.4nF tank capacitor has been fabricated. The output of oscillator has been rectified using high frequency rectifier rated for 24kV PIV and 30A in bridge configuration. Dummy load resistor rated for 2.5kΩ, 10kV, and 20kW has been assembled using 50kΩ, 1kW wire wound resistors. Photograph of the test setup is shown in Fig.4. Oscillator has been tested in the single ended mode up to 30kW at plate voltage of 6kV. The frequency was observed to be constant at 105 kHz with pure sine-wave.

Power Oscillator is also being used along with simulated tank circuit (Fig.5) for gun power supply testing. The power oscillator has been tested in push-pull mode with the HV multiplier system. The grid feedback imbalance has been corrected by adjusting the grid leak capacitor. RF balancing has been done using the trimmer capacitance plate kept between pressure vessel and RF electrodes. With this scheme, the operating frequency of the RF power source observed is 103kHz. The accelerator has been tested upto 1MeV, 7kW level satisfactorily. Further testing is in progress.

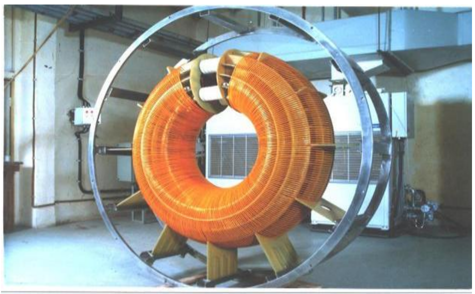

Fig. 3 RF transformer

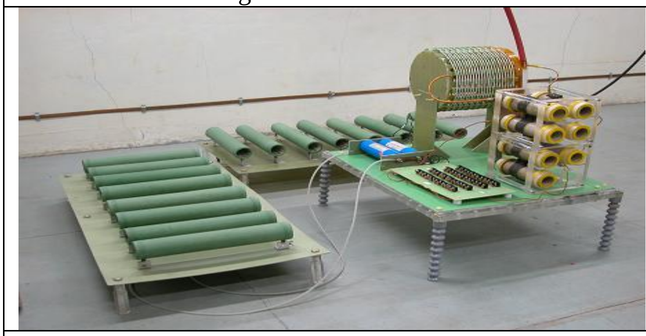

Fig.4Test setup for evaluating the oscillator

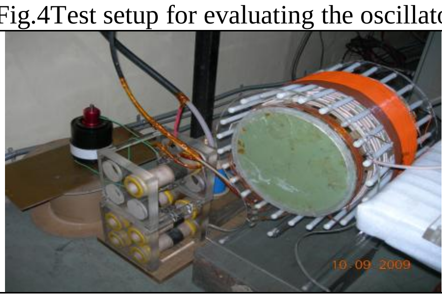

Fig. 5 Test tank circuit (110µH, 23nF) For gun power supply unit testing

REFERENCES

[1] R.I.Bakhtsingh, et.al "Design of 50kW, 300kV RF Source for 3MeV, 10mA Industrial Electron Accelerator" InPAC-2003, Feb, 2003, pp-447.

[2] E. May, Industrial HF Electric Power, p.42-156