PERFORMANCE OF 3MV VOLTAGE MULTIPLIER FOR 3MeV, 30kW DC ELECTRON BEAM ACCELERATOR AT EBC, KHARGHAR

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Abstract

In view of increasing demand of electron-beam treatment for value-addition of industrial products, BARC is setting up a 3MeV, 30kW DC accelerator at Electron Beam Center, Kharghar in Navi Mumbai. High-voltage source for this accelerator is a parallel-fed Cockcroft-Walton multiplier. The accelerator, presently undergoing commissioning phase, has delivered 7.0mA at 1MeV and 4.0mA at 1.5MeV energy. This paper presents operating performance details of the voltage multiplier in brief.

HIGH VOLTAGE SYSTEM

The ultra-high voltage DC required for acceleration of electron-beam is developed by a 74-stage parallel-fed capacitance-coupled, cascaded-rectifier system (similar to 'Dynamitron' in principle) driven by a 300kVp, 103kHz input source. Electron-current is generated by a LaB_6 cathode based 5kV electron gun located on top of a 2.8m tall accelerating column, which accelerates injected electron beam in a vacuum of 10^{-7} mbar. The voltage multiplier is configured in a cylindrical geometry around the accelerating column in SF_6 gas at 6kg/cm^2 pressure & enclosed in a vessel of 2.1m ID and 6.0m internal height.

The 3-phase input from mains is stabilized, stepped-up, rectified and filtered to achieve a variable 10kVDC, which is inverted at 103 kHz by a 50kW colpitts oscillator. An air-cored RF transformer located in a side-vessel steps-up this voltage at 300kVp, to feed a pair of semi-cylindrical RF Electrodes surrounding the voltage multiplier to develop 3MV DC at the UHV terminal.

DESIGN OF VOLTAGE MULTIPLIER

A parallel-fed CW multiplier offers numerous advantages over other HV generators viz. smaller ripple and regulation, high output-power at several MV level, low stored energy, lesser components and a self-healing dielectric, resulting in easier HV surge-protection and high reliability of operation.

Main sub-systems of the voltage multiplier include (i) a UHV terminal of 98cmOD x80cm height, (ii) the 80 Nos. of 97cmODx7cm(H) semi-circular corona-guards, (iii) an acrylic support-structure of 3.3m height and 64cmx64cm base, (iv) the 74 Nos. of rectifier-stacks of 176kV PIV and (v) a 3MV, 46GΩ resistive voltage divider [1].

Figure 1: (Left) multiplier sub-systems, (middle) acrylic-support with divider and (right) assembled multiplier.

Accelerating tubes are provided voltage grading by metal screened 250MΩ, 30kV resistor assemblies for even-distribution of the voltage in the accelerating column. Floating power for electron gun is acquired from the superimposed 50kV/103kHz component on corona-guards near high-voltage terminal. Fig.1 shows various components and the assembled HV multiplier. Design parameters are given in Table-1 below.

Table 1: Design parameters of voltage multiplier

Parameter	Value (as designed)	Value (as built)
Source Frequency	100- 120kHz	103 kHz
Step-up ratio	11	12.33
Capacitance (C_{SE})	≥ 3.6 pF	3.9 pF
Capacitance(C_{AC})	≤ 4.5 pF	4.4 pF
Regulation	10 %	11 %
Voltage stability	2%	± 0.3%

UHV Terminal

HV terminal is designed to form 100pF capacitance with ground and provide adequate space for locating electron-gun supplies inside. It is made of SS-304 with hemi-spherical shape and mirror-polished to limit HV stress and minimise surface-damage during HV sparks.

Corona-guards

These are designed to achieve specific geometric-capacitances [2] C_{SE} & C_{AC} for coupling 50kV, 103kHz on each corona-guard. They are fabricated from a specially-designed section of 6063-T6 aluminium and provided mirror-finish on exterior surfaces to limit electrical stress below 160kV/cm and achieve light-weight geometry.

Perspex Support-structure

Multiplier components viz. corona-guards, rectifier-stacks, HV terminal, voltage-divider etc. are supported on the Perspex-structure, which also provides necessary voltage-isolation between these components. It is fabricated from two 3.3mx64cmx52mm acrylic-sheets tied-together with 18 Nos. of SS-304 cross-plates using precisely designed studs and buffed/polished to withstand a working-stress of 14kV/cm(avg.) on insulator surface.

Rectifier-stacks

These are fabricated by series-stacking of 21 Nos. of 8kV, 350mA ultra-high frequency avalanche diodes and a lossy surge-limiting inductor (450µH, 2.1kΩ). The SLI limits forward surge current and blocks short-duration HV transients (~600kV) from reaching diodes. Each diode is surrounded by a polished, metallic cup-shield to protect them from external electric-fields and stray-electrons. Each rectifier-stack is shunted by a spark-gap in the multiplier to bypass HV surges to the ground during a HV spark in the multiplier.

PERFORMANCE OF THE MULTIPLIER

HV multiplier was tested in 6kg/cm^2 Nitrogen upto 1.4MV. Figure-2 shows various input-parameters i.e. HVDC input, RF Electrode voltage and HVDC power plotted against the multiplier voltage at no-load. Voltage step-up ratio of the multiplier is 12.33.

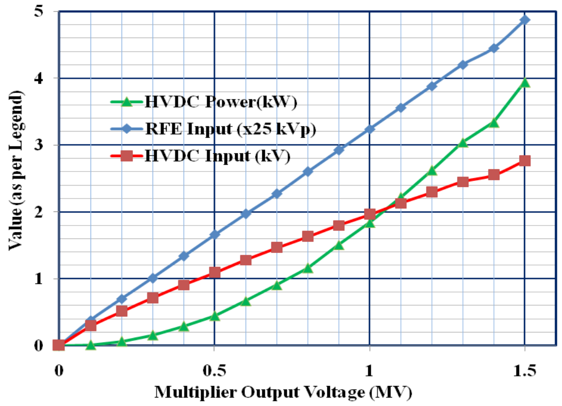

Figure 2: No-load input parameters of voltage multiplier.

The accelerator has been operated upto 7.0kW of beam power at 1.0MeV. Performance parameters with electron-beam load at 1MeV energy are plotted in Fig.3. The HVDC to UHVDC (i.e. electron-beam) power-conversion efficiency at 7kW output was found to be 48.2%. Extracted electron-beam on a collector in air is 4.85kW. Accelerator has also been operated upto 4.0mA of beam current at 1.5MeV in SF_6 gas medium.

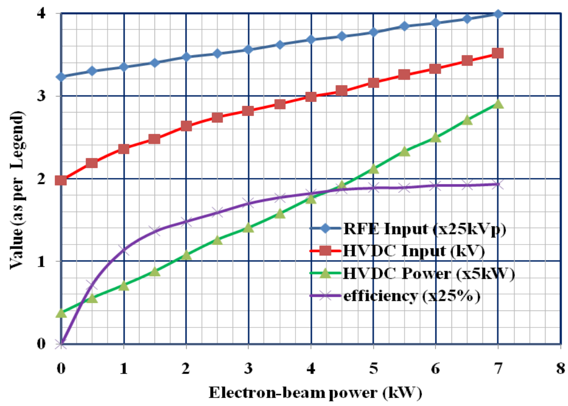

Figure 3: Performance parameters of the multiplier with electron-beam loading at 1.0MeV.

CONCLUSIONS

Voltage multiplier has performed as per the design values. During commissioning trials, multiplier has sustained more than 200 Nos. of spark break-downs without a single component failure observed till date.

REFERENCES

[1] D.K. Sharma et. al, "Design and Development of a Resistive Voltage Divider for 3MeV DC Accelerator", SEBTA'05, BARC, Mumbai, Sept. (2005), p-504.

[2] K. Nanu et. al, "Design of 3MV, 10mA, DC Power Source for E-beam Accelerator", InPAC'03, RRCAT, Indore, Feb. (2003), p-246.