HIGH VOLTAGE SURGE PROTECTION SYSTEM FOR GUN POWER SUPPLIES OF 3MeV, 30kW DC ELECTRON BEAM ACCELERATOR

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Abstract

A 3MeV, 30kW dc industrial electron beam Accelerator is being developed at EBC, Kharghar, Navi Mumbai. The electron gun located at 3MV terminal requires remotely controlled floating power supplies for filament and anode. As the control electronics operate at low voltages of the order of 15V, they are vulnerable for conducted & radiated noise from high voltage column discharges. The sensitive electronic components should be protected from common mode and differential mode HV surges. To minimize the surge voltages to safe operating limits of electronic components used, various methods were incorporated and tested in simulated and actual conditions. This surge protection scheme has been installed at 3MV dome and gun supplies were operated at 1.2MeV level. They have been withstanding several HV sparks & discharges in the Accelerator with nitrogen gas at 6kg/cm^2. The techniques such as spark gaps, electrostatic screen, surge limiting inductors, cascaded filters, isolation amplifiers, single point grounding and electromagnetic shielding have been described in this paper.

INTRODUCTION

There are various types of surges and protection schemes in the electrical power systems. The conventional lightening and switching surges are in the order of few µs rise time, few kA of current at few hundred kVs. But high voltage dc accelerators, while conditioning & load changes are prone to HV surges of the order of few nanosecond rise time. This can affect the associated electronic circuits which control and monitor the accelerator parameters. For a 3MeV dc accelerator, the estimated surge voltage is 600kV within 10ns of sparking. Hence the electronics inside the HV terminal have to be protected from the electromagnetic interference due to these surges. A comprehensive protection scheme is needed to minimize the hazardous EMI to safe values.

ANALYSIS OF HIGH VOLTAGE SURGE

The block schematic of the 3MV generator [1] and power supplies for electron gun is shown in Fig.1. The filament and anode power supplies are floating at -3MV. When there is a sparking between 3MV terminal and ground, the voltage appearing at gun power transformer (50kV/600V) is of the order of 600kV with 10ns time. The Spark channel resistance in Ohms is given by

$$R = \frac{kl}{Q} \qquad \text{-------- (1)}$$

where k = toepler constant (0.8x10^{-3} for air), ℓ = spark length between HV terminal and ground, in cm and Q = charge transferred through spark channel, A.sec. The Spark Channel Inductance in µH is given by

$$L = 0.002l\left[\ln\frac{2l}{\rho} - \frac{3}{4}\right] \qquad \text{--------- (2)}$$

Where ρ is the spark channel diameter in cm. For 3MeV system, ℓ = 33cm, dome to ground capacitance =100pF and R= 88Ω. As a thumb rule, a spark channel inductance of 15nH/cm gives 0.5µH and surge frequency of about 22MHz.

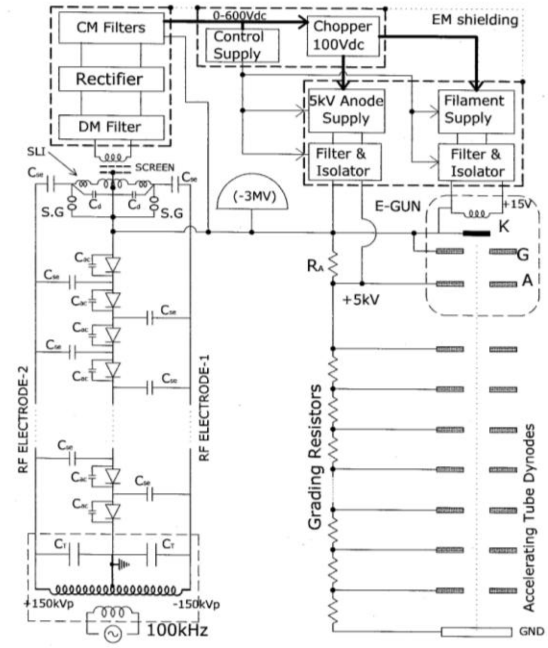

Figure1: Block Schematic of 3Mev system with Surge protection for floating Gun Power Supplies

There are two ways EMI noise can couple the electronics viz. common mode (CM) and differential mode (DM). The first step in surge suppression is achieved by suitable spark gap (S.G) [2] and surge limiting inductor (SLI). The common mode noise can be minimized by electrostatic screening between gun power transformer primary and secondary. The differential mode noise is attenuated by surge limiting inductors and clamping devices. Galvanic isolation of ground reference at HV terminal is also adopted for minimizing common mode noise. The radiated noise can be attenuated by electromagnetic shielding for frequencies above 1MHz.

Design Strategy of Surge Protection Scheme

The overall surge protection scheme should be able to attenuate the common mode and differential mode noise to <20V. This is the safe limit of electronic devices used in gun power supplies. The following stages of protection are adopted to achieve this goal.

- Spark gap with sure limiting inductor (SLI).
- Electrostatic Screen between primary & secondary of gun power extraction transformer.
- Differential mode filters
- Common mode filters for cut-off frequency of 10MHz
- Fast acting clamping devices like Tranzorbs.
- Minimizing ground looping in PCB and providing RC filters near to ICs, etc.
- Layout of power supplies and single point grounding
- Signal Isolation amplifiers for galvanic isolation.
- Electromagnetic shielding of power supplies for the frequency range >20MHz.

Implementation of surge Protection

Two spark-gaps, one across each half of the gun-supply transformer primary are incorporated and set at 4mm spacing to operate above 60kV. The estimated switching time is 2.17ns with jitter of 0.09ns for a 3MV spark on HV terminal. The surge limiting inductors rated for 250uH, 50kV in the transformer primary terminals protect and delay the 600kV surge to 50kV level within a typical 10ns breakdown period. Within this time, the spark gap closes and protects the transformer. The performance SLI has been evaluated in Pspice simulation software as shown in Fig.2

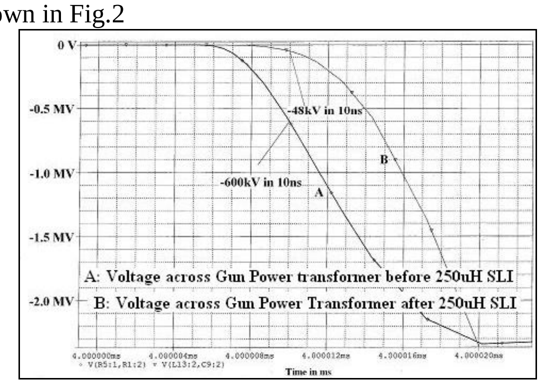

Figure2: Pspice results of Surge at gun power transformer

The capacitance formed between primary and secondary windings of 50kV/600Vtransformer is 50pF. An electrostatic screen using aluminium has reduced this capacitance to 0.5pF. The CMRR for this transformer is 30dB.

The differential mode filter in the secondary of transformer has to pass 100kHz, 600V and filter out higher frequencies. A π-mode LC filter having values 1µH & 1.25nF have been chosen. This attenuates differential mode surges by 12%.

Two stages of common mode filters in the 600V dc line have been designed with cut-off frequencies 150kHz & 1.5MHz. The CMRR for this cascade is 20dB.

A fast acting clamper rated for 600V is made of Tranzorb in series. The ground looping is minimized by suitable placement of components in PCBs. A nested electromagnetic shielding is adopted to attenuate magnetic fields and radiated EMI using nickel plated steel and aluminium enclosures respectively. The photography of the final assembly is shown in fig.3. Isolation amplifiers rated for 2kV galvanic isolation have been used for control signals and monitoring. Suitable RC filters have been designed for each IC. Single point grounding is implemented at 3MV terminal for all gun supplies.

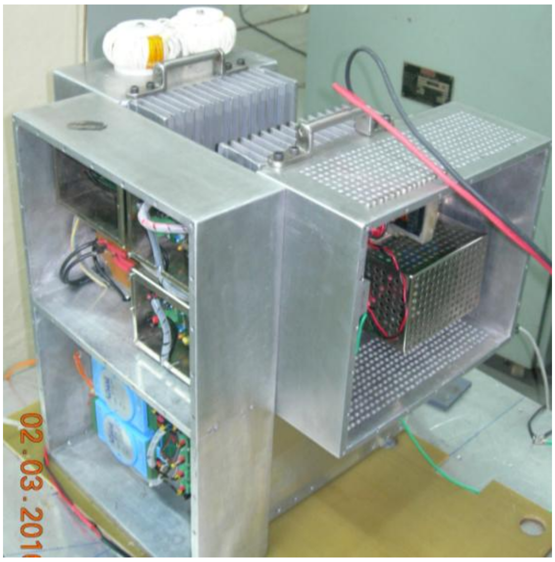

Figure 3: Photograph of Gun Power Supplies with Electromagnetic Shielding.

The gun power supplies with surge protection have been tested using a cable Marx surge generator rated for 40kV, 10ns. The results were extrapolated for 600kV input surge. The transmitted surge to electronics is as low as 20V.

CONCLUSION

The surge protection scheme has been implemented in the 3MeV dc accelerator and tested upto 1.2MeV in nitrogen gas at 6kg/cm^2. The maximum beam power is 7kW. The gun supplies functioned satisfactorily even after hundreds of HV discharges in the accelerator. The accelerator has been tested upto 1.5MeV with SF_6 gas at 3kg/cm^2 pressure.

REFERENCES

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[2] P. H. Ron, “High Voltage Spark gaps and Switching”, Proc. Technology of Electrical Insulation and HV Pulse Techniques, March 1-5, 1982, p.201-236.