Chapter 21

High Voltage Measurements in DC Accelerator

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DC accelerator employs DC high voltage potential to accelerate electrons or charge particles to high energy. The energy of accelerated particles are directly dependent on the high voltage terminal voltage. For acceleration, the high voltage is applied to a graded accelerating tube to provide uniform accelerating fields as much as possible, so that field concentration and resultant breakdowns are minimised. Another reason to provide a controlled acceleration gradient in the accelerating tube is to provide electric field pattern in the charged particle path to form the desired beam shape and size. Measurement of parameters related with the high voltage system requires special attention due to the chance of large transient voltages in the measurement circuits.

21.1 Accelerator Parameters

The HV terminal voltage, beam current and grading current are the parameters of the high voltage system used for particle acceleration. In addition to this, high voltage high frequency excitation voltage for the multiplier also required to be measured for establishing health of the system. The terminal voltage is measured by using a resistive voltage divider. The potential gradient in the accelerating column is established by a resistive voltage divider located along the accelerating column. The current through this resistive grading chain is called grading current. The grading current is used to establish healthy working conditions in the accelerating tube. Any deviation from the steady state current is an indication of arcing in the accelerating tube. This current can also act as a redundant voltage divider to measure the terminal voltage.

21.1.1 Terminal Voltage Measurement

The high voltage terminal measurement is done with a resistive divider chain made of a large number of high voltage resistors. Typically each element in the high voltage divider is capable of withstanding 40 kV to 50 kV DC. The current drawn by the divider should be a small fraction of the load current so that the presence of high voltage divider should not load the HV generator. More over the self dissipation of divider should not create significant temperature rise in the resistors. Thick film high voltage resistors offer temperature coefficient in the order of ± 100 PPM/°C to ± 150 PPM/°C. The temperature rise of resistors should be limited to achieve the desired accuracy. The resistance value of each resistor will be in the order of 500 MΩ or higher. Measurement of these high resistors cannot be done with normal multi-meters as their range is limited. Individual resistance values are measured with the help of a high voltage source and a multi-meter capable of reading micro amperes. To clearly establish the total value of the high voltage arm of the divider, every individual element is carefully measured and resistance value is recorded. The low voltage arm of the divider is kept closer to the control system to avoid requirement of signal transmitters in the radiation zone.

21.1.2 Grading Current Measurement

The grading resistors are similar to the high voltage divider. However their resistance value is generally lower than the high voltage divider. Higher currents through the grading resistors will allow the dynode voltage of the accelerating tube to be more firm even in the presence of stray currents due to electron beam. Number of resistors in the grading chain is fixed by the number of active dynodes in the accelerating tubes. The bottom end of the grading resistor chain is terminated on a high value resistor, which is protected by a low voltage spark gap. The leakage current from the divider is rend to the remote measurement circuits in current mode. A typical measurement scheme for accelerating potential, grading current and beam current is shown in Fig. 21.1. A simple calculation for voltage divider is tabulated in table 21.1.

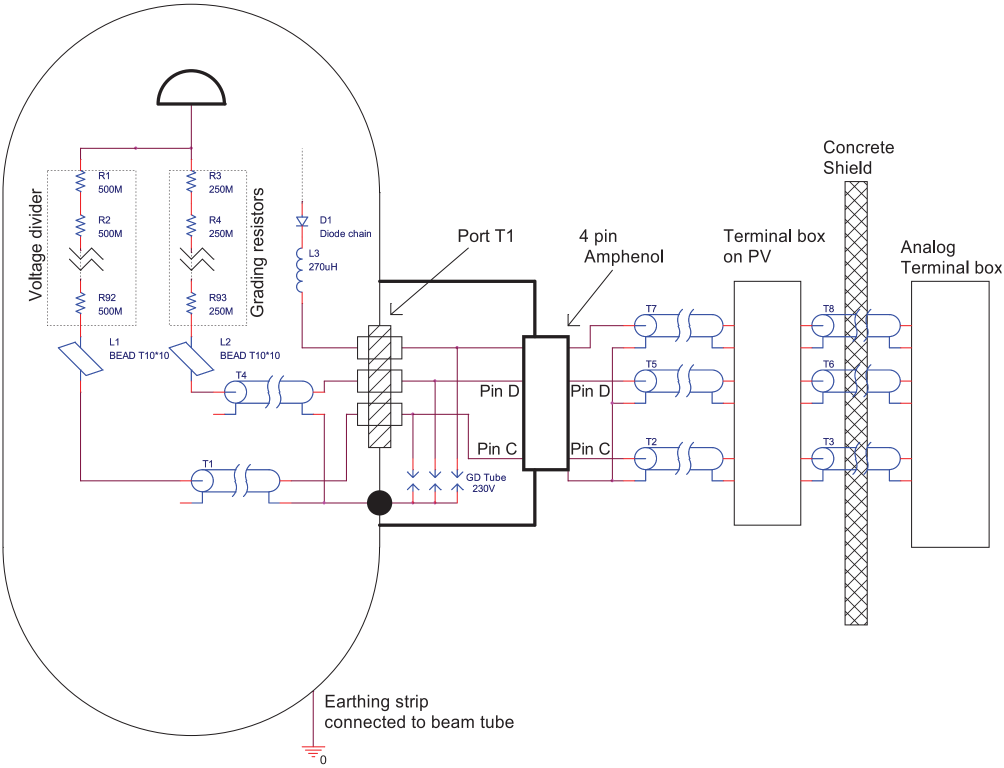

Figure 21.1: Accelerator voltage, current and grading current measurement.

Table 21.1: A simple calculation for voltage divider.

Individual resistor value in the HV arm	500 MΩ
No. of resistors	96
Total HV arm resistance = 96 × 500 MΩ	48 GΩ
Current passing at 5 MV	104.17 μA
Current passing at 3 MV	62.5 μA
Dome voltage per μA	48 kV
Voltage required across sampling resistor	3 V
Sampling resistor value required = 3/62.5 μA	48 kΩ
This value is parallel combination of isolator and measurement resistor.	
Isolator input impedance	2 MΩ
Hence, R_m = ($R_{required}$ × $R_{existing}$)/($R_{existing}$ - $R_{required}$) = 48000 × 2 MΩ/(2 MΩ - 48 kΩ)	49180 Ω

21.1.3 RF Voltage Measurement

The high frequency high voltage excitation voltage, which is used to power the multiplier is referred as RF voltage. For Cockcroft-Walton multipliers the operating frequency is in the audio frequency range. For the parallel couples voltage multipliers, the operating frequency is 100 kHz to 250 kHz. For measuring these high frequency high voltage levels, capacitive voltage dividers are used for measurement. For low frequency operation, the high voltage arm is made of NPO grade, discrete capacitors. For high frequency designs, much lower capacitances are sufficient. Parallel coupled multiplier designs, which use gas insulation, electrodes located close to the high frequency terminals can create sufficient capacitance to act as the high voltage arm.

The low voltage arm of capacitive dividers are made by highly stable mica capacitors. For transmitting the low voltage signal to long distances, direct cable connections should not be used as their capacitance can disturb the divider ratio. Hence the low voltage signal is rectified and transmitted. A circuit used for the low voltage arm is presented in Fig. 21.2. Diodes D3 and D4 add a bias voltage to compensate for the rectifier drop. It should be ensured that the rectification should allow current to flow in both directions from the capacitive divider taping points.

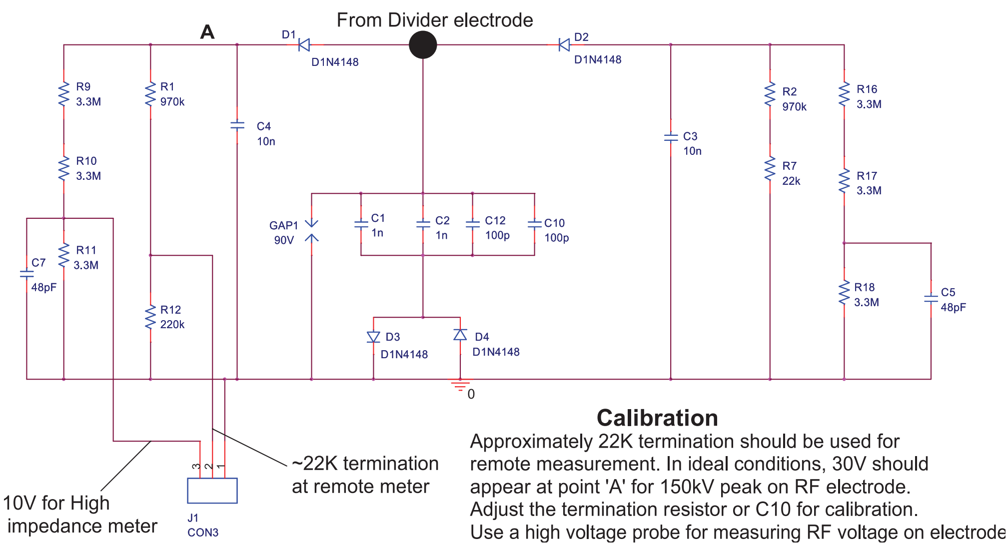

Figure 21.2: Capacitive divider lower arm.

21.2 Signal Conditioning for High Voltage System Signals

The signals from the high voltage system are prone to high voltage surges. Hence, these signals have to be properly protected from high voltage surges, so that the control system is not adversely affected. In order to achieve this goal a two-stage protection method can be used. In the first stage, the voltage level is clamped using transient voltage suppressor devices. In the second stage, isolators are used to provide galvanic isolation of the signals from the control system. A schematic representation of the signal flow is shown in Fig. 21.3.

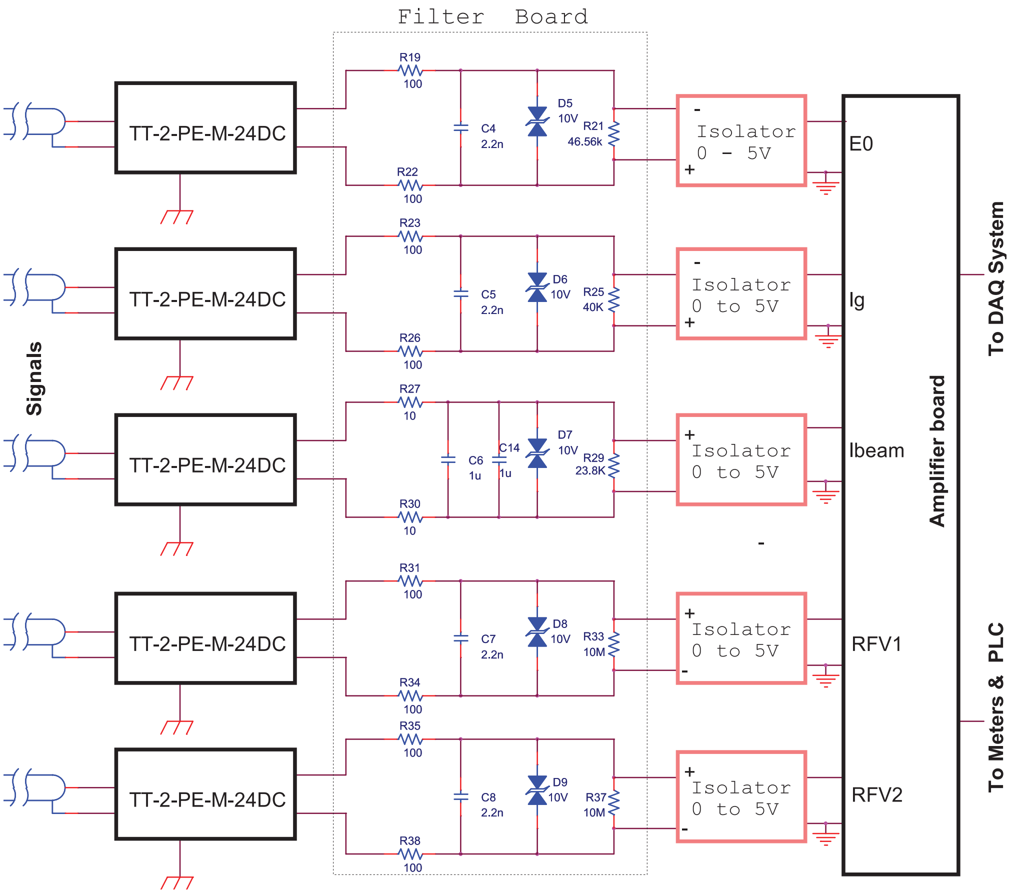

Figure 21.3: Signal conditioning.

21.3 Surge Protection Devices

Surge protection devices are used to clamp surge voltages appearing across power or signal lines. These devices are mainly categorised to Gas discharge tubes (GDT), Metal oxide varistors and Transient voltage suppression diodes (TVS), which are also commonly called as Tranzorbs [106].

Gas discharge tubes are miniature spark gaps, which are filled with an inert gas at less than atmospheric pressure. They can operate in a voltage range of 90 V to few kilo Volts. For continuous voltages they operate close to specified voltage levels. However, for fast transients, the breakdown voltage can reach 3 to 6 times of the specified voltage. Once the device is triggered, they behave like a short circuit until current through them reduce to small values. As the voltage across them can reach much higher values for short pulses with nanosecond rise times, additional filters have to be added to limit the voltage appearing across protected devices. The main advantage of these devices are the huge current diverting capability. Their life is limited by the amount of charge diverted and number of operations.

MOV on the other hand behaves like a non linear resistor and allows energy to be dissipated in them [107]. Their response time is in the range of 20 ns. These devices degrade over time if repetitive surges are applied. They exhibit considerable amount of capacitance and hence may not be suitable to use directly for high frequency circuits. Their leakage currents have to be considered for high impedance circuits. PCB mountable devices offer energy absorption capability up to 20 J. Larger devices are capable of many Kilo Joules. Multiple MOVs can be connected in parallel to absorb more energy.

Transient voltage suppression diodes are semiconductor diodes operating in avalanche mode. They are the fastest devices to respond to transients. Their response time is in the range of pico-seconds. However in practice, their lead inductance will be hampering the performance. Hence for use with very sharp rise time pulses, SMD devices with short lead inductance may be used. The energy absorption capability of these devices is expressed for standard transient waveforms in Watts. If the device ratings are not stretched beyond limits, these devices can offer trouble free operation for long time. However, these devices has to be protected by additional protection devices, since their energy absorption capabilities are limited.

It can be observed that devices capable of handling large amount of energy are slow to respond and the fast devices cannot absorb large amount of energy reliably. Hence, the surge protection devices are used as a cascade [108, 109]. Transient protection devices capable of absorbing large energy should be close to the source of transient, the fastest and low energy absorbing protection devices should be close to devices under protection, and their operation should be properly coordinated. Standards and documents for further reading are given in references [110–114].

Questions & Answers

Q1. What is the alternative method to measure terminal voltage?

A1. Generating voltmeter is a non contact method to measure terminal voltage. This method used mechanical means and is subjected to wear and tear.

Q2. What is the purpose of isolators in the signal conditioning chain?

A2. The surge protection devices reduce the voltage level to acceptable levels. However there could be common mode voltage lifting. Isolators remove common mode lifting and break ground loops.

Q3. Can we use resistive dividers in measuring high frequency RF voltage?

A3 Resistive dividers have associated parasitic capacitances. These capacitors will behave as low impedance and modify the divider ratio.

Q4. What is the difference between tranzorb and zener diode?

A4 Tranzorbs can safely handle much higher peak power levels than zeners and hence more suitable for transient suppression.