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Investigation of Test Wire for Crowbar Switch Test of KSTAR ECH Gyrotron Power-Supply*

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Abstract

- The power supply system is developed for the KSTAR ECH gyrotron tube, and it is being tested at POSCON. It supplies a high voltage of -80 kV and a current of 20 A to the gyrotron tube. When a fault develops in the gyrotron tube, the crowbar switch of the power supply is closed, and therefore the gyrotron tube is protected. The operation time of the crowbar switch and the dissipated energy in the gyrotron must be within 10 microseconds and 5.0-10 joule, respectively. The crowbar switch test will be done with a thin test wire substituting the gyrotron tube. For the crowbar switch test, however, we first have to determine the length and the diameter of the test wire that can survive for dissipated energy of up to 5.0-10 joule. We investigated the dissipated energy dependence of the test wire dimensions, and we observed the phenomena of the test wire cut and the burning with a discharging circuit. This paper presents the discharging circuit and the test wire characteristics.

Introduction

- The diode-type gyrotron for KSTAR ECH system is under fabrication by CPI in USA. The assembly of the parts of the gun, the cavity, and the collector has been finished except the superconducting magnet coils. Now, the cathode activation is being performed at the CPI. The superconducting magnet coils with a cryostat will be assembled in near future. The diamond window has been also fabricated and assembled to the output port.
- The power-supply system is composed of a main DC power supply and a acceleration power supply. The main DC power supply can supply the maximum voltage of –80 kV and the maximum current of 30 A. The acceleration power supply is able to supply the max 100 kV and max 100 mA. The main DC power supply has a crowbar switch. When we have an arc in the gyrotron tube, the arc energy will be diverted through the crowbar. Since the arc energy grows up in the gyrotron tube very fast, the crowbar switch must be operated within 10 μs for diverting the arc energy.
- The nominal operation scenario; the cathode is pulsed at the –60 kV to the ground and then the 50-60 μs later the body (anode) is pulsed at +20 kV to the ground. The collector is always set to ground voltage.
- The wire test is to simulate an arc to ensure that the maximum energy dumped into the gyrotron arc is limited to a level (5-10 joule) which will not damage the gyrotron. In our experiment, we find the proper wire that can survive up to 5-10 joule.

Gyrotron Tube Fabrication (CPI)

Diamond Window

Gyrotron Power-Supply System

VCB, Inverter, APS, Coil, Heater Power Supply

High Voltage Rectifier Tank & Capacitor Filter Deck

Capacitor Filter Deck & Crowbar

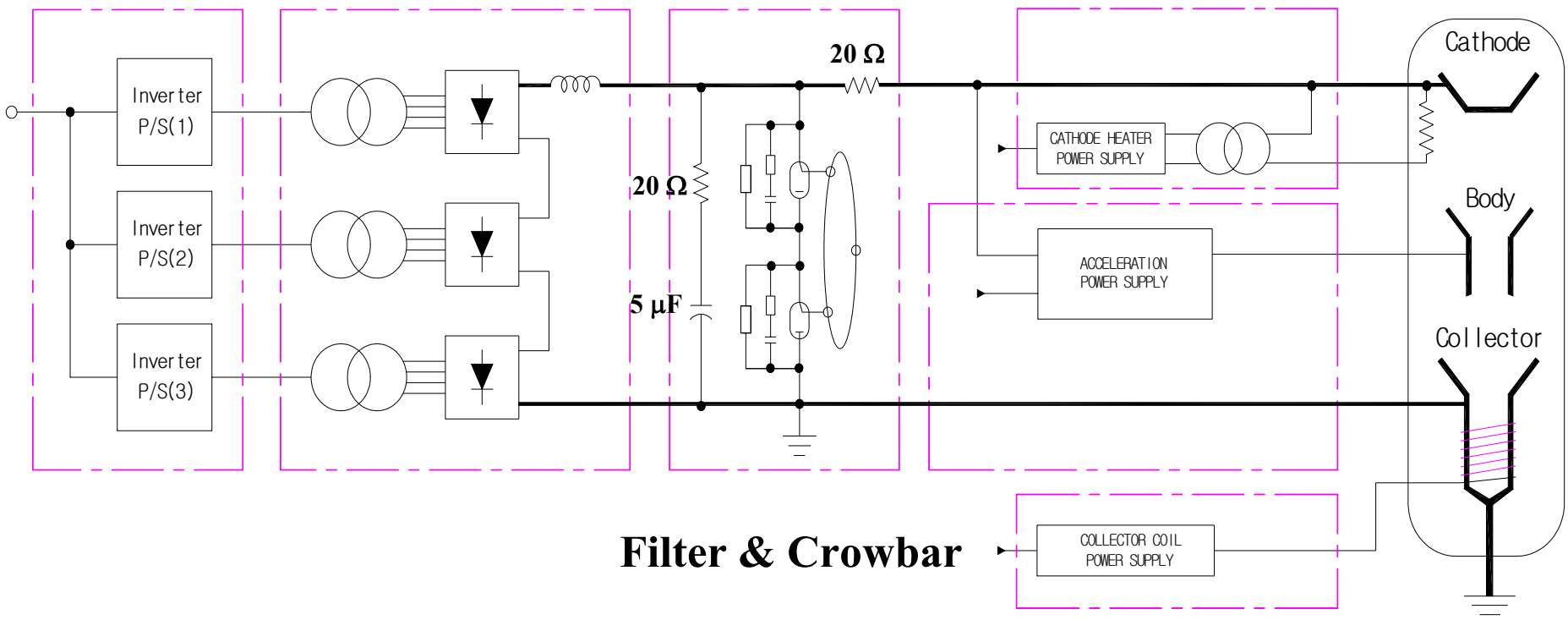
Capacitor Filter Deck & Crowbar Resistor Load

Crowbar S/W Requirements (CPI)

- Gyrotron Tube내 Arc 발생시 허용 소모 에너지 : 5-10 joule 이내 **(from CPI)**
  - Crowbar S/W 요구 사양 : 10 μs 이내 작동하여 Cathode Voltage 차단
  - 100 ns 동안 beam current 가 40 A 초과시 Crowbar S/W 작동

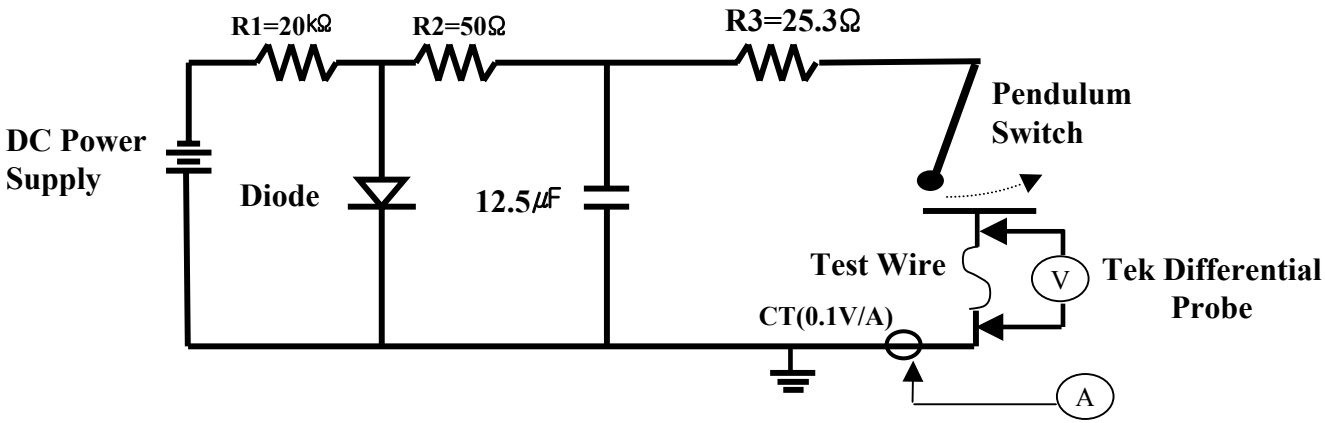
    (Current increasing rate : 0.4 A/ns rate)
- 80 kV 운전, Arc 발생시 Peak Current
  - V_c = 80 kV, R_d = 40 Ohm ; I = 80 kV/40 Ohm = 2 kA

    (Peak Current Rise Time = 0.4 A/ns x 2 kA = 5 μsec)



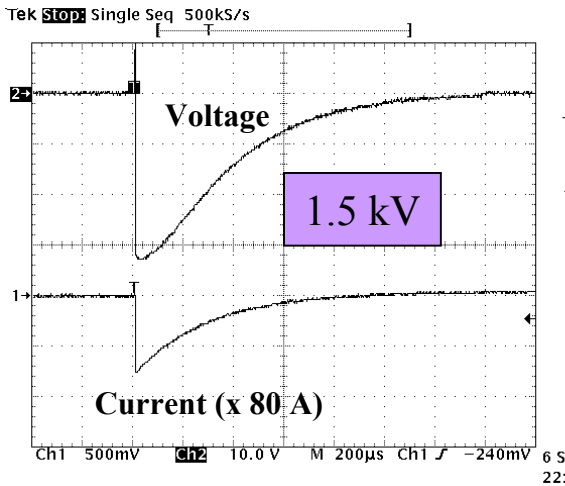
Filter & Crowbar

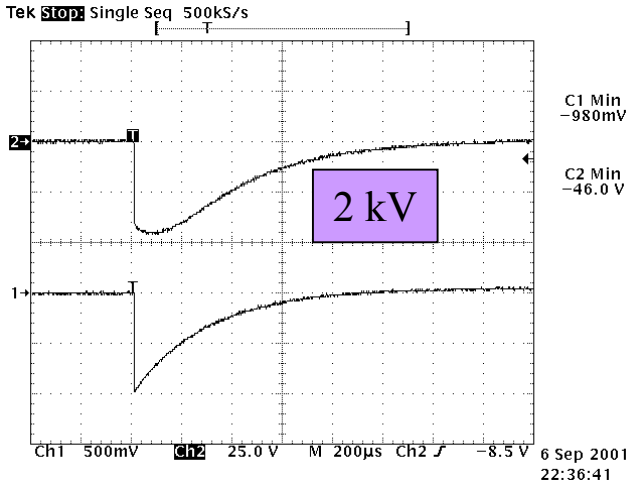
Experimental Setup

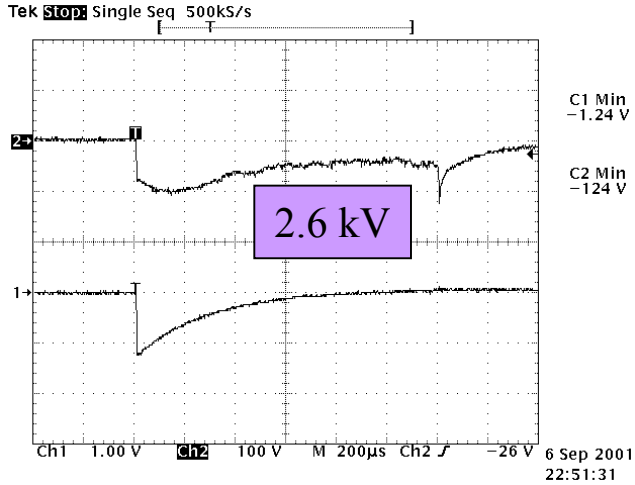


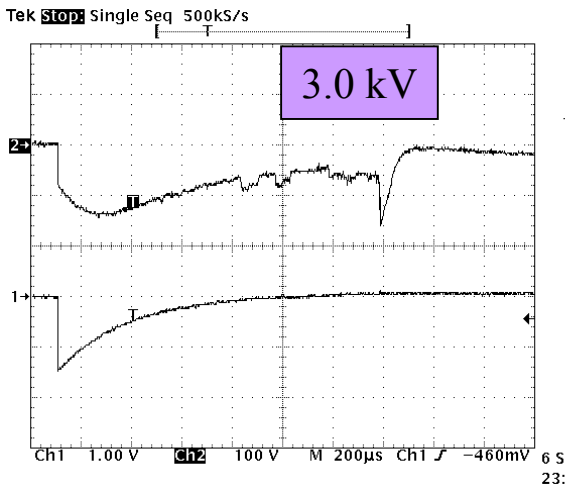
Waveforms

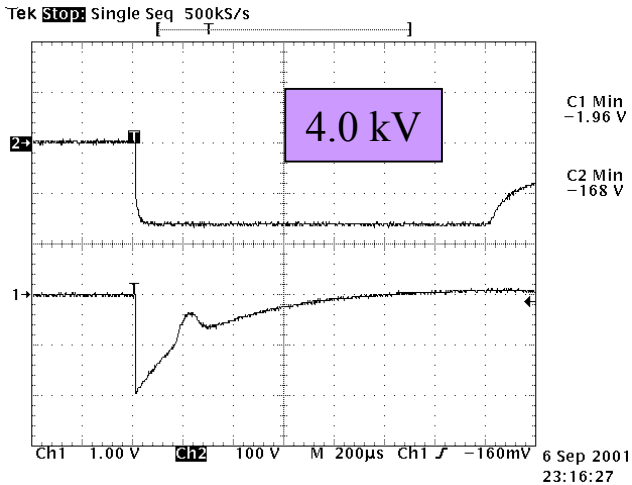
(90 μm Diameter, 5 inch Length wire)

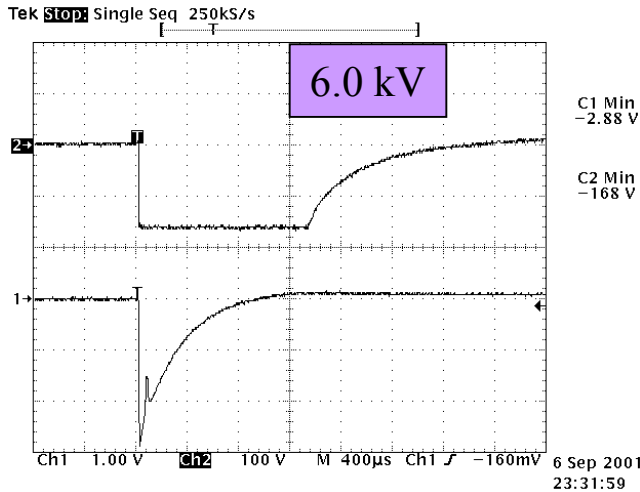








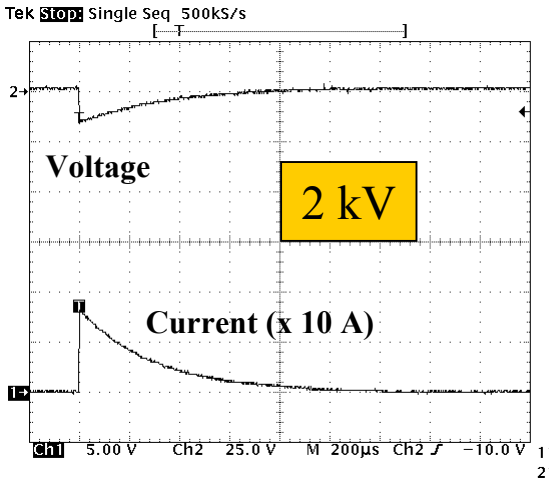


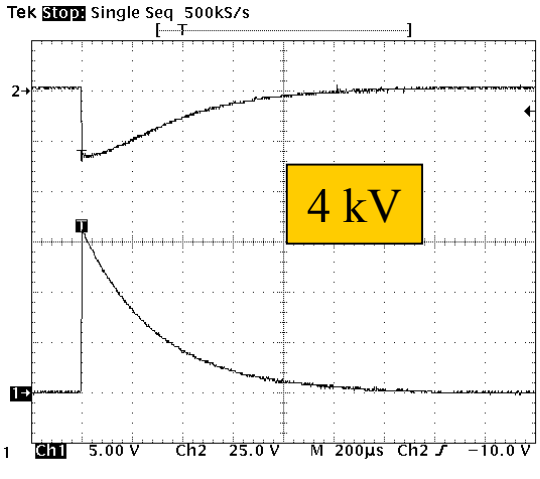


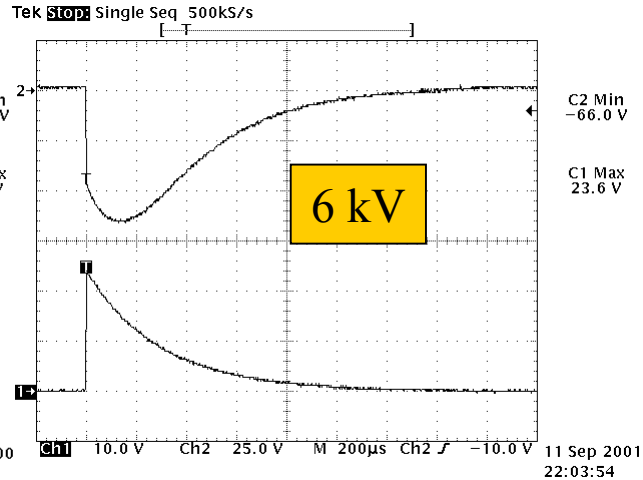
- **The wire cutting starts from the capacitor voltage of 2.6 kV.**

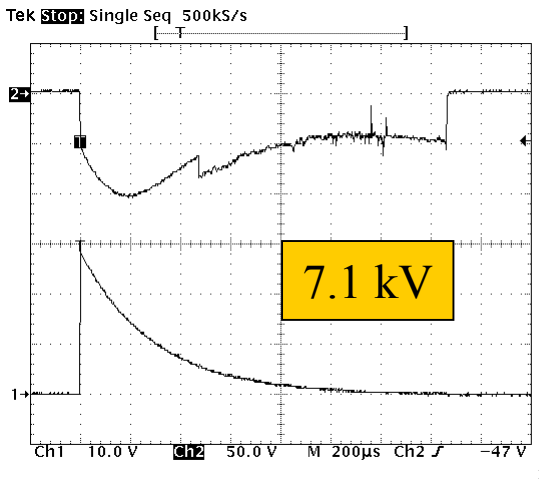
Waveforms

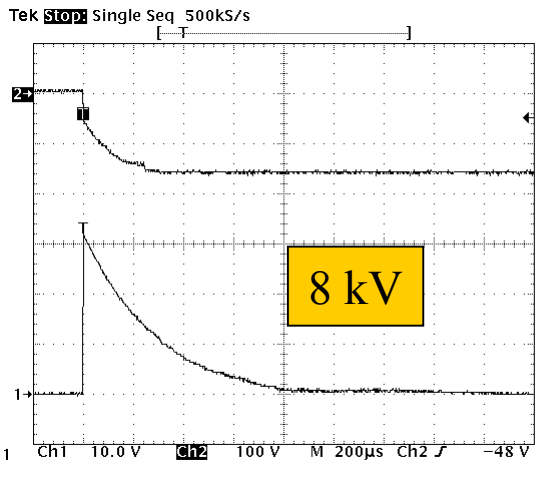
(120 μm Diameter, 5 inch Length wire)

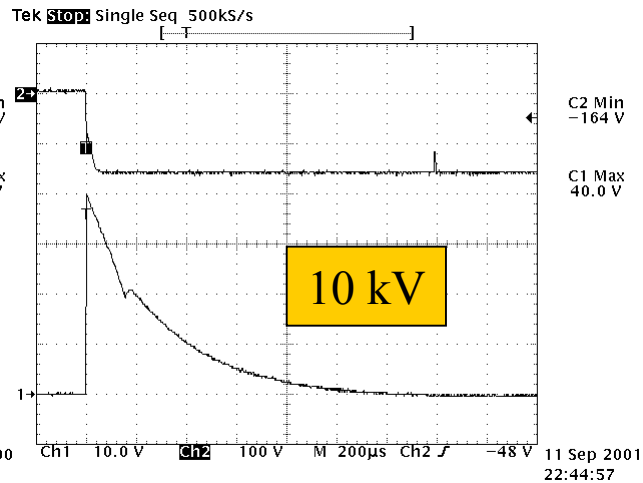








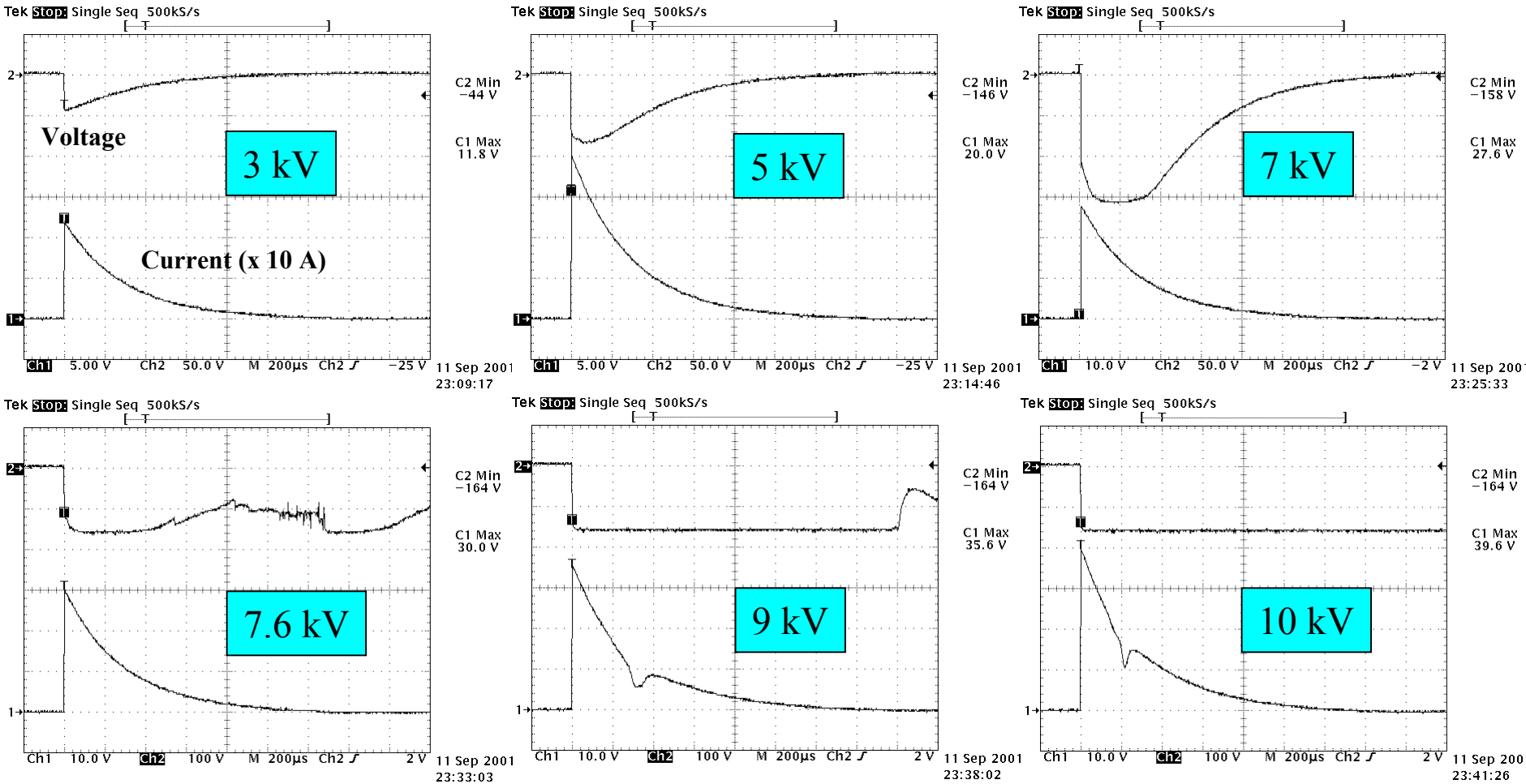




- **The wire cutting starts from the capacitor voltage of 7.1 kV.**

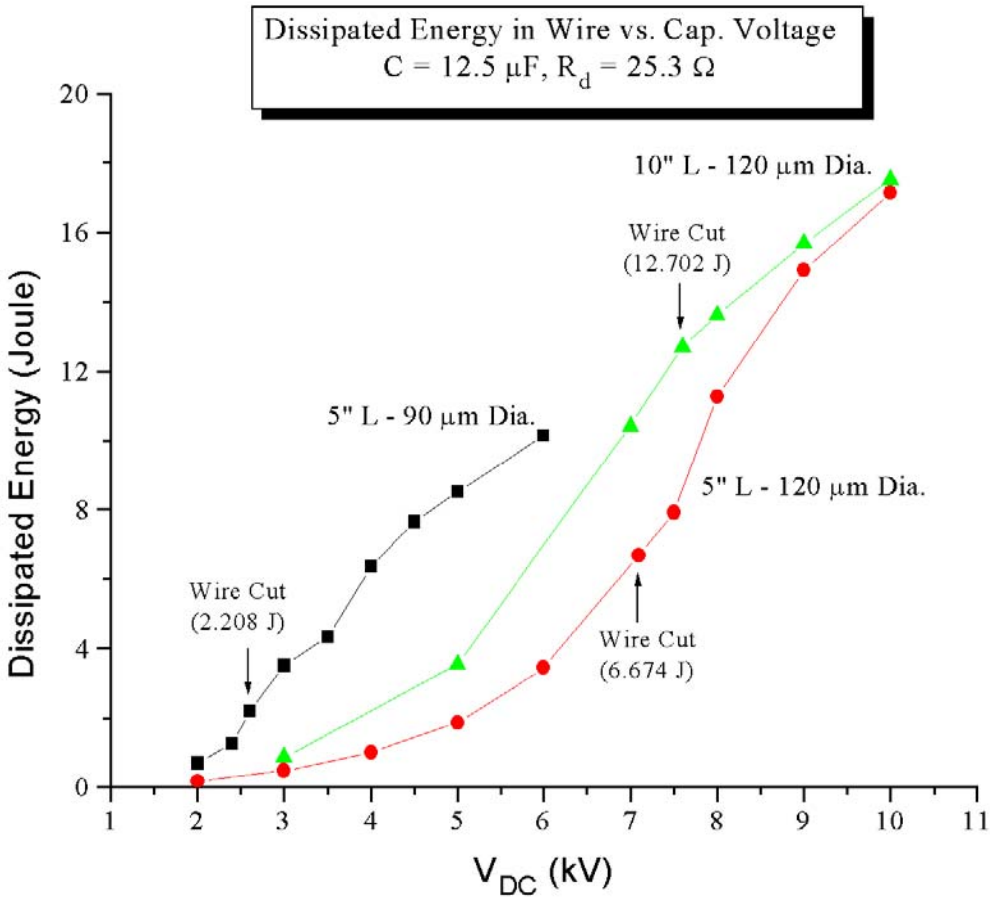
Waveforms

(120 μm Diameter, 10 inch Length wire)



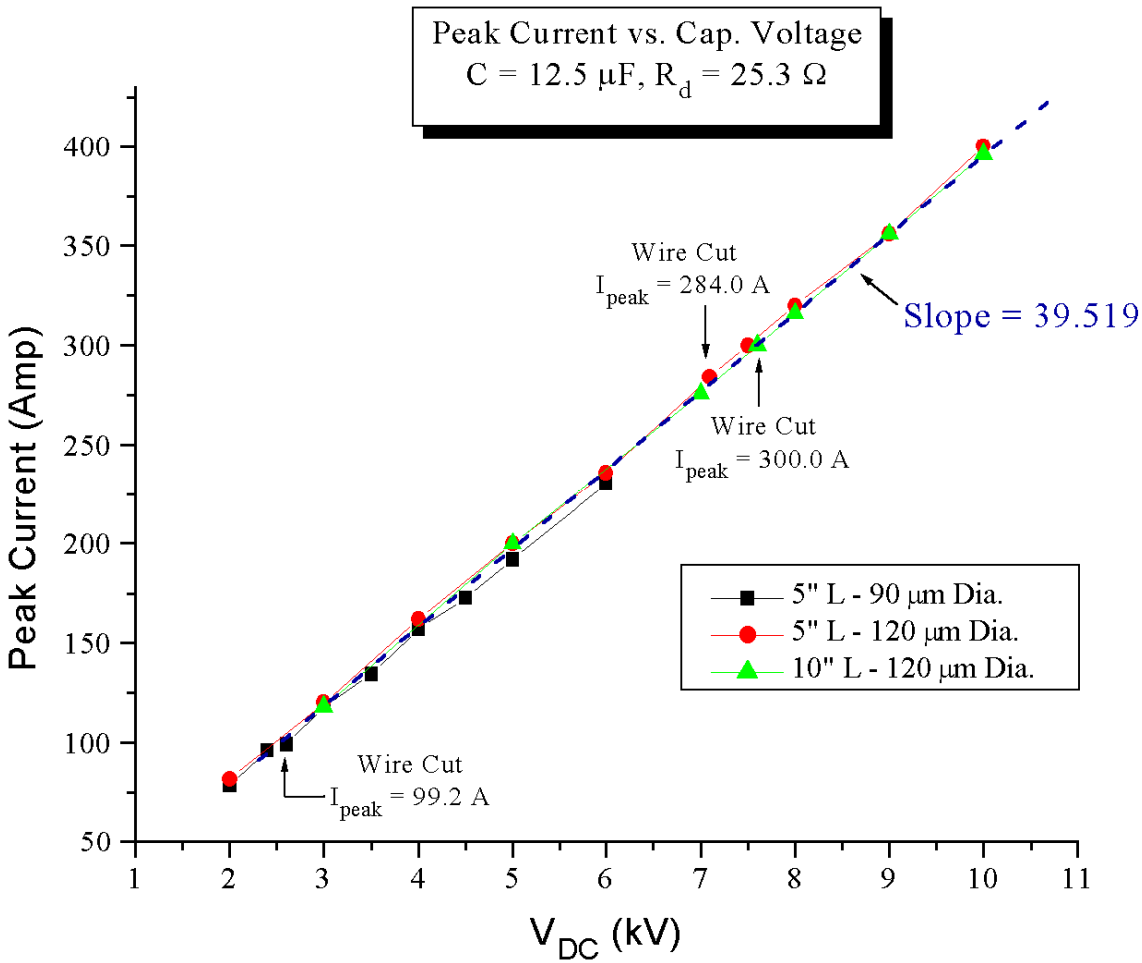
- **The wire cutting starts from the capacitor voltage of 7.6 kV.**

Dissipated Energy Calculations



- The dissipated energy through the wire is calculated from the integration of the voltage between wire times the current over the time. The 90 µm diameter wire with the length of 5 inch is cut at the dissipated energy of 2.2 joule. But, the 120 µm diameter wire with the same length is cut at the 6.674 joule. And for the wire with the length of 10 inch, the dissipated energy required for the cut increases to nearly two times as that of the 5 inch length wire.

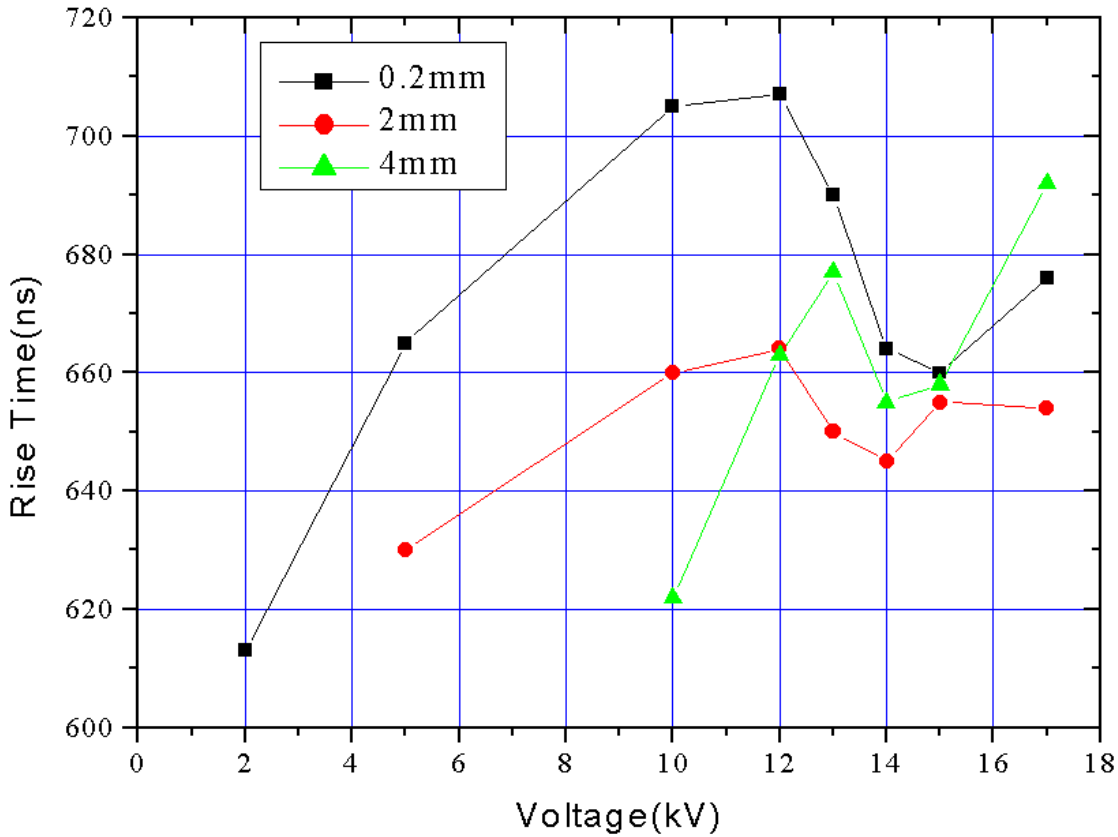
Peak Currents & Series Resistance



- The series resistance in the discharge loop can be calculated from the slope as shown in this figure. The fit shows the slope of 39.519. So, the resistance is 1000 x 1/39.519 = 25.3 Ω. This value is same as the resistance of the resistor connected in the discharge loop.

Peak Current Rise Time

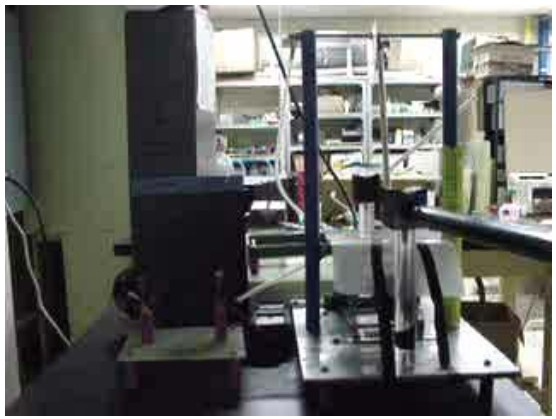
For Gap Distances of Pendulum Switch of 0.2 mm, 2.0 mm, and 4.0 mm

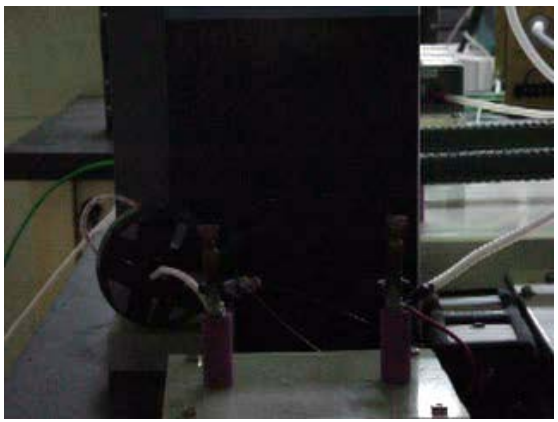


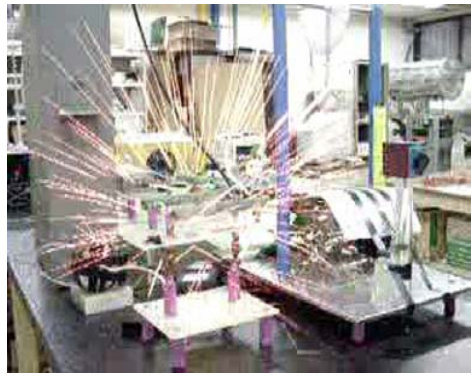
- The peak current rise time vs. capacitor voltage for the gap distances of pendulum arc switch. The average rise time is 0.66 μs for the capacitor voltage from 2 kV to 17 kV. It is expected the peak current rise time is in the range of 0.6 - 0.7 μs in our wire test circuit system. This rise time may be much lower than the rise time (5 μs) in the case of gyrotron tube arc.

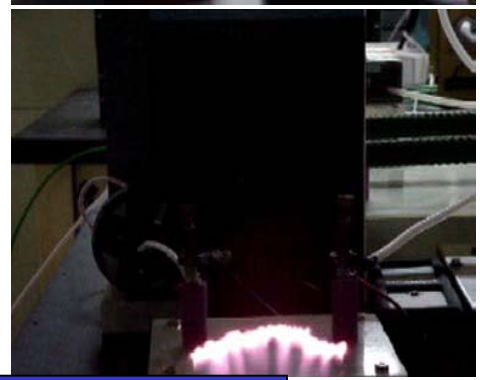
Wire Burning and Explosion

(Movies & Captured Image)









Movies

Captured Images

Conclusion

- This experiment shows the 0.120 mm diameter wire (5.0 inch length) is not melted until the dissipated energy reach 6.0 joules. This wire is able to be used for the crowbar switch test. However, the 0.90 mm diameter wire is melted for the lower dissipated energy of 2.0 joules. When we use the longer wire, the wire survive for the larger dissipated energy.

- As the capacitor voltage increases, we can see the phenomena of wire burning and the wire explosion with a detonation.

- The gyrotron power-supply system has two 20 Ω resistors in series and therefore the total resistance in the discharging loop is 40 Ω. We plan to do the wire test with the gyrotron power supply system.