

SYNCHRONIZABLE HIGH VOLTAGE PULSER WITH LASER-PHOTOCATHODE TRIGGER *

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Abstract

High gradient pulsed electron guns have been studied to suppress the space-charge induced transverse emittance growth of the electron beam in the injection stage. Synchronizable high-voltage (HV) pulsers are needed to power up high-gradient guns. In this article, we propose to build a HV pulser with a new switching technique that exploits a special trigger, a laser-photocathode subsystem. With this trigger, we not only utilize the laser beam energy efficiently, but also trigger the switch reliably. Calculations show that the properties of the switch can be improved greatly using this technique.

INTRODUCTION

To minimize the space charge induced transverse emittance growth in the injection stage of particle acceleration, pulsed high gradient electron guns have been studied extensively in recent [1-6]. High-gradient guns need a pulser having very low jitter and fast rising time in order to synchronize the voltage pulse with its electron bunch extraction whose duration only lasts several picoseconds. In lights of dielectric breakdown [7-9] and synchronization, we list some of the important parameters below that a pulser ought to have in the application of the high gradient guns, e.g. in a DULY dc/rf gun project [5, 10]:

1. Jitter time: < 500 ps
2. Rise time (10% to 90%): < 500 ps
3. Pulse width: 1 ~ 1.5 ns
4. Fall time: < 1 nanosecond

The pulse amplitude of the pulser is determined by individual experiments, usually ranging from hundreds of kilo-volts to mega-volts. In our dc/rf project, the highest voltage needed is 200 kV with negative polarity and the pulse repetition rate is 1~10 Hz adjustable.

So far the application of high gradient guns using conventional pulser technology is limited by large jitters inherent in the pulsers. There are serious technical challenges to balancing the four pulser's parameters: jitter, pulse width, pulse rise time, and high voltage level. In order to minimize the jitter related to switch technology, we present here a synchronizable HV pulser that is designed with a new gas spark gap switch. The switch will be triggered by a laser-photocathode subsystem that includes a laser with low jitter and short pulse length, a photocathode and an anode inside a transparent high vacuum cell, and trigger electrodes. For conventional laser triggered switches, the utilization ratio of laser optical energy is rather low because HV gases

normally have small absorption coefficients in the ultra-violet (UV) range, which is often used for triggering laser. For example, SF₆ under standard conditions has an absorption coefficient less than 0.002/cm for photons with a wavelength of 186 nm [11]. It means that the ratio of the photons absorbed by the gases to the total photons in the laser beam is less than 6% if such a laser beam passes through a 30-cm-long gas channel. Moreover, the coefficient tends to decrease with the increment of the photon wavelength in the UV spectrum. Therefore, most of photons in the beam passing through a common gas gap whose length is generally less than 30 cm simply waste their optical energy. For this reason, a high-energy laser system is needed to trigger a traditional HV spark gap switch and thus a high cost on the system will incur. To overcome the problem, we propose a double-trigger method for the triggering of the switch efficiently and reliably while improving the low jitter properties of laser-triggered switch.

DESCRIPTION OF THE PULSER

The pulser consists of several parts including a Marx generator, a laser, a main switch, and a coaxial transmission line. The interrelationship of each part is illustrated in Fig. 1.

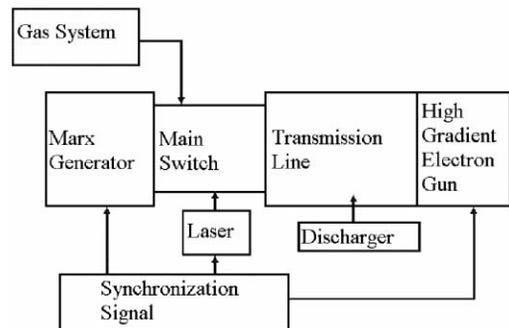


Figure 1: The internal interrelationship of the pulser.

A Marx generator is adopted as an energy storage device. It will form a HV pulse and, at the control of the main switch, release the pulse to the transmission line that is connected to the dc/rf gun. A discharger is installed on the line to regulate the width of the pulse. A key device in the pulser for synchronization is the main switch, whose jitter is a decisive factor of synchronization. Ultra-violet laser is used to trigger the main switch. Further measure to reduce the jitter will be applied by using photoelectron triggering that is described in later paragraphs. Parts description of the pulsers is described below.

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Marx Generator

The Marx generator is an efficient device to realize voltage multiplication. The energy can be stored in the generator and, when needed, released in nanoseconds. The Marx comprises a set of spark gap switches that, when fired, connect six capacitors in series. Its output pulse is near the sum of the voltages on the stage capacitors, i.e. $V_{out} = NV_0$, where N is the number of stages, and V_0 is dc charging voltage. A 6-stage Marx generator will output -240 kV theoretically for a dc charging voltage of -40 kV, comparable to the voltage range needed in the dc/rf project, i.e. from -160 to -200 kV. The parameters of the Marx are summarized in Table 1.

Table 2: Key Parameters for the Marx Generator

Charging voltage	-25 ~ -40	kV	Adjustable
Stage capacitance	2700	pF	
Stage number	6		
Charging resistor	10000	Ohm	
Highest stored energy	4.8	J	
Repetition rate	1 ~ 10	Hz	Adjustable
Output voltage	-160 ~ -200	kV	Adjustable

The first gas spark gap of the Marx will be triggered by an external electrical pulse. Though a Marx has large jitters (~ns) in each of its spark gaps, the synchronization of its output voltage with other devices can be achieved through a main gas spark gap connected to its output end. Closure of the switch under the laser triggering may be delayed 30 or 50 ns after the Marx has been fully erected, depending on the adjustment of the synchronization signal. It means that the Marx generator has to wait a short time (tens of nanoseconds) to discharge its energy after its erection. It is therefore important to require an extremely small jitter (<500 ps) in the closing of the main switch in order to achieve the synchronization.

Main Switch Triggered By Laser-Photocathode Sub-System

The innovative concept for reducing the main switch's jitter is the design of a vacuum cell that contains a photocathode plate and an anode plate. The photocathode collect the leftover optical energy of the laser beam after it passes through the gas spark gap in the main switch, and generate a large number of photoelectrons, which will be collected by the anode and will use feedback to trigger switch further. In such a way, more triggering energy returns to the switch gap. It is a great advantage to minimize switch jitters since triggering energy is one of the important factors impacting switches' jitters.

Two types of the main switch have been designed and are described here. The first one is a trigatron type illustrated in Fig. 2. The high-vacuum transparent cell is installed near the main electrodes 2 and 6. The photocathode is connected to Main Electrode 2, which is at a lower potential compared to that of Main Electrode 6,

through 2 metallic rod, while Anode 8 is connected to Trigger Electrode 7 electrically but isolated from Main Electrode 6 before gas breakdown. The laser system can be a Q-switch Nd:YAG laser working at its fourth harmonic of 1064 nm. The laser has very low jitter (<1 ps) and its pulse length can be made less than 100 ps.

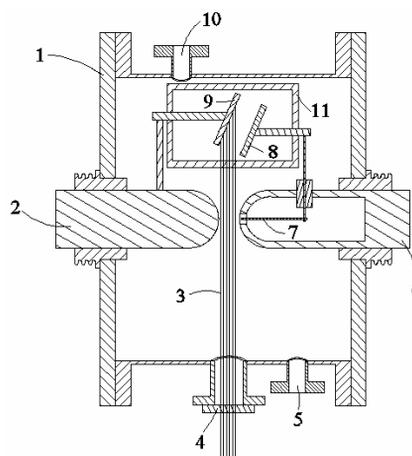


Figure 2: Trigatron type gas spark gap switch: 1. switch housing; 2 & 6. cylindrical main electrode; 3. laser beam; 4. laser window; 5. gas outlet; 7. trigger electrode; 8. anode; 9. photocathode; 10. gas inlet; 11 vacuum cell.

In operation, the laser beam is turned on by the synchronization signal, passes the gas spark gap between the two main electrodes, where it will ionize some of the gases, and reaches the photocathode's surface at last. After the photoelectrons are released by the laser beam, they move toward the anode plate under the electric field action and are collected by the plate. Photocurrent generated in the circuit from the anode to the trigger electrode will produce a voltage across the triggering gap between Main Electrode 6 and Trigger Electrode 7. Depending on the photoelectron charge and the capacitance between Main Electrode 7 and the trigger electrode circuit, the voltage can be so high that the breakdown in the triggering gap will occur immediately. The breakdown will close the main spark gap.

Table 2: Parameter of the switch model

Laser pulse energy	4	mJ
Percent of residual optical energy	80%	
Photocathode material	Magnesium	
Quantum coefficient [12]	5.00E-04	
Radius of the anode plate	1.5	cm
Distance between the anode and the photocathode	1.5	cm
Trigger circuit length	4	cm

To evaluate the potential of photoelectron triggering, we assume first no breakdown in the trigger gap before the last photoelectron is collected by Anode 8. The lowest voltage that can be produced by the photocurrent is estimated based on a switch model used in the dc/rf gun.

Parameters of the model are listed in Table 2. According to this model, the value of the photoelectrons' charge is 3.43×10^{-7} Coulomb. Capacitance between the trigger circuit and Main Electrode 6 is estimated less than 2.07×10^{-12} F. So the lowest voltage is 165.7 kV. Stored electrical energy between the trigger circuit and Main Electrode 6 is 28.4 mJ. The high photoelectron voltage and the high stored energy show the strong triggering ability of the photoelectrons.

A formula was derived to compute the transient time of the photoelectrons from the photocathode to the anode:

$$t = \frac{m_0 c}{eE} \arccos\left(1 - \frac{eEl}{c^2 m_0}\right) \quad (1)$$

where m_0 is electron's rest mass, e is the electron's charge, c is the light speed in vacuum, E is the electric field, and l is the distance between the photocathode and the anode. The longest transit time is determined by the last photoelectron in the case that it just leaves the photocathode while the anode's potential is at its lowest, i.e. 34.7 kV, relative to that of the photocathode. In this case, it is found that the longest transit time is 276 ps. The field propagation time from Anode 6 to Trigger Electrode 7 is less than 133 ps. So the longest delay time for the photoelectron pulse is less than 409 ps relative to the laser pulse. It is still very fast and can be acceptable in many applications. The minimum rising speed of the pulse is 405.1 kV/ns. The speed is much faster than those used in conventional electrical triggered switches, whose voltage rising speeds are generally less than 100 kV/ns. The data indicate the feasibility and advantage of the photoelectron triggering pulse.

The calculations above also reveal that the triggering pulse originating from the photocurrent is able to trigger the HV switch by itself, even if the laser beam is not used as the first trigger pulse to pass through the spark gap. This single triggering mechanism can be viewed as a modification to the double triggering mechanism.

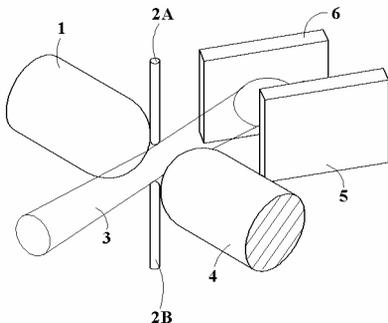


Figure 3: Field distortion type switch: 1 & 4. main electrodes; 2A & 2B. trigger electrodes; 3. laser beam; 5. anode; 6. photocathode.

The second type of the main switch is a field distortion one, shown in Fig. 3 schematically. Relevant calculations are not presented due to the space limit.

Transmission Line and Discharger

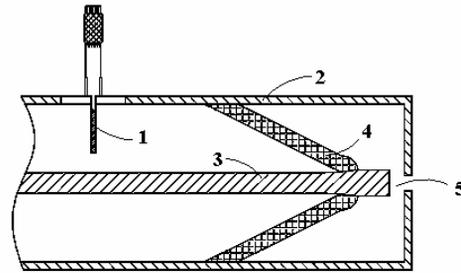


Figure 4: Discharger on the transmission line: 1. tip of the discharger; 2. outer conductor of the line; 3. center conductor of the line; 4. ceramic sealing; 5. gun vacuum gap.

A coaxial transmission line (see Fig. 4) will be used to transmit the HV wave from the Marx generator to a load (electron gun of a vacuum diode type) after the main switch closes. To increase the wave bandwidth and reduce the pulse attenuation, we select the impedance of the line as 75Ω . The load has a very large resistance ($1 \times 10^4 \Omega$) compared to the line impedance. So the voltage wave will be reflected nearly totally at the end of the transmission line. The amplitude of the voltage pulse will be doubled where the reflected wave overlaps with the incident wave. A discharger that is made with a small metallic rod is installed on the transmission line. The distance from its tip to the inner conductor of the transmission line can be adjusted by an adjustment device. The discharger can be employed to regulate the voltage wavelength because the gap between the tip of discharger and the center conductor can be adjusted so that the breakdown only occurs when the reflected wave overlaps with the incident wave there [13]. Voltage pulse length at the electron gun is thus the time of the wave transmitting from the discharger to the electron gun multiplied by two.

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