LASER TRIGGERED HV-SWITCH WITH WIDE VOLTAGE RANGE

M. Bieler
II. Institut für Experimentalphysik der Universität Hamburg, W.-Germany,
R. Fohrmann, Z. Mazur*, G. Sandels**, W. Wasowicz***, L.R. Xiao****
Deutsches Elektronen-Synchrotron DESY, Hamburg, W.-Germany

Abstract

The kicker magnets for the HERA beam abort system will be switched on by means of a laser triggered spark gap. Two different techniques have been checked to achieve a timing which is independent of the working voltage.

The time delay between laser output pulse and firing of the spark gap was measured to be 60 ns with a time jitter of less than 1 ns.

Introduction

Using lasers to trigger the discharge of a spark gap was already reported 20 years ago /1/. The light of visible or infrared lasers with an energy of a few Joules was focused by a lens on to the surface of one electrode. The metal plasma produced on the electrode leads to a discharge of the gap with a delay of several 100 ns especially for voltages which are only 50% of the self discharge value. At these voltages the time jitter was 20 ns. Close to the self discharge limit the values are an order of magnitude shorter.

Another approach to trigger a spark gap is to produce a plasma channel in the gas between the two electrodes. Using a long-focus lens the UV-light of an excimer laser, for instance a KrF-laser with a few mJ, can form such an ion channel in SF_6, which causes the spark gap to break down. At 50% of the self discharge voltage time delays of 40 ns with a jitter in the subnanosecond region have been reported /2/.

The laser triggered switch (LTS) described in this report is a combination of both methods /3/. The UV-light of a nitrogen laser was focused by a quartz lens on to one electrode of a spark gap. This paper reports on two different methods to avoid the big variation in lag time of the LTS as a function of the high voltage to be switched.

Laser-triggered switch

The electrode at which the laser light is focused can be the anode or the cathode. The possibility of the choice of the polarity gives rise to different behavior in the time delay of the discharge. The propagation time of the streamer which determines the lag is derived in Ref.1 and results in

$$t_d \;\alpha \ln\left(\frac{N_{crit}}{N_o}\right) / \; P\left(\frac{E}{p}\right)^m \tag{1}$$

where N_{crit} is the critical number of charge carriers for streamer development and N_o is the number of charge carriers initiated by the laser; m is a constant depending on the gas filling of the gap (m=9.2 for nitrogen). From (1) one can see that for constant pressure in the gap the lag is strongly dependent on the high voltage across the gap. Furthermore one can see that the delay depends also on the gas filling (via N_{crit}) and on the laser energy.

The nitrogen laser

There is a variety of nitrogen lasers on the market with different electrical, mechanical and optical properties. The threshold condition that a laser can trigger a spark gap depends on the energy, the diameter and on the divergence of the laser at the output window. An empirical value for this threshold, derived from a test of several types of lasers, is

$$n = E/(\alpha d)^2 \geq 0.1 \;\mu J/\mu m^2 \tag{2}$$

where E is the laser energy, α is the full angle of divergence and d is the diameter of the beam at the laser output. We should note that this is only a rough estimate and the number depends on the gas filling of spark gap, on the geometry of the laser channel and on the geometry of the spark gap.

The laser* used for the data presented in this report has an energy of 80 µJ, a divergence of 2 mrad and a beam diameter of 3 mm, i.e. the focused energy density is $n=2\;\mu J/\mu m^2$. The internal delay for the laser is 415 ns with a time jitter of better than 1 ns. An upper limit for the laser energy is given when the focused beam starts to melt holes into the surface of the electrodes. This has been especially observed for brass electrodes.

The spark gap

For the voltage range up to few tens of kilovolts there are many types of spark gaps available. Most useful are spark gaps which are designed to be electrically triggered by spark plugs.

A lens holder can replace the spark plug to allow the optical triggering by the laser (see Fig.1).

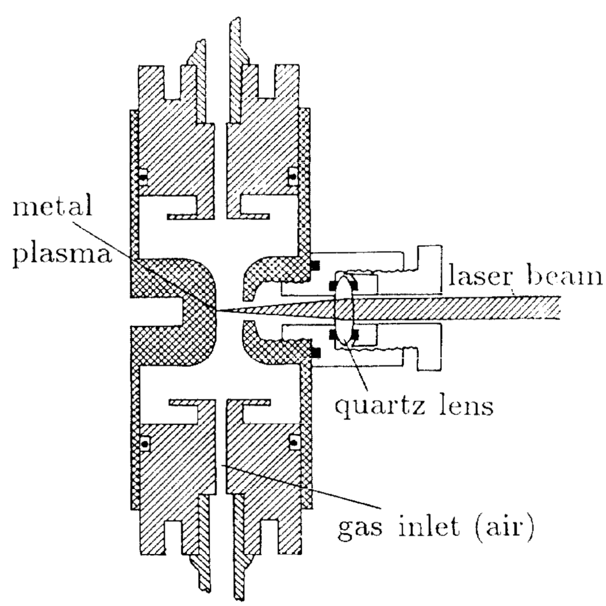

Fig. 1: Spark gap** with lens for laser triggering

Test results

To measure the performance of the LTS a 20 nF high voltage capacitor was discharged by the LTS into a 2 µH inductance. The laser energy was controlled by an attenuator disc. As predicted from (1), the time lag

*) Visitor from University of Warsaw
**) Visitor from Rutherford Appleton Laboratory
***) Visitor from K.F.A.P., Krakow
****) Visitor from Institute of H.E.P, Peking

*) SP 100, ING. KURT HIRSCHEL, Kornwestheim, W.-Germany
**) Tachisto SG301, Hartley Measurements Limited, Basingstoke, England

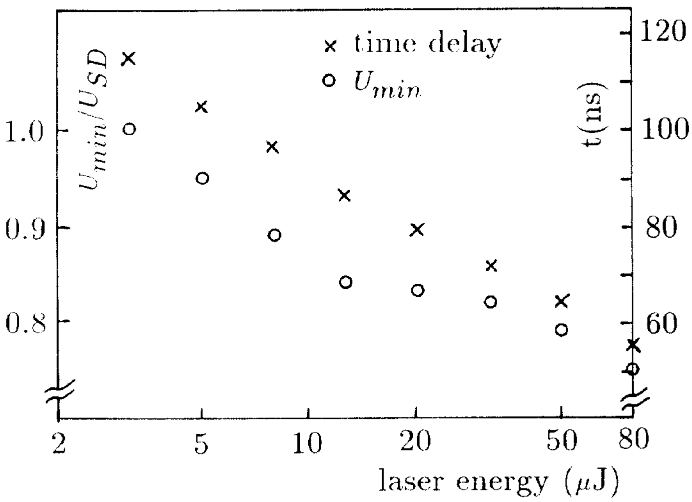

Fig. 2: Time delay and minimal working voltage vs laser energy

of the pulse falls logarithmically (see Fig. 2). The times were measured with a transient recorder by means of the signal from a pin diode with less than 1 ns rise time. From Fig. 2 one can also see that the minimal working voltage is a function of the laser energy.

The decrease of the time delay predicted from (1) is demonstrated in Fig. 3. Time jitters for different voltages have been measured to be of the

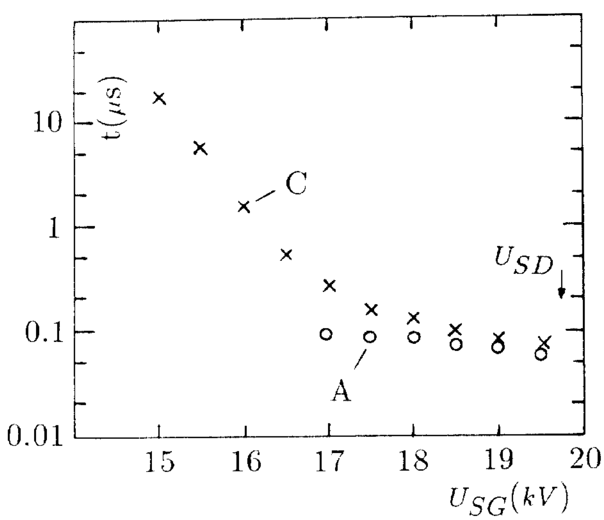

Fig. 3: Time delay for the two cases that the laser beam hits the anode (A) or the cathode (C).

order of 1% of the time delays. A complete curve for a voltage of 18 kV (1 kV below self discharge) is shown in Fig 4. It demonstrates that a time jitter in the subnanosecond region can be reached.

Extension to wide voltage range

The drawback of the LTS lies in the big variation of the time lag with the operation voltage. For instance in the case for the HERA beam abort system the LTS has to work between 1 kV and 20 kV depending on the proton energy. For the sake of reliability and simplicity, changes in the electronics or kicker magnet system should be avoided. As the only parameter the high voltage should track with the proton energy. In particular, the time delay and jitter should stay constant for all voltages. This section shows how we

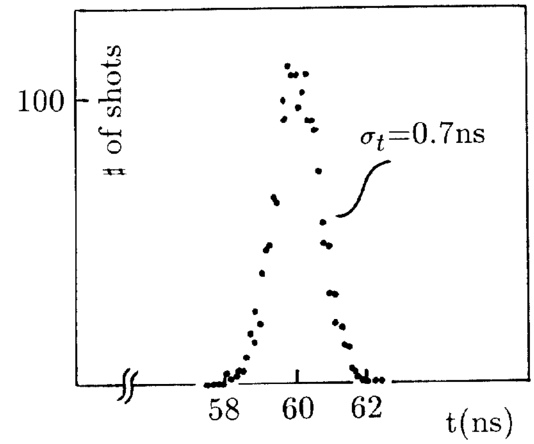

Fig. 4: Time jitter for U_{SG}=18 kV, laser beam hits the cathode

meet this boundary condition.

Principle

Two different circuits have been tested to avoid the time delay problem mentioned above (see Fig. 5):

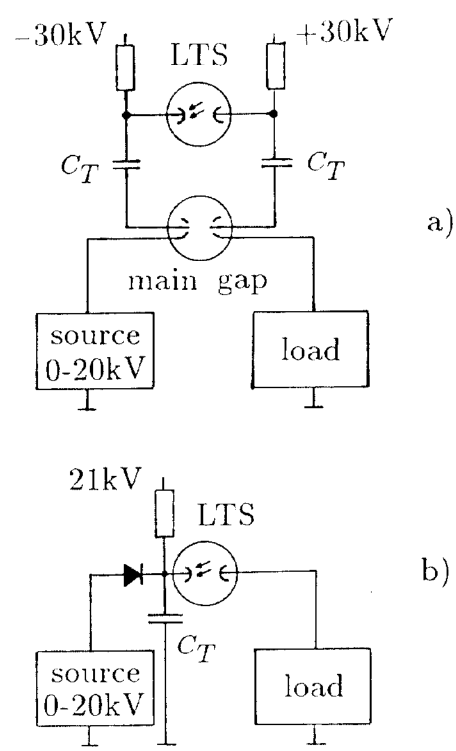

Fig. 5: Principle of wide-voltage-range switching
a) with an LTS as trigger device and
b) with an LTS, decoupled from the load by a diode, as main switch

a) This circuit makes use of the effect that with an intense ultraviolet light source nanosecond triggering is possible when one applies a 100% or more overvoltage to the spark gap/4/. The main gap is supplied with two electrodes, each having a spark plug for electrical triggering. When the LTS is switching, on each electrode an intense spark is initiated by discharging the triggering capacitor C_T. This ultraviolet light source, together with the 60 kV overvoltage applied to the main gap causes the main gap to switch with constant timing, irrespective of the source voltage. This timing is given only by the LTS which works at a constant voltage of 60 kV and therefore results in a constant time delay and jitter.

b) In this version the LTS serves also as the main spark gap and only one additional capacitor C_T and HV-power supply plus a decoupling diode is needed. Also in this version the LTS works at a fixed voltage independent of the source voltage. The additional diode can easily be built up from ordinary rectifier diodes.* When the spark gap is triggered by the laser, the LTS is switched on by the discharge of C_T, which has to be small compared with the source capacitance to have only a small influence on the pulse shape. The LTS stays switched on until the source is discharged.

HERA kicker switch

The application to the kicker magnets of the beam abort system is shown in Fig. 6:

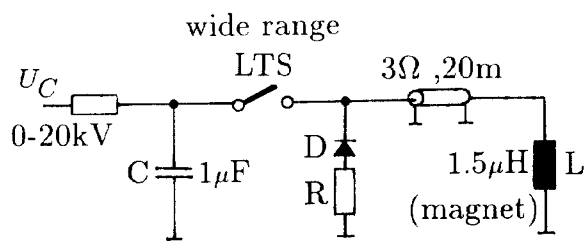

Fig. 6: Circuit diagram for HERA proton abort kicker system

A capacitor is discharged into the magnet (here represented by an inductance L). The diode D serves together with the resistor R for pulse shaping: after the sine wave rise of the current through the magnet, the voltage inverts, i.e. the diode conducts and the current will fall $I = I_0 \exp(-t/LR)$. As a result the magnetic field will have a fast rise, $t_{1/2} \approx 1$ µs, and a long exponential decrease with $\tau \approx 25$ µs. This shape is used to sweep the beam across the surface of the absorber block. From the two cases of Fig. 5 one gets the following result:

a) For a voltage range down to 3 kV one gets no significant delay difference in the pulse between the different working voltages. For 1 kV there is a delay of 700 ns (see Fig. 7a). Also remarkable is the big high frequency ringing of the pulse, initiated by the ± 30 kV trigger circuit.

b) There is no significant ringing or time delay for all working voltages (see Fig. 7b). The time jitter was measured to be less than 2.5 ns for voltages between 1 kV and 20 kV, when the spark gap was operated 1 kV below self discharge limit. In this value the time jitter of the laser, the trigger electronics and the spark gap are included.

*) The type 1N5408 for instance, which is a 3A diode, is good for 1 kA and 1 kV for a 10 µs long pulse.

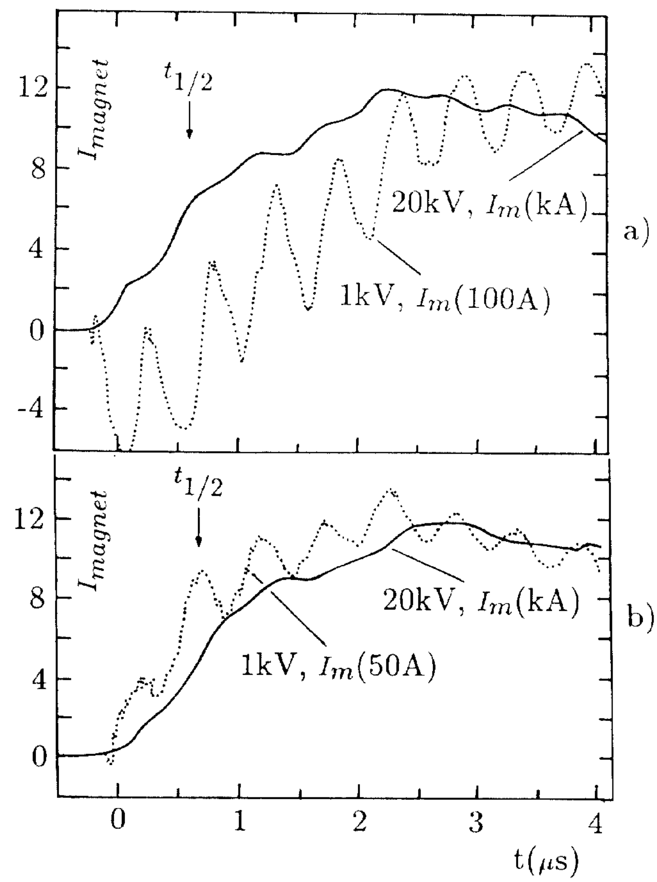

Fig. 7: Pulse shape of magnet current for main capacitor being charged to 20 kV and to 1 kV : a) circuit Fig. 5a and b) circuit Fig. 5b

References

/1/ A.H. Guenther, J.R. Bettis, IEEE Journal of Quantum Electronics, Vol.QE-3, No.11, pp.581-588, Nov. 1967
/2/ C.B. Edwards, F. O'Neill, M.J. Shaw, J.Phys.E: Sci. Instrum., Vol. 18, pp.136-141, 1985
/3/ A. Sieber, Institut für Plasmaforschung, Universität Stuttgart, private communication (diploma thesis), Oct. 1976
/4/ T.F. Godlove, Journal of Applied Physics, Vol.32, No.8, pp. 1589-1596, Aug. 1961