e2v technologies

Three-Electrode Spark Gap Preamble

INTRODUCTION

The range of three-electrode spark gaps offered by e2v technologies comprises hermetically sealed gas filled switches available with DC hold-off voltages from 3 to 50 kV.

Three-electrode spark gap applications include medical lithotripsy, crowbar circuits, high di/dt switches for laser firing and high energy switches.

PRINCIPAL FEATURES

- No Standby Power Consumption
- Consistent Breakdown Voltage
- High Current Capability
- Fast Switching
- Rugged and Reliable over Temperature Range
- Lightweight

THREE-ELECTRODE SPARK GAP SELECTION

When considering the choice of spark gap, the following factors should be taken into account:

- Application
- Peak current and waveform
- Coulombs per shot
- Repetition switch rate
- Main gap voltage
- Environmental conditions

The e2v technologies three-electrode spark gap preamble should be read in conjunction with the relevant product data sheet to gain a general understanding of the spark gap performance characteristics.

e2v technologies provides a technical customer support service for any queries and assistance.

PRINCIPLES OF OPERATION

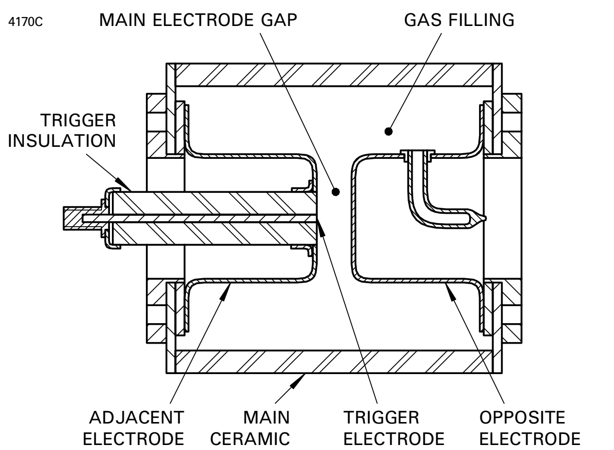

Fig. 1. Basic structure of a typical 3-electrode spark gap

Unlike simple two-electrode spark gaps, the provision of a third trigger electrode makes it possible to switch voltages far below the device's breakdown voltage (see Fig.1).

THREE-ELECTRODE SPARK GAP TERMINOLOGY

Hold-off Voltage

The highest DC voltage that the gap can hold off safely; usually it falls during the life of the gap and the ratings allow for this. The spark gap will break down within +10% of the specified voltage unless otherwise stated. A device can be manufactured to any voltage within the range stated.

Operating Range

A three-electrode device can be triggered in the recommended mode A, with a main gap voltage between 40% and 80% of the hold-off voltage (see Fig. 2).

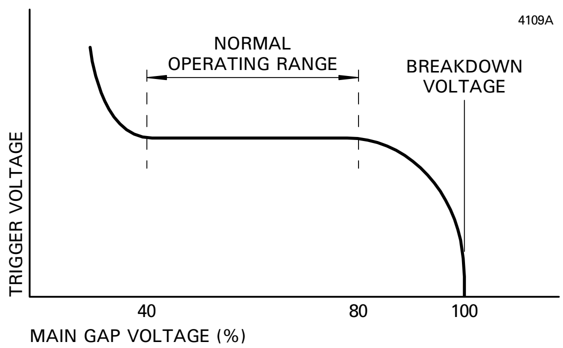

Fig. 2. Triggered operating voltage range

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Minimum Operating Voltage

This is 40% of the hold-off voltage.

Recovery Time

The time taken for the device to recover after an arc to a condition where it can hold off voltage again. In extreme cases a few seconds must elapse before re-application of the working voltage (see Operating Notes).

Delay Time

Delay time is circuit dependent and is the period between 90% of the rising trigger breakdown voltage and the time at which the peak current of the main discharge is achieved (see Fig. 3).

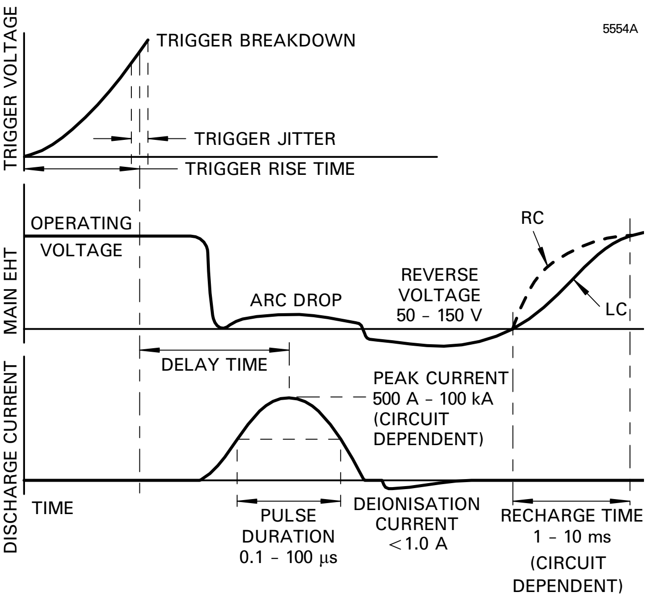

Fig. 3. Typical Waveforms for 3-electrode devices

Jitter

Jitter is the variation in delay time from shot to shot. The delay time jitter of the spark gap depends on the operating conditions being used. Low jitter is achieved by using a fast rise time trigger pulse and operating at about 80% of the hold-off voltage.

Insulation Resistance

The resistance of a three-electrode spark gap measured at 100 V dc between the opposite and adjacent terminals is typically >10 000 MΩ.

Life

The passage of current through a gap has a cumulative effect, causing a gradual reduction of the hold-off voltage. The life of the spark gap can be expressed as the cumulative charge in coulombs passed through the gap which reduces the hold-off voltage by 10%. Life shortens with increasing charge per discharge, peak current and increasing repetition rate. For further details see Operating Notes.

Maximum Charge Transfer

The laboratory verified, maximum charge transfer, single discharge handling capability of the spark gap with a defined pulse wave shape. The cumulative charge transfer figure used to express life is based on figures below this value specified at a relative pulse repetition discharge rate.

Recommended Repetition Rate

The maximum repetition discharge rate per second for optimum spark gap performance. For further details see Operating Notes.

OPERATING NOTES

Modes of Operation

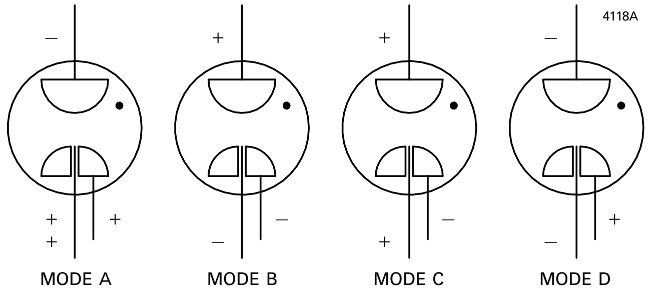

Fig. 4. Modes of Operation

Three-electrode gaps can be connected in four configurations, (see Fig. 4). However, the recommended mode of operation is mode A as stated below.

The adjacent electrode is positive with respect to the opposite electrode. The trigger electrode is positive with respect to the adjacent electrode. The opposite electrode can also be earthed (see Figs. 5a and 5b). Mode D operation is considered to be unsatisfactory for most applications.

Recommended Mode A Circuits

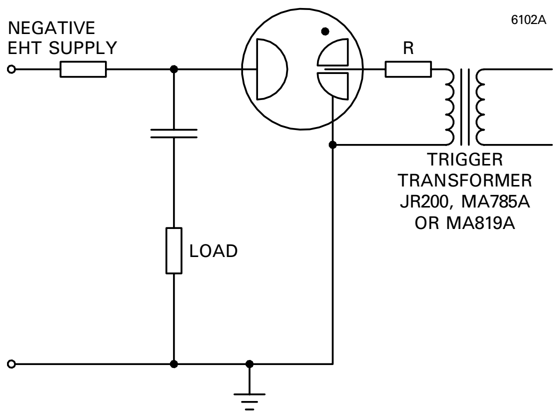

Fig. 5a. Mode A Negative EHT supply circuit

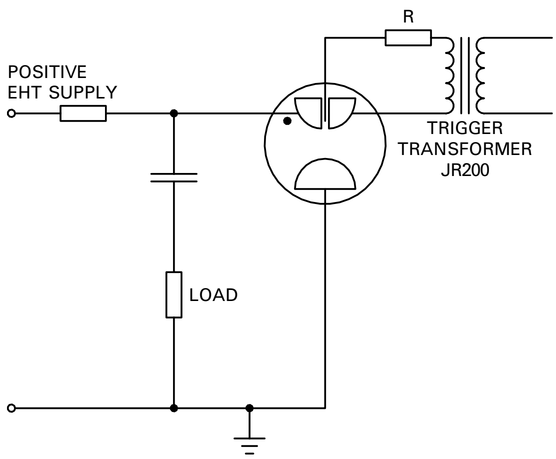

Fig. 5b. Mode A Positive EHT supply circuit

Triggering Requirements

All GXG series spark gaps can be triggered, if the main gap voltage is within the operating voltage range, by the application of a trigger pulse having a minimum open circuit peak amplitude of 50% of the hold-off voltage or 15 kV, whichever is the greater.

The recommended trigger pulse transformer for use with the GXG series spark gap is the e2v technologies type MA785A, or type JR200 if trigger isolation is required.

All GXT series spark gaps can be triggered if the main gap voltage is within the operating voltage range, by the application of a trigger pulse having a minimum open circuit peak amplitude of 50% of the hold-off voltage or 5.0 kV, whichever is the greater.

The recommended trigger pulse transformer for use with the GXT series spark gap is the e2v technologies type MA819A.

For optimum triggering, the rise time of the trigger pulse should be <1 μs with a current greater than 1 A.

Typical Firing Circuit

The circuit (see Fig. 6) is suitable for the GXG and GXT series spark gaps; for GX3002 with integral trigger transformer, only the front end circuit is required.

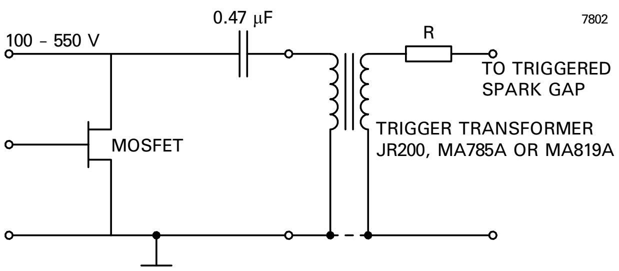

Fig. 6. High voltage trigger circuit

Conditioning

e2v technologies spark gaps are preconditioned during manufacture and are suitable for use in most applications. In some applications, further preconditioning in the customers' circuit may be necessary to stabilise the voltage hold-off when the spark gap is new.

End of Life Failure Modes

Figs. 7a and 7b depict two dominant failure modes. The hold-off voltage of the device falls very slowly during life until it reaches a critical point where it falls very rapidly; this is due to coating the internal insulator surface with a metallic film. The erosion and coating of the trigger ceramic is also possible, leading to the reduction of the operating voltage range.

Prefires

Prefires may occur without an untriggered discharge and the applied DC voltage is greater than the hold-off voltage (see Fig. 7a), causing the spark gap to break down.

Misfires

A misfire is a failure of the tube to break down with the command to trigger. When the minimum operating voltage of the tube increases slowly towards the DC hold-off voltage, the tube switching performance becomes erratic (see Fig. 7b). Generally, misfires occur at this time with the failure of the tube to operate at the required voltage.

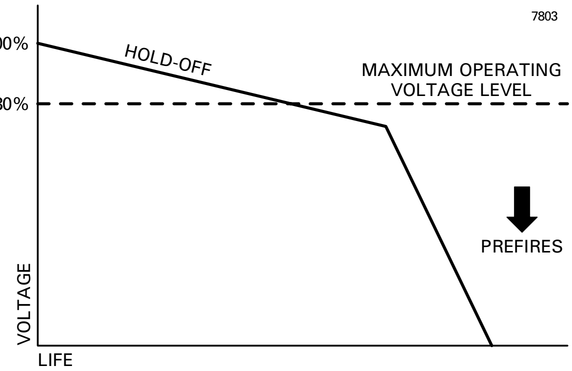

Fig. 7a. Prefire failure mode

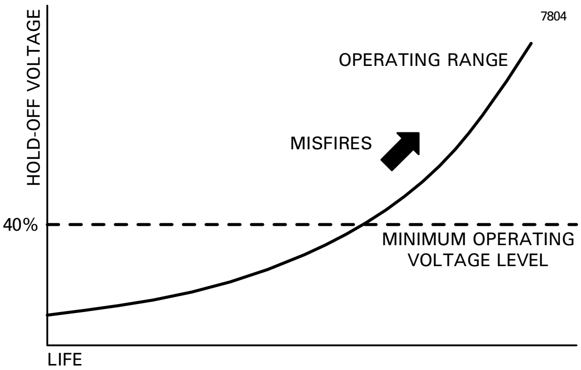

Fig. 7b. Misfire failure mode

Charge Transfer

The life of a spark gap increases with decreasing charge transfer. For example, the cumulative charge life for the GXG series is 1500 C at 1.5 mC per discharge (10 kA peak current), rising to 15 000 C at 1.5 mC per discharge (3.5 kA peak current). However, the relative peak currents and other circuit characteristics should be considered also.

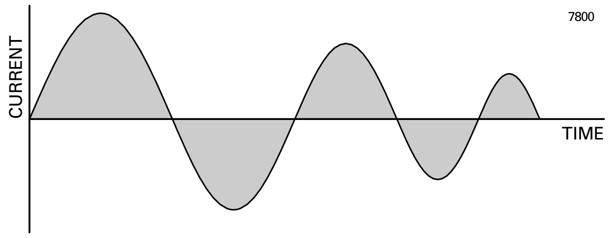

Fig. 8. A typical current pulse (circuit dependent)

For the ringing current pulse conducted by the spark gap (see Fig. 8), the charge transfer is the sum of the shaded areas, not the stored charge CV, where C = capacitance and V = charging voltage.

Gas Content

The gas content of a spark gap might be inflammable when mixed with air. Devices should not be operated if damage to the envelope is evident.

Repetition Rate

The life of a spark gap increases with decreasing repetition rate.

Recovery time with low duty operation is very short (microseconds) and high repetition rates are possible.

However, as the charge transferred per discharge increases, thermal effects begin to dominate and the maximum repetition rate decreases. At these levels, the recovery time may be many tens of milliseconds and under these conditions the charge/discharge cycle shown in Fig. 9 is preferred to prevent untriggered discharges.

Factors Affecting Life

It may be possible to extend the life of a spark gap by operating the device well below the stated operating characteristics.

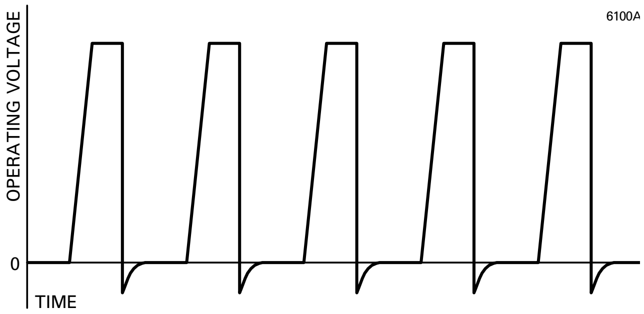

Fig. 9. Preferred Charge/Discharge Cycle

Peak Current

The life of a spark gap is governed primarily by the deposition of electrode material on the insulating surfaces. The rate of erosion of the electrodes may be related to peak current as follows:

$$\text{Rate of erosion} \propto (I_{pk})^{1.6}$$

Hence, limiting the peak current can increase spark gap life.

Rate of rise of current (di/dt)

Rates of rise in excess of 125 kA/μs are possible with spark gaps, but improvement in life can be achieved by operating at lower values.

Pulse Duration

For a given peak current, longer life will be obtained with shorter pulses.

Current Reversal

Reasonable life can be achieved with high current reversal, but for maximum life a critically damped circuit is desirable.

Polarity

Optimum life is obtained by using mode A operation (see Fig. 4).

Circuit Symmetry

Long life depends on even distribution of the discharge around the electrodes. The electromagnetic fields generated by the discharge may be sufficient to produce a preferred discharge path which in turn might lead to excessive local erosion and reduced life.

APPLICATION NOTES

Typical Applications

- Medical Lithotripsy
- Crowbar Circuits
- High Energy Switches
- High di/dt Switching
- High Voltage Switches for Laser Firing

The current and charge ratings are related to the life of the spark gap, measured as the number of discharges before the voltage limit is no longer reached; the compromise between life and discharge ratings can be varied over a wide range for any given type.

Pulse Generators

It is possible to use a spark gap as the switch in a pulse modulator at very high peak power levels. The life of the spark gap will be very much less than that of a thyratron developed for the same conditions, but might still be sufficient for applications requiring only a short or very intermittent operation. The advantages of a spark gap for this purpose include zero standby power, zero warm-up time, a long non-operating life and low cost.

Crowbar Circuits

This is a protection circuit where the load must be protected against faults within itself. In most cases, such faults will produce an increase in load current or voltage, so a 3-electrode gap must be used and triggered by a circuit arranged to sense the fault condition. Fig. 10 shows a simple crowbar circuit triggered by a current surge; in cases where the fault condition appears as a change in output or frequency, for example, the sensing circuit might be quite complex. A travelling wave tube crowbar circuit with a self-triggering 3-electrode spark gap is shown in Fig. 11.

The purpose of the crowbar circuit is to divert power from the load immediately after a fault occurs, giving time for a mechanical circuit breaker to operate. With an adequate trigger pulse having a fast rise-time, the breakdown time can be less than 1 μs; if the reaction time of the fault sensing circuit is similarly short it is possible to remove anode power from a pulse amplifier tube before the end of the pulse in which the fault first occurs.

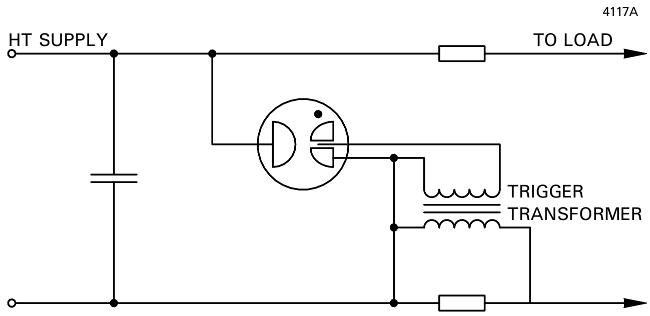

Fig. 10. Simple crowbar circuit triggered by fault current

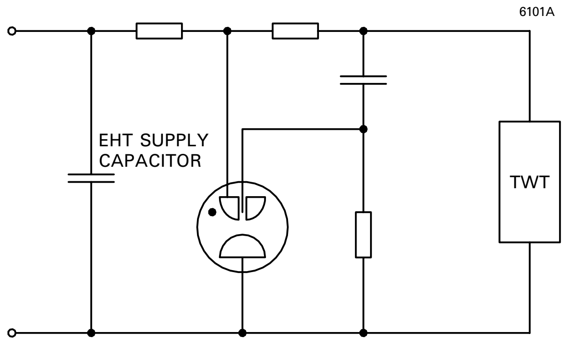

Fig. 11. TWT crowbar circuit with self-triggering 3-electrode spark gaps

TRIGGERED SPARK GAPS FOR MEDICAL LITHOTRIPSY

Currently there are a number of applications within the medical equipment field which use e2v technologies spark gaps as the integral power switching device, for example shock wave lithotripsy machines for the treatment of kidney stones.

A significant feature of e2v technologies triggered spark gaps is the wide operating range. This is a dominant attribute of many lithotripsy machines, providing added flexibility in addition to reliability and good operational performance.

e2v technologies manufactures two types of triggered spark gap - the GXG and the GXT, both ideally suited for lithotripsy applications. Operational main gap voltages range from 12 to 28 kV switching at the rate of 4 to 5 Hz.

Triggered Spark Gaps for Lasers

There are a number of applications in both civilian and military markets where CO_2 lasers can be used to advantage over other coherent light sources.

In all of the following applications the laser is used in a pulsed mode and the triggered spark gap has been found to be a most useful device for achieving this operation.

The demands of the laser are relatively simple; depending on the size of the device, pulses of energy from a storage capacitor charged to between 10 and 40 kV are fed to the laser by a spark gap switch.

In the military field, target designation and range finding applications use pulses of light directed at a target. The scattered light can then be used to direct a remotely released weapon onto the target; alternatively, the time for the reflected light pulses to return to the sender can be measured to give an accurate calculation of the target range. CO_2 lasers are well suited to these military roles because the 10 μm wavelength light output gives very good penetration through smoke and adverse atmospheric conditions and has the additional virtue of being relatively eyesafe.

The major civilian market for CO_2 lasers is in thermal printing equipment, where the light is used to burn such things as 'consume by' dates on food packages. In this case, a pulsed CO_2 laser is fired through a stencil containing the legend to be printed; the light is then focused onto the target using a simple lens system and the mark is produced by removing a thin layer of ink or burning slightly into the surface of the material. Food, drink, cosmetics and pharmaceuticals are now being marked in this way. The great advantage of this method of printing over conventional stamping techniques is one of speed.

The only limitation placed upon the switching element in these applications is that the energy must be transferred quickly from the capacitor to the laser. To achieve a lasing action, the rate of rise of current in the discharge circuit should exceed 10 kA/μs; values exceeding 125 kA/μs have been demonstrated with e2v technologies spark gaps. The gas-filled triggered spark gap is able to accommodate this quite adequately. All e2v technologies triggered spark gaps have triggered CO_2 lasers successfully.

The GXG and GXT devices were originally designed to operate at up to 100 pps, but are capable of operating at 500 pps in burst mode. At repetition rates of 100 pps and above, many hundreds of thousands of discharges are quickly accumulated, therefore a lifetime of several million discharges is a necessary feature of these spark gaps. Lives in excess of 10×10^6 discharges have been achieved with the GXG and lives in excess of 20 million shots in an actual laser system.

The GXG spark gap offers a delay time jitter of less than $\pm$200 ns, when operating at about 80% of the hold-off voltage. This is necessary if the shot-to-shot variation of the spark gap delay time and the delay time jitter are important for the operation of the complete system. Please consult e2v technologies before ordering if a low jitter is required.

As the number of applications for CO_2 lasers and lithotripsy increases, it is apparent that the triggered spark gap has much to offer in terms of compact size, instant start capability and independence from any ancillary power units.

Environmental

The thermal, shock and vibration tolerances of most spark gaps are adequate for normal domestic and industrial applications, but certain types are especially rugged.

Where an industrial application involves a corrosive or abrasive atmosphere, spark gaps will require the same protection as most electronic equipment.

Storage

Spark gaps should be stored preferably in the original packing in a non-corrosive atmosphere. If removed from their packing they should be protected from dust and industrial atmospheres until required.

Mounting and Connections

The rise time of the arc current is determined mainly by the inductance of the external circuit and connections; where the fastest possible switching is required, the gap can be built into the end of a coaxial line, matched to the circuit impedance. In general, the connections should be kept short and well spaced to minimise this inductance. For the same reason, the mounting position will normally be as close as possible to the load or protected equipment. In protection and single-pulse applications, the heat dissipated by the spark gap is not enough to require any assisted cooling, and the maximum temperature rating of the gap will not usually restrict the choice of mounting position.

Most spark gap applications involve high peak currents. Although the mean currents are relatively small, so that small section conductors can be safely used, the connections must be secure. Any poor or loose contacts will be eroded rapidly and are likely to fail completely.

SPARK GAP ENQUIRY OPERATING PARAMETERS FORM

Overleaf is e2v technologies' Spark Gap Enquiry Operating Parameters Form. Please detach or photocopy, then complete and return the form as indicated to the address shown, and e2v technologies will recommend the most suitable spark gap. All information will be treated in the strictest confidence.

INFORMATION CHECK LIST

Answering the following questions will enable e2v technologies to select the most suitable 3-electrode spark gap.

What is/are the:

- application,
- required DC breakdown voltage,
- required operating voltage range, min - max,
- value of the charge storage capacitor,
- maximum charge transfer,
- cumulative charge transfer,
- typical life shots expected,
- peak current, waveshape and cycle time,
- maximum switching rate per second,
- required dimension limits,
- environmental parameters, e.g. operating temperature, shock, etc?

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Spark Gap Enquiry Operating Parameters

Please complete as accurately as possible to allow the most suitable spark gap to be recommended. All information is treated in the strictest confidence.

Company Name and Address	
Contact Name Position	E-mail
Telephone No.	Fax No.
Application	
Discharge Circuit and Current Waveform (if known). Please sketch the discharge circuit below or attach a circuit diagram.	

Spark Gap Operating Conditions

Operating Voltage Range	
Peak Current	
Repetition Rate	
Life Required	
Other Requirements	