

10.3.1.3 Electrical sparks (spark discharges)

Electrical sparks (Fig. 10.2 illustrates different types of *spark generator*) are defined as discontinuous *electrical discharges* across a gap between at least two electrodes constituting the *analytical gap (spark gap)*. The *discharge current* is supplied by a cyclically charged capacitor C. After *spark ignition* the voltage across the analytical gap drops from the initial *capacitor voltage*, U_{cap} , to the low *burning voltage*, U_b , of an arc within a time that is short compared to the spark duration θ . Therefore, basically, sparks can be considered as interrupted arcs of higher *initial current*, I_0 or *peak current* and of a lower duty cycle than those treated in Section 10.3.1.2.4.

10.3.1.3.1 Charging circuit (Fig. 10.2)

The spark capacitor C is charged through the *charging circuit*, a rectifier, a *charging resistor* and electronic or other devices for the control of *charging current*, *peak capacitor voltage*, U_{cap} , and the phase. If the capacitor is always charged at the same polarity, a *dc spark* will result and in the case of an alternating charging voltage, an *ac spark*.

10.3.1.3.2 Discharge circuit (Fig. 10.2)

The *discharge circuit* connects the capacitor of capacitance C with the analytical gap. It may contain inductors, of induction L, a resistor of resistance R, and devices for triggering the spark for control and synchronization purposes, e.g. a *control spark gap (control gap)*.

Spark current, I , and burning voltage, U_b , may oscillate with the *spark frequency*, f , resulting in an *oscillating spark*. Suitable combinations of the *discharge impedances* lead to *critically damped*, $R = 2\sqrt{L/C}$, *overcritically damped* $R > 2\sqrt{L/C}$ or *undercritically damped* ($R < 2\sqrt{L/C}$) *discharges*. With a *controlled duration spark* the spark current is terminated by additional means.

An oscillating discharge current periodically passes through zero with consecutive re-ignition at the *re-ignition voltage* U_z which may be a few hundred volts. By securing a dc bias current, oscillating discharges can be prevented from being extinguished during part or during the full length of the spark duration (*dc biased oscillating discharge*). The amplitude of an oscillating spark current decreases with time, showing a *linear* or *logarithmic decrement* depending on the prevailing impedance.

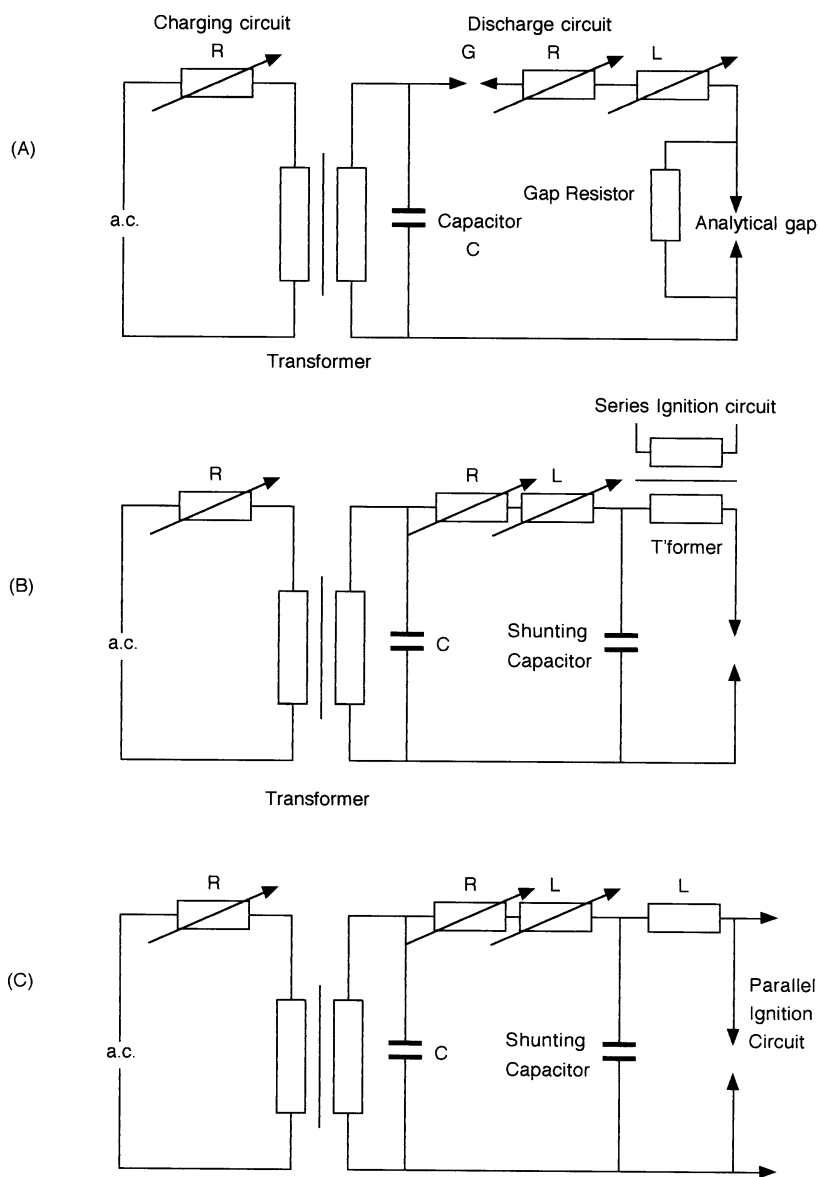


Fig. 10.2 Spark Generators

Notation to Fig. 10.2:

- (A) Controlled high voltage spark generator, G = stationary or rotary control gap, R = resistor, L = inductor, C = spark capacitor
- (B) Medium or low voltage spark generator with series ignition circuit
- (C) Medium or low voltage spark generator with parallel ignition circuit

In spectrochemical analysis, either a *single spark* or a sequence of sparks (train of sparks) can be used. *Spark repetition rates* are of the order of 50 to 100 s⁻¹.

The analytical gap is bridged by the electrically conducting *spark channel* through the *discharge atmosphere*. Electrode material is removed in the form of a *vapour jet* from the cathode. In the case of an *inert discharge atmosphere* electrode material is similarly removed from the cathode and, in other discharge atmospheres, from the anode, too. Due to the randomly distributed direction of the vapour jet, the vapour cloud produced in this way may be a current-carrying or a non-current-carrying plasma depending on whether it penetrates into the current-carrying spark channel or not.

10.3.1.3.3 High voltage sparks

A *high voltage spark* is a *self-ignited spark discharge* characterized by an initial capacitor voltage exceeding the *breakdown voltage* of the analytical gap or of the control gap. Typical capacitor voltages range from 10 to 20 kV. Other operating conditions may be as follows: 500 < C < 20,000 pf, 5 < L < 5,000 μH, 50 kHz < f < 1 MHz, 10 μs < θ < 1ms (where θ = spark duration).

A high voltage spark generator is called an *uncontrolled high voltage spark generator* if the breakdown of the analytical gap determines the initiation of the discharge. In this case, the *charging time constant* of the charging circuit determines the number of breakdowns per half cycle. In a *controlled high voltage spark generator* initiation of the discharge is governed by mechanical or electrical means. Either the voltage or the *breakdown time* can be controlled. The voltage control may be achieved by the defined breakdown voltage of a stationary control gap (*auxiliary spark gap*). The time control is achieved by a *triggerable stationary gap* or by the phase adjustment of a *synchronously rotating gap*. (Terms such as interrupters or synchronous interrupter are discouraged). Irradiation of the spark gaps by UV radiation obtained from an *ionization needle* or a discharge lamp, and a high ohmic *gap resistor* (Fig. 10.2(A)) helps to overcome *breakdown jitter*.

10.3.1.3.4 Medium voltage sparks

Spark discharges have to be externally initiated if the capacitor voltage U_{cap} is lower than the breakdown voltage of the analytical gap. If this capacitor voltage is still significantly higher than the re-ignition voltage U_z of the analytical gap, one speaks of a *medium voltage spark*. (Typical operating conditions for medium voltage sparks are: 500 < U_{cap} < 1500 V, 1 < C < 25 μF, 50 < L < 200 μH, 0.5 < R < 50 Ω). They are *externally ignited spark discharges*. Ignition is accomplished by means of a high voltage *ignition pulse*, also called an ignition spark. Critical damping occurs at resistances of a few ohms. A choice of discharges can, therefore, be made, i.e., *undercritically damped discharges*, and *overcritically damped*, long-lasting, low current, *arc-like discharges*. Spark frequencies of the oscillating discharges may be 2 < f < 20 kHz with a spark duration of 0.1 - 2 ms.

With undercritically damped sparks the number of oscillations, ρ , will be $1 < \rho < 5$. Apart from their different range of operating parameters, *medium voltage spark generators* require an *ignition circuit*. The igniting high voltage pulse can be introduced in series with the applied medium voltage across the gap by means of a high frequency step-up transformer (*Tesla coil*) to give *series ignition* (Fig. 10.2(B)). It can also be introduced in parallel with the gap voltage to give *parallel ignition* (Fig. 10.2(C)).

10.3.1.3.5 Low voltage sparks

These discharges are similar to medium voltage spark discharges. The capacitor voltage U_{cap} is of the same order as the mains supply voltage. To compensate for the low voltage, capacitors are accordingly large so as to provide the required spark energy. The number of oscillations per spark is small and *unidirectional discharges* are easily obtainable.

10.3.1.3.6 Spark stands

The *spark stand* contains the electrode holders, usually watercooled, for one or more electrode configurations. Provision is made optically, e.g. by a *projection screen*, or mechanically, to align the electrodes and to adjust the electrode gap. For discharges at pressures other than normal, or in atmospheres other than air, a *spark chamber* is employed. Such a chamber may also have a *spark confiner plate* or disc made of a non-conductive material such as boron nitride to confine the spark to a definite area of a sample surface. In order to remove the evaporated electrode material, the spark chamber is flushed by the continuous flow of the *working gas*.

10.3.1.3.7 Discharges in vacuum

High excitation energies may be achieved by means of spark discharges at very low pressures. These sparks are called *vacuum sparks*. To overcome the high breakdown voltage, a very high capacitor voltage is necessary. Breakdown can be achieved at lower voltage by means of a *sliding spark*, which is essentially a spark along a non-conducting surface (*surface spark*).

10.3.1.3.8 Spectral characteristics

Due to the short *interaction time* of the sparks with the electrodes, these generally remain cool. The high current density in the *burning spot* at the electrodes produces such a high local temperature that fractional distillation is significantly reduced in comparison with arc discharges. The plasma is usually considered to be in *local thermal equilibrium* (LTE) as soon as the initial voltage across the gap has dropped to the arc burning voltage. The temperatures and *electron pressure* in this period are of the same order as those of arc discharges. Soon after breakdown, the plasma is characterized by high temperatures

and high electron pressure, which are responsible for a pronounced continuous *spectral background*. By separating these two phases, with the help of *time-resolved spectroscopy*, it is possible to improve the line to background intensity ratios and correspondingly, the *power of detection*.