Appendix C

Spark-Over Voltages

Air gaps have been used for a long time against lightning surges or other kinds of transient overvoltages. Their response is much too slow for making accurate, dependable ESD protection, except in some specific cases where only a bulk breakdown device would be sufficient. However, the understanding of high-voltage arcing mechanism is useful for some testing and box design aspects, where clearances and arc creeping can lead to some peculiar ESD vulnerability of electronic equipment, as explained in Chapters 4 and 5.

The voltage at which a given air gap will arc depends on the shape of the electrodes, the micrometric roughness of their surfaces, the air pressure and temperature, and eventually their speed of approach if one electrode is mobile.

Provided that (a) the voltage is dc or at a frequency low enough to allow a complete deionization of the channel between two consecutive arcs and (b) the gap itself is dry and dust free, spark-over voltages are given by the law established by Paschen in 1889, from which the curves in Figures C.1 and C.2 are derived. They show that in the range of 0.3–3 atmosphere (1 atm = 1016 mbar, or 15 psi), the breakdown voltage is about proportional to the exact pressure and gap length. Little more accurate than the gross 10-kV/cm rule-of-thumb for sharp edges, a coarse approximation for millimeter to few centimeter gaps can be used: (1)

- For flat, or large radii spherical electrodes:

$$V\ (\mathrm{kV}) = 3pd + 1.3\sqrt{d}$$

- For sharp, needle electrodes:

$$V\ (kV) = pd + 0.7$$

where
d = gap length, mm
p = atmospheric pressure, atm

This simple law can give acceptable estimates within the gap range indicated. Unfortunately, it suffers from many limitations, making it unreliable, as soon

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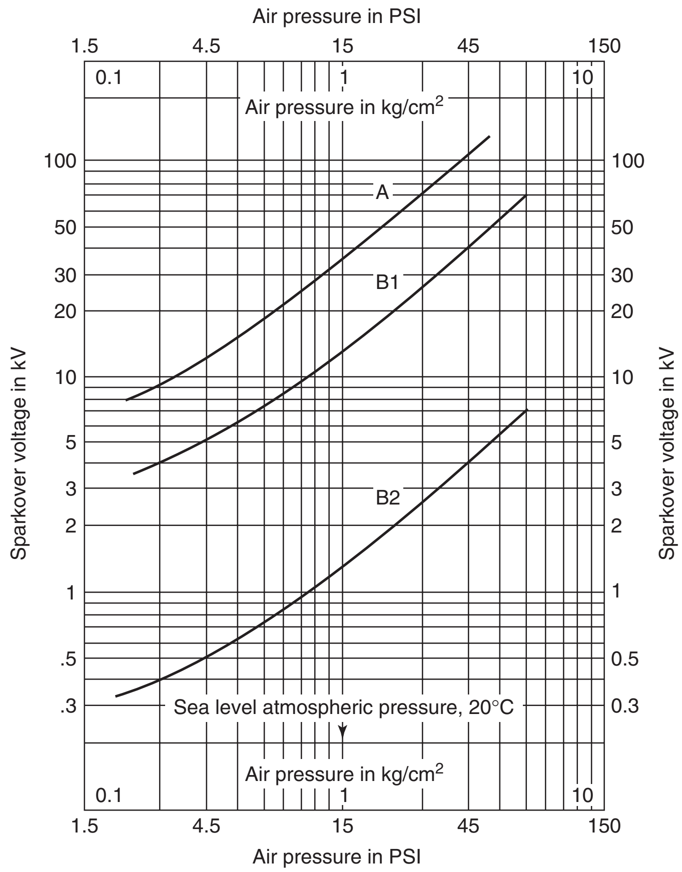

Figure C.1 Spark-over voltage versus air pressure for (A) smooth spherical electrodes, with diameter ≥ gap distance, for a 1-cm gap. (B1) needle gap, 1 cm; (B2) needle gap, 1 mm.

as some conditions are changed, as often is the case with natural or re-created ESD (2):

- When the speed of approach becomes significant, the air gap can with stand much greater voltages before it breaks, with values exceeding 10 kV/mm (2, 3).
- When the electrodes get very close, say in the submillimeter range, two mechanisms are interacting (2):
  - The normal gaseous discharge whereas gas electrons are freed and accelerated by the strong *E* field, getting enough energy to collide with other molecules, creating more ions (ionization) and starting an avalanche.
  - The surface discharge, where the microscopic surface irregularities start melting, due to the high current concentration, adding metal molecules into the plasma.

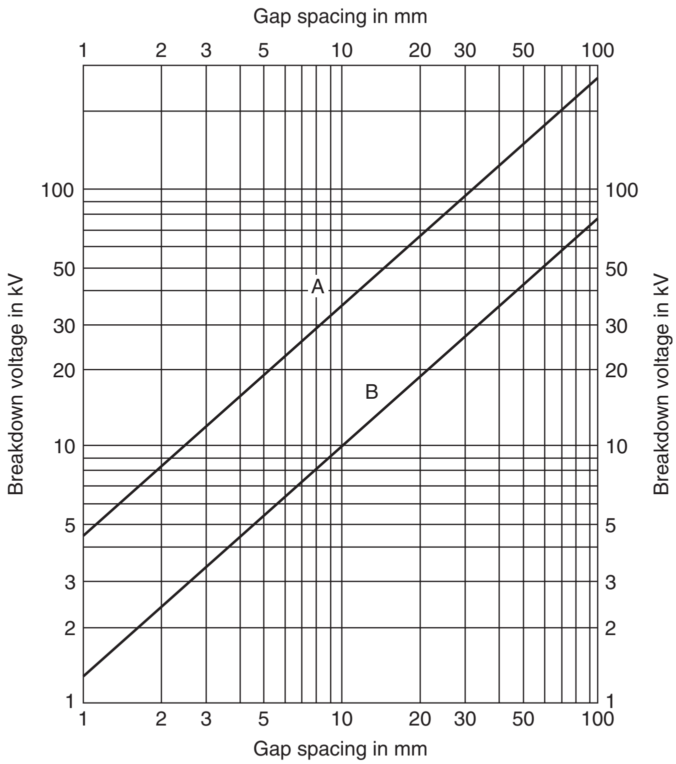

Figure C.2 Spark-over voltage versus gap spacing at normal atmospheric pressure: (A) smooth spherical electrodes, with diameter ≥ gap distance. (B) needle gap.

The breakdown voltage is also inversely proportional to the absolute temperature. Certain synthetic gases have higher arcing voltages than air. Sulfur hexafluoride (SF_6) and Freon 12 (CCI_2F_2) have a dielectric rigidity about 2.5 times higher than air, for similar conditions. This is why such gases, enclosed in a sealed bulb at high pressure, are used in high-voltage relays and switches with minimum arcing and multiple reclosures (showering arc) problems.

Finally, when the air pressure becomes very low (<0.01 atm), heading toward vacuum conditions, the air breakdown voltage ceases to fall off and, below about 6×10^{-3} atm, starts increasing again.

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