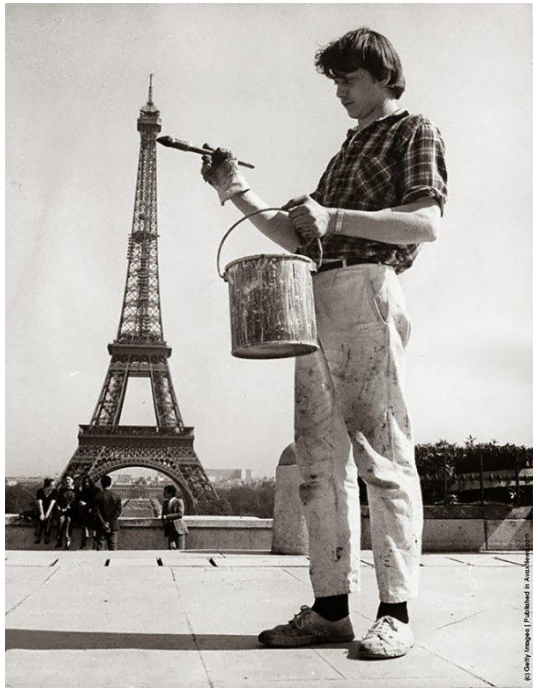
The high voltage testing of dielectric coatings thickness

Vladimir Syasko

NDT1 KRAFT Ltd, Czech Republic

ndtone.com

E-mail: info@ndtone.com

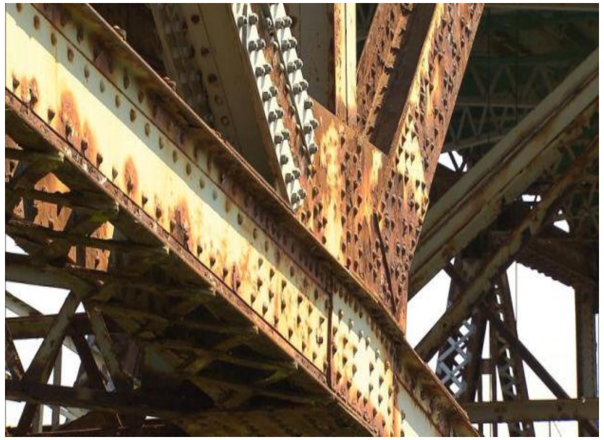


Modern industry needs a wide range of functional dielectric coatings that should provide waterproofing, anti-corrosion, dielectric, or other special properties of the treated surface. Ensuring the specified thickness of the protective coating is one of the main indicators of its quality

the simplest technologies for painting large-sized metal objects

corrosion of large metal objects ⇓

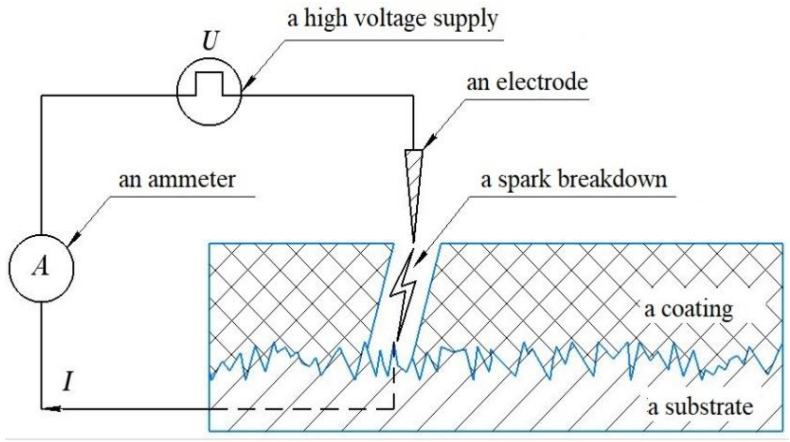
⇓ ***modern technologies of spot control of coating thickness of large metal objects using electromagnetic thickness gauges***



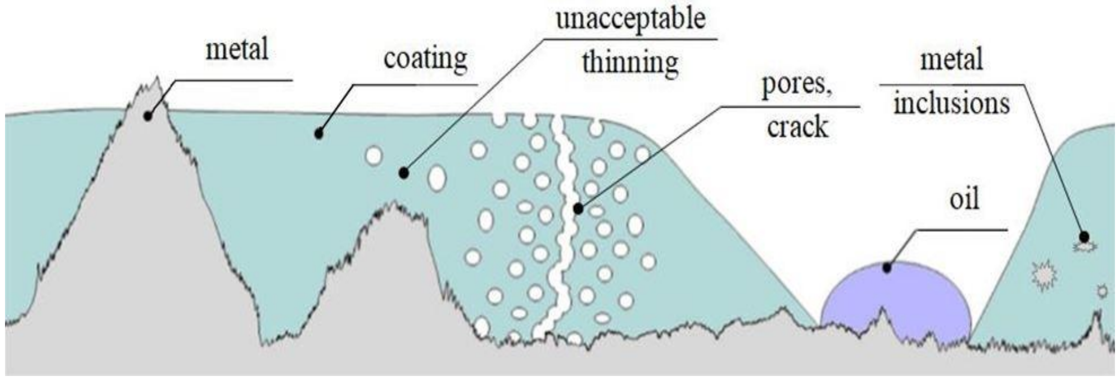
⇓

The lack of the possibility of one hundred percent objective control of the thickness of protective coatings does not allow obtaining reliable information about their quality

High voltage testing method (HVTM) - ”electrospark» method for testing and monitoring of coatings

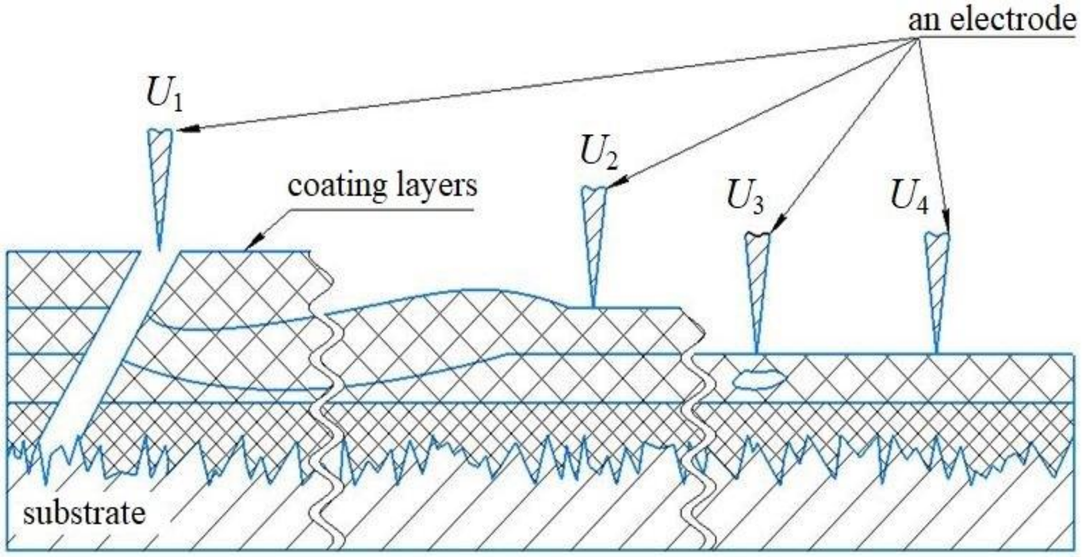


Schematic illustration of the HVTM operation principle. 1 — scheme for fixing the current of spark breakdown and signaling, 2 — high voltage source, 3 — electrode, 4 — spark breakdown of the air gap (defective area of the coating), 5 — dielectric coating, 6 — electrically conductive substrate.



Coating defects that can be detected using the *«electrospark»* method

Modern techniques for selecting the control voltage (U_1) allow only through defects in coatings to be detected. At the same time, the methods do not pay attention to the relationship between the breakdown voltage and the thickness of the controlled coatings (U_2) and, as a consequence, the breakdown voltage of coatings with an unacceptably small thickness (U_4) and blind defects of the coatings (U_3).



Schematic representation of the detecting defects process. U_1 - breakdown voltage for 4 layers of a coating, U_2 - breakdown voltage of 3 layers of a coating, U_3 - breakdown voltage of a blind defect (inner bubble) of a coating, U_4 - breakdown voltage for one layer of a coating.

⇓

A promising direction in the development of the high voltage control is the development of methods for detecting not only violations of the coatings continuity, but also their unacceptable thinning and internal bubbles by the occurrence of a spark breakdown of a defect area

Spark breakdown mechanisms of solid dielectrics

1) The **electrochemical** form of breakdown (electrical aging)

2) **Thermal** breakdown

3) **Electric** breakdown, is observed when the conditions for the development of thermal breakdown are not met, and the duration of exposure to the applied voltage (U_1 ... U_4) is extremely short (electric breakdown develops in a time <1 μs). The onset of electrical breakdown is caused by electronic processes occurring in a strong electric field and leading to an avalanche-like increase in the carrier concentration in the dielectric. The electric form of breakdown exhibits a weak dependence of the breakdown electric field strength on the time of voltage and temperature application.

Breakdown voltage $\boldsymbol{U_b}$ of most solid and gaseous dielectrics with coating thicknesses $\boldsymbol{h}$ > 50 μm is proportional to h:

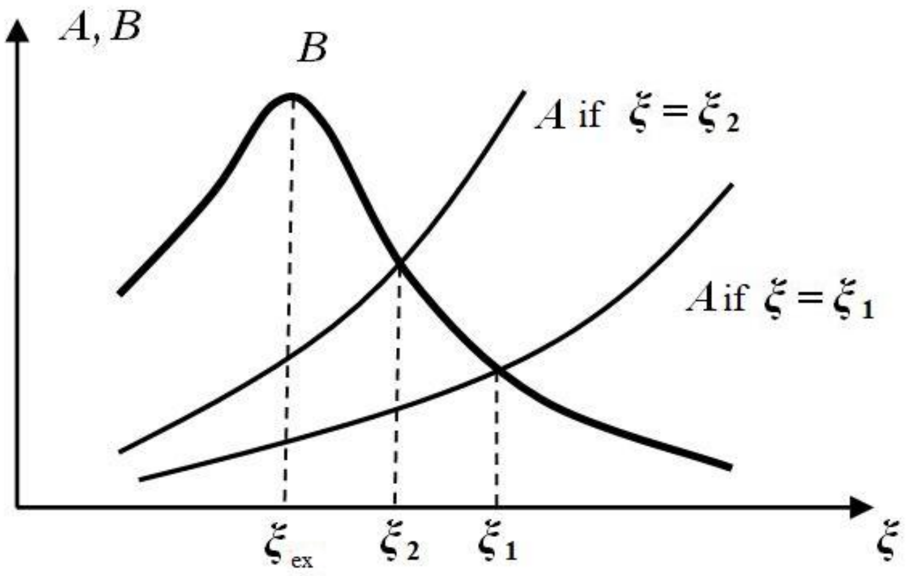
$$U_b = E_b \cdot h,$$

where: $\boldsymbol{E_b}$ – dielectric strength of the coating [kV/mm].

⇓

Thus, it is possible to calculate the breakdown voltage $\boldsymbol{U_b}$ in the area of a blind defect or unacceptable thinning of the coating, knowing the value of E_b of the controlled coating. The value of E_b can be determined by calculation or experimentally.

Dielectric strength calculation for solid dielectrics



The dependence of the acquired A and lost B energy by the electron on its energy ξ.

According to the band theory, an electron, that has some energy ξ , in the conduction band receives, per unit time, some energy A from the electric field, but, on the other hand, spends energy B on collisions with vibrations of dielectric atoms (energy is transferred to the dielectric in the form of heat)

⇓

If the electric field strength is sufficient for the electrons to reach the energy ξ_{ex} corresponding to the maximum losses, then the electrons will further accelerate and reach the ionization energy regardless of its value. This field strength can be identified with the electrical strength E_b and the value of E_b can be determined from the condition $A = B$ at $\xi \geq \xi_{ex}$.

Dielectric strength calculation for solid dielectrics

For a wide range of electrical insulating materials, based on the condition of fulfilling the criterion $A = B$:

$$E_b = K \cdot K_B \cdot (A_c^0)^{1.1} \cdot exp\left(\frac{a}{b + \lg(b)} + \frac{m}{n + \lg(\tau)}\right),$$

where: K – thickness-dependent ratio d of dielectric, τ – duration of exposure to applied voltage, K_B – breakdown probability, A_c^0 – energy of a channel formation, a, b, n, m – ratios.

The resulting formula is quite universal and can be used in calculations for various electrical insulating materials with a thickness of 0.01 to 40 mm with an applied voltage pulse duration $\tau_{pulse} = 0.1 - 10$ µs. In a simplified form, it can be written as follows:

$$E_b = 80 \cdot K_B \cdot (A_c^0)^{1.1}.$$

Where:

$$A_c^0 = A_c \cdot \frac{\gamma}{M} = 1{,}08 \cdot W_c \cdot \frac{\gamma}{M}, where\ A_c = W_c + B_c = 1{,}08 \cdot W_c,$$

and $W_c = \sum_{i=1}^{n} n_i \cdot D_i + m \cdot J$,

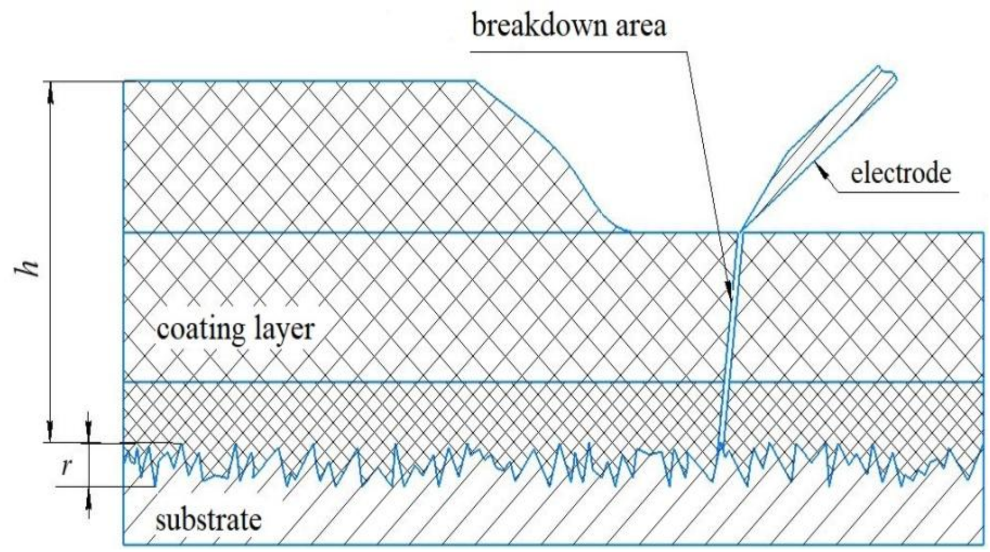
Where: γ – density; M – molecular mass; $n_i{\cdot}D_i$ – bond dissociation energy; $m{\cdot}J$ – ionization energy of atoms.

Dielectric strength calculation for solid dielectrics

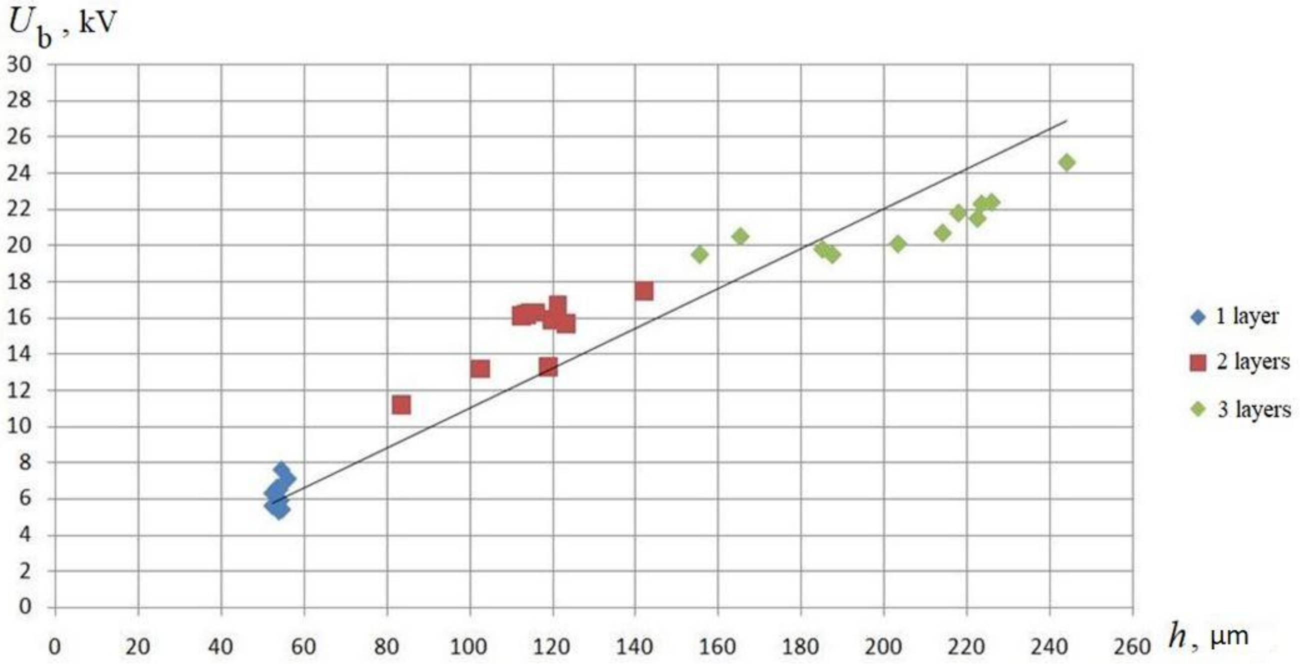
Calculated and experimental values of dielectric strength E_b for a number of dielectric materials with a thickness of d = 0.1 mm.

Dielectric	E_b, kV/mm	
	experimental	calculated
Polyethylene	67,5–70	62
Polystyrene	55–73	43
Fluoroplast -4	35	40
Crystalline quartz	67	67
Talc	32	37
Mica - muscovite	80 – 110	88

Experiment for study of the controlling unacceptable paint thinning possibility of by its breakdown voltage



Multilayer coating of a control sample and a diagram of the process for determining the breakdown voltage, *r* – the coating roughness.



Dependence of the coating breakdown voltage U_b on the coating thickness h.

U_b quasi-linearly increases with increasing h in accordance with the E_b of the coverage. Differences in the values of U_b for close coating thicknesses can be explained by some difference in the thickness hi at the breakdown point from the average value h of the controlled area.

⇓

The experiment shows that when choosing the appropriate calculated or experimentally determined value of U_b, it is possible to identify areas of the coating with an unacceptable minimum thickness (carrying out tolerance control) and coating bubbles.

Conclusion

As a result of the performed theoretical and experimental analysis of the high voltage testing method for controlling dielectric coatings, it was shown that it could be used not only for control the continuity of coatings, but also for identify places of unacceptable thinning or bubbles of coatings. Thus, the development of an appropriate methodology for calculating or experimentally determining the control voltage, which, in contrast to electromagnetic methods of thickness control, will allow one hundred percent control of the continuity and inadmissible thinning of paint and varnish and similar dielectric protective coatings.