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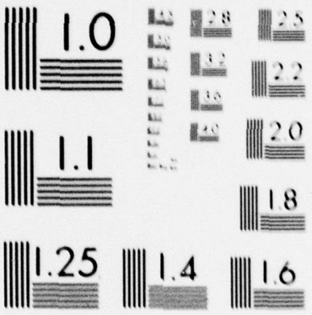

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by

Stanislaw Szpor

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FTD -ID(RS)T-2236-77

EDITED TRANSLATION

FTD-ID(RS)T-2236-77 23 January 1978

MICROFICHE NR: FTD-78-C-000193

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English pages: 15

Source: Prezemysl Chemiczny, Vol. 53, Nr. 6,
1974, pp. 325-330

Country of origin: Poland
Translated by: SCITRAN
F33657-76-D-0390
Requester: Dahlgren Laboratory
Approved for public release; distribution unlimited.

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LIGHTNING PROTECTION OF CHEMICAL INDUSTRY PLANTS THREATENED BY AN EXPLOSION

(Article for Discussion)

Stanislaw Szpor

ABSTRACT. Requirements are presented for modern lightning rods for industrial chemical plants which are threatened by an explosion of gas mixtures or dusts. These requirements in many regards are much more stringent than the presently applicable Polish and foreign standards. Types of lightning rods, protection conditions, parameters of lightning currents, resistivity of flange joints and other joints, **problems** in crane installations, water and sewer lines, central heating, electrical wiring, piping lines, storage tanks, rails, and the periodic inspection of lightning rods are discussed. Various electrical measurements are proposed.

Lightning rods have been used for nearly 200 years. It is universally accepted that the principle of operation consists of receiving the lightning discharge and conducting the lightning current to the ground. Other explanations were rejected a long time ago. By receiving the lightning discharge we mean that the upper parts of the rod and lines are hit by lightning, which misses the protected object. A wide variety of protection requirements are met. Parallel with the protection requirements, in the last few decades conditions for avoiding secondary discharges and avoiding casualties from discharges were formulated. The secondary discharge takes place between the lightning rod lines and pipes, electrical wires and other metal parts under the ground. The induction potential represents a threat of fire or explosion of gas mixtures or dust. These same voltages may electrocute a person who touches a valve or switch on an electrical device.

The chemical industry requires great care at lightning rod installations, especially when there is a potential danger of explosion from secondary discharges. Even the best existing domestic and foreign codes, which use simple rules and ignore certain dangers, do not provide sufficient protection. Plant designs should incorporate much more knowledge of the subject than the present codes require. This article attempts to aid the chemical industry in the formulation of the technical requirements. For electricians, designers, and contractors, a number of specialized articles are being prepared, intended for electrochemical journals.

Types of lightning rods; protection conditions

The lightning rods may be divided into isolated and non-isolated types. Among the non-isolated types one can distinguish the high and low lightning rods. In all three kinds, the lines may be vertical (rods, towers) or horizontal (lines).

Low, non-isolated lightning rods are very common for protecting objects of reduced importance. In Germany, Switzerland, and Poland, horizontal conductors (lines) are used. For a distance from a roof surface of much less than 1 meter, this protection is quite good if the roof is an insulator, that is, made of wood, tiles, cement-asbestor materials, straw, without large metallic elements. For the reinforced concrete roofs, often used in industrial buildings, the non-isolated low lightning rod does not provide sufficient protection. Full protection may be achieved using the high non-isolated lightning rods. A network of horizontal lines above the roof, for example, 2 m above the roof, is used or an array of much higher vertical conductors over the roof edges.

The other solution, which also assures complete protection, is the isolated lightning rod. This solution has been widely used here since World War II using the Soviet designs. Despite some advantages of horizontal conductors, one has to acknowledge the superiority of vertical conductors (spires, towers). In introducing this design, it is assumed that this eliminates the dangers of secondary discharge and electrocution and increases safety as compared with the non-isolated lightning rods. With the present state of knowledge and computational abilities, however, one can conclude that non-isolated high lightning rods are capable of providing the same degree of safety as the isolated lightning rods. This conclusion extends also to the chemical plants with a threat of explosion. One has to mention here that some recently produced isolated lightning rods were found to have serious defects.

For both mentioned solutions, one has to take into account the coverage conditions. Rather complex Soviet and Polish [1] requirements on this subject have been repeated in publications for decades, and they gave quite good protection in numerous installations. Their assumptions do not call for complete safety. These requirements may be recommended for use in buildings not threatened by explosions. New Polish codes [2] abandoned this principle of protection for unknown reasons.

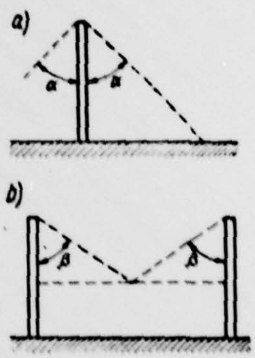

Figure 1. Shielding angles α and β: a - single discharge line; b - two discharge lines

Figure 1 shows the simple definitions of angles of coverage: a) shows the angle α for a single rod, and b) shows β between two rods. For the installation with the threat of explosion, the author advises against using angle α which turns out to be an unreliable quantity and does not result in great advantages in coverage. We recommend the angle β = 56°, which gives tan β = 1.5. In Figure 1b, one should not treat the lines AE and BE as the boundary of protected space, but should assume that point E determined by angle β determines the protected line CED. Such a shield should be considered completely safe. As an example, consider a network of horizontal lines 2 m above a flat roof and with a horizontal distance of 6 m (2 x 3 m). New Polish codes [2] require, for the explosion threat, angle α = 30° (rather risky) and angle β = 45° (exaggerated safety).

Lightning parameters, resistance of humans

The calculations involving the secondary discharge require the use of two lightning current parameters [3]: peak value in kiloamperes (kA) and the highest gradient in kiloamperes per microsecond (kA/μs). These parameters are needed also to determine the danger to humans, which require also the data on their resistance to the partial lightning currents. The lightning current peak value also enters the calculations of required cross section for the lightning rod conductors [4]. This aspect is generally solved, so that calculations are not repeated for each case.

The lightning currents were registered as early as the 1930's, but the oldest results and most extensive data had large errors. Measurements using the industrial smoke stacks in Upper Silesia are some of the new and more precise measurements. Both peak values and the maximum slopes vary within wide boundaries [3]. For example, 50% of lightning exceeds 30 kA and 35 kA/μs. However, these values should not be used in calculations of lightning protection, but much **higher** values corresponding to a smaller fraction of lightning bolts.

Three levels of safety calculations are proposed:

- for less important objects the values exceeded by 5 to 10% of lightning bolts, that is, 100 kA and 80 kA/μs;
- for important objects, the values exceeded by 1% of lightning bolts, that is, 250 kA and 150 kA/μs;
- for exceptionally high risks, the values exceeded by 0.1 to 0.2% of lightning bolts, that is, probably 400 - 500 kA and 200 kA/μs.

For the chemical plants with the threat of explosion, one should adopt at least the second level, but the third level is preferred.

In the literature devoted to lightning protection, one finds statistical evaluations, justifying the acceptance of low lightning parameters; for example, one catastrophic accident in a dangerous facility is allowed every 1000 years. However, if there are 100 of such facilities in a country, such a catastrophic accident will occur every 10 years.

Human body resistance to a current depends on the time that the current flow [5]. For potential drops in grounded resistances, the time scale is 50 μs. According to studies on animals, they can resist 50 A. For induction potential drops, the time scale is 1 μs, which corresponds to a resistance to 300 A (extrapolation of results on animals for longer times).

Potential drops for grounding

The peak value of the grounding potential drop is the product of grounding resistance and peak value of the lightning current. The resistance here is not the resistance measured with an ordinary instrument for low alternating currents, but the resistance related to lightning current. These conditions point to two particular properties. First, for shock currents of very short duration, the induction of large area grounding systems is important, for example, in chemical plants spread over hundreds of meters. These inductions practically cut off the distant grounding for the shock currents. Recently, a device was used to measure the resistance at low shock currents, developed at the Gdansk Institute of Technology [6]. The resistances were measured in large chemical plants (for 3 μs, resistances of 2 to 10 Ω were measured) while an ordinary meter for low a.c. current gave 0.1 to 0.2 Ω, totally unreliable for the purpose of lightning protection. Present codes completely ignore this problem. One could, of course, temporarily disconnect the distant groundings for the time of measurement with the small a.c. current, like pipelines, metal cable sheathing, ground conductors, etc. But disconnecting such a large number of connections would be very troublesome, time-consuming and impossible during plant operation. Besides, the shock measurements may give lower, more acceptable values than the measurements after disconnection.

Second, for large lightning shock currents, the grounding resistance is significantly lower than for the small shock currents due to the phenomena taking place in the ground. Lacking sufficient basis for a full exploration of this effect, one can adopt the resistance reduction coefficient equal to 0.5.

Usually the danger to a worker is not the full grounding potential but a fraction of it. Often a worker is standing on a floor without a basement, or directly on the ground, and touches a valve, electrical device, or machinery. The touched metal objects are usually grounded and so they are under full grounding potential. Without the devices proposed below, the worker's feet are under a fraction of the grounding potential. Between the worker's hand and foot there is a potential difference or a certain fractional voltage. The instruments for grounding measurement sometimes can measure the fractional resistance related to a fractional grounding voltage. The small a.c. current device turned out to be totally unsatisfactory in large chemical plants. The shock current instrument, on the other hand, was used successfully. The danger of electrocution was always found in the lowest floors and structures. Present codes, both domestic and foreign, ignore this danger.

As a very successful means of eliminating this problem, it is advisable to place a thick metal grid under the concrete or other floor or under the ground surface near the suspended structure, which is connected to the grounding and to the metal masses. The wire mesh should be, for example, 0.2 m x 0.2 m. The rods should be welded at crossings or wrapped with wire. In this manner, one obtains the so-called equipotential conditions, or the same potential on a floor surface, ground, valves, electrical apparatus, machinery or any other metal objects. The danger of worker electrocution is essentially removed. Because of the induction voltages, all the connections must be very short. If there is a basement under the floor, then sometimes a metal grid is not necessary. However, this is not a rule one could always count on.

By removing the danger of electrocution, one removes one of the dangers of secondary discharge, which takes place in the air gap between a metal object and a hand when the worker moves his hand toward a valve, electrical apparatus, or machinery.

Induction voltages

Since the early fifties [7, 8], three types of induction voltages, shown in Figure 2 under A, B, and C, have been distinguished. Present domestic and foreign codes take into account only type A. Although it represents the largest possible voltages, e.g., 2 to 3 times larger than type B (and even larger than C), the B and C type voltages may also cause secondary discharges.

The type A induction voltage is the main problem of non-isolated lightning rods. One merit of the latest version of the Polish code [2] is taking into account the distribution of lightning currents among many diverting conductors (connecting main rods with groundings), steel or reinforced concrete girders, pipes, etc. This is a factor which greatly relaxes the requirements, although the lightning current does not uniformly distribute itself among all the conductors or other elements. For example, for a multistory chemical structure with 40 girders, it was calculated that the maximum partial current in a single girder is such that the lightning current is distributed uniformly among 21 girders. Such a limitation of a partial current i_1 to a single conductor, as shown in Figure 2a, is very advantageous.

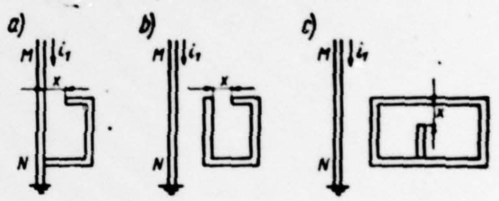

Figure 2. Conditions for three kinds of induction voltages; MN - cable with partial lightning current i_1; x - air gap in which a secondary discharge may take place

A calculation of the type A induction voltages determines the minimal air gap x, as shown in Figure 2a. Gaps above this minimum may be left without shunting and considered free of secondary discharge danger. Gaps below this minimum should be shunted with metal conductors carefully joined at both ends. Very often one finds the shunt with an excessive electrical resistance, finding the gaps requiring shunting in a large chemical plant is not easy. One has to pay attention to all large metal objects: lines leading outside of the building, steel and reinforced concrete girders, reinforced concrete ceilings, steel floors, storage tanks, machinery, pipes, electrical cables, distributing stations, steel platforms, stairs, barriers and steel latters, cranes, etc. There is the additional danger of secondary type A discharges when the worker brings his hand close to the valves, electrical apparatus, machinery, etc. The solution is to shunt such an object with the shortest possible cable, to the steel floor at the worker's feet (equipotential grid under the floor or any other metal object located at the worker's feet).

In addition to the insulation gaps x in the air, distances across walls, e.g., brick, are taken into account. Brick and concrete have an electric shock breakdown resistance which is about half as much as that for air, despite very optimistic German codes [9]. Required distances across brick or concrete should be twice as large as the air gap.

Girder reinforcements and reinforced concrete ceilings require shunting with other metal objects if the gap is smaller than the minimum distance. It is sufficient to use a welded connection to one of the reinforcing rods. If there is a large number of gaps needing shunting, their number may be reduced if justified by calculations.

The induction voltages of type B and C, which occur for conditions shown in Figures 2b and 2c, are important for isolated lightning rods; omission of these types in present codes causes the isolated lightning rods installed according to those rules to be not entirely safe.

Secondary discharges may also originate from temporary metal objects not connected to permanent ones. They may be, for example, pipes, beams, ladders, stairs, disconnected machinery, surveying stakes. Such objects should be removed before the thunderstorm season, from the sites with explosion threat and should be stored in a safe manner or provided with shunts.

Flange joints

Recently, as a result of studies conducted in the Polish chemical industry, the potential danger of secondary discharges in flange joints in pipes or other elements was discovered. If the resistance of such a joint exceeds certain defined value, then the partial lightning current flowing through it may cause a secondary discharge. This discharge may take place inside the joint, without any danger, or occur on the outside with a danger of gas mixture explosion.

In several chemical plants a large number of measurements on flanged joints valves and penetration were made using the Thomson bridge. Similar measurements were made on the shunts described above. They found either small and safe resistances or dangerously large ones. It appears that the large resistances are the results of severe corrosion. Perhaps it will be possible to use the Thomson bridge to find corroded flange joints during plant maintenance. One also finds large resistances caused by paint layers. This is especially true in improperly constructed shunts.

Crane installations

Crane installations in industrial buildings represent especially large dangers to grounding and induction voltages. In addition, both of these voltages may correlate with each other in dangerous ways.

The grounding voltages may be radically neutralized by the use of the equipotential grid described above. It is much more difficult to eliminate the induction voltages, especially for crane chains or calbes extending along many stores, of considerable vertical length. Additional difficulty arises because the corroded chain links have very large contact resistance, causing a danger of secondary discharge.

In searching on how to avoid the secondary discharges in cases where the worker moves his hand toward the crane hoist or the suspended object, we decided for an inexpensive and very effective solution in the form of an isolated crane suspension, for example, a nylon rope. The isolation distance should be calculated; it may be on the order of 0.5 m.

Water and sewer mains

Steel water lines and other lines must be taken into account in studying the induction voltages by analyzing the air gaps x between these pipes and other metal joints. One has to test the pipe joints with a Thomson bridge. Insulating pipes may be tolerated without any special precautions. Cast iron sewer pipes have flared joints with very large electrical resistances. The secondary discharges are likely to occur there. One has to use low resistance shunts on such a joint if the calculations do not allow omitting this precaution.

Pipes in the insulating jacket

The thermal insulation around steel pipe usually has an external shield in the form of a thin metal sheet. If the sheet metal segments are electrically connected, the partial lightning current for this pipe, or the induction current, localizes itself in the shield due to the skin effect. The danger then will exist due to the voltages on the shield resistances.

The resistance of the shield metal sheet is usually sufficiently low. Segmented connections resistances are much more important. In certain gasification plants the resistance measured across the soldered joint (very expensive) was less than 0.001 Ω, while across the solderless connection (folded) it was 1 Ω and sometimes lower than 0.1 Ω.

Inexpensive means of segment connection are possible, e.g., folding over and fastening with screws; however, the least expensive and a very effective solution is to avoid any connection between shield segments, that is, to leave gaps of about 10 mm. These gaps are admissible in shielded thermal insulation.

Electrical wiring

Electrical wires present similar dangers of secondary discharge just like the pipes. One has to analyze the air gaps and shunt gaps which are too small. Shunting is easy if the electrical wires are in metal conduit, steel or lead cable conduit. Shunting of such metal conduit at points close to a metal object or pipe is desirable. The partial lightning current carried through a shunt to the cable conduit does not create any danger as long as the conduit cross section is not too small. The lead sheath cross section may be too small only for a very long cable, which is easy to calculate. One can then use additional means, such as shielding cables which run close to the cable and are jointed at the ends, bends, and shunts.

Electrical wiring without metal conduit presents far more difficult problems in eliminating the secondary discharge in chemical plants. In the maze of pipes, storage tanks, and machinery, it is almost always impossible to run the electrical cable sufficiently far from the objects so that shunting is unnecessary. It would appear that the proper solution would be to connect the return (or "cold") wire with a pipe or other metal object at close points. However, this is not recommended because of many reasons, especially because the flow of partial lightning current to the "cold" line could break the insulation between "hot" and "cold" wires.

Assuring lightning safety in chemical plants using unshielded electrical cables is very difficult, complex, and expensive. It is much better to use shielded cables. Grounding cables between separate plant structures also presents the danger of insulation breaking down during lightning if they do not have metal shields. The metal shielding removes this possibility. If cables already exist without shielding, one can still make an effective shield, for example, from C beams.

Considering presently existing configurations in electrical installation, there is yet another objection: lightning insufficiency of grounding lines. Long grounding lines which make an electrical connection between electrical apparatus or machinery and the ground do not prevent discharges between the apparatus or machines and large metal masses. Lightning protection requires short connections in view of the discharge danger. Often, but not always, such a short connections exists independently of grounding lines. For example, the electrical apparatus mounted on metal girders has good grounding connections unless there is interference from paint layers or corrosion.

Overhead pipe lines

There is a question concerning overhead pipe lines; do pipes require lightning shielding and, if so, should the grounding lines be isolated or not? Steel pipes with walls thicker than 5 mm are not in danger. The thinner walled pipes could run beneath the thicker walled pipes. One still has to consider if leaks appear inside the pipes or its flange joints creating explosive gas mixtures, and if the local explosion caused by lightning can cause general fire. Such an analysis may lead to the use of discharge lines.

Vertical isolated discharge lines are placed along the overhead pipe lines with distances and height differences appropriate to general shielding requirements. The merits of such a solution are the small currents flowing through the pipes. Thus the danger of secondary discharges in flange joints is small. However, even these small currents could be threatened with secondary discharges at point of contact between pipes and supporting structures if there is a paint layer or layers of insulating material. One has to obtain good quality, low resistance contacts between the pipes and the supporting structure.

Column extensions represent non-isolated vertical discharge lines. The height of the discharge line should be adapted to the distances between columns, according to the general rules of shielding protection. This design causes very large partial lightning currents in pipes, and associated with it there is a great danger of secondary discharge in flange joints. Thus one must carefully control the resistance of such joints. One also has to pay attention to the contact resistances between pipes and support structures. Paint layers or other insulating layers may cause large secondary discharges. If properly constructed, the non-isolated discharge lines may be considered no worse than the isolated ones.

Storage tanks

One must decisively take a stand against the use of insulated vertical discharge lines (rods, masts) to protect storage tanks. They do not offer better protection than the non-isolated vertical discharge lines (rods) attached to the tank walls and are far more costly. One may state that many dangerous errors are encountered with isolated discharge lines **which** are virtually eliminated with non-isolated discharge lines.

The vertical discharge lines should properly protect all openings, vents, valves, etc., on a storage tank. One has to take into account the properties of these elements. The storage tank itself can withstand all lightning currents as long as the walls are thicker than 5 mm.

In one of the plants an unprotected storage tank had thermal insulation and then a metal sheet on the outside. The lightning current can melt the hole in such a sheet and the molten metal may cause a gas mixture explosion.

Rail tracks

Cars on rail tracks represent a danger of worker electrocution if he touches the car while standing on a floor without an equipotential grid. There is also a danger of secondary discharge when the worker moves his hand toward the car. One often encounters the solution: connecting the car to the nearest lightning rod grounding with a temporary flexible conductor. This method reduces but does not completely remove the danger.

In order to provide complete safety, the previously described metal grid should be placed underneath the floor near the tracks. This grid is connected every 5 - 10 m to the tracks using the shortest possible conductors and to the lightning rod groundings. This system function on the principle of equipotentialization.

Periodic testing of lightning rods

New Polish codes [2] require complete periodic testing which includes visual inspection of above-the-ground elements and grounding tests at least every 6 years where there is a danger of explosion. German codes [9] recently recommend much shorter time intervals: 0.5 to 1 year for the industrial plants with explosive substances, and 2 to 3 years for plants with the threat of explosion and chemical plants because of corrosion.

Periodic grounding resistance measurements do not reflect the corrosion progress. For example, the grounding cross section may be reduced by corrosion to 10% or less, but the resistance measurements may give the original value and not the increased one. Complete grounding corrosion can be detected only by a grounding resistance measurement. This is why Polish codes have required a partial grounding excavation and control of corrosion progress. However, these codes do not determine the rejection criterion for the corrosion progress, without which their usefulness is illusory.

Despite certain resistance, controls of grounding corrosion progress through periodic measurements of grounding resistance [10, 11] have been required in Poland. The difference between ground resistance and grounding resistance is that the ground resistance is localized in the earth around the grounding, and the grounding resistance is localized in the grounding metal. The first one is expressed in ohms, the second in milliohms. The measurements of grounding resistance requires the use of a good portable Thomson bridge, with an accuracy of 1% in all measurement ranges. The new grounding should be installed in a manner that allows this measurement method. For the periodic ground measurements in large chemical plants, one should use a shock instrument, according to the remarks formulated above [6].

One must also not forget periodic inspection of exposed elements. According to the new Polish codes [2] it is recommended that they be conducted once a year, preceding the thunderstorm season.

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Professor Stanislaw Szpor graduated from the Electrical Engineering Department of Warsaw Polytechnic School in 1931. Presently retired, he cooperates with the High Voltages and Electrical Apparatus Institute of the Gdansk Polytechnic Institute. His specialty — high voltages and electrical apparatus.

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