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TECHNICAL STANDARDS FOR GROUNDING OF LIGHTNING RODS IN SOME COU--ETC(U)
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by

M. Hadzi-Pesic



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TECHNICAL STANDARDS FOR GROUNDING OF LIGHTNING RODS IN SOME COUNTRIES

Mihailo Hadzi-Pesic, Dipl. Eng.

Over the last few years the technology for protection against atmospheric discharges (lightning) has been considerably improved. As the consequence some countries have undertaken to work out new regulations. **Austria** may be mentioned as an example where regulations about lightning rods, issued in 1970 (1) have been replaced by new, substantially different, regulations in 1973 [2]. Updating of regulations about lightning protection is in progress in other countries also. The Federal Republic of Germany is in the process of replacing their regulations "BLITZSCHUTZ UND ALLGEMEINE BLITZSCHUTZ BESTIMMUNGEN" - "ABB" issued as the eighth edition in 1968 by a new ninth edition, to be issued this year. In addition, preparation of the "INTERNATIONAL GUIDE FOR LIGHTNING RODS" is in its final phase.

It is believed that a review of requirements, standards, and recommendations of various countries will provide some guidelines for implementation of new "Technical Regulations for Lightning Rods" in Yugoslavia which have been in effect since 1968.

A lightning rod installation does not prevent a lightning strike from taking place. Instead the strike, within the area protected by the lightning rod, takes place at its tip and is conducted into the ground.

In this review we will be concerned only with the part of the lightning rod protection that is related to ground and grounding conductors.

Protection of buildings and installations from atmospheric discharges can be divided into two groups:

- external protection
- internal protection

The external protection is designed to accept lightning strikes and conduct them into the ground without causing damage to the object or installation to be protected, or without injuring a person present within the lightning rod zone.

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The internal protector has the purpose of preventing electrical breakthrough or jumps between parts of lightning rods and metal parts, electrical networks or tt-networks. These may occur because of too-short distances, because of ionization or because of induction.

The grounding is part of the lightning rod that connects the lightning rod installations to the ground.

Depending on the method of installation of grounding, lightning rods may be divided into two groups:

-- Surface grounding, where horizontal conductors are placed in the ground at the depth of 0.4 to 1.0 meters (it could be in form of tapes, rings, networks, and connected to foundations).

-- Deep grounding, where a conductor is buried vertically in the ground (could be in the form of tubes, rods, or plates).

-- A combined grounding represents an installation where surface and deep-type - grounding are combined together.

The grounding of lightning rods has a two-fold role. Primarily it must conduct the lightning current into the ground with a minimal potential differential on the ground surface. The other role of grounding is to shape the grounding potential of the object to be protected, and to minimize the voltage drop of contact and pace distance, to protect people present within the lightning strike zone. This is accomplished by installation of the surface grounding in the form of a closed or a partially open ring around the object to be protected from the lightning or by grounding to the foundation of a building constructed with reinforced concrete.

When a building is struck by lightning, the ground conductor (with reference to the ground) will have a voltage

$$U_g = R_g \cdot i + \frac{1}{2} L \frac{di}{dt}$$

(see Figure 1).

At the ground surface around the conductor, the voltage falls off as the distance from the conductor increases. The gradient of the voltage drop around the conductor depends upon how it spreads along the surface. From the edge of the conductor, along the ground surface, there are large voltage drops over a distance equal to one (walking) step. In order to reduce this voltage a surface grounding installation could be used or, if that is not possible, the ground surface can be covered with gravel or can be paved. The ground conductor should be considered as a

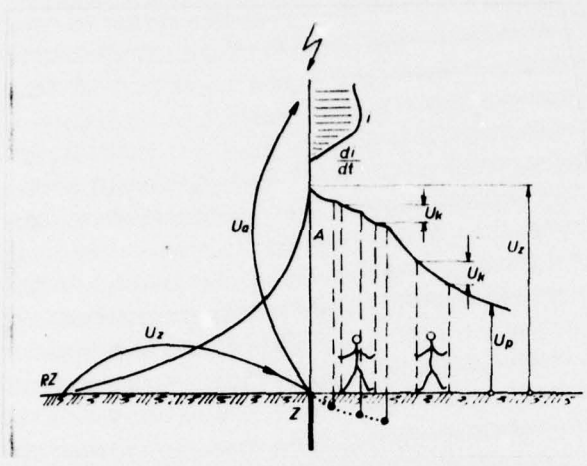


Figure 1: Voltage of a lightning rod and changes of potential on the ground surface during a lightning discharge

$$U_a L_a \frac{di}{dt} + i R_a$$

$$U_z i R_r + \frac{1}{2} L_t \frac{di}{dt}$$

- where:
- L_a - ground connector inductance
 - R_a - connector resistance
 - R_r - dissipation resistance
 - L_t - ground conductor resistance
 - i - lightning current
 - di/dt - rate of current dropoff
 - Z - ground conductor
 - U_a - ground connector voltage
 - U_z - ground conductor voltage
 - U_p - voltage of ground surface
 - U_k - voltage drop for a distance of one (walking) step
 - RZ - ground reference.

series connection of ohmic resistance, inductance and capacitance. An electric scheme equivalent to a grounded conductor is illustrated in Figure 2.

In planning protection against lightning, consideration should be given to economic justification of such an installation in view of the

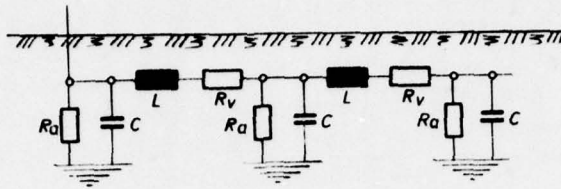


Figure 2: A scheme equivalent to a linear surface grounding; L - inductance of the ground conductor; R_v - resistance of the ground conductor; R_a - ground resistance.

damage that could be caused by lightning. In such a calculation important elements are the probability of a lightning strike and the maximum value of the lightning current.

In the proposal to the International Guide for Protection from Lightning, there are statistical data for maximum values of lightning currents (Figure 3), and the increments of current as a function of frequency of strikes (Figure 4). Depending upon the purpose and the value of the object or installation to be protected, 50% or 90% of the values shown are used in calculations as strike frequency probability.

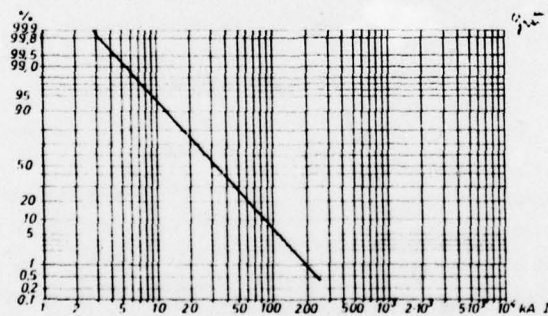


Figure 3: Maximum value of the lightning strike current as a function of the strike frequency.

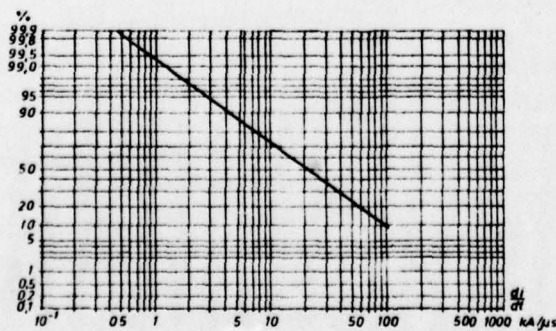


Figure 4: Current increments due to strike frequency.

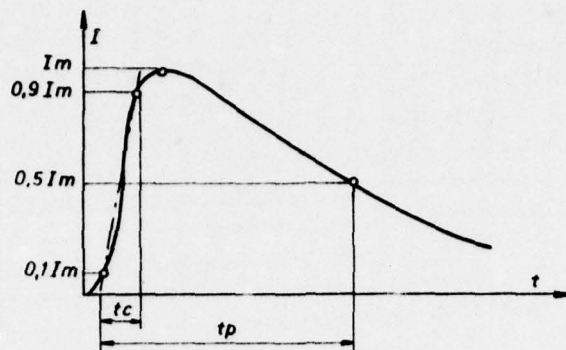


Figure 5: Maximum value of lightning current.

According to technical regulations on lightning rods in SFRJ, it was adopted that atmospheric discharge (normally) has a form of electric impulse with current strength of 60 kA. The time adopted for frontal discharge is two microseconds and the half-time of lightning duration is 50 microseconds (Figure 5). Similar values have been adopted in other countries.

The dissipation resistance of the grounding conductor (R_r) i.e., of the ground, is represented by the ratio of the voltage of the grounding conductor (U_z) and that of the current that flows through the ground either as direct current or as alternate current at 50 Hz.

The strike resistance of the grounding conductor (or the ground - R_u) is represented by the ratio of the voltage U_z and the electrical pulse of lightning which flows through the ground. Dissipation resistance of the grounding conductor during the flow of the electrical lightning pulse does not have a constant value. It is dependent upon the time and the form of the electrical pulse. The variability of this resistance increases with an increase of the specific resistance of the ground and with the length of the grounding conductor.

The effectiveness of the lightning rod grounding is characterized by the strike resistance of the grounding (R_u) rather than by the dissipation resistance (R_r).

The relation between these two forms of resistance is defined by the expression:

$$R_u = K \cdot R_r$$

The coefficient " K " depends on a number of factors which will be discussed later.

When planning lightning protection one should first determine the dissipation resistance for the given type of grounding.

In this review, we will show some methods used for calculation of grounding for lightning protection.

THE DISSIPATION RESISTANCE (R_r) for various forms of the grounding conductors can be calculated by the following methods:

01 - SURFACE GROUNDING

As was already mentioned, surface grounding refers to horizontally placed conductors buried to the depth of 0.4 - 1 m.

01 - 1 SINGLE-LINEAR GROUNDING CONDUCTOR is a horizontally placed conductor, where it is attached at its beginning to a single lightning rod (Figure 12a). Its dissipation resistance can be calculated from the following expression:

$$R_r = \frac{\rho}{2\pi l} \cdot \ln \frac{l}{d \cdot h}$$

where:

- ρ - specific ground resistance (Ωm)
- l - length of the ground conductor (m)
- h - conductor depth (m)
- d - diameter of the conductor material (m)
- R_r - dissipation resistance of the ground conductor (Ω)

The dissipation resistance of the grounding conductor of this type with the length of less than 20 m and diameter $d = 0.1$ m, can be approximately calculated by the expression:

$$R_r \approx 2 \cdot \frac{\rho}{l}$$

01 - 11 When the lightning rod is attached to the middle of the grounding conductor whose full length is "2 l ", its dissipation resistance is assumed to correspond to a parallel connection of two linear ground conductors, each leg having a length " l ".

If the two legs of the conductor form an angle of less than 180°, the dissipation resistance of the whole conductor is obtained by multiplying the resistance of one leg (R_{r_0}) of length " l " with the coefficient " f_1 ". The coefficient " f_1 " is given graphically in Figure 7.

$$R_r = f_1 \times R_{r_0}$$

01 - 12 The expression below represents dissipation resistance of a horizontal linear grounding conductor with "n" legs. All legs are joined together at one point where they are connected to the lightning rod. All legs are of equal length "l" and have equal angles between them.

$$R_r = f_2 \times R_{r_0}$$

where

R_{r_0} - dissipation resistance of a single leg

f_2 - factor taken from the graph in Figure 8.

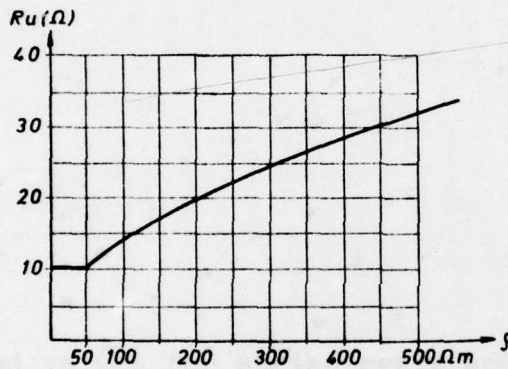


Figure 6: Permitted values for strike resistance of ground conductors.

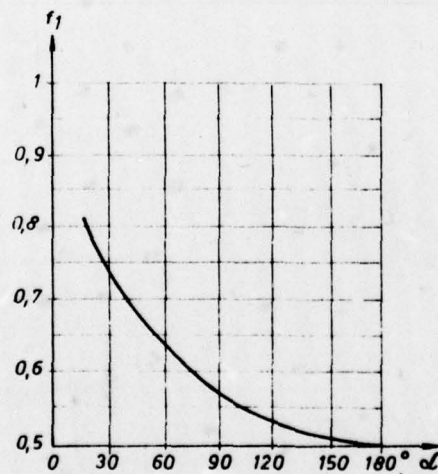


Figure 7 - Value of the factor f_1

01 - 2 RING TYPE GROUNDING CONDUCTOR is a conductor placed around an object in the form of a ring which may be either closed or open. If an area is surrounded by a conductor in the form of a CLOSED RING "A", (m^2), the dissipation resistance can be given by the approximate expression:

$$R_1 \approx 0,6 \frac{\rho}{\sqrt{A}}$$

A ring-type grounding conductor in square form and without one of the sides - OPEN RING TYPE with three legs of equal length "l" (m) - has 20% higher dissipation resistance than a closed ring type grounding conductor with the same area "A".

01 - 3 GRIT TYPE GROUNDING is installed in the form of a net placed horizontally in the ground. Its dissipation resistance is smaller than that of a ring type grounding conductor but greater than the dissipation resistance of a horizontally-placed, solid plate, grounding conductor of the same area "A".

01 - 4 NETWORK TYPE GROUNDING CONDUCTOR is installed in the form of a net, placed horizontally in the ground. Its area "A" (m²) has an approximate dissipation resistance of:

$$R_1 \approx 0,45 \frac{\rho}{\sqrt{A}}$$

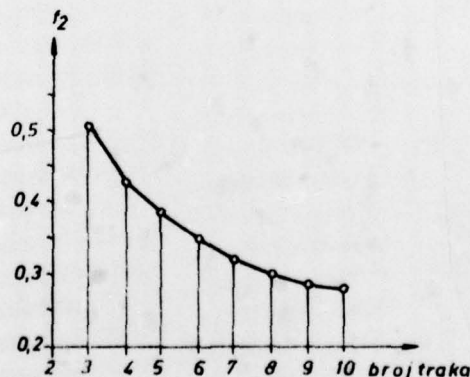


Figure 8: Value of the factor f_2

02 DEEP GROUNDING CONDUCTORS

By deep grounding conductors, we understand conductors that are buried vertically. They are also called VERTICAL GROUNDING CONDUCTORS.

02 - 1 ROD-TYPE GROUNDING CONDUCTORS

Rod type grounding conductors consist of one or more vertically-

buried water pipes or iron rods, heat-coated with zinc.

02 - 11 A SINGLE ROD GROUNDING CONDUCTOR of length "l" (m) and diameter "d" (m) has dissipation resistance of:

$$R_{r_v} = \frac{\rho}{2\pi l} \cdot \ln \frac{4 \cdot l}{d}$$

If the diameter of the grounding conductor is $d = 25 \text{ mm}$, or $d = 50 \text{ mm}$, the dissipation resistance can be approximately determined by the expression:

$$R_r \approx \frac{\rho}{l}$$

02 - 12 A DOUBLE ROD GROUNDING CONDUCTOR buried vertically with both rods of equal length "l" (m) and separated by the distance "a" (m) has the dissipation resistance:

$$R_r = f_3 \times R_{r_v}$$

where: f_3 - factor taken from the graph in Figure 9 which is dependent upon the ratio a/l ,

R_{r_v} - dissipation resistance of a single vertically buried grounding conductor.

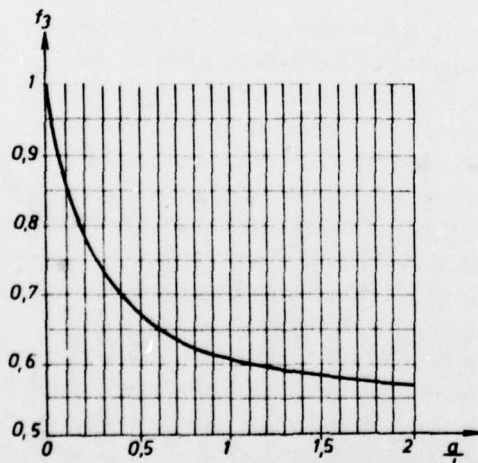


Figure 9: Value of the factor f_3

02 - 2 PLATE TYPE GROUNDING CONDUCTOR. A square metallic plate vertically buried to the depth of the underground water or to the depth where the upper edge of the plate is at least 1 m, below the ground surface, has a dissipation resistance which can be approximately calculated by use of the expression (4):

$$R_r \approx \frac{\rho}{4,5 \cdot a}$$

where: a - side of the square (m)
 ρ - specific resistance of the ground (Ωm)

03 COMBINED GROUNDING

Often, the grounding of lightning rods is done by a combination of vertically- and horizontally-placed conductors. As an example we can **consider** a horizontally-placed network for grounding of lightning and a single vertically-placed grounding rod. If the length of a mesh square of the network grounding conductor is " l_M " and the vertical conductor of length " l " (m) is connected at the network crossing point, the approximate value of the dissipation resistance can be calculated by the expression:

$$R_f = f_{l_4} \times R_{r_m}$$

where: f_{l_4} - factor taken from the graph in Figure 10 which depends upon the ratio l/l_M

R_{r_m} - dissipation resistance of the network grounding.

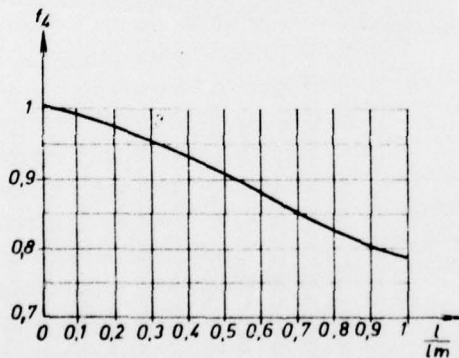


Figure 10: Value of the factor f_{l_4}

STRIKE RESISTANCE (R_u) of lightning rod grounding is, as mentioned before, determined by the expression:

$$R_u = K \cdot R_1$$

The coefficient " k " has a maximum value (3) of $k = 1.5$. This value of the coefficient " k " is used for single, surface grounding conductors (01 - 1) and for grounding conductors using multiple legs whose length

does not exceed the "limiting value" (Figure 11). The value of 1.5 is also used for factor "k" in case of the ring-type grounding conductors (01 - 2).

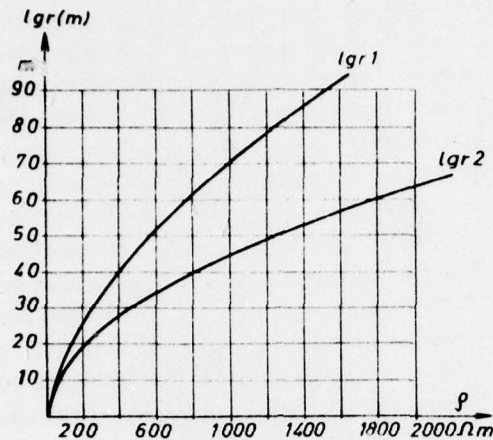


Figure 11: Limiting values for lengths of grounding conductors.

Because the dissipation resistance of a single surface grounding conductor is inversely proportional to its length, one should (the other factors being equal) give attention to the determination of the strike resistance of grounding. This resistance is not to be reduced by a calculated length of the conductor which exceeds the limiting value " l_{gr1} " (Figure 11).

For economical reasons, one may adopt (in place of the limiting value " l_{gr1} "), line " l_{gr2} " as the limiting value for the length of the grounding conductor, because for large lengths the strike resistance of grounding of single horizontal conductors does not change significantly.

When in calculations of the dissipation resistance of a single surface conductor, the required length " l " exceeds that of " l_{gr1} ", the length can be shortened to the limiting value " l_{gr1} " because a longer length of grounding is not needed to obtain the required striking resistance (see broken line in Figure 12a).

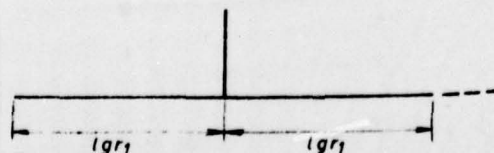


Figure 12a: Single linear grounding conductor.

When the lightning rod is connected to the middle of the grounding conductor (Figure 12b), the calculations can be carried out in the same manner as in the previous example. The strike resistance of the whole

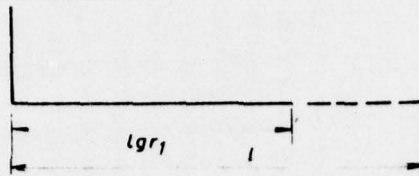


Figure 12b: Double linear grounding connector connected in the middle.

grounding conductor can be treated as two conductors of equal length " l_{gr1} " (01 - 11) connected in parallel.

The coefficient " k " has the value of unity ($k = 1$) for horizontal grounding (01 - 3), for deep grounding (02), and for combined grounding (03).

The strike resistance of grounding may be regarded as equal to the dissipation resistance for a linear horizontal grounding with " n " legs of 20 to 30 m length (01 - 12). The same relation can be used for any local grounding at a distance of 30 meters from the object carrying the lightning rod.

A linear grounding conductor 20 m long may be regarded as practically satisfactory for leading away a lightning strike. Consequently, this length should be utilized for calculations of the strike resistance.

The strike resistance of a lightning rod grounding must be smaller than the possible maximum value of this resistance. It can be calculated from the expression:

$$R_{u_{max}} = 1,2 \cdot \rho$$

where ρ is the specific resistance of the ground around the grounding (Ωm).

The strike resistance of grounding is illustrated in Figure 6 as a function of the specific resistance of the ground [3].

$$R_{u_{max}} = 1|\rho|$$

As may be observed from this diagram the specific resistance of the ground for up to 50 ohm-meters, is assigned a maximum value of strike resistance of $R_{u_{max}} = 10$ ohms.

If a lightning rod grounding has more individual grounding conductors which are not interconnected underground but only by the lightning rod installations on the roof, the total strike resistance will correspond to the above if the following requirement is fulfilled:

$$R_u \leq R_{u_{\max}}$$

The striking resistance for each part of the lightning rod grounding must be:

$$R_u \leq 2 \cdot R_{u_{\max}}$$

This condition must also be fulfilled for each separate grounding conductor or for more separate grounding conductors (no more than 3) which are interconnected underground.

When the resistance of a lightning rod grounding is not known or it is not known how the grounding was installed or which type was used, and the resistance cannot be determined according to the listed principles and therefore

$$R_u \geq \sqrt{2\rho}$$

the grounding does not satisfy the requirements for proper lightning protection.

When installing and planning a lightning protection for objects and installations one must take into consideration also the existence of other conductors around the object such as "plumbing network, electrical and tt cables with metallic shielding, gas pipes, pipes for heating or chemical processing and other metallic bodies. In principle, **in such** cases the grounding for lightning rods is connected (galvanized) to the metallic bodies as long as they are separated by less than three meters.

The regulations and **guidelines** of various **countries** give instructions for electrical connections or insulations. As an example, we may refer to the Yugoslav Technical Regulations for Lightning Rods (section 4.67 to 4.691).

In electrical power installations and lightning rods the so-called SINGLE POTENTIAL SURFACE GROUNDING [5] are used. The protective grounding for the high and low voltage power and lightning is connected into one system.

Lightning grounding may be placed into water only in exceptional cases when earth grounding is not possible. In such cases the grounding conductors are placed into the water in the same way that they would be placed in the ground. For calculations one must take into consideration the specific resistance of water, which is up to 200 ohm-meters, and of

wet clay at the bottom of the water, which may have a specific resistance up to 20 ohm-meters.

Grounding conductors should not be placed in water where swimming is permitted or wells which aren't permanently closed. The ground conductor should not be in the form of a metallic sphere.

Modern technology for lightning protection [3] uses mainly round conductors, particularly zinc-coated iron. For the horizontal grounding conductors, zinc-coated iron must have a minimum diameter of 10 mm, and deep grounding conductors must have a minimum area of 300 mm^2 , and a minimum length of 1.5 m. Plate-type zinc coated (iron) grounding conductors must have a minimum plate thickness of 3 mm. The lightning rod leading into the ground must have a minimum diameter of 16 mm. The iron must be zinc-coated under heat to a thickness of 275 gr. per 1 m^2 . The zinc coating should not crack or peel when round iron is bent and the diameter of the bending radius is larger than ten times the rod diameter. This test assures that the material complies with the corrosion resistance requirements.

In technical specifications and guidelines for lightning rods, various **countries** [6] have established requirements for lightning rod grounding.

I. AUSTRIA. The specifications [2] do not prescribe the resistance value for lightning rod grounding. For the specific resistance of the ground of up to 50 ohm-meters, R_u should be 10 ohms (see Figure 6). Closed-type ring conductors placed 0.4 m deep are recommended for grounding. When crossing or approaching a distance of 3 m from metal piping (water piping, steam piping, etc.), or metal-**shielded** cables, they must be connected (galvanized) to the grounding or they must be inserted into a pipe of insulating material with a minimum thickness of 3 mm. In that case the permitted distance is 0.4 meters. If the metal shielding of a cable is grounded, the above-mentioned requirements do not apply. Except for specific conditions, lightning rod grounding may utilize a plumbing network but piping for gases may not be used for grounding.

II. BELGIUM. Regulations on lightning rods [10] state that the strike resistance of grounding may have the values from 5 to 50 ohms depending on the specific resistance of the ground, height of the object to be protected and type of grounding.

III. BULGARIA. Technical regulations of 1972 [8] state that, for a specific resistance of the ground of 500 ohm-meters, the strike resistance of lightning rod grounding may be 40 ohms for each grounding conductor and should not exceed 20 ohms for total grounding installation. Resistance of grounding for factory chimneys, water-cooling towers, etc. may have values of up to 50 ohms. These regulations describe in detail the protective measures and methods for installing various types of grounding and objects.

IV. DENMARK. Danish regulations for lightning rods [7] require that the total resistance of grounding should be less than 2 ohms. Ring-type grounding is to be placed at a depth of 0.4 meters. Plumbing installations could be used as part of the ring conductor. Instead of the ring grounding plumbing networks, or metallic piping for gas or water heating systems can be used. Also a metallic plate or tape (which should not be made of copper) can be inserted into a well. The grounding may be of the surface type in the form of a tape or a deep type grounding which reaches the underground waters.

V. ENGLAND. The regulations state [9] that the total resistance of lightning rod grounding should not exceed the value of 10 ohms. Every rod must have its own grounding. In case of an object with "n" grounding conductors, the resistance of each should not exceed $R_u = n \times 10$ (ohms). It is recommended that vertical rod type grounding be used and should be buried to the depth of underground waters. Use could also be made of surface type grounding in the form of ring, ray, and other structures.

VI. HOLLAND. The Dutch regulations [12] state that total strike resistance of lightning rod grounding, which is connected either to a metallic plumbing network or to a grounding system of neighboring objects, should not exceed the value of 2.5 ohms. The average strike resistance of individual grounding conductors should be within the limits of $R_u = n \cdot R$ as long as the number of grounding conductors is equal to or less than 10. When the number of grounding conductors exceeds 10, the resistance of each may have the value $R_u = 10$, where "R" represents the total resistance of the grounding. When electrical installations are brought into the building by a cable, the metallic shield of the cable must be connected to the grounding of the lightning rod. The energy distribution system must have an entry cable placed inside a metallic tube which must be connected to the lightning rod grounding. The resistance of this

grounding should not exceed 1.5 ohms. If the system has only one grounding conductor, the resistance should not exceed 6 ohms.

VII. YUGOSLAVIA. In our regulations [4] section no. 4.62 states that the R_u value should not exceed 20 ohms for specific ground resistance of 250 ohm-meters. For specific ground resistance in excess of 20 ohm meters, the value for strike resistance may be up to 8% of the specific ground resistance.

VIII. SOUTH AFRICA. In South Africa where the specific resistance of the ground is high, the strike resistance should not exceed the value of 30 ohms [13]. Radial-type surface grounding is recommended. When deep-rod type grounding is used, the resistance of each of the grounding conductors should not exceed ten times the resistance of total grounding ($R_u = 10 \cdot n$ where "n" is the number of vertical grounding conductors). Plate-type grounding is not recommended.

IX. HUNGARY. Regulations of 1962 [11] state that the strike resistance of a single grounding conductor may have a value of 30 ohms. When the grounding conductors are connected into a single system, the **resistance** may have the value of up to 5 ohms. It is expected that new regulations will be issued this year which will adopt modern achievements for protection against lightning.

X. POLAND. In new technical regulations [18] the strike resistance of lightning rod grounding (depending on the specific ground resistance) may range from 10 to 50 ohms. Ring-type surface grounding placed at the depth of 1 m is recommended. The surface grounding conductor should not exceed the length of 35 meters for a specific ground resistance of up to 500 ohm-meters. For the ground resistance of 1000 ohm-meters, the length of grounding conductors should be 35-50 m, etc. In a dry ground the tape may have a length of up to 100 meters. For field granaries on dry ground, a grounding conductor of 15 m length is satisfactory. Large metallic installations such as water pipes which are within 3 m. distance from a lightning rod installation (grounding) must be connected into a single system.

XI. FR GERMANY. Technical guides for lightning rods [14] primarily recommend the use of ring-type surface grounding buried to 0.5 m, and separated by 1 m from the building foundation, or grounded to the foundation. When ring-type grounding cannot be installed, use can be made of other types such as radial or linear type up to 20 m long or a deep

grounding rod 6 m long or two rods each 3 m long and separated by a distance of 3 m or by grounding to a 1 m³ block of reinforced concrete. A secondary lightning rod must have a grounding conductor length of 5 m, or a deep grounding rod 3 m long. Metallic and non-metallic installations of water pipes or gas and steam distribution systems can be used for grounding. Such distribution systems must be connected to the lightning rod grounding when they are separated by less than 2 m. According to these guidelines (ABB) the resistance of lightning rod grounding does not have to be determined when there are no metallic objects in the vicinity of the grounding conductor. When there are underground objects within distance "D" (um) of the grounding conductor, the following relationship must be satisfied:

$$R = 5 \cdot D$$

The Postal Service determines the resistance of the lightning rod (2 ohms). Objects with explosive danger or posts higher than 20 m, require resistances of less than 10 ohms. It is required that lightning rod grounding comply with the requirements regarding voltage drops for (walking) step distance and touch. The voltage around the grounding conductor must be equalized.

XIII. U.S.S.R.. General specifications [15] require that strike resistance of lightning rod grounding not exceed 10 ohms. Linear and rod grounding types are used. In grounds with specific resistance exceeding 1000 ohm-meters, deep-rod type grounding must be used. Lightning rod grounding must not be connected to grounding of other objects. Lightning rods and conductors must be separated from metallic objects by at least 6 m. Metallic objects and installations inside or outside the building which are within distance of 30 m must be connected to a ring-type grounding, the resistance of which should not exceed 15 ohms. Connecting cables (power or tt) must have lengths of over 50 m as connections in air are not allowed for objects with lightning rods. The grounding resistance of metallic cable shields may be up to 20 ohms. At the point where cables enter the objects, they must be connected to a ring-type grounding of the buildings.

XIV. SWITZERLAND. Regulations [16] do not require that the resistance of the lightning rod grounding be determined. Use of ring-type grounding 0.5 m deep and separated from the foundation by 1 to 2 m is recommended. When present, plumbing installations with metallic pipes exceeding 50 m must be used as grounding for a single rod. In

cases where installation of a surface-type ring grounding is inconvenient, a rod-type vertical conductor may be used but it must be separated by one-half of its length from the foundation of the object. A tape type grounding using a wire 10 m long (minimum) can also be used. The wire can be placed into the ground in a wave-like manner. Rain gutters may be used as lightning rod leads. The gutter must be connected to the plumbing installation in the cellar at the point where they are closest to each other. In such a case the gutter may not have a separate grounding.

Objects located on rocks or ground of high specific resistance must have all rods - ground leads - connected to a ring-type ground. This ground is connected (by galvanizing) to plumbing pipes, metallic cable shields and cable car cables. If there is a possibility of mechanical damage to the ring conductor it must be protected by a metallic tube.

XIV. UNITED STATES OF AMERICA. Regulations [17] do not require that the resistance of the lightning rod ground be determined. Each lead must have a separate ground. Each metallic pipe buried in the ground (plumbing, steam pipes, etc.) must be used as a lightning rod ground.

For the ground with low specific resistance, vertically-buried rods 3 m long are satisfactory. For a ground with high specific resistance (sand, gravel, stone) use must be made of either tape-type surface ground, vertical rod, or deep plate ground. Depth is important for vertical-type grounding. Ring-type grounding must be buried to a depth of 0.6 m. In certain grounds surface type (ring or radial) grounding connectors are used.

XV. INTERNATIONAL GUIDELINES FOR LIGHTNING RODS. In the proposed guidelines [3] the values for resistance of grounding are not given. The methods for calculation of resistances for various forms of grounding against lightning reported here have been taken from the above proposed guidelines.

CONCLUSIONS

On the basis of the reported data, all specifications, regulations and guidelines prescribe the required resistance for lightning grounding or give dimensions and methods for installation and grounding. Common to all newer specifications is the requirement to determine the shape of the potential around the ground. This is required because of possible critical voltage at the distance of one (walking) step during an atmospheric

discharge which must be regarded as an impulse phenomenon.

It is felt that before defining a final form of our Regulations on Lightning Rods we should wait for publication of the International Lightning Rod Guidelines.

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