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REQUIREMENTS OF IEC AND CENELEC STANDARDS RELATED TO THE QUALITY AND LONG SERVICE TIME OF EARTHING SYSTEM FOR LIGHTNING PROTECTION

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Abstract - One of the main requirements for LPS (Lightning Protection System) earthing system is to provide its reliable long time service. The earthing system components embedded in soil: earth electrodes, earth conductors and clamps are usually exposed to much more severe environmental factors than those installed in open air area. Main phenomenon influencing their reliable performance is the corrosion affecting earthing system components. The extensive list of different requirements for design and dimensioning of earthing system elements of LPS is given in new series of IEC 62305 on lightning protection as well in the EN standards related to the specific test requirements for lightning protection system earth electrodes and conductors. Some of these requirements are characterized in the paper.

In 2003 started in Poland the long-term project of field corrosion tests of earth rods. The aim of these investigations was to compare the corrosion rate of two commonly used protective coating materials of steel earth electrodes: hot-dip zinc coatings and electrodeposited copper coatings. Preliminary results of earth rods field corrosion tests after 2 and 4 years exposure in different soil types are discussed in the paper.

1 INTRODUCTION

Components of LPS (Lightning Protection System) which are buried in soil, the earth electrodes and earthing conductors, are subjected to much severe environmental conditions than LPS components installed above ground or inside a structure. The LPS earthing system service life is determined primarily by the ability to resist the corrosion. However, usually the service time when the LPS has required technical parameters shall be not shorter than 25-30 years, which unfortunately is not indicated in the standards. In case of lightning protection of structures, the earth termination system shall be realized according to requirements of new series of IEC standards [1], where it is preferred an integrated earth termination system suitable for different purposes: lightning protection, low-voltage power systems, and telecommunication systems, and which shall fulfil following tasks:

- conduction of the lightning current into the earth;
- equipotential bonding between the down-conductors;
- potential control in the vicinity of conductive building walls;
- interception of the lightning current when propagating on the earth's surface.

In design process of any kind earth termination system it is important not only to describe the layout and number of earth electrodes, to determine their required earthing resistance or impedance but also to select properly the type of earth electrodes and conductors, material, shape and dimensions. It is important to assure high quality of earthing system components electrodes which shale assure long term proper functioning and stability of their technical characteristics. Most important are here adequate mechanical strength of material used for electrodes, conductors and clamps and their high corrosion resistance in different type of soils.

Corrosion of earth electrodes occurs at a rate depending on the type of metal used and the nature of environment. Factors such soil resistivity, moisture, dissolved salts forming an electrolyte, degree of aeration, temperature make this condition very complex one.

For better understanding of factors influencing protective properties of different coatings of steel earth electrode (zinc galvanized and electrodeposited copper) the experimental investigation have been performed worldwide both in field [3,4,5,6] and laboratory conditions [6,7], according to adequate standard requirements [2]. Results of this kind of investigations are helpful for engineers, designers and contractors, to make educated decisions on proper selection of earthing system components for LPS and other purposes.

2 OVERVIEW OF TEST REQUIREMENTS FOR EARTHING SYSTEM COMPONETS

When dimensioning and selecting material of earth termination system the following parameters shall be taken into account:

- the highest value of current dissipated into the earth,

- duration of current flow,
- geoelectrical and physical parameters of the soil.

The earth electrodes and conductors should be constructed of corrosion-resistant material having high mechanical strength and to be electrochemically compatible with the material of the connection elements and mounting elements. Direct connections between materials having different electrochemical potential shall be avoided, otherwise they are to be additionally protected against corrosion.

2.1 Materials and dimensions of earth electrodes and conductors

The materials and dimensions of earthing electrodes commonly used and recommended in related to lightning protection IEC standard [1] are copper or steel with different protective coatings (zinc galvanised or electrodepostied copper) with different shape and dimensions. There are some differences in requirements related to this paramters IEC standards worked out by different IEC Committee. It should be emphasized that all the three involved Committee (TC 81X, TC 99X and SC 64A) recommend a common earthing system, if possible.

The detailed analysis of tables included in IEC publications point out differences both in terms and in sizing figures. The aim of the proposed Table 1 was to group all the real values indicated by the different Committees into a common table. The values presented are the minimum among the ones used by different Committees and are still under consideration.

Table 1: Minimum sizes for earth electrodes of commonly used material from the point of view of corrosion and mechanical strength where embedded in the soil

Material		**Shape**	**Minimum dimensions**					**Comments**
			Vertical electrode ∅ [mm]	**Horizontal electrode [mm²]**	**Plate [mm²]**	**Thickness [mm]**	**Thickness of coating [µm]**	
Copper		Stranded wire		50				1,7 mm min. ∅ of each strand
		Solid round		50				8 mm ∅
		Solid tape		50		2		
		Solid round	15	[25]				[1,7 mm min. ∅ of each stand]
		Pipe	20			2		Wall thickness
		Solid plate			250 000			500 x 500 mm
		Lattice plate			360 000			600 x 600 mm
Steel	Galvanized	Stranded wire		70				1,7 mm min. ∅ of each strand
		Solid round	16	10			63	
		Pipe	25			2	49	Wall thickness
		Solid tape			90	3	63	
		Solid plate			250 000		45	500 x 500 mm
		Lattice plate			360 000		45	600 x 600 mm
		Cross profile	50 x 50 x 3					
	Copper coated	Solid round	14				250	electrodeposited copper coating
		Solid round	[15]				2000	with extruded copper sheath
		Round wire	14				70	electrodeposited copper coating
		Solid tape		90			70	electrodeposited copper coating
	---	Bare solid round		10				shall be embedded in concrete
		Bare or galvanized solid tape			75	3		shall be embedded in concrete and connected at least every 5 m with reinforcement
	Stainless	Solid round	15	10				
		Solid tape			100	2		
Note: Items in brackets values and comments are referred to earth electrodes not used for lightning protection								

2.2 Tests of conductors and earth electrodes required according to EN standard

According to the requirements of EN 50164-2 [2] earth electrodes and earth rods shall be tested mechanically and against environmental influence of corrosion.
The mechanical tests comprise bend test for coated earth conductors and adhesion tests for copper coated steel earth rods. After the mechanical tests of conductors the specimens shall show no sharp edges, cracks or peeling while specimens of copper coated earth rods shall show adherence to the parent metal. Separation of the copper from the steel is not acceptable.
Environmental tests for earth conductors and earth rods are laboratory tests. The arrangement of the specimen is totally immersed in a non-stirred purified water solution, which contains chloride ($CaCl_2$) and sulphate (Na_2SO_4) for 28 days. After the test the specimens of earth rods shall satisfy the following criteria:

- the specimens shall be straight, of good visual appearance and have no rough edges or burrs throughout their length;
- the specimens shall not exhibit any visual corrosive deterioration.

The environmental test performed according to [2] often do not represent the real environmental conditions for different real soil types in which the earth rods are embedded. Natural soil usually has wide range of annual changes of such parameters like moisture content, temperature and pH, which are seriously influencing the earth electrodes corrosion rate and finally its life time.

3 FIELD CORROSION TESTS OF EARTH ELECTRODES IN POLAND

As one of the most comprehensive corrosion study of metals in soil is regarded the long term observation of their behaviour in natural conditions. This kind of study have been realized by National Bureau of Standards (NBS) in USA [3] and started almost one hundred year ago. From 1910 to 1955 the NBS conducted an extensive underground corrosion study in which 36 500 specimens, representing 333 varieties of ferrous, nonferrous, and protective coating materials which were exposed in 128 test locations throughout the United States.
In 1924, an underground exposure test was initiated on a series of five different base metals, to which zinc coatings were applied by the hot-dip process. The test was terminated after 10 years.
The Naval Civil Engineering Laboratory (NCEL) in cooperation with the National Association of Corrosion Engineers conducted a 7-year program of testing metal rods for electrical grounding [4]. Copperbonded and zinc galvanized steel rods were included among other tested materials.
In 1992 was started the National Electrical Grounding Research Project (NEGRP) in USA with the aim to compare the long-term performance of different types of earthing electrodes In 2003, one of the original sites was excavated and the copperbonded and zinc galvanized rod samples were removed [5].
In 2003 the long-term project of earth rods' field corrosion tests was initiated in Poland [6]. Few tens of steel earthing rods with different protective coatings have been embedded in soil in different sites. The aim of this investigation was to assess the corrosion rate of rods in different sites and to compare the results with already published related to similar field tests of earthing electrodes carried out in the USA [3,4,5].

3.1 Polish project of field test of steel earth rods with zinc galvanized and copper electrodeposited copper coatings

The steel earth rods with zinc galvanized and copper electrodeposited coatings were embedded in two different sites in Poland (site A - Mielno and site B - Inowroclaw) to compare the influence of real environmental conditions on corrosion of steel earthing rods with copper and zinc coatings. Each of rods consisted of two mechanically joined elements with total length l = 3m. Rods with copper coatings had diameter 16 mm (5/8″), while diameter of steel rods with zinc coating was 20 mm. The zinc coating were two types using different technologies:

a) galvanized - hot deep coating,
b) electroplating

The copper coatings were made using original Galmar electroplating technology assuring thickness at least 250 μm of copper coating.
The aim of the long term observation is to study the corrosion rates in different soils of different kind commonly used steel rod coatings of in the same environmental conditions. This observation is based on comparison of coating stste and thicknes of individual rods after removal every two years from the two soil types in Poland.
In table 2 are given characteristics of earthing rods removed after two and four year years exposure in natural soil and comparison of their physical condition.
The pictures of fragments of earthing rod removed from the soil in two different exposure sites are shown in Fig.1 - Fig.6.

3.2 Results of corrosion field tests

Earth rods with electroplating copper coating
The measured average thickness of copper coatings of steel rods made by Galmar was after two and four year exposure in soil similar to the initial one.
Earth rods embedded in site A (Mielno) in the upper part (0,5 to 1,5 m from the erth surface) were covered with corrosion deposits joined with original soil, which were well adherent to the rod surface embedded. The lower part

of rod had no visible corrosion centres neither after two nor four years of exposure in soil (see Fig.1).

Table 2: Parameters of soil and earth rods tested

Soil parameters				Parameters of earth rods			
Site	Type	Resistivity [Ω m]	pH	Coating material	Coating thickness [micrometer]		
					Initial	After	
						2 years	4 years
A - Mielno	Sand	300 – 400 (av. 350)	6,5	Copper	260 - 360	260-360	260-350
				Zinc galvanized	50 - 60	40-50	30-40
				Zinc electroplated	20 - 25	0-15	0-10
B - Inowroclaw	Sand	80 – 120 (av. 100)	7,0	Copper	260 - 360	260-360	260-350
				Zinc galvanized	50 - 60	40 - 50	30-40
				Zinc electroplated	20 - 25	0-15	0-10

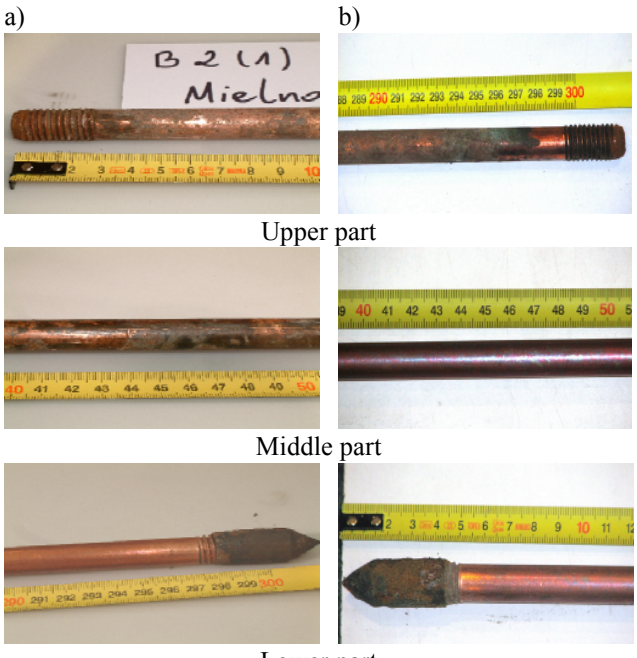


Fig.1. Pictures of earth rod elements with electroplated copper coating after two year exposure (a) and after four year exposure (b) in site A (Mielno).

The earth rods with copper coating embedded in site B (Inowroclaw) were covered in the upper part (up to 1,5 m from ground surface) with corrosion deposits in app. 90%, while the lower part (1,5 - 3 m) were covered with corrosion deposits in app. 5% only. The lower part of investigated earth rod did not have visible corrosion effects and was slightly lusterless with original metal color (see Fig.2).

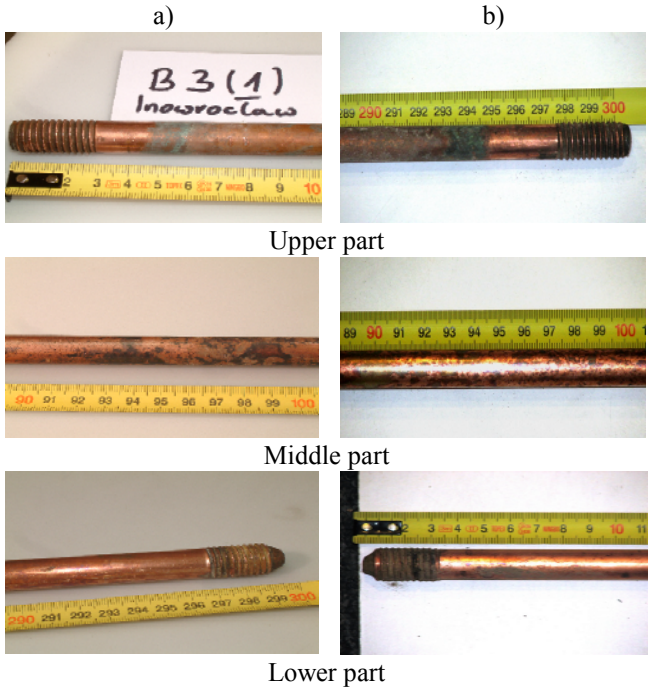


Fig.2. Pictures of earth rod elements with electroplated copper coating after two years exposure (a) and after four years (b) exposure in site B (Inowroclaw).

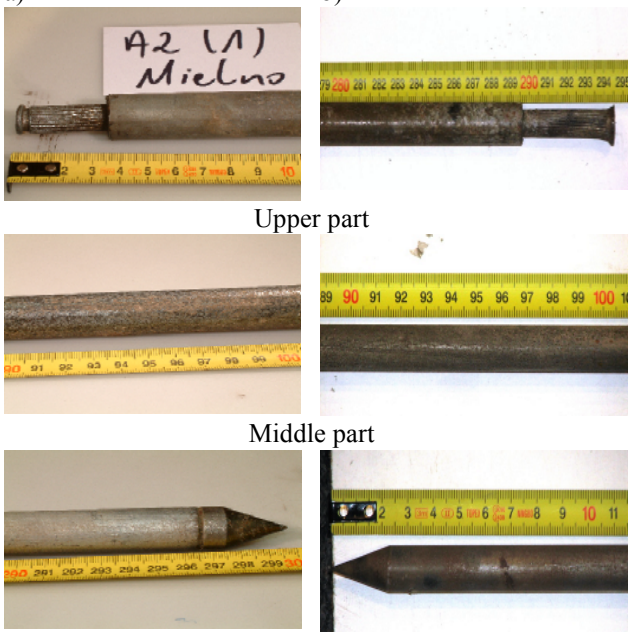
Earth rods with zinc galvanized – hot dip coating

The earthing rods with galvanized hot-dip zinc coating installed in both sites A and B were covered with corrosion products along their whole lengths. The thickness of coatings was much more less than the initial one (see Table 1). The corrosion deposits in upper part was visible on whole surface of upper part of rod but was decreasing with depth of rod embedment. When removing the rod after 2 years it was broken the connection with lower rod element in half of its total length, so also only the upper part of embedded rod removed after 4 years was shown in Fig.3 and Fig.4.

In described above soil types tested earthing rods with zinc coatings despite of its method of manufacture corroded uniformly within two years period, but no pitting corrosion process was observed.

In both sites A and B the zinc galvanized earth rods were corroding at a uniform rate of app. 5 – 6 micrometers per year.

a) b)



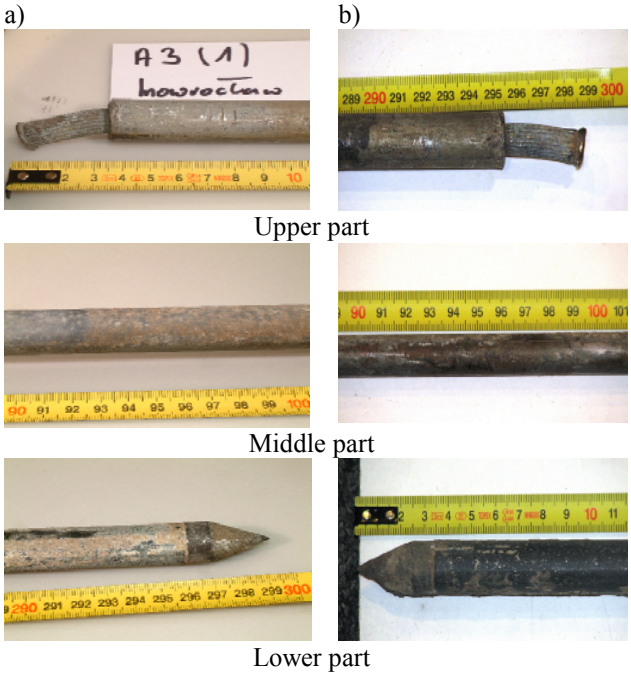
Upper part

Middle part

Lower part

Fig.3. Pictures of earth rod elements with hot-dip zinc coating after two year exposure (a) and four after year exposure (b) in site A (Mielno).

a) b)



Upper part

Middle part

Lower part

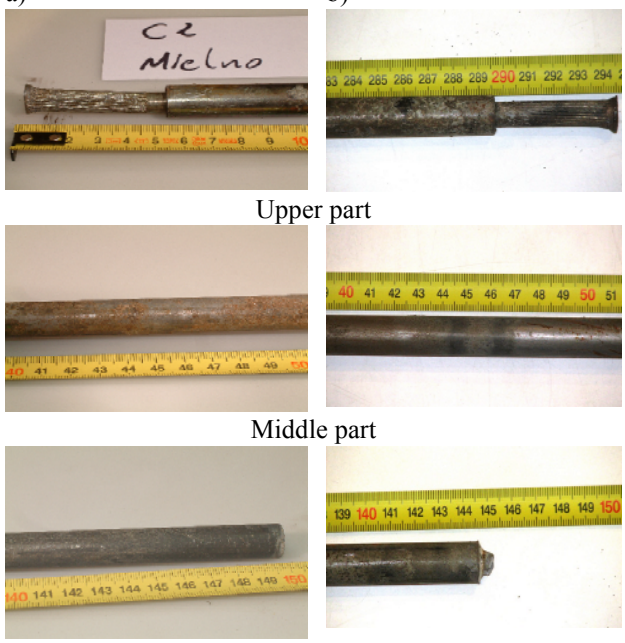
Fig.4. Pictures of earth rod elements with hot-dip zinc coating after two year exposure (a) and four after year exposure (b) in site B (Inowroclaw).

Earth rods with electroplating zinc coating

On the surface of earth rod with zinc galvanized coating exposed in site A (Mielno) was observed large areas without protective coating after two years exposure and total damage of coating along whole length of rod after four years exposure in soil.

The thickness of locally remained zinc electroplated coating was only up to 10 micrometer after four year exposure while for majority of earth rod surface the protective zinc cover corroded totally (see Fig. 5 and 6).

a) b)



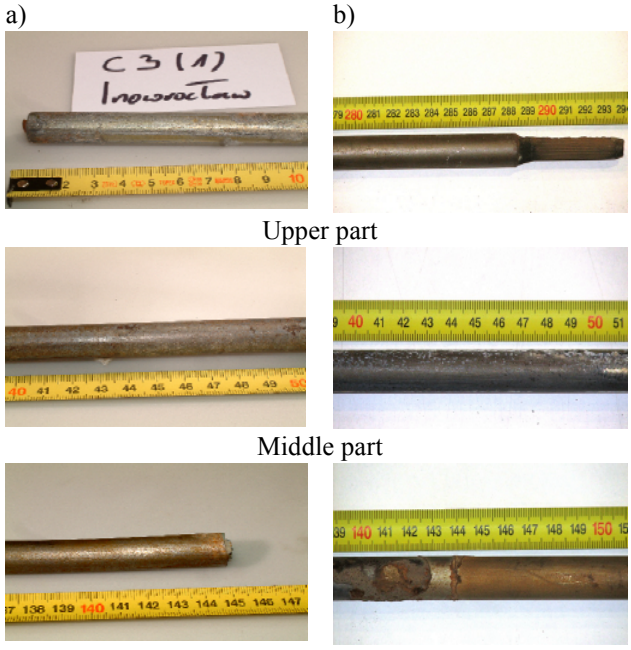
Upper part

Middle part

Lower part

Fig.5. Pictures of earth rod elements with electroplated zinc coating after two year exposure (a) and after four years exposure (b) site in site A (Mielno).

a) b)



Upper part

Middle part

Lower part

Fig.6. Pictures of earth rod elements with electroplated zinc coating after two year exposure (a) and four years exposure (b) site in site B (Inowroclaw).

4 CONCLUSION

In current IEC and EN standards related to earth electrodes the most important requirements are related to their quality and long term performance, namely to their mechanical strength and corrosion resistance. There is proposal of adequate IEC Technical Committees and Working Groups to unify those requirement in different standards related to earthing systems for different applications.

Dimensioning of earth electrodes and selection of protective coatings for steel rods and conductors shall base on practical test results performed by independent institutions and manufacturers of this kind of products worldwide, mainly in field conditions which are usually characterized by different environmental parameters.

The results of comparative field corrosion tests results of earth rods performed in Poland are in good agreement with similar tests results for earth rods with different type of protective coatings and different metals performed in USA in frames of long term study realized by NBS, NCEL and National Electrical Grounding Research Project.

All published field corrosion test results show evidence of better corrosion protection by copper coating of steel earth electrodes compared to zinc coatings made using different technologies and having different thickness of coating.

5 REFERENCES

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