Konrad SOBOLEWSKI [1], Kamila JANIA [2]

Warsaw University of Technology (1)
Jan Matejko Academy of Fine Arts in Cracow (2)

doi:10.15199/48.2016.07.25

The concept of using the tent structure as a measure of protection against lightning

Streszczenie. *Niniejszy artykuł przedstawia analizę możliwości wykorzystania konstrukcji namiotu jako środka ochrony odgromowej. Opisane zostały techniczne i użytkowe założenia konstrukcyjne, takie jak rodzaj użytego materiału, jak również przeprowadzone zostały obliczenia spodziewanych efektów oddziaływania wysokiego napięcia i dużego natężenia prądu na analizowane elementy konstrukcyjne. Przeprowadzone zostały również laboratoryjne badania wysokonapięciowe i wysokoprądowe. Artykuł kończą podsumowanie oraz wyciągnięte wnioski.*

Abstract*. In this paper was presented the concept of using the tent structure as a measure of protection against lightning. There are described technical assumptions for such structure with regard to used materials, as also calculated expected effects of influence high voltage and high current surges. Additionally high voltage and high current surge experiment set up and results were shown. (****Analiza możliwości wykorzystania konstrukcji namiotu jako środka ochrony odgromowej.****).*

Słowa kluczowe: wyładowania atmosferyczne, ochrona odgromowa, turystyka.
Keywords: lightning discharge, lightning protection, tourism.

Introduction

One of the most dangerous nature phenomena are earth-to-ground lightning discharges. They are characterized by large energy order of [MJ], current steepness about hundreds of [kA/μs], average peak current value about 40 [kA] and significant voltage drop close to [MV]. Very often it is enough to destroy or damage ground structures, as also life beings. As everybody knows the most secure place for people to stay till the lightning storm pass away are buildings with lightning protection structure (LPS). The problem is when there is no such place to take refuge, for example when human is during trip in open space or mountains area. Then you could use a dedicated construction to protect from rain and wind, as also maybe lightnings. This kind devices for individual protection were developed and proposed for using in XVIII century as set of air terminal and ground wire (fig. 1).

Fig. 1. Examples of the lightning personal protection system invented in XVIII century [1]

The effectiveness such solutions were very poor, because of lightning current has got route to ground via ground wire as also protected person. Better way for protection is to surround object (i.e. tourist) by conducted elements connected to ground, which may be something like a rack of tent. This construction may create some secure from lightning space [2].

Tent construction

The basis of the discussed tent construction were divided on two ways: practical and electrical. From a practical point of view it should be light (target weight below 1,5 [kg]), weatherproof, easy for transport and lay out. In contrast electrically it should made some protection against lightnings with itself immunity on lightning current effects. Especially the last criterion decided on difficulty of the assumed task. Under investigations were taken such parameters as material type for metal rack construction, type of connectors between rack segments, grounding and equipotential bonding measures for minimization step voltage.

As the result of conceptual work the tent presented on fig. 2 was built.

Fig. 1. Created tent in natural environment

To make the metal rack were used aluminum tube with inner radius $r_i=3$ $[mm]$ and outer one $r_o=5$ $[mm]$, which mean effective cross-section area was about 50 [mm^2].

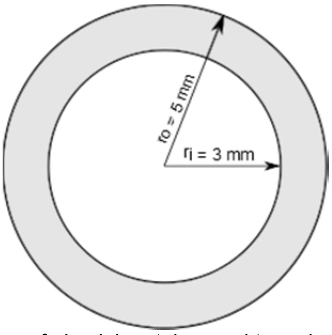
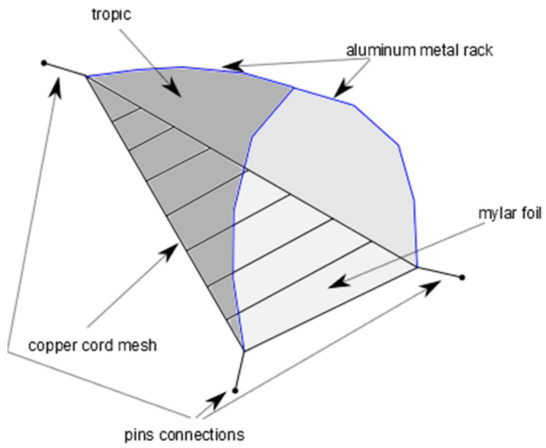


Fig. 2. Dimensions of aluminium tube used to make the metal rack

The tropic tent was made with waterproof Nylon material and it floor with electro insulation material called Mylar. Below floor was placed additional copper cord mesh (10 [mm^2] cord cross-section area with additional mylar foil and mended inside tunnels retardant cotton satin weave finished Pyrovatex) to equalize electric potential between lower ends of the rack segments as also below tent floor (fig. 4).

a)



b)

Fig. 3. a) diagram of tent parts connections, b) copper cord mesh after (left) and before (right) mended

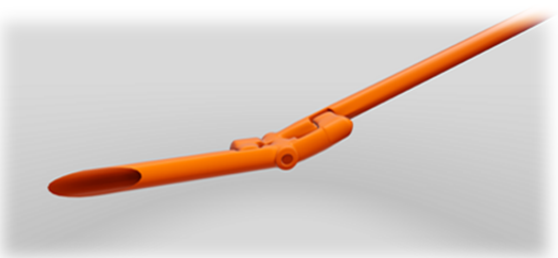


Fig. 4. Moveable connection between rack segments

Mylar is a material with very high electric insulation – for used thickness 0,35 [mm] it value is 433 [kV/mm] [3]. Pins, as element punched into ground and important in grounding process, had length of 20 [cm].

Preliminary calculations

Parameters of used materials for aluminum rack were verified and calculated according to the rules of lightning protection standards. In case of typical building for lightning downconductors are used metal rod with diameter of 6 [mm] or 8 [mm], which means cross-section area of 36 [mm2] or 64 [mm2]. Well known phenomenon is skin effect inside conductors observed with increasing of current frequency. The equivalent thickness of the conductive layer can be calculated from the following relationship:

(1) $$\delta = \sqrt{\frac{1}{\pi \cdot f \cdot \sigma \cdot \mu}}$$

where: δ – equivalent thickness of the conductive layer [μm], f – frequency of the current [Hz], σ - conductivity [S], μ - magnetic permeability $\left[\frac{V \cdot s}{A \cdot m}\right]$.

Assuming a rise time of a current surge at 10 μs a frequency of 100 kHz can be accepted. Following the execution of calculation (1) was obtained in this case the value of 290 [μm]. It means that wall thickness of 2 [mm] is proper value for this purpose.

Each segment of the tent rack construction was connected to another with moveable connection (fig. 5). Thereby whole construction was also pretty light. To consider potential risk of structure damage during lightning current flows have been carried out some calculations.

First of all were taken under consideration temperature rising according to equation (2)[4]:

(2) $$\Delta\theta = \frac{1}{\alpha}\left[\exp\frac{\frac{W}{R} \cdot \alpha \cdot \rho_0}{q^2 \cdot \gamma \cdot C_w} - 1\right]$$

where: $\Delta\theta$ – temperature rising [K], $\alpha = 4{,}0 \cdot 10^{-3} \left[\frac{1}{K}\right]$ – temperature resistance factor, $\frac{W}{R} = 2{,}5 \left[\frac{MJ}{\Omega}\right]$ – specific energy of the current pulse $i_0 = 100\,[kA]$, $\rho_0 = 29 \cdot 10^{-9}\,[\Omega\text{m}]$ – conductor resistivity, $q = 50\,[mm^2]$ – conductor cross-section area, $\gamma = 2700 \left[\frac{kg}{m^3}\right]$ – material density, $C_w = 908 \left[\frac{J}{kg\,K}\right]$ – heat capacity.

Obtained result from calculations was $\Delta\theta = 12\,[K]$ and due to parameters of surge current generator used in next part of examinations might be treat as the worst case.

Moreover were performed calculations for electrodynamic force affected on rack segments connections during lightning current flow. To do this task was used equation (3) [4]:

(3) $$F_m = \frac{\mu_0}{2\pi} \cdot i_m^2 \frac{l}{d} = 2 \cdot 10^{-7} \cdot i_m^2 \frac{l}{d}$$

where: F_m – electrodynamic force [N], $i_m = 100\,[kA]$ – maximum lightning current, $l = 0{,}5\,[m]$ – conductor length, $d = 0{,}1\,[m]$ – distance between end of conductor and connection point (fig. 6).

Obtained force value was $F_m = 10\,[kN]$ and like the previous result it was interpreted as the worst case, but due to geometrical configuration of the tent rack segments were expected much lower values of this force.

Mechanical parameters of the construction were not consider. Next step was to prepare and perform experimental tests in high voltage laboratory.

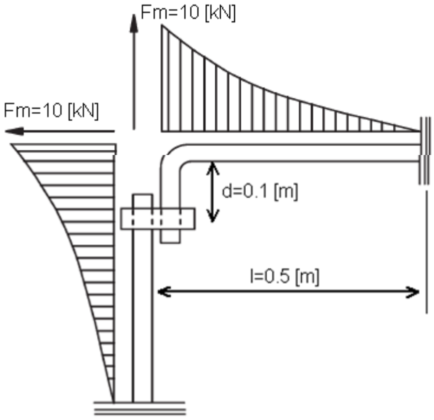


Fig. 5. Illustration of the worst case of electrodynamic force strength

Laboratory tests

Test procedure was split by two parts used two different surge generators: high voltage and high current. Measurement set up for high voltage test is presented on fig. 7.

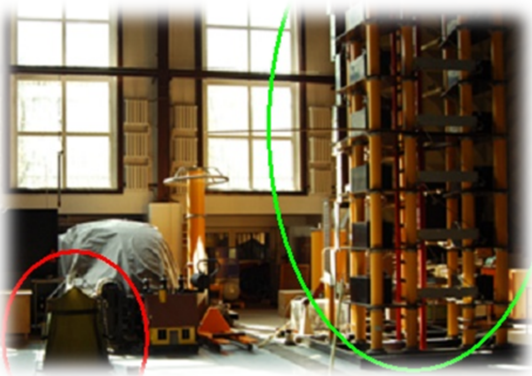


Fig. 6. Measurement setup for high voltage test

As a source of high voltage was used surge generator (marked by green circle on fig. 7) with maximum voltage level 2.4 [MV], but during tests this value was reduced to 1 [MV] maximum. Tested tent stay close to the high voltage electrode and when generator loads to set voltage level the spark to tent rack was initiated. Inside tent was placed imitation of tourist head, which was gently touched to the tropic (fig. 8). It was metal ball with copper tape dropped down on the insulated floor.

Fig. 7. Tourist head model inside tent touched tropic material

Two especially interested things were observed during this test: first about how tent construction react on high voltage, and second about in which point generated lightning will strike (to the rack construction or tourist head model inside). In most cases lightning hit to the rack, but when distance was higher and tourist head was a little closer to electrode than aluminum rack, lightning hit to them (fig. 9). Voltage value in this moment was about 1 [MV].

Fig. 8. The moment of lightning hit to modeled tourist head

In the effect of this strike a small hole in the tropic was fired, lightning current flow through the tourist and as sliding discharge on floor surface jump to ground. Next stage of experiment consisted in using high current surge generator. Measurement setup is presented on fig. 10.

Fig. 9. Measurement setup for high current impulse test

High current surge generator output was connected to the top of the aluminum rack and maximum current value was measured with current transformer (green square box on the left on fig. 10). During generations of five surges current value changes from 6 kA to 55 kA. Example shape of current surge is presented on fig. 11.

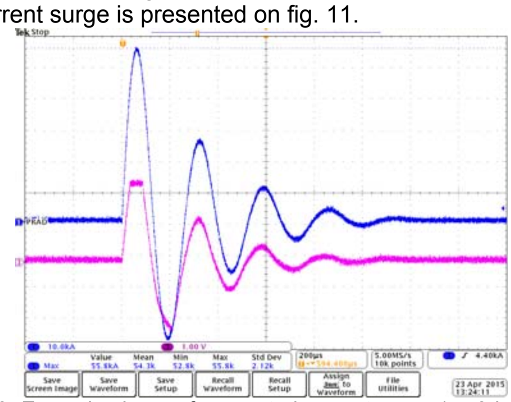


Fig. 10. Example shape of generated current surge (55,8 kA): blue color (1) means current value, pink color (3) means generator output voltage

Because of impedance of the aluminum rack shape of current surge had oscillations characteristic. Provided observations were concentrated especially on electrodynamic forces and temperature effects, but nothing unusual happened. Comparing to conducted calculations of electrodynamic forces, as also temperature rising, real values were significant lower due to lower value of current.

Fig. 11. Sparks during test with loosen screws

In this way it has been decided to loose little three screws on the rack segment connection for the last test – three first screws counting from the top. Measured maximum value of the surge current was 55 kA. In the result we might observed a lot of sparks in this places, but construction was not damaged (fig. 12).

After all tests some additional issues were observed like melted to ground ends of pins or burnt rack segments connections (fig. 13).

Conclusions

In this paper was presented some concept of using tent rack conducted construction as lightning protection measure. Performed investigations and experiments may lead to conclusion that this is not impossible to use. Materials used for tent construction assure electric safety for simulated tourist inside tested tent, except one situation when lightning directly hit tourist head. It means that is needed to optimize shape of the rack and maybe supplement it with additional horizontal segments created wider secure space (i.e. bold blue lines on fig. 14).

Fig. 12. Observed effects after current surge test: melted pins ends to metal ground plate, burnt rack segment connections

There also appeared new questions with unknown answers like influence of rain on electrical insulation tent materials, noise level or electromagnetic field strength inside tent during strike, as also step voltage measured on floor surface. All cases are worthy of future examinations, but even in presented tests surge current prefer path by aluminum rack to ground then by "tourist imitation" inside.

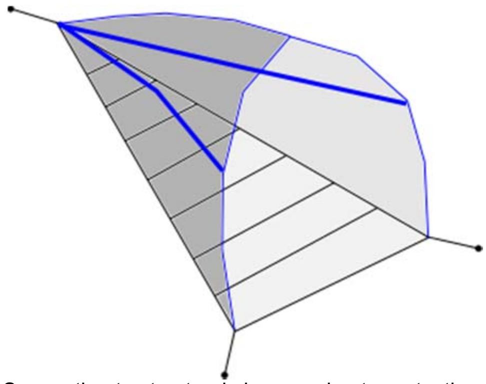


Fig. 13. Suggestion to structural changes due to protection zone

And the last conclusion, a kind of advice, is to watch attentive changed weather if some thunder clouds not coming to our location. If yes it need to try to hide in some lower parts of the mountains, inside forest or inside other safe objects. Because of possibility to provoke lightning strike by tent in very open space it should be used thoroughly.

***Authors**: **dr inż. Konrad Sobolewski**, Politechnika Warszawska, Instytut Elektrotechniki Teoretycznej i Systemów Informacyjno-Pomiarowych, Zakład Wysokich Napięć i Kompatybilności Elektromagnetycznej, ul. Koszykowa 75, 00-662 Warszawa, email: konrad.sobolewski@ee.pw.edu.pl ; **lic. Kamila Jania**, Akademia Sztuk Pięknych im. Jana Matejki w Krakowie, Wydział Form Przemysłowych, Katedra Metodyki Projektowania, ul. Smoleńsk 9, 31-108 Kraków, email: kamajania@gmail.com*

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