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NUMERICAL ESTIMATION OF ALUMINIUM SHEETS HEATING CAUSED BY ENERGY OF LIGHTNING STROKES

The article deals with the description of usage of developed numerical model for metal sheets temperature fields estimation for determination of aluminium plates temperature increase lability after direct lightning hits. The author proved that in the case of logarithmic coordinates application, there is an approximation possibility of every of graphical interpretations of relationships between the maximum temperature increase of aluminum sheet point opposite to the site struck by lightning and the time of main discharge, by two rectilinear sections.

Key words: *lightning strike, aluminium sheet temperature, method of reflections*.

Стаття присвячена опису застосування розробленої автором чисельної моделі оцінки температурних полів алюмінієвих листів для визначення зміни підвищень температури листів після безпосередніх ударів блискавки. Автор довів, що у випадку використання логарифмічних координат існує можливість апроксимації кожної з графічних інтерпретацій залежностей між максимумом підвищення температури в пункті протилежному місцю удару блискавки і часом головного розряду двома прямолінійними відрізками.

Ключові слова: *блискавка, температура алюмінієвих листів, метод відображень*.

The research investigations and analyses referred to heating of aluminium sheets after being struck by lightnings, have been performed up to now by a number of scientists dealing with lightning protection problems [1–7]. However, nobody undertook the comprehensive estimation of flash duration influence on maximum value of temperature increase in the point of aluminium sheet situated opposite to that struck by lightning.

In view of the above, the endeavours to obtain the results of such an estimation, which are both interesting for knowledge sake and practically useful, became a main aim for the author of the presented article. This aim has been achieved by the means of computational heat sources reflections method, applied in numerical model used for the needs of this publication. After description of the above model, the exemplary runs of temperature increase for different metal sheet thicknesses and for representative parameters values of lightning flashes have been presented, and then graphic interpretation of aforementioned results was given, as the family of curves. It was stated – for the first time in literature dealing lightning protection problems – that each of these curves may be approximated – in the case of logarithmic coordinates application – by two sections of straight lines.

The author hopes, that the present article and its final conclusions in particular, will contribute to further development of analyses related to protection of buildings against direct lightning strikes with application of aluminium sheets being the parts of air termination systems. This remark is regarded indirectementy also to sheets made of metals other then aluminium, which are taken into account in European standard from the range of lightning protection [8].

Characterization of numerical model applied. Some relatively effects of method of point heat sources reflections application have been popular since olden time among Polish research workers who deal with lightning protection problems [9–11], although none of them – excluding the author in this publication – signalized elaboration of numerical model, which takes into account this method principles.

The assumptions considered as basic for the aforementioned method applied herein are illustrated generally with the use of Fig. 1.

It consists in pictures of point type heat sources in two planes, so that analysis of temperature increase change within the metal sheet can be replaced by equivalent analysis performed for metal infinite body. It should be added, that assumption of point type emission of heat ensures some caution margin in interpretation of calculated results.

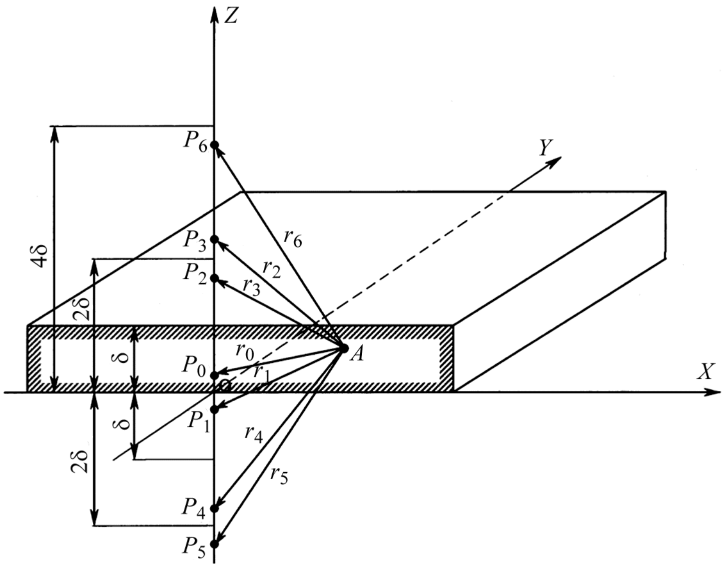

Fig. 1. Schematic diagram illustrating the assumptions on which heat sources reflections method is based.

In aforementioned infinite body a couple of parallel planes is determined; one of them is the same as assumed *Oxy* plane and equation for the other one is $z = \delta$ (where δ is the thickness of metal sheet). If the source of heat *Q* operating continuously is situated between these planes in point P_0, then further sources of heat *Q*, operating continuously too, should be introduced to infinite body – as it is given in Fig. 1 – in points P_1 and P_2, P_3 and P_4, P_5 and P_6 etc. (on assumed axis *Oz*).

Variability of temperature increase ΔT in time *t* – over ambient temperature value (which is assumed as equal to 20°C[11]) – in point *A* of metal sheet, situated in the distance r_0 from point P_0 is considered (while applying the method discussed) as the process caused by operation of infinite number of heat sources in points P_n of infinite body; they are connected with distances r_n (index *n* takes values from 0, through successive natural numbers, until it gets large enough upper limit; theoretically this limit should be equal to ∞).

Each of these heat sources, during the course of their operation (determined as heat-saturation period and marked by index *S*), causes increase of temperature in point *A*, which is calculated (for the established thermophysical parameters of aluminium) as follows:

$$\Delta T(r_n, t)_S = \Delta T(r_n)_{inf}\, \psi(r_n, t), \quad (1)$$

where $\Delta T(r_n)_{inf}$ – increase of temperature at the point *A* caused by operation of heat *Q* source situated in the point P_n of concerned infinite body; $\psi(r_n, t)$ – coefficient of heat saturation, defined as:

$$\psi(r_n, t) = 1 - \varphi_K(r_n, t), \quad (2)$$

where $\varphi_K(r_n, t)$ is error function [12, 13].

Total increase of temperature $\Delta T(t) = \Delta T(t)_S$ in point A – within the course of heat sources operation – is, in every moment, considered as a sum of temperature increases caused by individual heat sources.

After stopping the operation of heat Q source situated in point P_0 – at the moment $t = \tau$ – together with the other heat sources, there begins the temperatures leveling period(marked by index L). In the case of theoretical assumption, that during this period the continuous heat sources Q are still existing and are associated by heat Q antisources (delayed – in relation to sources – by time τ), the increase of temperature $\Delta T(t) = \Delta T(t)_L$ over the ambient temperature may be expressed in the following way:

$$\Delta T(t)_L = \Delta T(t)_S - \Delta T(t-\tau)_S \ . \qquad (3)$$

The author of the present article has been interested in particular case, for which co-ordinates x, y and z of point P_0 would be – in Fig. 1 – equal to 0, 0 and δ correspondingly and point A would be situated at the beginning of assumed system $Oxyz$ of these co-ordinates. The results of analyses referred to such a case are presented in the next section of this publication.

Results of calculations. As it was written earlier, the author at first presented the results of calculations related to exemplary runs of temperature increase at the points opposite to places of lightning strikes to aluminium sheets. Thicknesses of them within the range $\delta = 0.3 \div 0.7$ cm were taken into account, the same as assumed in paper [2]. It should be added that aluminium sheets within the above range of thickness δ are applied in construction processes of some oil tanks [8, 14, 15].

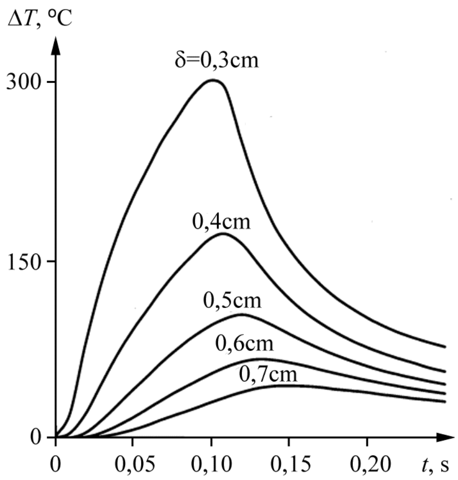

Fig. 2.

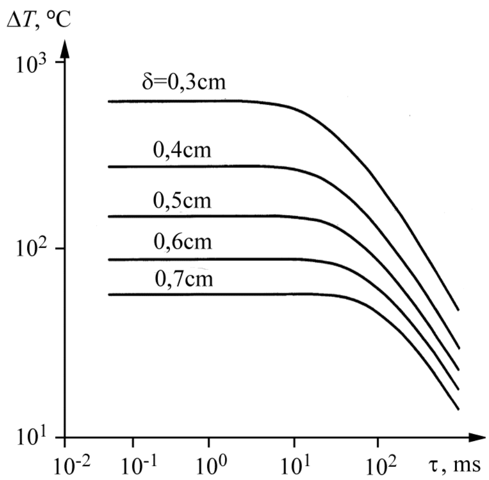

Fig. 3.

Fig. 2. Exemplary runs of temperature increase $\Delta T(t)$ at aluminium sheet point opposite to place struck by lightning having charge equal to 10 As and duration 0.1 s.

Fig. 3. Family of relationships between the maximum temperature increase ΔT_{max} and time τ.

Temperature increase runs in question are given in Fig 2. They correspond to average flash charge and average flash duration for moderate heights of structures hit by lightnings (it was assumed that these values amount to 10 As and 0.1 s accordingly [10]), equivalent value of voltage drop in the point of lightning strike (equal to 15V [2, 16]) and thermophysical parameters of aluminium selected in accordance with generally accepted principles, given – for example – in some publications from the range of electric welding [17, 18]. The author presented the mentioned runs of temperature increase in order to show how accurate calculation of $\Delta T = f(t)$ functions is possible with the use of heat sources reflections method. It should be added, that due to application of fast computer, determination of such functions can be done in relatively very short

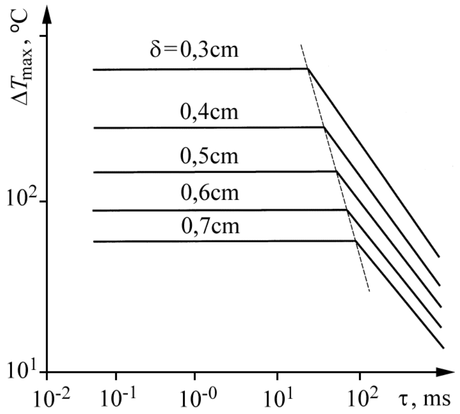

Fig. 4. Approximations of functions given in Fig. 3.

time. In this respect it was possible to perform quick appraisal of large group of dependences analogous to those given in Fig. 2, taking into consideration wide range of lightning durations τ = 0.07 ms÷1 s (this range corresponds to European conditions [19]).

Next, the author determined the maxima of these dependences – marked as ΔT_{max} – and family of worked up curves $\Delta T_{max}(\tau)$, given in Fig. 3. In connection of application in Fig. 3 logarithmic scales for maximum temperature increase ΔT_{max} and for time τ, approximations possibility of the above curves by the sections of two straight lines, was revealed (Fig. 4).

It should be added, that indication of useful approximations ability of functions shown in Fig. 3 the author treats as particular achievement of analyses made for the needs of this publication.

CONCLUSIONS

The method of heat sources reflections is very effective; it allowed to elaborate the numerical model of temperature fields estimation, which enables significant number of runs $\Delta T = f(t)$ obtainment as well as determination of their maxima for optional values of thickness δ and flash duration τ in relatively very short time.

Analysis of calculated temperature increase runs mentioned in foregoing conclusion, has proved, that maximum temperature increase of aluminium sheet at the point opposite to that of lightning strike, practically does not depend on time *τ* up to some its value – larger for more significant thickness δ – and then it shows a trend downwards (if the value of parameter τ increases); for that reason functions $\Delta T_{max} = f(\tau)$ obtained by the author, as per Fig. 3, can be approximated by means of two straight lines sections – in the way given in Fig. 4.

Applied approximations of dependences $\Delta T_{max} = f(\tau)$ legitimacy, displayed by the author, opened up good vistas before elaboration possibility of relatively simple numerical, probabilistic model of estimation of some buildings hazards by spatial explosions being results of direct lightning strikes to aluminum sheets (and also – as it comes from author's analyses not discussed in this article – to sheets made of metals other then aluminium which are taken into account as natural air termination components in European standard from the range of lightning protection).

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