The Process of Aluminium Moduls Warming in the Car Industry

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Jaroslav Mlýnek, Radek Srb

Abstract:
This paper concerns the heating of aluminium moulds in the car industry. The moulds are intended for the production of artificial leathers. The mould is sprinkled with a special powder and is subsequently warmed by infra heaters located above the mould. It is necessary to ensure approximately the same heat intensity radiation on the surface mould, and in this way, the same material structure and colour of the artificial leather. The mould surface is described by its elementary surfaces. A producer uses moulds of different sizes and they are often very rugged. We must keep track of possible collisions of heater locations. We have used a genetic algorithm to optimize heater locations for a given mould. In this article, we will focus on the calculation procedure of thermal radiation intensity on the mould surface and on the determination of the average aberration of radiation intensity for particular heater locations, which is an important part of our genetic algorithm.

Keywords: *intensity of heat radiation, experimental measurement of radiation intensity, interpolation in multidimensional space, software implementation*

1. Introduction

This article is focused on the technical problem of aluminium mould warming in the car industry. A mould weighs approximately 300 kg and is used for the production of artificial leathers in the car industry (e.g. the bonded artificial leather on a car dashboard and the surfaces of plastic parts in the car interior). The mould is sprinkled with a special powder and is subsequently warmed by infra heaters located above the mould to a temperature of 250°C. It is necessary to ensure approximately the same heat intensity radiation on the whole surface of mould. In this way, the same material structure and colour of artificial leather is ensured.

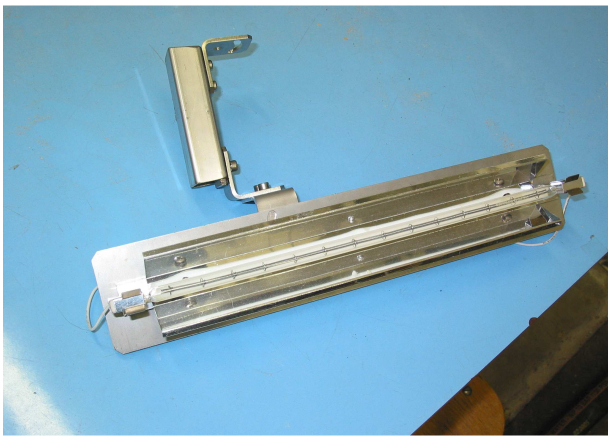

Fig. 1. Philips infra heater with 1000W capacity

The mould surface is described by its elementary surfaces. The moulds used by a producer may be of different sizes and they are often very rugged. We assume that the same type of heaters (in practical problems usually from 100 to 150 heaters) are used for heat radiation. An infra heater has a tubular form (see Fig. 1) and its length is usually between 15 and 25 cm. The heater is equipped with a mirror located above the radiation tube, which reflects back heat radiation in the adjusted direction.

The suitable positioning of heaters above the mould has been done by a technician on the basis of experience and is very labour-intensive and time-consuming. We have used a genetic algorithm to optimize the position settings of heaters. In this article, we will focus on the calculation of thermal radiation intensity on the mould surface and the determination of average aberration radiation intensity for particular heater locations, which is an important part of our genetic algorithm.

The experimentally measured values of heat radiation intensity in the surroundings of an infra heater were used during the calculation of radiation intensity on the surface of the mould.

A model of the radiated mould will be described in more detail in the following chapter.

2. Model of heat radiation

We will describe the model of heat radiation on the mould surface when using infra heaters. We will assume Euclidean space E_3 with a coordinate system $(O; x_1, x_2, x_3)$.

The mould surface is described by the elementary surface p_j, where $1 \le j \le N$ (i.e. mould surface P is described by N elementary surfaces). We assume that $\bigcup_{1 \le j \le N} p_j = P$ is true and $\operatorname{int} p_i \cap \operatorname{int} p_j = \emptyset$ for $i \neq j$. Every elementary surface is presented by the following parameters:

– its centre of gravity $T_j = \left(x_1^{T_j}, x_2^{T_j}, x_3^{T_j}\right)$;

– the unit outer normal vector $v_j = (\beta_j, \omega_j)$, where positively oriented angle β_j ($0 \le \beta_j < 2\pi$) determines the angle size of the positive part of axis x_1 and the vertical projection of the outer normal vector to a plane given by axes x_1 and x_2 (ground plane), the angle ω_j ($0 \le \omega_j \le \pi/2$) determines the angle size of the outer normal vector v_j and axis x_3 (see Fig. 2);

– the area of elementary surface s_j.

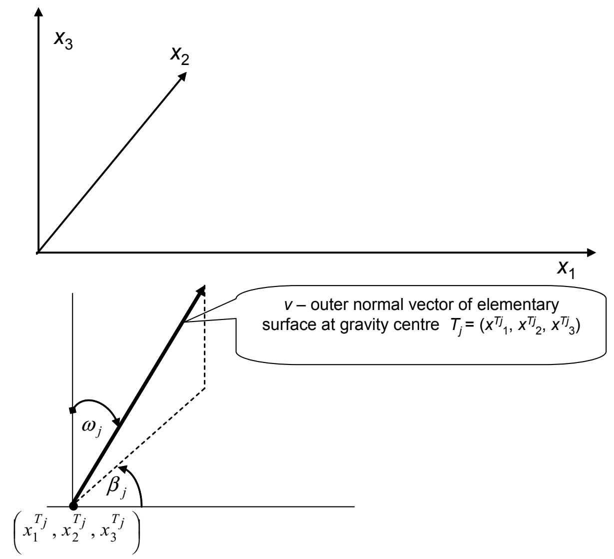

Fig. 2. Parameters determining the elementary surface p_j

Every elementary surface p_j is then defined by 6 parameters:

$$p_j : \left(x_1^{T_j}, x_2^{T_j}, x_3^{T_j}, \beta_j, \omega_j, s_j\right), \; 1 \le j \le N. \quad (1)$$

We assume all the heaters used have the same capacity and are the same sort of heaters. Every heater is represented by abscissa d[m] in length. The location of the heater is described by the following 6 parameters:

– coordinates of the heater centre $S = [\, x_1^S, x_2^S, \; x_3^S \,]$;

– radiation direction vector $u = \left(x_1^u, x_2^u, x_3^u\right)$, we assume the component x_3^u is negative (i.e. the heater radiates "down"), then the coordinate x_3^u of unit vector u is explicitly allocated;

– the unit vector r of the heater axis is given by the angle φ ($0 \le \varphi < \pi$), we define the vertical projection of vector r to a plane given by the axes x_1 and x_2 vectors, the angle size φ is given by this projection and positive part of axis x_1, vectors u and r are orthogonal.

The location of every heater Z is described by the following 6 parameters:

$$\text{Z: } \left(x_1^S, x_2^S, x_3^S, x_1^u, x_2^u, \varphi\right). \quad (2)$$

Then the location of M heaters is described by 6M parameters.

An infra heater is schematically demonstrated in Fig. 3.

3. Radiation intensity determination in heater surroundings

We will need to know the radiation intensity in heater surroundings to calculate the radiation intensity on the mould surface. We can't use radiation point source properties for this determination.

A mirror is placed above the heater and reflects the radiation back in the adjusted direction (see Fig. 1). The distribution function of radiation intensity in the heater surroundings is also not known. Thus an experimental measurement was taken of the radiation intensity of a given type of heater for selected points in the vicinity

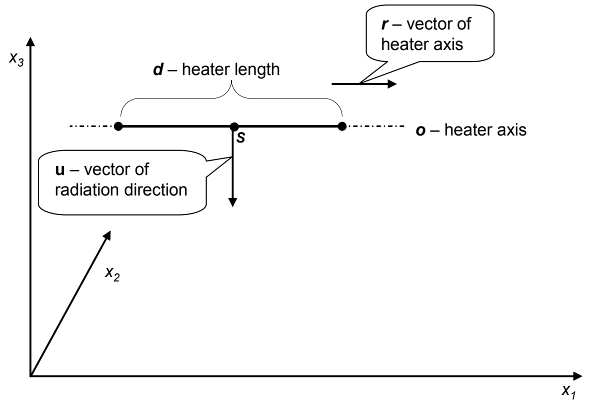

Fig. 3. Schematic representation of the heater

of the heater with the aid of a checking member. We accomplish the determination of the radiation intensity at the defined point with the help of interpolation in multidimensional Euclidean space.

3.1. Experimental measurement of radiation intensity

We will assume the heater location Z defined by relation (2) is given by parameters Z: $(0, 0, x_3^S, 0, 0, 0)$, i.e. the centre of a heater S lies on the positive part of axis x_3 , union radiation direction vector $u = (0, 0, -1)$ and vector of heater axis $r = (1, 0, 0)$ (in Euclidean coordinates). The experimental measuring of the radiation intensity in the vicinity of heater Z was accomplished at node points $a = [a_1, a_2, a_3, a_4, a_5]$ of the regular net in accordance with the setting of the elementary surface p_j given by relation (1) (here, points $[a_1, a_2, a_3]$ lie on a few planes parallel with the plane given by axes x_1 and x_2). Coordinates a_4 , a_5 determine the location of the unit outer normal vector (on an imaginary elementary surface with the centre of gravity at point $[a_1, a_2, a_3]$). The heater radiation intensity on the elementary surface depends not only on the distance of the elementary surface from the heater, but also on the direction of the outer normal vector in the centre of gravity of the elementary surface. The measurements were only performed in selected points $a = [a_1, a_2, a_3, a_4, a_5]$ for which $a_1 \ge 0$ and $a_2 \ge 0$ are true (with regard to the heater location and symmetry of the radiation) and $0 \le a_3 < x_3^S, 0 \le a_4 < 2\pi, 0 \le a_5 \le \pi/2$, where x_3^S is a component of heater centre S.

We will assume that the radiation intensity $I(b)$ for point b lies within the "hyperrectangle" net points determined by heater Z. We will use the linear interpolation of the function of 5 variables. We will assume that the point $b = [x_1^b, x_2^b, x_3^b, x_4^b, x_5^b]$ holds $a_{j,i_j} \le x_j^b \le a_{j,i_j+1}$ for $1 \le j \le 5$. Let us denote $m_j = \dfrac{x_j^b - a_{j,i_j}}{a_{j,i_j+1} - a_{j,i_j}}$ for $1 \le j \le 5$. Then it holds for the interpolation value at point b of the radiation intensity $I(b)$ of heater Z

$$I(b) = I(x_1^b, x_2^b, x_3^b, x_4^b, x_5^b) = \quad (3)$$

$$= \sum_{k_1=i_1}^{i_1+1} \dots \sum_{k_5=i_5}^{i_5+1} \left[I(a_{1,k_1}, a_{2,k_2}, a_{3,k_3}, a_{4,k_4}, a_{5,k_5}) \prod_{l=1}^{5} H(l, k_l - i_l) \right]$$

and where $H(l,0) = 1 - m_l$ and $H(l,1) = m_l$ (in more detail e.g. in [1]).

3.2. Interpolation of radiation intensity in general

Now we assume a general case of the heater location (we only assume that it holds true for the value of component x_3^u of the radiation direction vector $x_3^u < 0$, i.e. the heater radiates "down"). In this case we accomplish a transformation of coordinate axes x_1, x_2, x_3, x_4, x_5 and we transfer this problem to the problem described in paragraph 3.1. Here, at a transformation origin of coordinates $\overline{O}$ of the Euclidean space E_3 lies in the intersection of line k, which contains the centre of heater S and the direction line is given by the radiation direction vector u and plain ρ which contains point $[x_1^b, x_2^b, x_3^b]$ and is orthogonal to line k. The transformation of axis $\overline{x}_1$ is defined by the origin $\overline{O}$ and the vector of heater axis r, axis $\overline{x}_3$ is identical with line k and axis $\overline{x}_2$ is given by the origin $\overline{O}$ and vector n, where n is determined by the vector product of the vectors r and $-u$ (in more detail e.g. in [2]) and is given by the relation

$$n = (-u) \times r = \left(-\begin{vmatrix} x_2^u & x_3^u \\ x_2^r & x_3^r \end{vmatrix}, \begin{vmatrix} x_1^u & x_3^u \\ x_1^r & x_3^r \end{vmatrix}, -\begin{vmatrix} x_1^u & x_2^u \\ x_1^r & x_2^r \end{vmatrix} \right). \quad (4)$$

The transformed orthogonal system of coordinates $(\overline{O}; \overline{x}_1, \overline{x}_2, \overline{x}_3)$ is positively oriented. We establish new coordinates for the heater centre S and point $[x_1^b, x_2^b, x_3^b]$ in the transformed system. Consequently, we transform the coordinates of component x_4^b and x_5^b (which describe the location of the outer normal vector at the point $[x_1^b, x_2^b, x_3^b]$) with regards to the new coordinate system $(\overline{O}; \overline{x}_1, \overline{x}_2, \overline{x}_3)$. In this way, the general location of a heater is transferred to the problem described in paragraph 3.1.

4. Calculation of radiation intensity on the surface mould

In this chapter we will describe a procedure radiation intensity calculation on a particular elementary surface of a mould for given location of heaters. Then we can express the average difference of radiation intensity on the mould surface.

We denote L_j a set for all the heaters radiating on the j-th elementary surface for the defined locations of the heaters, $1 \le j \le N$. We will further denote I_{jl} [W/m^2] radiation intensity of the l-th heater on the j-th elementary surface. Then the total radiation intensity I_j on the j-th elementary surface is defined by the relation (in more detail e.g. in [3])

$$I_j = \sum_{l \in L_j} I_{jl}. \quad (5)$$

We will denote I_{opt} the recommended radiation intensity on the mould surface by the producer. We can determine the difference F_j of the radiation intensity on the j-th elementary surface I_j $(1 \le j \le N)$ from the recommended intensity I_{opt} upon the basis of the relation

$$F_j = \left| I_j - I_{opt} \right| \quad (6)$$

and the average aberration of radiation intensity F given the relation

$$F = \frac{\sum_{j=1}^{N} F_j s_j}{\sum_{j=1}^{N} s_j}, \quad (7)$$

where we recall that s_j denotes the area of the elementary surface p_j.

The genetic algorithm was used to optimize the locations of heaters. We searched for the minimum of function F in relation to the heater locations. Function F was used as an evaluation function (fitness) for this algorithm.

5. Practical example

We require the results of the radiation intensity calculation on the mould surface and the determination of the average aberration of radiation intensity on the mould surface. A software application was programmed in the Matlab language.

The parameters of the heaters were as follows: producer Philips, capacity 1600 W, length 15 cm, width 4 cm.

The heater characteristics were measured in 5 levels (planes) located below the heater at distances 5, 10, 15, 25 and 30 cm. Only one quadrant was measured (where values x_1 and x_2 were non-negative) at every level. 13 measurements were accomplished in axis direction x_1 at 20,1 mm intervals, 24 measurements were accomplished in direction x_2 with 10 mm intervals. The radiation intensity was measured for the small horizontal area (the fictive vertical outer normal vector) and for the small inclined areas (the fictive inclined outer normal vectors). The measurements were accomplished for the declination of the corresponding values $\beta_j = 0, \ \pi/2, \ \pi, 3\pi/2$ and $\omega_j = 0, \ \pi/6, \ \pi/3, \ \pi/2$ in relation (1).

The calculation was accomplished for the aluminium mould (0,6×0,4×0,12 m^3) displayed in Fig. 4. and 20 heaters.

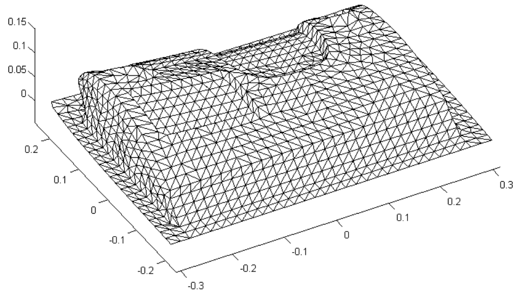

Fig. 4. Aluminium mould

In the first step of optimization procedure of genetic algorithm we set the initial locations of heaters. The parallel plane with axis x_1 and x_2 contains the centres of all the heaters and is in the distance g =10 cm over the maximum $x_{3,\max}$ of values $x_3^{T_j}$ of all centres of gravity T_j of the elements of mould surface. The locations of heaters defined by relation (2) is expressed in the form $Z : \left(x_1^S, x_2^S, x_{3,\max} + g, 0, 0, 0\right)$, i.e. the heaters radiate down and their vectors of the heater axis are parallel with axis x_1. We apply a procedure of genetic algorithm and we obtain optimized locations of heaters.

The calculated radiation intensity is described for 5 randomly chosen elementary surfaces in Tab. 1, where elementary surfaces are defined in accordance with relation (1).

Tab. 1. Calculated radiation intensity

Elementary surface (p_j)	Total radiation intensity (I_j) [kW/m^2]
(-0.2781, -0.1513, 0.0031, 3.1010, 0.7546, 0.00019)	38.97
(0.2326, -0.0563, 0.0700, 4.7372, 0.1886, 0.00017)	45.76
(-0.0008, 0.0189, 0.0838, 5.1672, 0.0714, 0.00025)	35.92
(-0.1881, 0.1934, 0.0581, 1.3879, 0.6898, 0.00018)	39.92
(0.0966, 0.0280, 0.0665, 5.9614, 0.0364, 0.00017)	43.58

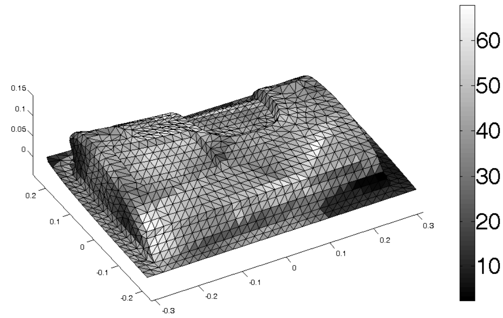

Fig. 5. Graphical representation of the calculation of radiation intensity

The recommended intensity is I_{opt} =44[kW/m^2], the average aberration of radiation intensity F is equal to $F = 11{,}21$[kW/m^2].

The calculated radiation intensity for individual elementary surfaces is demonstrated in Fig. 5 (the lighter shade of grey color denoting a higher heat radiation intensity).

The example described is illustrative. It is obvious that it is necessary to increase the number of heaters and to accomplish optimization of their locations.

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AUTHORS

Jaroslav Mlýnek* – Department of Mathematics and Didactics of Mathematics, Faculty of Sciences, Humanities and Education – Technical University of Liberec, Studentská 2, Liberec 1, 461 17, Czech Republic, jaroslav.mlynek@tul.cz

Radek Srb – Institute of Mechatronics and Computer Engineering, Faculty of Mechatronics, Informatics and Interdisciplinary Studies – Technical University of Liberec, Studentská 2, Liberec 1, 461 17, Czech Republic, radek.srb@tul.cz

*Corresponding author

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