TECHNICAL UNIVERSITY OF CLUJ-NAPOCA

ACTA TECHNICA NAPOCENSIS

Series: Applied Mathematics, Mechanics, and Engineering
Vol. 65, Issue I, March, 2022

DETERMINATION OF THE WHEEL TEMPERATURE, DURING STOPPING BRAKING OF RAILWAY VEHICLES, AT POINTS LOCATED AT THE DISTANCE X_R FROM THE WHEEL-SHOE FRICTION SURFACE

Liviu Sevastian BOCÎI

Abstract: *During stop braking, from high speeds, by means of the brake with shoes, the rolling surfaces of the wheels withstand thermal regimes that generate forces that affect driving safety.In this work, the calculation of the wheel temperature is presented using a calculation program (non-commercial), prepared by the author. After entering the initial data: the wheel load G_R [daN]; the mass factor γ[non-dimensional]; the initial speed of braking V [km / h]; the width of the shoe [m]; the thickness of the shoe [m]; braking deceleration [m / s^2]; the conductivity coefficient for the two materials of the friction coupling elements λ_R, λ_K [W/(m ℃)]; the density of the two materials ρ_R, ρ_K [kg/m^3]; the specific heat c_R, c_K [J/(kg ℃)]) can be calculated, in addition to other parameters, the temperature of the friction surface of the wheel (x_R = 0) also the temperature at different points located at a distance x_R = 5; 10; 15 mm, from the wheel tread. The values obtained by the calculation represent the variation in temperature at different points located at a distance x_R from the friction surface of the wheel vs. time (duration of braking). Figures 2-11 have represented, in temperature (f (x)) - time (x) coordinates, the variation of the temperature at the points located at the distance x_R (x_R = 0; 5; 10; 15 mm) , considering the following braking speed values: V = 160; 200 km / h, the load per wheel G_R = 7000; 9000 daN (Figures 2-5) and three values of the deceleration: a = 0.8; 1.1; 1.2 m / s^2 (Figures 6-11). Results obtained have made it possible to observe that at the same load per wheel, the increase in the initial braking speed leads to an increase in the wheel temperature. Also, at the same initial braking speed and the same load per wheel, a decrease in tread temperature is observed as deceleration decreases.*

Key words: *shoes brake, friction surface, temperature*

1. INTRODUCTION

The continuous increase in the speed of travel of rail vehicles has represented a challenge for scientists.

Experimental tests carried out on high-speed railways have shown that brake shoes require very long braking distances and therefore to maintain the same distance between signals, that is, the same braking space, it is necessary to develop new brake systems and at the same time perfecting the brake with pads increasing its performance.

The improvement of the brake shoe efficiency has been achieved by the following methods:

- The use of the shoes of a special construction [5-9];
- Optimization of the braking times;
- The mounting of the anti-lock devices in each vehicle.

The refinement of the shoe brake has been carried out through the introduction of modern electrical controls and distributors that ensure better braking characteristics.

The main disadvantage of the shoe brake is the large amount of heat produced by friction, which cannot be dissipated by the friction coupling elements.

In this work, the calculation of the wheel temperature is presented using a calculation program (non-commercial), prepared by the author. After entering the initial data: the wheel load G_R [daN]; the mass factor γ [non-dimensional]; the initial speed of braking V [km / h]; the width of the shoe [m]; the thickness of the shoe [m]; braking deceleration [m / s^2]; the coefficient of conductivity for the two materials

Received: 10.06.21; **Similarities**: 28.02.22: **Reviewed**: 14.03./14.03.22: **Accepted**:17.03.22.

of the friction coupling elements λ_R, λ_K [W/(m°C)]; the density of the two materials ρ_R, ρ_K [kg/m^3]; the specific heat c_R, c_K [J / (kg °C)]) can be calculated, in addition to other parameters, the temperature of the friction surface of the wheel (xR = 0) also the temperature at different points located at a distance x_R = 5; 10; 15 mm, from the wheel tread.

2. FORMULAS USED TO CALCULATE TEMPERATURE

In stopping braking of railway vehicles fitted with brake shoes, the variation of the temperature at points located at a distance x_R (see figure 1) from the wheel friction surface as a function of the ambient temperature (ΔT) , for a time less than the braking duration ($t < t_b$) is given by the relation (1), [2-3], [8], [13-15]:

$$\Delta T(t < t_b,\ 0) = \frac{q_a}{1 + \frac{1}{f_{F_o}} \cdot \frac{\sqrt{\lambda_K \cdot \rho_K \cdot c_K}}{\sqrt{\lambda_R \cdot \rho_R \cdot c_R}}} \cdot \left\{ \frac{2 \cdot \sqrt{t} \cdot e^{-\frac{x_R^2}{4 \cdot a_R \cdot t}}}{\sqrt{\pi} \cdot \sqrt{\lambda_R \cdot \rho_R \cdot c_R}} \cdot \left[1 - \frac{2}{3} \cdot \frac{t}{t_b} \cdot \left(1 + \frac{x_R^2}{4 \cdot a_R \cdot t}\right)\right] - \right.$$
$$\left. - \frac{x_R}{\lambda_R} \cdot \left[1 - \Phi\left(\frac{x_R}{\sqrt{4 \cdot a_R \cdot t}}\right)\right] \cdot \left[1 - \frac{t}{t_b} \cdot \left(1 + \frac{2}{3} \cdot \frac{x_R^2}{4 \cdot a_R \cdot t}\right)\right] \right\} \quad [°C] \qquad (1)$$

During cooling ($t > t_b$) the corresponding variation in temperature at points located at a distance xR from the friction surface of the wheel will be given by the relation (2):

$$\Delta T(t < t_b,\ 0) = \frac{q_a}{1 + \frac{1}{f_{F_o}} \cdot \frac{\sqrt{\lambda_K \cdot \rho_K \cdot c_K}}{\sqrt{\lambda_R \cdot \rho_R \cdot c_R}}} \cdot \left\{ \frac{2}{\sqrt{\pi} \cdot \sqrt{\lambda_R \cdot \rho_R \cdot c_R}} \cdot \left[\sqrt{t} \cdot e^{-\frac{x_R^2}{4 \cdot a_R \cdot t}} \cdot \left[1 - \frac{2}{3} \cdot \frac{t}{t_b} \cdot \left(1 + \frac{x_R^2}{4 \cdot a_R \cdot t}\right)\right] - \right.\right.$$
$$\left. - \frac{2}{3} \cdot \sqrt{t - t_b} \cdot e^{-\frac{x_R^2}{4 \cdot a_R \cdot (t - t_b)}} \cdot \left[1 - \frac{t}{t_b} \cdot \left(1 + \frac{x_R^2}{4 \cdot a_R \cdot t}\right)\right]\right] -$$
$$\left. - \frac{x_R}{\lambda_R} \cdot \left[\Phi\left(\frac{x_R}{\sqrt{4 \cdot a_R \cdot (t - t_b)}}\right) - \Phi\left(\frac{x_R}{\sqrt{4 \cdot a_R \cdot t}}\right)\right] \cdot \left[1 - \frac{t}{t_b} \cdot \left(1 + \frac{2}{3} \cdot \frac{x_R^2}{4 \cdot a_R \cdot t}\right)\right] \right\} \quad [°C] \qquad (2)$$

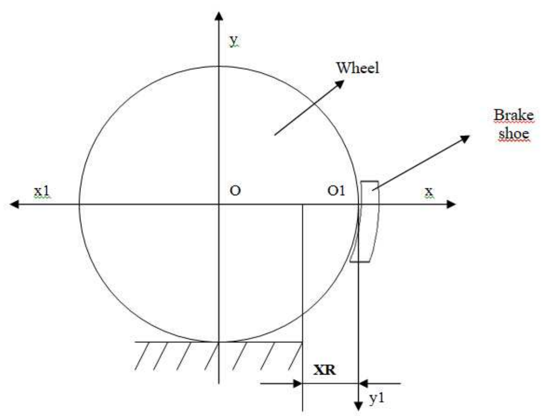

Fig. 1. Schematization of the wheel with the shoe applied to highlight the distance x_R

The value of the specific heat flux that appears at the beginning of braking (qa) is given by the relation (3):

$$q_a = \frac{(1+\gamma) \cdot G_R \cdot v^2}{g \cdot S_{oR} \cdot t_b} \quad [W/m^2] \qquad (3)$$

where: $(1+\gamma)$ - the mass factor (experimental);
v – the speed [m/s];
g – the gravitational acceleration [m/s^2];
tb – the duration of braking [s];
G_R – the load per wheel [daN];

S_{oR} – the friction surface of the wheel [m^2].
The Fourier coefficient necessary to determine the temperature correction factor is given by the relation (4):

$$F_{o(K,R)} = \frac{a_{K,R} \cdot t_b}{b_{K,R}} \qquad (4)$$

where: $a = \dfrac{\lambda}{\rho \cdot c}$ - is the coefficient of thermal diffusivity [m^2/h];
ρ - the material density of the friction coupling elements (ρ_R - for wheel, ρ_K – for shoe);
λ - the coefficient of thermal conductivity (λ_R - for wheel, λ_K - for shoe);
c – specific heat of friction coupling element materials (c_R - for wheel, c_K – for shoe).

3. CALCULATION PROGRAM.

The (non-commercial) calculation program for the temperatures at points located on the wheel at the distance x_R from the friction surface of the friction coupling elements of the brake shoe, in the case of standstill braking, has been prepared by the author and contains the following instructions [2-3], [6]:

INTRODATEINITIALE (the introduction of the initial data)
CALCULEPREG (preparatory calculations)
CALCULULTEMP (temperature calculation)
GRAFICA (graphics)
RESULTATE (results)

The initial data necessary to calculate the temperature (also the graphical representation of the temperature variation) by means of this program are the following:

- Load per wheel G_R [daN];
- The mass factor γ [no dimensional];
- The speed of the braking principle V [km/h];
- Shoe width [m];
- The thickness of the shoe [m];
- The slowdown [m/s^2];
- The coefficient of conductivity for the two elements of the friction coupling λ_R, λ_K [W/(m°C)];
- The density of the two materials ρ_R, ρ_K [kg/m^3];
- Specific heat c_R, c_K [J/(kg °C)].

The main results of this program are:

- The duration of braking tb [s];
- Friction surface S [m^2];
- Thermal flux q [W/m^2];
- The material constants of the two elements of the friction coupling:

$$\sqrt{\lambda_R \cdot \rho_R \cdot c_R} \qquad \sqrt{\lambda_K \cdot \rho_K \cdot c_K}$$

- The coefficient of thermal diffusivity of the two elements: a_R, a_K [m^2/h];
- The Fourier coefficient F_o, no dimensional;
- The correction factor f_{Fo}, no dimensional;
- The temperature [°C].

The program calculates and presents in a synthetic form (tables) the results listed above, also by means of the **GRAPH** procedure it represents the variation of the temperature in points located at a distance xR from the friction surface of the wheel as a function of time (the duration of braking).
Next, as an example, a case is analyzed using the program, in coordinates temperature (f (x) on the figures) - time (x on the figures). In this analysis, the temperature variation at points located at a distance x_R (x_R = 0; 5; 10; 15 mm) from the friction surface of the wheel has been represented, the speed of the beginning of braking has been considered: V = 160; 200 km / h), two loads per wheel: G_R = 7000; 9000 daN in figures 2 to 5 and four decelerations (a = 0.8; 1.0; 1.2; 1.3 m / s^2) - figures 6 to 11, for a load of 10,000 daN.

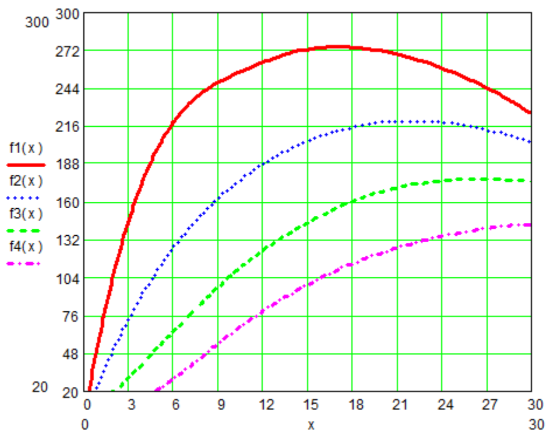

Fig. 2. The variation of the wheel temperature (f1 (x) $\rightarrow x_R = 0$ … f4 (x) $\rightarrow x_R = 15$ mm) for $G_R = 7000$ daN, a = 1,3 m/s^2, V = 160 km/h, *Vs.* time (braking duration – x in figures)

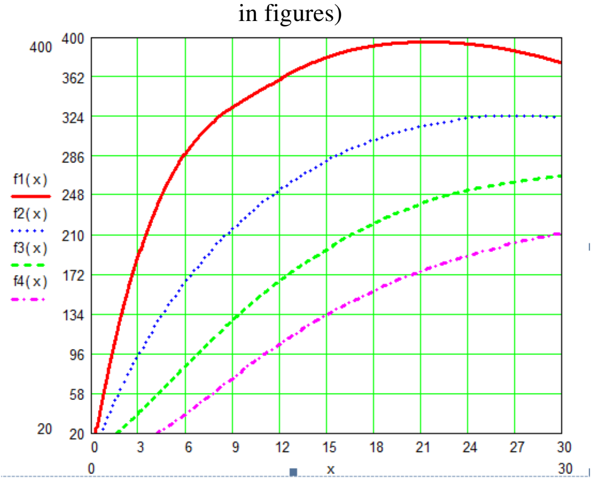

Fig. 3. The variation of the wheel temperature (f1 (x) $\rightarrow x_R = 0$ … f4 (x) $\rightarrow x_R = 15$ mm) for $G_R = 7000$ daN, a = 1,3 m/s^2, V = 200 km/h *Vs.* time (braking duration – x in figures)

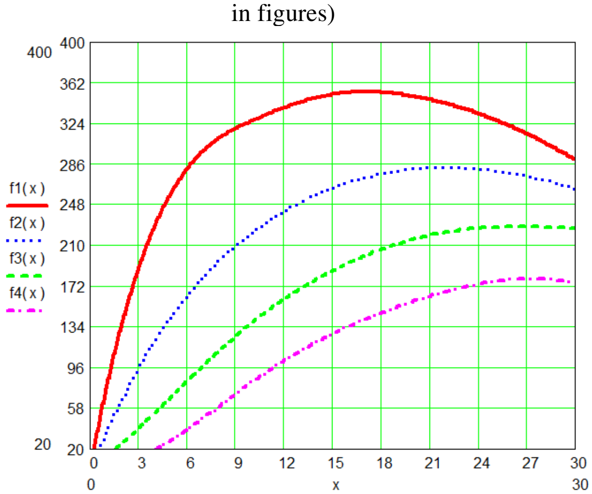

Fig. 4. The variation of the wheel temperature (f1 (x) $\rightarrow x_R = 0$ … f4 (x) $\rightarrow x_R = 15$ mm) for $G_R = 9000$ daN, a = 1,3 m/s^2, V = 160 km/h *Vs.* time (braking duration – x in figures)

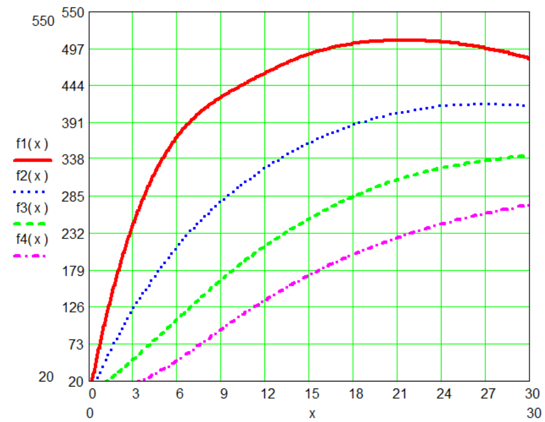

Fig. 5. The variation of the wheel temperature (f1 (x) $\rightarrow x_R = 0$ … f4 (x) $\rightarrow x_R = 15$ mm) for $G_R = 9000$ daN, a = 1,3 m/s^2, V = 200 km/h *Vs.* time (braking duration – x in figures)

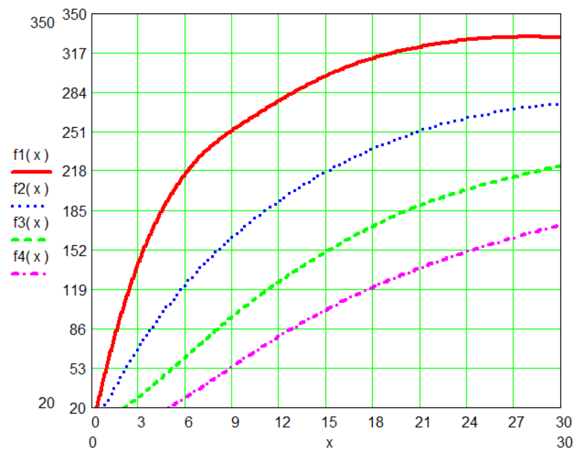

Fig. 6. The variation of the wheel temperature (f1 (x) $\rightarrow x_R = 0$ … f4 (x) $\rightarrow x_R = 15$ mm) for $G_R = 10000$ daN, a = 0,8 m/s^2, V = 160 km/h *Vs.* time (braking duration – x in figures)

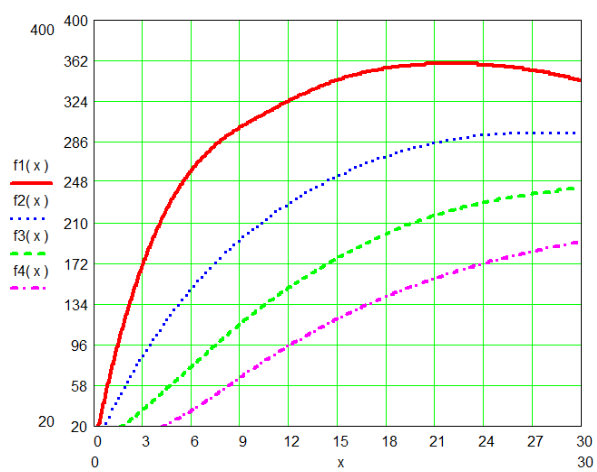

Fig. 7. The variation of the wheel temperature (f1 (x) $\rightarrow x_R = 0$ … f4 (x) $\rightarrow x_R = 15$ mm) for $G_R = 10000$ daN, a = 1,0 m/s^2, V = 160 km/h *Vs.* time (braking duration – x in figures)

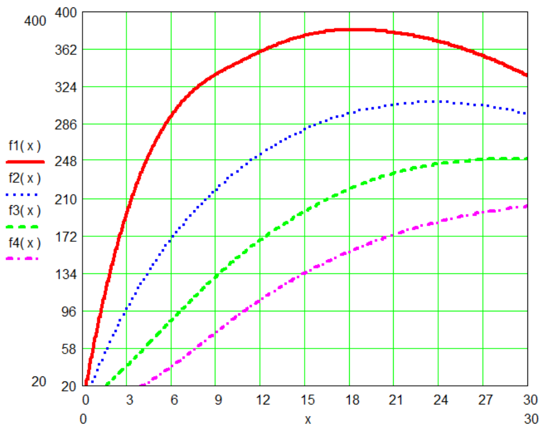

Fig. 8. The variation of the wheel temperature (f1 (x) $\rightarrow x_R = 0$ … f4 (x) $\rightarrow x_R = 15$ mm) for $G_R = 10000$ daN, a = 1,2 m/s^2, V = 160 km/h *Vs.* time (braking duration – x in figures)

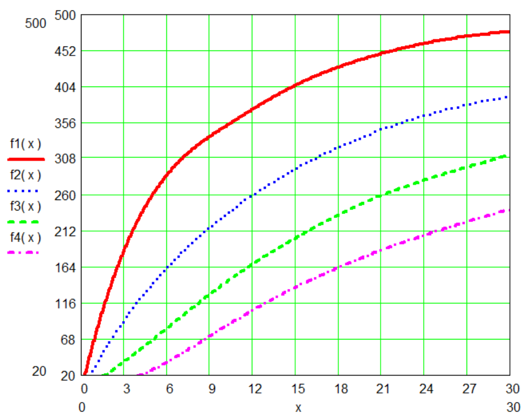

Fig. 9. The variation of the wheel temperature (f1 (x) $\rightarrow x_R = 0$ … f4 (x) $\rightarrow x_R = 15$ mm) for $G_R = 10000$ daN, a = 0,8 m/s^2, V = 200 km/h *Vs.* time (braking duration – x in figures)

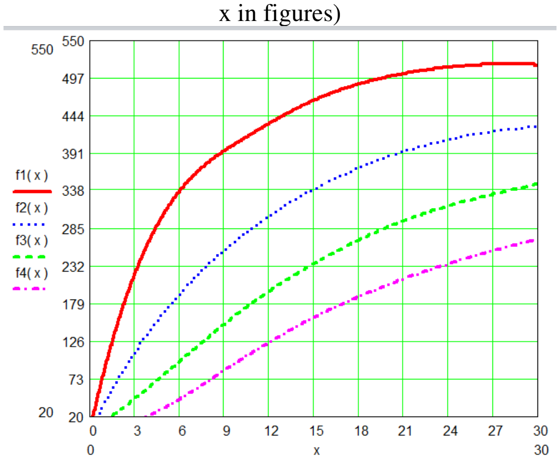

Fig. 10. The variation of the wheel temperature (f1 (x) $\rightarrow x_R = 0$ … f4 (x) $\rightarrow x_R = 15$ mm) for $G_R = 10000$ daN, a = 1,0 m/s^2, V = 200 km/h *Vs.* time (braking duration – x in figures)

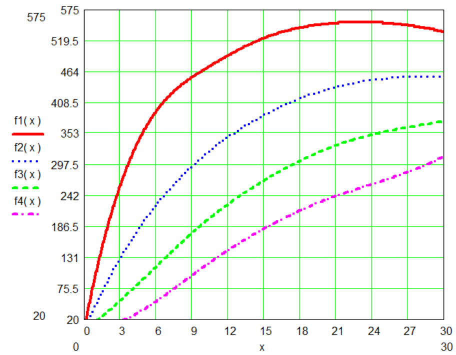

Fig. 11. The variation of the wheel temperature (f1 (x) $\rightarrow x_R = 0$ … f4 (x) $\rightarrow x_R = 15$ mm) for $G_R = 10000$ daN, a = 1,2 m/s^2, V = 200 km/h *Vs.* time (braking duration – x in figures)

5. CONCLUSIONS

From the analysis of the diagrams presented in Figures 2 to 11, the following conclusions result:

- In brake shoe braking, the rolling wheels withstand thermal regimes that generate forces on the wheel disc and on the crown;
- At the same load per wheel, an increase in the speed at the beginning of braking (from 160 km / h to 200 km / h) produces an increase in the temperature inside the wheel (especially at the crown) reaching values of approximately 267°C at a distance $x_R = 10$ mm from the friction surface of the wheel;
- For $x_R > 0$, a decrease in wheel temperature is observed, but the temperature values must be noted. For example, the value of approximately 250°C is obtained at a regime characterized by: $G_R = 9000$ daN, a = 1.3 m / s^2, V = 200 km / h, $x_R = 15$ mm, a value that will be transmitted by driving in the wheel disc leading, in the most unfavorable case, to a rotation of the wheel on the axle;
- At the same initial braking speed and the same load per wheel, a decrease in deceleration, for example from a = 1.2 m / s^2 to a = 0.8 m / s^2 leads to a decrease in temperature from about 310°C to 270°C, but at the same time requires a greater stopping distance;
- Likewise, at the increase in the speed at the beginning of braking (for example, from V = 160 km / h to V = 200 km / h), at the same deceleration (a = 1.0 m / s^2) and at the distance $x_R = 15$ mm, produces an increase

in the temperature of the wheel from 190°C to 270°C, considering a load per wheel G_R = 10,000 daN.

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Determinarea temperaturii roții, la frânarea de oprire a vehiculelor feroviare, în puncte sitúate la distanța x_R față de suprafața de rulare

Rezumat: În timpul frânării DE oprite de la viteze mari prin intermediul frânei cu saboți, suprafețele de rulare ale roților suportă regimuri termice care generează tensiuni cu efecte negative asupra siguranței circulației. În această lucrare este prezentat calculul temperaturii roții folosind un program de calcul (necomercial) elaborat de autor. După introducerea datelor inițiale: sarcina roții G_R [daN]; factorul de masă γ [nedimensional]; viteza inițială de frânare V [km / h]; lățimea sabotului [m]; grosimea sabotului [m]; decelerarea frânării [m/s^2]; coeficientul de conductivitate pentru cele două materiale ale elementelor cuplei de frecare λ_R, λ_K [W/(m°C)]; densitatea celor două materiale ρ_R, ρ_K [kg/m^3]; căldura specifică c_R, c_K [J/(kg °C)]) poate fi calculată, pe lângă alți parametri, temperatura suprafeței de frecare a roții (x_R = 0) și temperatura în diferite puncte situate la distanță x_R = 5; 10; 15 mm, față de suprafața de rulare a roții. Valorile obținute prin calcul reprezintă variația temperaturii în diferite puncte situate la o distanță x_R de suprafața de frecare a roții *Vs.* timp (durata frânării). În figurile 2-11 se prezintă, în coordonate temperatură (f (x)) - timp (x), variația temperaturii în punctele situate la distanța x_R (x_R = 0; 5; 10; 15 mm), având în vedere următoarele valori ale parametrilor: viteza de început al frânării: V = 160; 200 km / h, sarcina pe roată G_R = 7000; 9000 daN (Figurile 2-5) și trei valori ale decelerării: a = 0,8; 1.1; 1,2 m/s^2 (Figurile 6-11). Rezultatele obținute au făcut posibilă observația că la aceeași sarcină pe roată, creșterea vitezei inițiale de frânare duce la o creștere a temperaturii roții. De asemenea, la aceeași viteză de frânare inițială și aceeași sarcină pe roată, se observă o scădere a temperaturii suprafeței de rulare pe măsură ce decelerarea scade.

Liviu Sevastian BOCÎI, Professor, PhD, ”Aurel Vlaicu” University of Arad; Department of Automation, Industrial Engineering, Textiles and Transport; no 2, Elena Drăgoi Street, 310330 Arad, Romania, tel/fax: +40 257 250389; bociis@yahoo.com