UDC 621

RENATA DWORNICKA
Cracow University of Technology, Institute of Computing Science

HEATING AND COOLING OPERATIONS OF T-PIPE OF THE USE TRD REGULATIONS

1. Introduction

В статі представлено методику визначення максимальних допустимих швидкостей нагрівання і охолодження, розроблену на основі німецького стандарту TRD 301. Об'єктом досліджень є трійник, виконаний із сталі 13 HMF. У праці приведено геометричний опис трійника, властивості матеріалів, а також характеристику робочих умов. Представлені також отримані значення максимальних допустимих швидкостей нагрівання і охолодження.

The mentioned T-pipe is pressurized element of a power unit. Temperature’s changes appear there during starting, load changing and stopping. A non-homogeneous temperature distribution is a cause of thermal stresses. The stresses should not to exceed allowable values thus an identification of allowable heating and cooling rates is so important, particularly for the T-pipe [1-3]. The author presents the calculations of allowable heating and cooling rate conducted according to German TRD 301 regulations [4].

Ключові слова: стандарт TRD 301, трійник, властивості матеріалів.

2. Description of the approach and work methodology

2.1. Geometrical properties of the T-pipe and their mean substitutes

The calculation of allowable cooling and heating rates for the T-pipe made from ferritic steel 13HMF (Fig.1) was conducted. The T-pipe is typically utilized in pipelines of a fresh and overheated steam in a power unit of a power plant 360 MW.

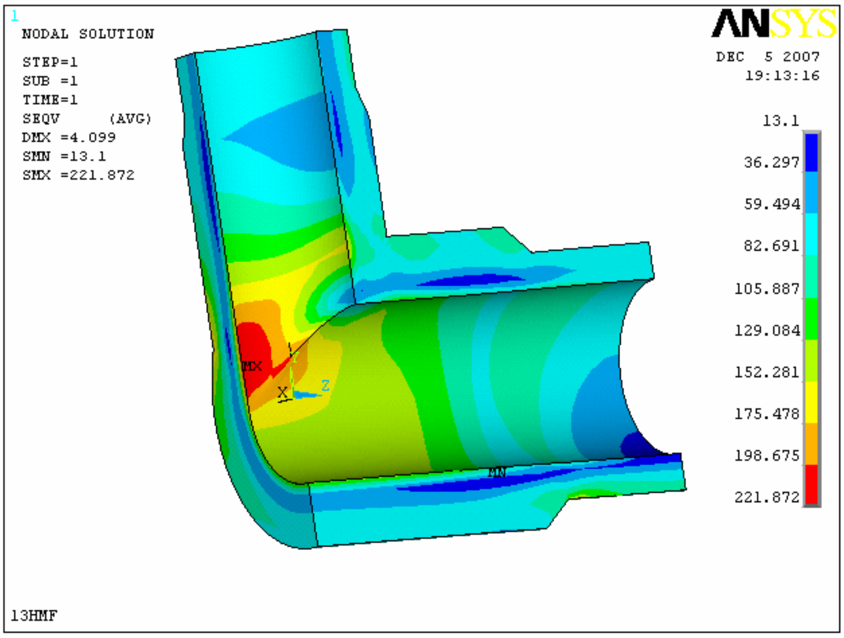

Fig.1. Dimensions of T-pipe made from ferritic steel 13HMF

Dimensions of the T-pipe are as following:

- external diameter of the T-pipe .... $d_a = 506$ [mm]
- internal diameter of the T-pipe .... $d_i = 290$ [mm]
- thickness of the T-pipe wall .... $s_e = 108$ [mm]
- external diameter of the ramification .... $d_A = 448$ [mm]
- internal diameter of the ramification .... $d_{Ai} = 290$ [mm]
- thickness of the ramification wall...................................... $s_A = 79$ [mm]
- ovality.. $U = 0\%$

2.2. Working environment for the T-pipe made from steel 13HMF

There was assumed that the element works in the following conditions:

- minimum pressure in a cycle.. $p_{min} = 0$ [MPa]
- maximum pressure in a cycle .... $p_{max} = 18$ [MPa]
- minimum temperature in a cycle .... $\vartheta_{min} = 20$ [^{o}C]
- maximum temperature in a cycle .... $\vartheta_{max} = 540$ [^{o}C]
- required start and stopping cycles .... $n = 2000$

- number of cycles (start from cold state 20°C) till cracking appears n_{max} = 5n = 10000

For the considered load cycle a reference temperature ϑ^* was calculated following the formula:

$$\vartheta^* = 0,75 \cdot \vartheta_{max} + 0,25 \cdot \vartheta_{min} \; [^\circ C] \qquad \vartheta^* = 410 \, [^\circ C] \tag{1}$$

2.3. Material properties

Material properties for the steel of 13HMF may be read from strength tables for an assumed temperature, evaluated according to linear interpolation or calculated according to table's factors. The greatest allowable pressure of a working medium is assigned as a working pressure p_4. For the mentioned element made from the steel 13HMF the following material properties were determined:

- minimum tensile strength at the environment temperature 20 [°C] $\sigma_{min\,B}$ = 490 [MPa]
- Poisson's ratio.. ν = 0,3
- elastic modulus .... $E_\vartheta = 1{,}841 \cdot 10^5$ MPa
- minimum yield strength.. $\sigma_{0.2/\vartheta*}$ = 224 [MPa]
- linear coefficient of thermal expansion............................. $\beta_{L\vartheta*} = 1{,}404 \cdot 10^{-5}$ [1/K]
- temperature equalization ratio .... $\alpha_{\vartheta*}$ = 528 [mm^2/min]

All variables mentioned above dependent on temperature relate to the reference temperature ϑ^* for the considered load cycle.

2.4. Stresses calculations

The calculations of stresses were the next stage. The stresses in the T-pipe originated from the working pressure p4 are equal to σ_{ip4} = 88,5 [MPa]. The stresses in the element originated from the minimum pressure are equal to σ_{ip} = 0 [MPa]. The minimum stresses in the cycle are equal to $\sigma_{i\,min}$ = -214,5 [MPa]. The maximum stresses in the cycle are equal to $\sigma_{i\,max}$ = 303 [MPa]. The stresses were calculated with the assumption that stress concentration ratio is equal to a'_m = 3,2.

When the maximum and minimum allowable stresses were determined, allowable differences of the temperature were calculated and – at last – allowable heating and cooling rates. For the simplicity, a code-based V factor was introduced:

$$V = \frac{a_{\vartheta*}}{\Phi_f \cdot s_b^2} \left[\frac{1}{\min}\right] \tag{2}$$

where: $\alpha_{\vartheta*}$ – temperature equalization ratio, Φ_f – shape factor, s_b – substituted wall thickness. The shape factor is evaluated from the formula:

$$\Phi_f = \frac{1}{8} \cdot \frac{(u_o^2-1)\cdot(3\cdot u_o^2-1)-4\cdot u_o 4\cdot \ln(u_o)}{(u_o^2-1)\cdot(u_o^2-1)^2} \qquad \Phi_f = -0,469 \tag{3}$$

where: u_0 – quotient of the external to internal diameters. Then V factor may be evaluated from formula (2) giving:

$$V = -0,073 \left[\frac{1}{\min}\right] \tag{4}$$

3. Achieved results

The allowable heating rate at the beginning of the starting phase is given by the formula:

$$v_{\vartheta 1} = V \cdot \Delta_{\vartheta 1} \left[\frac{K}{\min}\right] \qquad v_{\vartheta 1} = 2,119 \left[\frac{K}{\min}\right] \tag{5}$$

The allowable heating rate at the end of the starting phase is given by the formula:

$$v_{\vartheta 1'} = V \cdot \Delta_{\vartheta 1'} \left[\frac{K}{\min}\right] \qquad v_{\vartheta 1'} = 2,993 \left[\frac{K}{\min}\right] \tag{6}$$

The allowable cooling rate at the beginning of the stopping phase is given by the formula:

$$v_{\vartheta 2} = V \cdot \Delta_{\vartheta 2} \left[\frac{K}{\min}\right] \qquad v_{\vartheta 2} = -2,119 \left[\frac{K}{\min}\right] \tag{7}$$

The allowable cooling rate at the end of the stopping phase is given by the formula:

$$v_{\vartheta 2'} = V \cdot \Delta_{\vartheta 2'} \left[\frac{K}{\min}\right] \qquad v_{\vartheta 2'} = -2,993 \left[\frac{K}{\min}\right] \qquad (7)$$

4. Proposed procedure for calculation of heating and cooling rates for any element

Calculations were executed in system Mathcad using formulas from TRD 301 regulations. Presented below is a procedure enabling the calculation, allowable heating and cooling rates for a T-pipe of any geometry or other element working under conditions of high temperature and pressure. The first stage of the calculations is to provide the geometry of the element its theromophisical and strength parameters and conditions under which it will work (fig.4.1).

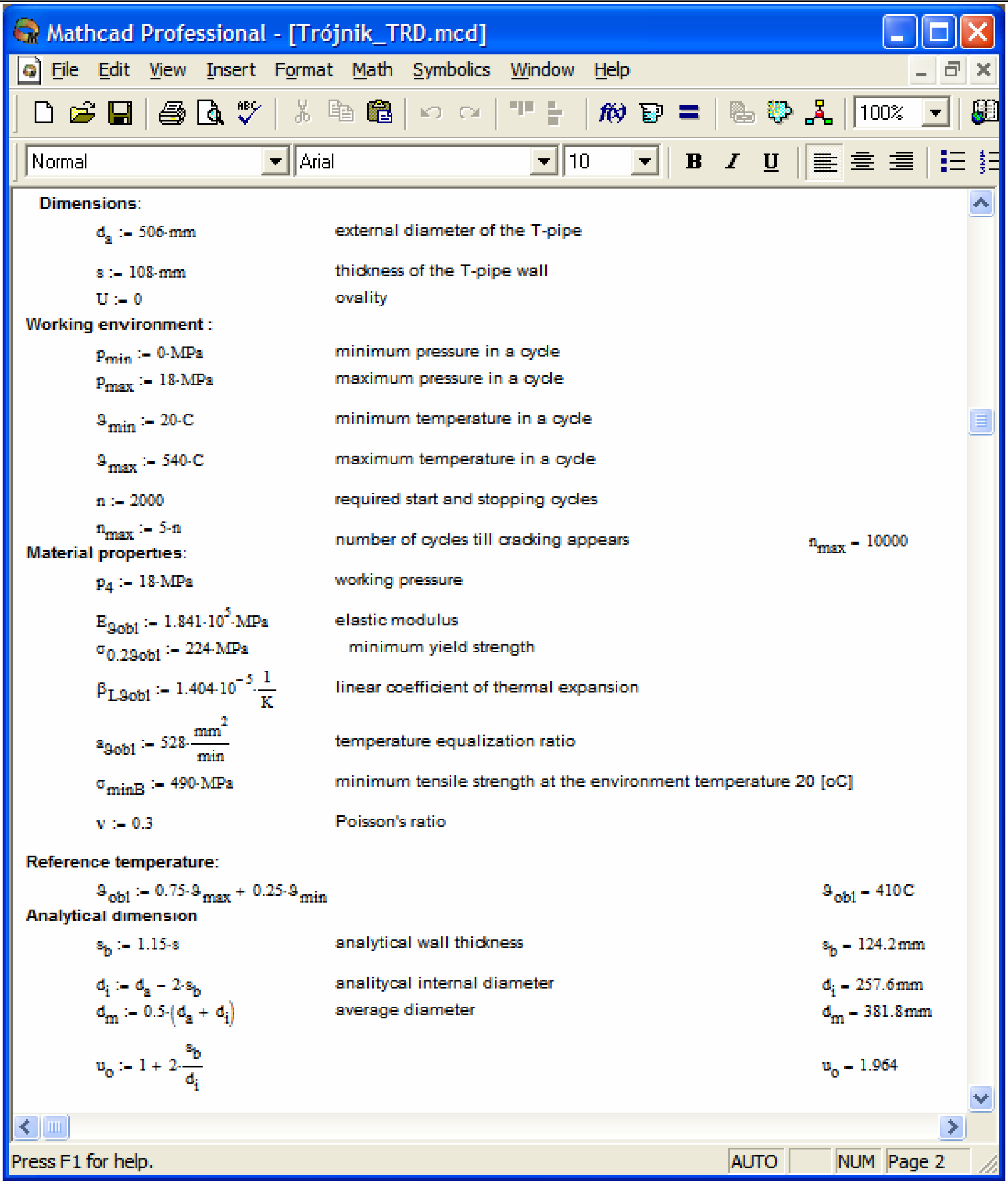

Fig. 4.1. The geometry, thermo-physical properties and working environment condition – definitions in Mathcad

Keeping determined geometrical parameters, the allowable amplitude of stress changes σ_a is evaluated. If the allowable range of stress changes at the reference temperature σ_a is greater than or equal to doubled minimum yield strength at the reference temperature, it is necessary to calculate reduced allowable range of stress changes (fig. 4.2). The next step are an evaluation of T-pipe stresses induced by pressure (fig. 4.3), minimum stresses in the cycle and maximum stresses in the cycle (fig. 4.4). The factor $f_u(p)$ – dependent on the ovality – is assumed to be equal to 0 on the cause of the assumption of the ovality $U = 0$.

Allowable amplitude of stress

$$S_1 := 78724.99997 + \frac{965775936.9\cdot K}{(\vartheta_{obl} - 13137.5\cdot K)} \qquad S_1 = 2.844\times 10^3$$

$$S_2 := 2877.06645 + \frac{4861735.668\cdot K}{(\vartheta_{obl} - 2542.868719\cdot K)} \qquad S_2 = 597.631$$

$$S_3 := 528.0508475 + \frac{261452.4563\cdot K}{(\vartheta_{obl} - 1448.305085\cdot K)} \qquad S_3 = 276.244$$

$$C_1 := \sqrt{\frac{S_2 - S_3}{S_1 - S_2}} \qquad B := \frac{S_1 - S_2}{(C_1)^2\cdot\left[1 - (C_1)^2\right]} \qquad A := S_1 - B\cdot(C_1)^2 \qquad C_1 = 0.378$$

$$B = 1.832\times 10^4$$
$$A = 222.585$$

$$\sigma_a := A + B\cdot(n_{max})^{\log(C_1)} \qquad \sigma_a = 597.631$$

$$\sigma_a := 597.631\cdot MPa$$

Press F1 for help. AUTO NUM Page 3

Fig. 4.2. Calculation of allowable amplitude of stress changes

Stresses from pressure calculations

$\alpha_{mo} := 3.2$ theoretical stress concentration factor $\alpha_{mo} = 3.2$

$f_4 := 1.0$ $\qquad f_4 = 1$

$f_u(p_4) := 0$ if U = 0 then $f_u(p_4) = 0$ $\qquad f_u(p_4) = 0$

$\alpha_m(p_4) := \alpha_{mo}\cdot f_4 + 2\cdot f_u(p_4)$ $\qquad \alpha_m(p_4) = 3.2$

$\sigma_{ip4} := \alpha_m(p_4)\cdot p_4\cdot\frac{d_m}{2\cdot s_b}$ stress from working pressure $\sigma_{ip4} = 88.533\,MPa$

$f_u(p_{max}) := 0$ $\qquad f_u(p_{max}) = 0$

$\alpha_m(p_{max}) := \alpha_{mo}\cdot f_4 + 2\cdot f_u(p_{max})$ $\qquad \alpha_m(p_{max}) = 3.2$

$\sigma_{maxip} := \alpha_m(p_{max})\cdot p_{max}\cdot\frac{d_m}{2\cdot s_b}$ stress from maksimum pressure $\sigma_{maxip} = 88.533\,MPa$

$f_u(p_{min}) := 0$ $\qquad f_u(p_{min}) = 0$

$\alpha_m(p_{min}) := \alpha_{mo}\cdot f_4 + 2\cdot f_u(p_{min})$ $\qquad \alpha_m(p_{min}) = 3.2$

$\sigma_{minip} := \alpha_m(p_{min})\cdot p_{min}\cdot\frac{d_m}{2\cdot s_b}$ stress from minimum pressure $\sigma_{minip} = 0\,MPa$

Press F1 for help. AUTO NUM Page 4

Fig. 4.3. Calculation of stresses induced by pressure

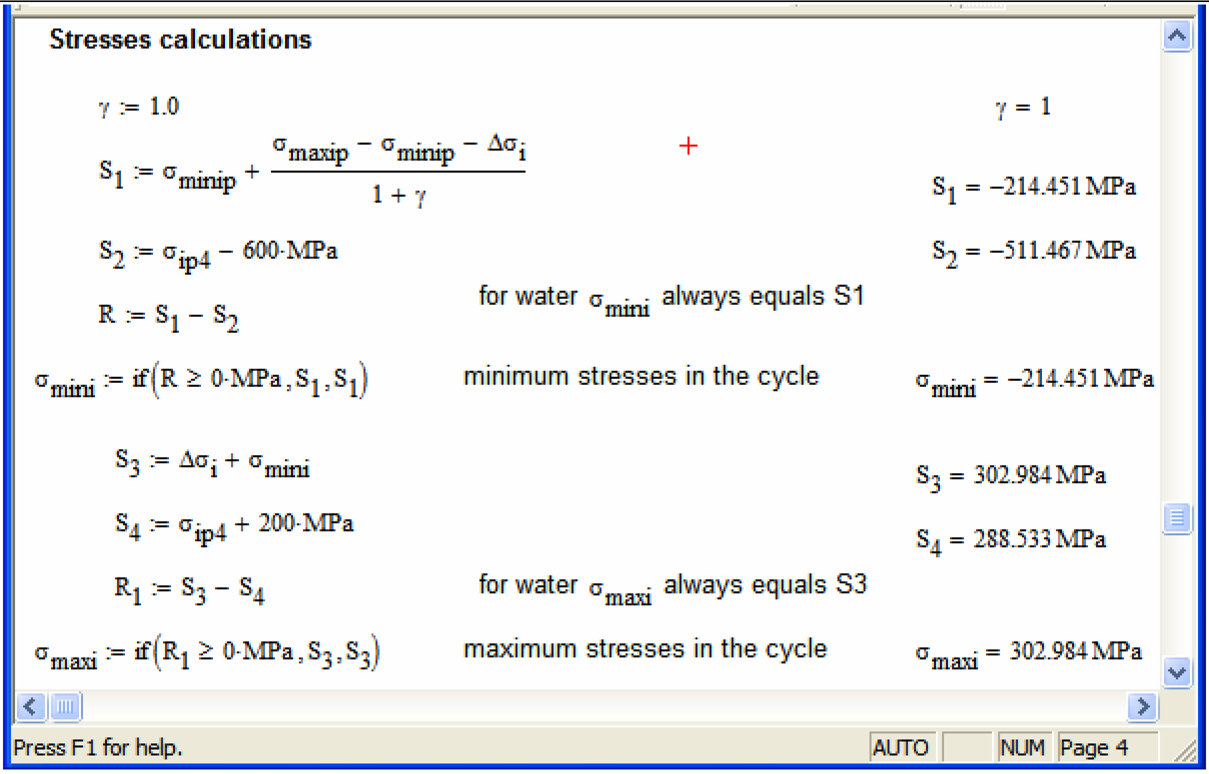

Fig. 4.4. Calculation of maximum and minimum stresses in the cycle

Keeping determined maximum and minimum allowable stresses, the allowable temperature differences is evaluated. The allowable temperature difference (a difference between element internal surface temperature and an average temperature of the wall) is evaluated on the base of formulas for four cases: the beginning of the starting phase, the end of the starting phase, the beginning of the stopping phase, the end of the stopping phase. For the formulas simplicity, the factor W is introduced (fig. 4.5). And finally the allowable heating and cooling rates are determined (fig. 4.6).

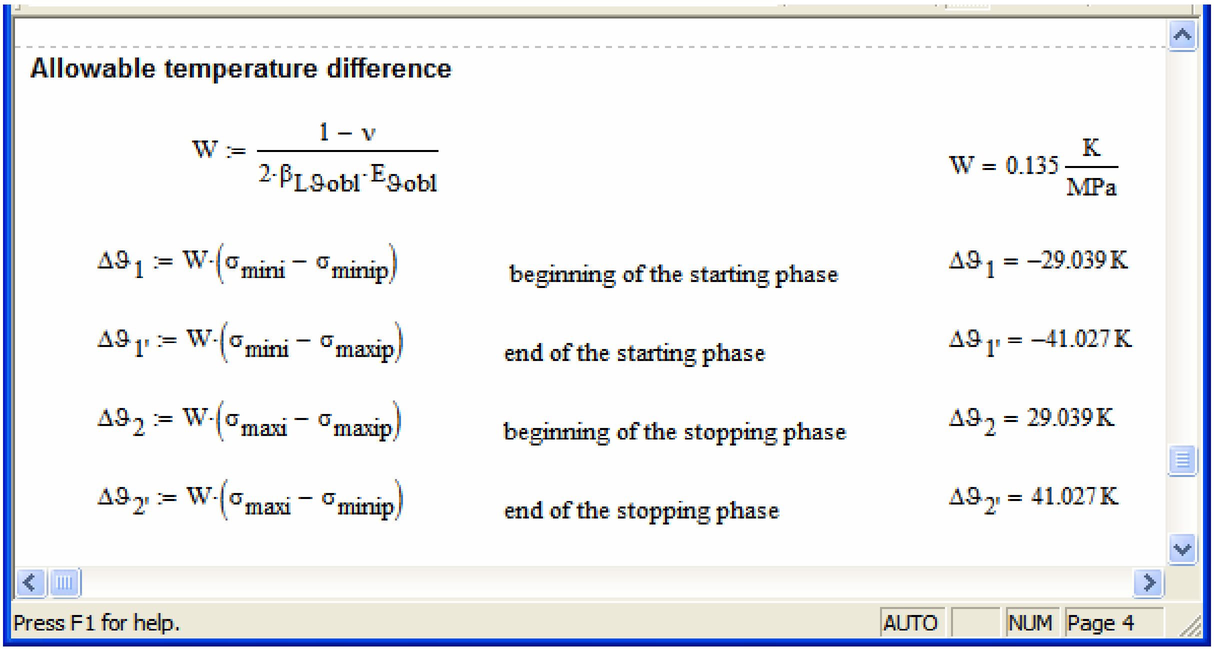

Fig. 4.5. Calculation of allowable temperature differences

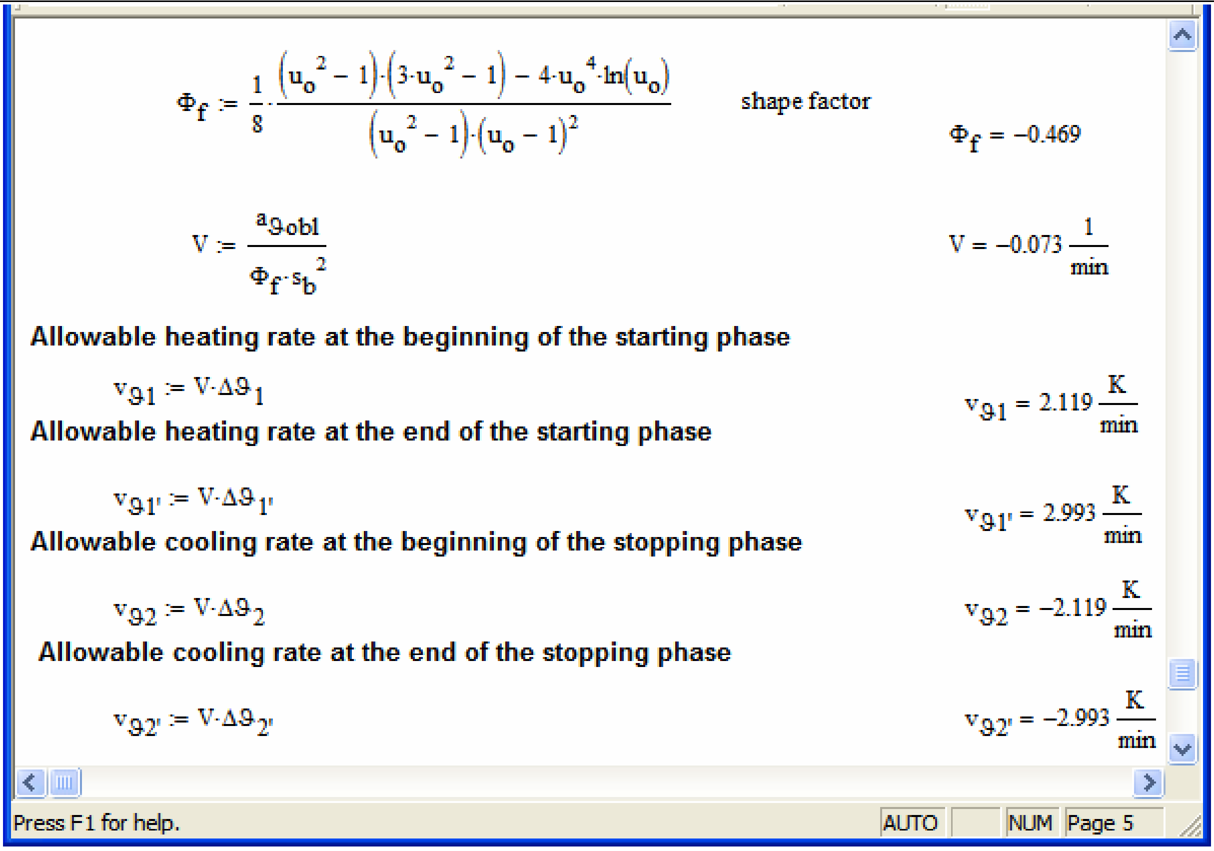

Fig. 4.6. Calculation of allowable temperature rates

4. Conclusion

The valid determination of the rates, which power plant pressurized elements may be heated and cooled with, is very important because assuming improper working parameters may lead to lesser durability of elements or their damage. The allowable cooling and heating rates for the T-pipe were calculated basing on TRD 301 regulations [4]. The details of the calculation are presented in this paper. This article presents a procedure enabling the calculation of allowable heating and cooling rates for any pressure element following definition of its dimensions, working parameters and thermophysical properties. This procedure has been suitably verified on such power unit components as: T-piece, main steam valve and drum.

References

1. Taler J., Duda P., Solving direct and inverse heat conduction problems, Springer Verlag, Berlin-Heidelberg, 2006.

2. Duda P., Taler J., Roos E., Inverse Method for Temperature and Stress Monitoring in Complex-Shape-Bodies, Nuclear Engineering and Design 3960 (2003) 1-17.

3. Duda P., Dwornicka R., Optimization of heating and cooling operations of steam gate valve, Structural and Multidisciplinary Optimization (early preview).

4. TRD 301, Technische Regeln für Dampfkessel, Carl Heymans Verlag, Köln und Beuth-Verlag, Berlin, 1986, 98-138.

Надійшла 16.11.2009 р.