Constructive Design Elements of Large Dimensions Cyclones

Professor Emeritus Ph. D. Eng. **Radu I. IATAN[1,*]**,
Ph. D. Candidate **Melania (MITUCĂ) CORLECIUC[2]**,
Lecturer Ph. D. Eng. **Gheorghiţa TOMESCU[1]**,
Assoc. Prof. Ph. D. Eng. **Anca Mădălina DUMITRESCU[1]**,
Lecturer Ph. D. Eng. **Luminiţa Georgiana ENĂCHESCU[1]**,
Assist. Prof. Ph. D. Eng. **Gheorghe-Cosmin CIOCOIU[1]**

[1] National University of Sciences and Technology Polytechnic Bucharest – Romania

[2] National Agency for Environmental Protection – Romania

* iatan.radu@gmail.com

Abstract: *The article addresses the issues specific to the constructive design of large cyclones, with tangential supply of the dust impurified gas. In this sense, the expressions for the stresses developed in the separation sections of the vortex finder tube and the flat sheet are established. The radial size of the plate, fixed also to the side body of the cyclone, is considered large. In this sense, the deformation states and stresses in the edges are accepted as not influencing each other.*

Keywords: *Large size cyclones, deformation states and stress*

1. Introduction

Over time, industrial production has been constantly developed, many technological processes being producers of dust-impure gases. As a result, it became increasingly important to protect the external environment against harmful effects. Cyclones are among the simplest systems used for dedusting dry gases in various industrial sectors. Among these, those with tangential supply of impurity gas stood out.
The technological design of the cyclones takes into account their geometry, the impurified gas flow and the number of revolutions/rotations in the downward movement. The theory developed by **Leith D**. and **Licht W**. (1972) [1] proved useful in the practical design of cyclones. In this context, it is taken into account that the velocity profile in a cyclone does not strictly coincide with the ideal, uniform shape.
Any technological design variant is based on theories that depend on the accuracy of the evaluation of the collection efficiency and the pressure drop in the cyclones [2 - 4]. The two characteristics represent two major criteria regarding the performance of a cyclone. Both are dependent on the dimensions of the cyclone, the height and width of the inlet ($a \cdot b$ – fig.1), the diameter of the gas outlet D_e, the length of the exhaust pipe S, the height of the cylindrical area h, the height of the cyclone H and the outlet diameter of the settled dust B.
Several simplified models and empirical correlations have been proposed, in the sense of the above.
Relying on the performance of a cyclone considered "benchmark" ultimately leads to a faulty design, considering that each cyclone has a specific behavior due to the unique physics of the impurity air flow [6]. The computational fluid dynamics (CFD) method has become a powerful aid in the design and evaluation of cyclones with the rapid advances in computer technology. Using this technique, there is a great potential to predict the characteristics of the fluid flow, the trajectory of the particles (adequate turbulence model) and the pressure drop in the cyclone [7]. Now, thanks to the increased processing performance of computers, at a relatively low cost, it has become possible to simulate cyclones with greater precision [8, 9].
The capacity of a cyclone is determined by the value of the cross section area of the supply pipe ($a \cdot b$, fig. 1) and the inlet velocity of the gas to be cleaned. This is in agreement, mainly, with the connection between the main dimensions of the cyclone and its pressure drop.
In the present paper, an appropriate methodology for the constructive design of a cyclone with

larger geometric dimensions, established as a result of the functional analysis, is used. As a study hypothesis, the joint between the cleaned gas exhaust tube and the large plate is considered. In this case, it is assumed that the stresses developed at the edges of the plate do not influence each other.

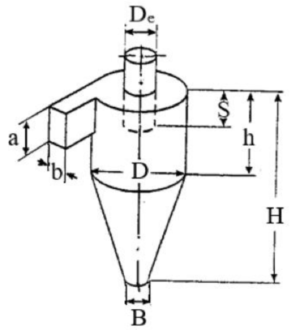

Fig. 1. Cyclone construction and characteristics [5]

2. Study hypotheses

As can be seen in figure 2. a, a practical way of fixing the exhaust tube of the cleaned gas discharged from the cyclone is that of a flat plate, fixed by welding to the outer cylindrical body of the cyclone.
In order to be able to evaluate the stress states in the areas with discontinuities of the structure analyzed in the present case, some appropriate study hypotheses are considered. Thus:
a) The constructive elements are made of homogeneous metallic material, joined by welding (the values of the longitudinal elasticity modules can be considered different or equal: $E_1 = E_2 = E_3 = E$; the values of the transverse contraction coefficients can be considered different or equal: $\mu_1 = \mu_2 = \mu_3 = \mu$).
b) The stress is considered in the elastic domain.
c) The working temperatures are considered to be different, within the calculation relationships. If it is estimated that the differences are insignificant, during the calculation the values of the thermal gradients are easily equalized ($\Delta T_1 = \Delta T_2 = \Delta T_3 = \Delta T$). In this vein, thermal deformation factors can be taken into account $\alpha_1 = \alpha_2 = \alpha_3 = \alpha_4$, with different values for construction materials or for special thermal regimes.
d) Constructive elements 1 and 3 are considered to be longer than the values of the half-wave $h_1 < \ell_{sc1} \approx 1,77 \cdot \sqrt{D_{m1} \cdot \delta_1}$; $h_3 < \ell_{sc3} \approx 1,77 \cdot \sqrt{D_{m3} \cdot \delta_3}$; $h_1, h_3 -$ lengths/heights of constructive elements 1 and 3; $l_{sc1}, l_{sc3} -$ the half-wave lengths of the two cylindrical portions 1 and 3; $D_{m1}, D_{m3} -$ the average diameters of elements 1 and 3; ($D_{m1} = D_{i1} + \delta_1$; $D_{m3} = D_{i3} + \delta_1$; $D_{i1} = D_{i3} -$ (inner diameters of tubes 1 and 3; $\delta_1, \delta_3 -$ thicknesses of tubes 1 and 3 (in general, $\delta_1 = \delta_3$,since only one tube is used). Having the same geometry of constructive elements 1 and 3 (fig. 2), the cylindrical stiffnesses are equal $\Re_1 = \Re_3$.
2) It is considered that the flat plate 2 (fig. 2) has a thickness greater than the wall thickness of the purified gas exhaust tube.

3. Continuity equations of deformations. Connection loads

Notations

Q_{01}, Q_{02} – unitary bond shear forces (fig. 2); M_{01}, M_{02} – radial bending moments, unitary (fig. 2); $R_{m1} = 0,5 \cdot \left(D_{i1} + \delta_1 \right) = R_{m3}$; $\overline{P}_1, \overline{P}_2 -$ unitary axial forces distributed along the median circumferences of the dust exhaust tube; p_1, p_2 – pressure distributed inside the dust exhaust tube, respectively on the outer surface, located inside the cyclone; $R_{m4} = 0,5 \cdot \left(D_{i4} + \delta_4 \right)$ – the average radius of the cylindrical element 4; D_{i4}, δ_4 – the inner diameter of the outer body of the cyclone, respectively the thickness of its wall; $k_j, \Re_j$ – factors for mitigating the intensity of the connection loads along the corresponding cylindrical ferrules, respectively the cylindrical stiffnesses of the mentioned ferrules (usually $k_1 = k_3$; $\Re_1 = \Re_3$).

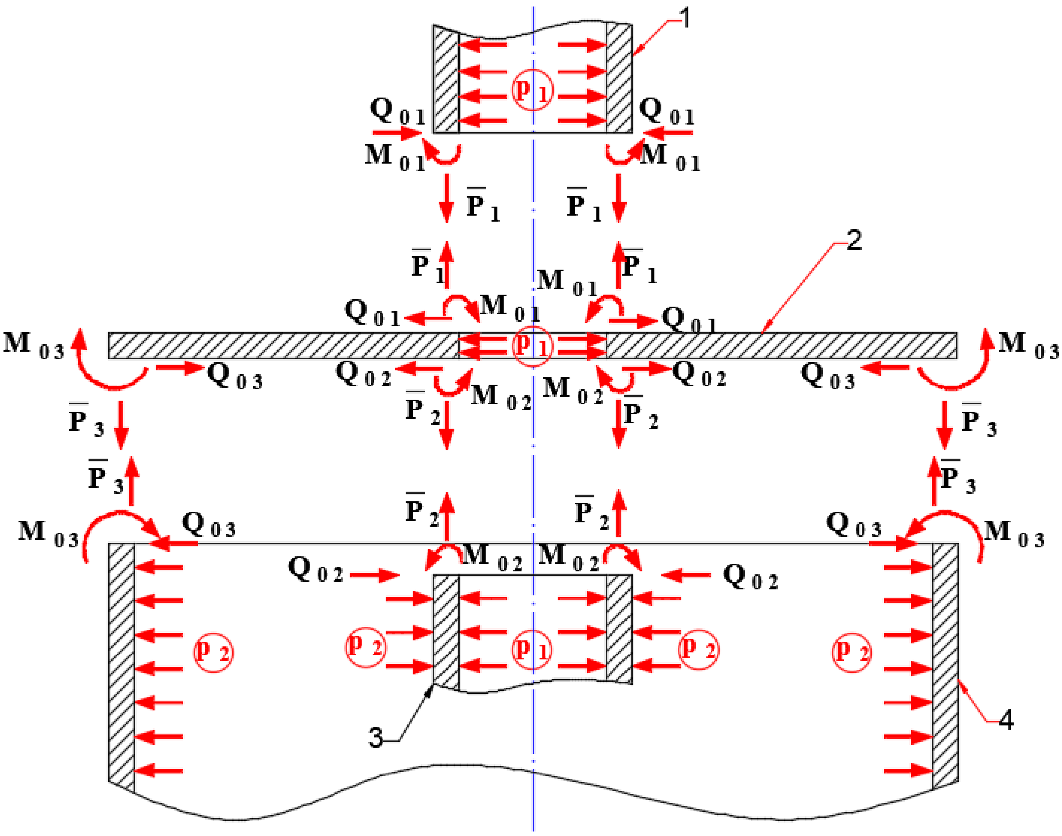

Fig. 2. The joint of the exhaust tube of the purified gas from the cyclone with the cover of the outer body
1- the upper (outer) part of the gas exhaust tube; 2 – flat tube fixing plate; 3 – the inner part of the cleaned gas exhaust tube; 4- the outer cylindrical body of the cyclone

Writing the continuity equations of radial deformations and rotations for elements 1 and 2, respectively 2 and 3, results the algebraic system written in the form:

$$[A] \cdot \{ S_l \} = \{ T_l \}, \tag{1}$$

where the determinant of ***influencing factors*** has the form:

$$[A] = \begin{bmatrix} a_{11} & a_{12} & a_{13} & a_{14} \\ a_{21} & a_{22} & a_{23} & a_{24} \\ a_{31} & a_{32} & a_{33} & a_{34} \\ a_{41} & a_{42} & a_{43} & a_{44} \end{bmatrix}; \tag{2}$$

vector (transposed) of connection loads: $a_{ij}\,(i=1,\ldots 4;\; j=1,\ldots 4)$:

$$\{S_l\} = \{Q_{01}\;\; M_{01}\;\; Q_{02}\;\; M_{02}\}^T; \tag{3}$$

vector (transposed) ***of free terms***: $b_j\,(j=1,\ldots 4)$:

$$\{T_l\} = \{b_1\;\; b_2\;\; b_3\;\; b_4\}^T. \tag{4}$$

From the equation (1), the values of the connection loads are inferred, in the form:

$$\{S_l\} = [A]^{-1}\cdot\{T_l\}, \tag{5}$$

where $[A]^{-1}$ represents the inverse of the determinant of the influencing factors (the value of the determinant is not null).
Expressions of influencing factors are presented as:

$$a_{11} = \frac{1}{2\cdot k_1^3\cdot\mathfrak{R}_1} + \frac{1}{4}\cdot\delta_2^2\cdot f_{jMR_{m1}} - \frac{1}{\delta_2}\cdot R_{m1}\cdot c_{1p_r};\quad a_{12} = -\frac{1}{2\cdot k_1^2\cdot\mathfrak{R}_1} - \frac{1}{2}\cdot\delta_2\cdot f_{jMR_{m1}};$$

$$a_{13} = -\frac{1}{4}\cdot\delta_2^2\cdot f_{jMR_{m1}} - \frac{1}{\delta_2}\cdot R_{m1}\cdot c_{1p_r};\; a_{14} = \frac{1}{2}\cdot\delta_2\cdot f_{jMR_{m1}};\; a_{21} = \frac{1}{2\cdot k_1^2\cdot\mathfrak{R}_1} - \frac{1}{2}\cdot\delta_2\cdot f_{jMR_{m1}};$$

$$a_{22} = -\frac{1}{k_1\cdot\mathfrak{R}_1} + f_{jMR_{m1}};\; a_{23} = \frac{1}{2}\cdot\delta_2\cdot f_{jMR_{m1}};$$

$$a_{24} = -f_{jMRm1};\; a_{31} = \frac{1}{4}\cdot\delta_2^2\cdot f_{jMR_{m1}} + \frac{1}{\delta_2}\cdot c_{1p_r}\cdot R_{m1};\; a_{32} = -\frac{1}{2}\cdot\delta_2\cdot f_{jMR_{m1}}; \tag{6}$$

$$a_{33} = -\frac{1}{2\cdot k_1^3\cdot\mathfrak{R}_1} - \frac{1}{4}\cdot\delta_2^2\cdot f_{jMR_{m1}} + \frac{1}{\delta_2}\cdot R_{m1}\cdot c_{1p_r};\; a_{34} = \frac{1}{2\cdot k_1^2\cdot\mathfrak{R}_1} + \frac{1}{2}\cdot\delta_2\cdot f_{jMR_{m1}};$$

$$a_{41} = \frac{1}{2}\cdot\delta_2\cdot f_{jMR_{m1}};\; a_{42} = -f_{jMR_{m1}};\; a_{43} = -\frac{1}{2}\cdot\delta_2\cdot f_{jMR_{m1}} - \frac{1}{2\cdot k_1^2\cdot\mathfrak{R}_1};$$

$$a_{44} = f_{jMR_{m1}} + \frac{1}{k_1\cdot\mathfrak{R}_1}.$$

The expressions of the free terms (radial displacements: b_1, b_3 ; rotations: b_2, b_4):

$$b_1 = \frac{(4-\mu_1)\cdot p_1}{16\cdot k_1^4\cdot\mathfrak{R}_1} + \frac{E_1\cdot\alpha_1\cdot\delta_1}{4\cdot k_1^4\cdot\mathfrak{R}_1\cdot R_{m1}}\cdot\Delta T_1 + \frac{1}{2}\cdot\delta_2\cdot F_i(p_1, p_2) - \frac{1}{2}\cdot\delta_2\cdot c_{kp_2}\cdot p_2 +$$

$$+\left(c_{1p_r}\cdot p_1 - c_{2p_r}\cdot p_2\right)\cdot R_{m1} - C^{\bullet}_{1T}\cdot R_{m1} - \frac{C^{\bullet}_{2T}}{R_{m1}}; \tag{7}$$

$$b_2 = -F_i(p_1, p_2) + c_{kp_2}\cdot p_2; \tag{8}$$

$$b_3 = \frac{(4-\mu_2)}{16\cdot k_1^4\cdot\mathfrak{R}_1}\cdot(p_2 - p_1) - \frac{E_3\cdot\alpha_3\cdot\delta_3}{16\cdot k_3^4\cdot\mathfrak{R}_3\cdot R_{m3}}\cdot\Delta T_3 + \frac{1}{2}\cdot\delta_3\cdot F_i(p_1, p_2) - \frac{1}{2}\cdot\delta_3\cdot c_{kp_2}\cdot p_2 -$$

$$-\left(c_{1p_r}\cdot p_1 - c_{2p_r}\cdot p_2\right)\cdot R_{m3} - \frac{1}{R_{m1}}\cdot c_{5p_r} + \overset{\bullet}{C}_{1T}\cdot R_{m1} + \frac{\overset{\bullet}{C}_{2T}}{R_{m1}}; \tag{9}$$

$$b_4 = F_i\left(p_1, p_2\right) - c_{kp_2}\cdot p_2 . \tag{10}$$

In the previous expressions, auxiliary quantities are used:

$$A_{11} = -\frac{R_{m1}^2}{2\cdot\Re_2}\cdot\left(\frac{1-\mu_2}{1+\mu_2} - \frac{2\cdot R_{m1}^2}{R_{m4}^2 - R_{m1}^2}\cdot ln\frac{R_{m1}}{R_{m4}}\right); \tag{11}$$

$$A_{12} = \frac{R_{m1}^2}{4\cdot\Re_2}\cdot\left(\frac{1-\mu_2}{1+\mu_2} - \frac{2\cdot R_{m1}^2}{R_{m4}^2 - R_{m1}^2}\cdot ln\frac{R_{m1}}{R_{m4}}\right); \tag{12}$$

$$A_{21} = \frac{1}{2\cdot\Re_2}\frac{1+\mu_2}{1-\mu_2}\cdot\frac{R_{m1}^4\cdot R_{m4}^2}{R_{m4}^2 - R_{m1}^2}\cdot ln\frac{R_{m1}}{R_{m4}}; \tag{13}$$

$$A_{22} = -\frac{1}{4\cdot\Re_2}\frac{1+\mu_2}{1-\mu_2}\cdot\frac{R_{m1}^4\cdot R_{m4}^2}{R_{m4}^2 - R_{m1}^2}\cdot ln\frac{R_{m1}}{R_{m4}}; \tag{14}$$

$$F_{1p} = B_1\left(R_{m1}\right) - \frac{1}{2}\cdot R_{m1}\cdot A_{11} - \frac{1}{R_{m1}}\cdot A_{21};\; F_{2p} = B_2\left(R_{m1}\right) - \frac{1}{2}\cdot R_{m1}\cdot A_{12} - \frac{1}{R_{m1}}\cdot A_{22}; \tag{15}$$

$$B_1\left(R_{m1}\right) = -\frac{R_{m1}^3}{4\cdot\Re_2}\cdot\left(ln\frac{R_{m1}}{R_{m4}} - \frac{1}{2}\right); \quad B_2\left(R_{m1}\right) = \frac{R_{m1}^3}{4\cdot\Re_2}\cdot\left(ln\frac{R_{m1}}{R_{m4}} - \frac{1}{2}\right); \tag{16}$$

$$K_1 = -\frac{R_{m1}\cdot R_{m4}^2}{4\cdot\Re_2}\cdot\left[\frac{\left(1+\mu_2\right)\cdot ln\,\beta_2}{\left(1-\mu_2\right)\cdot\left(\beta_2^2-1\right)} + \left(\frac{1}{1+\mu_2} + \frac{\beta_2^2\cdot ln\,\beta_2}{\beta_2^2-1}\right)\cdot\frac{1}{\beta_2^2}\right]; \quad \beta_2 = \frac{R_{m4}}{R_{m1}}; \tag{17}$$

$$K_2 = \frac{R_{m1}\cdot R_{m4}^2}{4\cdot\Re_2}\cdot\left[\frac{\left(1+\mu_2\right)\cdot ln\,\beta_2}{\left(1-\mu_2\right)\cdot\left(\beta_2^2-1\right)} + \left(\frac{1}{1+\mu_2} + \frac{\beta_2^2\cdot ln\,\beta_2}{\beta_2^2-1}\right)\cdot\frac{1}{\beta_2^2}\right]; \tag{18}$$

$$C_{31}\left(R_{m1}\right) = -\frac{R_{m1}^2\cdot R_{m4}^2}{8\cdot\Re_2}\cdot\left[-\frac{2\cdot R_{m4}^2}{R_{m1}^3}\cdot\left(\frac{3+\mu_2}{1+\mu_2} - \frac{2\cdot R_{m1}^2}{R_{m4}^2 - R_{m1}^2}\right) - 4\cdot\frac{1+\mu_2}{1+\mu_2}\cdot\frac{2\cdot R_{m1}}{R_{m4}^2 - R_{m1}^2} - \right.$$
$$\left. -\frac{R_{m4}^2}{R_{m1}^3}\cdot\left(2\cdot ln\,\frac{R_{m4}}{R_{m1}} + 1\right)\right]; \qquad C_{32}\left(R_{m1}\right) = \frac{1}{2}\cdot C_{31}\left(R_{m1}\right); \tag{19}$$

$$c_{1p_2n} = \frac{R_{m4}^4}{16\cdot\Re_2\cdot R_{m1}}\cdot\left[\frac{3}{\beta_2^4} - \frac{3+\mu_2}{1+\mu_2}\cdot\frac{\beta_2^2+1}{\beta_2^4} - \frac{3+\mu_2}{\left(1-\mu_2\right)\cdot\beta_2^2} + 2\cdot\frac{1-\mu_2}{\left(1+\mu_2\right)\cdot\beta_2^4} - \right.$$
$$\left. -\frac{8\cdot\mu_2\cdot ln\,\beta_2}{\beta_2^2\cdot\left(\beta_2^2-1\right)\cdot\left(1-\mu_2\right)}\right]; \tag{20}$$

$$c_{3p_2n}=\frac{R_{m4}^2}{16\cdot\Re_2}\cdot\left[\frac{1}{1+\mu_2}\cdot\left(3+\mu_2-\frac{4}{\beta_2^2}+k\right)\cdot\frac{1}{\beta_2}-\frac{1}{\beta_2^2}+\right.$$

$$\left.+\frac{k}{1-\mu_2}\cdot\beta_2+\frac{4}{\beta_2^3}\cdot ln\,\beta_2\right];\ k=\frac{1}{\beta_2^2}\cdot\left[3+\mu_2-4\cdot\left(1+\mu_2\right)\cdot\frac{ln\,\beta_2}{\beta_2^2-1}\right];\tag{21}$$

$$f_{1MR_{m1}}=\frac{R_{m4}^2}{\left(\beta_2^2-1\right)\cdot\Re_2\cdot R_{m1}}\cdot\left[\frac{1}{\left(1+\mu_2\right)\cdot\beta_2^2}+\frac{1}{1-\mu_2}\right];\tag{22}$$

$$f_{2MR_{m1}}=\frac{R_{m4}}{\left(\beta_2^2-1\right)\cdot\left(1+\mu_2\right)\cdot\Re_2}\cdot\left(\frac{R_{m1}}{R_{m4}}+\frac{1+\mu_2}{1-\mu_2}\cdot\frac{R_{m4}}{R_{m1}}\right);\tag{23}$$

$$c_{1p_r}=-\frac{1-\mu_2}{E_2}\cdot\frac{R_{m1}^2}{R_{m4}^2-R_{m1}^2};\ c_{2p_r}=-c_{1p_r};\ c_{3p_r}=\frac{1}{\delta_2}\cdot c_{1p_r};\tag{24$_1$}$$

$$c_{4p_r}=-\frac{1-\mu_2}{E_2}\cdot\frac{R_{m4}^2}{\left(R_{m4}^2-R_{m1}^2\right)\cdot\delta_2};\ c_{5p_r}=-\frac{1+\mu_2}{E_2}\cdot\frac{R_{m4}^2\cdot R_{m1}^2}{R_{m4}^2-R_{m1}^2}.\tag{24$_2$}$$

$$C_{1T}^{\bullet}=\frac{1}{R_{m4}^2-R_{m1}^2}\cdot\left(-R_{m1}^2\cdot B_{1T}+R_{m4}^2\cdot B_{2T}\right);\ C_{2T}^{\bullet}=\frac{R_{m1}^2\cdot R_{m4}^2}{R_{m4}^2-R_{m1}^2}\cdot\left(B_{1T}-B_{2T}\right);\tag{25}$$

$$B_{1T}=\frac{1}{4\cdot k_1\cdot\Re_1}\cdot\frac{E_1\cdot\alpha_1\cdot\delta_1}{R_{m1}^2}\cdot\Delta T_1;\tag{26}$$

$$B_{2T}=\frac{1}{2\cdot R_{m4}^2}\cdot\left[\left(1+\mu_2\right)\cdot\left(R_{m4}^2-R_{m1}^2\right)\cdot\alpha_2\cdot\Delta T_2\right]+\frac{E_4\cdot\alpha_4\cdot\delta_4}{2\cdot k_4\cdot\Re_4}\cdot\Delta T_4;\tag{27}$$

$$\overline{P}_1=\frac{D_{i1}^2}{4\cdot D_{m1}}\cdot p_1;\ \overline{P}_2=\frac{D_{i3}^2}{4\cdot D_{m3}}\cdot p_2=\frac{D_{i1}^2}{4\cdot D_{m1}}\cdot p_2;\tag{28}$$

$$k_j=\sqrt[4]{3\cdot\left(1-\mu_j^2\right)}\Big/\sqrt{R_{mj}\cdot\delta_j};\ \Re_j=\frac{E_j\cdot\delta_j^3}{12\cdot\left(1-\mu_j^2\right)};\ j=1,3,4.\tag{29}$$

Note: The following bibliographic sources and the expressions specified above were used for writing the radial deformations and rotations:

a. 1 - *the effect of unitary axial forces,* $\overline{P}_1, \overline{P}_2$ uniformly distributed on the inner contour of plate 2 (fig. 4. 5) is introduced by means of the expression:

$F_i\left(p_1, p_2\right)$, choosing $F_{i1}\left(p_1, p_2\right)$ or $F_{i2}\left(p_1, p_2\right)$ or $F_{i3}\left(p_1, p_2\right)$,

where:

$F_{i1}\left(p_1, p_2\right)=F_{1p}\cdot p_1+F_{2p}\cdot p_2-$ variant I [1, 44, 47, 48];

$F_{i2}\left(p_1, p_2\right)=K_1\cdot p_1+K_2\cdot p_2-$variant II [44, 49, 50];

$F_{i3}\left(p_1, p_2\right)=C_{31}\left(R_{m1}\right)\cdot p_1+C_{32}\left(R_{m1}\right)\cdot p_2$ - variant III [44, 51];

b. 1 - *the effect of the uniformly distributed pressure on the lower surface of the plate 2, at the level of the inner circumference*, is appreciated by means of the quantity:

$$c_k(p_2)\text{, choosing } c_1(p_2) \text{ or } c_2(p_2),$$

where:

$c_1(p_2) = c_{1p_2n}$ - variant I [44, 49, 50, 52];

$c_2(p_2) = c_{3p_2n}$ - variant II [44, 51, 53, 54];

c. 1 - *the simultaneous effect of the unit radial moments developed by M_{01}, M_{02} and by the unit cutting forces* Q_{01}, Q_{02}, along the circumference of radius R_{m1}, is included by means of the quantities:

$$f_{jMR_{m1}}\text{, choosing } f_{1MR_{m1}} \text{ or } f_{2MR_{m1}},$$

where:

$f_{1MR_{m1}}$ - variant I **[44, 49, 50]**;

$f_{2MR_{m1}}$ - variant II **[44, 51, 53, 54]**;

d. 1 - *the simultaneous effect of the radial pressure developed on the inner surface of the plate 2 by the unitary pressures* p_1, p_2 and shearing forces Q_{01}, Q_{02} is included by means of the quantities $c_{1p_r}, c_{2p_r}, c_{3p_r}, c_{4p_r}, c_{5p_r}$ [44];

e. 1 - *the temperature effect*, developed in the form of radial displacement, is illustrated by the quantities $C^{\bullet}_{1T}, C^{\bullet}_{2T}$ [44, 55].

4. Stress states

Radial and annular stresses

Notations:

$(\sigma_1)_{jx}, (\sigma_2)_{jx}$ – radial and annular stresses for the cylindrical element $j = 1, 3$; $\left[(\sigma_1)_{1x}\right]_{p_1,\Delta T_1}, \left[(\sigma_2)_{1x}\right]_{p_1,\Delta T_1}$ – the radial and annular stresses developed by the pressure p_1 and the thermal gradient ΔT_1, specific to the cylindrical element 1; $(c_{i\sigma r})_{jx}$, $(c_{i\sigma i})_{jx}$ - influence factors for the radial and radial stresses developed in the cylindrical elements 1 and 3 ($j = 1, 3$); $\left[(\sigma_1)_{3x}\right]_{p_1,p_2,\Delta T_1}, \left[(\sigma_2)_{3x}\right]_{p_1,p_2,\Delta T_1}$ – the radial and annular stresses developed by the pressures p_1, p_2 and the thermal gradient ΔT_3, specific to the cylindrical element 3; M_{1x}, Q_{1x}, T_{1x} – the radial, unitary bending moment, the unitary shearing force and the unitary annular force, dependent on the current distance x_1, along the cylindrical element 1, under the action of the connection loads M_{01} and Q_{01} (fig. 2); M_{3x}, Q_{3x}, T_{3x} – the unitary radial bending moment, the unitary shear force and the unitary annular force, dependent on the current distance x_3, along the cylindrical element 3, under the action of the connection loads M_{02} and Q_{02} (fig. 2).

Note: After solving the equality (5), the signs of the connection loads are analyzed. If the sign is

negative, proceed to a new representation in figure 2, so that, further, it can be correctly established which are the mechanically most demanding surfaces. It is desirable that the maximum demands exist on the surfaces that do not come into direct contact with the working agents.
Next, we move on to the assessment of the *radial and annular stresses*, along the sections of the tube for the clean gas evacuation, for a flat state of static stress.

Action of external loads

The radial σ_1 and annular σ_2 stresses, constant along the length of cylindrical elements 1 and 3 (fig. 2), have the forms:

- *For the cylindrical element 1* (fig. 2):

$$\left[(\sigma_1)_{1x}\right]_{p_1,\Delta T_1} = \left[(\sigma_1)_{1x}\right]_{p_1} + \left[(\sigma_1)_{1x}\right]_{\Delta T_1} = p_1 \cdot R_{m1} \big/ (2 \cdot \delta_1) + E_1 \cdot \alpha_1 \cdot \Delta T_1 ; \quad (30)_1$$

$$\left[(\sigma_2)_{1x}\right]_{p_1,\Delta T_1} = \left[(\sigma_2)_{1x}\right]_{p_1} + \left[(\sigma_2)_{1x}\right]_{\Delta T_1} = p_1 \cdot R_{m1} \big/ \delta_1 + E_1 \cdot \alpha_1 \cdot \Delta T_1 ; \quad (30)_2$$

$$\left[(\sigma_2)_{1x}\right]_{p_1} = 2 \cdot \left[(\sigma_1)_{1x}\right]_{p_1} . \quad \left[(\sigma_1)_{1x}\right]_{\Delta T_1} = \left[(\sigma_2)_{1x}\right]_{\Delta T_1} = E_1 \cdot \alpha_1 \cdot \Delta T_1 . \quad (30)_3$$

- *For the cylindrical element 3* (fig. 2):

$$\left[(\sigma_1)_{3x}\right]_{p_1,p_2,\Delta T_1} = \left[(\sigma_1)_{3x}\right]_{p_1,p_2} + \left[(\sigma_1)_{3x}\right]_{\Delta T_3} = (p_1 - p_2) \cdot R_{m3} \big/ (2 \cdot \delta_3) + E_3 \cdot \alpha_3 \cdot \Delta T_3 ; \quad (31)_1$$

$$\left[(\sigma_2)_{3x}\right]_{p_1,p_2,\Delta T_1} = \left[(\sigma_2)_{3x}\right]_{p_1,p_2} + \left[(\sigma_2)_{3x}\right]_{\Delta T_1} = (p_1 - p_2) \cdot R_{m3} \big/ \delta_3 + E_3 \cdot \alpha_3 \cdot \Delta T_3 ; \quad (31)_2$$

$$\left[(\sigma_2)_{3x}\right]_{p_1,p_2} = 2 \cdot \left[(\sigma_1)_{3x}\right]_{p_1,p_2} ; \quad \left[(\sigma_1)_{3x}\right]_{\Delta T_1} = \left[(\sigma_2)_{3x}\right]_{\Delta T_1} = E_3 \cdot \alpha_3 \cdot \Delta T_3 . \quad (31)_3$$

Action of the connection loads

In this case, the variation of the connection loads, calculated in the separation planes of the constructive elements (cylindrical elements and flat plate), have the forms [4, 5]:

- ***For the cylindrical element 1*** (fig. 2):

$$M_{1x} = M_{01} \cdot (f_4)_{1x} - (1/k_1) \cdot Q_{01} \cdot (f_2)_{1x} ; \quad (32)_1$$

$$Q_{1x} = 2 \cdot k_1 \cdot M_{01} \cdot (f_2)_{1x} - Q_{01} \cdot (f_3)_{1x} ; \quad (32)_2$$

$$T_{1x} = 2 \cdot k_1 \cdot R_{m1} \cdot \left[k_1 \cdot M_{01} \cdot (f_3)_{1x} - Q_{01} \cdot (f_1)_{1x} \right], \quad (32)_3$$

where:

$$(f_1)_{1x} = e^{-k_1 \cdot x_1} \cdot cos\,(k_1 \cdot x_1) ; \; (f_2)_{1x} = e^{-k_1 \cdot x_1} \cdot sin\,(k_1 \cdot x_1) ; \quad (32)_4$$

$$(f_3)_{1x} = e^{-k_1 \cdot x_1} \cdot \left[cos\,(k_1 \cdot x_1) - sin\,(k_1 \cdot x_1) \right] = (f_1)_{1x} - (f_2)_{1x} ; \quad (32)_5$$

$$(f_4)_{1x} = e^{-k_1 \cdot x_1} \cdot \left[cos\,(k_1 \cdot x_1) + sin\,(k_1 \cdot x_1) \right] = (f_1)_{1x} - (f_2)_{1x} . \quad (32)_6$$

For the cylindrical element 3 (fig. 2):

$$M_{3x} = M_{02}\cdot(f_1)_{3x} - (1/k_3)\cdot Q_{02}\cdot(f_2)_{3x}; \qquad (33)_1$$

$$Q_{3x} = 2\cdot k_3\cdot M_{02}\cdot(f_2)_{3x} - Q_{02}\cdot(f_3)_{3x}; \qquad (33)_2$$

$$T_{3x} = 2\cdot k_3\cdot R_{m3}\cdot\left[k_3\cdot M_{02}\cdot(f_3)_{3x} - Q_{02}\cdot(f_1)_{3x}\right], \qquad (33)_3$$

where:

$$(f_1)_{3x} = e^{-k_3\cdot x_3}\cdot cos\,(k_3\cdot x_3);\ (f_2)_{3x} = e^{-k_3\cdot x_3}\cdot sin\,(k_3\cdot x_3); \qquad (33)_4$$

$$(f_3)_{3x} = e^{-k_3\cdot x_3}\cdot\left[cos\,(k_3\cdot x_3) - sin\,(k_3\cdot x_3)\right] = (f_1)_{3x} - (f_2)_{3x}; \qquad (33)_5$$

$$(f_4)_{3x} = e^{-k_3\cdot x_3}\cdot\left[cos\,(k_3\cdot x_3) + sin\,(k_3\cdot x_3)\right] = (f_1)_{3x} + (f_2)_{3x}, \qquad (33)_6$$

the current elevations x_1 and x_3 being measured along cylindrical elements 1 and 3, starting from the separation planes with plate 2 (fig. 2).

The expressions of the radial and annular stresses developed by the connection loads along the cylindrical elements have the following forms:

- ***For the cylindrical element 1*** (fig. 2):

$$\left\{(\sigma_1)_{1x};(\sigma_2)_{1x}\right\} = \left\{\left[(\sigma_1)_{1x}\right]_{p_1,\Delta T_1}\cdot\left(c_{i\sigma r}\right)_{1x};\ \left[(\sigma_2)_{1x}\right]_{p_1,\Delta T_1}\cdot\left(c_{i\sigma i}\right)_{1x}\right\}; \qquad (34)_1$$

$$\left(c_{i\sigma r}\right)_{1x} = 1 + \left\{\left(\pm 6\cdot M_{1x}/\delta_1^2\right)\Big/\left[p_1\cdot R_{m1}/(2\cdot\delta_1) + E_1\cdot\alpha_1\cdot\Delta T_1\right]\right\}; \qquad (34)_2$$

$$\left(c_{i\sigma i}\right)_{1x} = 1 + \left\{\left[\pm 6\cdot\mu_1\cdot M_{1x}/\delta_1^2 + T_{1x}/\delta_1\right]\Big/\left[p_1\cdot R_{m1}/\delta_1 + E_1\cdot\alpha_1\cdot\Delta T_1\right]\right\}. \qquad (34)_3$$

- ***For the cylindrical element 3*** (fig. 2):

$$\left\{(\sigma_1)_{3x},(\sigma_2)_{3x}\right\} = \left\{\left[(\sigma_1)_{3x}\right]_{p_1,p_2,\Delta T_3}\cdot\left(c_{i\sigma r}\right)_{3x},\ \left[(\sigma_2)_{3x}\right]_{p_1,p_2,\Delta T_3}\cdot\left(c_{i\sigma i}\right)_{3x}\right\}; \qquad (35)_1$$

$$\left(c_{i\sigma r}\right)_{3x} = 1 + \left\{\left[\pm 6\cdot M_{3x}/\delta_3^2\right]\Big/\left[(p_1 - p_2)\cdot R_{m3}/(2\cdot\delta_3) + E_3\cdot\alpha_3\cdot\Delta T_3\right]\right\}; \qquad (35)_2$$

$$\left(c_{i\sigma i}\right)_{3x} = 1 + \left\{\left[\pm 6\cdot\mu_3\cdot M_{3x}/\delta_3^2 + T_{3x}/\delta_3\right]\Big/\left[(p_1 - p_2)\cdot R_{m3}/\delta_3 + E_3\cdot\alpha_3\cdot\Delta T_3\right]\right\}. \qquad (35)_3$$

Note: The plus sign in equations $(33)_{2,3}$ and $(35)_{2,3}$ is taken into account for the inner surfaces of the cylindrical components $j = 1, 3$ (fig. 2), according to the scheme accepted for the study.

In the sense of the above, the variations of the functions M_{1x}, T_{1x}, respectively M_{3x}, T_{3x} must be analyzed. The sections where these sizes are maximum are positioned, reflecting the bending stress (M_{1x}, M_{3x}), respectively the tension/compression stress in the annular direction (T_{1x}, T_{3x}). The elevations are deduced (x_{1M} - for the radial, unitary moment M_{1x} and x_{1T} - for the unitary annular force T_{1x}); (x_{3M} - for the radial unit bending moment M_{3x} and x_{3T} - for the annular unit force T_{3x}):

$$\left\{ x_{1M,}\ x_{1T} \right\} = \frac{1}{k_1} \cdot \left\{ arctg\left(\frac{Q_{01}}{Q_{01} - 2 \cdot k_1 \cdot M_{01}} \right); arctg\left(\frac{2 \cdot k_1 \cdot M_{01} - Q_{01}}{Q_{01}} \right) \right\}, \quad (36)_1$$

$$\left\{ x_{3M,}\ x_{3T} \right\} = \frac{1}{k_3} \cdot \left\{ arctg\left(\frac{Q_{02}}{Q_{02} - 2 \cdot k_3 \cdot M_{02}} \right); arctg\left(\frac{2 \cdot k_3 \cdot M_{02} - Q_{02}}{Q_{02}} \right) \right\}. \quad (36)_2$$

Equivalent stresses

Notations

$\left[\left(\sigma_{ech} \right)_{1x} \right]_{p_1, \Delta T_1}$, $\left[\left(\sigma_{ech} \right)_{3x} \right]_{p_1, p_2, \Delta T_3}$- equivalent stresses evaluated according to the pressures acting on the cylindrical elements 1 and 3 and the corresponding thermal gradients, as external loads with constant values; $\left[\left(\sigma_{ech} \right)_{1x} \right]_{p_1}$, $\left[\left(\sigma_{ech} \right)_{1x} \right]_{p_1, p_2}$ – equivalent stresses established based on the thermal effect of elements 1 and 3; $\left[\left(\sigma_{ech} \right)_{1x} \right]_{M_{1x}, T_{1x}}$, $\left[\left(\sigma_{ech} \right)_{1x} \right]_{M_{3x}, T_{3x}}$ - equivalent stresses evaluated in relation to the unit radial moments M_{1x} and M_{3x}, respectively the tensile/compressive unit forces T_{1x} and T_{3x}; $\left\{ \left(\sigma_{ech} \right)_{1x} \right\}_{max}$, $\left\{ \left(\sigma_{ech} \right)_{3x} \right\}_{max}$ - total equivalent stresses, calculated by summing the influences given by the external and connecting loads; σ_{1a}, σ_{3a} - the admissible resistance of the material of cylinder 1 or 3 ((fig. 2); , $\left(\sigma^{\bullet}_{ech} \right)_{1x}$, $\left(\sigma^{\bullet}_{ech} \right)_{3x}$ - equivalent stresses calculated with the influence of unit shearing forces Q_{1x} and Q_{3x}; $\left[\left(\sigma^{\bullet\bullet}_{ech} \right)_{1x} \right]_{max}$, $\left[\left(\sigma^{\bullet\bullet}_{ech} \right)_{3x} \right]_{max}$- maximum equivalent stresses calculated with the influence of pressure, temperature, unit radial bending moment, of the bond shear forces and of the shear given by the connection unit shear forces (individual effects).

Equivalent stresses developed by external loads – constants

In the context of the assumption that the pressures and thermal gradients - external loads - are constant values along the cylindrical elements 1 and 3, the equivalent stresses, in this case, are not dependent on the elevation (the theory of the energy of shape variation is taken into account - (***Huber– Hencky – Mises*** variants) [54, 56]:

- ***<u>For the cylindrical element 1</u>*** (fig. 2):

$$\left[\left(\sigma_{ech} \right)_{1x} \right]_{p_1, \Delta T_1} = \sqrt{ \begin{array}{c} \left[\left(\sigma_1 \right)_{1x} \right]^2_{p_1, \Delta T_1} + \left[\left(\sigma_2 \right)_{1x} \right]^2_{p_1, \Delta T_1} - \\ - \left[\left(\sigma_1 \right)_{1x} \right]_{p_1, \Delta T_1} \cdot \left[\left(\sigma_2 \right)_{1x} \right]_{p_1, \Delta T_1} \end{array} }; \quad (37)_1$$

$$\left[\left(\sigma_{ech} \right)_{1x} \right]_{p_1, \Delta T_1} = \sqrt{ \begin{array}{c} 3 \cdot \left[p_1 \cdot R_{m1} / \left(2 \cdot \delta_1 \right) \right]^2 + \\ + 3 \cdot \left[p_1 \cdot R_{m1} / \left(2 \cdot \delta_1 \right) \right] \cdot \left(E_1 \cdot \alpha_1 \cdot \Delta T_1 \right) + \left(E_1 \cdot \alpha_1 \cdot \Delta T_1 \right)^2 \end{array} }, \quad (37)_2$$

or, for individual effects:

$$\left[\left(\sigma_{ech}\right)_{1x}\right]_{p_1} = \sqrt{3}\cdot p_1\cdot R_{m1}/\left(2\cdot\delta_1\right);\ \left[\left(\sigma_{ech}\right)_{1x}\right]_{\Delta T_1} = E_1\cdot\alpha_1\cdot\Delta T_1\ . \qquad (37)_3$$

- ***<u>For the cylindrical element 3</u>*** (fig. 2):

$$\left[\left(\sigma_{ech}\right)_{3x}\right]_{p_1,p_2,\Delta T_3} = \sqrt{\begin{array}{l}\left[\left(\sigma_1\right)_{3x}\right]^2_{p_1,p_2,\Delta T_3} + \left[\left(\sigma_2\right)_{3x}\right]^2_{p_1,p_2,\Delta T_3} - \\ -\left[\left(\sigma_1\right)_{3x}\right]_{p_1,p_2,\Delta T_3}\cdot\left[\left(\sigma_2\right)_{3x}\right]_{p_1,p_2,\Delta T_3}\end{array}}\ ; \qquad (37)_4$$

$$\left[\left(\sigma_{ech}\right)_{3x}\right]_{p_1,p_2,\Delta T_3} = \sqrt{\begin{array}{c}3\cdot\left[\left(p_1-p_2\right)\cdot R_{m3}/\left(2\cdot\delta_3\right)\right]^2 + \\ +3\cdot\left[\left(p_1-p_2\right)\cdot R_{m3}/\left(2\cdot\delta_3\right)\right]\cdot\left(E_3\cdot\alpha_3\cdot\Delta T_3\right)+\left(E_3\cdot\alpha_3\cdot\Delta T_3\right)^2\end{array}}\ , \qquad (37)_5$$

or, for individual effects:

$$\left[\left(\sigma_{ech}\right)_{3x}\right]_{p_1,p_2} = \sqrt{3}\cdot\left(p_1-p_2\right)\cdot R_{m3}/\left(2\cdot\delta_3\right);\left[\left(\sigma_{ech}\right)_{3x}\right]_{\Delta T_3} = E_3\cdot\alpha_3\cdot\Delta T_3\ . \qquad (37)_6$$

Equivalent stresses developed by the connection loads

In the present case, it is considered that the connection loads are dependent on the variable length along the considered cylindrical element.

The appropriate relationships are adopted:

- ***<u>For the cylindrical element 1</u>*** (fig. 2):

$$\left(\sigma_{1M}\right)_{1x} = 6\cdot M_{1x}/\delta_1^2;\ \left(\sigma_{2M}\right)_{1x} = \mu_1\cdot\left(\sigma_{1M}\right)_{1x};\left(\sigma_{1T}\right)_{1x} = 0;\left(\sigma_{2T}\right)_{1x} = T_{1x}/\delta_1; \qquad (38)$$

the equivalent stresses existing inside or outside cylinder 1 can be evaluated with relations of the form:

$$\left[\left(\sigma_{ech}\right)_{1x}\right]_{M_{1x},T_{1x}} = \sqrt{\left(\sigma_{1M}\right)^2_{1x} + \left[\left(\sigma_{2M}\right)_{1x} + \left(\sigma_{2T}\right)_{1x}\right]^2 - \left(\sigma_{1M}\right)_{1x}\cdot\left[\left(\sigma_{2M}\right)_{1x} + \left(\sigma_{2T}\right)_{1x}\right]}\ , \qquad (39)$$

respectively:

$$\left[\left(\sigma_{ech}\right)_{1x}\right]_{M_{1x},T_{1x}} = \sqrt{\left(1-\mu_1+\mu_1^2\right)\cdot\left(\sigma_{1M}\right)^2_{1x} + \left(2\cdot\mu_1-1\right)\cdot\left(\sigma_{1M}\right)_{1x}\cdot\left(\sigma_{2T}\right)_{1x}}\ . \qquad (40)$$

In the case of neglecting the effect of the unit stretch/compression force, the following is reached:

$$\left[\left(\sigma_{ech}\right)_{1x}\right]_{M_{1x}} = \left(\sigma_{1M}\right)^2_{1x}\cdot\sqrt{\left(1-\mu_1+\mu_1^2\right)};\ \left[\left(\sigma_{ech}\right)_{1x}\right]_{T_{1x}} = T_{1x}/\delta_1\ . \qquad (41)$$

- ***<u>For the cylindrical element 3</u>*** (fig. 2):

$$\left(\sigma_{1M}\right)_{3x} = 6\cdot M_{3x}/\delta_3^2;\ \left(\sigma_{2M}\right)_{3x} = \mu_3\cdot\left(\sigma_{1M}\right)_{3x};\left(\sigma_{1T}\right)_{3x} = 0;\left(\sigma_{2T}\right)_{3x} = T_{3x}/\delta_3; \qquad (42)$$

the existing equivalent stresses on the inside or outside of cylinder 1 can be evaluated with relations of the as:

$$\left[\left(\sigma_{ech}\right)_{3x}\right]_{M_{3x},T_{3x}}=\sqrt{\left(\sigma_{1M}\right)_{3x}^{2}+\left[\left(\sigma_{2M}\right)_{3x}+\left(\sigma_{2T}\right)_{3x}\right]^{2}-\left(\sigma_{1M}\right)_{3x}\cdot\left[\left(\sigma_{2M}\right)_{3x}+\left(\sigma_{2T}\right)_{3x}\right]}\ , \tag{43}$$

respectively:

$$\left[\left(\sigma_{ech}\right)_{3x}\right]_{M_{3x},T_{3x}}=\sqrt{\left(1-\mu_{3}+\mu_{3}^{2}\right)\cdot\left(\sigma_{1M}\right)_{3x}^{2}+\left(2\cdot\mu_{3}-1\right)\cdot\left(\sigma_{1M}\right)_{3x}\cdot\left(\sigma_{2T}\right)_{3x}}\ . \tag{44}$$

When neglecting the effect of the unit stretching/compression force T_{3x}, the equation is reached:

$$\left[\left(\sigma_{ech}\right)_{3x}\right]_{M_{3x}}=\left(\sigma_{1M}\right)_{3x}^{2}\cdot\sqrt{\left(1-\mu_{3}+\mu_{3}^{2}\right)}\ ;\qquad \left[\left(\sigma_{ech}\right)_{1x}\right]_{T_{3x}}=T_{3x}/\delta_{3}\ . \tag{45}$$

Note: The equivalent stresses developed by the connection loads must be calculated in the planes where they are extreme (expressions (4. 75) $_1$ and (4. 75) $_2$).

Equivalent stresses (with the effect of unit shear forces)

The shear stresses developed by the unit shear forces and unit radial bending moments, for cylindrical elements 1 and 3, can be evaluated with the relation:

$$\left\{\tau_{1x},\tau_{3x}\right\}=\left\{Q_{1x}/\delta_{1}\ ,\ Q_{3x}/\delta_{3}\right\}\ , \tag{46}$$

where Q_{1x} and Q_{3x} have the forms (32) $_2$, (33) $_2$.

When the shear effect is also taken into account, the expression of the equivalent stress changes according to the expression [56]:

$$\left\{\begin{array}{l}\left(\sigma^{\bullet}_{ech}\right)_{1x}\\ \left(\sigma^{\bullet}_{ech}\right)_{3x}\end{array}\right\}=\left\{\begin{array}{l}\sqrt{\left(\sigma_{ech}\right)_{1x}^{2}+3\cdot\tau_{1x}^{2}}\\ \sqrt{\left(\sigma_{ech}\right)_{3x}^{2}+3\cdot\tau_{3x}^{2}}\end{array}\right\}. \tag{47}$$

This time, the influence of the unitary shearing force Q_{1x}- relation (32) $_2$ – respectively Q_{3x} - equality (33) $_2$, in the possible assessment of the maximum values of the equivalent stresses, according to the expressions (38), also intervenes. The estimated sections along cylinders 1 and 3 (fig. 2) can be calculated using the expressions:

$$\left\{\begin{array}{l}x_{1Q}\\ x_{3Q}\end{array}\right\}=\left\{\begin{array}{l}\left(1/k_{1}\right)\cdot arctg\left[\left(k_{1}\cdot M_{01}+Q_{01}\right)/\left(k_{1}\cdot M_{01}\right)\right]\\ \left(1/k_{3}\right)\cdot arctg\left[\left(k_{3}\cdot M_{02}+Q_{02}\right)/\left(k_{3}\cdot M_{02}\right)\right]\end{array}\right\}. \tag{48}$$

Equalities can be used:

$$\left\{\left(\sigma_{ech}\right)_{1x}\right\}_{max}=\left[\left(\sigma_{ech}\right)_{1x}\right]_{p_{1},\Delta T_{1}}+\left[\left(\sigma_{ech}\right)_{1x}\right]_{M_{1x},T_{1x}}+\ \tau_{1x}\ , \tag{49}$$

for cylinder 1, respectively:

$$\left\{\left(\sigma_{ech}\right)_{3x}\right\}_{max}=\left[\left(\sigma_{ech}\right)_{3x}\right]_{p_{1},p_{2},\Delta T_{1}}+\left[\left(\sigma_{ech}\right)_{3x}\right]_{M_{3x},T_{3x}}+\ \tau_{3x}\ , \tag{50}$$

for cylinder 3.

The total equivalent stress can also be evaluated by means of partial equivalent stresses, of the pressure, thermal effect, unit radial bending moments, the unit stretch/compression forces, respectively the shear stresses, written in the following forms:

$$\begin{aligned}\left[\left(\ddot{\sigma}_{ech}\right)_{1x}\right]_{max} &= c_p \cdot \left[\left(\sigma_{ech}\right)_{1x}\right]_{p_1} + c_{\Delta T} \cdot \left[\left(\sigma_{ech}\right)_{1x}\right]_{\Delta T_1} + \\ &+ c_M \cdot \left[\left(\sigma_{ech}\right)_{1x}\right]_{M_{1x}} + c_T \cdot \left[\left(\sigma_{ech}\right)_{1x}\right]_{T_{1x}} + c_Q \cdot \sqrt{3} \cdot \tau_{1x}\,,\end{aligned} \tag{51}$$

for cylinder 1, respectively:

$$\begin{aligned}\left[\left(\ddot{\sigma}_{ech}\right)_{3x}\right]_{max} &= c_p \cdot \left[\left(\sigma_{ech}\right)_{3x}\right]_{p_1, p_2} + c_{\Delta T} \cdot \left[\left(\sigma_{ech}\right)_{1x}\right]_{\Delta T_3} + \\ &+ c_M \cdot \left[\left(\sigma_{ech}\right)_{3x}\right]_{M_{3x}} + c_T \cdot \left[\left(\sigma_{ech}\right)_{3x}\right]_{T_{3x}} + c_Q \cdot \sqrt{3} \cdot \tau_{3x}\,,\end{aligned} \tag{52}$$

for cylinder 3.

In the previous relationships $c_p, c_{\Delta T}, c_M, c_T, c_Q$, are selection factors for the effect of specified loads: pressure/pressures, thermal gradient, unit radial bending moment, unit annular tension/compression force, unit shear force. When the coefficients have values equal to unity, the load effect is present, while when the coefficients have zero values, it is removed.

Note: It is necessary to evaluate the maximum values of the equivalent stresses - the relations (49) and (50), respectively (51) and (52) - on the surfaces of the cylindrical elements 1 and 3, to be compared with the admissible resistance characteristic of the construction materials, under the operating conditions. Thus, $\left\{\left(\sigma_{ech}\right)_{1x}\right\}_{max} \le \sigma_{1a}$ or $\left\{\left(\sigma_{ech}\right)_{3x}\right\}_{max} \le \sigma_{3a}$.

5. Conclusions

In what precedes, the analysis of the stress states developed in the cylindrical sections of the cleaned gas exhaust tube is considered. The two sections can be made of different materials or of the same material, in which case the calculation relationships are adapted accordingly. Working hypotheses, specific to the considered case, are considered. The basic hypothesis, accepted in this case, is that the flat plate of the cyclone, to which the exhaust tube is fixed, is an extended construction (characteristic of supercyclones - large sizes), without mutually influencing the edges, both for deformations and for stresses.

An interesting mention is to introduce into the study the mechanical characteristics of the construction material at the time of the analysis, it being known that the respective values change during the use of the cyclone. Only in this way is a correct evaluation of the prescription of extending the service period of the mechanical structure, or not ($\sigma_{cd} = c_d \cdot \sigma_c$; σ_{cd} – yield limit of the tested material after the period of use; c_d - the degradation factor of the characteristics of the metallic material).

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