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SIMULATION OF THE FLOW COMPRESSED AIR USING THE FANNO`S TRANSFORMATION

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Abstract: The compressed air flow in the pneumatic networks is studied from thermodynamic point of view. Generally speaking, the flow issue is presented as next: knowing the characteristics p_1 (pressure), v_1 (specific volume), T_1 (temperature) and the fluid speed w_1, in the initial section (point 1), of a specific pipe section. It is asked the determination of the *p, v, T* and w characteristics in a certain section. Presuming the compressed air is a monophasic homogeneousness fluid, the conservation laws using allows the determination of the equations that rules the fluid evolution. On the basis of the Fanno flow analysis could be proposed a model for the characteristics *p, v, T, w* values calculation. The proposed model validation is made means the experimental data, obtained through "in situ" exploration of a pneumatic mining network.

Key words: mass flow gas, Fanno transformation, pneumatic network, characteristic parameters.

1.INTRODUCTION

The study of the gas flow in the long pipe networks needs, depending on the requested gasodynamic elements, two approaches:

- admeasurements calculus, when knowing the necessary volumetric flow to be transported on a specific pressure regime, could be established the pipes crossed areas and the necessary loading;
- verification calculus, when knowing the network geometric characteristics (diameters, lengths, roughness, elevation mark, configurations) and the available loading, could be verified the network transport capacity, that is for given p_1, T_1, v_1 parameters and the w_1 gas speed in the initial section of the pipes network, should be calculated the *p, T, v* and *w* parameters values, in some section and, particularly, p_2, T_2, v_2 and w_2, obtained at the network extremity.

2. APPLICATION OF THE EQUATIONS OF BALANCE-SHEETS TO PNEUMATIC NETWORK

A series of characteristics specific for the mining pneumatic networks allow the simplifying of the gasodyinamics's system of equations.

In the structure of the compressed air's transport and distribution networks there are sections of finite length pipes and constant sections. Excepting the lines on the shafts, raises and inclined planes, the sections can be considered horizontal, (the slope on the main galleries being of 4 $^o/_{oo}$). As the flow takes place at temperatures close to the environment's temperature, we can neglect the component in the energetic balance due to the calorific interaction of the system with the outside environment.

The simplifications are refers to:

$$d\Omega = 0;\ \Omega = constant;\ D = constant \tag{1}$$

$$dh = 0;\ h = constant \tag{2}$$

$$\delta q_{ext} = 0 \tag{3}$$

In order to simplify the mathematical expressions, we shall re-write mass balance equation $G = \frac{\pi \cdot D^2}{4} \cdot \frac{w}{v}$ as follows:

$$\frac{w}{v} = c\ ,\ where\ c = \frac{4G}{\pi D^2} \tag{4}$$

By integration of the energetic equation:

$$wdw = \delta q_{ext} - gdh - di \tag{5}$$

between the initial section Ω1 and a certain section Ω, we shall obtain:

$$w = \sqrt{2(i_1 + \frac{w_1^2}{2} - i)}$$

Eliminating directly δl_{fr} between mechanical equations $wdw = -vdp - gdh - \delta l_{fr}$ and specific friction work $\delta l_{fr} = \frac{\lambda}{D} \cdot \frac{w^2}{2} dx$, we obtain the following relation:

$$w\frac{dw}{dx} = -v\frac{dp}{dx} - \frac{\lambda}{D} \cdot \frac{w^2}{2} \qquad (6)$$

In order to be able to complete the system, we must determine the fluid transformation law along the pipe. From the relations (4) and (5), we shall obtain:

$$w = c \cdot v = \sqrt{2(i_1 + \frac{w_i^2}{2} - i)}$$

Realizing this relation between its specific volume v and the enthalpy *i*, the evolution of the fluid takes place according to Fanno's transformation.

Fanno's curve, represented in the dynamic diagram *(p-v)* or in the entropy diagrams *(T-s), (i-s),* are the parametric equations (4) and (5) with *w* as parameter.

There is a double infinity of Fanno's curves, each being determined by the value of the constant *c,* on the one hand and by the sum $i_1 + \frac{w_1^2}{2} = i_1 + \frac{c^2 v_1^2}{2}$, on the other hand.

If the initial status is given, then i_1 and w_1 are known and Fanno's curve only depends on the constant *c.*

The simple infinity of Fanno's curves passing through a point l (representing the initial status) can be easily constructed for a certain fluid on a thermo-dynamic diagram following the itinerary of the lines *v = constant* and *i = constant.*

For each value of *c,* the equations (4) and (5) make for each value of *w* to correspond a line of equal interval *v* and a line of constant enthalpy *i* whose intersection is a point of the curve corresponding to the considered value of *c.* If the fluid is a perfect gas, it is possible to analytically explain Fanno's equation of transformation according to *p* and *v* or according to *i* and *s.* Admitting that the specific isobar heat c_p = *constant,* assuming the validity of Joule's law, the relation (5) can be written as follows:

$$\frac{w^2 - w_1^2}{2} = i_1 - i = c_p(T_1 - T),$$

or, based on the equation of status $p \cdot v = z \cdot R \cdot T$, when *z = 1:*

$$\frac{w^2 - w_1^2}{2} = \frac{c_p}{R}(p_1 v_1 - pv) \ or$$

$$p_1 v_1 - pv = \frac{R}{2c_p}(w^2 - w_1^2) = \frac{Rc^2}{2c_p}(v^2 - v_1^2) = b(v^2 - v_1^2)$$

,where:

$$b = \frac{Rc^2}{2c_p} = \frac{R}{2\frac{k}{k-1}R} \cdot \frac{w_1^2}{v_1^2} = \frac{k-1}{2k} \cdot \frac{w_1^2}{v_1^2} = \frac{k-1}{2k}c^2$$

Therefore the transformation law is expressed by:

$$pv + bv^2 = p_1 v_1 + bv_1^2 = constant, \ or \qquad (7)$$

$$pv(1 + \frac{bv}{p}) = constant \qquad (8)$$

The following fact can be noticed:

$$\frac{bv}{p} = \frac{k-1}{2k} \cdot \frac{w_1^2}{v_1^2} \cdot \frac{v}{p} = \frac{k-1}{2k} \cdot \frac{w^2}{v^2} \cdot \frac{v}{p} = \frac{k-1}{2} \cdot \frac{w^2}{kpv} = \frac{k-1}{2} \cdot \frac{w^2}{a^2} \qquad (9)$$

From the relation (9) we can understand that, when the flow speed *w* is small compared to the sound speed in the fluid, the term $\frac{bv}{p}$ becomes negligible in comparison with the unit and the transformation slightly backs away from the isothermal line.

For

$$w = 5 - 20 m/s, k = 1{,}4, \frac{bv}{p} = 0.000027 - 0.00068$$

3. THE CALCULUS CHARACTERISTIC PARAMETERS USING FANNO`S TRANSFORMATION

As the transformation law is known, we resume the mechanical equation (6) under the form of:

$$d\frac{w^2}{2} = -vdp - \frac{\lambda}{D} \cdot \frac{w^2}{2} dx \qquad (10)$$

and we transform it in order to obtain a relation between *v* and *x.*

From *b*'s expression of definition, we can extract*:*

$w^2 = \frac{2kb}{k-1} v^2$, where $d\frac{w^2}{2} = \frac{2kb}{k-1} vdv$

Based on equation (7), there can be written:

$p = \frac{p_1 v_1 + bv_1^2}{v} - bv$ and

$$dp = \frac{p_1 v_1 + bv_1^2}{v} dv - bdv$$

Eliminating *p* and *w* from (10), we get the following relation:

$$\frac{2kb}{k-1} vdv = \frac{p_1 v_1 + bv_1^2}{v} dv + bvdv - \frac{\lambda}{D} \cdot \frac{kb}{k-1} v^2 dx$$

Dividing by v^2 in order to separate the variables v and x, we shall obtain:

$$b\frac{k+1}{k-1}\cdot\frac{dv}{v}=(p_1v_1+bv_1^2)\frac{dv}{v^3}-\frac{\lambda}{D}\cdot\frac{kb}{k-1}dx$$

Integrating this equation between sections Ω_1 and Ω we shall obtain:

$$b\frac{k+1}{k-1}ln\frac{v}{v_1}=-\frac{p_1v_1+bv_1^2}{2}(\frac{1}{v^2}-\frac{1}{v_1{}^2})-\frac{kb}{k-1}\lambda\frac{x}{D}$$

, *or*

$$\frac{k-1}{2k}(\frac{p_1}{bv_1}+1)(1-\frac{v_1^2}{v^2})-\frac{k+1}{k}ln\frac{v}{v_1}=\lambda\frac{x}{D} \qquad (11)$$

In the above-mentioned equality, we replace the ratio $\frac{v}{v_1}$ with $\frac{w}{w_1}$, according to relation (4) and the fraction $\frac{p_1}{bv_1}$ with the expression (9), so that we obtain:

$$\frac{l}{k}(\frac{a_1^2}{w_1^2}+\frac{k-1}{2})(1-\frac{w_1^2}{w^2})-\frac{k+1}{k}ln\frac{w}{w_1}=\lambda\frac{x}{D} \qquad (12)$$

The ratio of pressures can be calculated using the transformation law (7) knowing the ratio $\frac{v}{v_1}$ that can be calculated with the relation (11):

$\frac{p}{p_1}=\frac{v_1}{v}+\frac{bv_1}{p_1}\frac{v_1}{v}-\frac{bv_1}{p_1}\frac{v}{v_1}$, or replacing $\frac{bv_1}{p_1}$ using equation (9):

$$\frac{p}{p_1}=\frac{v_1}{v}\left[1+\frac{k-1}{2}\frac{w_1^2}{a_1^2}\left(1-\frac{v^2}{v_1^2}\right)\right] \qquad (13)$$

For the temperatures' report, assuming that compressed air is assimilated to a perfect gas we shall have:

$$\frac{T}{T_1}=\frac{p}{p_1}\cdot\frac{v}{v_1} \qquad (14)$$

The relations (12), (13), and (14) allow the construction of the curves representing the variations of v, w, p and T, according to x and to the extreme conditions along the entire pipe network.

4. THE INTERPOLATIONS OF FANNO`S TRANSFORMATION

For a perfect gas, Fanno's transformation can be easily represented in a *T-s* diagram. Considering as variables the temperature T and the specific volume v, the entropy's variation of a perfect gas, starting with its initial l condition, is expressed in the considered temperature interval, assuming that $c_v=$ *constant:*

$$s\text{-}s_1=c_v\,ln\frac{T}{T_1}+R\,ln\frac{v}{v_1}$$

On the other hand, relation (7) can be written as follows:

$$p_1v_1-pv=R(T_1-T)=b(v^2-v_1^2)=bv_1^2\left(\frac{v^2}{v_1^2}-1\right)$$

from where the following results:

$$\frac{v}{v_1}=\sqrt{1+\frac{R(T_1-T)}{bv_1^2}},$$

and in this case the specific entropy's variation becomes:

$$s-s_1=c_v\,ln\frac{T}{T_1}+\frac{R}{2}ln\left[1+\frac{R(T_1-T)}{bv_1^2}\right] \qquad (15)$$

According to this formula, a certain point of Fanno's curve is obtained crossing the point characteristic for the *l* initial status and corresponding to a value given to constant *b,* adding to the right, starting from the curve $v=v_1$ whose equation is:

$\Delta s_v=c_v\,ln\frac{T}{T_1}$, a length equal with $\frac{R}{2}ln\left[1+\frac{R(T_1-T)}{bv_1^2}\right]$

If it is traced in the coordinates *T-s,* starting out from point *l* representing the fluid's initial status, Fanno's curve corresponding to a given value of parameter *c* or *b,* it can be noticed that this curve is entirely comprised between a domain limited by an isothermal line $(T\le T_1')$, an isochore line$(v\le v_{max})$ and an isentropic line $(s\le s_{max})$.

From equation (7) we can notice that the maximum specific volume attained, when $p=0$ and therefore $T=0$, has the value:

$$v_{max}=\sqrt{v_1^2+\frac{p_1v_1}{b}}$$

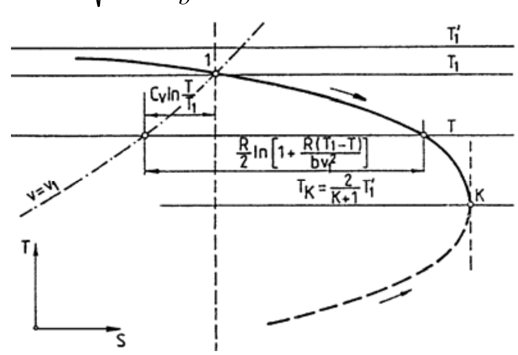

Fig. 1. *The representation in coordinates T-s of Fanno's transformation*

The relation (15) of the entropy's variation highlights the fact that along Fanno's curve the entropy tends towards $-\infty$, when the temperature tends to T_1 value, so that:

$$1+\frac{R\left(T_1-T_1'\right)}{bv_1^2}=0$$

from where we can deduce the fluid's (total) braking temperature's expression when in status l:

$$T_1'=T_1+\frac{bv_1^2}{R}=T_1+\frac{w_1^2}{2c_p} \qquad (16)$$

where: T_1 is the static temperature; $\frac{w_1^2}{2c_p}$ - dynamic temperature.

Fanno's curve asymptotically tends (to high temperatures) to the isothermal line $T_1 = T'_1$. Taking into account the equality (9), the expression of T_1' can be written as follows:

$$T_1'=T_1\left(1+\frac{bv_1^2}{RT_1}\right)=T_1\left(1+\frac{bv_1}{p_1}\right)=T_1\left(1+\frac{k-1}{2}\cdot\frac{w_1^2}{a_1}\right) \qquad (17)$$

There is an isentropic line $s=s_{max}$ tangent to Fanno's curve in the actions inversion point. All isentropic lines for which I intersect the curve in two points, one for $w<a$ and the other one for $w>a$.

The point where the fluid's speed is equal to the local isentropic line's speed of the sound $w=a$ is the contact point of the curve with the isentropic line $s=s_{max}$. The conditions $\delta q_{ext}=0$ and $\delta l_{fr}>0$ involve ds > 0, namely the fluid evolves alongside the curve only in the direction of the increasing entropies.

If initially $w_1 < a_1$, the fluid evolves on the superior part of the curve, in the direction of the temperature's decrease, the increase of velocity realizing through expansion.

If initially $w_1 > a_1$, the fluid evolves on the inferior part of the curve, the decrease of velocity realizing through compression accompanied by the increase of temperature. Both evolutions lead to the same extreme status K characterized by $s=s_{max}$, $w_k=a_k$, p_k, v_k and T_k.

$$\left(M^2-1\right)\cdot\frac{dw}{w}=\frac{d\Omega}{\Omega}-\frac{k-1}{a^2}\cdot\delta q_{ext}-\frac{1}{a^2}\delta l_t- -\frac{k}{a^2}\delta l_{fr}-\frac{dG}{G}-\frac{g}{a^2}dh \qquad (18)$$

Characterizing the analytical expression (18) of the actions inversion law for imposed conditions $\delta q_{ext}=0$, $d\Omega=0$, $dG = 0$ and $dh = 0$, we reach similar conclusions.

Therefore, equation (18) becomes:

$$\left(\frac{w^2}{a^2}-1\right)\frac{dw}{w}=-\left[\frac{1}{v*c_p}\left(\frac{\partial v}{\partial T}\right)_p+\frac{1}{a^2}\right]\delta l_t \qquad (19)$$

Based on the status equation for perfect gases and on the thermal equation, the equality (19) can also be written as follows:

$$\frac{ds}{dw}=-\frac{w^2-a^2}{kwT} \qquad (20)$$

The relations (19) and (20) show that as long as $w < a$, the derivative $\frac{ds}{dw}$ is positive, therefore the entropy of the gas increases. In the point where the flow speed reaches the local isentropic speed of sound $w = a$, the derivative $\frac{ds}{dw}$ cancels, which means that the entropy reaches the maximum value.

If the speed continues to increase beyond the local isentropic speed of sound, $\frac{ds}{dw}<0$ would follow, which means that after reaching the maximum, the entropy should record a decrease. But this comes to contradict that fact that with friction the entropy increases, so that the hypothesis of speed increase over the sound speed does not stand. From the analysis of relation (18) results that in the case of an adiabatic flow with friction in a tube with a constant section, the fluid can be accelerated up to the velocity of sound, but it will not be able to exceed this value as this is conditioned by the release of heat, while friction heat is permanently supplied to the flowing fluid (both in the case of subsonic flow and supersonic flow).

Experience shows that after reaching the critical velocity $w_k = a_k$, the flow, losing its stationary feature, transforms into a pulsatory flow characterized by the gas's successive expansions and contractions. These phenomenon are accompanied by loses if energy and therefore the increase of entropy.
If the amplitude of the oscillations is higher, there may occur breaks of the pipe.

The critical condition is reached after the fluid has covered a certain pipe length – the critical length l_k.

Avoiding the pulsations that accompany the critical condition is accomplished either by ensuring a pipe length inferior to the critical length, or by setting up throttles on the pipe which would diminish the fluid's speed to acceptable values.

5. THE INTERPRETATION OF FANNO`S TRANSFORMATION

The main characteristic measures that interest us in the case of limit status are: T_k, v_k, p_k, w_k and l_k. These characteristics of the limit status can be obtained in various ways:

We equal the angular coefficients corresponding tot the isentropic line and to Fanno's curve in the dynamic diagram *(p-v)*.

$$\frac{dp}{dv} = -k\frac{p}{v} = -\left(\frac{p}{v} + 2b\right)$$

In this situation the parameters p_k and v_k of the limit status are the roots of the following equations:

$$k\frac{p_k}{v_k} = \frac{p_k}{v_k} + 2b \qquad (21)$$

$$p_k v_k + bv_k^2 = p_1 v_1 + bv_1^2 \qquad (22)$$

From equation (21) we have: $(k-1)p_k \cdot v_k = 2bv_k^2$, and based on equation (22):

$(k-1)p_k v_k = 2\left(p_1 v_1 + bv_1^2 - p_k v_k\right)$, or

$(k+1)p_k v_k = 2\left(p_1 v_1 + bv_1^2\right)$

Applying the equation of perfect gases to the critical status, with the help of the braking temperature's expression (16), we shall have:

$$p_k v_k = RT_k = \frac{2}{k+1}\left(p_1 v + bv_1^2\right) = \frac{2R}{k+1}\left(T_1 + \frac{w_1^2}{2c_p}\right)$$

from where the following results:

$$T_k = \frac{2}{k+1}\left(T_1 + \frac{w_1^2}{2c_p}\right) = \frac{2}{k+1}T_1' \qquad (23)$$

We shall obtain a result expressing the fact that function (15), which describes Fanno's transformation in the *T-s* diagram has a maximum for $T = T_k$.

$$\left(\frac{ds}{dT}\right)_k = \frac{c_v}{T_k} - \frac{R}{2\left(\frac{bv^2}{R} + T_1 - T_k\right)} = \frac{c_v}{T_k} - \frac{R}{2\left(T_1' - T_k\right)} = 0$$

$\dfrac{R}{(k-1)T_k} = \dfrac{R}{2\left(T_1' - T_k\right)}$, from where $T_k = \dfrac{2}{k+1}T_1'$ results

By simple substitution operations from equations (21) and (22) we obtain:

$v_k^2 = \left(p_1 v_1 + bv_1^2\right)\dfrac{k-1}{b(k+1)}$ or

$$v_k = \sqrt{\left(p_1 v + bv_1^2\right)\frac{k-1}{b(k+1)}} \qquad (24)$$

$$p_k = \frac{2b}{k-1}v_k = \frac{2b}{k-1}\sqrt{(p_1 v_1 + bv_1^2)\frac{k-1}{b(k+1)}} \qquad (25)$$

Based on the equation of debit conservation we deduce the following:

$$w_k = w_1\frac{v_k}{v_1} = w_1\sqrt{\frac{k-1}{k+1} + \frac{2}{k+1}\cdot\frac{a_1^2}{w_1^2}} \qquad (26)$$

Most of the times, in practical calculations we are interested in the ratios:

$\dfrac{T_k}{T_1}, \dfrac{v_k}{v_1}, \dfrac{p_k}{p_1}$ and $\dfrac{w_k}{w_1}$

$$\frac{T_k}{T_1} = \frac{2}{k+1}\cdot\frac{T_1'}{T_1} = \frac{2}{k+1} + \frac{k-1}{k+1}\cdot\frac{w_1^2}{a_1^2} \qquad (27)$$

$$\frac{v_k}{v_1} = \sqrt{\frac{k-1}{k+1}\left(\frac{p_1}{bv_1} + 1\right)} = \sqrt{\frac{k-1}{k+1}\left(\frac{2}{k-1}\cdot\frac{a_1^2}{w_1^2} + 1\right)} =$$

$$= \sqrt{\frac{k-1}{k+1} + \frac{2}{k+1}\cdot\frac{a_1^2}{w_1^2}} \qquad (28)$$

$$\frac{p_k}{p_1} = \frac{v_k}{v_1}\cdot\frac{w_1^2}{a_1^2} = \frac{w_1^2}{a_1^2}\sqrt{\frac{k-1}{k+1} + \frac{2}{k+1}\cdot\frac{a_1^2}{w_1^2}} =$$

$$= \frac{w_1}{a_1}\sqrt{\frac{k-1}{k+1}\cdot\frac{w_1^2}{a_1^2} + \frac{2}{k+1}} \qquad (29)$$

$$\frac{w_k}{w_1} = \frac{v_k}{v_1} = \sqrt{\frac{k-1}{k+1} + \frac{2}{k+1}\cdot\frac{a_1^2}{w_1^2}} \qquad (30)$$

Identification of equation (25) with equation (9) written for the conditions of the limit point *K* under the form:

$p_k = \dfrac{2b}{k-1}\cdot\dfrac{a_k^2}{w_k^2}v_k$ and $p_k = \dfrac{2b}{k-1}v_k$

leads us to the conclusion that $w_k = a_k$, namely during the critical status, the fluid's speed is equal with the local isentropic speed of sound.

For the calculation of the critical length, we shall use relation (12) put under the following form:

$$\frac{1}{k}\left(\frac{a_1^2}{w_1^2} + \frac{k-1}{2}\right)\left(1 - \frac{w_1^2}{a_k^2}\right) - \frac{k+1}{k}ln\frac{a_k}{w_1} = \lambda\frac{l_k}{D}$$

where from the following results:

$$l_k = \frac{D}{\lambda}\left[\frac{1}{k}\left(\frac{a_1^2}{w_1^2} + \frac{k-1}{2}\right)\left(1 - \frac{w_1^2}{a_k^2}\right) - \frac{k+1}{k}ln\frac{a_k}{w_1}\right] \qquad (31)$$

6. EXAMPLE OF CALCULUS

On the transoms of mining pneumatic network we were determined the characteristic parameters v, w p, T, using MathCad program and initial condition that were determined by measurements.

The used-up equations are the equation of Fanno`s transformation (11), (12), (13), (14).

In the annexes 1 and 2 is presented two examples of the calculus.

We were calculated the critical parameters, for the verification of the relations (27) - (31).

The results are presented in graphic mode in figures 2 and 3 for the selected transoms. Comparing the analytic results with the experimental determinations it was noticed differences of 2-3%.

These differences come from the neglect of some phenomena: heat transfer, miss of pressure due to partially obstructing of section of flow by impurity, miss through leakiness, flange joints.

Example nr.1

$x := 360$

$k := 1.4 \quad a := \frac{k-1}{2\cdot k} \quad a = 0.143 \quad d := \frac{k+1}{k} \quad d = 1.714$

$p1 := 5.945\cdot 10^5 \quad D := 0.2 \quad \lambda := 0.0261 \quad m := \lambda\cdot\frac{x}{D}$

$M := 1.71 \quad v1 := 0.143 \quad m = 46.98$

$n := \frac{4\cdot M}{\pi\cdot(D)^2} \quad n = 54.431 \quad b := \left(\frac{k-1}{2\cdot k}\right)\cdot(n)^2 \quad b = 423.248$

$v := 0.1 \quad c := \left(\frac{p1}{b\cdot v1} + 1\right) \quad c = 9.823\times 10^3$

$$\text{root}\left[a\cdot c - a\cdot c\cdot\frac{(v1)^2}{(v)^2} + d\cdot\ln(v1) - m - d\cdot\ln(v), v\right] = 0.145$$

$w1 := 8.82 \quad a1 := 345 \quad vs := 0.145$

$w := 8.8$

$$\text{root}\left[\frac{1}{k}\cdot\left(\frac{a1^2}{w1^2} + \frac{k-1}{2}\right)\cdot\left(1 - \frac{w1^2}{w^2}\right) - \left(\frac{k-1}{k}\right)\cdot\ln\left(\frac{w}{w1}\right) - \lambda\cdot\frac{x}{D}, w\right] = 9.016$$

Example no.2

$$p := p1\cdot\left(\frac{v1}{vs}\right)\cdot\left[1 + \frac{k-1}{2}\cdot\frac{w1^2}{a1^2}\cdot\left(1 - \frac{vs^2}{v1^2}\right)\right] \qquad p = 5.863\times 10^5$$

$$T1 := 298 \qquad T := T1\cdot\frac{p}{p1}\cdot\frac{vs}{v1} \qquad T = 297.999$$

$$Tk := T1\cdot\left(\frac{2}{k+1} + \frac{k-1}{k+1}\cdot\frac{w1^2}{a1^2}\right) \qquad Tk = 248.366$$

$$vk := v1\cdot\sqrt{\frac{k-1}{k+1} + \frac{2}{k+1}\cdot\frac{a1^2}{w1^2}} \qquad vk = 5.107$$

$$pk := p1\cdot\left(\frac{w1}{a1}\cdot\sqrt{\frac{k-1}{k+1}\cdot\frac{w1^2}{a1^2} + \frac{2}{k+1}}\right) \qquad pk = 1.388\times 10^4$$

$$wk := w1\cdot\sqrt{\frac{k-1}{k+1} + \frac{2}{k+1}\cdot\frac{a1^2}{w1^2}} \qquad wk = 314.961$$

$$lk := \frac{D}{\lambda}\cdot\left[\frac{1}{k}\cdot\left(\frac{a1^2}{w1^2} + \frac{k-1}{2}\right)\cdot\left(1 - \frac{w1^2}{wk^2}\right) - \frac{k+1}{k}\cdot\ln\left(\frac{wk}{w1}\right)\right] \qquad lk = 8.322\times 10^3$$

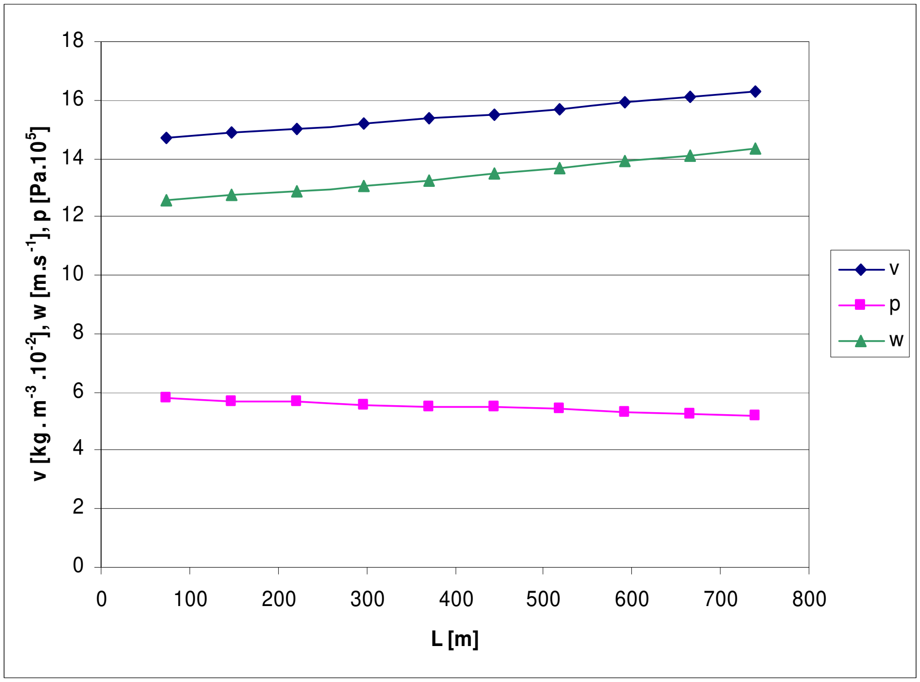

Fig. 3. *The variation of characteristic parameters on a transom of 740 m*

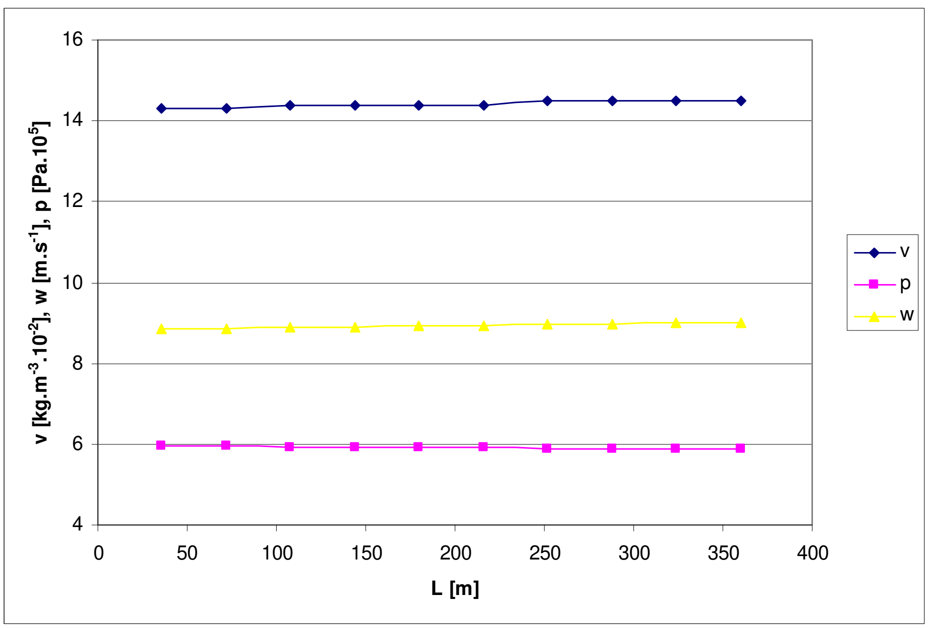

Fig. 4. *The variation of characteristic parameters on a transom of 360 m*

7. CONCLUSIONS

For the analytic description of the flow air through pneumatic networks we were used Fano`s transformation. This one is a useful instrument, obtaining good results for the exploration of main transport transoms.

In the case transoms of distribution, the diameters, the flows and the pressures is changed depending on consuming. The precision of the calculus is growing down and the system of equations is complicated.

Fanno`s transformation could be applied in particularly transoms and calculus volume is growing up significantly.

Nomenclature

a - velocity of sound in compressed air, m·s^{-1}
c_p – isobar specific heat of air, J·kg^{-1}·K^{-1}

c_v – isochore specific heat of air, J·kg^{-1}·K^{-1}
d – derivation symbol
D – diameter of pipe, m
g - gravity acceleration, m·s^{-2}
G – mass flow, kg·s^{-1}
h – elevation mark, m
i – specific enthalpy, J·kg^{-1}
k – adiabatic exponent
l_{fr} – specific friction work, J·kg^{-1}
l_t – specific technical work, J·kg^{-1}
l_k – critical length of the transom, m
M – Mach cipher
p – air pressure, N·m^{-2}
R - characteristic constant of air, J·kg^{-1}·K^{-1}
q_{ext} - specific transfer of heat into environment, J·kg^{-1}
s – specific entropy, J·kg^{-1}·K^{-1}
T – absolute temperature, K
v – specific volume, m^3·kg^{-1}
w - velocity of flow air, m·s^{-1}
x – two characteristic points distance, m
z – compressibility coefficient
δ - ·elementary variation symbol
λ - coefficient of fluid-dynamic resistant
Ω - transversal surface of flow, m^2

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