Solutions to increase the energetic efficiency of pneumatic mining distribution networks

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Abstract: - The paper deals with establishing the energetic performances of industrial pneumatic networks, emphasizing characteristic losses. Loss reduction solutions are also proposed. The quantification of the effects of the proposed measures regarding the increase of the energetic efficiency of the network is made. For example, it was ***released*** a comparative analysis between real estate and feasible state with 25% imposed lossed.

Keywords: - Compressed air, transport and distribution mining network, energy losses, pressure losses, energetic efficiency.

Nomenclature:

a, a_f – air-tightness coefficients of flange connections and mobile connections;
D_i – the interior diameter of the segment, m;
L_c – the equivalent length of the segment, m;
M - mass flow, kg/s;
N – Power, [kW].
p – pressure, N/m^2;
R - constant nature of air, J/(kg·K)
T_0 – compressed air temperature at the outlet of the buffer reservoir, K;
w –speed, m/s
α_i – equivalence coefficient of consumers;
δ_i – the width of the even obstruction, (the reduction of the interior ray of the pipe in case of an even obstruction);
φ_i – simultaneity coefficient of consumers;
λ_i – the fluido-dynamic resistance coefficient of the segment;
ρ – density of the gas, kg/m^3;

1 Introduction

A. Compressed air – energetic vector of industrial systems

Compared to other energy systems compressed air shows the following advantages[4]:

- it is an elastic and flexible medium not destroying consumers when overstressed;
- it has a reasonable capacity to accumulate energy per volume or weight unit and it becomes competitive at high pressure when mechanical component storage and thermal component storage are combined;
- it uses part of the energy consumed due to irreversibility as kinetic energy during its flow;
- by a comprehensive assessment it is less polluting compared to other energy systems;
- it is safe in explosive atmospheres;
- in underground mine workings, when exhausted from pneumatic equipment, it cleans the atmosphere up, and in emergency (collapses, people trapped underground) the pneumatic network allows trapped staff to be supplied with air, water and food;
- it supports a high number of accumulation - discharge cycles, without diminishing rated capacity;
- it shows a simple construction and high operating reliability;
- multiple use of pneumatic energy.

B. Types of Compressed air Transport and Distribution Networks

The general diagram of a fluidic installation is presented in Fig. 1.

Due to the appearance, during the yearly operation, of flow variations inside a fluidic installation, the following measures are going to be defined: $Q_{d\ max}$ – maximum daily flow, and in case of daily fluctuations, $Q_{h\ max}$ – maximum hourly flow.

Fig. 1. General diagram of a fluidic installation

The generating machine station and the compensation reservoir is dimensioned according to the $Q_{d\ max}$ while the pipe network is dimensioned according to $Q_{h\ max}$.

The purpose of the compensation reservoir is to catch up the excess flow during the minimum consumption periods and to supply the extra necessary flow during peaks[6], [7].

In the case of branched networks each consumer is supplied from a single direction. The characteristic of loop networks is that each consumer is supplied from at least two directions[4],[6].

The new elements brought forward and studied by the paper are the following:

- *Pneumatic Network Energetic Performance Establishment New Method;*
- *Case Study Regarding Energetic Indicators of a Real Pneumatic Network*

2 Formulating the problem

A. Pneumatic Network Energetic Performance Establishment Method

In order to transform the calculations into algorithms, the configuration of the networks presented in this paper was transformed into a form easier to be dealt with by using a computer (Fig. 5). The transformation was made without the modification of the thermal-fluidic-dynamic parameters of the segments of the network. The only change is that certain segments with invariable geometrical parameters have been divided in additional segments in order to obtain calculation loops with an identical number of steps.

Known parameters: pneumatic network configuration, segments length, consumer required compressed air flows, compressed air pressure and temperature at the outlet of the compressor station, the polytrophic factor of the flow on a segment[4],[8].

Calculated parameters: significant point pressures, segment pressure losses, segment flow losses, consumer losses, segment temperature, segment transport capacity, segment power losses.

1) The pressures in the significant points are determined considering a linear variation depending on the width of the segment.

2) Knowing both the pressure values in the significant points as well as the polytrophic factor, the following values are determined:

- mean pressure on the segment:

$$p_m = \frac{p_1 + p_2}{2} \tag{1}$$

- the temperatures at the end of the segments:

$$T_2 = T_1 \cdot \left(\frac{p_2}{p_1}\right)^{\frac{n-1}{n}} \tag{2}$$

- mean temperatures on the segment:

$$T_m = \frac{T_1 + T_2}{2} \tag{3}$$

- the densities at the end of the segments:

$$\rho_1 = \frac{p_1}{R \cdot T_1}; \rho_2 = \frac{p_2}{R \cdot T_2} \tag{4}$$

- mean densities on the segments:

$$\rho_m = \frac{\rho_1 + \rho_2}{2} \tag{5}$$

3) Based on the calculated and known parameters, the pressures in the coal face (p_c), the coefficients of equivalence of the consumers (α_i) and the coefficients of non-air tightness at the mobile connections (φ_i), the following is determined:

- the mass flow required by the consumers[4]:

$$M_{util} = 0.00847 \cdot p_c^{0.76} \cdot \sum n_i \cdot \alpha_i \cdot \phi_i \quad \text{[kg/s]} \tag{6}$$

where: p_c is the absolute pressure at the consumer, in bar; n_i the number of identical consumers.

- the mass flow lost at fittings and connections[3]:

$$\Delta M = a_f \cdot D_f \cdot p_{ma}^{1,3} \cdot L_{cf} \sum n_i \cdot \varphi_i \quad \text{[kg/s]} \tag{7}$$

where: D_f is the diameter of the hose, in m; p_{ma} – mean pressure on the hose, in bar; L_{cf} – equivalent length of the hose, in m;

- the total mass flow delivered in the coal face $M_{total} = M_{util} + \Delta M$

4) Mass flow losses are determined on the segments of the pneumatic pressure[3]:

$$\Delta M'' = a \cdot D \cdot p_m^{1,3} \cdot L_c \quad \text{[kg/s]} \tag{8}$$

5) The total mass flow spread on each segment starting from the coal face towards the compressors M_{is}.

6) The pressure losses on the segments – Δp_i and on the hose – Δp_f are determined[4]:

$$\Delta p_i = \frac{8\lambda_i L_c M_{is}^2 R T_m}{\pi^2 \left(D_i - 2\delta_i\right)^5 p_m 10^5} \quad [\text{N/m}^2] \tag{9}$$

$$\Delta p_f = \frac{8\lambda_f L_{cf} M R T_m}{\pi^2 D_f^5 p_{ma} 10^5} \left(\frac{M_t}{\sum n_i \varphi_i}\right)^2 \quad [\text{N/m}^2] \tag{10}$$

7) The pressures in the significant points of the network are determined according to pressure losses previously determined.

8) The determinations from points 2 to 7 are reiterated, until the differences between two values of the lost pressure on the segment are negligible (within the precision imposed limits).

The elements of the calculation for the balance of power on the segments of pneumatic network are:

a. The speeds at the ends of the segments and the average speeds on the segment are determined[4]:

$$w_{i1}=\frac{M_{is}}{\dfrac{\pi\left(D_i-2\delta_i\right)^2}{4}\rho_{i1}};\quad w_{i2}=\frac{M_{i\,tranzit}}{\dfrac{\pi\left(D_i-2\delta_i\right)^2}{4}\rho_{i2}};$$

$$w_{im}=\frac{w_{i1}+w_{i2}}{2}$$

b. The balance of powers in the coal face and on the segments of the network is determined[4]:

- practical power:

$$N_{iu}=\left(\frac{p_{i2}}{\rho_{i2}}+\frac{w_{i2}^2}{2}\right)\frac{M_{i\,tranzit}}{1000}\quad[\text{kW}]$$

- lost power:

$$N_{ip}=\left[\frac{p_{i2}}{\rho_{i2}}+\frac{w_{i2}^2}{2}+\frac{\Delta p_{i12}}{\rho_{im}}-\frac{R}{n_i-1}\left(T_{i1}-T_{i2}\right)\right]\frac{\Delta M_{i12}}{1000}+$$
$$+\left[\frac{\Delta p_{i2}}{\rho_{im}}-\frac{R}{n_i-1}\left(T_{i1}-T_{i2}\right)\right]\frac{M_{i\,tranzit}}{1000}$$

- total power: $N_{it}=N_{iu}+N_{ip}$

$$N_{it}=\left(\frac{p_{i1}}{\rho_{i1}}+\frac{w_{i1}^2}{2}\right)\frac{M_{is}}{1000}$$

[kW] - relation of verification

In the relation of the lost power there is a term which appears with the significance of an expansion mechanical work due to the variation of density.

The balance equations of power represent particular forms of Saint-Venant's equation:

$$\frac{w_2^2-w_1^2}{2}+p_2V_2-p_1V_1-\int_{V_1}^{V_2}p\,dV+L_{t\,12}+\Delta H=0\quad(11)$$

B.Case Study Regarding Energetic Indicators of a Real Pneumatic Network

The real configuration of the approached pneumatic network is presented in Fig. 2. Segments 0-A-B-1, 1-2 and 2-3 are transport segments, while segments 1-a-b-c, 2-a-b-c, 3-a-b-c are distribution segments. The transport and distribution segments 1-a-b, 2-a-b, 3-a-b are composed of metallic pipes, while the final distribution segments marked with b-c for each place of consumption are made of flexible pipes (hoses).

In order to automatise the determination characteristic parameters of compressed air going supplied through the network in Fig. 2, a canonical diagram presented in Fig. 5 is therefore proposed.

The losses of flow, pressure and power on the significant segments of the network have been determined using a calculus programme. The results of the calculations for the real balance, the balance of the imposed losses, are centralised in Table 1 and presented in figures 4, 5, 6, and 7.

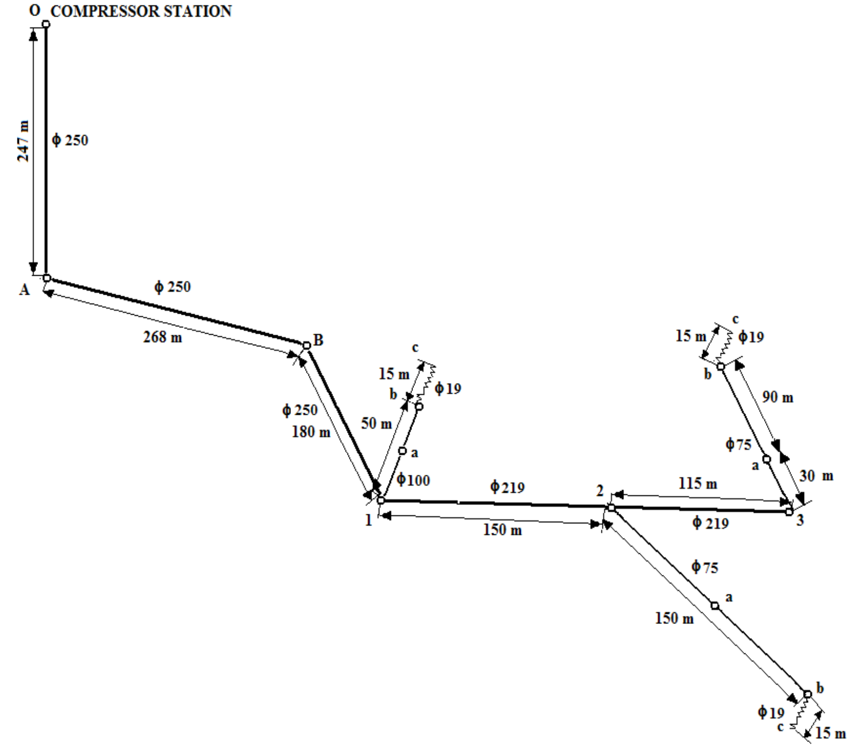

Fig. 2. Real configuration of the pneumatic network

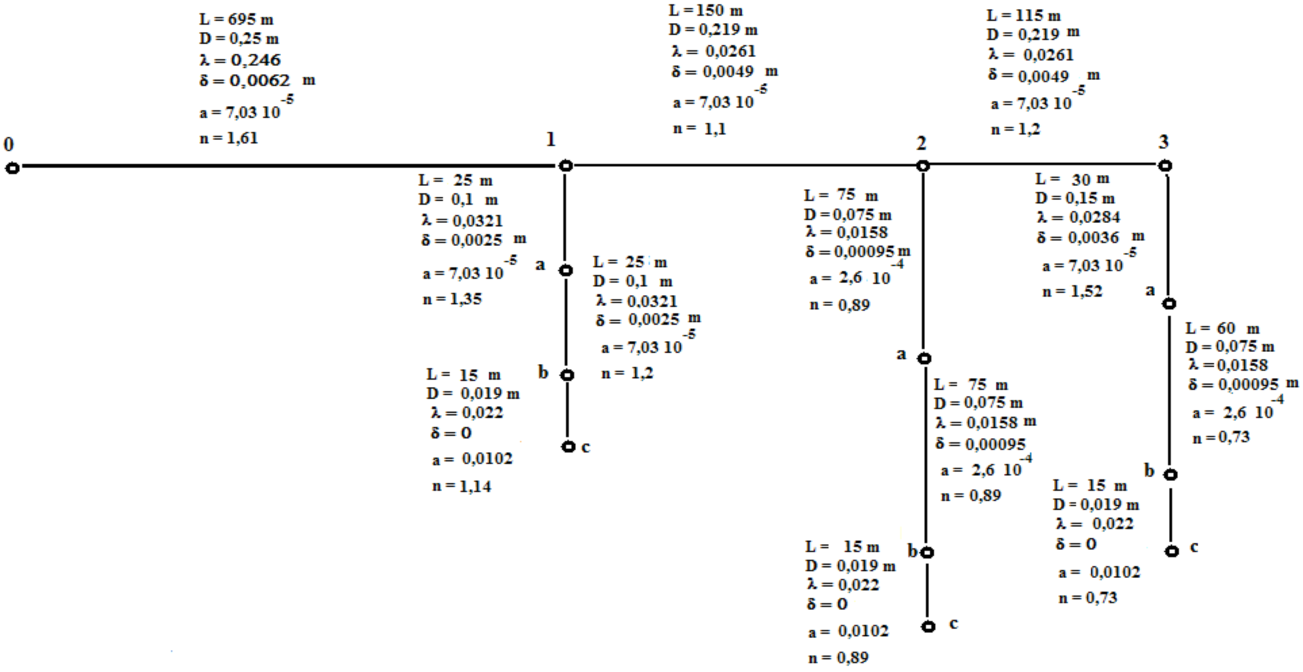

Fig. 3. Canonical diagram of the studied network

Table1
Real balance the balance of 25% imposed lossed

Nr	Compared measure	Real balance		Imposed flow losses balance 25%		Differences recorded based on the comparison between scenarios	
		Quantity	%	Quantity	%	Quantitative differences	Relative differences expressed in %
Weight balance							
1	Compressor outlet flow	0.641 kg/s	100	0.42 kg/s	100	0.221 kg/s	3447
2	Practical flow	0.315 kg/s	49.14	0.315 kg/s	75	-	25.86
3	Network flow loss	0.235 kg/s	36.661	0.1 kg/s	22.821	0.135 kg/s	$\frac{0.235-0.1}{0.235}*100=57.44$
4	Consumer flow loss	0.09 kg/s	14.041	0.009 kg/s	2.179	0.081 kg/s	$\frac{0.09-0.009}{0.09}*100=90$
Pressures Balance							
1	Network pressure loss	0.451 bar	8.5	0.326 bar	0.098	0.125 bar	$\frac{0.451-0.326}{0.451}*100=27.72$
2	Consumer available pressure	4.844 bar	91.5	2.985 bar	90.2	1.859 bar	$\frac{4.844-2.985}{4.844}*100=38.37$
Thermal-fluidic powers (kW_t)							
1	Compressor outlet power	56.006 kW	100	36.696 kW	100	19.31	$\frac{56.006-36.696}{56.006}*100=34.48$
2	Practical power	28.513 kW	50.911	22.04 kW	60.06	6.473	$\frac{28.513-22.04}{28.513}*100=22.7$
3	Network power loss	20.497 kW	36.598	8.748 kW	23.839	11.749	$\frac{20.49-8.748}{20.49}*100=57.32$
4	Consumer power loss	6.911 kW	12.34	5.91 kW	16.104	1.001	$\frac{6.911-5.91}{6.911}*100=14.48$

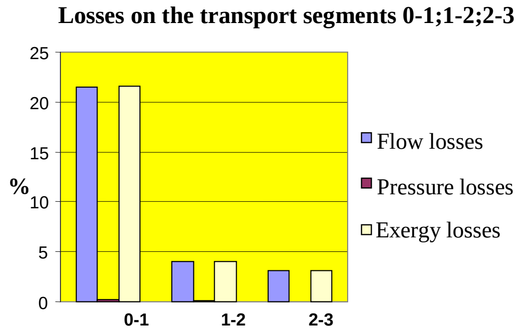

Fig. 4. Losses on the transport segments

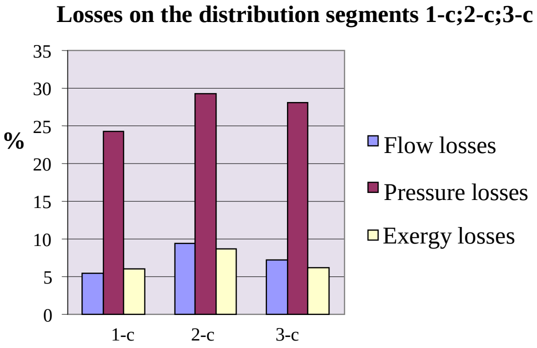

Fig. 5. Losses on the distribution segments

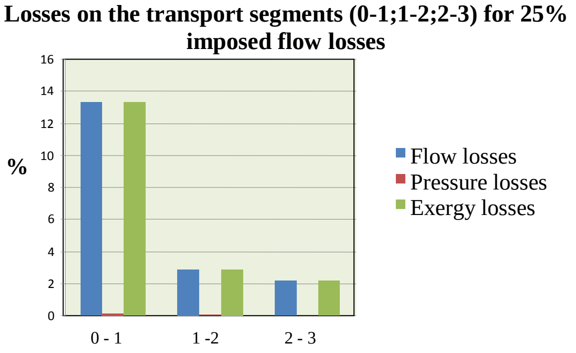

Fig. 6. Losses on the transport segments for 25% imposed flow losses

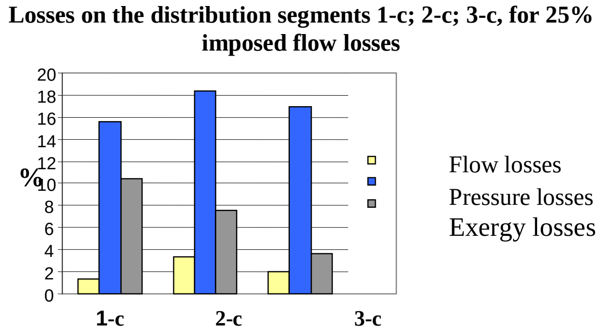

Fig. 7. Losses on the distribution segments for 25% imposed flow losses

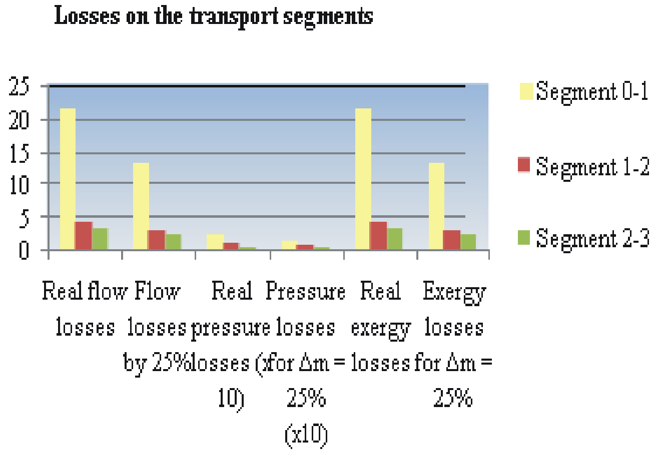

Fig. 8. Comparative analysis of losses on transport segments

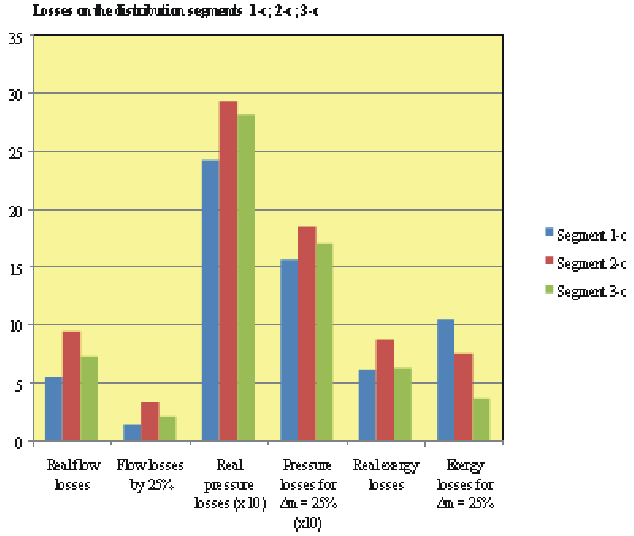

Fig. 9. Comparative analysis of losses on distribution segments

3 Solutions for the increase of energetic efficiency of the studied mining pneumatic network

Actions to eliminate humidity from the compressed air.

Ensuring a compressed air consumption waveform to flatten out the load curve.

Improving air tightness on the network for the operation at high pressures with with reduced specific consumptions.

Reducing flow losses at non-tightness spots, by exploring and maintaining the pneumatic network according to the norms and regulations.

Introducing the breakdown monitoring of compressed air consumption.

4 Conclusions

The calculations made for both the real case as well as for the situation with imposed flow losses, lead to the following conclusions (according to Table 1 and Fig. 4, 5, 6, 7, 8, and 9).

1) The most significant energy losses on the network are recorded due to flow loss through non-tightness spots – at a flow loss of 50.702% (36.661% network losses and 14.041% consumer losses), corresponds an energy loss of 48.938% (36.958% network losses 12.34% consumer losses); the influence of pressure losses is insignificant as a percentage in the energetic balance of the system compressor – network – consumer.

2) Imposing a flow loss of 25% the following relative pressure (1.287%) and energy (8.995%) losses reductions are obtained.

3) It is observed from the mass balance of the network that the flow losses are found in a proportion of 36.661% on the flange connected network, compared to those at the consumer (14.041%).

4) Reducing, with technical organisational measures, the flow losses to 25%, a percentage of 13.84% economies on the network and respectively 11.862% at the consumer are realised.

5) The measure for the reduction of flow losses is reflected in the energetic balance through the relative increase of the proportion of energy consumer losses from 12.34% to 16.104% and the relative reduction of the proportion of network energy losses from 36.598% to 23.839%.

Acknowledgment

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