

HEAD LOSS CALCULATION IN VENTILATION NETWORKS USING THE EQUIVALENT RESISTANCE (EQUAL FRICTION) METHOD

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This method may be applied in two situations: when the total air pressure drop for the system is given and when some values for the so-called economical velocity are imposed along the successive ducts. In the first case, the method consists in determining the necessary diameters for some ducts and for all the system. Thus, in this case, the total available pressure is divided to the total length of the main duct, giving as result the friction loss per meter of duct, also known as friction loss factor or specific linear pressure drop [Pa/m], which includes both major and minor losses.

Key words: air pressure loss, ventilation duct system, airflow rate, equivalent resistance, nomogram.

Цей метод може бути застосований у двох випадках: коли дано загальний перепад тиску в системі і коли наведено деякі значення так званої економічної швидкості суміжних повітроводів. У першому випадку метод полягає у визначенні необхідних діаметрів окремих труб і системи загалом. Тоді тиск в цілому ділиться на загальну довжину головного повітроводу і обчислюються втрати через тертя на метр труби, або також відомі як коефіцієнт втрат через тертя або лінійна втрата тиску, що складаються з основних і другорядних втрат.

Ключові слова: втрата тиску повітря, система повітроводів вентиляції, швидкістьповітряного потоку, еквівалентний опір, номограми.

Introduction

The presented method gives a simplified approach for determining both the major and minor head losses for air distribution networks. Through the method, these losses are evaluated simultaneously, which allows, on one hand to obtain low energetic consumption, and on the other hand, a fast balancing of the branches in order to attain the designed airflow rates.

At a global level, the entire air transporting network offers the same specific pressure drop, measured in Pa/m and which includes both major and minor losses.

When air is moving along the air pipe network, it can be accepted that the conditions for considering air as an incompressible gas are fulfilled; therefore the perfect gas laws are applicable.

For making the computing easier, a certain equivalence coefficient is introduced by multiplying the exponent 2 of air flow volume, obtaining a result which is proportional to the total head loss. Therefore, this coefficient is a hydraulic similitude factor [1].

By the means of this coefficient, no more iterative calculations will be used for the pressure balancing throughout the system. For applying the method, three diagrams were proposed, combining together the necessary data for dimensioning a ventilation network.

Determination of total air pressure loss H

The applicability range of the method includes situations which can be reduced to two distinct cases:

- the value of total air pressure loss for the network is given or is imposed;
- some particular values of so-called economical velocity are requested for the consecutive ducts along the network [2].

Whether in the situations corresponding to the first case, the framework of the method determines the necessary diameter for each duct, the second case situations are solved by determining the diameters and the air pressure loss for each sector and in the entire network.

Thus, in the first case, the available pressure H (which must overcome the major and minor losses) is divided to the length of the main branch (considered usually as being the longest branch and having the biggest local pressure drops) [1], [3].

$$R = \frac{H}{\sum \ell}, \quad [\text{Pa/m}] \quad (1)$$

where $\sum \ell$ means the total duct length of the main branch.

On a certain branch, the “ n ” duct, having ℓ_n length, will generate a total pressure loss H_n , as follows:

$$H_n = R \cdot \ell_n, \quad [\text{Pa}] \quad (2)$$

The air pressure losses in junctions result from balancing the pressure at the knots.

Knowing the air pressure drop for each individual duct, the length of the ducts, the necessary airflow volume and the sum of local pressure drop coefficients, the design diameter of the duct may be determined [1], [4].

The total air pressure H for the main branch is:

$$H = \left(\frac{\lambda \cdot \ell}{d} + \sum \xi \right) \cdot \frac{\rho \cdot v^2}{2}, \quad [\text{Pa}]; \quad (3)$$

where: λ is the friction coefficient; ℓ – the duct length; d – the equivalent diameter; ξ – the local pressure drop coefficient; ρ – air density; v – average air velocity.

Knowing that the duct has circular section and transports the airflow rate D , from the continuity equation comes:

$$v = \frac{4D}{\pi \cdot \rho \cdot d^2}, \quad [\text{m/s}]; \quad (4)$$

Replacing this expression of the velocity in (3) we find:

$$H = \left(\frac{\lambda \cdot \ell}{d^5} + \frac{\sum \xi}{d^4} \right) \cdot A \cdot D^2, \quad [\text{Pa}]; \quad (5)$$

where:

$$A = \frac{16}{\pi^2 \cdot \rho}, \quad [\text{m}^3/\text{kg}]; \quad (6)$$

is a quantity which can be considered as constant for a certain network.

The μ coefficient is introduced:

$$\mu = \frac{\lambda \cdot \ell}{d^5} + \frac{\sum \xi}{d^4}, \quad [\text{m}^{-4}]; \quad (7)$$

therefore relationship (5) becomes:

$$H = A \cdot \mu \cdot D^2, \quad [\text{Pa}]. \quad (8)$$

To a certain value of the μ coefficient may correspond different combinations of the quantities ℓ , d and $\sum \xi$, whereas for $D = \text{ct.}$ și $\mu = \text{ct.}$, the air resistance of the network is constant. So, air ducts having different lengths, diameters and local pressure drop coefficients but providing the same value for the μ coefficient, are called similar. In other words, the μ coefficient is a hydraulic criterion (or dimensionless group) of similarity [5], [6]. By the means of this μ coefficient, it is no longer need to make tedious repetitive calculations in order to balance the pressure in junctions, when dimensioning a ventilation network [5], [6].

The equal friction method. Total air pressure loss calculation using the equivalent resistance

When the head loss corresponding to a certain airflow rate is known, the following equations may be written in the case of a junction where two branches 1 and 2 meet:

$$\begin{cases} H_1 = H_2 \\ D = D_1 + D_2 \end{cases}, \quad (9)$$

where: D is the resulting airflow, from the summation of the branches airflows [1], [7].

Therefore:

$$\mu_1 \cdot D_1^2 = \mu_2 \cdot D_2^2, \quad (10)$$

or:

$$\frac{D_1}{D_2} = \sqrt{\frac{\mu_2}{\mu_1}}. \quad (11)$$

The relationship (11) may be written as follows:

$$\frac{D_1 + D_2}{D_2} = \frac{\sqrt{\mu_1} + \sqrt{\mu_2}}{\sqrt{\mu_1}}; \quad (12)$$

At the considered junction we may write:

$$\mu_p (D_1 + D_2)^2 A = \mu_2 \cdot D_2^2 \cdot A; \quad (13)$$

where μ_p is the equivalent coefficient of the two ducts connected in parallel.

The relationship (13) becomes:

$$\sqrt{\mu_p} = \sqrt{\mu_2} \frac{D_2}{D_1 + D_2}. \quad (14)$$

Based on (12) și (14), it follows:

$$\frac{1}{\sqrt{\mu_p}} = \frac{1}{\sqrt{\mu_1}} + \frac{1}{\sqrt{\mu_2}}. \quad (15)$$

By generalization, for n ducts connected in parallel, the equivalent coefficient μ_p is:

$$\frac{1}{\sqrt{\mu_p}} = \sum_{i=1}^n \frac{1}{\sqrt{\mu_i}}. \quad (16)$$

The relationship (16) presents an analogy with the connection in parallel of the electrical resistors.

When two consecutive ducts 1 and 2 transporting the same airflow rate are discussed (series connection), the following equations may be written:

$$\begin{cases} D_1 = D_2 = D_s \\ H_s = H_1 + H_2 \end{cases}, \quad (17)$$

where H_s is the total head loss for the two ducts and D_s is the airflow rate which passes through the ducts. Thus:

$$\mu_s A \cdot D_s = \mu_1 \cdot A \cdot D_1 + \mu_2 \cdot A \cdot D_2, \quad (18)$$

becomes:

$$\mu_s = \mu_1 + \mu_2, \quad (19)$$

where: μ_s is the equivalent coefficient of the two ducts connected in series.

By generalization, for n ducts connected in series, the equivalent coefficient μ_s is:

$$\mu_s = \sum_{i=1}^n \mu_i. \quad (20)$$

The relationship (20) presents an analogy with the connection in series of the electrical resistors.

The total head loss of the entire air distribution network is the main value used for the calculation of the fan necessary pressure.

When the values D , ℓ and $\sum \xi$ are known for each duct, the equivalent diameters of the ducts are determined by the means of nomograms [1].

In the relationship (7), for the similarity coefficient, we substitute the friction coefficient λ by its value given by Prandtl, von Karman and Nikuradse:

$$\frac{1}{\sqrt{\lambda}} = 1,14 - 2 \lg \frac{\varepsilon}{d}, \quad (21)$$

and the result is:

$$\mu = \frac{1,14 - 2 \lg \varepsilon + 2 \lg d}{d^5} + \frac{\sum \xi}{d^4}. \quad (22)$$

For ventilation ducts made of steel plate, the absolute roughness is $\varepsilon = 0,1$ mm, so we obtain:

$$\mu = \frac{9,14 - \lg d^2}{d^5} + \frac{\sum \xi}{d^4}. \quad (23)$$

where d is the equivalent diameter of the section, [m].

For circular pipes, the equivalent diameter is the same with the geometrical diameter, but for rectangular ducts having the side ratio $a/b \leq 10$, the equivalent diameter must be calculated with the following formula:

$$d = 1,3 \cdot \sqrt[8]{\frac{a^5 b^5}{(a+b)^2}}; [\text{m}] \quad (24)$$

The relationship (23) is presented below under a nomogram form (Figure 1), in which three independent variables are combined: μ , d and $\sum \xi$. The mass airflow rate D is added, too. The variables involved in this graphical representation have the following ranges:

- airflow: 100...50.000 kg/h;
- head loss: 6...300 mmH₂O;
- similarity coefficient: 0,01...1000;
- length of a pipe: 1...40 m;
- local pressure drop coefficient: 0...2,5;
- air velocity: 1...40 m/s.

Example of using the nomogram for air pressure loss calculation

Following, we give an example how to use this nomogram. If it is known that a ventilation duct having a length of 30 m transports 3000 kg/h air with total pressure losses of 70 mmH₂O and the local pressure drop coefficient is 1,05, find the equivalent diameter of the duct and air velocity through the duct. Using diagram I (Figure 1), for $D=3000$ kg/h (point A) and the head loss 70 mmH₂O (point B), we obtain point C, from which results the equivalent coefficient $\mu=10$. From the same diagram, for $\ell=30$ m and $D=3000$ kg/h, we obtain point D, which is projected on the vertical axis to the right of the diagram, in point E. In diagram II (Figure 1), joining the point E with point F (corresponding to local pressure drop coefficient $\sum \xi = 1,05$), we obtain on curve $\mu = 10$, the G point which gives the ventilation duct diameter, $d=240$ mm. From diagram no. III (Figure 1), for $D=3000$ kg/h (point I) and $d = 240$ mm (point H) results the air velocity in the duct, $v=18,5$ m/s.

Conclusions

This calculation method allows a more simple and rapid determination of total loss of pressure in a ventilation duct network, just by using a nomogram. Is a very useful tool for the designers of ventilation systems in order to make an accurate calculation of ventilation ducts and total pressure drops along the air route.

The method is easier to use than the classical method of calculation (pressure balancing method) and therefore is recommended for air ducts quick calculations and for making technical and economic estimates of the ventilation systems.

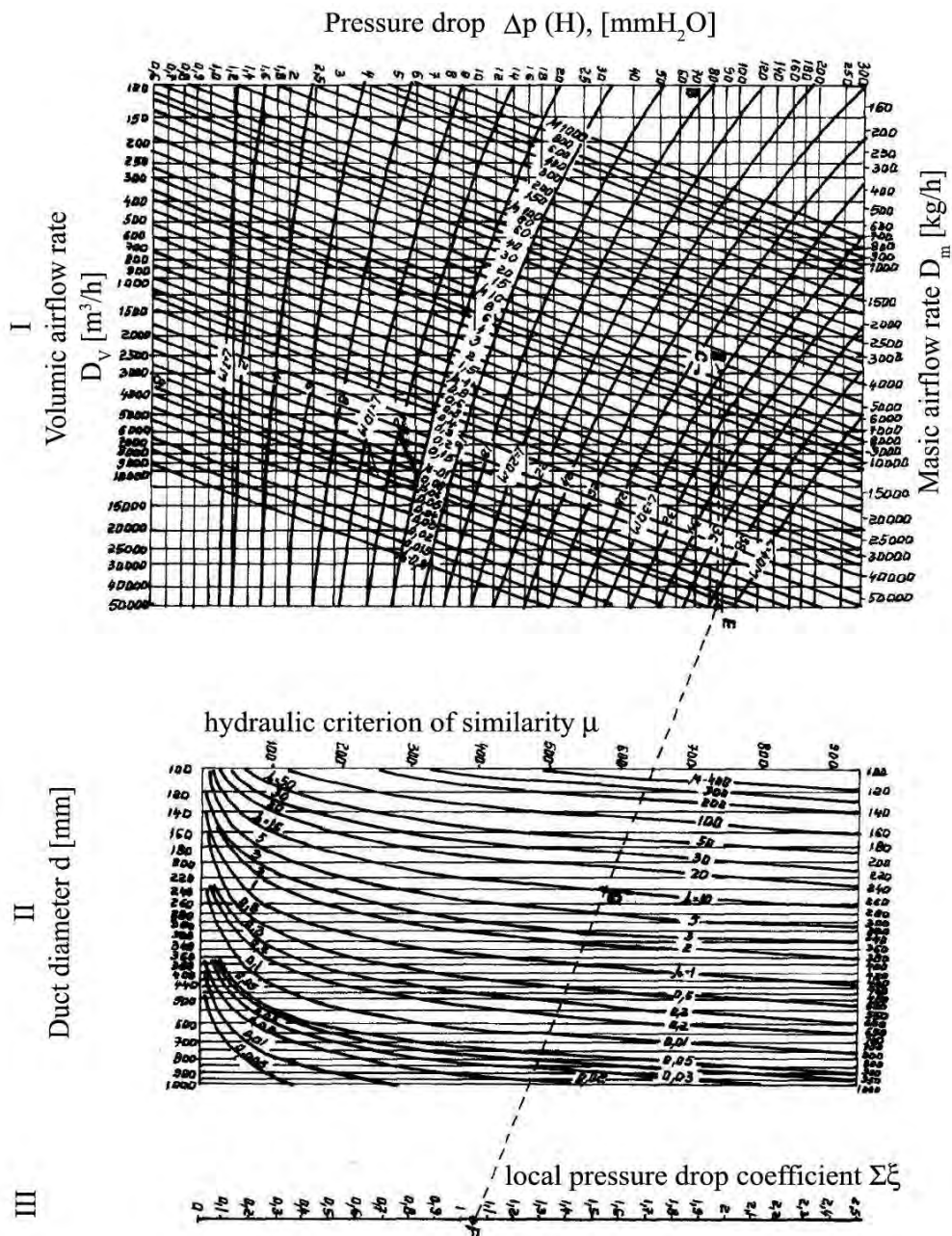


Fig. 1: Total air pressure loss calculation using the equivalent resistance

It can be used both to calculate the longest and loading air route and to balance the secondary branches of the ventilation networks. Pressure losses in branches will be determined by imposing the pressure balance in the junctions. Knowing the head loss for each individual duct, the length of the ducts, the necessary air flow volume and choosing the sum of local pressure drop coefficients, the design diameter of the duct may be determined.

The method respects the romanian regulations regarding the designing and the execution of ventilation duct systems [8], [9], therefore it can be easily used.

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RESISTANCE AND FLOW CHARACTERISTICS OF FREE AIR FLOWING THROUGH END VENT HOLE OF CYLINDRICAL PIPELINE IN UNLIMITED SPACE

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In the article there are analyzed analytically and given approximate numerical values of resistance and flow characteristics of free air flowing through the end vent hole of cylindrical pipeline in unlimited space.

Key words: local resistance, flow characteristic, leakage, suction.

Проаналізовані аналітично і визначені наближені числові величини опірних і витратних характеристик вільного перетікання повітряного потоку через вільний отвір трубопроводу в необмежений простір.

Ключові слова: місцевий опір, витратна характеристика, витікання, всмоктування.

Statement of the problem

In the literature are ambiguously interpreted analytical basis to determine the resistance and flow characteristics of free end vent holes in the pipeline leakage air flow into unlimited space and air suction from the unlimited space. There is also no definite guidelines for the experimental determination of the local resistance of the holes, especially during the suction.

For example in the [5, 6, 7] the coefficient of local resistance by the free outflow air flow into the atmosphere $\zeta_{\text{внт}}$ equal to one, according to [5, 7] the coefficient of local resistance by the free suction $\zeta_{\text{всм}}$ is also taken as equal to one, although the phenomena that occur in outflow and suction is different [1, 2], indicating that at the air intake from the unlimited space in the hole pressure loss is always lower than the losses in the outflow of air flow in unlimited space.