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CALCULATION OF THE AIR PATH OF AN AUTONOMOUS TRIGENERATION SYSTEM

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Abstract

The topic of resource and energy saving is relevant for most industrial enterprises, in this regard, solutions aimed at saving resources, including trigeneration systems, are being introduced everywhere. The directions of improving the elements of autonomous trigeneration systems are relevant. The work considers the concretization of the previously known approach to the calculation of the air path of air conditioning systems, taking into account the peculiarities of the functioning and geometry of small trigeneration systems. A detailed algorithm is presented for a particular case of the air path of a small local trigeneration system. The results of calculations of the model are presented, as well as comparison with the results of similar calculations. The calculation methodology previously used in the work was applied only when calculating the elements of ventilation and air conditioning systems for buildings and structures. The full pressure losses during air movement in the channel at various air speeds were calculated. A duct fan was selected taking into account the aerodynamic calculation results. The obtained operating parameters of an electrical fan for the air flow distribution unit in the air conditioning subsystem can be used to develop a model for tracing the impact of external factors on operation of the air conditioning subsystem. Calculation of air path parameters will make it possible to determine the geometric dimensions of the air flow distribution unit in the air conditioning system of the autonomous trigeneration system.

Keywords: Trigeneration, air conditioning subsystem, air path, air flow, fan

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1. Introduction

It is necessary to calculate the air path parameters for determination of characteristics, namely geometric dimensions of the air flow distribution unit in the air conditioning system of the autonomous trigeneration system.

The air path is an element of the air flow distribution unit which distributes the air flow entering the air conditioning subsystem of the autonomous trigeneration system. A fine-pored filter and a coarse-pored filter, which additionally cool the air due to the adiabatic throttling effect, are successively arranged in the unit housing between the fan and evaporator. It allows for increasing the amount of cold air generated by the air conditioning system.

When calculating the parameters of the air path for the air flow distribution unit in the air conditioning subsystem of the autonomous energy-saving trigeneration plant, it is necessary to determine the air path resistance and select the electric fan parameters according to the required capacity and heat while taking into account the pressure, density, speed of air flow, mass and volumetric air flow rates, and temperature/humidity parameters (Mikhailov, 2016). These parameters are important for set-up of the air conditioning system and for efficiency monitoring.

This methodology was previously used to calculate the parameters of the air path in ventilation systems of buildings and constructions. Calculation in this work is made for an autonomous trigeneration system. The following conditions are introduced in the calculation.

Air ducts of the air path are leakproof. According to tightness they pertain to class "N" of the Russian Standard. The maximum losses are 1.61 (l/s)/m2.

The air path wall surface is not rough, the air path has a smooth internal surface, therefore the minimum aerodynamic losses, friction coefficient and specific pressure losses will be minimum.

2. Problem Statement

The air path parameters have been previously studied in the works by Tabunshchikov (1981), Suprun (1996), Vasiliev (1957), Baturin (1990), Ibrahim and Kayfeci (2020), Fong and Lee (2017), Grinkrug (2009). Works in the field of study of the parameters of the air conditioning subsystem in the autonomous energy-saving trigeneration system were carried out by Burkov et al. (2019), Zaychenko et al. (2019).

Resistance of the air conditioning subsystem was calculated using formula (1)

$$p_{\kappa} = \sum_{i=1}^{m} \Delta p_{eli} + \sum_{j=1}^{n} \Delta p_{eli} + \sum_{p=1}^{k} \Delta p_{fr\cdot p'}$$

where Δp_{el} - resistance of individual elements of the air conditioner: air coolers and heaters, filters;

Δ pl — local resistances of the air conditioner air path;

Δ fr — friction resistance at individual straight sections of the air conditioner air path.

Aerodynamic calculation was made after layout of the air conditioning subsystem. Thereat, its air duct was subdivided into individual simplest resistance elements, which are most close to the already experimentally studied cases given in the special reference literature (Barkalov et al., 1992).

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Thereat, it must be borne in mind that air path friction resistance is of rather a small value as compared to local resistances and resistances of heat exchangers, filters etc.

The total pressure losses in the natural ventilation channel were determined using formula (2)

$$\Delta P = h \cdot R \cdot n + \sum \xi_i \cdot \frac{\rho_{вн} \cdot w^2}{2}, \text{ Pa,} \quad (2)$$

where R – specific pressure losses due to friction, determined according to air speed and equivalent diameter $d_{эw}$ Pa/m;

n – correction factor which takes into account the impact of air duct material roughness on friction

w – air speed w=0.5…1.0 m/s;

$\sum \xi_i$ – sum of local resistance coefficients at the air path in the channel, which comprises:

- ξ for fan is determined with the free area ratio , ξ=1.32;
- ξ for a double-layer adjustable-density filter which implements the Joule-Thompson effect, ξ=1.2.

3. Research Questions

The total pressure losses in the natural ventilation channel were:

$$\Delta P = 0{,}5 \cdot 0{,}055 \cdot 1{,}17 + 3{,}52 \cdot \frac{1{,}204 \cdot 0{,}5^2}{2} = 0{,}85, \text{ Pa}$$

Then a designation of constant values was introduced:

A=5.0 m;

$$B = \sum \xi_i \cdot \frac{\rho_{вн}}{2} = 2{,}12, \text{ m}$$

The channel’s aerodynamic characteristic took the following form:

$$\Delta P = A \cdot R \cdot n + B \cdot w^2, \text{ Pa.}$$

The channel’s aerodynamic characteristic was plotted in the following sequence:

1. The minimum values of recommended air speed w=0.5 m/s were specified and the air amount, removed via the channel at the given speed, was determined:

$$L_1 = w \cdot F_{ch} \cdot 3600, \text{ m3/h,}$$

$$L_1 = 0{,}5 \cdot 0{,}056 \cdot 3600 = 100{,}8, \text{ m3/h,}$$

where F_{ch} – channel cross-sectional area, m2.

2. The total pressure losses in the channel at the given speed were determined

$$\Delta P_1 = A \cdot R \cdot n + B \cdot 0{,}5^2$$

$$\Delta P_1 = 5{,}0 \cdot 0{,}055 \cdot 1{,}17 + 2{,}12 \cdot 0{,}25 = 0{,}85$$

3. The aerodynamic constant of the network was determined

$$a = \Delta P_1 / L_1^2 = 0{,}0084$$

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Finally, the formula for determination of total pressure losses during air movement in the channel at different air speeds took the following form

$$\Delta P_i = a \cdot L_i^{\,2} \text{ , Pa,}$$

where Li – flow rate of air removed via the channel, at the corresponding air speed.

The full pressure losses during air movement in the channel at various air speeds were as follows:

$$\Delta P_1 = 0{,}85 \text{ , Pa}$$

4. The pressure losses in the channel were determined using the found dependency and substituting into it the air flow rate values, determined according to air speed within the recommended values. The calculation results were presented in tabular form (Table 1):

Table 1. Values of total pressure losses in the channel

w , m/s	0,5	0,6	0,7	0,8	0,9	1,0
L_i , m^3/h	68,40	82,08	95,76	109,44	123,12	136,80
ΔP_i , Pa	0,85	1,23	1,67	2,18	2,76	3,41

The obtained values were used to plot the network aerodynamic characteristics $\Delta P = a \cdot L^2$ in Figure 1.

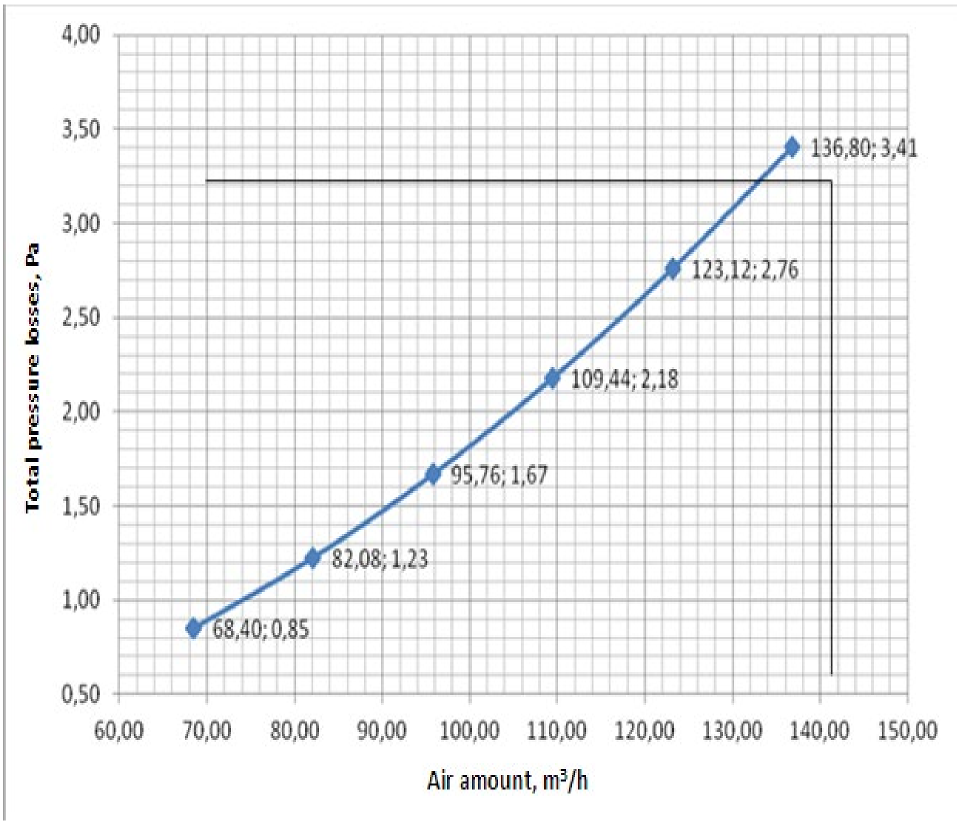

Figure 1. Graphic method for determination of air flow rate through the channel

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The intersection of the lines, which correspond to the head value and the network aerodynamic characteristic $\Delta P = a \cdot L^2$, determines the value of air flow rate through a single channel L_{ch}.

The obtained values were used to plot the network aerodynamic characteristic $\Delta P = f(d)$ (Figure 2).

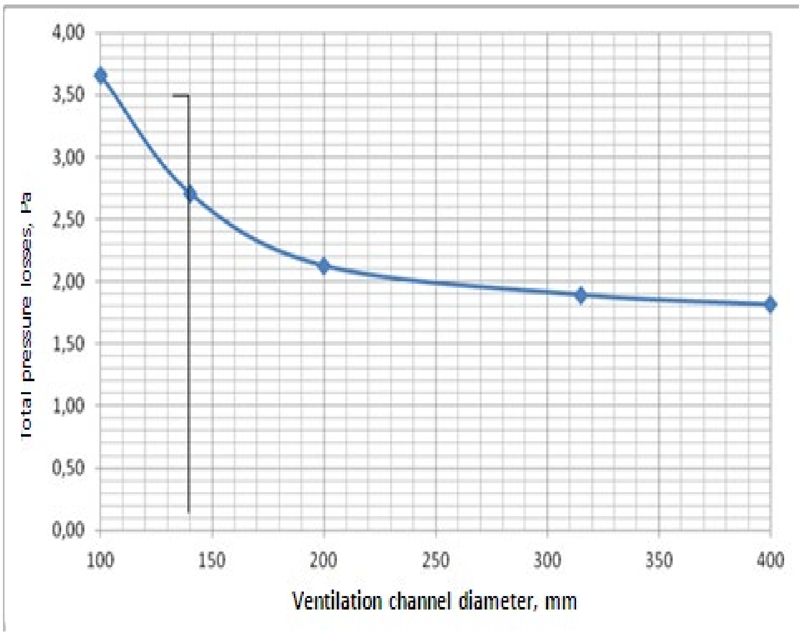

Figure 2. Graphic method for determination of channel standard size

The intersection of the lines in Figure 3, which correspond to the total available head and channel characteristic, determines the required channel diameter. The design value was the nearest standard size of the channel – 110 mm.

4. Purpose of the Study

The work objective is to calculate the parameters of the air path in order to determine the geometric characteristics of the air flow distribution unit in the air conditioning system of the autonomous trigeneration system.

5. Research Methods

The methodology of air path parameter calculations is based on aerodynamic and thermodynamic analysis of the actual cycles of the air flow distribution unit.

6. Findings

Type of used fan was selected taking into consideration the operation conditions – characteristics of the air medium moved by the fan.

The following conditions of use of conventional fans were also taken into account:

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- absence of fibrous, sticky, aggressive and explosive admixtures, as well as substances causing corrosion or chemical decomposition of fans;
- temperature of moved air not higher than 80 ˚C;
- concentration of dust and other solid particles not more than 100 mg/m3.

Use of conventional fans meets these conditions.

Given the aforesaid explanations, we should consider the use of low-pressure duct radial fans.

In order to reduce fan vibration transfer to the air duct, fans are mounted using sealing insulating tape.

The initial data for fan selection was:

- estimated air flow rate $L_{est}^{П1}$;
- total pressure losses in the system determined using formula 4

$$\Delta P_{П1} = \Delta P_c + \sum \Delta P_{об} \text{ , Pa,} \quad (4)$$

where ΔP_c – pressure losses in the air duct network determined by aerodynamic calculation, Pa;

$$\Delta P_c = 118$$

$\sum \Delta P_{об}$ - total pressure losses in installed equipment:

$$\sum \Delta P_{об} = \Delta P_{реш} + \Delta P_{кл} + \Delta P_{ф}^{кон} + \Delta P_{в.н.} + \Delta P_{ш} \text{ , Pa.}$$

$$\sum \Delta P_{об} = 40 + 3{,}1 + 340 + 50 + 44 = 478 \text{, Pa}$$

$$\Delta P_{П1} = 478 + 118{,}5 = 595{,}5 \text{, Pa}$$

A fan was selected according to the individual operating characteristics developed with consideration of the optimal technical and economic indicators. The use of several electric motor types with different consumed power and rotation speed is provided for each standard fan size.

A fan was selected as follows. The estimated capacity and total pressure losses in the system were used to find the coordinate intersection point on the fans' characteristics $L - \Delta P_{П1}$

If the point was located between the fans' operating characteristics, it was offset vertically onto the above-lying characteristic. The intersection of the vertical line, corresponding to the estimated air flow rate, and the fan characteristic makes it possible to determine the maximum possible fan head during movement of the given air flow rate. In other words, value of fan head $P_в$ when moving the estimated air amount shall exceed the total pressure losses in the system, i.e., the following conditions shall be met when selecting a fan: $P_в \geq \Delta P_{П1}$.

The fan operating parameters were determined for the finally selected fan model:

- fan head P_f= 630, Pa;
- electric motor electric power N = 14 W;
- mean electric motor speed n = 2650 rpm.

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The given fan shaft rotation speed n_2 is acceptable from the viewpoint of driven electric motor type and fan driving method (transmission). The operating point is within the zone of stable fan operation.

Thus, Profit 4 duct fan was selected for the determined parameters. The fan specifications are given in Table 2.

Table 2. Specifications of Profit 4 duct fan

Specification	Value
Depth, mm	80
Built-in depth, mm	80
Net weight, kg	0.314
Height, mm	103
Gross weight, kg	0.35
Power, W	14
Dust and moisture protection rating, IP	24
Noise level, Db	35
Diameter, mm	100
Width, mm	103
Type	axial

7. Conclusion

The parameters of the air path for the air flow distribution unit in the air conditioning system of the autonomous trigeneration system were calculated in the work. The total pressure losses in the natural ventilation channel were found to be equal to 0.85 Pa, at the speed of 100.8 m3/h. The aerodynamic constant of the network was found to be equal to 0.0084. The total pressure losses during air movement in the channel at various air speeds were 0.85 Pa. The fan operating parameters were determined: fan head Pf= 630, Pa; electric motor electric power N = 14 W; mean electric motor speed n = 2650 rpm. The characteristics of the selected fan, data obtained by calculation, will be used in calculation and determination of geometric characteristics of the air flow distribution unit in the air conditioning subsystem of the autonomous trigeneration system.

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