Verification of the ventilation dampers’ aerodynamic characteristics

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Abstract. Engineering solutions of air conditioning systems require the operation analysis and the aerodynamic characteristics verification of the ventilation dampers installed on ventilation, air heating, air conditioning, supply and exhaust smoke ventilation systems to prevent air overflow and combustion products from one room to another, as the dampers’ characteristics affect the systems’ technological reliability and energy efficiency as a whole. Thus, the leakage through the closed dampers leads to a decrease in the useful work of the ventilation unit, characterized by the efficiency coefficient, which is due to the mismatch between the actual and the calculated performance of the ventilation systems. This removes the fan operation from the optimal area. The non-tightness reasons of the ventilation dampers for various purposes were analyzed. To reveal these reasons, the experiments were carried at a laboratory-industrial stand. The use of modern computer programs for processing the experimental data made it possible to build the mathematical models providing the necessary conditions for the adequacy and reliability of the ventilation dampers’ studies. A visual description of the digitized three-dimensional flow in the investigated ventilation damper is given. This description can be used in the future to accurately assess the characteristics of ventilation dampers affecting the ventilation systems’ technological reliability and energy efficiency.

Introduction
The risk assessment of technological systems [1], including the ventilation systems, is based on the determination of both the probability and the size of the adverse effects of their action. Considering the harm due non-compliance with technical regulations, design and operational indicators, three main questions are analyzed: what can fail (hazard identification); the probability degree of the failure (frequency analysis); the consequences of this event (impact analysis).

In order to increase the ventilation systems’ efficiency, it is also necessary to analyze the cost of ensuring its technological reliability. For this purpose, the factors should be ranked and the main indicators should be divided into groups, for example, sanitary-hygienic reliability indicators, technological reliability indicators, and energy consumption indicators. An important condition for ensuring the ventilation systems’ technological reliability is to ensure their design parameters determined during design. In the air ducts’ sections of general ventilation, air heating systems, local air inleakage, air conditioning, emergency ventilation systems for regulation and the combustion products’ penetration prevention into the premises during fire, it is necessary to provide the additional devices (air dampers, closures, collectors, fire-fighting dampers, etc.) taking into account the functional purpose of the premises, functional fire hazard class and the categories on explosion-fire and fire hazard of premises according to the requirements [2].

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Discussion
The unidirectional valve’s installation should be provided for protection in case of non-working ventilation from the flow of harmful substances from one room to another, located on different floors, if the outdoor air flow in these rooms is determined from the harmful substances’ assimilation conditions.

The drawoffs’ transit sections of general ventilation systems, air heating, local exhausts, air conditioning, emergency ventilation, i.e. any ventilation systems with a standardized fire resistance limit should be provided according to the [3] air tightness class B. In other cases, the drawoffs sections may be taken as air tightness class A. Air leakage and air inleakage in plenum and exhaust installations, ventilation system elements should not exceed leakage values according to the air tightness class A.

The criterion for choosing the tightness class is also the permissible percentage of air leakage in the system under operating conditions (air intake in the equipment and drawoffs operating under reduced pressure, or air loss in the equipment and drawoffs operating under increased pressure) [4].

The total loss and air inleakage $L$, m$^3$/h, through the leakage in the drawoffs’ transit sections of each system (or the calculated part of the system) according to [5] should not exceed the air flow rate calculated by the formula.

$$L = f \Sigma A_i$$  \hspace{1cm} (1)

where $\Sigma A_i$ – is the total expanded area of all the drawoffs’ transit sections of one ventilation system (or the calculated part of the system), m$^2$;

$f$ – is the specific losses or air inleakage, m$^3$/h, per 1 m$^2$ of the air drawoff’s expanded area, calculated by the formula

$$f_i = n_i p$$  \hspace{1cm} (2)

where $n_i$ – denotes the indicator depending on the standardized class of the drawoffs’ system air-tightness (Table 1);

$p$ – is the average static pressure of the calculated (tested) part of the system, Pa.

| Tightness class | Indicator $n_i$ |
|----------------|----------------|
| A              | 0.097          |
| B              | 0.032          |
| C              | 0.011          |
| D              | 0.004          |

Different parts of the system may have different classes of tightness; each part should be calculated separately under the pressure provided in the design for this part [6].

To prevent the excessive energy losses and maintain the required airflow, the allowable leakage in the system should not exceed 6%.

Since the formula (1) implies the dependence of allowable total losses and air leakage on the total deployed area of all the drawoffs; transit sections in one system, it is obvious that for the extended systems with high productivity and, therefore, the significant drawoffs’ cross-sections, the air inleakage amount can exceed the permissible 6% of system performance.

The regulatory literature states that the tightness class is also regulated for equipment. Fans (including canal type), air conditioners, supply chambers, air heaters, heat exchangers, dust collectors,
filters, valves, silencers should be selected according to the estimated air flow taking into account air inleakage and losses due the equipment leakage - according to the manufacturer’s instructions or according to [7].

Air inleakage and air leakage through the fire dampers and exhaust and supply smoke ventilation drawoffs should be accepted in accordance with the requirements [4].

The reference in the standard to “inleakage and air leakage through the fire-fighting drawoffs” means that leakage requirements for the fire-fighting dampers exist in Russia, but air inleakage $G_{da}$, m$^3$/h through the closed fire-fighting dampers’ leakage are accepted according to the test samples’ specific smoke and gas permeability actual values and not more than defined by the formula:

$$G_{da} = F_d (\Delta P_d/S_d)^{0.5},$$  \hspace{0.5cm} (3)

where $F_d$ – is the flow area of the damper, m$^2$;  
$\Delta P_d$ – is the pressure difference in the closed damper, Pa;  
$S_d$ – is the specific characteristic of the damper smoke and gas permeability resistance, m$^3$/kg.

At the same time the minimum permissible value of smoke and gas permeability resistance for the dampers of different design cannot be more than 1,6–10$^3$ m$^3$/kg, and the maximum permissible value of gas flow through the closed damper (leakage) shall not exceed

$$Q_{damp, max} = 74,7 F_{damp} P_{damp}^{1/2},$$ \hspace{0.5cm} (4)

where $Q_{damp, max}$ – the maximum allowed gas consumption through the closed damper, m$^3$/h;  
$P_{damp}$ – is the overpressure on the damper, Pa;  
$F_{damp}$ – is a sectional area of the damper, m$^2$.

Thus, the standard instructions establish some limiting leakage values without analysis of their emergence reasons and the actions for their reduction.

The influence of the ventilation dampers’ characteristics on the technological reliability and energy efficiency of ventilation systems was investigated in [8, 9]. So, from the data shown on Table 2, obtained as a result of the production building ventilation systems’ certification, there follows a significant difference in useful work, characterized by the efficiency factors used in assessing the technological reliability of ventilation units and ventilation systems as a whole.

The main reason for this is the discrepancy between the actual and the calculated performance of the ventilation systems, therefore, the calculated fan flow, which leads it out of the optimal operation area due to the irrational changes in the network characteristics and the operating point movement.

The measurements showed that the main reason for this phenomenon, is the leakage of ventilation dampers for various purposes, which determined the need for a detailed study of their quality [10]. The criterion for choosing the tightness class is the permissible percentage of air leakage in the system under operating conditions (air inleakage in equipment and the drawoffs operating under reduced pressure, or air loss in equipment and drawoffs operating under increased pressure).

Total losses and air inleakage $L$, m$^3$/h, through the drawoffs’ leakage in each system (or the calculated part of the system) should not exceed the values according to GOST R EN 13779 (Formula 1).  

The method for testing the fire resistance dampers is described in GOST R 53301-2009 [9], and the provisions for studying the aerodynamic characteristics in EN1751 “Ventilation for buildings - Air terminal devices - Aerodynamic testing of damper and valves” were also taken into account as well as GOST 10921-90 “Radial and axial fans” [11, 12].

The laboratory and industrial stand on which the ventilation valves were tested is shown in Figure 1.

The procedure for testing dampers for fire resistance is described in [9], as well as provisions for investigation of aerodynamic characteristics of [11, 12].
For the ventilation dampers’ operation parameters physical modeling and the creation of various measurement conditions, the devices and measuring instruments were used, in particular, the pressure, humidity and temperature transmitter VIASALA PTU330 DO920002.

Table 2. Comparison of the ventilation systems $\eta_{sys}$, % and their fans’ $\eta_{fan}$ efficiency, %.

| Symbol | $\eta_{sys}$, % | $\eta_{fan}$, % | $\eta_{sys/fan}$, % |
|--------|----------------|----------------|-------------------|
| P-1    | 21             | 73             | 0.28              |
| P-2    | 18.2           | 74             | 0.25              |
| P-3    | 20.52          | 73             | 0.28              |
| P-4    | 18.14          | 74             | 0.25              |
| P-5    | 15.46          | 71.4           | 0.22              |
| V-1    | 56.06          | 83             | 0.68              |
| V-2    | 56.06          | 83             | 0.68              |
| V-3    | 50.18          | 81             | 0.62              |
| V-4    | 50.18          | 81             | 0.62              |
| V-5    | 31.43          | 73             | 0.43              |
| V-6    | 28.78          | 72             | 0.40              |
| V-7    | 55.81          | 84             | 0.66              |

The laboratory-industrial stand where the ventilation dampers were tested is shown in Figure 1.

Figure 1. Aerodynamic laboratory and industrial stand.

The test results of the ventilation damper type KL-0.71 are summarized in Table 3. A graphical interpretation of the results is presented in Figures 2 and 3. In order to obtain the full information about the flow pattern, it is necessary to know the flow rate at each point of the device and to create a velocity profile [13, 14, 15]. The velocity profile is described by the functions containing at least three coordinates. In a transient flow, the time function should be added. The description of the velocity profile is made in the form of systems of differential equations in partial derivatives. It is extremely difficult to calculate this system. The experimental solution to the problem of measuring velocities in all parts of the flow is very time consuming, especially since it is not possible everywhere to measure velocity without disrupting the
flow structure. In addition, the solution of practical problems with the help of the speed field is possible only in principle [16].

**Table 3. Ventilation damper test results.**

| No. | P, Pa | Pm, Pa | T2, °C | T1, °C | Q, m³/c | Pv, Pa | V, m/s | ξ |
|-----|-------|--------|--------|--------|---------|--------|--------|---|
| 1   | 897   | 153    | 20.4   | 20.3   | 14 853  | 196    | 8.18   | 4 |
| 2   | 771   | 151    | 20.5   | 20.3   | 13 774  | 188    | 7.59   | 5 |
| 3   | 640   | 144    | 20.6   | 20.4   | 12 575  | 175    | 6.93   | 5 |
| 4   | 526   | 136    | 20.6   | 20.5   | 11 380  | 161    | 6.27   | 6 |
| 5   | 416   | 127    | 20.7   | 20.5   | 10 123  | 147    | 5.58   | 7 |
| 6   | 327   | 119    | 20.8   | 20.5   | 8 977   | 135    | 4.95   | 8 |
| 7   | 249   | 110    | 20.8   | 20.5   | 7 833   | 122    | 4.32   | 10 |
| 8   | 207   | 104    | 20.9   | 20.7   | 7 144   | 114    | 3.94   | 11 |
| 9   | 165   | 96     | 21     | 20.7   | 6 380   | 104    | 3.52   | 13 |
| 10  | 129   | 88     | 21.1   | 20.7   | 5 642   | 94     | 3.11   | 16 |
| 11  | 121   | 87     | 21.3   | 20.7   | 5 469   | 93     | 3.01   | 16 |
| 12  | 118   | 85     | 21.4   | 20.7   | 5 402   | 91     | 2.98   | 16 |
| 13  | 63    | 72     | 21.5   | 20.7   | 3 948   | 75     | 2.18   | 26 |
| 14  | 54    | 69     | 21.5   | 20.7   | 3 655   | 72     | 2.01   | 29 |
| 15  | 52    | 66     | 21.8   | 20.8   | 3 591   | 69     | 1.98   | 29 |
| 16  | 40    | 53     | 21.8   | 20.8   | 3 149   | 55     | 1.74   | 30 |
| 17  | 19    | 40     | 22     | 20.8   | 2 171   | 41     | 1.20   | 48 |
| 18  | 16    | 38     | 22.3   | 20.8   | 1 994   | 39     | 1.10   | 54 |
| 19  | 12    | 30     | 22.5   | 20.9   | 1 728   | 31     | 0.95   | 57 |
| 20  | 8     | 22     | 22.8   | 20.8   | 1 412   | 22     | 0.78   | 62 |
| 21  | 6     | 19     | 22.9   | 20.8   | 1 224   | 19     | 0.67   | 72 |
| 22  | 5     | 17     | 23.1   | 20.9   | 1 118   | 17     | 0.62   | 77 |
| 23  | 4     | 15     | 23.3   | 20.9   | 1 000   | 15     | 0.55   | 85 |
| 24  | 3     | 11     | 23.3   | 20.9   | 866     | 11     | 0.48   | 83 |
| 25  | 0     | 11     | 23.2   | 20.9   | 0       | 11     | 0.00   | 249 |
| 26  | 0     | 5      | 23.1   | 21     | 0       | 5      | 0.00   | 227 |

In computer modeling, it is necessary to write program code, which should present the properties of the materials, physical processes, the different characteristics’ dependencies on each other [17, 18]. The work used a software complex SolidWorks, which provides the products’ development of any degree of complexity and purpose, has a possibility to analyze various physical phenomena and characteristics, including in the field of gas and hydrodynamics when setting the boundary conditions in accordance with the study objectives [19, 20]. Figures 4-7 show various implementations of such studies to determine the velocity distribution in order to give the most accurate assessment of the damper under investigation [21].
Figure 2. The dependence of the damper KL-0.71 aerodynamic resistance on the capacity.

Figure 3. Dependence of the KL-0.71 damper aerodynamic resistance from the average speed in the element.

Figure 4. Full pressure field in the damper section (Blades’ position - A "completely open").

Figure 5. Full pressure field in the damper section (Blades’ position - B “50% closed”).
Summary

The various alternatives’ visual representation of the processes under study is the digitized three-dimensional flow description results’ visualization in the object under study in its dynamic development and can be used in further analysis of the ventilation dampers’ characteristics in order to increase their technological reliability and in the development of new designs that fully meet the increasing requirements for ventilation systems.

References

[1] GOST R 51901.1 - 2002 Risk management. Risk analysis of technological systems (Moscow)
[2] SP 60.13330.2016. Heating, ventilation and air conditioning. Updated edition of SNiP 41-01-2003. - Enter. 2017-06-17 (Moscow)
[3] SP 7.13130.2013 Heating, ventilation and air conditioning. Fire safety requirements (Moscow)
[4] GOST R EN 13779-2007 Ventilation in non-residential buildings. Technical requirements for ventilation and air conditioning systems (Moscow)
[5] GOST R 53301-2009 Dampers fire ventilation systems. Test method for fire resistance (Moscow)
[6] Timoshenko V N 2005 Aerodynamic characteristics of ventilation system fire dampers Ventilation AVOK 3.
[7] Bolomatov V N 2017 Air tightness: problems and solutions Ventilation. Heating. Air conditioning: AVOK 6.
[8] GOST 10921-90 Radial and axial fans. Aerodynamic test methods (Moscow)
[9] GOST_12.3.018-79 Occupational safety standards system (SSBT). Ventilation systems. Aerodynamic test methods (Moscow)
[10] DIN EN 15727-2010 Ventilation for buildings - Ducts and ductwork components, leakage classification and testing; German version
[11] EN ISO 5167-1 (2003-03) Measuring the flow and quantity of liquids and gases using standard constricting devices
[12] CEN EN ISO 5167-2-2003 Measurement of fluid flow by means of pressure differential devices inserted in circular cross-section conduits running full 2 (ISO 5167-2:2003)
[13] CEN EN 12792-2003 Ventilation for buildings. Symbols, terminology and graphical symbols
[14] GOST 8.586.2-2005 (ISO 5167-2: 2003) Measurement of the flow rate and amount of liquids and gases using standard constricting devices 2 Diaphragms Technical requirements (Moscow)
[15] GOST R EN 12238-2012 Ventilation of buildings. Air distribution devices. Aerodynamic testing and application evaluation for mixing ventilation (Moscow)
[16] GOST 8.586.3-2005 (ISO 5167-3: 2003) State system for ensuring the uniformity of measurements (GSI). Measurement of the flow rate and amount of liquids and gases using standard constricting devices. Nozzles and Venturi nozzles. Technical requirements (as amended) (Moscow)

[17] ISO 3966(2008-07) Measurement of fluid flow in closed conduits - Velocity area method using Pitot static tubes

[18] GOST 31.96-2012 Industrial fans (Moscow)

[19] DIN EN 1751-2014 Ventilation for buildings - Air terminal devices - Aerodynamic testing of damper and dampers

[20] Burtsev S I, Denisikhina D M 2006 Mathematical modeling of turbulent transfer processes in the professional practice of ventilation and air conditioning technology ABOK 5 40-49

[21] GOST 32549-2013 (EN 12239: 2001) Ventilation of buildings. Air distribution devices. Aerodynamic tests and appraisal for displacement ventilation (Moscow)