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AIR FLOW IN AN INDUSTRIAL VENTILATION SYSTEM

ABSTRACT *Ventilation devices are produced in large quantities therefore it is desirable to reduce the power consumption of their damper actuators. The electric power consumed by the actuators depends on the size of the damper and to some extent on the pressure generated by the air stream flowing through the ventilation ducts. The air pressure mainly depends on the air flow rate inside the duct and varies with changes in the damper angle settings. The article presents the results of air flow simulations in a ventilation duct and the resulting torque acting on a damper installed symmetrically in relation to the axis of the air duct.*

Keywords: *dampers, damper actuators, air duct*
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1. INTRODUCTION

The number of devices installed to control humidity and temperature indoors, in industry and others areas is very large so the issue of limiting the power consumption of damper actuators is very important. One of the factors that determines the power consumption of these devices is the pressure on the damper blade caused by the air flowing through the ventilation duct. The flow of air through the ventilation ducts is usually unforced and results from the difference between the internal and external air pressures. This applies in a residential area or in premises with a low degree of pollution. In an environment such as large conference rooms or in industrial facilities it is necessary to use forced air flow [1, 2]. In these cases, the velocity of the air stream pushing the damper blades in the ventilation duct is a decisive factor in terms of actuator selection.

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The aim of this study was to analyze the speed of the air flow in the duct and the resulting pressure on damper blades. Simulations were carried out on a two-dimensional mathematical model of a ventilation duct. The movement of air in the test section is described using the Navier-Stokes equations. The ANSIS Type Fluid Flow and Fluid Element Type 2D-planar computer programs were used. For these calculations different assumed values were specified, such as the damper position indicated by the angles (β) (Fig. 1), air velocity in the ventilation duct calculated to a plane perpendicular to the axis of the ventilation duct, and the cross section of the duct.

Changes in the damper position (β) depend upon the humidity and temperature desired in the ventilated area, or depends upon the content of CO_2 or other gases, and occurs as a result of the damper actuator being switched on and off. Any change in the damper position is followed by a change in the air pressure on the surface of the damper blade. Therefore to choose an actuator of the appropriate power, the degree of air pressure and the resulting changes in torque on the damper blade should be analyzed. In large industrial plants, where the technological processes depend on carefully selected climatic conditions, the actuators are often in use and hence their power consumption is significant.

2. ASSUMPTIONS MADE FOR THE CALCULATIONS

In the Type Fluid computer program the Navier-Stokes equations was used with the following assumptions:

- a steady state of the air flow,
- a constant air temperature in the ventilation duct,
- fixed atmospheric pressure at the outlet of the air duct,
- the specific gravity of the air equal to 1.2 kg/m^3 with a viscosity of 18.053e-6 Pa s,
- the surfaces of the ventilation duct and the damper are smooth,
- the ventilation duct has a square cross-section,
- the velocity vector at the ventilation duct inlet has the same value throughout the entire duct area. This means that at all the nodes of the mesh used in the computer program for the entire air duct cross section (at the inlet, except for the duct walls), the length and direction of the velocity vectors are equal,
- the speed (v) of the air flow in the duct (Fig. 1) varies from 1 m/s to 10 m/s;
- the ventilation duct section is not subject to gravitational forces,
- the surface of the damper has dimensions of either 1 m^2 or 0.36 m^2 and the thickness of the damper blade is equal to 2 mm,
- the influence of air humidity on the value of the forces acting on the damper was ignored.

Figure 1 shows a model of part of a ventilation duct with a square cross-section with angles α, β indicating different damper positions, relative to a plane perpendicular to the axis of the duct.

For the initial conditions established above, calculations were made for different values of the air velocity (v), specifically for v = 10 m/s, 5 m/s and 1 m/s.

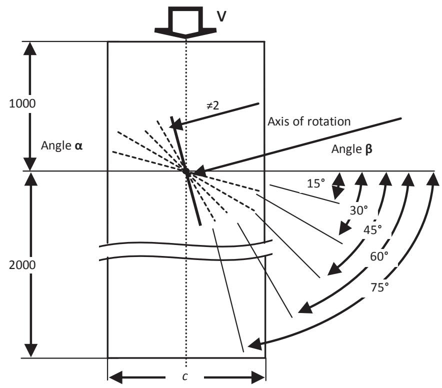

Fig. 1. Model section of the ventilation duct with the indicated direction of air flow and damper positions. The damper can change its position about an axis of symmetry in terms of the angle *β* from closed *β* = 0° to fully open when *β* = 90°; *c* – width of the square ventilation duct – equal to 600 mm, and 1000 mm

The results of the calculations for the air velocity distribution inside the duct are in Figures 3 and 4 for ventilation ducts with cross sections of 0.36 m^2 and 1 m^2. These Figures show the air velocity (*v*) distribution along a straight line extended from one wall of the ventilation duct to the other, parallel to the surface of the damper (see Fig. 2). In the length of the damper is indicated by the line from letters *a* to *b* (Fig. 2), and the length of this line extended to the walls of the ventilation duct by letters *c* and *d*. At the diagrams in Figures 3 and 4, there is shown the air velocity distribution at different damper setting angles, in this case for angles from 30° to 75°.

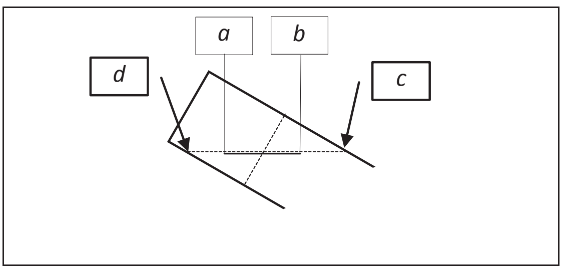

Fig. 2. Damper from point *a*, to point *b*, at an angle *β* = 45°; the line from *c* to *d*, parallel to the damper surface and extended to the side walls of the air duct, defines the range used for the calculations

Considering the results received for a ventilation duct with a cross-section of 0.36 m^2 one can observe that with changes in the damper angle *β* (Fig. 1) the air velocity distribution along a plane contiguous with the damper surface but 5 mm above the dumper surface and extended to the walls of the air duct changes. The point of the minimum air velocity on the damper surface, with the decrease of angle *β*, moves along the damper surface from point a, towards the centre (see Fig. 3). This point of minimum air velocity moves similarly for larger 1 m^2 cross section of the ventilation duct (Fig. 4). The minimum speed of the air on the surface of the damper moves with a decrease in angle *β* toward the centre.

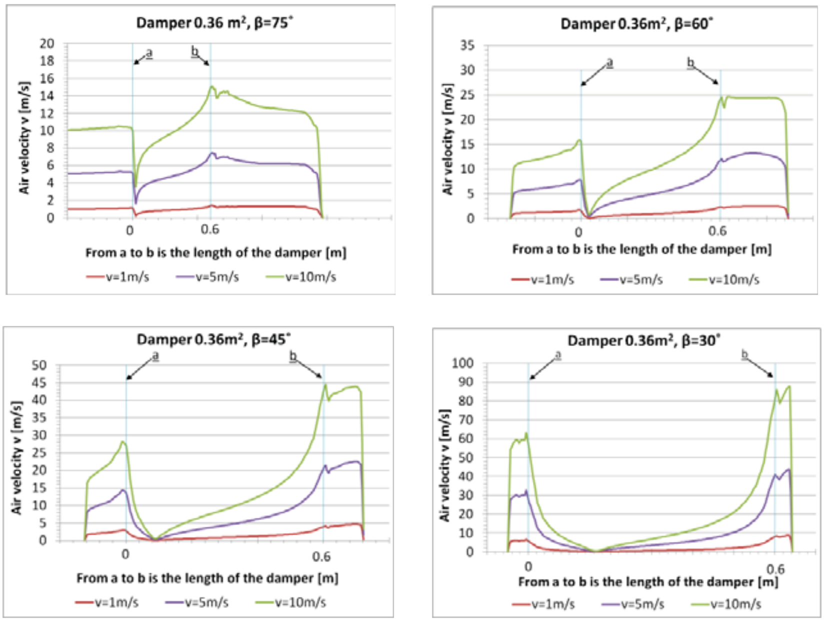

Fig. 3. Air velocity distribution along a line parallel to the damper surface The damper is placed between points 0 and 0.6

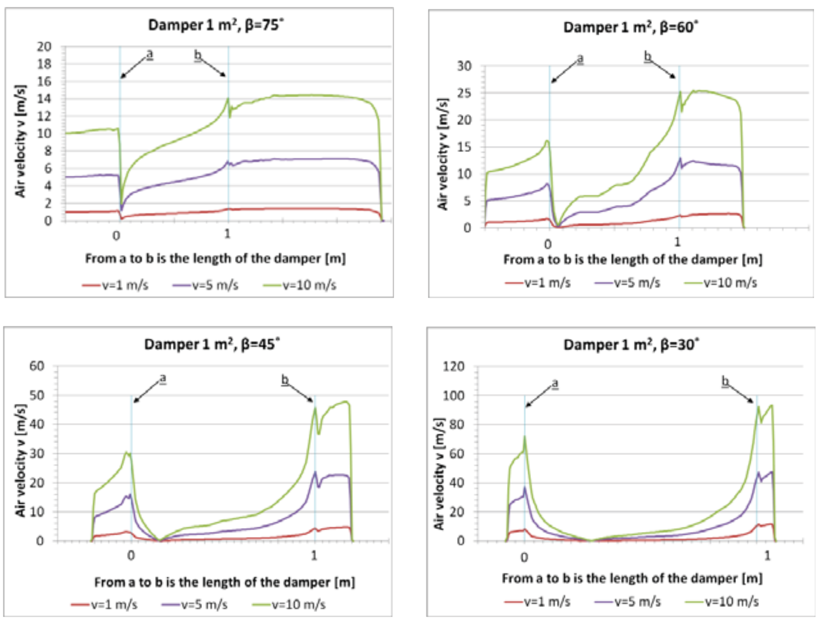

Fig. 4. Air velocity distribution along a line parallel to the damper surface Damper is placed between points 0 and 1

The calculated rates of the air flow velocity for the air duct $S = 0.36\ \text{m}^2$ and $S = 1\ \text{m}^2$ along a straight line 5 mm above the damper surface extended to the side walls of the duct, for several values of angle β between 75° and 30° are in Figures 3 and 4. The area occupied by the damper itself runs from point *a* to point *b* Figure 3. The air velocity distribution along a line parallel to the damper surface changes from 0 to 0.6 (Fig. 3) and than on both sides of the dumper till the side walls of the air duct rises with β decrease.

Similarly the calculated rates of the air flow velocity from the air duct inlet of $S = 1\ \text{m}^2$ along a straight line 5 mm above the damper surface extended to the side walls of the duct, for several values of angle β from 75° to 30° is in Figure 4. The area occupied by the damper runs from point 0 to point 1 (Fig. 4). The air velocity, behind the dumper surface, along a line parallel to the damper surface and extended to the side walls of the air duct rises with β decrease (Fig. 4).

4. CALCULATION OF THE FORCE ACTING ON THE SURFACE OF THE DAMPER

The above calculation results of the air velocity distribution in the ventilation duct were used to determine the distribution of the air pressure at every points not on the damper's surface but along the entire line parallel to this surface and extended to the walls of the duct. The calculated air velocity and air pressure along the surface of the damper for an example setting at angle $\beta = 60°$ is shown in Figure 5.

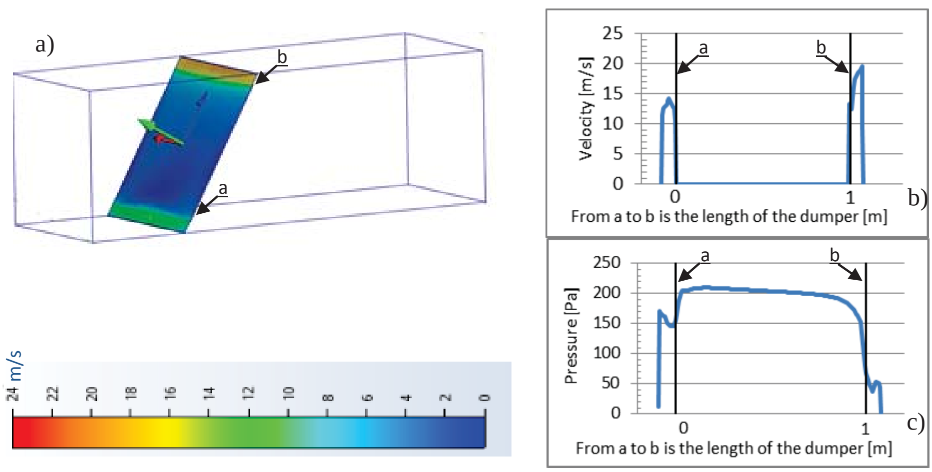

Fig. 5a. Air duct with the damper set at $\beta = 60°$, calculated air velocity distribution and pressure of the air acting along a straight line contiguous with the damper surface and extended to the walls of the ventilation duct (Fig. 5c)

With the damper set at an angle of 60° to the axis of the ventilation duct (Fig. 5a), the velocity (*v*) (Fig. 5b) of the air flowing on the side of the damper angle (*β*) (see Fig. 1) is greater than the air speed on the other side. In addition the pressure acting on the side of the damper angle (*α*) is higher than on the side of the angle (*β*) (Fig. 5c). The increased air pressure on one side of the angle (*α*) causes an imbalance in the air pressure on the damper blades and therefore generates asymmetry and torque, which must be overcome by the actuator.

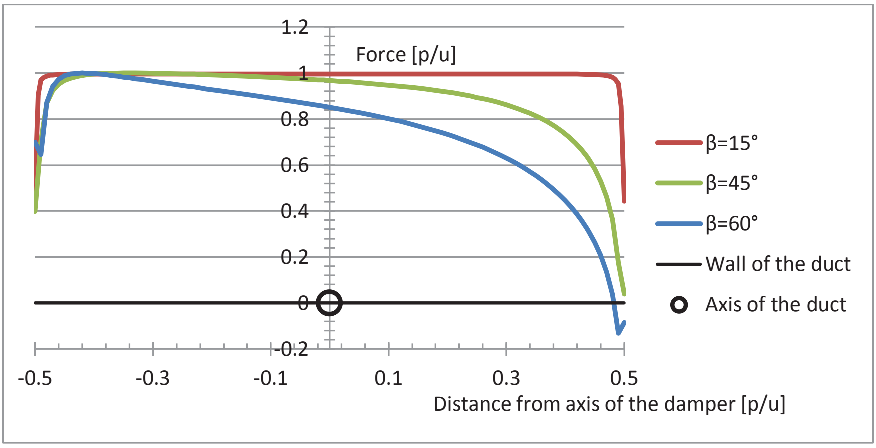

Fig. 6. Forces along a line perpendicular to the axis of the damper position for *β* = 15°, *β* = 45°and *β* = 60°

The distribution of the force produced by the air acting perpendicular to the surface of the damper at different damper angles *β*, as a function of the distance from its axis of rotation, varies according to Figure 6. (The simulation results are expressed in relative units).

As a result of the analysis performed above, it should be emphasized that the force, and the torque, acting on the damper increases as angle *β* increases.

5. CALCULATIONS OF THE TORQUE ACTING ON THE SURFACE OF THE DAMPER

In view of the above results of the calculations of the air velocity distribution it was possible to determine the torque acting on the damper as a function of different damper angles *β*, from 15°to 75° (see Fig. 7) and for air duct areas of 0.36 m^2 and 1 m^2 (Fig. 8).

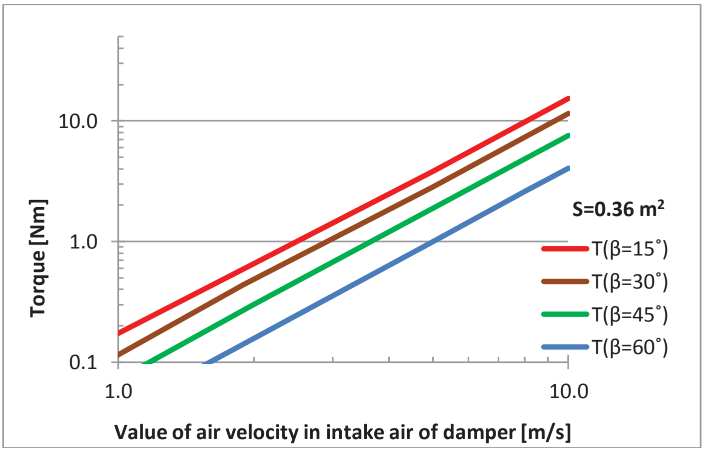

Fig. 7. Torque values as a function of the air flow velocity (*v*), acting on the damper in a ventilation duct with a cross section *S* = 0.36 m^2 for different angle values (*β*)

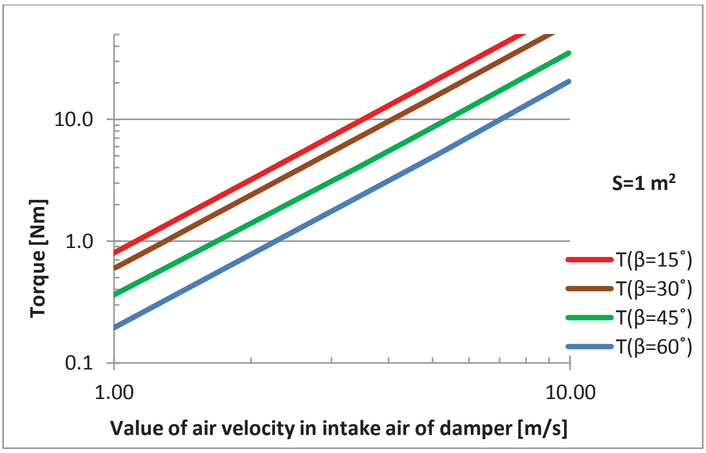

Fig. 8. Torque values as a function of the air flow velocity (*v*), acting on the damper in a ventilation duct of a cross section *S* = 1 m^2 for different angle values (*β*)

6. COMPARISON BETWEEN THE CALCULATED AND MEASURED TORQUE

To evaluate the results received by the computer simulation method were compared with results received experimentally. Measurements were made by Mrs. Paulina Kosowska at the Cracow University of Technology [9] but for a different air duct cross section and for different air velocities. Therefore, to match these measurement conditions, with the simulations of the air flow over a damper placed symmetrically in a duct were made for air velocity in the ventilation duct inlet of v = 4 m/s and v = 6 m/s and for a flat damper with the dimensions 0.2 m × 0.35 m × 0.002 m. A comparison of the calculation results with the laboratory measurements was made are shown in Figure 9 and in Table 1.

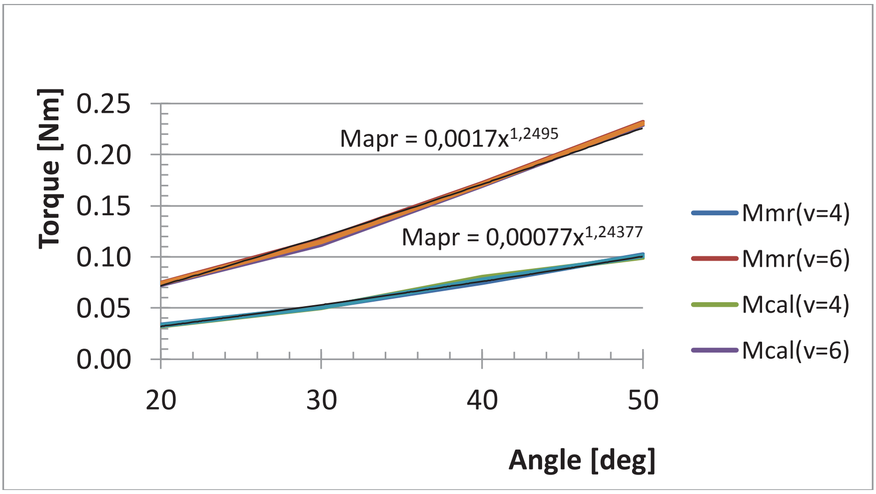

Fig. 9. Comparison of the calculations done in the Electrotechnical Institute and the measurements made in the Cracow University of Technology for a damper of 0.2 m × 0.35 m × 0.002 m subjected to air velocities of v = 4 m/s and v = 6 m/s

Table 1

***v* [m/s]**	4	4	4	4	6	6	6	6
β	70°	60°	50°	40°	70°	60°	50°	40°
M_{cal} [Nm]	0.030	0.054	0.076	0.103	0.066	0.116	0.171	0.239
M_{mr} [Nm]	0.033	0.051	0.075	0.102	0.075	0.117	0.172	0.232

Table 1 contains the values of the torque measured (M_{mr}) [9], calculated (M_{cal}) acting on a damper with dimensions 0.2 × 0.35 × 0.002 m set at angles from β = 40° to β = 70° at air flows velocity v = 4 m/s and 6 m/s on inlet of the air duct. The results are plotted as functions $M = f(\beta)$ for the two air velocities and approximated by means of the equations given on Figure 9.

It can be seen that with the simulation method used it is possible to determine, with a good degree of accuracy, the value of the torque that is acting on the surface of the damper due to the air flowing in the ventilation duct.

7. CONCLUSIONS

The calculation of the impact of the air flowing in straight ventilation ducts was performed for model ducts. Calculating the velocity and pressure of the air acting on the damper determine the changes in the torque acting on the damper, and this in turn enables to identify of the required power of the actuator.

The graphs Figures 7 and 8 of the torque acting on the dumper surface depend largely on the speed of the air in the duct, the dimensions and the angle of the damper position. With an increase in cross-section of the duct increases the dumper surface and thus the torque acting on the damper blades. We believe that for the dampers having a significant impact of the air flow on the blades and thus with significant torque of this impact it would be reasonable to reduce the load by modification of the dumper it self.

The distribution of air velocity and air pressure on the damper surface at different angles (β), and different preset air speed values (from 2 m/s up to 10 m/s) for two different ventilation duct cross section values of $S = 1\ m^2$ and $S = 0.36\ m^2$ were made. On the basis of the calculation results it can be stated that:

- With the air flow in the duct at a constant speed increasing damper angle β increases the torque acting on the damper and thus increases the actuator power required to overcome this torque. A reduction in the air velocity results in a reduction in the torque.
- With a reduction in the cross section of the ventilation duct while retaining the same air flow speed, the torque on the damper decreases.
- The position of the minimum air velocity acting on the damper surface changes according to the setting of angle β. The minimum speed of the air on the surface of the damper moves with a decrease in angle β in the direction to the axis.
- When the damper position is fully closed or fully open the torque acting on the damper is in both cases $M = 0$.
- With the increase of the air velocity at the inlet at the ventilation duct the adiabatic process should be considered.

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PRZEPŁYW POWIETRZA W PRZEMYSŁOWYM UKŁADZIE WENTYLACYJNYM

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STRESZCZENIE *Urządzenia klimatyzacyjne są produkowane w bardzo dużych ilościach i należy dążyć do zmniejszenia poboru mocy ich siłowników. Zużycie energii przez siłowniki zależy od wymiarów przepustnic i w pewnym stopniu od nacisku powietrza wymuszanego przez wentylatory w kanale wentylacyjnym. Ponadto nacisk powietrza zależy od kąta ustawienia przepustnicy. W artykule obliczono nacisk powietrza na przepustnicę instalowaną symetrycznie w kanale wentylacyjnym i wynikający z tego moment obrotowy przepustnicy.*

Słowa kluczowe: *przepustnice, siłowniki, kanał wentylacyjny*