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Air torque position damper energy consumption analysis

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ABSTRACT

The damper used for the control of airflow in heating, ventilation and air conditioning systems can constructively be adapted to measure the air velocity with its moment characteristic. It is a device that indirectly determines the air velocity by measuring the position of the blades and the air stream moment acting on it. The subject of this paper is energy consumption of the air torque position damper depending on its structure. The aim is to compare the energy consumption of four possible types of dampers with non-cascading blades: with one blade, with two cross-guided blades, with two parallels-guided blades and with two blades, one of which is a measuring blade and the other remains fixed in horizontal position. The case when there is a straight section of a duct both in front of and behind the damper was considered. Adequacy of the existing mathematical model and energy consumption for all four types of dampers was determined experimentally. It was found that the damper with two blades of which one is a measuring blade and other remains fixed in horizontal position had minimal energy consumption.

1. Introduction

A need for simple measurement of airflow rate motivated researchers to examine the possibility of using dampers as a measuring device. Dampers are otherwise used in Heating Ventilation Air-Conditioning systems (HVAC) to control the airflow rate. Air torque position (ATP) damper is a device that can be used to measure the velocity of air indirectly in HVAC systems by measuring the position of the blade and the moment (torque) of air acting on blade. On the basis of the measured air velocity, the airflow rate can be determined from the continuity equation. This measuring device was developed as a result of scientists' aspiration to predict the moment characteristic of a butterfly valve.

In the beginning, researchers were focusing on the moment characteristic of the butterfly valve and they were making theoretical predictions [1–4]. The first author who experimentally verified the mathematical model of the moment characteristics of the butterfly valve was Sarpkaya [5,6]. He developed and verified the mathematical model of the moment characteristic of the butterfly valve with a thin blade, under the assumption that the airflow is irrotational and incompressible. Hasennpflug [7] corrected Sarpkaya's mathematical model by using the potential flow theory. Morris et al. [8] developed a mathematical model of the moment characteristics of the butterfly valve by taking into account the compressibility of the fluid.

Federspiel applied the knowledge and experience collected in the field of prediction of the moment characteristic of the butterfly valve to design and develop the ATP damper. He extended the mathematical models of Sarpkaya and Hasennpflug to make them applicable for the damper with more blades, as well as for the case when the axis of rotation is dislocated from the axis of the blade in longitudinal and transverse directions [9]. In the process of development of the mathematical model, Federspiel considered the case of irrotational and incompressible flow of air around one blade of the damper, Fig. 1.

Federspiel developed the mathematical model by using basic equations of fluid mechanics: the equation of continuity, Bernoulli equation and the momentum equation. Regulation dampers in HVAC systems are installed in three positions: with the straight duct section in front of the damper placed at the outlet of the duct, with the straight duct section behind the damper placed at the entrance of the duct and with straight duct sections both in front of and behind the damper.

For all three positions of the ATP damper in HVAC systems, Federspiel [9] discovered the same correlation between the air velocity v in front of the damper, the blade angle of attack α and the moment of air stream acting on the blade M:

$$v|v| = G^2(\alpha)\frac{2M}{\rho A_u D_h}. \quad (1)$$

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Nomenclature

A	cross section area [m^2]
b	side of a square [m]
B	blade width [m]
C_Q	flow coefficient [–]
d	distance between the force point of attack and blade center [m]
D	diameter [m]
D_h	hydraulic diameter [m]
F	force [N]
g	gravitational acceleration [m/s^2]
G	correlation function [–]
H	duct height [m]
l	length of leverage [m]
L	blade length [m]
m	mass [kg]
M	moment [N m]
Q	volumetric flow rate [m^3/s]
p	pressure [Pa]
P	power of flow [W]
p_m	gauge [Pa]
p_a	atmospheric pressure [Pa]
t	temperature [°C]
v	velocity [m/s]
W	blade thickness [m]
x	the longitudinal distance from the axle to the center of pressure [m]
y	the lateral distance from the axle to the center of pressure [m]

Greek symbols

α	angle of attack (measured from horizontal plane) [°]
δ	distances between center of axle and damper blade, normal to damper blade [m]
Δ	distances between center of axle and damper blade, along to damper blade [m]
Δp	pressure drop [Pa]
ΔP	power loss of ATP damper [W]
ε	relative power loss [–]
ρ	air density [kg m^{-3}]
γ	moment correction factor [–]
φ	angle of attack (measured from vertical plane) [°]

Subscripts, superscripts

1	location of air velocity measurement, blade
2	location immediately in front of a damper blade, blade supporter
a	longitudinal
C	center of axle blade
c	contraction
D	center of the pressure
d	downstream, dead
l	lateral
mer	measured
u	upper stream
n	normal
p	pressure
O	center of axle

The denominator of the mathematical model Eq. (1) is the density of air ρ. By placing sensors to measure the pressure and temperature of the air stream directly in front of the blade of the ATP damper, air density ρ can be calculated from the equation of the state for an ideal gas. In this way, air velocities can be measured with an ATP damper at different operating conditions.

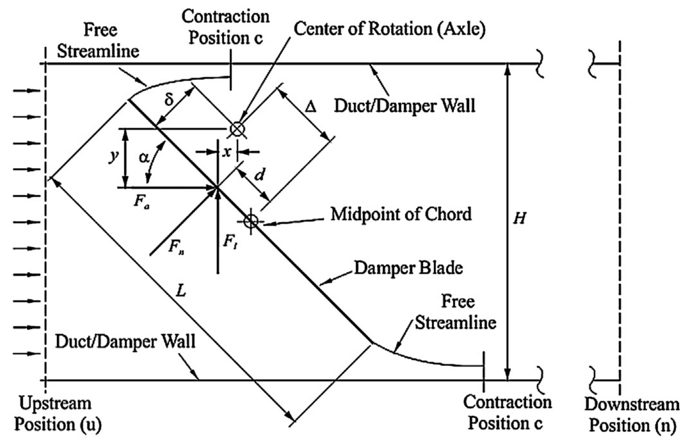

Fig. 1. Schematic presentation of the ATP damper with a single blade [9].

The correlation function Eq. (1) is [9]:

$$G(\alpha)=\left(\frac{D_h}{y/C_{Q,a}^2+x/C_{Q,l}^2\cdot tg\alpha}\right)^{1/2}. \qquad (2)$$

The correlation function depends on the damper's blade angle of attack. It is a semi-empirical mathematical model, because its variables, the longitudinal flow coefficient $C_{Q,a}$ and the lateral flow coefficient $C_{Q,l}$, have to be determined experimentally.

Federspiel conducted the verification of the mathematical model Eq. (1) with the damper which had following characteristics: square cross section of 0.61 m × 0.61 m, straight duct section behind the damper placed at the entrance of the duct, four oppositely driven plane blades (cascading blades). He verified the mathematical model that can be used to accurately measure the air velocity at different operating conditions. The difference between the measured and the model velocity was ±10% of the measured velocity or ±5% of the full scale [10]. It was also found that, when the ATP damper was opened more than 70%, local resistance behind the damper had a significant impact on the measurement accuracy and adequacy of the mathematical model [10].

Damper blades placed in the air stream, as well as the duct itself, produce resistance against the airflow and hence comes the energy loss. So far, there was no research on the subject of the ATP damper's energy consumption. Nowadays, due to high energy costs, a lot of attention is focused on energy and the reduction of energy consumption. For this reason, the subject of this research is focused on energy consumption of this type of damper.

Becelaere analyzed the effect of different constructions of regulation dampers on its characteristics [11]. Among other things, he found that dampers with cross-guided blades have higher pressures than dampers with parallels-guided blades. As a result, the airflow rate in systems with cross-guided blades is lower. According to the analogy with the damper used to regulate the airflow rate, it is expected that the design of the ATP damper has an impact on its characteristics. The main hypothesis of this paper is that the design of the ATP damper can significantly reduce its energy consumption without affecting the functionality and accuracy of air velocity measurement.

The aim of the study was to analyze the energy consumption of structurally different types of ATP dampers and determine which type of damper has the lowest energy consumption, while maintaining the functionality and accuracy of air velocity measurement under different conditions.