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Survey of Control Characteristics of Circular Air Dampers in Variable Air Volume Ventilation Systems

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Abstract

Due to the fact that importance of energy efficiency of building services is consistently growing also demand based VAV ventilation systems are becoming more common. Almost all available terminal VAV dampers on the market are single blade dampers, but is this damper configuration the most suitable for VAV functionality? The aim of this study was to test the control characteristics of the most widespread circular damper configurations. The results show that under typical operation conditions IRIS diaphragm type damper control characteristics are the most suitable for VAV functionality in means of linearity between damper opening position and relative air flow.

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Keywords: Variable air volume; VAV dampers; VAV system control.

1. Introduction

Variable air volume (VAV) systems are getting more widespread over Europe due to their advantage to control ventilation rates in every room individually according to the actual requirements therefore avoiding unnecessary high ventilation rates at low occupancy periods and saving energy [1] [2].

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Nomenclature

A	Damper authority factor in a particular ventilation system
dP_{damper}	Pressure drop in the damper at rated air flow at fully opened position, Pa
dP_{system}	Pressure drop across rest of the system, Pa (between the two points where constant pressure drop is maintained)
P1-P4	Total pressure measuring probes
D1	Tested VAV damper
D2-D3	Balancing dampers
BD	Bypass damper
F1	Fan
FM	Air flow measuring probe

Two of the reasons for the increasing VAV system popularity are the Building energy efficiency tendencies in Europe: the Energy Performance of Buildings Directive (EPBD) recast [3] and the Ecodesign requirements for ventilation units [4]. Also research suggests that in office buildings HVAC systems are responsible only for 1.5% of embodied energy [5] but more than half of operational energy. Large scale implementation of VAV systems also would greatly contribute to buildings life-cycle energy consumption.

In some countries VAV systems or in means of energy efficiency equally efficient ventilations systems for some applications are a national code requirement for example Energieeinsparverordnung (EnEV) energy standard in Germany [6] and ASHRAE Standard 90.1 in the USA [7].

The performance of VAV dampers influences the overall system efficiency, life span and the stability. The performance of VAV dampers can be understood as the capability to measure and control the air flow precisely. Which can be done if there is a certain degree of linearity between the relative air flow and relative damper position. The damper control linearity is mostly influenced by damper configuration and its authority factor in the system. Although in literature for different types of dampers different recommendations to achieve best control characteristics can be found. For the droplet shaped damper the recommended minimum differential pressure is 5Pa [8]. For rectangular multiblade dampers recommending limitations of authority factor in the system [9] [10]. There is a lack of studies where control characteristics of different configuration VAV dampers can be compared under similar operating conditions. The information of damper control characteristics is necessary to optimize the damper performance and avoid long periods of damper operation in weak control region.

The aim of this study was to compare control characteristics of different types of dampers under different authority levels and air velocities and to describe regions of optimal control for each damper type individually. The specific objectives for this study were:

1. Construct an experimental ductwork system;
2. Experimentally measure the control curves for:
    a. Single blade damper with high leakage (leaky damper);
    b. Single blade damper with low leakage (tight damper);
    c. Damper with an IRIS type diaphragm [11];
    d. Conical diaphragm damper. (The lamellas of the diaphragm is placed in a conical pattern) [12];
3. Describe operational conditions under which optimal control can be achieved.

2. Methodology

A special air duct system with air flow and pressure measuring equipment was constructed to simulate conditions for the measurements. To avoid pressure reading errors in the duct system a CFD simulation was performed, in order to validate air velocity profile in points where pressure reading probes were placed. Autodesk Simulation CFD 2013 Version 13.1 was used to perform CFD analysis. The experiments were conducted for 125mm diameter circular dampers under different air velocities and different damper authority factors. The damper authority in a particular system can be described with the following formula [13]:

$$A = \frac{dP_{damper}}{dP_{system}} \tag{1}$$

Damper operation in a ventilation system was simulated by keeping constant pressure drop between two pressure reading probes P1(or P2) and P4 while closing the VAV damper D1. Dampers D2 and D3 were used to generate additional pressure drop in the duct system thus changing the (D1) authority level.

While closing the VAV damper D1 and keeping constant pressure drop across the system (points P2 or P1 and P4) relations between relative air flow and relative damper opening position was measured and documented (see figure 1). According to information found in literature [9] the linearity curve between relative damper opening position and relative air flow rate does not have to be perfectly linear. Generally, the linearity is sufficient if the slope of the flow vs. stroke curve throughout the operational range varies by less than the factor of 2 [9]. In other words, if the damper position is changed by 20% the air flow should change between the limits of 10 to 40%.

In every pressure reading point the total pressure was measured using pressure reading probes. The pressure reading probes measured the total pressure on traverse pane of the duct section area. Six pressure reading points on the probe were positioned according to log-linear rule [9].

The measurements were conducted for four different types of dampers (see also figure 2):

1. Single blade damper without a sealing (further SB-l);
2. Single blade damper with tight sealing (further SB-t);
3. Diaphragm type damper (further IRIS);
4. Conical diaphragm damper [12] (further CON);

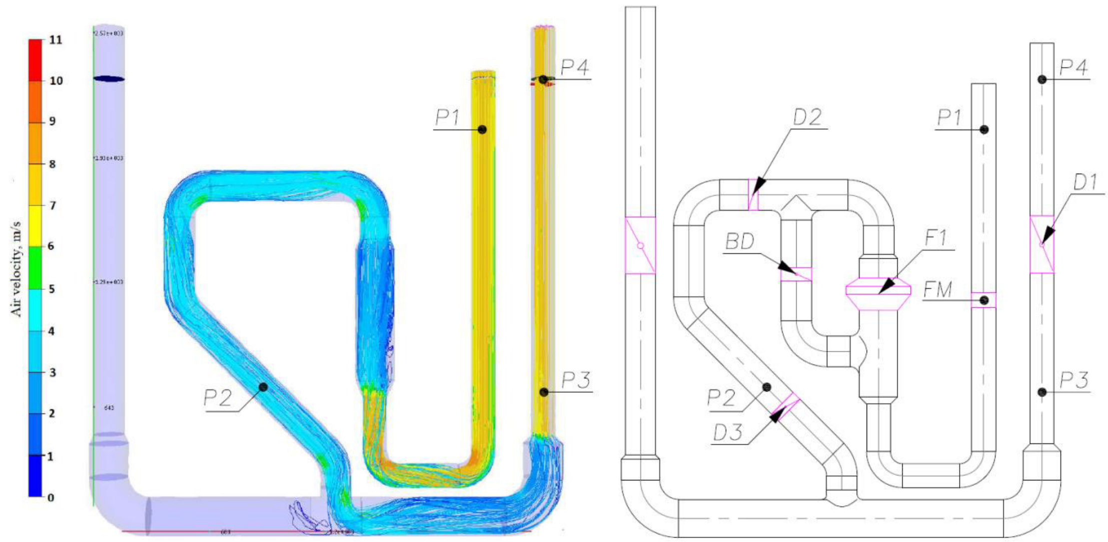

Figure 1. Air duct system. Visualization of CFD simulation results and placement of measuring probes.

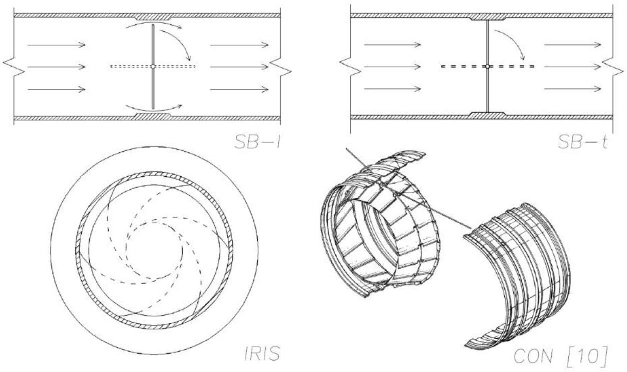

Figure 2. A Schematic drawing of the dampers used for the study

The measurements for each damper were conducted for three scenarios with different air velocities:

1. Scenario. Duct air velocity 3m/s (low velocity system);
2. Scenario. Duct air velocity 5m/s (Typical operating conditions for comfort systems);
3. Scenario. Duct air velocity 7m/s (High velocity, industrial systems);

3. Results

According to the results the variations of air velocity between 3 m/s and 7m/s had minor effect on the control characteristics; the maximum measured difference was 6% (see figure 3) of airflow at the same opening position and authority level which is within the pressure reading error of the measurement probes.

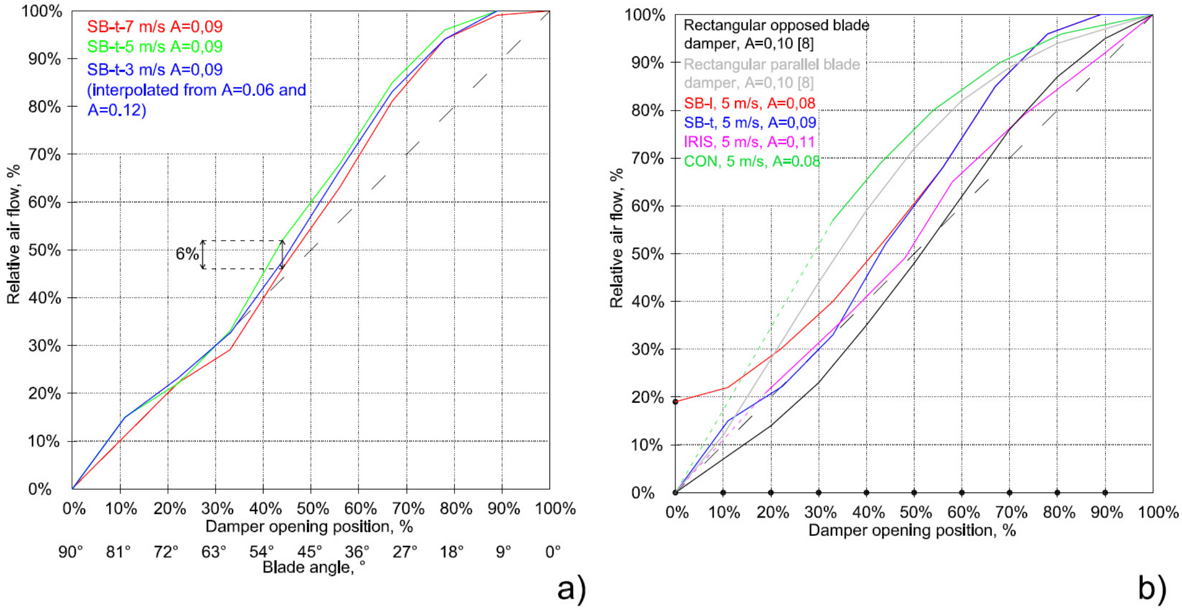

Figure 3. a) comparison of control characteristics of SB-t damper at similar authority levels but different air flow velocities, b) comparison of control characteristics of tested dampers and information about other damper type control characteristics described in literature sources

Further in this study the results measured at 5 m/s air velocity will be reported. The control characteristics were mostly influenced by damper type and authority level in the duct system. These results agree with previous studies [13] [14]. The measured control curves at similar authority A=~0.10 curves were also compared with control curves reported in previous studies [9] (see figure 3).

Two variations of circular single blade dampers were tested: damper with high air leakage rate and a damper with practically no leakage. Both dampers had sufficient linearity in ventilation systems with traditional damper authority levels A= 0.05..0.10. The linearity of control was not sufficient at extremely high authority levels (0.35 and higher) that are not likely to occur during normal operation. Also the control for both dampers is not sufficient at low authority levels and opening positions close to fully open. The linearity of SB-l damper was weak at nearly closed position due to high leakage rate (see figure 4.). Generally the regions of weak control linearity can be avoided by limiting blade opening position, in practice this can be done indirectly by proper choice of system static pressure and fan control method, for example, damper position monitoring [15] [16].

Apart from single blade dampers the control characteristics for two diaphragm type dampers was also documented. The tested dampers were IRIS damper (damper with a diaphragm that is placed perpendicularly to air flow) [11] and CON damper (damper with a diaphragm consisting of lamellas placed in conical pattern) [12]. Both of the dampers cannot be fully closed therefore they can have only limited regulation capabilities. The IRIS type damper had sufficient linearity in ventilation system with authority level between A=0.06..0.20 what is a typical damper authority in most cases. In fact, at authority levels of ~0.20 the linearity was close to perfect. Week control characteristics only occurred at extremely high authority levels (0.40 and higher).

The CON damper performed well in ventilation systems with extremely high authority levels (0.35 and higher), but had weak linearity at nearly opened position and low authority level. (see figure 5.)

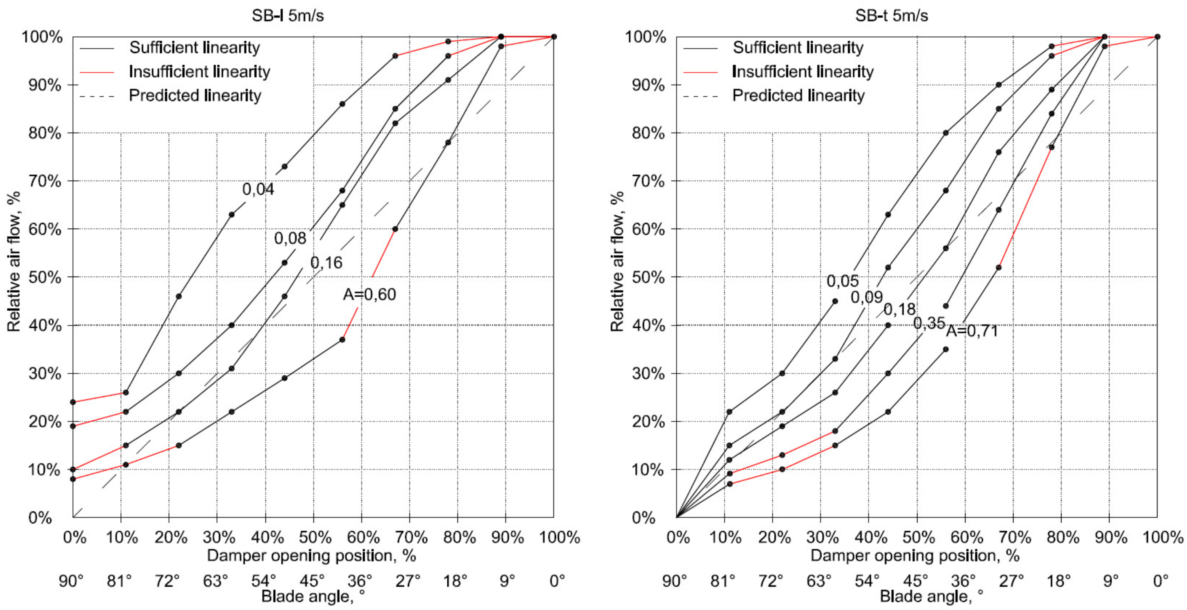

Figure 4. Measured control characteristic curves of SB-l and SB-t dampers at 5m/s velocity

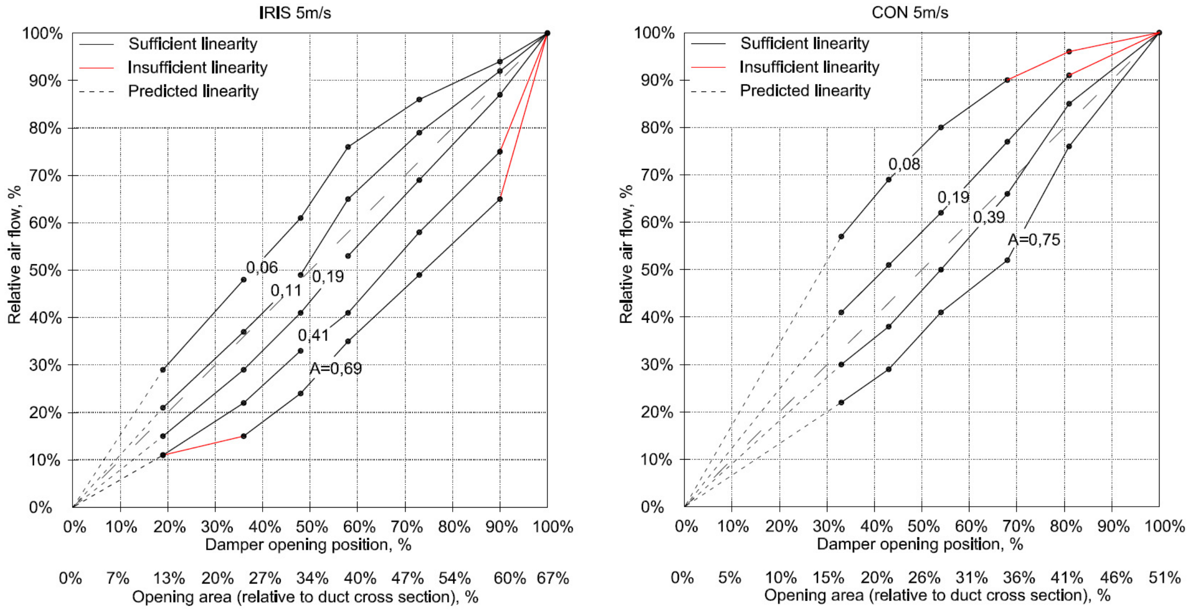

Figure 5. Measured control characteristic curves of IRIS and CON dampers at 5m/s velocity

To ensure a proper operation, stability and precision of a VAV ventilation system the VAV dampers should be operated in conditions where the linearity is sufficient. Recommended limitations of damper authority level and opening position are summarized in table 1.

The control curves of single blade dampers under typical operating conditions were sufficiently linear if the damper position was not close to fully opened. If the single blade damper has high leakage rate the operation near fully closed position can be problematic as well.

IRIS type damper control linearity under typical operation conditions was the best among the dampers studied in this paper. The inability of the damper to fully close is a limitation to its practical application in VAV systems.

The CON damper application in VAV systems is limited due to its inability to fully close (similar as the IRIS damper). Also weak linearity at typical damper operational conditions makes it less favourable for use in VAV systems in means of achieving best control. However, this study does not consider the damper acoustic parameters (what would be an advantage of CON damper) which is an important characteristic for practical damper application in ventilation systems especially variable air volume ventilation systems.

Table 1. Recommendations for achieving optimal damper control characteristics

Damper:	SB-l (Single blade with high leakage)	SB-t (Single blade with low leakage)	IRIS (diaphragm)	CON (conical diaphragm)
Recommended damper authority	A < 0.60	A < 0.30	0.04 < A < 0.40	0.08 < A
Authority levels for best performance	0.10 < A < 0.20	0.05 < A < 0.20	0.10 < A < 0.20	0.20 < A < 0.40
Recommended actuator position range	20% - 80% (20° - 70°)	0% - 80% (20° - 90°)	0% - 100%	0% - 80%

4. Conclusion

According to the research performed on four types of the most widespread circular damper configurations following conclusions can be made:

- The control characteristics of single blade dampers at typical authority levels are sufficient if the damper position is not close to fully opened, what should be taken in to consideration when choosing fan control method;
- In case of single blade damper, low leakage rate is crucial to achieve good linearity;
- The linearity characteristics of CON damper makes it less favourable for application in typical VAV ventilation systems;
- IRIS damper can have the best control characteristics in VAV systems if it can be modified to be able to fully close and withstand the wear off from opening and closing cycles.

Suggestions for further research:

IRIS damper could be successfully employed as a VAV damper, however it would be necessary to carry out more research about the abilities of precise flow measurement options and the control characteristics for IRIS dampers with tight shut off ability.

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