Energy and Buildings 128 (2016) 503–510

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

Constant design air flow industrial ventilation systems with regenerative dust filters: Economic comparison of fan speed-controlled, air damper controlled and uncontrolled operation

Christof Lanzerstorfer [a,*], Florian Neder [a], Rainer Schmied [b]

[a] School of Engineering/Environmental Sciences, University of Applied Sciences Upper Austria, Stelzhamerstraße 23, A-4600 Wels, Austria
[b] Kappa Filter Systems GmbH, Im Stadtgut A1, A-4407 Steyr-Gleink, Austria

ARTICLE INFO

Article history:
Received 11 September 2015
Received in revised form 14 May 2016
Accepted 13 July 2016
Available online 15 July 2016

Keywords:
Ventilation system
Fabric filter
Fan operation
Flow control
Variable-speed drive

ABSTRACT

Variable speed drives for fans in small and medium-size ventilation systems with a constant design air flow, including a regenerative filter for dust separation, are evaluated in this paper. In the past, variable speed drives were considered for systems with varying air flow. It was found that this is also an appropriate measure to reduce the operating costs of such systems. With the chosen approach the calculated payback period based on 24 h operation is between 0.7 and 1.7 years, depending on the size of the system. For systems in a two-shift operation the payback periods are still in the range of 1.4–3.4 years. The profitability of the installation of fan speed-control based on 12,000 service hours is in the range of 80–150%. A new operation mode, in which the filter cleaning is triggered at a fixed pressure drop of the filter cake, would further reduce the payback period and improve profitability. Systems with automatic damper flow control are much less economical. However, for the assumed conditions such systems are still better than uncontrolled systems. The installation of speed-control for fans in ventilation systems with a constant design air flow is therefore highly recommended for an economical design.

1. Introduction

Most of the power consumption of ventilation systems is caused by the motor of the suction fan which is required to provide the necessary draught and to overcome the pressure drop of the system caused by ducts, dampers, dust filters and other equipment. Therefore, measures for the reduction of the operating costs of such systems often aim to reduce the pressure drop of the system [1]. Another energy-saving strategy in ventilation systems is the use of highly efficient electric motors [2,3]. In many ventilation systems the required air flow is not constant. To save energy the air flow can be reduced to a level that still delivers the required air quality (ventilation on demand). Therefore, the ventilation air volume is controlled by the use of variable speed drives for the fans to match load requirements [2,4,5]. Depending on the variation of the ventilation demand, electrical energy savings by the use of variable speed drives are typically in the range of 25–50% [6]. The other operating alternatives are operation at the maximum capacity of the fan or flow control with a control damper increasing the pressure loss in the suction line. However, the power consumption of the fan motor is higher with both alternatives [7,8].

Numerous studies deal with the energy optimization of heating, ventilation and air-conditioning systems (HVAC) for buildings. In these systems the main purpose of ventilation is the control of the room atmosphere with respect to temperature and carbon dioxide concentration by replacing the air with fresh air. Ventilation on demand by the use of variable speed drives for the ventilation fans was investigated for various kinds of buildings such as detached family houses [9], schools [10–12], university buildings [13] and office buildings [14,15]. This operation enabled a reduction in power consumption of the fan in the range of 35–50% [9,13]. The reduction in the total energy consumption of the fan and the heating were reported to be in the same range [10,16].

Papers on the use of variable speed drives for fans in industrial applications concentrate on two areas: cement kiln fans [17–22] and mine ventilation fans [23–25]. In mine ventilation the control of the atmosphere is essential, whereas cement kiln fans are a part of the kiln off-gas de-dusting system. For cement kiln fans electrical energy savings of 25–40% are reported for speed-controlled operation [17,19]. The reported electrical energy savings in mine ventilation are up to 50% or 60% [25]. Other industrial applications of variable speed drive fans are described for cooler fans [26], fans

* Corresponding author.
E-mail address: c.lanzerstorfer@fh-wels.at (C. Lanzerstorfer).

http://dx.doi.org/10.1016/j.enbuild.2016.07.032
0378-7788/

Nomenclature

Δp_S	Pressure drop of the air collection system, Pa
Δp_{FM}	Pressure drop of the filter medium, Pa
Δp_{FC}	Pressure drop of the filter cake, Pa
P_{sh}	Shaft power of the fan, W
P_{el}	Electric power demand of the fan, W
P_R	Rated power of the fan motor, kW
η_{fan}	Efficiency of the fan
η_{drive}	Efficiency of the electric drive
$\dot{V}$	Volumetric flow rate, m^3/s (at fan inlet conditions)
ΔCAI	Additional investment costs, €
Δp_{st}	Difference in static pressure, Pa
p_A	Ambient pressure, Pa
p_{st}	Static pressure, Pa
n	Polytropic exponent
κ	Isentropic exponent
f	Factor according VDI 2044
k_0–k_3	Coefficients in fan volumetric flow calculation
h_0–h_3	Coefficients in fan efficiency calculation
A–D	Coefficients in motor efficiency calculation according ÖVE/ÖNORM EN 60034-30
R(t)	Resistance of the system

Indices

1	At fan inlet
M	At design point of the fan (maximum pressure drop)
C	Ventilation system with volumetric air flow controlled by a speed-controlled fan
U	Ventilation system with uncontrolled volumetric air flow

in a boiler house [27] and for laboratory exhaust fans [28]. The reported electrical energy savings are about 50% [28]. The payback period of the additional investment cost for the installation of a frequency converter to enable speed-controlled operation depends on the variation of the required ventilation air flow and the electricity cost per unit. It is generally less than two years [26,27,29,30].

Common to all the above-mentioned applications of variable speed drives for ventilation fans is the variable demand for the ventilation air volume flow. However, in many ventilation systems for processing units e.g. for gas, laser and plasma-cutting, blast machines, grinding, brushing and polishing operations in metalworking or mechanical sand processing in foundries, the required ventilation air flow is constant. However, in these systems the operating conditions for the fan are not constant because the resistance of the installed filter for de-dusting increases gradually due to the separated dust, thus reducing the air flow. The total pressure drop of such a system is the sum of the pressure drop of the air collection system and the pressure drop of the filter, which results from the pressure drop of the filter medium and the pressure drop of the filter cake formed by the separated dust. The pressure drop of the filter medium (residual pressure drop) increases slightly when the filter medium is in use because some dust particles in or on the filter are not removed during the regenerative cleaning process. The pressure drop of the filter cake is zero for the cleaned filter medium and increases during the filtration cycle. The rate of the increase depends on the dust concentration, the dust characteristics (particle size, shape of the particles) and on the specific air flow rate (air to cloth ratio). At the end of each filtration cycle the filter is regenerated by a compressed air pulse detaching the filter cake. After regeneration the pressure drop of the filter cake is again zero. Thus the pressure drop of the filter system is not constant [31,32]. Fig. 1 shows the course of the pressure drop which is usually found in small and medium-sized fabric filters. During each filtration cycle the pressure drop increases from the residual pressure drop of the filter medium to the chosen maximum pressure drop, when the regenerative cleaning is started.

In large filters the cleaning is spread more evenly over time because only a part of the large filter area is cleaned at once. In the cleaned part of the filter area the resistance is reduced. Hence, the pressure drop has to be the same for the whole filter area, the air flow through the cleaned filter area increases, and the flow in the un-cleaned area decreases until the pressure drops are equal in both areas. Thus, the reduction in the pressure drop is smaller in this case.

The aim of this study is to investigate the economic feasibility of the use of frequency converters for speed-controlled operation of the fan and air damper control in small and medium size ventilation systems with a constant design air flow. The evaluation is made on the premise that a new ventilation system is built. The basic design of the ventilation system investigated does not have flow control. It consists of an air collection system, a regenerative fabric filter for dust separation and a centrifugal fan. The additional investment costs for both controlled systems and the energy savings of controlled operation are estimated for both systems. From these results the payback periods for the required additional investments are calculated.

2. Ventilation system design

Ventilation systems are usually designed for operation at the maximum pressure drop of the system which is reached just before regeneration of the filter medium is triggered (shown in Fig. 2 as point M). When the filter medium is clean, the pressure drop is smaller. In an uncontrolled system the starting point of each filtration cycle also has to be on the performance curve of the fan. Therefore, the air flow is higher. The corresponding operation point is shown in Fig. 2 as point U. During the build-up of the filter cake the operation point moves gradually from U to M, the regeneration of the filter medium brings the operation point back to U. In the course of the time of use the operation point at cleaned filter medium U is shifted slowly in the direction of M. This is caused by the limited efficiency of the filter regeneration. The efficiency of a fan is not constant either. Usually, the fan is selected to have the highest efficiency at the design point. The more the operation point differs from the design point, the lower the efficiency of the fan. Depending on the gradient of the performance curve and the fan efficiency, it often happens that the power consumption is higher for operation points with a reduced pressure drop.

With the installation of a control damper in the suction line the fan can always be operated at the design operation point (M) because the controlled pressure drop of the damper compensates for the variable pressure drop of the filter cake. In this case the power consumption is constant.

The installation of a frequency converter in the power supply line of the fan motor enables constant air flow operation by speed control. The fan performance curve is shifted towards less capacity (flow and pressure) when the speed is reduced. In this case the operation point with a clean filter medium would be C. In the course of the filtration cycle it moves gradually from C to M as a filter cake is formed by the separated dust and is shifted back to C when the filter is regenerated. With increasing time of use the starting point of the filtration cycle C moves slowly in the direction of M. The efficiency of the fan is also lower at C, but due to the remarkable reduction in pressure drop the fan's power consumption is much lower.