Improving the energy efficiency of pneumatic extraction systems by automating the process of air flow rate adjustment

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Abstract: An important problem and a fundamental flaw associated with the operation of pneumatic extraction systems is their high energy consumption. One way to reduce energy consumption is to use a frequency converter to adjust the speed of the fan motor. This paper presents an automatic control system based on feedback from the flow velocity of air in the main pipe system. The solution effectively helps improve the energy efficiency, that is, reduces energy consumption.

Keywords: energy efficiency, pneumatic hood installation, feedback, air flow velocity

1. Introduction

Air extraction systems are used, inter alia, for disposal of waste generated during mechanical wood processing. They are used to capture and collect shavings and dust generated by mechanical wood processing, as well as for transport of a mixture of dust and air to the dust collector [4–5]. Lack of an efficient extraction system may result in excessive buildup of dust and even explosive dust-air mixtures [8–10]. The requirement for effective operation of such a system is to provide adequate air flow rate in each extractor hood. Correct distribution of the air flow in all branches can be achieved if the flow resistance of the side arms of the transport channels have a correspondingly lower level of fan pressure [2, 6].

Depending on the installation used, it may consist of a bus coupler or collector. In the bus coupler system, suction pipes are sequentially attached to the main pipe, whose diameter gradually increases. Waste transportation is influenced by the total pressure difference in the inlet and outlet of the fan. The test system described in this paper is a collector, used in the expansion tank (collector) to enable alignment of the pressure drop in the exhaust pipes and ensure adequate air intake distribution at individual extractor hoods. Installation of the collector system is also possible as a sectional action, thanks to the shut-off valves on the exhaust pipes for machine tools [7]. Depending on the number of active valves, the speed of the air flow in the ducts can be altered [1, 3, 7]. Previously, the test system speed was manually controlled by employees, who read the value from the meter set to the frequency converter (inverter) of the appropriate fan motor speed. Adjustment, however, is time consuming, and sometimes cannot be executed when the machine is turned on only momentarily. For convenience, most employees also selected the highest engine speed, at which woodchip is always transported, showing no concern for energy savings.

In view of the fact that on 5 April 2006, Directive 2006/32/EC of the European Parliament and of the Council on end-use efficiency and energy services entered into force and a law on energy efficiency was created on 15 April 2011 [12], it was decided to improve energy efficiency in the carpentry extraction system. Energy efficiency, by law, is defined as the ratio of the size of the resulting effect of a utility facility or installation of technical equipment, in normal conditions of use or operation and the amount of energy consumed by an object, a technical device or installation, necessary to achieve this effect.

This paper aims to investigate how the energy consumption of the fan motor can be improved by automating the process of adjusting the air flow rate through the use of the frequency converter and the automatic control of air velocity in the main line.

2. Description of the test system

Figure 1 presents a schema of the installation in which the test was conducted. Figure 2 presents an overview of the installation. The following components can be identified: 1 – band saw, 2 – lathe, 3 – circular saw, 4 – heavy planer, 5 – surface planer, 6 – spindle moulder, 7, 8 – two-disc grinder, 9 – horizontal pipeline, 10 – fan, 11 – dust collector.

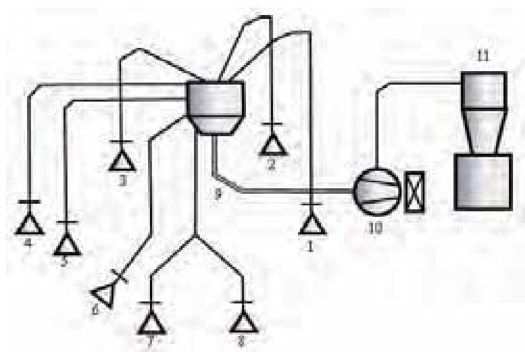

Fig. 1. View of the pneumatic extraction test system
Rys. 1. Schemat badanej pneumatycznej instalacji odciągowej

Fig. 2. View of the pneumatic extraction test system
Rys. 2. Widok badanej pneumatycznej instalacji odciągowej

The fan is powered by a three-phase motor of power rating 11 kW and maximum speed 2980 rpm. It is controlled by a Hitachi J300 inverter.

To check the speed of the air flow in a pneumatic extraction system, pressure measurements should be made at specific points of the installation [6, 12]. Measurement accuracy requires that the flow is stabilized, a stream is the least disturbed. It should be remembered that in order to maintain an appropriate distance from the interfering elements, measurements should not be made directly behind the fan, where speeds can be opposite to the main direction of the air movement. Long straight sections of pipe (multiple wire diameter D) should be as follows: 8–10D before the measuring section, and 3–4D behind the measuring point. However, these episodes can be reduced and taken about 4D before and 1–2D behind the cross-section [11]. In fact, finding a reasonably long, straight section can be difficult. In this case, a test section should be found, where the slightest disturbance is expected to the flow. When measuring the performance of industrial plants, it is acceptable to read the value of the dynamic pressure at a single point of measurement within 0.2D of the wall, and at least 5D from the point of disturbances in straight air flow [2, 5].

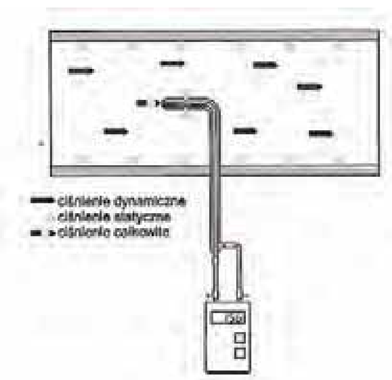

Fig. 3. Prandtl tube with micro manometer [3]
Rys. 3. Rurka Prandtla wraz z mikromanometrem [3]

The primary and most well-known device for measuring air flow velocity is the Prandtl tube (also known as a pitot-static tube) (fig. 3). The apparatus consists of two concentric tubes bent at the end at a right angle, so that the head tube is directed perpendicular to the flow direction. The tip of the tube is rounded to facilitate access. The nose tube has one front opening for receiving the total pressure and a number of holes located at the periphery for receiving the static pressure. Both inputs are combined individually with connectors located in the tail pipe. Also featured is a direction indicator, allowing for correct positioning of the tube relative to the direction of flow.

Currently, most air velocity measurements are carried out with modern portable digital micromanometr equipped with Prandtl tubes, that have a built-in pressure conversion tool. An example of such a micromanometer, that was used for comparative measurements described in this article, is shown in fig. 4.

Fig. 4. Digital micro manometer TESTO 521 cooperating with Prandtl tube
Rys. 4. Mikromanometr cyfrowy firmy TESTO typu 521 współpracujący z rurką Prandtla

In order to determine the air flow rate through the section, velocity measurements in pneumatic extraction installations are carried out, that is the evaluation determination of the dynamic pressure in the test section [1, 6]. The basic formula for the calculation of the flow rate by measuring the dynamic pressure is represented as follows:

$$V = 1{,}291\sqrt{P_d}\,[m/s] \tag{1}$$

where:
V – velocity of air flow [m/s],
P_d – dynamic pressure [Pa].

As the average flow velocity in the transport channel is known, the volumetric flow of air is calculated from the product of the velocity and the channel cross-sectional area:

$$\dot{V} = \frac{\pi D^2}{4} \cdot V\,[m^3/s] \tag{2}$$

where:
$\dot{V}$ – Air volume flow [m^3/s],
D – Channel cross-sectional area [m^2],
V – Flow velocity [m/s].

3. The automatic control system

Automatic control is made based on the feedback from the air velocity in the main duct system. It consists of three main elements (fig. 5):

- a built-in PC card controller DACBoard-3000 that calculates the differential pressure signal obtained from the sensor voltage. On this basis, the speed, the speed control deviation and the control signal of the inverter are calculated.
- the inverter control system with motor and fan. The inverter is controlled by a 0–10 V output, the frequency of which corresponds to 50–0 Hz.
- the Prandtl tube and differential pressure sensor SX-01 made by Honeywell with the electronics, forming a feedback loop. A view of the test is illustrated in fig. 5.

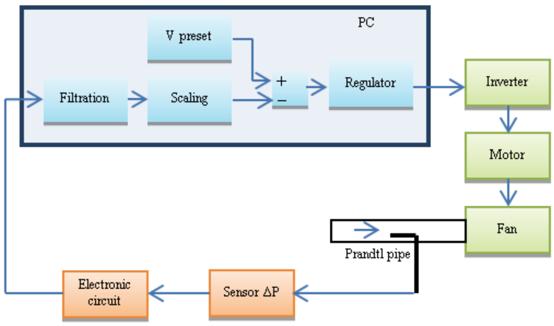

Fig. 5. Schematic diagram of the automatic air flow speed control system
Rys. 5. Schemat układu automatycznej regulacji prędkości przepływu powietrza

The main problem encountered during the study was a noisy signal generated by a differential pressure sensor. This was associated with the specific measurement, because the flow in the pipe was turbulent. A large part of this was noise interference generated by the inverter. The inverter switching transistors caused interference to measuring instruments installed in the vicinity. Protection against faulty instrumentation was avoided, among other things, by installing them away from the inverter. Noise reduction in the power supply can also be achieved through the addition of an EMI filter on the inverter input.

In the system under study, however, filters were not installed and a supply line to the control signal from the differential pressure sensor had a length of about 10 m, which meant that it acted as an antenna. Therefore, the controller should use an appropriate system to eliminate interference (fig. 6).

A regression function was selected for this purpose, by which the collected data can be searched with an estimate function. Then, the resulting value is created through effective and non-linear functions determined experimentally, scaled to the differential pressure signal, and calculated on the basis of the air flow rate.

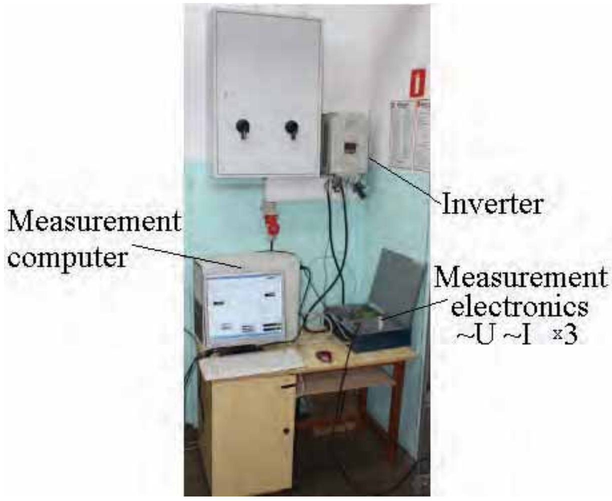

Fig. 6. View of a research station
Rys. 6. Widok stanowiska pomiarowego

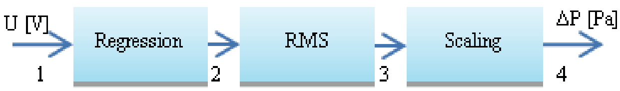

Fig. 7. Suppression of the differential pressure sensor
Rys. 7. Układ eliminacji zakłóceń z czujnika różnicy ciśnień

Figure 8 shows waveforms at various points of noise suppression.

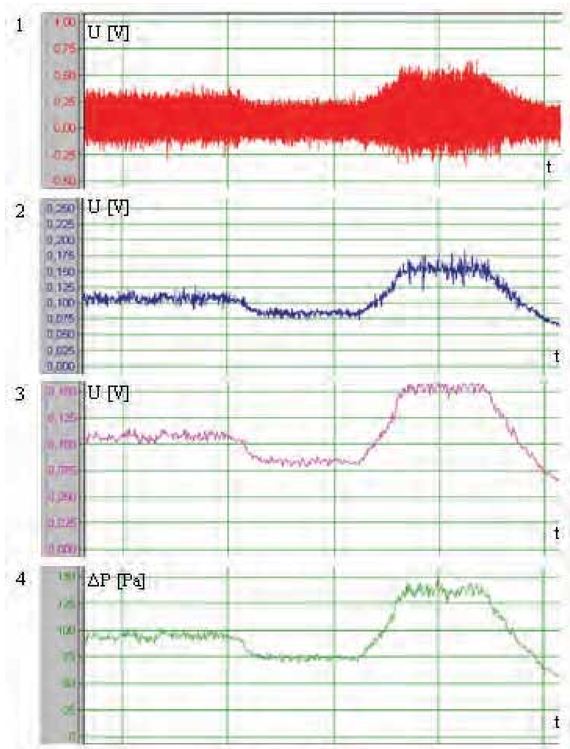

Fig. 8. Waveforms at various points of the interference suppression
Rys. 8. Przebiegi sygnałów w poszczególnych punktach układu eliminacji zakłóceń

The next stage of research was to see how the power consumed by the motor would use the above-described automatic control system. Several attempts were made, the results of which are described in the chart below. In the first two cases, the speed preset was set at 13 m/s. Figure 9 shows a visible case that was found, in which valves were opened and a reduction in engine speed and power consumption occurred.

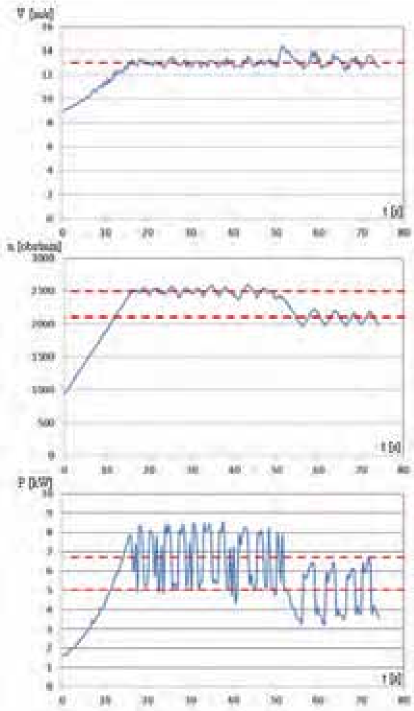

Fig. 9. Wave forms with valves opening
Rys. 9. Przebiegi podczas otwierania zasuw

Figure 10 shows a reversed situation. In the third situation (fig. 11) another setting was made, where velocity increased from 12 m/s to 14 m/s. Such a situation may occur when the wood dust is treated with a higher moisture content and is heavier, which leads to the need for greater speed. Figure 11 shows that during the increase in speed preset, the power consumed by the motor increased as well.

4. Conclusions

The results of this study have led to the conclusion that despite the noise on the signal, the feedback control system fulfills its role: It maintains a constant flow rate in the main line, regardless of the number of open valves. Therefore, a rapid change in the system operating speed can be achieved, according to the technological requirements. After thoroughly testing the measures described above, a control algorithm was applied to a microprocessor controller. In analyzing a cycle of work in a carpenter's shop, where rotating individual machines are used, it can be seen that with automatic control, the flow rate in the system will always oscillate around the preset speed and the engine will never draw more power than it is required, which will measurably affect the energy economy.

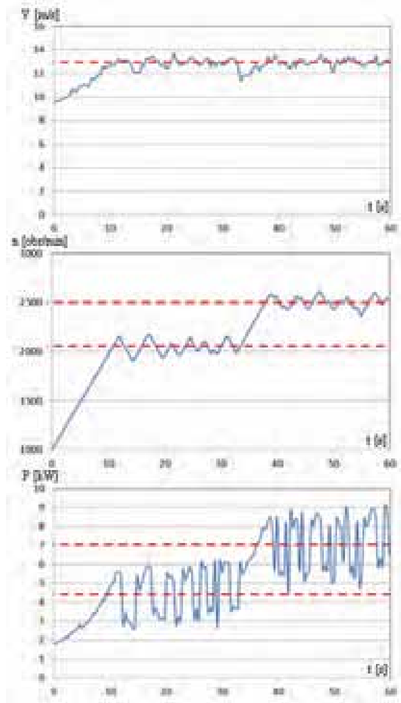

Fig. 10. Wave forms with valves closing
Rys. 10. Przebiegi podczas zamykania zasuw

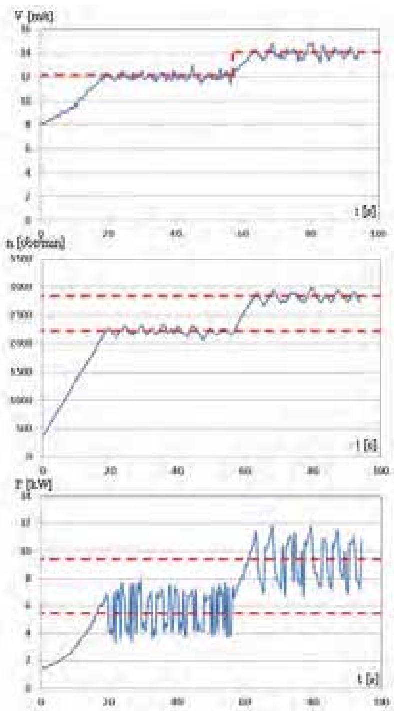

Fig. 11. Wave forms when velocity is changed
Rys. 11. Przebiegi podczas zmiany prędkości

For the detailed calculation of the percentage of energy savings, a consumption kWh meter should be installed on the motor and the power consumption checked for a longer period of time (a few days) with the automatic control system being on and off.

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Poprawa efektywności energetycznej pneumatycznej instalacji odciągowej poprzez automatyzację procesu regulacji prędkości przepływu powietrza

Streszczenie: Istotnym problemem i zasadniczą wadą związaną z eksploatacją pneumatycznych instalacji odciągowych jest ich duża energochłonność. Jednym ze sposobów zmniejszenia zużycia energii jest zastosowanie przetwornicy częstotliwości do regulacji prędkości obrotowej silnika wentylatora. W artykule zaprezentowano układ automatycznej regulacji w oparciu o sprzężenie zwrotne od prędkości przepływu powietrza w przewodzie głównym instalacji. Zastosowane rozwiązanie skutecznie wpływa na poprawę efektywności energetycznej, czyli na zmniejszenie zużycia energii.

Słowa kluczowe: efektywność energetyczna, pneumatyczna instalacja odciągowa, sprzężenie zwrotne, prędkość przepływu powietrza

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