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A fan for solid-fuel furnaces

Abstract. *The paper presents a fan with DC brushless motor used to circulate air in the combustion chamber of a solid-fuel furnace. A way of constructing the permanent magnet motor using much less steel and copper than present motors has been shown. Thanks to the use of sensorless control, the control system of the motor is simple and allows for continuous speed control. It consumes much less energy than previous designs. The motor and control system can be applied in other fans.* ***Wentylator do pieców na paliwa stałe***

Streszczenie. *W pracy pokazano wentylator z bezszczotkowym silnikiem prądu stałego przeznaczony do nadmuchu powietrza do komory spalania w piecu na paliwa stałe. Pokazano konstrukcję silnika z magnesami trwałymi, na który zużyto znacznie mniej żelaza i miedzi w porównaniu z silnikiem dotychczas stosowanym. Dzięki zastosowaniu sterowania bezczujnikowego układ sterowania silnika jest prosty i umożliwia płynną regulację prędkości obrotowej. Nowy wentylator zużywa znacznie mniej energii niż wentylatory stosowane dotychczas. Taki silnik i układ sterowania może być stosowany w wentylatorach o innym przeznaczeniu.*

Keywords: fan, brushless motor, sensorless control
Słowa kluczowe: wentylator, silnik bezszczotkowy, sterowanie bezczujnikowe

Introduction

Fans with rated power of below 100W are equipped with single-phase asynchronous motors with run capacitors or motors with short-circuited coils. They control the volume of air being exhausted by adjusting the rotational speed of the motor driving the fan. In most cases, the rotational speed of such motors is changed in a step fashion by changing the number of coils by means of tapping. Sometimes the rotational speed is controlled by changing the supply voltage by means of phase control. In these cases, the efficiency of the motor is low and one can save large amounts of energy by using a different type of motor. In this work, we present a new fan drive of much higher efficiency. Our drive is built on the basis of a brushless DC motor. Using this type of engine [3], [4], [5], [9], [14] eliminates problems connected with motor start and with controlling the speed of the fan. In addition, when using the supply voltage of 12V, the fan can be fed from a battery (for example a car battery) in case there is an outage of the power grid. This is hugely significant if the fan supplies air to a solid-fuel furnace because in this case one has to shut down the furnace and forgo heating in case there is no power supply and no air circulation.

Design assumptions

When designing the construction of the fan it was assumed that the as much as possible should be used of the existing solution. We used the existing rotor and case of the fan, while changing only the motor driving the fan. We designed a new, brushless DC motor with permanent magnets, since this is the only type of motor guaranteeing a high efficiency at low power. Due to the quickness and easiness of assembly and the price of the magnets, we adopted a solution with cubic, neodymium interior magnets. A further advantage of this design choice is the impossibility of the magnets becoming unglued and of the associated motor failures. It was assumed that the speed of the fan should be controllable in a range of between 300 and 2700 rpm.

Design and function of the system

The drive system of the fan consists of a brushless DC motor and a control system based around a specialized processor. In typical applications three signals describing the position of the rotor with respect to the stator are needed for correct operation. Sensorless control [1], [2], [6], [7], [8], [10], [11], [12], [13] was used in the presented drive, which additionally reduced the cost of the drive and improves its reliability. The controller uses a measurement of the rotation voltage in an unpowered phase of the coil [6] to sense the position of the rotor. In figure 1, we show the magnetic circuit of our motor. Computations of the properties of this circuit were conducted in the new version of the FEMM software. Figures 2, 3 and 4 show the internal construction and the view of a complete fan. In fig. 5 we show a block diagram of the control system with a marked spot where a battery can be connected in case of failure, while Fig. 8 shows the complete control system of the designed motor.

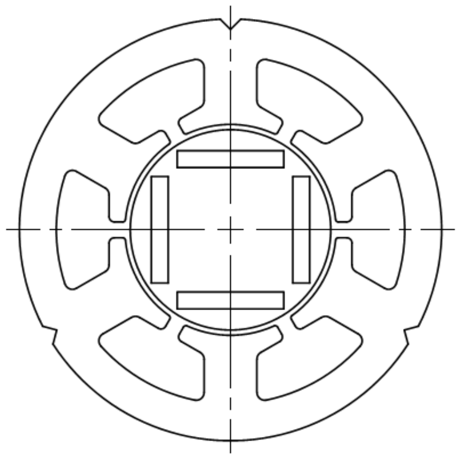

Fig. 1. Magnetic circuit of the designed motor

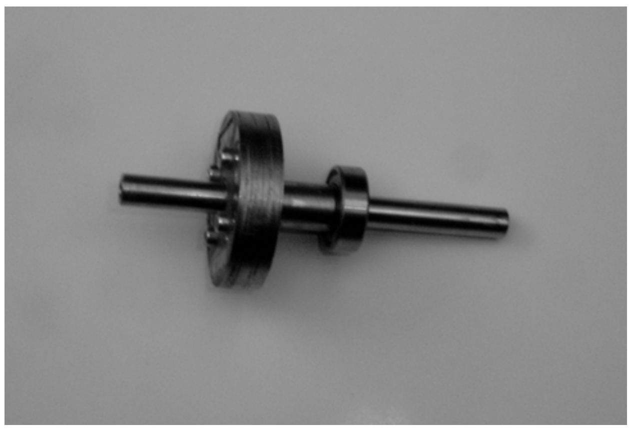

Fig. 2. View of the rotor

Fig. 3. View of the stator with coils

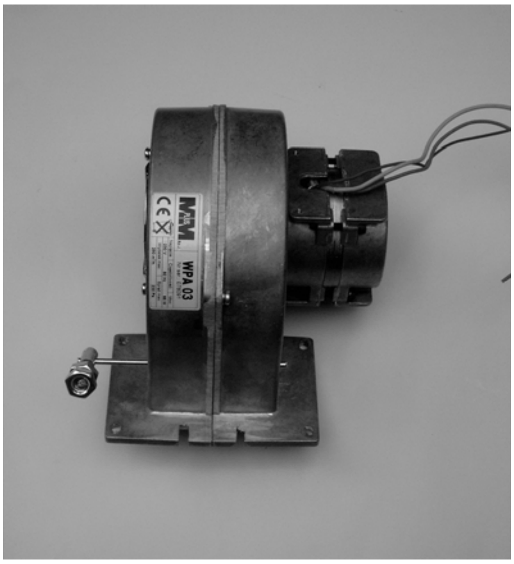

Fig. 4. View of the complete fan

As mentioned above, a sensorless control system using a voltage measurement in unpowered coil was used to adjust motor rotational speed. By determining the zero crossing of the back emf one can easily control the motor. The easiest way of controlling the motor with back emf is the observation of the neutral point voltage. The ideal voltage waveforms at this point are shown in Fig. 6, and actual ones in Fig. 7.

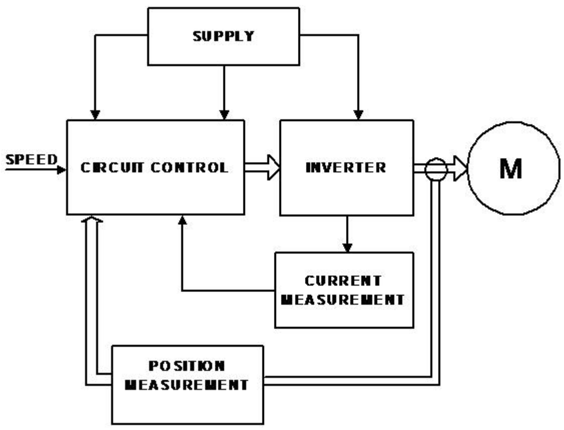

Fig. 5. Block diagram of the motor power system

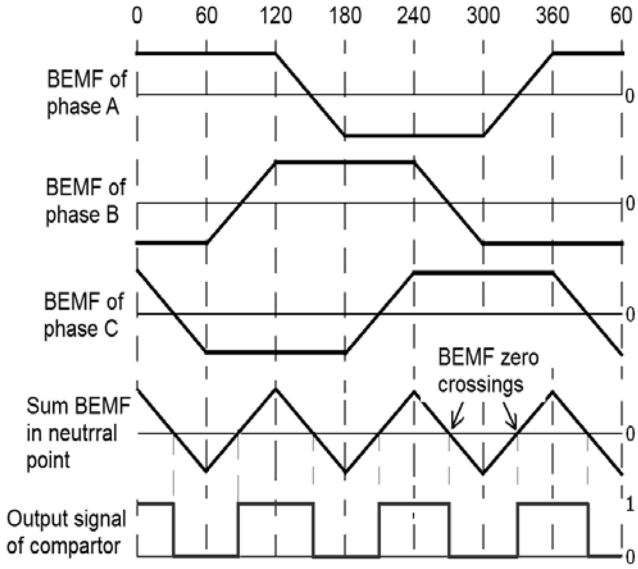

Fig. 6. Ideal waveforms of back emf and their sum in the neutral point

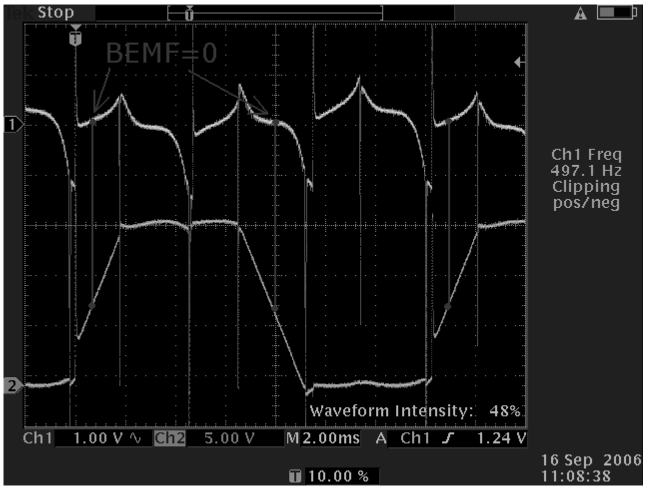

Fig. 7. Actual voltage waveform in neutral point (yellow) and back emf of one phase (blue) with marked zero crossings

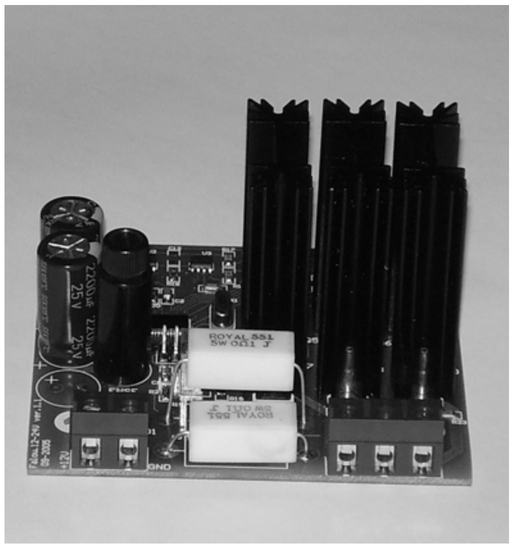

Fig. 8. View of the motor control system

The instant back emf crosses zero in unpowered phase is not synonymous with the switching-on of further transistors of the circuit shown in Fig. 5. To determine the instant of inverter valve commutation one has to use a delay depending on the speed of the rotor in which the rotor covers the distance equal to 30 electrical degrees. Methods based on the observation of the back emf can be used for rotational speeds ranging from 10 to 100%. Below these values, the back emf is too small to properly determine the position of the rotor [5], [10]. Fig. 8 shows a control system constructed according to the described principle of operation.

System tests

System tests included motor start-up and operation checks for speeds ranging from 5 to 100% under normal supply voltage as well as supply voltage reduced by 15%. In all cases, the operation of the drive was stable, and there were no problems during start-up. The fan with the new motor consumes much less power, as evidenced by the results of measurements of power consumption included in Table 1.

Table 1. results of measurements of power consumption

Rotational speed [rpm]	2700	2200	1800	1000	500
Power consumed by old fan [VA]	69	53	35		
Power consumed by new fan [VA]	41	32	19	13	9

As can be seen from the measurements the fan with the new motor consumes 40% less energy on average than a fan with asynchronous motor.

Conclusions

The presented fan is only slightly more expensive than the one used so far and ensures a stable and adjustable rotational speed. The low price results from both the simplicity of the motor itself and a small number of elements of the control system. As demonstrated by the measurements, the fan uses considerably less energy. Due to the nominal voltage of 12 V, the fan can be powered from a battery. This is important in case of power grid outage. Material savings are also significant here. Their scale – the reduction of the magnetic circuit and coil weight is evidenced in Fig. 9 presenting the rotors of a new and old solution.

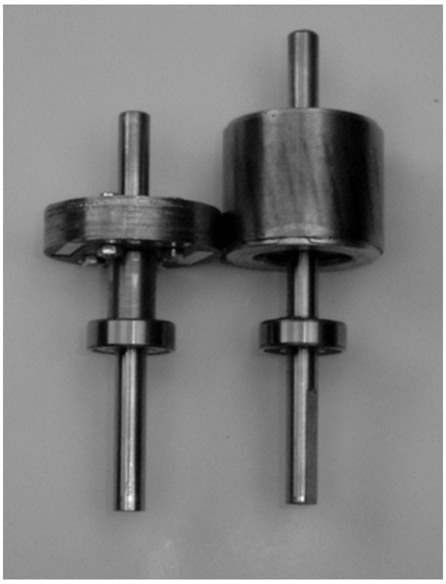

Fig. 9. Comparison of rotors of a new and old motor

The most important feature of a new solution is the ability to work during power outages, thus ensuring continued heating of buildings.

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