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FLOWMETER BASED ON HEAT TRANSFER FUNDAMENTALS

The article deals with problem of flow measurement of ventilators for cooling purposes. Measurement method is based on calorimetric principle which is the measurement method of equipment called Thomas cylinder. The whole measuring mode with description of individual elements of measuring equipment and process of measured data processing is introduced. In conclusion there is a list of measured values of tested ventilator and ventilator characteristic is created.

Key words: flowmeter, measurement method, measuring equipment, calorimetric principle, Thomas cylinder.

Introduction

Calorimetric method that is used for ventilator flow measurement is generally based on elementary relation:

$$P = Q_m \cdot c_p \cdot (T_2 - T_1), \quad (1)$$

or

$$P = \rho \cdot Q_V \cdot c_p \cdot (T_2 - T_1), \quad (2)$$

where P – thermal power, W; Q_m – mass flow, $\text{kg} \cdot \text{s}^{-1}$; Q_V – volume flow, $\text{m}^3 \cdot \text{s}^{-1}$; c_p – specific heat capacity, $\text{J} \cdot \text{kg}^{-1} \cdot \text{K}^{-1}$; T_1 – temperature before heating, K; T_2 – temperature after heating, K; ρ – air density, $\text{kg} \cdot \text{m}^{-3}$.

While using the calorimetric method for ventilator flow measurement the flow can be formulated by the relation (2)

$$Q_V = \frac{P}{\rho \cdot c_p \cdot (T_2 - T_1)}, \quad (3)$$

The relation says that ventilator flow measurement by calorimetric method consists in heat performance measurement of given air flow, measurement of air temperature change ($T_2 - T_1$) caused by heat given to the air flow and knowledge of value of specific heat capacity c_p depending on actual conditions of air flow.

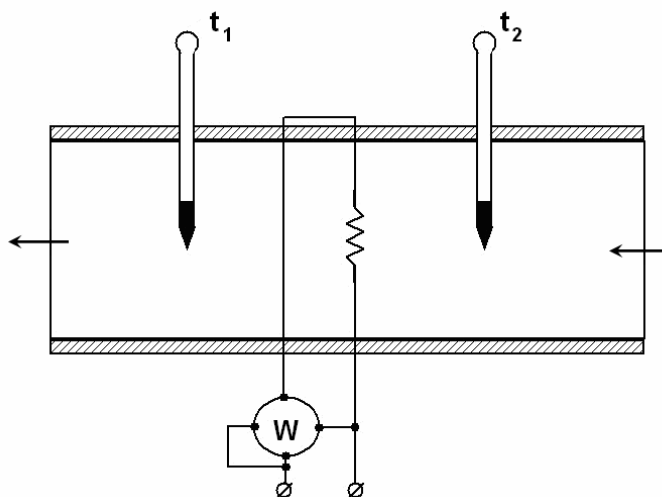


Figure 1. Working principle of heat transfer measurement

The equipment called Thomas cylinder which uses described principle is described in figure 1. The air flow goes through the duct (mostly with circle cross section) whose walls are made from material with very low heat conductivity (high heat resistance). Inside of Thomas cylinder there is air heating element. Thomas cylinder uses the difference of temperature of coming air which comes and goes out from heat isolated measurement cylinder and which is heated by known heat power P . The measurement part of Thomas cylinder consists of two temperature detectors created by thermocouples. They are placed on opposite ends of measurement cylinder and the thermocouples are placed in grate which covers the whole cross section of cylinder. Thermocouples of both temperature detectors are differentially connected – each thermocouple of incoming air temperature detector is connected with thermocouple of outgoing detector in a way that the thermo voltage can be subtracted. The final voltage is proportional to average difference of temperature of incoming and outgoing air flow in the whole cylinder cross section. Between temperature detectors is electric heating element with constant heating value and it is reeled to cover the whole cylinder cross section. The air flow Q_V is calculated from input power of heating element, difference of temperature of incoming and outgoing air, specific heat capacity and density of air according to the relation (3).

Problem definition

The equipment for flow measurement – Thomas cylinder together with balancing pipes has the aerodynamic resistance. The aerodynamic resistance of measurement equipment raises aerodynamic resistance of ventilator circuit. This cause smaller flow in ventilator in time of measurement compared to the real conditions. In order to eliminate the effect of aerodynamic resistance of measurement equipment is used method based on com-

pensation of loss of pressure in section of measurement equipment. The scheme of equipment utilizing this method is shown on figure 2. Intake opening of ventilator is hermetically connected to large volume chamber. From the other side there is compensating ventilator, measurement machine – Thomas cylinder together with adjusting pipe-line. The air flows through the pipes, Thomas cylinder, compensating ventilator, chamber and circuit of ventilator. Micromanometer connected to the chamber and surrounding air records the pressure loss on the section of Thomas cylinder and adjusting pipe-line. Compensating ventilator is supplied from frequency changer which can change its power and adjust the pressure difference on zero. In this condition between inside of chamber and atmosphere there is no pressure difference, so it means the influence of aerodynamic resistance of Thomas cylinder and adjusting line is eliminated. Measured flow in this case responds to the real maximum flow in ventilator. Thomas cylinders are produced with different diameters. Its measurement range depends on diameter of cylinder. With regard to the measurement precision the average speed of flow in cylinder should be in range

$$u = (1 \div 10), \quad (4)$$

The lower-bound of speed is the result of the fact that while very low speeds of flow in certain places of cross section of cylinder there cannot be a flow and measurement grates will not have mean temperature of flowing air. The upper bound results from tensile properties of grate. While high speeds of flow there can be a wire tension in grates which can lead to change of grates' resistance. According to the relation (4) the measurement range of cylinder depends on its diameter

$$Q_V = u \cdot S = (1 \div 10) \cdot \frac{\pi}{4} \cdot D^2 = (0,8 \div 8) \cdot D^2, \quad (5)$$

where D – inner diameter of Thomas cylinder, m; u – velocity of agitated air, $\text{m} \cdot \text{s}^{-1}$; Q_V – air flow of cylinder, $\text{m}^3 \cdot \text{s}^{-1}$.

The increase of air temperature in cylinder should not exceed certain range. The recommended range for increase of temperature is $\Delta T = (4 \div 8 \text{ } ^\circ\text{C})$. The lower-bound is dependent on measurement accuracy. The higher temperature increase is, the higher measurement sensitivity there is. The upper bound is dependent on heat losses through the cylinder walls and other circumstances.

Description of measuring apparatus

To make the measurement by Thomas cylinder more precise and effective the whole measurement equipment was embed by measuring probes and appliances that enable the collection of data online and consequential interpretation of all relevant data in computer. Calorimetric method as was described in introduction requires the measurement of following data.

air in calculation of flow throw ventilator. This capacity is changed with the temperature and with the moisture content in air. These data are scanned by individual probe thanks to the five-channel device Almemo. This device enables connection to PC thanks to the serial interface RS232. The complete calculation of flow which can be done on the basis of measured data saved online in PC requires also the atmospheric pressure value. The atmospheric pressure is measured by station barometer and it is put manually into the software before the measurement. The measuring and calculating software enables after clicking on correspondent measured value also its time progress.

Measuring accuracy procedure

The most important value of ventilators especially those that are used for chilling is determination of transport amount which is characterized by flow. After launching of tested ventilator placed on measurement equipment the measurement software starts. This software enables saving all measured and calculated values into output file either in text format or xml format. These saved data can be further processed by spreadsheet program.

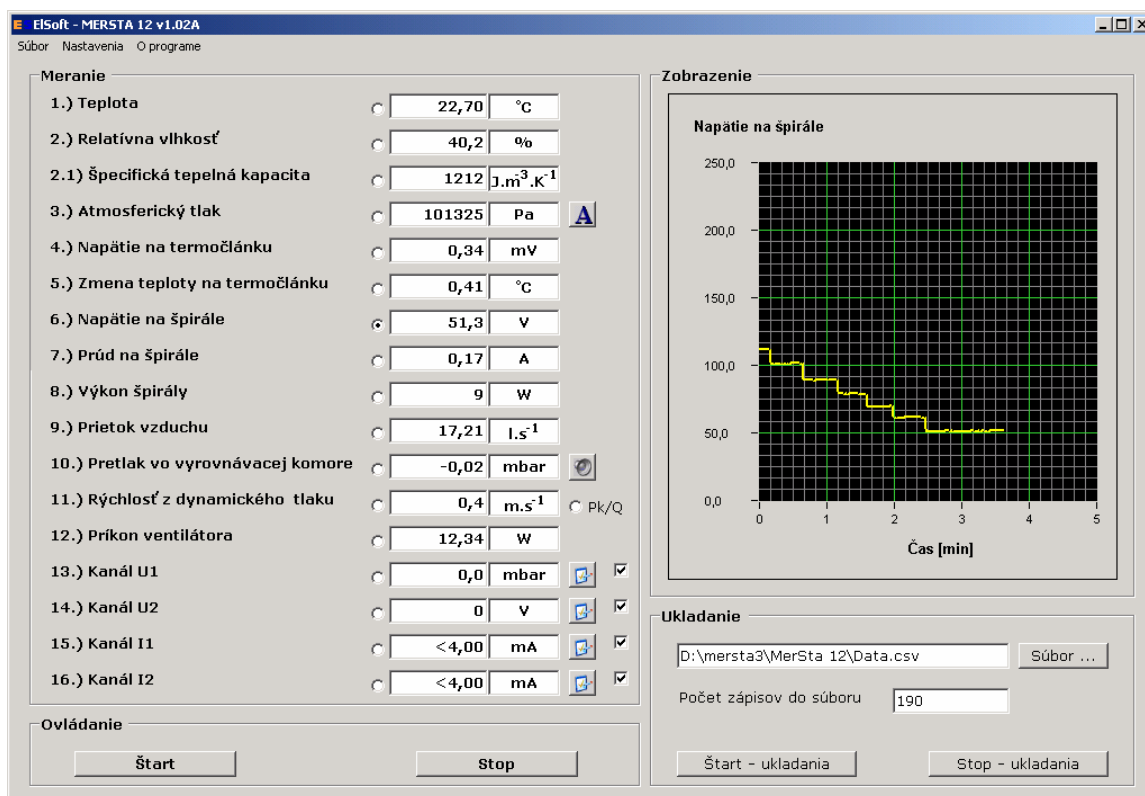


Figure 3. Screen view of measuring software with presentation of voltage on heater element course

For determination of ventilator characteristics it is important to measure value of flow in various pressure loss of pipes. The pressure loss of pipes can be simulated by throttling the entrance pipes cross section. Since the compensating ventilator which serves for balancing of pressure in surge chamber was embed by frequency changer it was important to verify whether it has negative influence on measurement results. For this purpose there have been series of measurements. In the first set of measurements by means of frequency changer the operating speed of compensating ventilator were set to balance the pressure difference between surge chamber and atmosphere on the zero value. Then by the means of regulation equipment the negative pressure in surge chamber was increased and the flow was measured. In the second set of measurements the negative pressure in surge chamber was created by lowering of operational speed of compensating ventilator by frequency changer.

Results of observation

Lowering of operational speed of compensating ventilator by frequency changer led to negative pressure till the value 36 Pa. Another negative pressure increase was possible only by regulating device. The maximum negative pressure which could be made by tested ventilator was 90 Pa. Following the measured values in figure 4 there is ventilator characteristics. It is clear that in a direction to maximum flow the values are different. The more different deviation is in figure 5 where the approximation curves are drawn by regression analysis. We can conclude that for the most precise results it is advisable to use only throttling by regulating device for ventilator characteristics drawing.

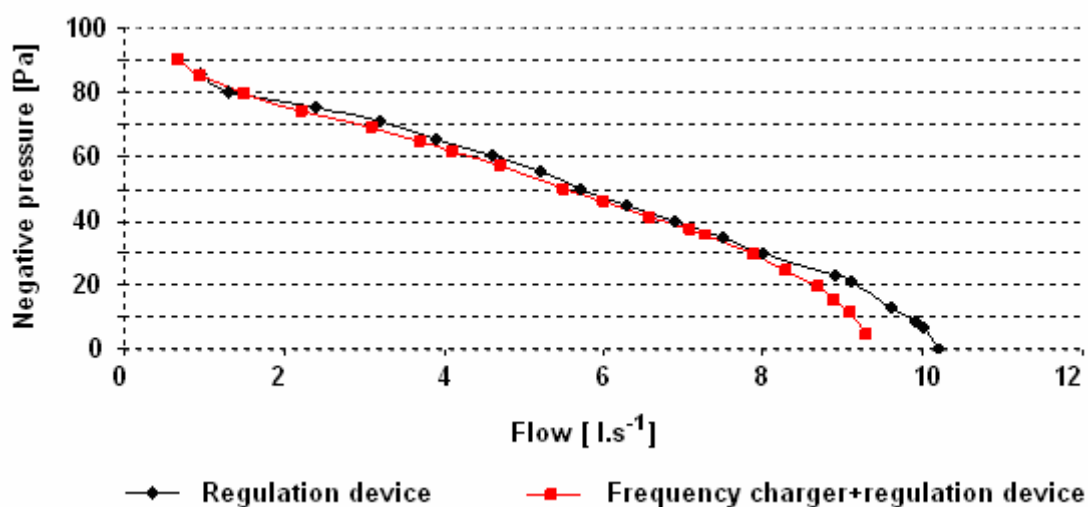


Figure 4. Measured values progress at measurement on Thomas cylinder

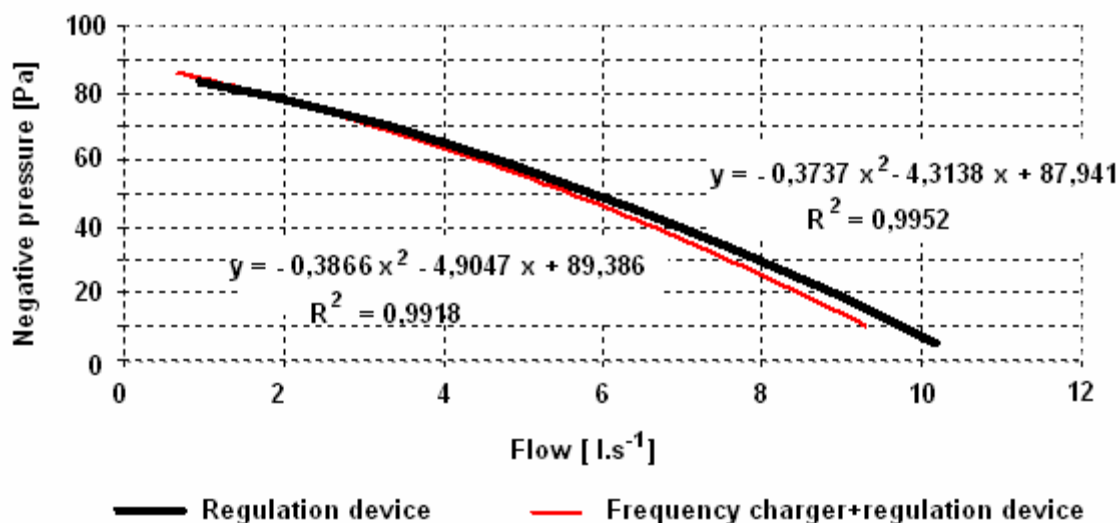


Figure 5. Ventilator characteristic based on regression analysis

Conclusion

There are many measurement methods and procedures for air flow measurement. They are more or less precise. The most precise method is method based on calorimetric principle. Calorimetric principle is used also in measurement by Thomas cylinder. Although this method is precise it is based on measurement of quite big range of parameters and the calculation of flow is rather complicated. If the whole measurement equipment is designed in a way that all the necessary data are gathered and processed in PC, the measured flow is directly displayed on pc screen without necessity of further calculations.

Thomas cylinder is specifically suitable for measurement of ventilator flow used for cooling the electrical machines in which the determination of cooling performance of air flow is important. This way of measurement has also other advantages. All measured values necessary for flow calculation are recorded and saved in external text file. These values can be further effectively processed in spreadsheet processor. It means that we can get ventilator performance characteristics or time response of particular measured values. The measurement is less laborious and time consuming then measurement by vane anemometer or thermoanemometer. Not to influence the values necessary for ventilator characteristics measured by Thomas cylinder by some serious mistake it is important for the negative pressure in surge chamber to be made only by throttling of regulation device.

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