Conception and Fabrication of the Wind Tunnel Control System

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Abstract. This paper presents the effect of preliminary work aimed at modifying the control system of an open aerodynamic tunnel. A functional solution of a complex control system using different data transmission protocols in the communication between individual components and subsystems is shown. As a result, the assumed effect of the tunnel control system operation is achieved by combining components through interfaces and protocols from the own solutions (e.g. user protocol in the RS485 interface) to the specific protocols of the component, converters and system executive components.

Keywords: wind tunnel, single-chip microcomputer, data transmission

1 Introduction

Aerodynamic tunnels are used during wind micro-turbines testing. One of the issues determining the correct operation of the tunnel in the research process is to ensure the adjustment of parameters of the air stream supplied to the test section and maintenance of their stable values.

The object of research described in this paper was the open aerodynamic tunnel, working with the matrix of 4 fans powered by inverters. In the initial period it was used with manual control of operating parameters. The control system was modified by the application of automatic system of tunnel's working parameters control and maintenance. Modification was carried out to obtain automatic control and stabilization of airflow parameters in the aerodynamic tunnel measuring zone.

Proceedings of the 8th International Conference on Information and Communication Technologies in Agriculture, Food and Environment (HAICTA 2017), Chania, Greece, 21-24 September, 2017.

The presented aerodynamic tunnel is used for testing micro wind turbines, which are used for example for off-line power supply in agriculture in irrigation, street lighting, autonomous metering, lighting or signaling systems.

2 State of art

In laboratory tests of objects subjected to the air stream, different types of aerodynamic tunnels are used in open-loop and closed-loop air flow versions (Calautit et al., 2014). The basic function of the testing aerodynamic tunnel is to induce and maintain in the controlled manner the airflow at the fixed speed (Cooperman, Martinez, 2015).

The way to induce the controlled airflow under laboratory conditions is to use a single high output fan or a fan assembly, providing the desired output. Using a solution with a set of several fans allows shaping characteristics of the air stream, in which the airflow velocity may vary in cross section of this flow (Hernández et al., 2013, Wong et al., 2017).

For measuring air velocity, instruments with different construction and principles of operation are used. Rotary cup or propeller anemometers, thermo-anemometers, ultrasonic anemometers and impact pressure tubes combined with differential pressure sensors (Zbieć, Obrębski 2014). Four Prandtl tubes were used for control of the described wind tunnel, which by measuring the total and static pressures allow determining the dynamic pressure exerted on the face of the impact tubes by the air stream with the defined speed.

When designing new wind turbine solutions and renewable energy installations, numerical modeling methods are commonly used (Maeda et al., 2017, Burlando et al., 2015, Bendjebbas et al. 2016). Studies are carried out with respect to the profiles of wind turbine blades and the whole wind turbine structure (Seifert et al. 2015,) in particular to improve the performance of wind turbines (Bottasso, Cacciola et al. 2014, Wong et al. 2017).

Validation of numerical models is carried out during experimental research, for example using wind tunnels (Maeda et al., 2017, Wekesa et al. 2016, Bottasso, Campagnolo et al. 2014, Li et al., 2017).

Obtaining a sufficiently stable airflow at the outlet of an aerodynamic tunnel requires the use of automatic control. Control systems using PLCs (Alphonsus, Abdullah, 2016) or hybrid solutions (Ali et al. 2012) with single-chip microcontrollers are used (Zbieć, Obrębski 2014).

3 Characteristics of the tested aerodynamic tunnel

The aerodynamic tunnel (figure 1), modified by the use of a new system of control and maintenance of the air stream parameters, consists of the following components: fans 1, constant section segment 2, stabilizer of the air stream 3 and the segment ended with the confusor based on the Witoszyński confusor profile 4.

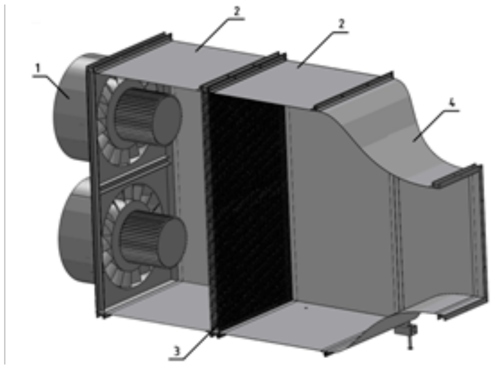

Fig. 1. Construction of tested aerodynamic tunnel: 1 - fan, 2 - pre-chamber, 3 - stabilizer of the air stream, 4 Witoszyński confusor (Pietkiewicz et al.2015a)

A system consisting several subsystems, using for communication different interfaces and protocols, was utilized to control the operation of the fans:

- measurement of the air stream velocity based on dynamic pressure at several points (micro-unit sensor)
- fans output adjustment (Frequency converter)
- analysis and information processing in the control process (PLC),
- visualization of parameters (PLC + HMI)
- visualization and recording of tunnel operation (PC)

The main element providing information on the current air stream velocity is a set of sensors designated as a micro-unit sensor. Each of these units is based on a single-chip microcomputer with a 32-bit AMR core. The air velocity measurement is realized by a differential pressure sensor, which works with the Prandtl tube. The micro-unit sensor has been developed as a universal module allowing the use of necessary physical quantities transducers in order to obtain information about values of variables subjected to the control process. These are piezoelectric differential pressure sensors in the presented system (figure 2).

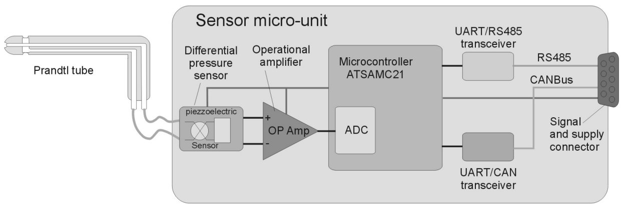

Fig. 2. Sensor micro-unit entity/component structure

A system of four Prandtl tubes was applied in the described aerodynamic tunnel. They are arranged in such a way, that piezometric holes measuring the total pressure generated by the air stream be in one fourth of each diagonal of the outlet section of the tunnel (figure 3). Connecting Prandtl tubes with the pressure transducers using pneumatic conduits allows the transfer of the pressure, that is measured by the impact measure tubes, to the transducers, which then pass the digital signal to the module controlling the operation of inverters that supply the fans.

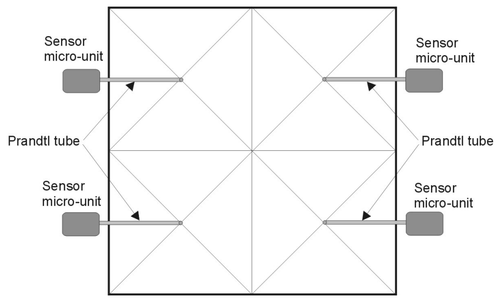

Fig. 3. Sensor micro-unit entity/component structure

The network protocols applied in the position include functional system division into the part responsible for the air stream velocity and shape control and the layer of data acquisition, parameterization and HMI monitoring. In order to provide temporarily deterministic signal transmission in the feedback loop between micro-unit and the PLC controller, acting as the regulating device, a protocol based on the Master-Slave communication in the application layer was developed.

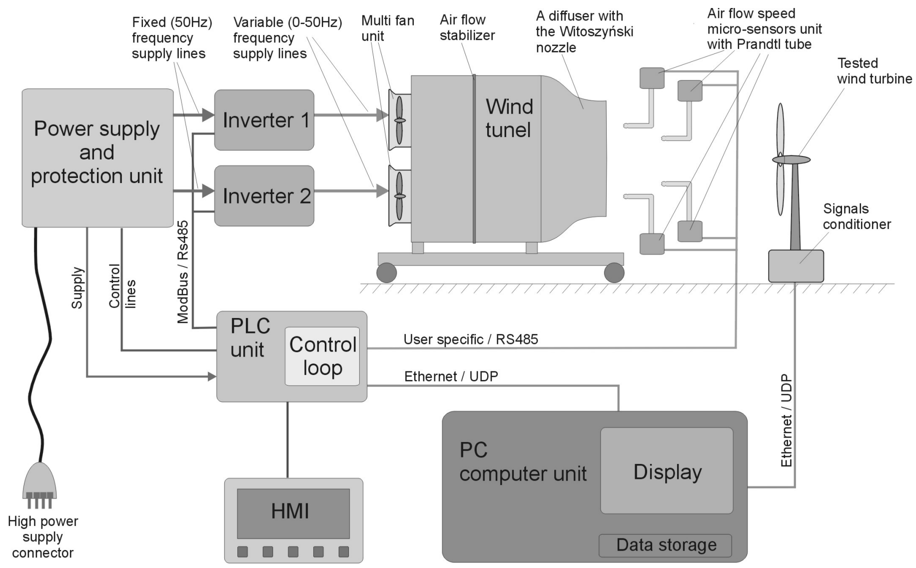

Fig. 4. Structure of the aerodynamic tunnel control system

Measurements made using transducers connected to the micro-unit sensor are pre-processed and conditioned in the microcomputer of the Sensor micro-unit and then transmitted to the computer of the master control subsystem (PLC) alternatively by one of two basic RS485 or CAN interfaces (figure 4). The PLC controller processes information from the air stream velocity sensors and based on the adjusted, demanded airflow velocity, generates a control signal to the supply inverters of the fans' motors. Communication between the PLC controller and the inverter takes place using the ModBus protocol. Information from the PLC to the inverters and the feedback from the inverters to the PLC are sent by this interface (figure 4).

Data transmission in the system PLC controller - Inverter is also realized using the Master-Slave protocol based on ModBus drivers implemented in these apparatuses. Due to the required high network capacity and the availability of interface typical for most PCs, UDP Ethernet protocol was applied in the HMI layer.

Visualization and recording of data in a PC unit was realized in the LabView environment. The developed application assures the opportunity to observe the operating parameters of the aerodynamic tunnel and functioning effects of components and devices subjected to tests in the air steam generated by the aerodynamic tunnel.

3 Summary

Modification of the aerodynamic tunnel control system, presented in this paper, allows the velocity of the air stream in the measuring zone to be maintained at the set level without the interference necessity of the operators. Integration of the control system with the acquisition system of measurement data of a tested wind turbine through the PC Unit allows the complex study of wind turbines and aerodynamic components with the operation parameters control and recording of the tunnel and the tested object.
This is a system combining advantages and specificity of different data transmission interfaces and protocols between the individual elements of the control system in order to obtain the assumed functional properties of the aerodynamic tunnel test system.

Acknowledgments. The presented works were carried out within the framework of the project: Functional models and studies of the construction of a quasi-autonomous lighting or signaling point, (Decision of the Minister of Science and Higher Education No 5119/B/T02/2011/40 from the 4th May 2011).

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