Approbation of the Laser Doppler Anemometer Lad-08 on the Secondary Standard Test Rig for Air Flow Speed

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Abstract. In the field of fundamental metrology and ensuring the unity of measuring instruments, the role of optical information methods, systems and technologies of non-contact diagnostics of dynamic processes is extremely relevant. The profiles of the axial velocity component were measured in the working section of the secondary standard test rig for air flow speed. The flow kinematics inside the working section is studied using a laser Doppler anemometer (LDA) with an adaptive temporal selection of the velocity vector (LAD-08).

1. Introduction

In the field of fundamental metrology and ensuring the unity of measuring instruments, the role of optical information methods, systems and technologies of non-contact diagnostics of dynamic processes is extremely relevant. Primary standards make the metrological base of modern technological civilization. Its presence determines the belonging of countries to the group of industrialized countries. At present, in Russia there is an urgent issue of updating the primary State standards based on the latest scientific achievements and the latest elemental base.

All-Russian D. I. Mendeleyev Institute for Metrology (VNIIM, St. Petersburg) is succeeding the activities of the Depository of Weights and Measures, the first in Russia and one of the world's oldest state metrological institutions. And it is one of the largest world centers of scientific and practical metrology. It is the national leading organization for basic research in metrology. It is the main center of state standards of Russia. The most important state task is to ensure the uniformity of measurements in the country at the international level through the use of state standards of units of physical quantities, improving existing standards and creating new ones through fundamental and applied scientific research. VNIIM has 54 primary and 200 secondary state standards of the Russian Federation.

To ensure scientific research and to provide measurements of the air flow rate in industry, Russia operates a very large fleet of working measuring instruments: about 500 thousand pieces. Due to the growing attention to issues of increasing efficiency and safety in the energy sector, industry and transport, to environmental problems, the need for means of measuring air flow rate is steadily increasing.

In 2012, for the first time, the development and creation of precision laser information diagnostic tools for the primary Standard test rig for air flow rate GET-150-2012 were performed based on the
methods of precision semiconductor laser Doppler anemometry [1]. Many characteristics of the created system of precision laser diagnostics and calibration exceed the characteristics of the best world analogues. The optical information diagnostic system of the standard contains a Doppler anemometer based on a semiconductor laser with a wavefront stabilizer, an anamorphic optical scheme with improved spatio-temporal uniformity of the probe optical field, a single-photon photodetector with an extended dynamic range, and a programmable system for automated experiments and calibrations [1].

Due to the application of a number of original ideas, methods and technical solutions, the expanded uncertainty of the primary State special standard of the air flow rate unit GET-150-2012 is ensured at the level of 0.14-0.3% when measuring the air flow velocity in the range of 0.05-100 m/s.

In Russia, when transferring the unit size to working measuring instruments, the four-link structure of the verification scheme is used: the primary State standard — secondary standards — working standards of the 1st and 2nd category — working measuring instruments. At the State Regional Centers for Standardization, Metrology and Testing of Rosstandart, more than 20 standard aerodynamic installations are used for testing working measuring instruments.

Secondary standards or copy standards are located in Central Aerohydrodynamic Institute named after N.E. Zhukovsky, and a set of reference measurement instruments is in FBSU GGO named after A.I. Voeikov.

Tests of the Doppler Laser Meter LAD-08S were carried out on the state secondary standard of the airflow velocity unit in NIO-7 of Central Aerohydrodynamic Institute on the secondary standard test rig for air flow velocity - EMC 0.05 / 100 installation.

The purpose of the tests was to verify the technical capabilities of the measuring system on the secondary standard of the air flow rate unit by measuring the air flow velocity profiles in the working section of the state secondary standard of the air flow unit in the range of 10-290 mm from the inner surface of the working section with aerodynamic flow velocities in the range from 1.34 to 10.03 m/s with an accumulation time in the measuring flow not exceeding 60 s and the number of measurements at a point not exceeding 4000.

2. The secondary standard test rig for air flow speed
The secondary standard test rig for air flow speed (Fig. 1) [2] represents an open wind tunnel with a closed test section.

![Figure 1. The photo of test rig.](image-url)
Dimensions of the latter (300×300 mm) are selected taking into consideration the size of the most modern anemometers under the requirement to minimize power of the fan electric drive. Calculations have demonstrated possibility to implement the maximum air flow speed of 100 m/s. Functional block diagram of the test rig is shown in Fig. 2. The test rig includes aerodynamic circuit, power unit of the fan electric drive and measuring system of the aerodynamic circuit. They are: inlet header that provides flexible vortexless collection of the air from the premises; honeycomb; stagnation chamber that serves to mix air flows and produce uniformly turbulent structure of the flow; nozzle that is intended for making high-quality flow in the test section through ninefold prepressure and optimal profile. There is the test section for placing the test meters. It has octagonal 300 × 300 mm cross-section; diffuser that supports smooth mating between squared test section and round input of the fan providing flow without separation; exit diffuser that has squared cross-section with 7°-semi-cone angle. Such solution provides sufficiently smooth flow output to the premises and reduces pressure pulsation of the fan significantly.

Power unit is designed as a radial fan. The fan drive is provided with asynchronous three-phase motor. The motor power supply is implemented through a frequency converter ensuring supply frequency within the range between 1 and 50 Hz (the corresponding step is 0.1 Hz). Varying the supply voltage frequency in the mentioned limits allows for setting air flow speed in the test section equal to 1–100 m/s.

Metrological performances of the test rig are determined by a genuine measuring system; it enables making simultaneous and independent measurements of the total pressure p₀, static pressure p and their difference Δp = p₀ − p in the flow. It is a conventional approach to measure dynamic pressure Δp and static pressure p in order to evaluate low speed of the flow. In addition, one has to measure atmospheric pressure, temperature and air humidity for taking into account variations of air density. The stated parameters appear sufficient to evaluate speed of the flow. The total pressure p₀ caused by speed losses in honeycomb and measured as a complementary parameter makes it possible to obtain error estimates for dynamic velocity pressure.

![Functional block diagram of the test rig](image-url)

**Figure 2.** Functional block diagram of the test rig.[3]
3. Velocity measurement

The flow kinematics inside the working section is studied using a laser Doppler anemometer (LDA) with an adaptive temporal selection of the velocity vector (LAD-08). The measuring device was designed and manufactured at the Kutateladze Institute of Thermophysics SB RAS, in Novosibirsk. The diagram illustrating the LAD-08 complex operation principle is shown in Fig. 3 b. The laser-optic velocity measuring circuit contains a laser, two orthogonally oriented acoustic light modulators with traveling waves, a transmitting-receiving optical system, consisting of a series of mirrors and lenses arranged at the optical unit, and a photomultiplier tube. The photomultiplier tube transmits the signal to the quadroture mixer. The quadroture mixer passes the signal to the Doppler signal processor, which transmits the processed data to the computer. The test volume is scanned by moving the optical unit by a coordinate spacer. LAD-08 operates as follows. After passing through the acoustic light modulators the laser beam is diffracted into the zero and minus first orders. The split beams pass through a series of optical elements of the system and then are sent to the tested area of the flow by the lenses.
Intersecting in that area, laser beams form an interference pattern with the known space-time periodic structure. The particle moving through the intersection area scatters the light. The photocurrent appears at the output of the detector, producing a frequency pulse in the radio range with the Doppler frequency shift, which is the known linear function of particle velocity. The signal duration is equal to the time of particle passage through the volume of intersection. The LAD-08 measures two projections of the velocity vector in the range of 0.001-400 m/s with a relative error of no more than 0.5%. The size of the intersection area is 0.1x0.1x0.5 (mm). The coordinate spacer moves the measurement unit in the area of 250 x 250 x 250 (mm) with an accuracy of 0.1 mm.

4. Results
The profiles of the axial velocity component were measured in the range of 10-270 mm from the inner surface of the working section of the secondary standard test rig for the air flow speed at a velocity in the flow core of 1.48 m/s, 4.18 m/s, 7.11 m/s, and 10.03 m/s (Fig. 4). The relative error in measuring the average values of the axial velocity component at the measuring point of 10 mm did not exceed 4.1% (Fig. 5). In the range of 20–290 mm from the porthole, the relative error in measuring the average values of the axial velocity component did not exceed 1.1%.
Figure 5. The profile of relative measurement error of mean axial velocity.

Conclusions
In the field of fundamental metrology and ensuring the unity of measuring instruments, the role of optical information methods, systems and technologies of non-contact diagnostics of dynamic processes is extremely relevant. The profiles of the axial velocity component were measured in the range of 10-270 mm from the inner surface of the working section of the secondary standard test rig for the airflow speed at a velocity in the flow core of 1.48 m/s, 4.18 m/s, 7.11 m/s, and 10.03 m/s. The flow kinematics inside the working section is studied using a laser Doppler anemometer (LDA) with an adaptive temporal selection of the velocity vector (LAD-08). The relative error in measuring the average values of the axial velocity component at the measuring point of 10 mm did not exceed 4.1% (Fig. 5). In the range of 20–290 mm from the porthole, the relative error in measuring the average values of the axial velocity component did not exceed 1.1%.

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