18

Optoelectronic Measurements in Science and Innovative Industrial Technologies

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1. Introduction

Optoelectronic measurements makes it possible to find real information about real world quantities (M.Planck) with advantages of the absence of contact, performing operations in a parallel optical form and with modern element base of optoelectronics and photonics. Experiment and practice (according to N.Wiener) play a key role in obtaining adequate information. Adequate experimental information in science allows one to create adequate theoretical models and verify numerical computer calculations and codes. Adequate information, along with resources, has become a decisive industrial factor practically in all fields. To obtain such information, one often needs industrial organization of physical experiments with new data processing methods and modern measurement base of ''innovative technologies'' in informatics, lasers, and photonics.

Investigations of fine effects are based on the creation and development of methods to extract data from noise-like signals. Bandwidth narrowing and synchronous detection imply a deterministic effect on the object, processing of responses, and organization of information exchange. The interaction with the object is performed at all stages. This enables to extract a maximum possible amount of information. Complete use of the information implies, methodologically, the use of a multidisciplinary approach, the creation of an infrastructure for fast performance of experiments, and a highly qualified optimistic team.

The material is presented as a sequence of sections based on a unified methodology and illustrating, step-by-step, the efficiency and fruitfulness of the fundamental principles and scientific ideas proposed in informatics of optoelectronic measurements illustrated by important practical results. Most significant and prominent results were selected for this presentation. These large-scale and productive results are successfully used in various fields of science and technology.

Laser diagnostics of multiphase flows, information monitoring in hydropower engineering and hydraulic turbine machine building, metallurgy, and railway transport, glass industry and medicine, semiconductor electronics and nanotechnology, atomic and oil and gas industries - this is a list of fields where the fundamental scientific ideas being proposed are successfully used. These results can help to solve, in many cases, the problem of import

product replacement and provide a considerable increase in the effectiveness and safety of numerous new industrial technologies.

2. Semiconductor laser Doppler anemometry of multiphase flows

High-precision nondisturbing optoelectronic measurements of the kinematics and structure of multiphase flows in the regime of back light scattering are needed in experimental mechanics, physics, chemistry, biology, medicine, ecology, and engineering. Velocity information is obtained when measuring the Doppler shift of the frequency of laser radiation scattered by small suspended particles and phase inhomogeneities moving in the flow. Nanotechnologies, experimental hydro-, gas-, and plasma-dynamics of multiphase systems, safety, resources, and ecology of power engineering, aviation, rocket, and nuclear engineering, shipbuilding, ground-based transport, machine-tool building, and instrument making--this list of fields for which such systems are vitally important is far from complete. Recently, of special importance are code verification in Computational Fluid Dynamics (CFD) and computer models of flows in science and innovative industrial technologies. Such laser information systems, which are highly competitive with the best foreign analogs, simple and safe, are also necessary for educational purposes (Meledin, 2009).

This high level of achievements is based on a series of papers, published in the 80s and 90s, on the creation of systems based on gas lasers and development of the first injection laser emitters for optical instrument making - jointly with Ioffe Physico-Technical Institute, RAS, and under the guidance of Zh.I. Alferov, Nobel laureate for physics (Arbuzov et al., 1992). This produced the world's first Doppler meters of velocity and linear sizes of hot rolled metal for metallurgy on semiconductor lasers (the Altair series presented below). This significant scientific progress resulted in creating in 2003 an information-measurement system called LAD-0x within the framework of a program on import product replacement, Siberian Branch of the Russian Academy of Sciences. This took place three years before the appearance of the world's best analog, DANTEC (Meledin, 2008).

Semiconductor lasers (with an efficiency of 20-60 %) made it possible to create information-measurement systems with fundamentally new functional capabilities. These systems are efficient and small in comparison to systems based on gas lasers (with an efficiency of 0.03 %). However, the quality, space, and time coherence of optical radiation and applicability in metrology of semiconductor lasers make them inferior to gas ones (Belousov & Meledin, 1985; Belousov et al., 1988).

In order to replace highly coherent gas lasers by semiconductor ones in information-measurement interferometric systems, some theoretical and experimental investigations have been performed. Theoretical studies on some peculiarities of formation and recording of optoelectronic signals under the photonic constraint and investigations on stability of anamorphotic schemes have been carried out. Also, new methods for parametric stabilization of wavefronts and photoelectronic transformations of optical signals with a dynamic energy range up to 10^{16} have been created (Rahmanov et al., 2006).

An important line of investigation was transition from flows with artificial light-scattering particles used in some foreign methods to processing of signals of natural suspensions with unusual characteristics of light scattering. Only in this case it has become possible to create onboard underwater systems to study the fine microstructure of hydrophysical ocean fields.

A nontrivial scientific task is to create Doppler information-measurement semiconductor laser systems operating with back light scattering from random suspensions in flows. To

solve this problem, a series of multidisciplinary and fundamental investigations had to be carried out: in informatics, signal processing methods, quantum optics and optoacoustics, radio physics, one-photon reception, data collection and processing systems, etc (Dubnistchev et al., 1987; Belousov et al., 1988, 1996, a, 1990, a).

In the field of processing and transforming optoelectronic signals from random suspensions, some methods have been created to handle ergodic processes with operations separated in time and having maximum possible field energy concentration in the measurement volume and maximum signal-to-noise ratio (Meledin et al., 1999; Dubnistchev et al., 2000, 2003).

Information-measurement semiconductor Doppler laser systems for diagnostics of multiphase flows (LAD-0x system), designed for noncontact measurement and visualization of two and three components of the velocity vector of gas-liquid multiphase, turbid flows, and concentration of light-diffusing particles, have been created. Also, a variant of the information-measurement scheme of a three-component anemometer based on a combination of two two-component systems has been developed. Each two-component system has all elements of optical and electronic subsystems and operates with an external computer via a standard network channel. Owing to the TCP protocol, the computer can be placed in an arbitrary place (for instance, in another city), and some physical experiments can be performed in a remote mode, in closed and dangerous zones, and at test sites, and can be used for distance education. In these systems, Russian-made algorithms and components are used, which have no foreign analogs.

The LAD-0x information-measurement semiconductor Doppler laser systems are used in the following Russian scientific and educational organizations: the Institute of Hydrodynamics (diagnostics of vortices and internal waves), the Institute of Thermophysics SB RAS, the Institute for Safety of Nuclear Power Engineering RAS (heat and mass exchange, safety of nuclear power engineering, nanotechnologies), Perm State University (investigations of convection), Tomsk State University (investigations of forest fires), Research Center of Power Engineering Problems, and Kazan Scientific Center, RAS. These systems are requested by many of the Russian organizations (Anikin et al., 2004; Meledin et al., 2000, 2001, 2003).

The information-measurement semiconductor Doppler laser systems created for diagnostics of multiphase flows meet the modern requirements and forecasts on the expected development of fundamental and applied science in the nearest future.

At the VII Moscow International Salon of Innovations and Investments in 2007, these developments were rewarded with Golden Medals and First-Rank Diplomas. At the VIII Moscow International Salon in 2008, they were rewarded with diplomas and Silver Medals, received the titles of laureates of the VII Contest of Russian Innovations (nomination: "The best 2008 Industrial Innovation of Russia," and were rewarded with diplomas and small Golden Medals of the Sibpolitekh-2008 International Industrial Exhibition.

3. Hydropower engineering and hydraulic turbine machine building. Optoelectronic for optimization of operation modes and safety of hydropower plants information

3.1 Dynamic monitoring of the geometry of loaded rotors of super-high-power generating units of the Neporozhny Sayano-Shushenskaya HPP

Dynamic monitoring of unique super-high-power generating units requires solving some serious scientific problems. The dynamic shape of a rotating rotor is a very important parameter determining the safety of operation of the aggregate on the whole. The purpose

of this work was to create an information system based on methods and technology of monitoring the geometry of loaded rotors of super-high-power generating units of the Sayano-Shushenskaya HPP to increase the efficiency of their operation and safety.
The power of one hydrogenerator is the same as that of the power-generating unit of a nuclear power plant (735 MW), the stator diameter is 17 m, the rotor diameter is 14 m, the rotor weight is 750 tons, and the linear velocity at the edge of a rotating rotor is 100 m/s. The consequences of a failure with the energy accumulated in the rotor are comparable to those of a failure at a nuclear plant.
Selective mechanical control of the rotor and stator shapes is performed by the operators when the aggregate is unloaded and completely stopped. This information is used to predict changes in the rotor shape while the aggregate is running. It is evident that the deformation of the rotating rotor shape and the dangerous decrease in the gap between the rotor and stator cannot be reliably estimated.
The well-known control methods used when the generator is stopped cannot be employed when the aggregate operates under normal loading. The major reason for this is as follows: there are considerable electromagnetic fields and no free space for recording equipment near the rotor. Information monitoring of the rotor geometry must be continuous, noncontact, and remote. Under conditions of considerable electromagnetic noise, vibrations, temperature differences, and dust, the monitoring must not affect the operation of the existing systems.
From the above scientific investigations, a method for information dynamic monitoring of the rotor shape of a loaded super-high-power energy aggregate at the Sayano-Shushenskaya HPP, based on a semiconductor lidar with coherent-optical feedback and hardware-software processing of optoelectronic signals, was proposed and implemented for the first time. The lidar was placed in the hot air chamber of the stator and adjusted relative to the rotor rotation axis. A sounding beam was directed to the rotor surface through a narrow extended channel of air cooling and ventilation in a 10x20x500 mm stator body.
Scanning of the rotor surface shape, which moved at 100 m/s, by the semiconductor lidar was made in the transverse direction. After software-hardware processing of the lidar signal, the frequency, being directly proportional to the distance to the rotor surface, was determined. Then, phase averaging of the data was made. Using the averaged data, a rotor surface profile was constructed and tolerance control was made.
The figures show some rotor poles and a standard diagram of deviation (in millimeters) from a constant radius of 6700 mm. This information about the rotor surface shape of an operational hydroelectric generator of the most powerful hydropower plant in Russia was obtained for the first time. The tests were performed on operational hydroelectric generator no. 4 of the Sayano-Shushenskaya HPP (type: RO 230-v-677). These full-scale experiments and tests have confirmed that the basic scientific principles on which this development, which is relatively simple to implement, is based are applicable and efficient. The measurement error of the experiments did not exceed 1% (Kulikov et al., 2010).
The results of this series of works were rewarded with a First-Rank Diploma and Golden Medal of the VII Moscow International Salon of Innovations and Investments (2008).

3.2 Hydropower engineering: laser diagnostics of flows downstream of hydroturbines to increase efficiency and safety

The Power Machines - LMZ (Saint-Petersburg) is the largest turbine construction plant in Russia. This open stock company produces power turbines. In the past 90 odd years of

development and creation, more than 2300 turbines with a total power of about 300 million kW, more than 670 hydroturbines with a total power of about 62 million kW, about 1000 hydroturbine regulators, and 60 pre-turbine gates have been produced. The Power Machines - LMZ is a leader in domestic and world hydroturbine construction. Power Machines - LMZ turbines operate at large hydropower plants, such as Volga, Bratsk, Krasnoyarsk,
Ust Ilimsk, Sayano-Shushenskaya (Russia), Maika, Site 1, Jenpeg (Canada), Sobradinho (Brazil), Uites (Mexico), Hoabin (Vietnam), and many others. With its hydraulic turbines operating in 30 countries of Europe, Asia, Africa, and America, the LMZ gained substantial experience in hydroturbine construction. Power Machines - LMZ plans are to supply hydroturbines, regulators, and gates for electric power plants in India, Argentina, Iraq, Kazakhstan, Latvia, and Russia.
The important scientific problem of obtaining information about the real dynamic characteristics of a multiphase cavitating flow at the outlet of a hydroturbine has been solved specially for the Power Machines - LMZ. In 2004 through 2005, new information-measurement methods and 2D laser systems, LAD-05 and LAD-06, and a 3D laser information-measurement system, LAD-056, were created and introduced. These systems are designed for bench testing, optimizing, and certifying various turbine models, verifying CFD calculation codes, and increasing the efficiency of operation and safety of domestic power engineering. Some foreign projects (DANTEC and others) were also considered, but the above systems were chosen owing to their scientific and technical parameters (Meledin et al., 2006, a,b,c).
New Doppler laser information-measurement systems were created on the basis of the fundamental investigations described above. These are used to determine the kinematic parameters of twisted hydrodynamic flows and the influence of parameters of large-scale helical vortex structures on the transfer processes in twisted flows downstream of the hydroturbine wheel. Such systems were installed on a large cavitation stand of the Silovye mashiny-LMZ.
First full-scale experiments for all operational modes of the Frensis turbine have been performed. A 2 % total estimate for the error of the flow rate of a two-phase cavitating flow has been obtained. The three-dimensional velocity fields of a multi-phase flow at the hydroturbine outlet have been constructed (Sadbakov et al., 2004).
The results of comprehensive testing of information-measurement Doppler laser systems for diagnostics of gas-liquid flows downstream of hydroturbines have verified their technical characteristics. The systems have been found to be suitable for exploitation, bench tests, optimization, subsequent certification of various turbine models, and verification of the CFD calculation code. These systems have provided an increase in the efficiency of operation and safety of domestic hydropower engineering.

4. Metallurgy. Laser monitoring of velocities and linear sizes of hot rolled metal body

Obtaining adequate information about the velocities and linear sizes of a hot rolled metal body in metallurgy is a complicated multidisciplinary scientific problem. The light-diffusing surface of a hot rolled metal body (with a temperature of up to 1200°C) is a set of random roughnesses. The resulting optical signal is formed by the superposition of light waves scattered with random phases on a set of centers confined simultaneously within a sounding

optical field. Multiple interference increases the phase noise, forms a multi-fractal small-contrast signal, and decreases the accuracy of measurement. Permanent oxidation, which affects the light scattering and disturbs the Doppler spectra, takes place on the hot metal body surface.

Being linearly displaced, the rolled metal body participates in a multiple motion: there are vibrations, turns, inclinations, and bends forming optoelectronic signals with a very large dynamic energy range. The convective flows near a hot rolled metal body cause considerable refraction, which modulates light both in space and in phase, and contain a moving suspended aerosol. There is a lot of mud and water, in particular, in the form of moving films. Measurement of sizes is also a difficult scientific problem of boundary recognition and stable interpolation of signal losses. And, finally, since huge masses and energies are involved in metallurgic processes, high reliability and stability are needed for the entire operation of information-measurement complexes.

On the basis of the fundamental results obtained in our investigations, a number of information laser control systems have been created. These are used to sound moving rolled metal body surfaces, record the Doppler frequency shift of scattered coherent light, which is proportional to the velocities of the objects, accumulate information, perform statistical software-hardware processing, and form standard signals for metrological support, monitoring, and control of the technological processes.

The information systems made it possible to obtain, in real time, adequate information (not available previously) about the velocity and geometry of rolled metal bodies with an error of less than

0.1 %. Also, they provided automatic monitoring and increased stability of the technologies used for unstable and worn materials and fuels in variable environmental conditions. Since the obtained information was adequate and accurate, a considerable economy and an increase in the products of higher quality have been obtained.

The first Russian Qazar-M information-measurement optoelectronic system that was successfully used at the Novosibirsk Metallurgy Plant up to 2006, was developed and introduced in 1986. In period from 1985 through 1987, first laser noncontact Doppler meters of velocity and rolled metal length of the "Altair" series were developed and tested in conditions of real metal production on semiconductor lasers developed at the Ioffe Physico-Technical Institute (by Zh.Alferov and D.Garbuzov). At their creation, these systems were the world's first developments.

In 1986, the Institute of Economics and Industrial Production Organization, Siberian Branch of the USSR Academy of Sciences, made an estimate of the economic effect obtained by introducing the information-measurement laser complexes into ferrous metallurgy. The estimate is of certain interest. This is as follows: the economy in the metal is 1,422,744 tons/year and the total economic efficiency exceeds 105,000,000 rubles (in 1986 prices). The effect was very impressive, and in 1986 the USSR Ministry of Instrument Making, Automatization, and Control Systems and the USSR Ministry of Ferrous Industry adopted a program on the creation and introduction of Doppler laser measurement systems for metallurgical purposes in the industry.

To measure the velocity and rolled metal length on the basis of *He-Ne* and semiconductor lasers, Qazar, Altair, and LI-803 optoelectronic Doppler information-measurement systems have been developed. In the Qazar and LI-803 meters, *He-Ne* lasers are used as sources of coherent radiation. A number of integrated research-and-development works have been performed, and small lots have been produced. In 1993, LI-803m information-measurement

systems were created and tested at large metallurgy enterprises, namely, at Nizhnetagilsk and West Siberian metallurgical plants. These systems had an ultra-long-range measurement distance of 3 to 5 m (the maximal distance of the existing foreign meters was 2 m) and a maximal measurement zone depth of more than 200 mm. The major technical characteristics of these information-measurement systems were higher than those of existing foreign analogs and were better suited for real conditions of domestic metal production (Meledin, 1995).

A number of methods for controlling and testing the accuracy characteristics of some information systems oriented to industrial technologies have been validated both theoretically and experimentally. An automated software-hardware stand complex to test and adjust information systems and to assess long-term stability and reproducibility of their metrological characteristics has been created (Belousov et al., 1990 - b, 1996 - b).

Accurate verification of the information obtained in this way is rather easy. A section of 10.00 m length measured with an error of 1 cm can be considered as a reference object of 0.1 % accuracy. As such an object moves at any regime in the measurement zone of the information-measurement complex, the latter, after integration of the measured velocity, must indicate a length of 10.00. The complex is tested in a "black box" regime as a whole, from the basic scientific ideas to the peculiarities of practical realization, because an error in any method, algorithm, or element may make accurate operation of the entire system impossible.

Multiple industrial tests of these systems have been carried out. Specifically, the Qazar-3M meter has been tested at the West Siberian Metallurgical Plant, on a continuous-supply mill 850/730/580 after a roughing train. The temperature of rolled 150x150x80,000 blocks (St3 PS steel) was about 1000°C. The error of measuring the linear sizes of hot rolled metal bodies by these systems in real industrial conditions was 25 times less than that of the standard production system for the inspection of rolled body lengths. The tests have shown that the Doppler laser measurement systems have considerable advantages in accuracy and reliability. It has been proved experimentally that information monitoring of the rolled metal production technology in real time and high quality of adjustment of the successive series of rolling mills in production lines are feasible.

Comprehensive tests of these information-measurement systems were made in 1994 at the Nizhnetagilsk Metallurgical Plant in a rolling shop of broad-flanged beams. This shop is the last in the entire technological chain of the complex, and this new advanced technology provided maximum output.

It was found experimentally that the average deviation of the rolled metal length from the real value measured by the system is less than 0.05 % and the maximal deviation does not exceed 0.099 %. These errors had a compensatory bias component produced by the errors of the setup in tests of the system optoelectronic sensor at a rolling mill. Since that time, the system of information laser control of hot rolled metal, LI-803m, has replaced the standard IDSh measurement complex, since its functional characteristics, accuracy, and reliability are by an order of magnitude higher.

Information-measurement systems to control the transverse size of hot rolled metal based on the original scientific idea of measuring the size of the object by estimating its integral radiance in the near infrared region have been developed. It has been shown, both theoretically and experimentally, that the estimates obtained above are stable to the distortions of visible object boundaries produced by refraction, aerosol diffraction, etc. First accurate measurements of the transverse sizes of hot rolled metal with an error less than

0.2 % at a distance of 5 to 15 m from the dangerous zone have been obtained (Bakakin et al., 1997).

The successful scientific idea has made it possible to create a small inexpensive information-measurement complex. The efficiency of this complex was proved in tests performed at the Nizhnetagilsk Metallurgical Plant. Information about the distributions of sizes of hot rolls and the roll temperature was obtained for the first time. The following data were also obtained for the first time: the flange height variation of hot beams, temperature variation along the roll, and spatial boundaries of ''tongues''.

A second series of tests of the system was made at the West Siberian Metallurgical Plant in 1997. Information about the spatial distributions of transverse sizes of hot rolled metal in a breakdown mill after the finishing train was obtained for the first time.

Since 1994, the LI-803m information-measurement complexes have been used in the production record system of a broad-flanged beam shop at the Nizhnetagilsk Metallurgical Plant. The continuous reliable operation of the system provided accurate measurements of the velocity and length of hot and cold rolled metal with a total error not exceeding 0.1 % and a daily volume of controlled products of 3,000,000 US dollars (in the prices of 1994). In the process of introducing the information system, it was found experimentally that the economic effect reached 100,000 US dollars per day and the pay-back period was not more than two days.

For the first time, information-measurement systems and laser software-hardware complexes for monitoring and controlling technological information on hot metallurgical rolled metal with characteristics even better than those of the foreign analogs have been created. These measurement complexes have been introduced and successfully used at large ferrous metallurgical enterprises of Russia: at the Nizhnetagilsk Metallurgical Plant (from 1993 up to now), the West Siberian Metallurgical Plant (from 1992 through 2001), and the Novosibirsk Metallurgical Plant (from 1986 up to now).

5. Transport. Information monitoring of the railway wheel geometry

Railway wheels and wheel pairs are very complicated geometrical objects. In production, they are subject to various operations: heating, pressing, rolling, calibrating, turning, and thermal treatment. In operation, they are intensively worn out and periodically turned to restore the profiles of the roll surface.

Information monitoring of the geometry is required at all stages of production control and life cycle of railway wheels. The number of major parameters to be controlled reaches 14. Traditional contact control methods are inefficient and selective, which inevitably increases the percentage of defective articles and accidents.

A joint work was initiated with the producers of railway wheels at the Nizhnetagilsk Metallurgical Plant in 1994. A new method to control the geometry of a rotating hot wheel by scanning the projection of the linear velocity vector at a point of measurement of the instantaneous radius was proposed and implemented. The velocity was effectively measured by a Doppler laser information-measurement system at a distance of several meters.

It was shown that this non-traditional use of anemometers to control the geometrical parameters of axially symmetric industrial products effectively solves the problems of measurement and control of the shapes of bodies with complicated geometries, in particular, when manufacturing hot railway wheels. The measurement error depended on the radius

and the rate of radius change (the degree of asymmetry) of the object. It was about ± 0.1 % for an eccentricity of about 20 %.

The method was tested experimentally from 1994 through 1995. The measurement error was less than 0.1 % at a linear wheel surface velocity of up to 10 m/s, a surface temperature of up to 1100°C, and sounding angles $\beta \leq 30°$. Unfortunately, for some reasons in the period from 1995 through 1997, the work on the project was stopped. Nevertheless, a basis for the future fast development of dynamic measurement of the railway wheel geometry was created (Meledin, 1995).

The year 2001 marked a second stage in the development of this theme. A Laboratory on Optoelectronic Information Technologies, organized by the Technological Design Institute of Scientific Instrument Engineering jointly with the Institute of Thermophysics, SB RAS, started works on creating an Automated diagnostic complex to measure the wheel pairs of railroad carriages at approaching a railroad station (Center for Introduction of New Equipment and Technologies of the Russian Ministry of Railways, contract 1733-02/UCV/UPS-17/10 of 2001/08/22), and also joint works with the West-Siberian Railroad on Express diagnostics of moving wheel pairs of railroad carriages (called a Complex and an Express, respectively, under the guidance of Prof. V. Meledin).

The best foreign analog, the Argus system that was developed in 2000, had a length of 18 m, a weight of 11 tons, a power consumption of 30 kW, and operated at air temperatures of -10… +40°C (not suitable for Russia). The system cost was 3 million dollars, and no license was on sale. It is evident that to rapidly create a system for information monitoring of the geometry of railway wheels at reasonable costs, fundamentally new scientific ideas and a nonstandard approach to solving this complicated scientific and technical problem should be used.

At the start of these works, a method for obtaining information about wheel geometry based on laser anemometry was tested. Results of the testing were good, but the method was not simple enough to implement. After some scientific investigations, another method based on dynamic laser triangulation was used. The method had a relatively simple calibration in field conditions at considerable temperature differences and easy organization of additional measurement channels.

A rolling wheel pair of a moving train participates in numerous kinds of motion: translational motion along the rails and rotational motion. As the wheels move, the rails sag resiliently in the vertical direction with an amplitude of up to several centimeters, and the wheel pairs make small transverse damped oscillations. We proposed a new method for information monitoring of the geometry of railway wheels. In this method, the instantaneous coordinates of the ends of four crossed radius-vectors directed to the moving wheel pairs with self-scanning surfaces are recorded synchronously. They are modeled by beams of laser distance meters. The synchronously recorded data are accumulated, and the wheel shape is reconstructed with the use of dynamic models. Tolerance control of the reconstructed 3D virtual images of the wheel pairs is made.

The data processing was made by rejecting the unreliable observations, forming continuous sequences, interpolating the signal dropouts, and matched filtering, which improved considerably the signal-to-noise ratio. The calculations were made in quasi-real time (as far as it was possible for the standard operating system used in calculations).

The above-mentioned information-measurement complex, which used a method of dynamic 3D size control in a virtual system of coordinates, had sets of laser optoelectronic meters on the outer and inner sides of the wheel pair. The meters had special signal processors and

communication channels with a calculator and a network server. Special software based on those methods and algorithms was created for the complex.
A peculiarity of the information-measurement complex was an untied base, which decreased the upper frequency of the microseisms, and a passive aerodynamic shield of the optical surfaces. The shield had a special design taking into account the active transport of atmospheric aerosols by the turbulent vortices produced by a moving train.
Because of some unscheduled actions of the Russian Ministry of Communications, the system was made very quickly (about six months since the contract signing; two months from the start of funding to the handing-over of an operational specimen at a time when the Trans-Siberian Railway was specially blocked off for this purpose).
The operational specimen of the Complex system (named after the corresponding project code) provided reliable monitoring of the geometry of railway wheels. This noncontact and remote monitoring can be used for a moving train under real weather conditions and in the presence of dust, mud, and other contaminants. As a result of these works, first laser measurement complexes have been created, which were tested in real conditions (at the Agryz station of the Gor'ky Railroad, from November through December, 2001). The algorithms were proved to be robust under various weather conditions (-20°C; rain, snow, and hoarfrost) and various train velocities (10… 25 km/hour).
Taking into account these successful results, in 2002, the Department of Railroad Cars provided additional funding of this theme. In February 2002, the Complex was given to a special organization headed by S.Plotnikov. Now, a simplified variant of the complex (without dynamic models and virtual systems of coordinates, only local measurements are made) is widely used on the Russian railroads.
At present, more than 38 large Russian railroad stations have been provided with a measurement system of the Complex type (Meledin, 2008, 2009).

6. Molecular electronics. Measurement complex for investigation and optimization of new-generation nonvolatile memory (from 2010 through 2012)

The electronics sector for memory chip production is on the verge of new serious changes. In the last 30 years, the physical principles on which modern memory elements are based have been unchanged. Major efforts of the electronic industry have been focused on the problem of miniaturization of electronic devices. At present, the possibilities of miniaturization have practically been exhausted. Since the need for cheap and versatile memory microchips is increasing, electronic companies carry out intensive investigations of new physical phenomena and materials to create a new generation of memory devices. Molecular and polymer materials are the first among the active and functional materials. These materials allow generation and real development of molecular electronics.
Searching for new conceptual and technological ideas, many electronic companies cooperate with universities and research institutes all over the world. Korean and American companies, which are major producers of memory microchips, have especially active cooperation. Spansion, a joint American-Japanese company, a world leader in the production of flash memory microchips (of the NOR type), is a daughter enterprise of the American AMD company and the Japanese Fujitsu company. The Spansion supports investigations on the creation of a new-type nonvolatile memory in the Siberian Branch of RAS.
The new generation of nonvolatile memory microchips under development has a resistive type of nonvolatile memory based on changing the conductivity of unit nanoelements. The

nanoelement of memory has a sandwich structure, in which the active material located between two electrodes changes the conductivity under the action of pulses of an electric field. This type of memory makes it possible to create passive memory arrays. This decreases considerably the number of transistors required for addressing unit elements.
Resistive memory types are most adequate for the logic of construction of electronic circuits. The new memory type allows one to create multilayer structures. This provides a considerable increase in the information density without changing the design lithographic norms and a minimum in the energy consumption.
Testing, investigating, and optimizing this type of memory cells call for the creation of a fundamentally new type of information-measurement complex. At the start of these works, there were no analogs of such a complex both in research and industry. There are special and rather contradictory requirements on the characteristics of an information-measurement complex to investigate and optimize the nonvolatile memory of a new generation.
When pulses of programming or deleting information (pulse duration: 10 ns, front: from 2 to 3 ns) act on a memory cell, simultaneous data reading (memory cell resistance measuring) takes place. Memory cell resistance may vary in the range from several hundreds of ohms to several hundreds of megohms. At a time constant of 3 ns and a resistance of 150 kiloohms the effective capacity of the system, including the cell, conductors, and electronic circuit, must not exceed 0.02 picofarads.
The creation of electronic devices with such parameters is a complicated scientific and technical problem.
Data recording, reading, and deleting in a memory cell are determined by the size and sequence of the corresponding electric pulses. Since the characteristics of individual resistive elements are widely spread, a mode switching control based on fast feedbacks in current and voltage is performed.
The complicated scientific and technical problem of organizing fast feedback (from 3 to 4 ns) between the resistance measured and the pulse duration of programming or deleting has been solved.
Sufficient complex phase stability and operating speed for recording and exchanging information with a nanoelement in a molecular cell have been provided.
The program interface is implemented via a COM-object. This allowed planning and performing experiments with any program packages supporting COM-automatization (OrignPro, Matlab or Excel).
Stability and long-term cycling operation have been achieved in this information-measurement electrometric complex for the memory element, which is based on modern concepts of molecular electronics. Operation in a multi-bit mode with a typical time constant of 3 ns at a cell resistance of 150 kiloohm has been ensured (Glavny et al., 2007).

7. Technical vision systems and multi-dimensional signal processing. Information monitoring in the glass industry

The purpose of this work was to create an optoelectronic computer method for obtaining information about the mass of a free falling object using its image, in other words, a computer implementation of the well-known method of weighting judged "by eye."
In a classical method to measure the volume V of a complex-shaped body, the body is divided along the vertical axis y by parallel sections of area $S(y)$ and height Δy. The total volume of the body is equal to the sum of N volumes of the thin truncated solids.

Reconstructing the boundary shape requires a series of measurements of transverse sizes of sections at all heights y by rotating the body about the vertical axis. If optical methods are used for measurements, the plane projections of the body at different angles must be recorded. A similar approach is used in tomography.

There exist certain classes of objects with topologically similar parallel sections where the volume can be measured by recording a single plane projection. The topological similarity means that any parallel section has an area S associated with a special transverse size ($2r$) by a coefficient ξ that does not change at any continuous scale transformation. In this case, the condition $S(y) = \xi \cdot r^2(y), \forall y \in [a,b], \xi = const$, is satisfied for any coordinate y.

Here, r is the distance from the vertical axis to the plane section boundary and ξ is a topological calibration coefficient determined by the shape of the section boundary.

When the geometry of sections is determined optically, the volume V of a body with topologically similar parallel sections is calculated by taking into account the topological and geometrical calibrations as $V = \lim_{N\to\infty} \sum_{n=0}^{N} S(y_n)\Delta y_n K_n(\beta) \approx \xi \cdot \sum_{n=0}^{N} r^2(y_n)\Delta y_n K_n(\beta)$, where $r(y)$ is the projection of the transverse size of a body of revolution onto the observation surface as a function of the coordinate y along the vertical axis. The geometrical calibration coefficient K depending on the vertical coordinate y and parameter β is introduced to compensate for the optical hardware distortions of the results of measurements of S and y. The coordinates a of the lower edges and the coordinates b of the upper edges of the body are also determined along the vertical axis.

A particular case of objects with topologically similar parallel sections is glass gobs formed in the production of glass bottles. The shapes of gobs solidifying in flight are close to those of bodies of revolution, and for the latter the condition of topological similarity of plane sections is satisfied. To estimate the volume of such an object, it is sufficient to measure the sizes of projections of sections $r(y)$ onto the recording plane, given the topological ξ and geometrical K calibration coefficients. The measurement error is due to inaccurate determination of transverse size projections at various coordinates $r(y)$ and violation of topological similarity. An important property of the objects with topologically similar parallel sections is insensitivity of volume estimation by plane images to possible vertical axial deformations.

The spatial coordinates $r(y)$, a, and b are determined by a program method of analyzing bitmap images. Spatial coordinates x and y in the image plane are selected and tied to an absolute system of coordinates. The image of a glass gob (A) is transformed into a video signal by a TV camera by line-wise scanning. A scanning coordinate-sensitive photodetector (B) "cuts" the droplet projection into lines. In this case, each line corresponds to one parallel section of the object.

This method was implemented in an information monitoring system for the glass industry. Now it is used as a scientific basis for engineering by other organizations. The system was created for obtaining noncontact real-time information about the masses of freely falling hot gobs of fluid glass in the production of glass works (bottles). The system operation is preliminary optical processing of the images of freely falling hot glass gobs, introducing the video signal into a computer, real-time analyzing the video flow, extracting the geometrical information, calculating the volume and mass of gobs, and statistical processing of the results.

The inner volume of a bottle is determined by the mass of the glass gob (the outer bottle sizes are determined by the geometry of the mould). In dosing fluid glass, the glass parameters are near the crystallization point and greatly affect the stability of operation of the gob former. The number of rejects reaches 30 to 45 %. The mass of a glass gob can be measured only "by eye," as the droplet falls from the gob former to the mould of a suck-and-blow automatic machine. The glass is hot; there are intense convective and aerodynamic stratified flows and strong refraction. The air has considerable amounts of aerosol particles produced by the black-lead lubrication of the gob former scissors. In two-three hours, the unprotected optical devices become completely dirty. The systems used for measurement should not hamper the operation of the available technological equipment and should be located at a distance of no less than 3 to 10 meters from the objects measured. The required accuracy is 0.5 %.

In the system, information undergoes some successive transformations, and each of them introduces its own errors. Temperature is a major perturbing factor. This parameter affects the quantum yield of the photomatrix, the levels of its dark current, the leakage currents of all semiconductor elements, and the accuracy of binding to the levels of black and white in the processing chain of a TV signal. It has been shown that for obtaining an accurate and reproducible estimate of the spatial boundaries of a self-luminous object with an error of 0.2 %, the video camera should be thermally stabilized with an error not exceeding 0.1°C.

A second important factor is luminosity of the object. The temperature of hot glass gobs is about 1000°C, and they have high luminosity. The temperature and luminosity of their surface can change due to intensive cooling by a cold air flow. A method to stabilize the threshold discrimination level of a video signal has been developed. This method performs statistical estimation of the image, levels of black and white, and provides accurate spatial discrimination of the boundaries when the luminosity of the object changes.

A method for passive aerodynamic protection of the optical surfaces of an information-measurement system was proposed. With this method, no atmospheric aerosol can get into the boundary layer, the optical surfaces are not dirty, and the time of undisturbed operation of the system is increased from 3 to 4000 hours.

The image of a falling gob of molten glass is formed by a receiver based on a video matrix. A video signal comes to the computer of a workstation for subsequent real-time processing. The workstation software receives video flow from a TV camera, detects the object in the field of vision, binds the object to the frame boundaries, and performs spatial filtration, spectral selection of the image, noise elimination, and amplitude discrimination by the Heaviside step function. After this, the gob mass is calculated. The calculated mass values are kept in a local database of the workstation. The monitor screen shows the gob mass variation in real time.

If the gob mass is greater than some given limits, the program generates warning and control signals. With these signals, an operator (or an actuating mechanism) introduces corresponding corrections to the technological process. Three watchdog timers controlling the major program modules maintain the operation of the workstation software.

A real-time information monitoring system for noncontact measurement of the masses of freely falling hot glass gobs is used by the Ekran (Novosibirsk). This low-cost system is used to fabricate glass bottles. The system provides noncontact technological control of the masses of hot glass gobs and generates warning signals when the mass of gobs exceeds the tolerance zone boundaries. The mass measurement error is between 0.5 and 1 %. The use of

monitoring based on this method in the glass industry has decreased the number of rejects by a factor of 3 to 5 (Meledin et al., 1999, 2000, 2001, 2002).

8. Medicine. Optoelectronic complexes for endoscopy

Endoscopy is one of the most important trends in the development of medical science and practice. Endoscopic operations are widely used for diagnostics and treatment of various human diseases. Karl Storz endoscopes developed in Germany and used in 140 countries are a world standard. Their quality meets the most stringent requirements of medical diagnostics, and the cost reaches a considerable amount of 2000 to 5000 US dollars. Since the optical devices in existing endoscopes are complicated and expensive, they cannot be employed on a mass scale and easily used in scientific investigations and experiments.

The purpose of this work was to create optoelectronic endoscopic complexes of a new generation, which permit operation with disposable tools in medicine, scientific investigations and experiments, and technical introscopy.

A standard endoscope has several high-quality image-transmitting rod lenses with complicated centering (H. Hopkin's scheme) and a fiber highlighter. Because of high temperature, humidity, autoclaving, and chemical treatment, frequent sterilization of the endoscope reduces its lifetime and worsens image quality. The propagation of HIV and acute viral hepatitis makes the problem of creating disposable sterile endoscopes especially important. The performance of hundreds of operations on different patients with the same endoscope without reliable sterilization creates a moral and ethical problem for the doctors and a serious risk for the patients. The limited reliability of modern endoscopes due to high sensitivity of lens centering to mechanical deformations is also a problem.

Our endoscope has been created as a means of optical diagnostics of multiphase flows in closed cavities. A new optical scheme for the endoscope has been created. Its advantages are a high resolution, high reliability, small cost (20 to 100 US dollars), simple construction at good image quality, and high sterility owing to the use of disposable tools.

One can see from the comparative table that the parameters, except for the number of lenses, depth resolution, and admissible deformation, do not differ considerably. A major advantage of this endoscope is that it has a small number of lenses, since the complexity of an endoscope is determined by the complexity of its optics. Advantages of the endoscope are also simplicity, easy assembly and disassembly, and large admissible deformations. The endoscope allows the use of disposable elements of plastic or traditional optics. A number of endoscopes with these advantages have been created.

A scientific problem is obtaining information about the frequency-contrast characteristic and distortion of the optical and optoelectronic schemes of endoscopes under considerable uncompensated aberrations. At the start of this work, there were no suitable methods. A method for obtaining information about the parameters of endoscopes has been proposed and validated. It is based on the reconstruction of the test signal by using a distorted image of the test object, calculation of the frequency-contrast characteristic as the ratio of cross spectrum of the input optical signal and the reconstructed test one to spectrum of the reconstructed test signal, and determining the spatial distribution of distortion curves. The method has been implemented on the above-mentioned optoelectronic stand for obtaining information about the characteristics of endoscopes.

This work was initiated, supported, and awarded by the technology park of the city of Katzrin, Golan (Israel). An international company, Optiscope Technologies, Ltd., has been

created. For these endoscopes, a number of patents, among them two American patents, have been taken out. Now further development of the technology of precision plastic casting of a disposable endoscope is being performed by a Carl Zeiss daughter enterprise in Germany (Meledin, 2008).

9. Machine building. Optoelectronic diagnostics of coordinates and shapes of 3d objects

In power engineering and machine building, there is a wide class of products. Specifically, these are: low-rigid large products with complex shapes, such as blades of hydroturbines, steam and gas turbines, and compressors, box and shell casings, airscrews of flying vehicles, screw propellers of ships, impellers, covering discs, etc. The cost of large blanks is high, and requirements on the quality of products are very rigid. Therefore, the problem of high-precision control of coordinates and shapes of 3D objects at all stages of mechanical treatment is very important.

The purpose of this work was to create new methods and information systems as refined and easy to manufacture as possible for obtaining information about the full geometry of 3D objects with sizes from several millimeters to tens of meters.

A new method for stable processing of sets of spatially modulated images with a stepwise shift has been proposed. It minimizes the error in determining the phase with noise of constant mathematical expectation and variance. In this case, the phase difference estimation of sets of spatially modulated fields is independent of the background intensity distribution.

The method is successfully used in the form of a program code. A generalized algorithm to obtain a solution to a system of transcendental equations at arbitrary phase shifts has been constructed. The complexity of the algorithm with respect to the number of interference patterns with different phase shifts has been estimated. The method is insensitive to additive noise with constant mathematical expectation and variance. An estimate of the root-mean-square deviation of the phase obtained and the reconstruction accuracy of the relief surface of the object measured has been obtained.

The method is used in an information-measurement system to obtain information about the geometry of 3D objects. The object under investigation is sequentially illuminated by a structured light, which is a system of parallel bright halftone bands a constant spatial frequency and linearly varying shift of the initial phase. Phase triangulation and the method of phase steps are used to reconstruct the shape of the surface investigated. The method is insensitive to additive random noise and the illumination source and receiver (video camera) characteristics.

The considerable advantages of the method are used in an information-measurement system. In this system, an office projector for exposing objects with typical sizes of tens of meters is used as an illuminator and spatial modulator (Dvojnishnikov et al., 2010).

The information-measurement system created on the basis of the method of stable processing of sets of spatially modulated images with a stepwise shift has modern characteristics, and some parameters of the system surpass those of existing systems. Some peculiarities of the system are as follows: high accuracy of measurements, which is independent of the reflective properties of the surface, automatic calibration and verification of data, dynamic real-time synthesis of images of the surface measured, automatic comparison of measured data with model data, adaptive generation of the structure of

lighting of the object investigated to identify its problem zones, and simultaneous parallel measurement of coordinates at more than 600,000 points (Meledin, 2010).

10. Optoelectronic diagnostics in atomic power engineering

10.1 Three-dimensional velocity fields of heat carrier flow in fuel assembly of power reactor

To raise competitive capacity of Russian atomic plants and substantiate safety of the active zones, new methods should be created for obtaining experimental information about the heat-exchange and hydraulic characteristics of water-moderated water-cooled power reactors. The safety can be increased by validating the reserves prior to heat exchange crises determined by the construction of active zones with different spacer grids and flow turbulizers. At the start of this work, there was no detailed comparative information about the fields and turbulent velocity pulsations in assemblies with different spacer grids for geometrical and operational conditions typical for water-moderated reactors.

Since the thermal-hydraulic processes taking place in an assembly are very complicated, full theoretical calculation of such parameters is not possible. The 1D methods used at present provide only conservative forecasts, and the 2D and 3D methods need data on the turbulent characteristics of flows and corresponding information obtained experimentally. The absence of reliable and detailed experimental information hinders not only effective design of the active zone elements of reactor plants, but also development and verification of the corresponding calculation codes.

The purpose of the work was to create a new method for obtaining information about the local and integral hydrodynamic characteristics of heat carrier flows in models of fuel assemblies with various spacer grids.

A new combined method for obtaining information about the detailed local and integral hydrodynamic characteristics of heat carrier flows in a model of fuel assembly with spacer grids has been proposed. The method is based on semiconductor laser Doppler anemometry, video anemometry, and immersion of the optically transparent reactor model into an immersion liquid with a refraction coefficient equivalent to a model one.

If a phase object - a transparent body - is immersed into a liquid with a refraction coefficient equal to that of the object material, the object will be invisible. However, the object boundaries, which determine the hydrodynamics and heat exchange, will remain. The structure of the flows will also remain. There will be no refraction and scattering of light by the boundaries of the object. Thus, it will be possible to obtain reliable information about the processes screened by the object boundaries by optical methods (notice that this idea goes back to H.G.Well's novel "The Invisible Man"). For the first time, it is possible to obtain information from the previously inaccessible space zones by noncontact nondestructive methods.

The method has been tested experimentally with a model problem on the propagation of the heat carrier flow induced by a rotating central rod and disc in a system with multiple rods imitating fuel elements of a power reactor. Semiconductor laser Doppler anemometry and computer video anemometry are used in this method to obtain information about the heat carrier flow at a horizontal section of the reactor model. The method algorithms use spatial transformations that can obtain information at any spatial section of the fuel assembly.

For the first time, 3D vector velocity fields and fields of velocity modules of the heat carrier flows excited by a rotating central rod or a disc have been obtained, and 2D and 3D

characteristics of the flows have been determined. The efficiency of turbulizing and mixing grids of the models of power reactor fuel assemblies has been estimated. For the first time, experimental information about 2D and 3D kinematic characteristics of heat carrier flows, which can be used to verify calculation codes and fuel assembly models of power reactors, has been obtained (Bolshov et al., 2006; Meledin, 2006).

10.2 Geometry of spacer grid of power reactor fuel assembly

A method to obtain information about the geometry, shading zone, and spatial structure has been proposed. It is used to obtain, by program methods, spatial information from scanned images of spacer and intermixing grids of fuel assemblies of power reactors.

It has been shown that this method can be implemented to create a noncontact information system to determine the shading areas of spacer and mixing grids with an absolute measurement error of about 2 μm by a standard modern scanner and specially developed software.

An algorithm to process scanned images has been developed. It consists of the following sequence of operations: obtaining of the initial scanned image of the grid; normalization and adaptive threshold discrimination; morphological filtration; segmentation; adaptive classification by threshold estimation of the logarithm of the area of segmented elements; recognition of channels, interchannel spaces and joints; recording into the database; construction of a non-dimensionalized drawing and formation of statistics of the objects.

With the help of the method, the following information is chosen and displayed in the drawing:

1. Channels and their geometrical centers (circles and equivalent diameters).
2. Interchannel spaces and their geometrical centers (red circles).
3. Welds and their geometrical centers.
4. Grid of geometrical centers of channels (lines and sizes).
5. Grid of geometrical centers of interchannel gaps (lines and sizes).
6. Grid of geometrical centers of welded joints (lines and sizes).

This method is simple and inexpensive. It can serve as a basis for a wide range of applications in atomic and other industries where precision size control in a range limited only by the sizes of the scanner used is required (Meledin, 2008, 2009).

11. Computer visualization: dynamic structure of boiling jet

Here, the capabilities of information diagnostics based on image processing and computer visualization of processes in atomic power engineering are demonstrated.

The problem of catastrophic breakdown of a high-pressure pipeline with a moving overheated heat carrier was investigated experimentally (the pipeline diameter is 40 mm, the initial pressure is 8.3 MPa, and the temperature is 235°C). In the process of catastrophic breakdown, due to a fast pressure drop, a steam explosion takes place and a shock wave front, which can destroy the neighboring pipelines, is formed.

The purpose of this work was to extract important information from an image sequence constructed by a high-speed camera. This was done to study in detail the steam explosion mechanisms, shock wave front formation, and to take some precautions.

The method is based on the fact that there is a small difference in the light scattering by aerosols at different wavelengths to different solid angles. The vortex structures of the flow act like separators, selecting droplets in their sizes and light scattering properties. Therefore,

it is possible to reliably identify and visualize the space zones of initial vortex structures. This can be done by identifying even small colour gradients in the images and enhancing them by morphological methods. All the image processing operations are made by computer programs. Therefore, the method can be classified as a computer visualization method (Pribaturin et al., 2006).

12. Optoelectronic for physical experiments

12.1 Computer video anemometry of floating bubbles

In recent years, two-phase bubble flows have been intensively studied, since they are widely used in heat and power engineering, metallurgy, pharmaceutics, and chemical industry. By digital processing of images from a high-speed camera, one can obtain versatile information about the motion of bubble media. The purpose of this work was to create a method of computer video anemometry to obtain reliable 2D and 3D characteristics of bubble flows and to test the method on simple processes.

The motion of gas or vapor inclusions in a liquid space is typical for two-phase bubble media. These are the processes of bubble floating in a stationary liquid space, gas- and vapor-liquid flows in pipes and channels of various geometries, boiling of a liquid, breakdown of gas or vapor formations, etc. The liquid and the bubbles have different optical properties. Owing to this fact it is possible to recognize the spatial boundaries of bubbles by computer image processing.

Three-dimensional images can be obtained by placing, with the help of auxiliary mirrors, images of lateral projections in free zones of the field of vision of the camera, recognizing and successive processing the data of orthogonal projections. With a time sequence of information blocks of the same object, one can determine the dynamics of its shape change and obtain quantitative data about its velocity.

A method of computer video anemometry has been developed. It consists of filming the motion of the medium by a digital high-speed camera, recognizing objects of interest in the images, and digital data processing. The speed of filming is determined by the camera, the velocity of the object under study, and the quality of images. The speed can reach 2000 frames per second.

The method allows not only to obtain simple information about a linear velocity, but also to construct 2D and 3D trajectories of motion. These data are very important for physics of two-phase flows. The average velocities and pulsating 2D and 3D velocity vector components were measured. The streamlines and parameters of rotation were reconstructed. Some measurements of turbulent characteristics were made. The typical pulsation frequencies of the shapes and volumes of bubbles have been determined. In fact, the computer anemometry method developed for bubble flows is a dynamic analog of tomography. As in tomography, one can select any section and then decompose it in detail to obtain quantitative characteristics of velocity profiles and gas content.

Some algorithms for computer processing of a video series with modern image processing methods have been developed. Spectral and adaptive spatial filtration, morphological analysis and segmentation, as well as nonlinear field transformations, were used. The noise was decreased by filtering of spectrally averaged frames by a dynamically formed adaptive spatial filter. A dynamic energy range of light signals was provided by compensating the spatial brightness inhomogeneity of sources by choosing relevant brightness levels in the vicinity of bubbles by adaptive spatial loop filters. The image sharpness is increased by

inverse convolution with a given point blurring function by the Lucy-Richardson algorithm. Then, optimal threshold discrimination, transition to binary images, distant transformations, morphological analysis, and image segmentation were performed. The use of nonpermutable nonlinear transformations increases considerably the threshold sensitivity of the method. As a result, dynamic fixation of the weak-contrast and small bubbles in a field with nonuniform illumination is provided.

While processing a sequence of images, each bubble to be recognized is assigned a mark. Full information about a bubble was written into the base. Information about the bubble center coordinates, area, linear sizes of the approximating ellipsoid, eccentricity, inclination angle of the main axis, perimeter of the bubble, and shape of its boundaries was recorded. This database made it possible not only to reconstruct the trajectories of motion of any bubble contained in the initial frame and to construct the gas content matrix, but also perform 2D and 3D visualization of the bubble motion. It should be noted that in some cases, by analyzing the database information it is possible to look at certain phenomena from a new viewpoint. For instance, with some virtual reality methods (simultaneous rotation of the object and the camera in a 3D experimental data space), for the first time we have experimentally demonstrated that the gas content has vertical stratification near the bubble generation source. In this case, the spatial discrete levels could be seen only at a certain small angle (Bolshov et al., 2006).

12.2 Gravitational-capillary waves and hydrodynamic quasicrystals

The fundamental problem of exciting gravitational-capillary waves on the surface of a liquid layer by an electric field was first considered in the 60s. Another attempt was made at the Institute of Automation and Electrometry of the Siberian Branch of the USSR Academy of Sciences in the early 80s; the attempt was, however, not very successful. Experimental investigations of such phenomena were hindered by the absence of adequate information systems capable of accumulating statistics and making formalized descriptions of various experimentally obtained wave structures to verify theoretical models. At the start of this work in 1999, no full linear theory of wave formation on the surface of a viscous liquid at any thickness of the dielectric layer and any wave numbers was constructed, and no satisfactory explanation of the contradictory experimental data obtained earlier was available.

Based on these investigations, a method to extract information from shadow pattern images (shadowgraphs) of gravitational-capillary waves by decomposing the 2D Fourier spectrum of the shadowgraphs into a set of spatial wave vectors and sorting the vectors with respect to the vibrational modes being excited was proposed. Wavelet decomposition of the spatial structures reconstructed was used to investigate the nonlinear regimes.

The phenomenon was investigated experimentally and representative statistics was collected on a special unit based on this method. The appearance, evolution, and transformation of ordered wave structures, change in the wave regimes, and transition to spatial chaos by varying the control parameters were investigated.

In the experimental investigations with this method, it has been shown that there is good agreement with a linear theory. It has also been shown that in the nonlinear case in such electrohydrodynamic systems there appear organized dynamic structures called ``hydrodynamic quasicrystals.'' The figure shows an example of such structures. It should be noted that this pattern is dynamic and the shapes of such ``crystals'' periodically change

in time. There appear and develop some ``dislocations'' in the crystals, which cause a periodic change in the structural order.
Phase stroboscopy of the wave surface of a liquid dielectric was used for computer visualization on the basis of the above-proposed method. This was done to obtain shadowgraphs and a detailed spectral pattern of the wave structures of various types of quasicrystal.
The figure shows the result of wavelet decomposition of a central transverse gravitational-capillary wave in a strong oscillating electric field. This procedure made it possible to identify information about the spatial-frequency modulation. The shadowgraph profile along a coordinate, 2D spatial Fourier spectrum, and wavelet spectrum are shown. In the wavelet spectrum, one can clearly see spatial nonlinear frequency modulation of a large-scale wave component. It should be noted that it is very difficult to reconstruct this spatial frequency modulation by other existing methods.
For the first time, good agreement between the experimental data and the above-mentioned linear theory has been obtained with this method (Meledin et al., 2005, a,b).

13. Oil production. Multiphase borehole flowmeter survey

Oil-producing companies must provide a survey of their boreholes in accordance with Russia State Standard P8.615-2005 introduced on March 1, 2005 and valid since March 1, 2006. However, ''today… is no measurement equipment with parameters of accuracy meeting the requirements of the new national standard. With available expensive foreign systems, the oil production may become economically unprofitable'' (*TechSovet* 4(35), April 1, 2006).
Scientifically, the problem of measuring the flow rate of multiphase flows has also not been solved. The main reason is that there is a great variety of the existing hydrodynamic structures and regimes. The structures of flows of a mixture of oil, gas, water, and solid particles vary in a wide range from homogenized to stratified, with different velocities of individual phases. The properties of a multiphase mixture depend on the temperature, pressure, density, air salinity, etc.
Practically all methods of flow rate measurement are optimized for some combination of hydrodynamic regimes and, in explicit or implicit form, use their characteristic physical properties. Since the number of combinations of such properties is large, the number of existing methods is also large. Unfortunately, however, each of them has a rather narrow ''ecological niche.''
We relate the complicated scientific problem of multiphase flowmeter survey to informatics. The capabilities of modern computer processing systems make it possible to store in databases numerous virtual images of real objects and rapidly solve problems of multidimensional optimization, search, and comparison. The basic scientific idea of our method is not to decrease the variety of existing hydrodynamic regimes by simplifying information flows and signals, but to increase it as far as possible. The variety of existing regimes provides the formation of wideband multidimensional data best suited to calculate correlations with an etalon. A shortcoming of the approach is that either a preliminary training of the system or a pre-constructed etalon should be available.
These ideas were used as the basis for a new method to obtain information about the phase flow rate of a gas-liquid flow. In this new method, acoustic ultrasound Doppler speckle interferometry for the flow regions with singularities is used and the multidimensional

signals obtained are compared with a basic etalon by using elements of artificial intelligence with genetic program algorithms.

There are many methods for measuring the oil watering, but almost all of them are sensitive to the presence of salts in water due to formation of ionic conduction. By increasing the operating frequencies to 1 GHz and more the problem is simplified, but not solved. The resulting error is considerable, about tens of percent.

Its bias component is compensated by making calibrations for each borehole, which must be regularly controlled. Therefore, isotopic methods, which are insensitive to fluid ionic conduction, are most widely used now. However, they are very sensitive to the presence of extremely small concentrations of H-ray contrast salts.

A new method, insensitive to ion-salt conduction, was proposed to obtain information about oil watering based on phase diagnostics of superposition of radio frequency waves with a frequency of 2.4 GHz in a resonator of special shape. Phase measurements of superposition of radio frequency waves demonstrated insensitivity to salt in the fluid in the range of concentrations up to 500 g/l.

The creation of experimental stands is an important part of works on methods for obtaining information about multiphase flows. They make it possible to verify the performance of these methods in a wide range of hydrodynamic regimes. A fully automated experimental stand was created. It provides the formation of a multiphase flow with flow rates of liquid up to 120 l/min and of gas up to 400 l/min with contour diameters of 25, 60, and 100 mm. This stand was used to calibrate methods and flow meters and to teach the program systems with elements of artificial intelligence integrated into the flow meters.

In December 2007, this scientific basis was used to create a prototype of a new information-measurement complex for multiphase borehole flow meter survey and optimization of oil production. The parameters of the system met State Standard P8.615-2005. Some industrial tests of the complex were made at the Kalchinsky oilfield of the Tyumenneftegaz company. This experimental specimen for works in real field conditions was created in half a year.

In the industrial tests at the Kalchinsky oilfield, it was found that the experimental information-measurement complex for multiphase borehole flow meter survey at boreholes 300/7 and 301/7 successfully operated uninterruptedly during five days at environmental temperatures from -36°C to -10°C, providing real-time measurements of the borehole fluid flow rate with a measurement error of 3% (Meledin, 2008, 2009).

14. Conclusion

Some basic principles of semiconductor laser Doppler anemometry and location of multiphase flows with natural light diffusers have been proposed. They form a fundamental scientific basis for a wide class of information optoelectronic measurement systems.

First high-power semiconductor stabilized laser emitters for Doppler anemometry and scientific instrument making (jointly with the Ioffe Physico-Technical Institute) have been created.

Methods to form, receive, and perform software-hardware processing of complex optoelectronic and acoustooptical signals and images under the photon constraint have been developed. Also, methods for signal processing, in particular, on the basis of wavelets and multifractal formalism, and information methods for dynamic monitoring of 3D geometry of objects and automatic control of information systems have been created.

Information-measurement systems and laser software-hardware complexes for technological information control of hot rolled metal in metallurgy have been created. (The daily economical effect at the largest enterprise of this industry - the Nizhnetagilsk Metallurgical Plant - was up to 100,000 US dollars; such complexes have been continuously operated since 1994.)
Information-measurement systems for semiconductor laser diagnostics of multiphase flows in hydraulic turbine machine building have been created. They increased the safety of domestic hydropower engineering (Power Machines - LMZ, 2003-2008).
The problem of replacing the imported information-measurement diagnostic semiconductor laser Doppler systems with adaptive time selection and visualization of the velocity vector for investigations of gas-liquid multiphase flows by similar domestic systems has been solved. These systems were created three years before the best foreign analogs and were used at many domestic scientific enterprises and higher educational establishments, from 2003 through 2007.

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Software-hardware information-measurement complexes based on systems for technical vision and processing of multidimensional signals for science and new industrial technologies have been created (Table 1). These are:

- first laser information-measurement complex to control the geometry of railway wheels of moving trains and increase the safety of railroad traffic (the Complex system, 2001, widely used on Russian railroads);
- system for information monitoring of masses of freely falling hot glass gobs by using their dynamic images (the Ekran, 2000);
- optical-electronic complexes of a new generation for medicine (disposable endoscopes of the Optiscope Technologies Ltd.; works were performed by a Carl Zeiss branch, from 2000 through 2007);
- information system to monitor the geometry of loaded rotors of super-high-power plants based on laser lidars (the Sayano-Shushenskaya HPP, 2006);
- information-measurement complex for investigation and optimization of nonvolatile memory of a new generation, to be introduced in 2010-2012, which is based on switching the conductivity of unit nanoelements of sandwich structure (the Fujitsu and the AMD, from 2004 through 2006);
- information-measurement and hardware-software complexes of multiphase flow meter, State Standard P 8.615-2005, for borehole flowmeter survey and optimal oil production control (the NPK VT, TNK-BP, Tyumen, 2008).

These fundamental scientific results have made a considerable contribution to the development of physical diagnostics, informatics of optoelectronic measurements, and creation of many new information monitoring technologies to increase efficiency and safety, which are successfully used in science and various fields of technology.

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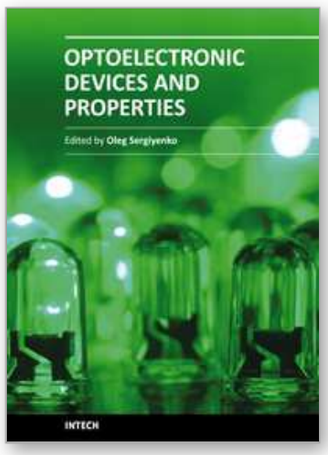

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