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**CONTACTLESS MONITORING TECHNOLOGIES IN SMART
MANUFACTURING FACILITIES.
(The Development and Advancement of Real-Time Online
Contactless Monitoring Technologies Based on the Fundamental
Principles of Electromagnetic Resonance Spectroscopy)**

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Abstract

This work examines contemporary approaches to the development of the ecosystem and infrastructure of smart manufacturing facilities designed to accommodate startups and innovative enterprises engaged in the development and implementation of advanced intelligent manufacturing technologies. Particular attention is given to the creation of a specialized technological environment that takes into account the characteristics, functional requirements, and interrelationships of the supersystems and subsystems of modern smart manufacturing. Contactless monitoring systems are considered one of the key elements of such infrastructure, enabling the acquisition, processing, and analysis of information on the condition of manufacturing equipment and ongoing technological processes without direct physical interaction with the monitored components. The work examines the prospects for the development of real-time online monitoring technologies based on the fundamental principles of electromagnetic resonance spectroscopy. Particular emphasis is placed on the integration of contactless monitoring systems with advanced processor-based systems incorporating elements of artificial intelligence and artificial neural networks for automated data processing, detection of deviations, and improvement of manufacturing process control. Special consideration is given to the potential application of these technologies in high-technology manufacturing processes, including the production of printed circuit boards, thin-film microassemblies, and high-speed electronic components, where the speed, accuracy, and contactless nature of monitoring may be essential for maintaining stable technological parameters and ensuring the quality of manufactured products. The proposed approach is aimed at the further development of intelligent manufacturing ecosystems that integrate contactless monitoring methods, digital data processing, artificial intelligence, and automated control systems within a unified technological infrastructure of a smart manufacturing facility.

Keywords: *Technology; Contactless Monitoring; Smart Manufacturing Facilities; Printed Circuit Board Manufacturing; Thin-Film Microassembly Manufacturing; Printed Circuit Boards; Thin-Film Microassemblies; High-Speed Electronic Components*

Introduction

Under current conditions, the establishment of manufacturing facilities intended to accommodate startups developing new smart technologies creates a need for a specialized ecosystem that takes into account the characteristics and requirements of smart-technology supersystems. One of the essential subsystems within such an ecosystem comprises contactless monitoring elements and their associated processors, which, in turn, incorporate elements of artificial intelligence and artificial neural networks.

This field is relatively new, and Kateryna Vorobiova has made a significant contribution to its development through her fundamental publications and books.

In her developments, Kateryna Vorobiova has successfully integrated concepts relating to the preparation and optimization of manufacturing-facility interiors with the development of infrastructure components for smart manufacturing complexes, as well as with advanced technological solutions aimed at increasing the processing speed of electronic systems in order to meet the anticipated requirements associated with quantum computers and their processor-based equivalents.

RITM Technology (Dimensional Selective Metal Etching)

Printed Circuit Board Module

A module for the installation, cooling, management, and monitoring of high-energy optoelectronic systems, and a method for manufacturing the same, comprising:

- at least one double-sided printed circuit board having, on one side thereof, geometrically aligned and mutually electrically insulated electrically conductive and thermally conductive topological structures;
- at least one integrated heat-conducting pad arranged on the opposite side of the printed circuit board and thermally connected to the heat-conduct-

ing structures located on the first side of said printed circuit board;

- thermally conductive channels connecting each of the heat-conducting structures on one side of said printed circuit board to the integrated heat-conducting pad located on the opposite side of said printed circuit board;
- wherein said integrated heat-conducting pad and said thermally conductive channels are electrically insulated from the electrically conductive topological structures.

High-Speed Jet Electrochemical Deposition

High-speed jet electrochemical deposition is a **galvanic process performed within a selectively oriented, directed electrolyte flow incorporating a continuous recirculation system that continuously renews the electrolyte.**

The system comprises:

1. **An electrolyte reservoir** operating under specified electrolyte-maintenance parameters, including: nickel and copper concentrations;
 - temperature;
 - acidity or alkalinity level (pH);
 - density;
 - electrical conductivity.
2. Due to the technological advantages of the proposed process, the use of **organic brightening additives is not required.**
3. **A pump equipped with a filter.**
4. **An anode for jet electroplating**, comprising a component soluble in the particular type of electrolyte and a component insoluble in that electrolyte, arranged sequentially in the direction of electrolyte flow.

The insoluble component is made of a **composite conductive carbon-graphite fabric**. It is positioned parallel to the surface being metallized and is arranged downstream of the soluble component, immediately upstream of the surface to be coated (the cathode).

Both components are connected to a **positive electrical potential** and have selectively adjustable permeability to the electrolyte. The anode incorporates a system for the uniform distribution of electrolyte across the surface of the soluble component. This distribution pattern is subsequently reproduced across the insoluble component and, consequently, across the surface being metallized – the cathode.

The manufacturing process further comprises:

- removal of the photoresist;
- etching of the iron from one side to a depth corresponding to one-half of the thickness of the steel strip;
- removal of etching products from the surface, first by aerodynamic treatment and subsequently by hydrodynamic treatment;
- encapsulation with a flowable polymer composition, performed in the following sequence:
 - filling with a monomer;
 - subsequent polymerization;
 - thermal stabilization;
- etching of the iron from the opposite side using the same technological principles;
- encapsulation from the opposite side using the same technological principles;
- application of a protective coating to the electrically conductive structures;
- vacuum deposition onto all thermally conductive structures of a multilayer system comprising semiconductor nanostructured polycrystalline diamond films.

Integration with Contactless Monitoring Technologies

A significant contribution made by Kateryna Vorobiova consists in combining and integrating contactless monitoring technologies and systems with the technologies used for manufacturing specialized circuit boards by means of dimensional selective metal etching.

Given that this technological combination and integration were implemented within a relatively short period of time, it is appropriate to examine in greater detail the

resulting concepts and potential applications of contactless monitoring technologies in modern smart manufacturing environments.

Inventions in the Field of Contactless Monitoring of Drinking Water and Cow's Milk Quality

The quality of drinking water is one of the fundamental factors determining the quality of human life. In conventional water-quality monitoring methods, electrical conductivity is generally regarded as an important indicator of water purity.

The higher the concentration of contaminants in water, the lower its electrical resistance tends to be; conversely, the purer the water, the higher its electrical resistance.

For a long time, this approach was considered sufficient. However, increasing concerns associated with intentional contamination risks, together with the unprecedented scale of environmental pollution, have created a need for more comprehensive and reliable methods of water-quality monitoring.

These are by no means the only factors determining the urgent need for more comprehensive water-quality control, but they represent important considerations.

Many existing technologies, instruments, and systems for water-quality monitoring have a relatively limited range of technical capabilities and do not simultaneously cover all parameters that may require continuous monitoring. Consequently, there is a need for technologies capable of detecting potentially hazardous changes in water quality before contaminated water reaches the end user and poses a potential risk to human health.

Milk is one of the important components of a balanced diet and, since water constitutes a substantial proportion of its composition, it likewise requires mobile, reliable, and accurate monitoring technologies adapted both to increasingly stringent quality requirements and to evolving regulatory standards.

In milk-quality monitoring, particular importance is also attached to the ability of monitoring systems to adapt to new technological conditions and industrial processing methods.

Based on these considerations, it is reasonable to conclude that there is a need for continuous monitoring of the quality and

condition of both drinking water and milk prior to their use or consumption.

Technologies intended to address these requirements have been developed, and a brief description of the proposed technological solutions is provided below:

1. Device for Real-Time Monitoring of the Current Quality Status of Drinking Water

The device is designed for the real-time monitoring and assessment of the current value of a comprehensive digital indicator characterizing the dynamic quality status of drinking water. The device may also be adapted for use in process-water quality monitoring systems at the inlet to an industrial process, as well as for monitoring wastewater quality prior to discharge into a sewerage system or prior to its return to the technological process following regeneration.

The Comprehensive Digital Indicator of the Dynamic State of Water and Aqueous Solutions is an integral parameter that, based on frequency, amplitude, electrical resistance, resonance characteristics, inductance, and a set of dynamic characteristics of the water flow, provides an integrated representation of the current content and concentration of components present in the water, as well as the relationships, including biological interactions, between these components and the measured parameters.

The device for real-time selective identification of the current value of the Comprehensive Digital Indicator of the Dynamic Quality Status of Drinking Water is a compact system designed for integration into water-supply pipelines and water-flow meters. It may also be configured for operation under field conditions using solar power.

The device is characterized by minimal energy consumption.

The device comprises functionally interconnected systems for the inlet, outlet, monitoring, and transformation of the water flow. The water-flow transformation system incorporates an aerodynamic mechanism for removing gases from the water flow.

The device may be configured both for stationary operation and for rapid on-site analysis.

Neither operation of the device nor the associated monitoring procedure requires specialized training of the operator or end user.

2. Device for Real-Time Monitoring of the Current Quality Status of Cow's Milk

The device is designed for the real-time monitoring and assessment of the current value of a Comprehensive Digital Indicator characterizing the dynamic quality status of cow's milk.

The Comprehensive Digital Indicator of the Dynamic State of Cow's Milk is an integral parameter that, based on frequency, amplitude, electrical resistance, inductance, and a set of dynamic characteristics of the milk flow, provides an integrated representation of the current content and concentration of components present in cow's milk, as well as the relationships, including biological interactions, between these components.

The device for the real-time selective identification of this Comprehensive Digital Indicator is a compact system designed for operation on dairy farms or under field conditions, including configurations powered by solar panels.

The device is characterized by minimal energy consumption.

The device comprises functionally interconnected systems for the inlet, outlet, monitoring, and transformation of the milk flow. The milk-flow transformation system incorporates an aerodynamic mechanism for removing gases from the milk flow.

The device may be configured both for stationary operation and for rapid on-site analysis.

3. Comprehensive Integrated Water and Aqueous Solution Quality Indicator and a Device for Its Real-Time Identification

The Digital Indicator of the Dynamic Quality Status of Drinking Water is an integrated parameter determined by comparing a signal pulse transmitted to the sensor with the corresponding parameters generated within the pipeline as a result of resonance phenomena occurring in the water flow. The comparison is performed on the basis of frequency, amplitude, electrical resistance,

and inductance, in combination with a set of dynamic characteristics of the water flow. Taken together, these parameters provide an integrated representation of the current content and concentration of components present in the water.

The device for the real-time selective identification of this indicator is a compact system designed for operation within municipal or main water-supply pipelines, as well as under field conditions, including configurations powered by solar panels.

The device is characterized by minimal energy consumption.

The device comprises functionally interconnected systems for the inlet, outlet, monitoring, and transformation of the water flow being analyzed. The water-flow transformation system incorporates an aerodynamic mechanism for removing gases from the flow.

The Comprehensive Integrated Water Quality Indicator also incorporates a Comprehensive Integrated Sensor Indicator, which represents a constant value for each specific sensor type, its design parameters, and the parameters of the signal supplied to the sensor. According to the presented experimental data, the constancy of this indicator has been confirmed by a series of tests comprising more than 1,000 test cycles performed using four different types of sensors.

The device may be configured both for stationary operation and for rapid on-site analysis.

4. Comprehensive Integrated Cow's Milk Quality Indicator and a Device for Its Real-Time Identification

The Digital Indicator of the Dynamic State of Cow's Milk is an integrated parameter that, based on frequency, amplitude, electrical resistance, inductance, and a set of dynamic characteristics of the milk flow, provides an integrated representation of the current content and concentration of components present in cow's milk.

The device for the real-time selective identification of this indicator is a compact system designed for operation on dairy farms or under field conditions, including configurations powered by solar panels.

The device is characterized by minimal energy consumption.

The device comprises functionally interconnected systems for the inlet, outlet, monitoring, and transformation of the milk flow. The milk-flow transformation system incorporates an aerodynamic mechanism for removing gases from the milk flow.

The device may be configured both for stationary operation and for rapid on-site analysis.

5. Dynamic Indicator of the Current Somatic Cell Count in Cow's Milk and a Device for Its Real-Time Selective Identification

The Digital Indicator of the Dynamic State of Cow's Milk is a parameter that, based on frequency, amplitude, electrical resistance, inductance, and a set of dynamic characteristics of the milk flow, provides an integrated representation of the current content and concentration of somatic cells in cow's milk.

The device for the real-time selective identification of this indicator is a compact system designed for operation on dairy farms or under field conditions, including configurations powered by solar panels.

The device is characterized by minimal energy consumption.

The device comprises functionally interconnected systems for the inlet, outlet, monitoring, and transformation of the milk flow. The milk-flow transformation system incorporates an aerodynamic mechanism for removing gases from the milk flow.

The device may be configured both for stationary operation and for rapid on-site analysis.

Dynamic Comprehensive Indicator of the Current Fat Concentration in Cow's Milk and a Device for Its Real-Time Selective Identification

The Digital Indicator of the Dynamic State of Cow's Milk is an integrated parameter that, based on frequency, amplitude, electrical resistance, inductance, and a set of dynamic characteristics of the milk flow, provides an integrated representation of the current content and concentration of fat or fatty acids in cow's milk. The device for the real-time selective identification of this indicator is a compact system designed for operation on dairy farms or under field conditions,

including configurations powered by solar panels. The device is characterized by minimal energy consumption. The device comprises functionally interconnected systems for the inlet, outlet, monitoring, and transformation of the milk flow, wherein the milk-flow transformation system incorporates an aerodynamic mechanism for removing gases from the milk flow. The device may be configured both for stationary operation and for rapid on-site analysis.

Dynamic Comprehensive Indicator of the Current Lactose Content in Cow's Milk and a Device for Its Real-Time Selective Identification

The Digital Indicator of the Dynamic State of Cow's Milk is an integrated parameter that, based on frequency, amplitude, electrical resistance, inductance, and a set of dynamic characteristics of the milk flow, provides an integrated representation of the current lactose content in cow's milk. The device for the real-time selective identification of this indicator is a compact system designed for operation on dairy farms or under field conditions, including configurations powered by solar panels. The device is characterized by minimal energy consumption. The device comprises functionally interconnected systems for the inlet, outlet, monitoring, and transformation of the milk flow, wherein the milk-flow transformation system incorporates an aerodynamic mechanism for removing gases from the milk flow. The device may be configured both for stationary operation and for rapid on-site analysis.

Comprehensive Integrated Indicator of Mastitis in Cows and a Device for Its Real-Time Identification

The Digital Indicator is an integrated parameter that, based on frequency, amplitude, electrical resistance, and inductance, serves as an integrated equivalent or indicator of the occurrence of mastitis in a cow. The device for the real-time identification of this indicator is a compact system designed for operation on dairy farms or under field conditions, including configurations powered by solar panels. The device is characterized by minimal energy consumption.

The device comprises functionally interconnected systems for the inlet, outlet, monitoring, and transformation of the milk flow, wherein the milk-flow transformation system incorporates an aerodynamic mechanism for removing gases from the milk flow. The device may be configured both for stationary operation and for rapid on-site analysis.

Device for Real-Time Selective Identification of Cow's Milk Quality During Its Transfer to a Collection Tank Following Milking

The device is a compact system designed for operation on dairy farms or under field conditions, including configurations powered by solar panels. The device is characterized by minimal energy consumption. The device comprises functionally interconnected systems for the inlet, outlet, monitoring, and transformation of the milk flow, wherein the milk-flow transformation system incorporates an aerodynamic mechanism for removing gases from the milk flow.

Device for Contactless Monitoring of Cow's Milk Condition Parameters

The device comprises systems for introducing milk into the monitoring zone and removing the milk flow from the monitoring zone, as well as an integrated electronic sensor monitoring module equipped with an interface. The device may further comprise a signal identification system and a device for accelerated comparison of identified signals with a reference signal or reference value.

Device for Simultaneous Monitoring of Multiple Cow's Milk Condition Parameters During Transportation

The device may be implemented in two configurations. The first configuration is designed for installation on milk transport tanks for monitoring milk quality during transportation and during the transfer of milk for subsequent processing into dairy products. The second configuration is designed for installation on flexible or rigid pipelines through which milk is transferred to storage tanks. This configuration may additionally provide real-time temperature measurement functionality.

Device for Rapid Analysis of Cow's Milk Quality

The device is a compact portable instrument comprising an internal chamber into which milk, or another liquid, is introduced for analysis. A sensor is positioned around the chamber and is selectively configured to monitor a specific parameter of the milk or other liquid. The device requires no adjustment or calibration and incorporates several levels of protection.

Device for Selective Rapid Analysis of Cow's Milk Quality Parameters

The device is a compact portable instrument comprising an internal chamber into which milk, or another liquid, is introduced for analysis. A sensor positioned around the chamber is selectively configured to monitor a specific parameter of the milk or other liquid. The device requires no adjustment or calibration and incorporates several levels of protection.

Contactless Sensors for Monitoring Milk Levels in Tanks

The device monitors the level of milk, or another liquid, within a dedicated section of a pipeline connected to the tank in which the liquid level is being monitored. The device may be implemented in several configurations. It may be positioned inside the liquid-containing tank or externally to the tank and may incorporate different sensor configurations.

Device for Comprehensive Monitoring of Milk Levels in Tanks with Simultaneous Assessment of the Integrated Milk Quality Indicator at the Monitored Level

The device monitors the level of milk, or another liquid, within a dedicated section of a pipeline connected to the tank in which the liquid level is being monitored. The specified pipeline section simultaneously functions as a resonant sensor configured to monitor and assess the integrated milk quality indicator and as a liquid-level sensor. The device may simultaneously monitor physical characteristics of milk or another liquid, including electrical conductivity, density, and acidity level.

Device for Comprehensive Monitoring of Milk Levels in Tanks with Simultaneous Assessment of the Somatic Cell Count in Milk at the Monitored Level

The device monitors the level of milk, or another liquid, within a dedicated section of a pipeline connected to the tank in which the liquid level is being monitored. The specified pipeline section simultaneously functions as a resonant sensor configured to monitor the somatic cell count and as a liquid-level sensor. The device may also simultaneously monitor physical characteristics of the milk or other liquid, including electrical conductivity, density, and acidity level.

Device for Comprehensive Monitoring of Milk Levels in Tanks with Simultaneous Assessment of Milk Fat Content at the Monitored Level

The device monitors the level of milk, or another liquid, within a dedicated section of a pipeline connected to the tank in which the liquid level is being monitored. The specified pipeline section simultaneously functions as a resonant sensor configured to monitor fat concentration and as a liquid-level sensor.

Device for Comprehensive Monitoring of Milk Levels in Tanks with Simultaneous Assessment of Lactose Content at the Monitored Level

The device monitors the level of milk, or another liquid, within a dedicated section of a pipeline connected to the tank in which the liquid level is being monitored. The specified pipeline section simultaneously functions as a resonant sensor configured to monitor lactose concentration and as a liquid-level sensor.

Device for Comprehensive Monitoring of Milk Levels in Tanks with Simultaneous Assessment of Blood Traces in Milk at the Monitored Level

The device monitors the level of milk, or another liquid, within a dedicated section of a pipeline connected to the tank in which the liquid level is being monitored. The specified pipeline section simultaneously functions as a resonant sensor configured to monitor the concentration of blood traces and as a liquid-level sensor.

Device for Comprehensive Monitoring of Milk Levels in Tanks with Simultaneous Sequential Assessment of the Concentrations of Basic Milk Components at the Monitored Level

The device monitors the level of milk, or another liquid, within a dedicated section of a pipeline connected to the tank in which the liquid level is being monitored. The specified pipeline section simultaneously functions as a resonant sensor configured to monitor selected parameters and as a liquid-level sensor.

Device for Comprehensive Monitoring of Milk Levels in Tanks with Simultaneous Assessment of the Concentrations of Multiple Basic Milk Components at the Monitored Level

The device monitors the level of milk, or another liquid, within a dedicated section of a pipeline connected to the tank in which the liquid level is being monitored. The specified pipeline section simultaneously functions as a resonant sensing system configured to monitor parameters and concentrations of components in milk or another liquid and incorporates multiple sensors, each configured to monitor an individual parameter. Each sensor simultaneously functions as a liquid-level sensor.

Device for Modifying the Turbulence Level of a Milk Flow

The device is designed for the dynamic transformation of a turbulent milk flow, creating a localized region of laminar flow in which the milk is monitored using a resonant sensor. During flow transformation, the device additionally releases air from the milk flow and stabilizes its hydrodynamic characteristics.

Device for Preparing a Milk Flow for Real-Time Monitoring of Its Condition Parameters

The device is designed for the dynamic transformation of the milk flow with the formation of a localized region of laminar flow in which milk monitoring is performed using a resonant sensor.

Device for Real-Time Monitoring of Gas Content in Milk

The device comprises a resonant sensor configured to detect changes in a set of milk

parameters depending on the concentration of air or another gas present in the milk. The device may simultaneously monitor the degree of filling of the pipeline through which the milk flows and the turbulence level of the milk flow within the pipeline.

Milk Aeration Process Control System with Real-Time Monitoring of Air Content in Milk

The system is designed to control the milk aeration process while monitoring the level of air content in the milk. The system incorporates feedback from a resonant sensor and adjusts the parameters of the compressed-air supply according to the concentration of air in the milk. The system comprises a resonant sensor, an interface, and a signal converter configured to transform signals received from the sensor into control signals transmitted to the compressed-air source, thereby enabling adjustment of the pressure and flow rate of the compressed air. The system further incorporates an aerodynamic function for introducing air into the milk.

Information on the Verification and Testing Results of a Method for Selective Separation of Various Materials Dissolved in Water or Aqueous Solutions and Subsequent Monitoring of Their Concentrations Using Resonance Technologies

When analyzing water contaminated with dissolved metal ions and other substances, significant difficulties arise in accurately determining the actual concentration of each individual material or metal. In addition to the technology presented previously, a new invention has been developed that enables high-precision selective separation of substances contaminating water or other liquids into groups characterized by specific resonance frequencies. The sensitivity of the measuring instrument makes it possible to distinguish resonance frequencies with an accuracy down to the microhertz range. According to the presented results, this accuracy makes it possible to distinguish materials and chemical-mechanical complexes contained in water or aqueous solutions with a precision of up to 0.00001 grams. Preliminary testing demonstrated that measurement

accuracy does not depend on the presence or absence of organic compounds or combinations of such compounds and other materials in the water or aqueous solution. The preliminary verification results confirm the possibility of real-time active monitoring of liquids to determine the concentrations of individual substances without direct contact with the monitored liquid and without additional or auxiliary procedures. The concentration of each component is determined separately, providing an independent result with the required accuracy using the same measuring instrument.

A digital monitoring and control system was developed to manage the measurement process. According to the presented materials, the system underwent a complete testing cycle in cooperation with one of the leading Japanese companies in the course of practical monitoring tasks. The results were assessed as exceeding the capabilities of the referenced existing technologies by 1,000 times or more. The tested technology is characterized by substantial technological flexibility and may be implemented using only those capabilities required for a particular application, where appropriate, thereby also allowing the cost characteristics of the technology to be adjusted according to the requirements of the specific application site.

Brief Description of the Resonance Method

The method involves generating an alternating electromagnetic field within the space containing the sample under examination. This field serves as an intermediary between the resonant circuit and the test sample. On the one hand, the resonant circuit functions as an emitter of this field and, on the other hand, as a receiver or sensing element responsive to changes introduced into the electromagnetic field by the test sample. Even in the absence of a test sample, the alternating electromagnetic field generated by the solenoid represents the superposition of two electromagnetic fields varying in opposite phase. One field is generated by changes in the magnetic induction of the solenoid and produces a vortex electric field in accordance with the Maxwell–Faraday equation. The other field is generated by changes in the electric field re-

sulting from the potential difference between the outermost, most widely separated turns of the solenoid when the sample is positioned inside the solenoid, or by the potential difference between the turn closest to the surface of the sample and the sample itself when the sample is positioned opposite the end of the solenoid. This produces a vortex magnetic field in accordance with Ampère’s circuital law with Maxwell’s correction.

Under the influence of an external alternating electromagnetic field, various electrical phenomena may be induced in the test sample, depending on its nature, including linear and eddy conduction currents, linear and eddy displacement currents, as well as linear and eddy ionic currents representing the ordered motion of ions. In accordance with the principle of field superposition, these electrical phenomena introduce distortions into the external alternating electromagnetic field. These distortions are detected by the solenoid of the resonant sensor. The resonant circuit incorporating this solenoid changes its behavior in a manner analogous to the addition of supplementary circuit elements, namely a capacitor, an inductor, and a resistor. The combination of the additional capacitive, inductive, and resistive components constitutes an additional impedance introduced into the system by the test sample. This is the parameter measured by the resonant sensor.

Changes in the parameters of the resonant circuit are reflected in changes in its amplitude and frequency characteristics, specifically in its resonant frequency and resonant amplitude. By analyzing these changes, the impedance characteristics of the test sample can be evaluated.

Interference Immunity

Mechanical parameters such as viscosity, density, transparency, and pressure, provided that the medium is incompressible, should not directly affect the measured electrical parameters of the substance. Flow velocity within a pipeline and turbulence represent processes occurring on time scales substantially slower than the megahertz-frequency processes involved in impedance measurement and therefore are not expected to exert a significant influence on the measurement process. Hardness is a chemical characteris-

tic determined by the components present in the substance. Temperature generally affects impedance; however, measuring temperature and compensating for its influence during impedance measurements does not represent a particularly complex technical task.

Selective Monitoring of Component Concentrations in Water and Aqueous Solutions

In simplified terms, the selective measurement and monitoring of concentrations of metal salts and other substances dissolved in water can be explained as follows. Water has an anomalously high dielectric constant, which is associated with the large dipole moment of water molecules. Consequently, the overall polarization response in an alternating electric field will depend substantially both on the concentration of nonpolar impurity molecules and on molecules having dipole moments different from that of water.

This difference provides the basis for the resonant method of selectively measuring impurity concentrations in water or aqueous solutions. When water is introduced into an oscillatory circuit, it determines the position of its characteristic resonance and corresponding resonance line. Each impurity introduced into the water or aqueous solution within the oscillatory circuit causes a shift in this resonance and its corresponding resonance line. Different impurities, depending on their concentrations, produce different resonance shifts.

A family of such dependencies, each corresponding to a particular metal or other component, makes it possible to selectively determine the magnitude of the resonance-line shift and, accordingly, the concentration of each impurity in the water or aqueous solution. The family of dependencies is established through chemical calibration using conventional chemical analytical methods.

For solutions and liquids that are not aqueous, the methodology and underlying logic of selective component-concentration measurement are similar. The principal difference is that one of the components of the solution or liquid whose molecules exhibit the highest dipole moment within that particular system is selected as the reference component for measurement.

Preliminary Investigation of the Sensitivity of Resonant Monitoring Technology for Milk Analysis

At the preliminary stage of testing and evaluating the sensitivity of the resonant monitoring technology, samples representing several fundamentally different types and conditions of milk were examined. These included samples of whole natural milk obtained during morning manual milking and divided into three principal groups: samples collected at the beginning of milking, characterized by the lowest concentration and an acidity value of 6.7 units; samples collected during the main phase of milking, characterized by an intermediate concentration, an average optimal concentration of the constituent components, and an acidity value of 6.8 units; and samples collected during the final phase of milking, characterized by the highest concentration of the principal components and an acidity value of 6.9 units.

The investigation also included samples of the same milk after 24 hours of storage at room temperature; samples of the same milk after 24 hours of refrigerated storage at +3 °C; samples of four types of commercially available milk having different characteristics; samples of all milk types supplemented with preserved blood; samples supplemented with sucrose; samples supplemented with glucose; samples supplemented with sugar; and samples supplemented with milk fat followed by mechanical mixing.

Objectives of the Preliminary Investigation

The preliminary investigation was intended to determine the degree of contrast in the reflected resonant signals obtained when comparing all of the milk samples described above. Another objective was to demonstrate the possibility of selectively identifying, from the multiple combinations of signal parameters obtained, those groups of parameters for which the differences and signal contrast between different types of milk are maximal, thereby providing the level of assessment and measurement accuracy required by leading European manufacturers of integrated technological equipment for dairy production and consistent with the requirements and limitations of applicable European Union standards.

1. Demonstration of the Possibility of Selectively Identifying Indicators and Assessing the Somatic Cell Count in All Types of Milk, with Comparison Against the Readings of Somatic Cell Counting Instruments Developed and Marketed Internationally by Recognized Leading Manufacturers Complying with the Highest Technical Standards and Requirements.
 2. The workstation prepared by the company conducting the development for the preliminary studies was integrated into the infrastructure of a specialized and optimized standard clean-room environment intended for research activities.
 3. General Characteristics of the Measurements and Studies Conducted.
 4. The acidity of all prepared milk samples was measured using standard measuring instruments, and corresponding measurements were performed using the experimental resonance-monitoring unit.
 5. The somatic cell count in all milk samples was measured using standard equipment manufactured by DeLaval, and the corresponding integral signal from the same milk samples was measured using the experimental resonance-monitoring unit.
 6. A precisely defined quantity of blood was added to a measured milk sample, after which the resulting integral signal was measured using the experimental resonance-monitoring unit.
 7. A precisely defined quantity of milk fat was added to a measured milk sample, after which the resulting integral signal was measured using the experimental resonance-monitoring unit.
 8. A precisely defined quantity of urea was added to a measured milk sample, after which the resulting integral signal was measured using the experimental resonance-monitoring unit.
 9. A precisely defined quantity of glucose was added to a measured milk sample, after which the resulting integral signal was measured using the experimental resonance-monitoring unit.
 10. 10. A precisely defined quantity of sucrose was added to a measured milk sample, after which the resulting integral signal was measured using the experimental resonance-monitoring unit.
 11. A precisely defined quantity of fructose was added to a measured milk sample, after which the resulting integral signal was measured using the experimental resonance-monitoring unit.
 12. *1Conclusions Based on the Results of the Preliminary Experimental Verification, Drawing on the Publications and Developments of Kateryna Vorobiova.*
 13. The resonance-monitoring technology is capable, with the required degree of accuracy, of distinguishing whole-milk samples obtained during the initial, middle, and final phases of the milking process on the basis of an integrated comprehensive indicator.
 14. The resonance-monitoring technology is capable, with the required degree of accuracy, of distinguishing whole-milk samples obtained during the initial, middle, and final phases of the milking process and of differentiating between the same samples after different periods of storage at room temperature.
 15. The resonance-monitoring technology is capable, with the required degree of accuracy, of distinguishing whole-milk samples obtained during the initial, middle, and final phases of the milking process and of differentiating between the same samples after different periods of storage at room temperature when specified quantities of blood have additionally been introduced.
 16. The resonance-monitoring technology is capable, with the required degree of accuracy, of distinguishing whole-milk samples obtained during the initial, middle, and final phases of the milking process and of differentiating between the same samples after different periods of storage at room temperature when specified quantities of glucose have additionally been introduced.
- The resonance-monitoring technology is capable, with the required degree of accuracy, of distinguishing whole-milk samples obtained during the initial, middle, and final phases of the milking process on the basis of an integrated comprehensive indicator. It is also capable of differentiating between the same samples after different periods of storage at room temperature when specified

quantities of urea have additionally been introduced.

Figure 1. *The figure shows a startup researcher's workstation located in a clean room within a restored industrial facility*



The resonance-monitoring technology is capable, with the required degree of accuracy, of distinguishing whole-milk samples obtained during the initial, middle, and final phases of the milking process on the basis of an integrated comprehensive indicator. It is also capable of differentiating between the same samples after different periods of storage at room temperature when specified quantities of milk fat have additionally been introduced.

The resonance-monitoring technology is capable, with the required degree of accuracy, of distinguishing whole-milk samples obtained during the initial, middle, and final phases of the milking process that have different somatic cell concentrations. It is also capable of differentiating between the same samples after different periods of storage at room temperature.

The resonance-monitoring technology is capable, with the required degree of accuracy, of distinguishing whole-milk samples obtained during the initial, middle, and final phases of the milking process that have different somatic cell concentrations. It is also capable of differentiating between the same samples after different periods of storage at room temperature while simul-

taneously assessing and distinguishing the acidity levels of the same milk samples. The experiments confirmed the validity of the strategy selected for the preliminary testing, which is based on an at least two-stage calibration system for the resonant sensor. At the first stage, calibration is performed at the level of the integral signal based on the characteristics of phenomena occurring in the milk. At the second stage, calibration is performed using a selectively identified combination of resonant responses exhibiting the most pronounced contrast in frequency, capacitance, and amplitude characteristics in the milk samples under investigation, specific to each monitored parameter and characteristic.

Overall, the system demonstrated high sensitivity to the applied signals, high selectivity in signal discrimination and comparison, a sufficient level of repeatability of the results, stable operation in accordance with the adopted methodology, sufficient accuracy in determining the integral components of the signals, sufficient autonomy and resistance to external influences and interference, as well as the ability to be operated in a stable, reliable, and controlled manner by an operator without formal specialized professional training.

The results of the preliminary studies provide a basis for proceeding, at the next stage of the project, to the development of applications for the selective monitoring of all required milk parameters and to the fundamental design and development of the necessary resonant-sensor configurations.

The results obtained from the adjustment and modification of the sensors' operating parameters, together with the overall characteristics of the sensor control and digital testing processes and the associated infrastructure, support the conclusion that reliable remote control of individual sensors and groups of sensors can be implemented, including synchronization of their principal measurement and analytical functions. The results also indicate the possibility of adapting the sensors to the specific operating requirements and varying conditions encountered on dairy and commercial farms and at dairy-processing enterprises.

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