Kateryna Vorobiova

Ecosystem and infrastructure of smart food production

Arrow Science & Technology

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ECOSYSTEM AND INFRASTRUCTURE OF SMART FOOD PRODUCTION

Innovative transformation of the smart manufacturing ecosystem with real-time online monitoring

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The book examines modern approaches to the development of the ecosystem and infrastructure of smart confectionery production based on digital technologies, artificial intelligence, artificial neural networks, and TRIZ principles. Particular attention is given to the creation of compositional and integrative technical solutions aimed at improving production efficiency, developing innovative confectionery products, and enhancing methods of design, patent protection, and commercialization. The book also discusses industrial design criteria, systematic search methods for technical solutions, the application of composite materials, and new approaches to evaluating product durability and reliability in rapidly evolving markets.

Special attention is devoted to the design of devices for dynamic mixing, homogenization, and encapsulation of liquid components, as well as to digital modeling and testing methods for innovative technologies. The book presents the principles and applications of electromagnetic resonance sensors for monitoring technological processes and biochemical parameters, including prospects for the non-contact monitoring of blood composition and other physiological indicators. It is demonstrated that the integration of intelligent manufacturing systems, advanced sensor technologies, digital engineering tools, and innovative materials provides the foundation for a new generation of highly efficient, adaptive, and competitive confectionery production systems.

Keywords: *Confectionery production; Digital technologies of the confectionery production ecosystem; Rules and criteria of industrial design applied to advanced smart confectionery production; Application of electromagnetic resonance sensors; Systematic search; Durability of a new product*

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INTRODUCTION

Modern multidisciplinary digital technologies of food and confectionery production incorporating elements of artificial intelligence and artificial neural networks, as well as the psychological nuances and marketing aspects of confectionery products created through the development and application of these technologies in conjunction with TRIZ.

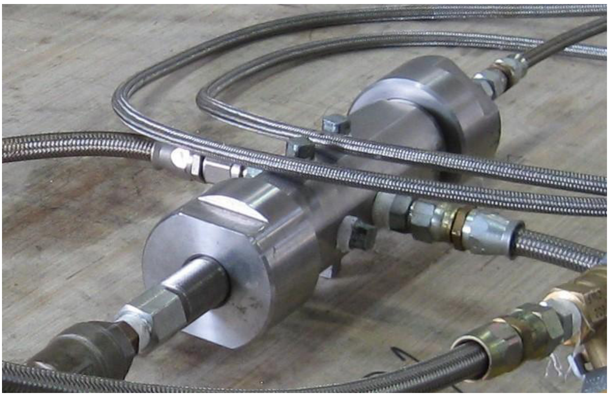

Figure 1. – A device for the online mixing and simultaneous homogenization of liquid fractions used in confectionery production, with the optional formation of encapsulated structures before injection into heating chambers and thermodynamic units of specialized confectionery processing equipment

Changes in the rules and criteria of industrial design as applied to advanced smart confectionery production.

The introduction of new so-called smart technologies, the application of new so-called smart materials and composites, and the replacement of traditionally accepted manufacturing methods with unconventional approaches that facilitate and constitute an essential condition for technological leaps or breakthroughs, as well as increased production efficiency that begins to meet the criteria and characteristics of smart manufacturing, is today commonly referred to as a comprehensive innovation process.

This process may differ significantly under various technical and technological cultures and at different starting levels for initiating innovation activities. However, the urgent need to begin such a process exists, and this fact raises no doubts.

In recent years, the economies of virtually all industrially developed countries have adopted and continue to adopt an increasingly innovation-driven character.

While at the beginning of this process innovative breakthroughs were localized primarily within the fields of high technologies, microelectronics, and so-called ultra-precision digital technologies, today the innovation process is becoming increasingly focused on classical core technologies, energy systems, medicine, transportation, and smart modular confectionery technology complexes, thereby encompassing all fundamental spheres of human activity.

In order to increase the competitiveness of their confectionery products and technologies, entrepreneurs are compelled to continuously seek new ways to improve efficiency, reduce energy intensity and direct energy consumption, enhance environmental safety, and strengthen economic stability within individual enterprises or companies producing innovative and integrative confectionery products as part of the modern confectionery production ecosystem and the independent process of production development and preparation.

Figure 2. – The figure also shows a device for the online mixing and simultaneous linear homogenization of liquid components, with the optional formation of encapsulated structures before their delivery to the heating and thermal processing chambers of thermodynamic units incorporated into confectionery production equipment

The device is equipped with nine inlet ports and is capable of simultaneously mixing and homogenizing nine components of a mixture. Such a configuration has not been used previously, partly because there was no specific need for such a large number of components in confectionery formulations.

New opportunities in the design and verification of technical solutions also introduce elements of compositional design concepts, which are becoming key criteria within the tools and methodology of modern industrial design.

NEW PRODUCT

A new perspective on the durability of a new product.

Until quite recently, product durability was one of the most important criteria determining its commercial value. Today, however, as the time interval between the market introduction of a new product and the release of an even newer product continues to decrease, this period has become so short that it often makes little sense within the innovation process to focus excessive attention, effort, and resources on increasing durability beyond the time span between the introduction of an existing confectionery product and the market launch of a newer or upgraded version.

Since this period may vary significantly depending on the type of product, the concept of durability itself becomes less clearly defined over time and is no longer a critical objective of an invention.

There is also another subjective factor related to durability that should be taken into consideration. Established market expectations regarding the expected lifespan of different categories of products influence many commercial factors, including the quantity of products required and therefore sold, as well as their actual market price.

Imagine that a technical solution is developed that significantly increases product durability. In such a case, the demand for replacement products decreases while consumers remain willing to pay the existing price for the product.

This may lead to reduced sales volumes for companies manufacturing the product and place them before a choice – either accept the innovation or attempt to block its implementation and commercialization. In practice, many companies choose the latter option and resist the adoption of such innovations. As a result, the primary loser in this process is often the inventor, whose invention is either rejected by the market or not fully understood by its participants.

A new perspective on the reliability of a new product.

The issue of the reliability of a new product and the new criteria for evaluating and calculating reliability are also undergoing fundamental changes. First and foremost, this concerns the relationship between product reliability and the warranty obligations of the manufacturer to the consumer.

Very often, the costs associated with fulfilling warranty obligations are comparable to the cost of the product itself.

Thus, reliability is a factor that, as one of the objectives achieved through an invention, can determine the level of commercial success, naturally in combination with other technical and operational advantages resulting from the implementation of the invention.

In this context, the subjective factor of time also plays an important role. Reliability that significantly exceeds the period for which it is actually required may become a negative factor and create unforeseen difficulties for the inventor in situations where an ultra-reliable product proves to be commercially unprofitable for the manufacturer.

New opportunities for improving the efficiency of systematic search and analysis of prior technical solutions with regard to novelty.

It is evident that new information technologies create new opportunities for the systematic search for similar solutions during the development and refinement of a technical solution under consideration.

Let us assume that, during the preliminary design of a compositional structure, it becomes necessary to combine and integrate several classical solutions together with new digital technologies that connect them into a unified composition. This may be considered a first level of horizontal integration. Subsequently, it may become necessary to move to the next level of integration by incorporating algorithms, software products, and interfaces that provide connectivity with the previous level of integration.

At this stage of searching and analyzing existing solutions, it becomes particularly important to assess the anticipated impact of incorporating elements of artificial intelligence and artificial neural networks into the overall system architecture of the product under development.

The question then arises: how should the search be conducted, in which directions should it proceed, and how can it be organized most effectively in order to identify existing analogs of the proposed compositional solution?

In the author's view, once the composition has been defined, the most effective approach is to begin a systematic search by first decomposing the composition and identifying the non-obvious, independent, and autonomous technical solutions contained within it.

After completing this stage, it is advisable to select one of these technical solutions as the core or base solution. A search should then be conducted around this base solution, gradually incorporating the other technical solutions that form part of the composition. The search should proceed sequentially, examining the base solution in combination with each additional technical solution until the complete composition has been assembled, with the objective of ultimately approaching the ideal final result.

New opportunities for evaluating the usefulness, feasibility, and practicality of optimizing, modifying, and modernizing existing technical solutions in the field of confectionery production.

Very often, the new is simply the well-forgotten old.

Therefore, when defining objectives and deciding to initiate an innovation process aimed at developing a new confectionery product with non-obvious parameters and characteristics, it is advisable to determine whether any functional elements of the intended composition have already been invented in the past.

If such a solution, or an equivalent one, is identified, then the replacement of materials, the use of new components, and the incorporation of digital control and monitoring systems into the future composition may enable the creation of a new technological configuration. Such a configuration may possess the potential to be integrated into a higher-level system while retaining all the properties and characteristics of non-obviousness.

The impossibility of successful commercialization of confectionery products without establishing the principles of compositional hierarchy and the compositional ecosystem structure of a new technical solution.

As practice demonstrates, the possibility of selling or licensing autonomous technical solutions becomes virtually zero if such solutions are not initially linked to systems or solutions of a higher technological and functional level.

Inventions of a compositional nature, which incorporate at least a conceptual framework for integration into higher-level technological, structural, and digital systems, tend to be implemented more confidently and within shorter timeframes. This is because investors, purchasers, and license holders can find the methodology and mechanisms of such integration clearly described in both the specification and the claims of the integrative and compositional technical solution.

COMPOSITIONAL ECOSYSTEM

Proposed techniques and methods for developing a compositional style in the creation of new innovative solutions.

Thus, the compositional principles of a technical solution represent a design-engineering and technological approach to the development of new technical solutions with regard to their integration into existing technological schemes and configurations, including modern smart machines and smart confectionery production systems.

Since the methodology of such integration is often non-obvious, unique, and characterized by substantial novelty, the description and claims of an invention possessing a compositional nature, a multi-level architecture of cause-and-effect relationships among the components of the composition, and distinctive features integrated into the design and technological relationships of the composition, largely determine the commercial success of these innovations, particularly in the field of confectionery production.

Undoubtedly, the proven effectiveness of incorporating elements of artificial intelligence and artificial neural networks creates additional interest in commercialization due to the significant advantages associated with their application.

Techniques and methods for transitioning from the established compositional foundation of a new technical solution to the core basis of an integrative invention for a new confectionery product.

The engineering and technological composition involved in the development and production of confectionery products often requires additional, and frequently fundamentally new, relationships between the components and elements of the composition. In other words, even when a clearly defined engineering and technological composition exists in terms of its properties and structure, transforming it into a finished innovative product requires identifying suitable methods for integrating the composition into the final confectionery product, which itself may be integrated across multiple levels and structural configurations.

The possible approaches to integration may vary considerably. The essential requirement is that the final result of the integration should produce a significant leap in performance or quality that is unprecedented and non-obvious when evaluated in the context of prior experience within the confectionery production ecosystem.

The impact of limitations on the number of patent claims on the ability to ensure reliable protection of compositional technical solutions in the field of confectionery production.

Limiting the number of patent claims inherently complicates the reliable protection of an invented object. However, a properly developed compositional structure at all hierarchical levels can, on the contrary, strengthen both the degree and scope of protection.

The ideal case is a system of cause-and-effect relationships that makes it possible to achieve the declared non-obvious effect only within the proposed system of compositional interactions, with clearly defined conditions and characteristics determining both the composition itself and the independent functions of each element within that composition.

Due to limitations in space and claim structure, it is advisable in a compositional invention to emphasize only those characteristics and relationships that do not concern the already known independent features and functions of the individual elements and components, but instead arise specifically as a result of forming the composition and from the spheres of functional influence that the components exert upon one another.

It may be stated that, when appropriately selected components are subordinated within a composition to the conditions and properties of a newly created technological system, a new and non-obvious integrated system of characteristics, relationships, feedback mechanisms, and functions emerges. These features are possible only within the framework of that particular composition and, moreover, possess a tendency toward the further development and improvement of internal compositional relationships.

Adherence to these principles makes it possible, within a limited number of patent claims, to focus attention exclusively on the principal distinguishing characteristics of the composition while ensuring the maximum possible level of protection and the highest degree of clarity regarding the essence of the invention despite its non-obvious nature.

Proposed structure of an independent patent claim based on a compositional technical solution.

As the author determined through initial practical experience, and as recommended by specialists, an independent patent claim, when the invention represents a complex confectionery composition, should contain at least three principal parts.

The first part contains the formulation of the commercial essence of the compositional invention relating to the confectionery product and its production process. It should disclose the purpose and necessity of compositional integration in order to:

- clearly define the objective of the composition;
- establish the limits of functional relationships within the composition and explain the necessity of each component for the formation, normal operation, and effective functioning of the composition;
- formulate the designation and name of the composition representing the complex confectionery product.

The second, limiting part contains all fundamental information regarding the invention as such and includes the characteristics of all basic technical solutions associated with the components of the composition. At the stage of drafting the patent claims, these elements are not classified as containing substantial novelty in the commercial, engineering, technological, and functional relationships of the composition.

The third, distinguishing part contains information regarding the components, their interrelationships, materials, integrative elements, and the associated software products and their fundamental algorithms. Each of these elements, individually or in any combination, creates aspects of substantial novelty for the compositional, multi-level, and repeatedly integrated technical solution directed toward the creation of a fundamentally new confectionery product.

Proposed structure of a dependent patent claim based on a compositional technical solution for the creation of a smart confectionery product and its production process.

Limitations on the number of patent claims assign a special role to each claim within the overall strategy for establishing and protecting the novelty and non-obviousness of an invention.

Based on this principle, the second, limiting part of such a patent claim should contain all fundamental local and specific information relating to the invention itself. It should include a local and specific characterization of all basic technical solutions associated with the components of the composition that, at the stage of drafting the patent claims, are not regarded as containing elements of substantial novelty in the formulation, engineering, technological, and functional relationships of the composition, but nevertheless provide a clearly defined and convincing level of non-obviousness.

The third, distinguishing part contains local, technically focused information regarding the components, their interrelationships, materials, integrative elements, and the associated software products and their fundamental algorithms. Each of these elements, individually or in any combination, creates localized and specific elements of substantial novelty for a non-obvious, compositional, and multi-level integrated technical solution relating to the confectionery product.

Proposed methodology for designing prototypes of compositional technical solutions for confectionery products and production systems, enabling the testing and

verification of the effectiveness of each innovative element within the confectionery product composition.

The design of a prototype or experimental model of an innovative compositional product is most effectively carried out using engineering design software and its analytical engineering applications. The author prefers to use the software package SolidWorks, as this tool makes it possible to create a functioning model of a compositional technical solution and perform simulation-based verification of its operating cycle without resorting to the costly design and manufacture of physical prototypes.

ANALYSIS AND EXAMPLES

Analysis of identified analogs and prototypes of a new compositional technical solution.

If, as a result of the search process, homogeneous baseline technical solutions are identified that may, in a preliminary assessment, be regarded as analogs or prototypes of the proposed compositional technical solution for a confectionery product, they should be evaluated in various configurations and combinations of integration with additional elements and components of the composition under consideration.

If information regarding such prototypes or analogs is available in digital format, it is advisable to use the capabilities of SolidWorks to construct models of the identified technical solutions and perform digital simulations of their operating cycles. The results can then be compared with the corresponding operating cycles of the proposed invention – the compositional technical solution for a smart confectionery product.

Examples of compositional technical solutions that have been accepted by the market.

Examples of non-obvious compositional technical solutions include many well-known products and systems in the fields of computing technology, communications equipment, tablet computers, and numerous other products intended for both mass and specialized markets.

Ambiguities in the wording of patent applications covering the complex technical solutions underlying these products have led, and continue to lead, to numerous patent disputes and legal conflicts.

Broader application of compositional technical solutions and their integrated extensions and interpretations may help reduce the intensity of such disputes and may also facilitate the successful introduction of innovative confectionery products to the market.

There is also an exceptionally important aspect of the modern design process corresponding to TRIZ Principle No. 40, which is applied in the pursuit of the ideal final result.

Principle 40. Application of composite materials.

– Transition from homogeneous materials to composite materials.

As is well known, the mere replacement of one material with another is generally not recognized as an invention. A composite confectionery material, in itself, may constitute the subject matter of an original invention. However, in many cases, when a conventional structural material is replaced with a composite material, the properties and capabilities of the resulting product change so significantly that the product becomes entirely new, previously unknown, and characterized by fundamentally new non-obvious functions as well as unique technical and consumer characteristics.

Of course, implementing such a substitution requires an amount of work comparable to the development of a fundamentally new technology or a fundamentally new smart confectionery product. Such tasks are typically within the capabilities of companies possessing strong research and development divisions.

To supplement the analytical framework, it is useful to consider information regarding the laws of development and evolution of technical solutions known from TRIZ.

As of today, a number of so-called laws governing the development of technical and technological solutions have been proposed. However, the correctness and precision of their definitions and formulations have not been conclusively proven.

Law of system completeness.

A necessary condition for the fundamental viability of a technical system is the presence and minimum operability of its principal components.

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Law of energy conductivity within a system.

A necessary condition for the fundamental viability of a technical system is the uninterrupted flow of energy through all parts of the system.

Law of coordination of the rhythmic behavior of system components.

A necessary condition for the fundamental viability of a technical system is the coordination of the rhythmic behavior (oscillation frequency, periodicity) of all system components.

Law of increasing system ideality.

The development of all systems proceeds in the direction of increasing their degree of ideality.

Law of uneven development of system components.

The development of system components proceeds unevenly. The more complex the system, the more uneven the development of its components.

Law of transition to a supersystem.

Having exhausted its possibilities for development, a system becomes incorporated into a supersystem as one of its components. Further development then proceeds at the level of the supersystem.

Law of transition from the macrolevel to the microlevel.

The development of the working elements of a system proceeds first at the macrolevel and subsequently at the microlevel.

Law of increasing the degree of substance–field interactions.

The development of technical and commercial systems proceeds in the direction of increasing the number of substance–field interactions. As practice has shown, TRIZ and ARIZ have unfortunately not been fully adapted to the requirements and criteria of smart confectionery production or to the integrative use of artificial intelligence and artificial neural networks. As a result, they do not entirely correspond to the current realities of research and innovation design teams for a number of significant reasons.

Unfortunately, during the evolution of systematic design methods and equipment, no comprehensive adaptation of TRIZ and ARIZ has been carried out to meet the actual conditions and requirements of smart confectionery production. This applies not only from technical and technological perspectives but also from a psychological perspective, particularly regarding preparation for marketing development, commercialization strategies, and patent and licensing strategies for smart confectionery products. The transition to computer-based design and engineering methods has dramatically reduced the time required for the technical preparation of new innovative products and production processes. This has created a new psychological model for perceiving the innovation process, one that has provided little incentive for the optimal application of TRIZ methodologies.

The use of computer simulation has significantly reduced the number of design errors and has virtually eliminated the introduction of unsuccessful solutions and confectionery products that would otherwise require subsequent correction and modernization.

Therefore, under current conditions, it is often psychologically more justified to completely replace outdated equipment and processes with new innovative solutions rather than pursue gradual modernization, which is frequently limited in both effectiveness and novelty.

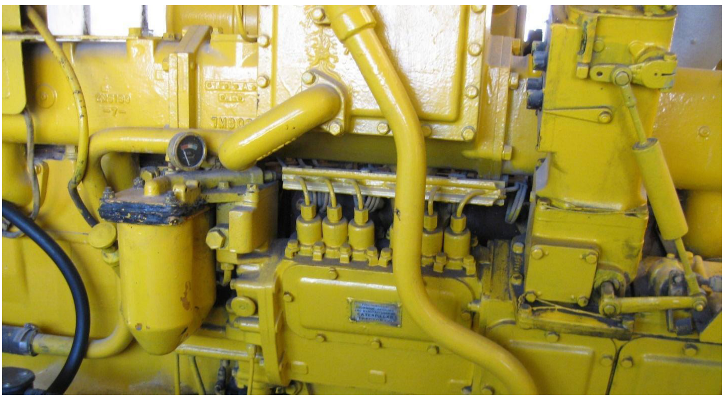


Figure 3. – The figure shows a diesel generator being modernized through the integration of a device for mixing and homogenizing a fuel blend consisting of diesel fuel and methanol into its fuel supply system

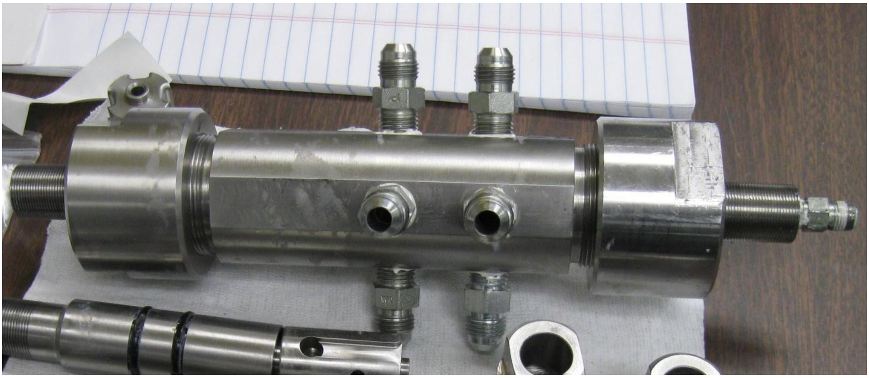


Figure 4. – The figure illustrates a device for the online mixing and homogenization of liquid components of confectionery mixtures and other culinary formulations prior to their injection or transfer into the thermal processing chamber of a thermodynamic unit within industrial production equipment

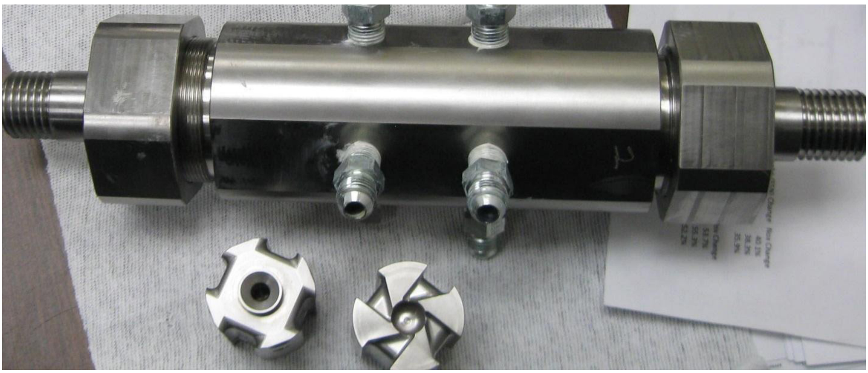


Figure 5. – The figure also illustrates a device for the online mixing and homogenization of fuel mixtures prior to their injection into the combustion chamber of a thermodynamic unit with internal working components

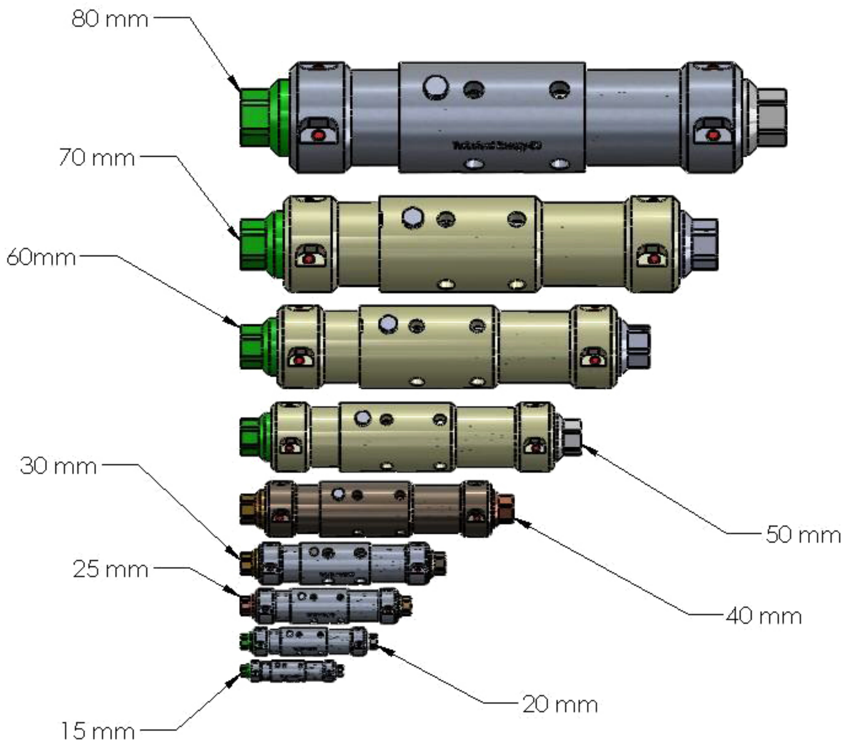


Figure 5–1. – The figure presents a range of sizes of devices for the online mixing and homogenization of liquid confectionery components or fuel mixtures prior to their injection into the combustion chamber of a thermodynamic unit

The development process of a project involving the integration of a device for the dynamic mixing of fuel components into the fuel supply systems of thermal equipment, including boilers of all types.

All nine standard sizes of the devices for the online mixing and homogenization of confectionery or fuel mixtures prior to injection into the combustion chamber of a thermodynamic unit possess an equivalent internal structure and a uniform design of their internal components.

Figure 6. – The figure presents instruments for monitoring and measuring the parameters of the resulting confectionery or fuel mixture

With regard to boilers, for example, the device should incorporate a nozzle to provide a higher level of compatibility with fuel delivery systems supplying fuel to the combustion chamber or burner.

The development of such a nozzle constitutes one of the integral components of the project.

At the same time, the device itself may be presented as a standalone product or as a compact burner for thermal chambers used in confectionery production.

This applies equally to boilers that use diesel fuel as well as to boilers that use natural gas as fuel.

All variants and operational versions of the device, together with the corresponding application technologies, may be developed simultaneously and in parallel.

For devices intended for the dynamic mixing of fuel components in which liquid fuel plays the dominant role, a number of paradoxical effects arise that are characteristic of all applications, including those associated with confectionery production.

The first paradox is characterized by the fact that, within a pipeline having the same cross-sectional area, under the same initial pressure conditions and the same initial flow rate of an incompressible liquid component, an annular vacuum zone is formed without any additional expenditure of energy.

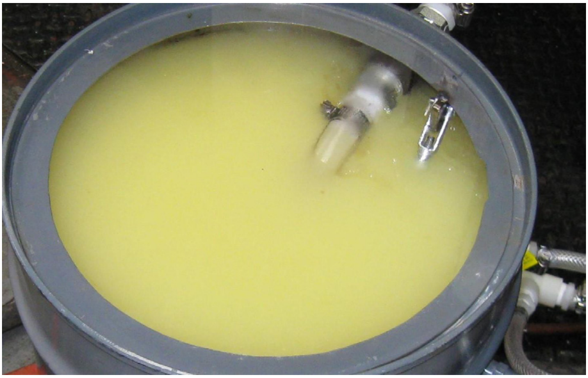


Figure 7. – The figure shows, as an example, the appearance of the fuel mixture after restoration of its structure

Figure 7–1 – The figure illustrates the internal structure of the device

Figure 8. – The figure shows the appearance of the fuel mixture before restoration of its structure

This zone serves as a distinctive boundary between the incompressible liquid and the compressible mixture of that liquid with a gas, in this case – air.

The second paradox lies in the fact that, within the same pipeline, the liquid entering the pipeline changes its physical properties from those of an incompressible working medium to those of a compressible working medium.

Figure 9. – The figure shows systems incorporating artificial intelligence and artificial neural networks that are used during the qualification testing of the technology and the device

The third paradox lies in the fact that, at the point where the flow changes its physical properties, the liquid and gaseous component streams are coaxial, with the liquid component stream surrounding and enclosing the gaseous component stream.

Figure 10. – The figure also shows systems incorporating artificial intelligence and artificial neural networks that are used during the qualification testing of the technology and the device.

The directions of movement of the flows at the specified point coincide.

The fourth paradox lies in the fact that, within the zone forming the boundary between the incompressible portion of the flow and the compressible portion of the flow, a region of deep rarefaction or vacuum is created under conditions where two coaxial flows each generate an annular rarefaction zone. One such zone is produced by the incompressible liquid flow, while the second annular rarefaction zone is generated by the compressible air flow.

Both of these zones are coaxial with respect to one another, and the flow thickness within them does not exceed 100 micrometers for the liquid and 25 micrometers for the gas.

The linear velocity within each flow in the rarefaction zone exceeds 100 meters per second, despite the fact that no additional sources of energy are utilized.

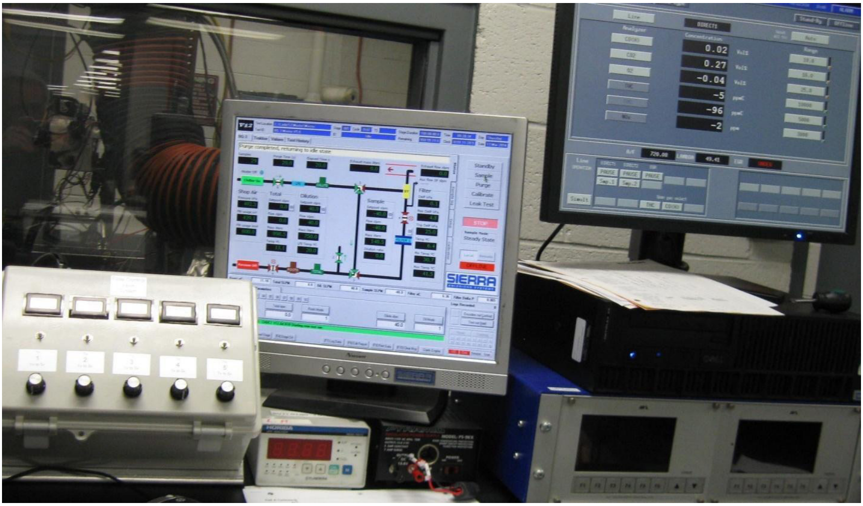


Figure 11. – The figure also shows fragments of systems incorporating artificial intelligence and artificial neural networks that are used in confectionery production during the qualification testing of the technology and the device

The fifth paradox lies in the fact that the mixture flow accumulates the kinetic energy of the flows of all its components, and the kinetic energy of the mixture leaving the device exceeds the kinetic energy of the liquid component entering the device.

The sixth paradox lies in the fact that, under conditions of deep rarefaction and high linear flow velocities, a large number of capsules containing confectionery liquid components or composite fuel are formed within the boundary zone separating the incompressible liquid region from the compressible mixture region. More than 27 million spherical capsules with diameters not exceeding 50 micrometers are generated per liter of mixture or fuel composite.

Within these capsules, the compressible element – air – forms the core, while the incompressible element – a liquid or a homogeneous mixture of liquids – forms the shell.

The seventh paradox lies in the fact that, when required, an additional liquid component of the fuel or confectionery composite, such as water, can be drawn into the boundary zone between the compressible and incompressible portions of the flow.

In this case, no additional energy is required either to entrain the water into the flow of the liquid fuel component or to mix it with that component. Only the energy of the liquid fuel flow itself is utilized.

Figure 12.

Application of the electromagnetic resonance method based on the principles of electromagnetic resonance spectroscopy for the systematic and comprehensive monitoring of biochemical processes associated with the physiological activity of the human body.

Operating principle of an electromagnetic resonance sensor based on the methods of electromagnetic resonance spectroscopy.

The method involves the creation of an alternating electromagnetic field in the space where the sample under investigation is located.

This field serves as an intermediary between the resonant circuit and the test sample.

On one hand, the resonant circuit acts as the emitter of this field, while on the other hand it serves as the receiver (sensitive element) of the changes in the electromagnetic field introduced by the test sample.

Under the influence of the external alternating electromagnetic field, various electrical phenomena may be induced within the test sample, depending on its nature. These phenomena may include linear and eddy conduction currents, linear and eddy displacement currents, as well as linear and eddy ionic currents resulting from the ordered movement of ions.

In accordance with the principles governing the formation of electromagnetic fields, these electrical phenomena introduce distortions into the external alternating electromagnetic field. These distortions are detected by the solenoid of the electromagnetic resonance sensor (ER sensor).

The resonant circuit, which includes this solenoid or its microelectronic equivalent, alters its behavior as though additional components had been incorporated into the circuit, namely a capacitor, an inductor, and a resistor. The combined capacitive, inductive, and active resistances constitute an additional impedance introduced into the system by the test sample, and it is this attribute that the ER sensor measures.

Changes in the parameters of the resonant circuit are reflected in changes to its complex amplitude–frequency characteristic. Specifically, both the resonant frequency and the resonant amplitude of the circuit are altered.

By analyzing these changes, it is possible to evaluate the most active, reliably measurable, and otherwise informative parameters of the sample under investigation.

As follows from the above description of the operating principle of the electromagnetic resonance sensor based on the methods of electromagnetic resonance spectroscopy, the complex response obtained from the measured object can be utilized in all applications where eddy-current testing instruments (electromagnetic sensors) are employed.

In addition, electromagnetic resonance sensors can be used in all applications involving the measurement of characteristic parameters of an object placed between electrodes, such as in radio-frequency impedance/material analyzers.

The principal advantage of the ER sensor over the aforementioned methods is its substantially higher sensitivity – at least an order of magnitude greater. This enhanced sensitivity is achieved through the use of a resonant circuit in its most reduced form, consisting solely of an inductive coil or its microelectronic equivalent, which utilizes its own inter-turn capacitance to form the oscillatory circuit.

Single and two-component applications.

This category includes all applications in which a single electromagnetic resonance sensor is sufficient and provides two output parameters for indication: resonant frequency and resonant amplitude.

These applications include all forms of defect detection and inspection, as well as applications that monitor changes in one or two parameters, such as chemical–mechanical processing, film and coating deposition processes, moisture determination in materials and objects, measurement of water salinity, and similar applications.

Construction of an analytical system.

For applications requiring the measurement and/or monitoring of changes in complex, multicomponent systems, and especially in confectionery systems, it becomes necessary to construct an analytical system consisting of multiple sensors, each operating at its own unique working frequency.

The initial data used for the construction of such a system for the chemical, physical, or comprehensive integrative analysis of the investigated object are spectra obtained using the methods of Electrochemical Impedance Spectroscopy (EIS) and/or Dielectric Relaxation Spectroscopy (DRS), employing the measurement equipment associated with these methods, including radio-frequency impedance/material analyzers, pulse generators, and similar instruments.

To construct these spectra, reference samples of the investigated object are used, containing known variations in chemical components or known variations in the physical properties of the object.

The extent to which these reference samples comprehensively represent all possible states of the investigated object directly affects the measurement accuracy of the electromagnetic resonance analytical system.

Subsequently, using a chemometric* approach, the operating frequencies for the electromagnetic resonance sensors included in the analytical system are determined on the basis of the obtained spectra.

The number of sensors within the system should be greater than or equal to the number of components under investigation.

The primary criteria for selecting the operating frequency are the maximum impedance variation corresponding to changes in the concentration of the investigated component or physical property, as well as the contrast of this response against variations caused by other components or physical properties.

PROPOSED RESEARCH PROJECT

Non-contact blood composition monitoring (as an example).

This method involves the installation of a system of electromagnetic resonance sensor modules along blood vessels at locations where the vessels are situated closest to the surface of the body.

Moreover, different types of blood may serve as the object of investigation, including arterial, venous, and capillary blood.

The creation of such a system requires a substantial amount of preparatory work in order to determine both the required number of sensors and their appropriate operating frequencies.

To accomplish this, at least two different approaches may be employed: the synthetic approach and the analytical approach.

Synthetic approach.

This approach involves a gradual transition from simple measurements to more complex ones.

The full range of instruments used in Electrochemical Impedance Spectroscopy (EIS) research may serve as measurement equipment, including pulse generators, impedance meters, and similar devices.

The methodology of these investigations consists of acquiring and analyzing EIS spectra within the radio-frequency range of 1–1000 MHz for various concentrations of individual blood components dissolved in distilled water, as well as their combinations.

It is most practical to begin with single-component solutions of dextrose and sodium chloride.

The objective of the research is to identify those "promising" regions of the spectra where changes in the amplitude or phase of the EIS spectrum exhibit the strongest correlation with changes in the concentration of the component being measured (for example, dextrose).

Subsequently, solutions or suspensions of all other chemical and biological blood components are investigated individually in order to identify, within the previously selected promising frequency ranges, those regions where the influence of non-target components on the total electrochemical impedance is minimal.

To further refine the operating frequencies of the electromagnetic resonance sensing elements, the acquisition and analysis of electromagnetic spectra are repeated, but this time using mixtures rather than single-component solutions.

While the analysis of spectra obtained from simple single-component solutions may be performed manually, the analysis of complex combinations of components generally requires the application of chemometric* methods.

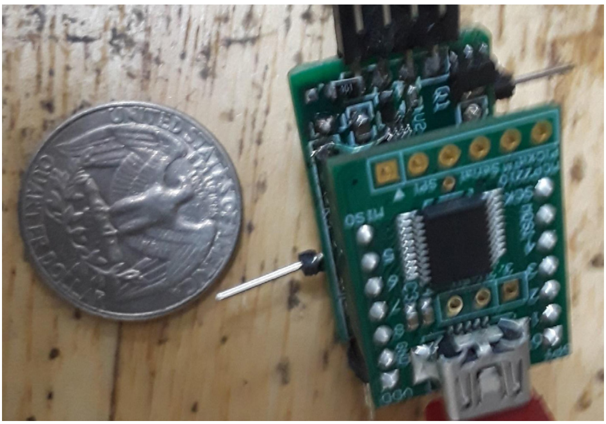


Figure 13.

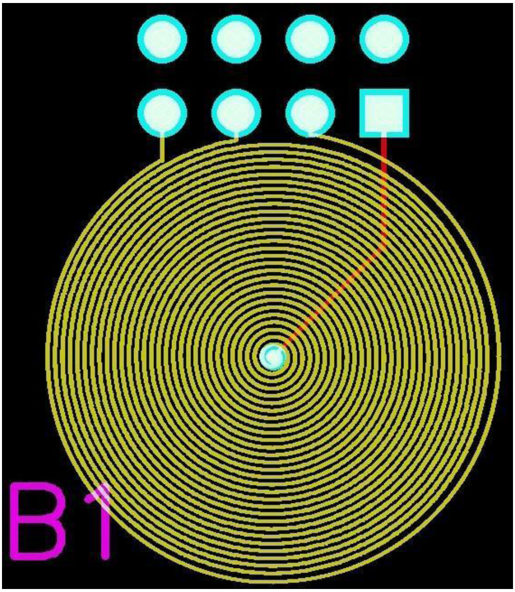


Figure 14.

After the operating frequencies have been determined, a sensor system is constructed and calibrated using samples that encompass all possible combinations of blood-component concentrations.

The system is then tested on human subjects in parallel with conventional blood analyses in order to determine the necessary correction coefficients for the calibration data, taking into account the potential influence of the skin, blood-vessel walls, and muscle tissue.

Analytical approach.

This method involves the periodic acquisition of EIS spectra through the direct two-electrode measurement of the impedance of body regions adjacent to blood vessels. Simultaneously with the acquisition of the spectra, blood samples must be collected and their component composition determined. Subsequently, by comparing variations in the EIS spectra with changes observed in the blood analyses and applying chemometric* methods, correlation coefficients between impedance and blood-component concentrations at different frequencies can be determined.

By analyzing these correlation coefficients, the operating frequencies for the sensors are selected.

After the system of electromagnetic resonance sensing elements has been constructed, a series of measurements must be carried out for calibration purposes, accompanied by parallel blood sampling and determination of blood-component composition.

Non-contact monitoring of acupuncture points.

In all diseases, whether physical or psychological, there are sensitive areas located at specific points on the body's surface that disappear once the disease has been cured.

These are the so-called acupuncture points (the anatomical locations of these acupuncture points can be found in an acupuncture atlas).

As a rule, such points appear as small nodules similar to fibrous rheumatic nodules commonly found on the back of the neck, shoulders, or lumbar region.

In many cases, however, instead of a nodule, the manifestation may take the form of a band of muscular tension within a muscle group accompanied by a particularly firm and compacted area.

These locations are often slightly swollen or exhibit changes in coloration.

Dr. Voll developed his method based on changes in electrical conductivity at acupuncture points.

His instrument is essentially a conventional direct-current ohmmeter, operating at a frequency of zero hertz.

EIS technology can provide an order of magnitude more information about the condition of an acupuncture point than the Voll method and, in the case of electromagnetic resonance sensing elements, can do so without direct electrical contact.

Nevertheless, for investigating changes in the electromagnetic characteristics of acupuncture points resulting from various diseases, a two-electrode configuration in combination with appropriate measuring instruments may be employed.

Following comprehensive EIS investigations and the selection of optimal operating frequencies, it becomes possible to construct a system of electromagnetic resonance sensing elements capable of monitoring a person's health status and providing warnings regarding deviations from the normal functioning of the body.

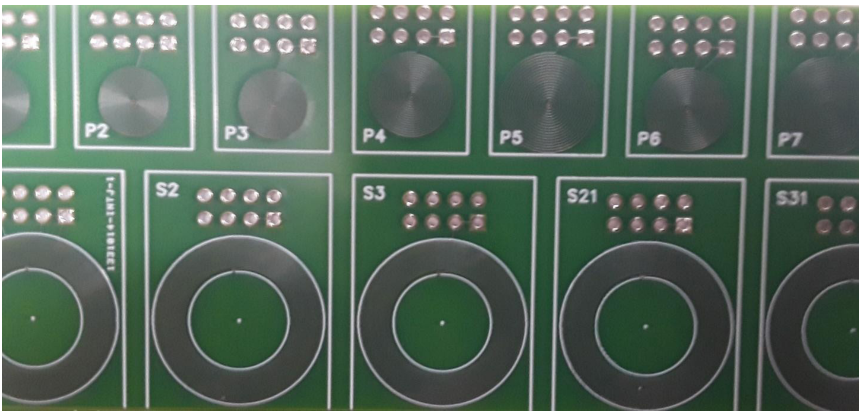
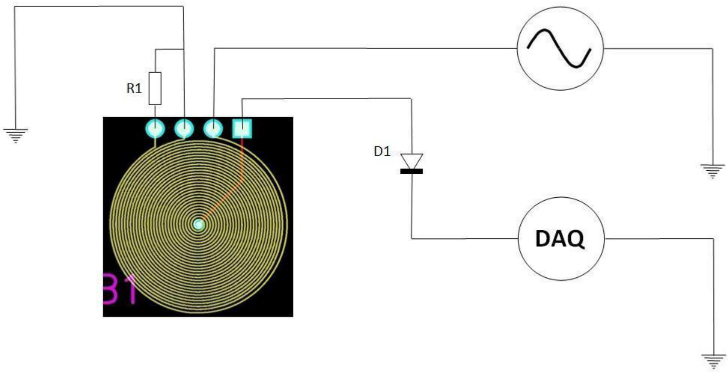


Figure 15.

Schematic of planar Impedance Resonance Sensor connection



Excitation coil is connected to generator with frequency sweep. Resistance of R1 depends on output resistance of the generator and length of line between the sensor and the generator. If the length of line is less then ¼ of wavelength, the resistor can be omitted. Sensing coil is connected to Data Acquisition (DAQ). If operating frequency of the sensor is more than frequency capability of the DAQ, then the diode can solve that problem.
Both the generator and the DAQ are connected to personal computer and work under control of computer program. The program calculates resonant frequency and amplitude of the sensor and measure their changes caused by presence of analyte under test.

Figure 16.

The possibility of this type of monitoring has been only minimally explored to date; however, if positive results are obtained, this project may prove to be one of the most practical and effective approaches.

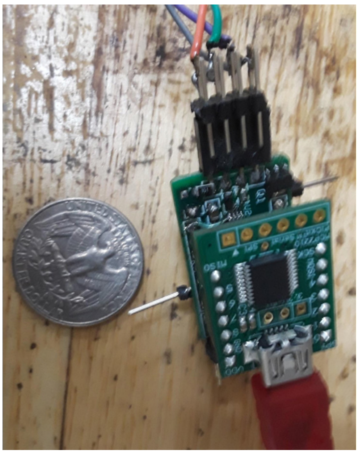


Figure 17.

Report on the completion of the first and second stages of the project – Sensor module for non-contact monitoring of glucose concentration levels and their equivalents in blood using methods and devices characteristic of electromagnetic resonance spectroscopy. Report on the completion of the first stage of the project – Sensor module for non-contact monitoring of glucose concentration levels and their equivalents in blood using methods and devices characteristic of electromagnetic resonance spectroscopy.

The first stage of the project includes the following operations (10 items in total):

– determination of the initial technical requirements for the sensor module;

– determination of the initial technical specifications and performance characteristics of the sensor module;

– identification of the principal distinguishing features and elements of fundamental novelty within the sensor-module design;

– selection of the primary foundational invention forming the basis of the sensor-module design and application parameters;

– determination of the principal design and technological characteristics of the sensor module;

– preparation of the primary instructions and justifications for the procedures and methodology of sensor-module application;

– determination of the principal characteristics and profiles of construction materials used in the assemblies and components of the sensor module;

– development of a program and methodology for preliminary evaluation testing of the design and its possible modifications depending on the active sensor-module model;

– development of initial technical requirements for specialized technological equipment required to implement the program and methodology for preliminary evaluation testing of the design and its modifications depending on the active sensor-module model;

– development of initial technical requirements for specialized laboratory control and analytical equipment required to implement the program and methodology for preliminary evaluation testing of the design and its modifications depending on the active sensor-module model.

The labor intensity of implementing the first stage of the project (all work performed using the full-time efforts of two employees, with a total labor input calculated at an average hourly rate of USD50 per employee) was as follows:

– determination and formulation of the initial technical requirements for the sensor module; conducting a prior-art search covering at least 20 years to qualify and confirm the novelty level of the principal technical solutions required by the initial technical requirements; comparison and coordination of the parameters of the initial technical requirements with the requirements and limitations of applicable standards (6 working hours for each employee);

– determination of the initial technical specifications and characteristics of the sensor module; conducting a prior-art search covering at least 20 years to qualify and confirm the novelty level of the principal technical solutions required by the initial technical specifications; comparison and coordination of the parameters of the initial technical specifications with the requirements and limitations of applicable standards (6 working hours for each employee);

– identification of the principal distinguishing features and elements of fundamental novelty of the sensor-module design; preliminary development of patent and licensing strategy parameters for the base sensor-module design and all associated assemblies and components; conducting a prior-art search covering at least 20 years to qualify and confirm the novelty level of the principal technical solutions;

– qualification and formulation of sensor-module types and design configurations, including: a cylindrical housing with a flat coil at the working end; a cylindrical housing with a combined sensor consisting of a flat coil and a standard coil perpendicular to the flat coil; and a standard coil transformed into a ring worn on the patient's finger (9 working hours for each employee);

– selection of the principal foundational invention underlying the design and operating parameters of the sensor module; conducting a prior-art search covering at least 20 years to qualify and confirm the novelty level of the principal technical solutions; preparation of documentation required for transferring ownership of the invention and all associated international documentation to the full ownership of the technology development company (3 working hours for each employee);

– determination of the principal design and technological characteristics of the sensor module; conducting a prior-art search covering at least 20 years to qualify and confirm the novelty level of the principal technical solutions; additional modeling of the feasibility of installing a miniaturized sensor module based on a flat-coil microassembly onto the contact surfaces of smart watches and mobile phones (2 working hours for each employee);

– determination of the principal instructions and justifications governing the procedures and methodology of sensor-module application; conducting a prior-art search covering at least 20 years to qualify and confirm the novelty level of the principal technical solutions, including original solutions involving the application of so-called smart technologies and devices; identification and qualification of new implementation directions for various sensor-module configurations intended for online monitoring of different parameters in flowing liquids and aerosols using elements of artificial intelligence and artificial neural networks (4 working hours for each employee);

– determination of the principal characteristics and profiles of construction materials and specialized coatings used in sensor-module assemblies and components; development of techniques for coating the flat sensor coil with an artificial diamond film (10 microns thick); verification and analytical evaluation of coating the flat sensor-coil surface with irradiated polyethylene film; conducting a prior-art search covering at least 20 years to qualify and confirm the novelty level of the principal technical solutions, including original solutions involving the use of smart technologies and devices (2 working hours for each employee);

– development of a program and methodology for preliminary evaluation testing of the design and its modifications depending on the active sensor-module model; conducting a prior-art search covering at least 20 years to qualify and confirm the novelty level of the principal technical solutions, including original solutions involving the application of smart technologies and devices (3 working hours for each employee);

– development of initial technical requirements for specialized technological equipment required to implement the program and methodology for preliminary evaluation testing of the design and its modifications depending on the active sensor-module model; conducting a prior-art search covering at least 20 years to qualify and confirm the novelty level of the principal technical solutions required by the initial technical requirements for specialized technological and laboratory equipment; comparison and coordination of the parameters of the initial technical requirements with the requirements and limitations of applicable standards (9 working hours for each employee);

– development of initial technical requirements for specialized laboratory control and analytical equipment required to implement the program and methodology for preliminary evaluation testing of the design and its modifications depending on the active sensor-module model; conducting a prior-art search covering at least 20 years to qualify and confirm the novelty level of the principal technical solutions required by the initial technical specifications; comparison and coordination of the parameters of the initial technical requirements and initial technical specifications with the requirements and limitations of applicable standards for laboratory control and analytical equipment (6 working hours for each employee).

The total minimum labor input for all work performed during the first stage, excluding depreciation costs, social contributions, and all categories of associated expenses, amounted to 100 hours – equivalent to one full working week for each employee, corresponding in total to the advance payment of USD5,000 allocated for this stage.

Stage 1.

Development of engineering and technological documentation for prototype manufacturing.

Preparation of the technical assignment for development.

Coordination and approval of the technical assignment with the manufacturer.

Preparation of the initial technical requirements for the product.

Definition of the product's technical characteristics.

Coordination and approval of the technical characteristics and technical requirements with the manufacturer.

Development and approval of technological instructions for the manufacturer.

Report on the completion of the second stage of the project – Sensor module for non-contact monitoring of glucose concentration levels and their equivalents in blood using methods and devices characteristic of electromagnetic resonance spectroscopy.

Stage 2.

Preliminary design.

Technical design.

Working design documentation.

Development of models for CNC machining equipment.

Transfer of documentation to the prototype manufacturer.

Coordination with the manufacturer regarding manufacturing technology and acceptance inspection procedures.

Development and approval, in coordination with the manufacturer, of the program and methodology for preliminary acceptance testing.

APPENDIX – 01

Methodology for selecting the operating frequencies of sensors.

This methodology describes the first stage required for constructing a monitoring system for the concentration of components within a mixture under investigation.

A mixture is defined as any combination of components in which one component is predominant by volume and is considered the conventional solvent, while the remaining components are regarded as conventional dissolved components.

The concept of a conventional solvent is not limited to a liquid single-component substance capable of forming solutions with other substances. It may also be a mixture of gaseous, liquid, or even solid substances (for example, a compound material) that can serve as the basis for the formation not only of solutions but also of suspensions, mists, and foams.

Accordingly, the conventional dissolved components may exist not only in a dissolved state but may also be present in the mixture as suspended particles, bacterial colonies, mist droplets, gas bubbles within foams, or filler particles within compound materials.

Search for the optimal operating frequency of a sensor for constructing a monitoring system for a single component within a mixture.

Such a monitoring system may be used in technological processes where the concentration of one component can vary while the concentrations of all other components remain constant.

Preparation of samples for measurement.

Two samples must be prepared with concentrations of the investigated component corresponding to the lower and upper limits of the expected concentration variation range.

Scanning.

Using pulse generators, the prepared samples are scanned by frequency across the full bandwidth of the pulse generator, in this case from 0.100 MHz to 170 MHz.

During the scanning process, the pulse-generator readings are recorded in the form of changes in amplitude and phase shift of the current passing through the sample relative to the harmonically varying probing voltage with a stabilized constant amplitude.

Analysis of results.

Based on the scanning results, several frequencies should be selected at which the difference between the amplitudes of the investigated samples reaches the highest values, as well as several frequencies at which the difference in phase shifts reaches the highest values.

The selected frequencies will serve as the initial data for the design and manufacture of trial resonant sensors.

Selection of the optimal sensor.

The selection of frequencies based on the results of sample scanning using a pulse generator is preliminary in nature.

To determine the optimal operating frequency for a single-component concentration-monitoring system, it is necessary to test each trial resonant sensor using not just two samples, but at least ten samples containing different concentrations of the investigated component within the expected concentration range.

After testing all prototype sensors, the best-performing sensor can be selected. Preference should be given to sensors that, in addition to high sensitivity, exhibit a monotonic change in their readings corresponding to changes in the concentration of the monitored component, thereby simplifying subsequent calibration.

In addition, lower operating frequencies are generally preferable from the standpoint of electromagnetic noise immunity and interference resistance.

When selecting the final sensor design, any applicable structural and design constraints must also be taken into consideration.

Search for the optimal operating frequencies of sensors for constructing a monitoring system for two components within a mixture.

Such a monitoring system may be used in technological processes where the concentrations of two components can vary while the concentrations of all other components remain constant.

Preparation of samples for measurement.

Two samples must be prepared for each investigated component, with concentrations corresponding to the lower and upper limits of the expected concentration range. In addition, a reference sample in which both investigated components are completely absent must be prepared.

Scanning.

Using a pulse generator, the prepared samples are scanned across the full operating frequency range of the pulse generator (in our case, from 0.100 MHz to 170 MHz).

During the scanning process, the pulse-generator readings are recorded in the form of changes in amplitude and phase shift of the current flowing through the sample relative to the harmonically varying probing voltage maintained at a stabilized constant amplitude.

Analysis of results.

For each investigated component, based on the scanning results, several frequencies should be selected at which the difference between the amplitudes of the investigated samples reaches the highest values, as well as several frequencies at which the difference in phase shifts reaches the highest values.

It is also necessary to identify frequencies, or frequency ranges, at which sensitivity to one component is absent while sensitivity to the other component is present.

The obtained frequency selections should then be analyzed.

Depending on the comparison results, several possible algorithms for selecting the operating frequencies of the sensors may be applied.

Variant in which frequencies exist where sensitivity to only one component is present.

This variant is the most preferable for constructing a monitoring system for the concentrations of the investigated components.

If such frequencies exist for both one component and the other, the selection of operating frequencies is obvious:

for the manufacture of experimental resonant sensor samples, it is necessary to select operating frequencies at which, in the absence of sensitivity to one component, sensitivity to the other component is at its maximum.

At least one such frequency should be selected for each component.

If such frequencies exist only for one of the components, then for the manufacture of experimental resonant sensor samples for this component, operating frequencies should be selected at which, in the absence of sensitivity to one component, sensitivity to the other component is at its maximum. For the other component, operating frequencies should be selected from its set of frequencies at which the difference in sensitivity to the investigated components is the greatest.

Variant in which there are no frequencies exhibiting sensitivity to only one component, but the resulting frequency selections do not coincide.

In this case, for the manufacture of experimental resonant sensor samples, operating frequencies should be selected from each frequency set at which the difference in sensitivity to the investigated components is the greatest.

Variant in which the resulting frequency selections coincide.

This variant is the most challenging for constructing a monitoring system for the concentrations of the investigated components.

If the frequency set for one component completely coincides with the frequency set for the other component, it is necessary to verify whether the proportional relationship between changes in amplitude or phase shift for one component and changes in amplitude or phase shift for the other component is maintained across all frequencies.

If all results coincide, the scanning procedure should be repeated using different values of the probing voltage.

If no differences can be identified, then the investigated components are most likely indistinguishable from the perspective of electrochemical electromagnetic spectroscopy.

Nevertheless, even in this case, it is possible to manufacture several prototype sensors operating at different frequencies corresponding to the highest sensitivity to changes in the concentrations of the investigated components, since a resonant sensor exerts a more complex influence on the investigated sample than a pulse generator, owing to the additional effect of the magnetic field.

If testing of these sensors demonstrates, at least at one frequency, a change in the proportional relationship between sensitivities to concentration variations, then there is a fundamental possibility of constructing a monitoring system for the concentrations of the investigated components. Moreover, the selectivity of such a system will increase as the difference in the sensitivity ratio becomes greater.

Selection of the optimal sensors.

The selection of frequencies based on the results of sample scanning using a pulse generator is preliminary in nature.

To determine the optimal operating frequencies for a two-component concentration-monitoring system, it is necessary to test each trial resonant sensor using not merely two samples, but at least ten samples containing different concentrations of the investigated components within the expected range of concentration variation.

After testing all prototype sensors, the optimal sensor pair can be selected. Preference should be given to sensors that, in addition to high sensitivity, exhibit a monotonic change in their readings corresponding to changes in the concentrations of the monitored components, thereby facilitating subsequent calibration.

In addition, lower operating frequencies are preferable from the standpoint of electromagnetic noise immunity and interference resistance.

When selecting the sensors, any applicable design and structural constraints must also be taken into account.

APPENDIX – 02

Comprehensive investigations of the influence of the distance between the radiating element and the monitored liquid volume on the accuracy and sensitivity of sensor-module readings.

The active objects of the study consisted of flat-coil variants implemented as printed circuit boards with a specialized topology designed to simulate the operation of a sensor module installed within the mobile cylinder of the testing and measurement apparatus.

In this configuration, the flat coil was mounted within the bore of the non-contact monitoring and measurement module based on electromagnetic resonance spectroscopy and was isolated from the monitored liquid by a membrane manufactured from irradiated polyethylene.

Six membrane size categories were prepared for testing, with each size category including six different cross-sectional geometric profiles.

Following the completion of the full cycle of comparative testing, a membrane with a rectangular cross-section and a thickness of 0.5 millimeters was determined to be the most effective according to all evaluated parameters.

All subsequent measurements and comparative analyses were therefore conducted using a module housing equipped with this type of membrane.

Figure 18.

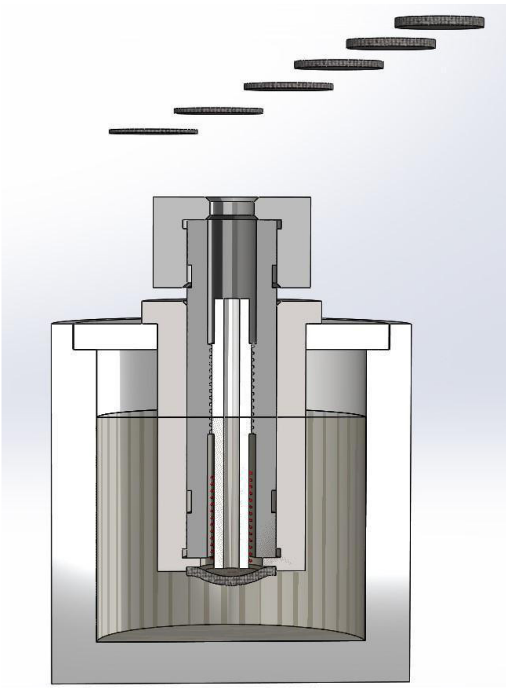


Figure 19.

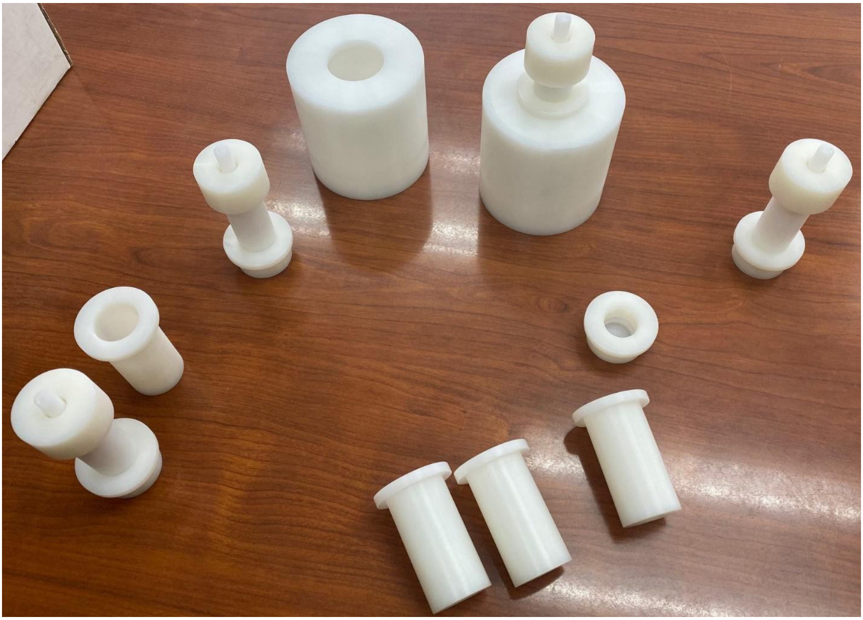


Figure 20.

For further experiments, a sensor-module design incorporating direct contact between the printed circuit board surface and the flat coil is adopted. In this configuration, the effective distance between the plane of the printed circuit board topology and the signal-entry surface of the measured volume is equal only to the thickness of the protective coating applied to the printed circuit board surface – 50 micrometers. The diagram demonstrates the maximum sensitivity and measurement accuracy of the flat-coil-based sensor when the only separation between the controlled object and the flat coil is the 50-micrometer-thick protective coating. As can be seen from the diagram, the level of signal energy saturation and resonant signal reflection is at its highest when this arrangement is used.

At the same time, the edge effect associated with the outer diameter of the printed circuit board flat coil does not influence the power characteristics of the pulses or their reflected derivatives.

In the case of manufacturing the printed circuit board flat coil using RITM technology and achieving a board thickness of only 50 micrometers, the influence of edge effects and their associated destabilizing phenomena is effectively reduced to zero.

It should also be noted that the distance between the radiating surface of the flat coil and the plane defining the upper boundary of the measured volume (in the present tests, the monitored liquid containing various concentrations of sugar or its equivalents) is independent of whether this distance is occupied by a membrane or by air.

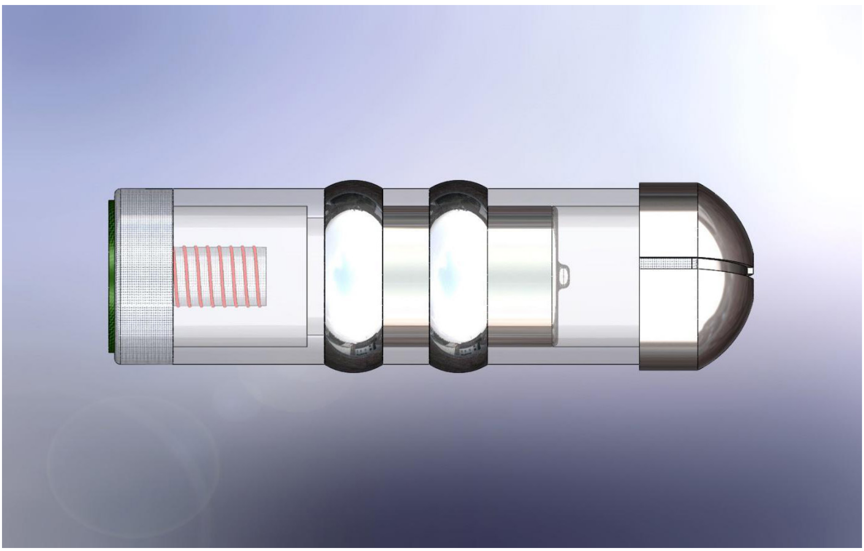


Figure 21.

APPENDIX – 03

Application (examples) of the electromagnetic resonance method for monitoring biochemical processes associated with the physiological activity of the human body consuming smart innovative confectionery products.

Operating principle of the electromagnetic resonance sensor.

The method involves creating an alternating electromagnetic field within the space occupied by the sample under investigation. This field acts as an intermediary between the resonant circuit and the test sample. On the one hand, the resonant circuit serves as the emitter of this field, while on the other hand it acts as the receiver (sensitive element) of the changes in the electromagnetic field introduced by the test sample. Under the influence of the external alternating electromagnetic field, various electrical phenomena may be induced in the test sample, depending on its nature. These phenomena may include linear and eddy conduction currents, linear and eddy displacement currents, as well as linear and eddy ionic currents (ordered movement of ions).

In accordance with the principles of electromagnetic fields, these electrical phenomena introduce distortions into the external alternating electromagnetic field. These distortions are detected by the solenoid of the electromagnetic resonance sensor (ER sensor).

The resonant circuit that incorporates this solenoid alters its behavior as if additional elements – a capacitor, an inductor, and a resistor – had been added to the circuit.

The combined capacitive, inductive, and active resistances constitute an additional impedance introduced into the system by the test sample, and it is this attribute that the ER sensor measures.

Changes in the parameters of the resonant circuit are reflected in changes to its frequency response characteristics, specifically through changes in the resonant frequency and resonant amplitude of the circuit. By analyzing these changes, it is possible to evaluate the impedance of the investigated sample.

As follows from the above description of the operating principle of the electromagnetic resonance sensor, the complex response obtained from the measured object can be utilized in all applications where eddy-current testing instruments are employed.

In addition, electromagnetic resonance sensors can be used in all applications involving impedance measurements of objects positioned between electrodes, such as radio-frequency impedance/material analyzers. The principal advantage of the ER sensor over the aforementioned methods is its significantly higher sensitivity – at least an order of magnitude greater. This enhanced sensitivity is achieved through the use of a resonant circuit in its most reduced form, consisting solely of an inductive coil that utilizes its own inter-turn capacitance to form the oscillatory circuit.

Single- and two-component applications.

This category includes all applications in which a single electromagnetic resonance sensor is sufficient and provides two output parameters as indicators: resonant frequency and resonant amplitude.

These applications include all forms of defect detection and inspection, as well as applications that monitor changes in one or two parameters, such as chemical–mechanical processing operations, film and coating deposition processes, moisture-content determination in materials and objects, water salinity measurement, and similar applications.

Construction of an analytical system.

For applications requiring the measurement and/or monitoring of changes in complex, multicomponent systems, it becomes necessary to construct an analytical system consisting of multiple sensors, each operating at its own unique working frequency. The initial data used for the construction of such a system for the chemical and/or physical analysis of the investigated object are spectra obtained using the methods of Electrochemical Impedance Spectroscopy (EIS) and/or Dielectric Relaxation Spectroscopy (DRS), employing the measurement equipment associated with these methods, including radio-frequency impedance/material analyzers, pulse generators, and similar instruments.

To construct these spectra, reference samples of the investigated object are used, containing known variations in chemical components or known variations in the physical properties of the object. The extent to which these reference samples comprehensively represent all possible states of the investigated object directly affects the measurement accuracy of the electromagnetic resonance analytical system.

Subsequently, using a chemometric* approach, the operating frequencies for the electromagnetic resonance sensors included in the analytical system are determined on the basis of the obtained spectra. The number of sensors within the system should be greater than or equal to the number of components under investigation.

The primary criteria for selecting the operating frequency are the maximum impedance variation corresponding to changes in the concentration of the investigated component or physical property, as well as the contrast of this response against variations caused by other components or physical properties.

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