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HIGH-EFFICIENCY ELECTROCHEMICAL PROCESSING TECHNOLOGIES. (Methods and Devices for Non-Contact Resonance Inspection in High-Efficiency Electrochemical Processing, Including High-Speed Metallization Technologies and Atmospheric Water Harvesting)

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Abstract

This article examines current approaches to the development of New Smart Manufacturing Technologies based on the integration of digital technologies, advanced composite materials, intelligent control systems, and modern engineering methodologies into contemporary manufacturing processes. Particular attention is given to the application of systems engineering principles for optimizing production processes and achieving the Ideal Final Result (IFR) in accordance with the concepts of the Theory of Inventive Problem Solving (TRIZ) and the Algorithm for Inventive Problem Solving (ARIZ).

The paper discusses the influence of digital transformation, intelligent manufacturing, and innovative engineering solutions on the evolution of industrial production systems. Special emphasis is placed on the development of integrated manufacturing ecosystems capable of improving production efficiency, product quality, resource utilization, process reliability, and operational sustainability. The article presents modern engineering approaches to the integration of intelligent monitoring systems, real-time process control technologies, non-contact inspection methods, artificial intelligence, and advanced manufacturing infrastructure into unified smart production environments. These technologies significantly expand the functional capabilities of manufacturing systems while increasing productivity, precision, automation, and decision-making efficiency.

The proposed concepts may serve as a scientific and engineering foundation for the development of next-generation smart manufacturing systems within the framework of Industry 4.0, digital transformation, and intelligent industrial ecosystems, providing new opportunities for innovation, sustainable industrial development, and continuous improvement of manufacturing technologies.

Keywords: *Electrochemical Processing; Electrochemical Resonance Spectroscopy; Non-Contact Resonance Inspection; High-Speed Metallization Technology; Atmospheric Water*

Harvesting; Advanced Composite Materials; Ideal Final Result (IFR); Theory of Inventive Problem Solving (TRIZ); Algorithm for Inventive Problem Solving (ARIZ); New Smart Manufacturing Technologies; Intelligent Manufacturing Systems; Smart Production Ecosystems; Digital Manufacturing; Real-Time Process Monitoring; Non-Contact Inspection Technologies; Innovative Engineering Solutions; Industrial Digital Transformation; Production Process Optimization; Advanced Manufacturing Infrastructure; Industry 4.0.

1. Introduction

At the present stage of industrial development, manufacturing processes are increasingly characterized by the comprehensive integration of digital technologies, intelligent control systems, and advanced composite materials into conventional production methods. Under these conditions, it is essential to utilize these technological advancements effectively and to fully exploit the engineering advantages they provide in achieving the Ideal Final Result (IFR).

As established by the classical principles of the Theory of Inventive Problem Solving (TRIZ) and its further development through the Algorithm for Inventive Problem Solving (ARIZ), innovative system-oriented approaches to manufacturing provide a comprehensive set of engineering tools that, when applied in combination, enable production systems to approach the Ideal Final Result most appropriate for a particular technology, manufacturing process, or engineering device.

The emergence of new technological components, digital engineering solutions, and advanced manufacturing concepts has made it possible, through appropriate system integration and carefully selected implementation strategies, not only to redefine the concept and evaluation criteria of the Ideal Final Result but also to refine its engineering characteristics in accordance with contemporary manufacturing requirements.

In the context of the globalization of industrial production and the transition of technologically advanced economies toward innovation-driven models of development, it has become necessary to reconsider both the organizational principles governing manufacturing systems and the strategic objectives that define modern production processes.

In several industrialized countries, this new concept of manufacturing – integrating the latest technological achievements across every stage of production and throughout the development of manufacturing equipment – has become known as New Smart Manufacturing Technologies.

Practical experience gained during the design, development, and implementation of smart manufacturing systems demonstrates that these technologies exhibit a continuous tendency toward expanding the application of original engineering solutions to increasingly complex production environments.

This expansion follows a progressive, multidirectional pattern, gradually extending beyond primary manufacturing operations to encompass numerous supporting processes, including monitoring, quality assurance, process optimization, and production control.

A representative example is the widespread adoption of **real-time non-contact inspection** technologies, which constitute one of the key elements of intelligent manufacturing systems. These technologies fundamentally transform conventional inspection methodologies by providing substantially higher measurement accuracy, operational reliability, and process efficiency while eliminating physical interaction with the object under investigation.

The practical implementation of this technology initially began in the agricultural sector, where increasing demands for efficient water management, particularly in large-scale irrigation projects, created the need for advanced non-contact monitoring systems.

Considering the immediate industrial demand, the first practical application focused on non-contact monitoring of pH (acidity) levels in water and aqueous solutions.

2. The principal characteristics of the proposed non-contact resonance-based pH monitoring technology include:

- the measurement range for pH determination in water and aqueous solutions is not limited by the operating

principles of the non-contact resonance inspection method;
- measurement accuracy can be adjusted according to specific application requirements, with a minimum resolution of **0.1 pH units**, consistent with internationally accepted measurement standards;
- measurement accuracy is independent of the concentration of organic compounds present in the liquid and is unaffected by the chemical aggressiveness of the aqueous solution, since all inspection procedures are performed remotely without direct physical contact with the monitored medium.

Since irrigation systems account for the largest consumption of water and typically involve the introduction of fertilizers and other chemical additives, the next stage of technological development focused on **non-contact monitoring of nutrient and fertilizer concentrations** in irrigation solutions.

When the composition of the nutrient solution is known in advance, the integrated sensing system incorporates a corresponding number of **selective resonance sensors**, each individually configured to detect a specific chemical component within the solution.

The proposed system provides a measurement accuracy of approximately **0.5 mg/L** for individual chemical constituents.

Because the electrical conductivity of water and aqueous solutions is one of the principal indicators of water quality, the subsequent expansion of this technology involved the implementation of **non-contact monitoring of electrical conductivity**, thereby further extending the functionality of intelligent electrochemical process control systems.

3. Electrical Conductivity Monitoring of Water and Aqueous Solutions

The methodology for monitoring the electrical conductivity of water and aqueous solutions is based on principles similar to those employed for non-contact pH measurement.

For successful industrial implementation, a measurement accuracy of approximately **1 μS/cm** is considered sufficient for the majority of technological applications.

The logical continuation of this technological development was the introduction of **integrated non-contact quality assessment methods** for water and process liquids.

Integrated Quality Monitoring of Water and Aqueous Solutions

Two principal approaches are proposed for comprehensive quality monitoring.

The first approach utilizes a **single integrated resonance sensor** that provides an overall indication of the general quality characteristics of water or another liquid by generating a composite quality parameter.

The second approach employs a **multisensor integrated module** consisting of a number of selective sensors corresponding to the required monitoring parameters. Each sensor is individually configured to monitor a single physicochemical parameter or the concentration of a specific component.

The successful implementation of this stage of technological development established the basis for the subsequent expansion of non-contact resonance monitoring technologies toward the determination of **heavy metal concentrations** in water and aqueous solutions.

4. Monitoring of Heavy Metal Concentrations in Water and Aqueous Solutions

Heavy metal monitoring may be performed using either a **generalized** or a **selective** measurement approach.

In the generalized configuration, the sensor module provides an indication of the overall presence of heavy metals within the monitored liquid.

In the selective configuration, the integrated sensor module incorporates individually tuned resonance sensors, each designed to detect and quantify a specific heavy metal.

The integrated sensing platform may simultaneously incorporate additional sensors for comprehensive monitoring of overall water quality, enabling the simultaneous evaluation of multiple physicochemical parameters within a single measurement system.

Since organic compounds are widely used in numerous industrial process solutions, the next stage in the evolution of non-contact resonance technologies involved the development of methods for monitoring **organic**

compound concentrations in technological aqueous solutions.

5. Monitoring of Organic Compound Concentrations in Water and Aqueous Solutions

Monitoring of organic substances may be performed either as a **total organic concentration measurement**, representing the cumulative concentration of all organic compounds present, or as a **selective analysis** of individual organic components.

For selective measurements, the integrated resonance sensor module incorporates individually calibrated sensors dedicated to each target organic compound.

Because the proposed measurement technique operates without direct contact with the monitored liquid, it eliminates contamination of the sample and minimizes measurement errors associated with conventional contact-based analytical methods.

Although numerous conventional techniques are available for temperature measurement, the proposed non-contact resonance method provides significant advantages for modern industrial production lines by enabling continuous **active temperature monitoring** without requiring the insertion of temperature probes into electrochemical reactors or other complex chemical processing equipment.

6. Temperature Monitoring of Water and Aqueous Solutions

The methodology for non-contact temperature monitoring is based on principles similar to those employed for electrical conductivity measurements.

The proposed technology enables continuous real-time monitoring while eliminating direct interaction between the sensing elements and the monitored medium.

For advanced manufacturing processes, particularly semiconductor fabrication and **photolithography technologies** involving silicon wafers, the **dielectric permittivity** of water and process solutions represents one of the most critical technological parameters affecting process stability and product quality.

Consequently, the next stage of technological development focused on extending non-contact resonance monitoring methods to the determination of the **dielectric permittivity** of water and aqueous solutions.

7. Monitoring of the Dielectric Permittivity of Water and Aqueous Solutions

The monitoring methodology for dielectric permittivity is analogous to that employed for determining the concentration of organic compounds in water and aqueous solutions.

All measurements are performed using selectively configured resonance sensors or integrated sensor arrays mounted externally on the pipeline surface or supplied as a dedicated pipeline section designed for installation within an existing piping system.

During project implementation, specialized software will be developed to identify and process resonance sensor signals, enabling accurate interpretation of monitored physicochemical parameters and determination of their concentrations within water and aqueous solutions.

The project also предусматривает the development of a standardized range of sensor configurations suitable for installation on pipelines with diameters ranging from 10 mm to 120 mm.

In addition, sensor manufacturing technology will be optimized to achieve economically viable production costs for integrated water-quality monitoring systems intended for agricultural and industrial applications.

Further refinement of sensor designs and monitoring methodologies has led to the concept of a specialized non-contact analytical instrument capable of verifying the compliance of drinking water with environmental regulations and public health standards through comprehensive real-time quality assessment.

8. Applications of the Non-Contact Instrument for Verifying Compliance of Drinking Water with Quality Standards

The proposed instrument has two principal configurations. The first configuration is designed for permanent installation directly on the water pipeline immediately upstream of the consumer tap within residential buildings. The second configuration is a portable device intended for rapid testing of drinking water samples collected directly from the tap into a dedicated pipeline section equipped with the integrated resonance sensor.

Both versions of the instrument feature a compact, ergonomic, and functional design. The housing is manufactured from engineering-grade polymeric materials, primarily polyvinyl chloride (PVC), providing durability, ease of operation, and suitability for continuous domestic use.

The operating principle of both configurations is based on **comparative resonance analysis**, in which the signal generated by the monitored water sample is continuously compared with a previously established reference resonance signature.

The reference signal is obtained from water that fully complies with applicable drinking water quality standards. The resonance sensor is capable of detecting extremely small deviations from this reference signal.

The estimated detection thresholds are as follows:

- heavy metals: approximately 5×10^{-9} g/L;
- radioactive isotopes: approximately $1 \times \times 10^{-12}$ g/L;
- hardness salts and silicates: approximately 1×10^{-6} g/L;
- organic acids, phenolic compounds, surfactants, detergents, and mineral fertilizer residues: approximately $1 \times \times 10^{-7}$ g/L.

All concentrations are expressed per one liter of water.

The proposed instrument is not intended to selectively identify every individual contaminant. Instead, owing to its exceptionally high sensitivity, it provides an integrated assessment of water quality and detects contamination levels approaching approximately 50% of the maximum permissible concentrations considered potentially hazardous to human health. Such performance enables continuous domestic monitoring of drinking water quality and allows preventive measures to be taken before contaminant concentrations reach hazardous levels.

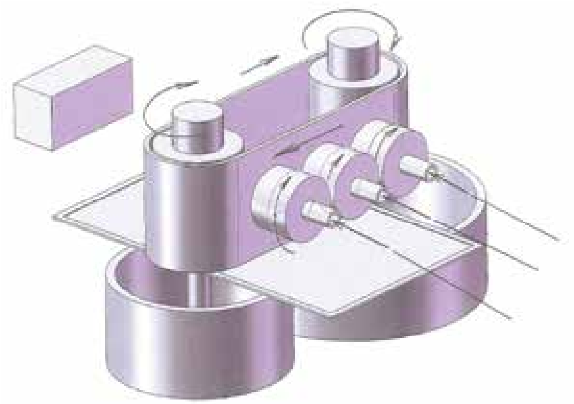
Public health authorities in many developed countries recommend continuous monitoring of drinking water quality. However, the widespread implementation of this recommendation has been limited by the absence of reliable, accurate, user-friendly, and economically affordable monitoring instruments suitable for large-scale domestic application.

The proposed instrument configurations are designed to comply with applicable safety requirements governing both construction materials and operational performance.

Both versions are well suited for industrial production and do not require specialized manufacturing technologies. Consequently, they can be manufactured efficiently by small and medium-sized enterprises while maintaining competitive production costs.

This manufacturing approach also enables **regional assembly**, allowing final assembly to be performed close to the target markets. Such decentralization reduces transportation costs, minimizes warehousing requirements, and facilitates rapid product distribution.

Figure 1.



Block Diagram of a Seawater Desalination Module Utilizing High-Speed Electrochemical Salt Deposition onto a Moving Porous Cathode Manufactured from Carbon–Carbon Composite Fabric

As illustrated by the three-dimensional model of the proposed seawater desalination module, seawater is supplied to three rotating anodes, through which it is uniformly distributed onto a moving porous cathode manufactured from carbon–carbon composite fabric.

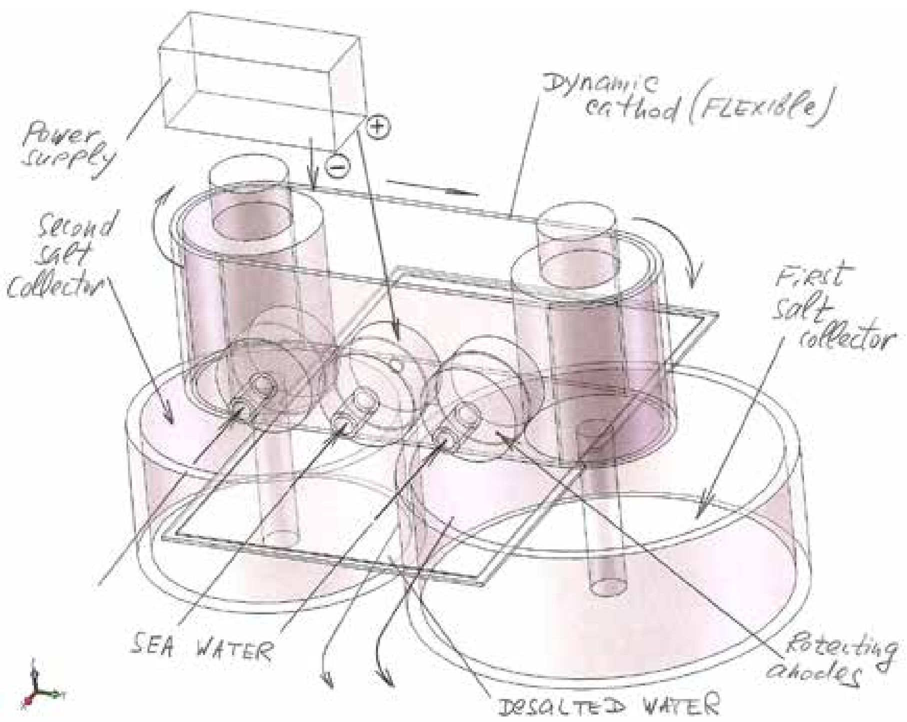
The module performs a complete cycle of high-speed electrochemical salt deposition, during which dissolved salts contained in seawater, acting as a natural electrolyte, are continuously deposited onto the moving conveyor-type cathode.

As the cathode conveyor passes around the drive drums, the deposited salt is mechanically separated from the cathode surface and collected in a dedicated salt collection chamber.

This technology addresses one of the principal limitations of conventional reverse osmosis (RO) desalination systems, namely the discharge of highly concentrated brine back into the marine environment after desalination. In the proposed electrochemical process, dissolved salts are recovered directly as a solid product, thereby significantly reducing the environmental impact associated with concentrated brine disposal.

Furthermore, unlike membrane-based reverse osmosis technologies, the proposed approach enables the development of compact, autonomous, and modular desalination units with relatively low production capacities tailored to local requirements. For example, a single module may be designed to produce approximately 50 m^3 of desalinated water per hour, providing an efficient solution for decentralized water supply systems, industrial facilities, coastal infrastructure, and remote regions requiring reliable freshwater production.

Figure 2.



Conceptual Model of a Seawater Desalination Module Based on High-Speed Electrochemical Salt Deposition with Complete Recovery of Salt in Solid Form

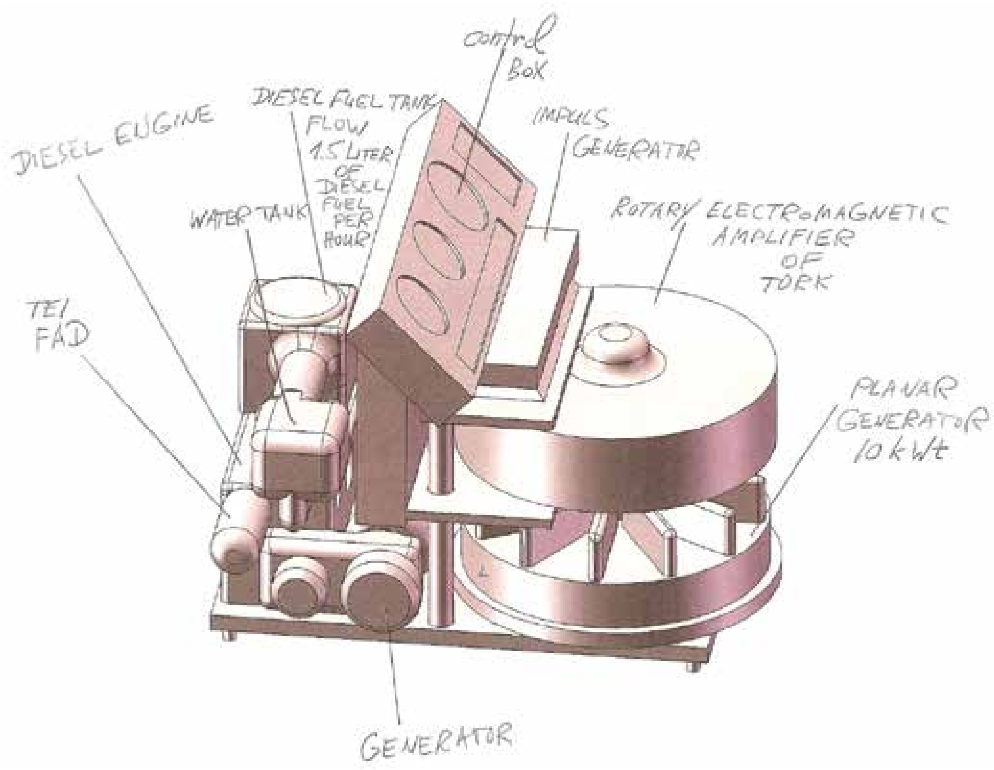
Figure 2 illustrates the conceptual design of a seawater desalination module utilizing high-speed electrochemical salt deposition, enabling the complete recovery of dissolved salts from seawater in dry solid form.

As discussed previously, the application of high-speed electrochemical coating technologies, originally developed for automated production lines and flexible manufacturing modules in the microelectronics industry, makes it possible to create an entirely new generation of engineering systems operating at a significantly larger industrial scale. This technological transition demonstrates that innovative manufacturing principles developed for one industrial sector can be successfully adapted to fundamentally different technological applications.

The proposed desalination technology represents a practical example of how engineering concepts originating in precision manufacturing can be integrated into large-scale water treatment systems through the principles of New Smart Manufacturing Technologies. Such integration facilitates the development of compact, modular, energy-efficient, and environmentally sustainable production systems capable of solving complex engineering problems using intelligent manufacturing approaches.

To further illustrate the progressive expansion of smart manufacturing principles, the following section examines the technological evolution of atmospheric water harvesting systems, demonstrating how innovative engineering concepts can be systematically enhanced by incorporating the characteristic features of New Smart Manufacturing Technologies.

Figure 3.



Three-Dimensional Model of an Innovative Diesel Generator Module for Atmospheric Water Harvesting Systems

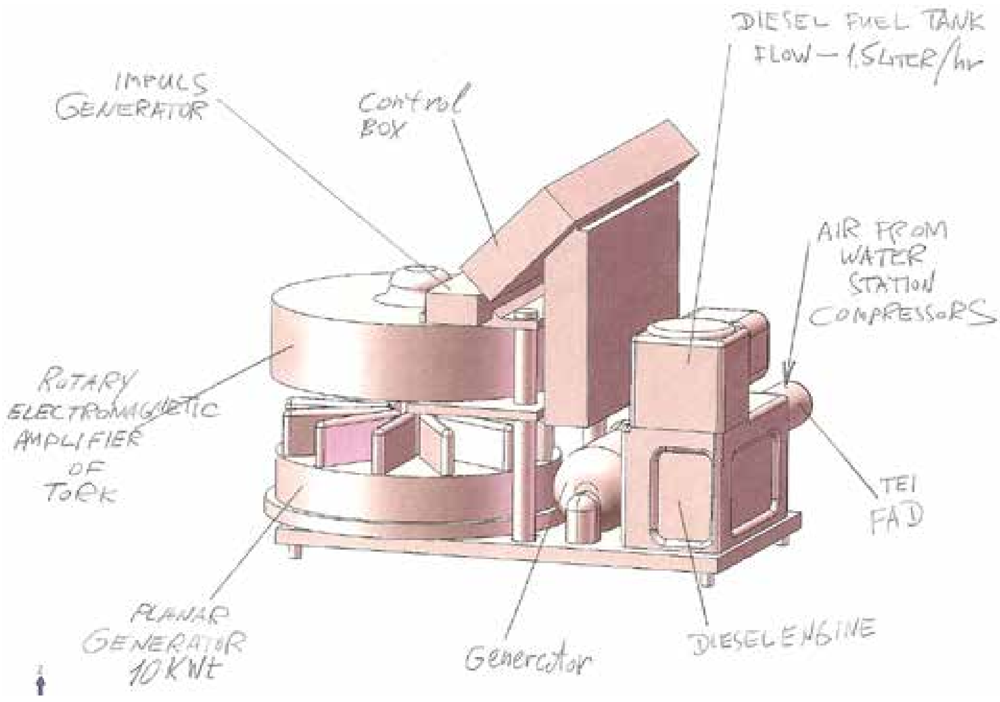
Figure 3 presents a three-dimensional model of an innovative diesel generator module incorporating several advanced engineering components that establish fundamentally new operating conditions and significantly improve the performance of industrial systems designed for atmospheric water harvesting through condensation.

The proposed diesel generator module is also designed to incorporate an automatic fuel emulsion preparation and control system, together with an online fuel homogenization system. The integration of these technologies provides a number of important engineering and operational advantages, including:

- reduction of nitrogen oxide (NO_x) emissions in the exhaust gases;
- decreased fuel consumption;
- increased engine torque;
- improved vibration stability of the power generation unit;
- reduced aerodynamic noise levels during operation.

The combination of these intelligent engineering solutions contributes to enhanced energy efficiency, improved environmental performance, increased operational reliability, and optimized overall performance of atmospheric water generation systems operating under the principles of New Smart Manufacturing Technologies.

Figure 4.



Three-Dimensional Model of an Intelligent Diesel Generator Module Incorporating Advanced Engineering Technologies

Figure 4 presents a three-dimensional model of an advanced diesel generator module integrating several of the innovative engineering technologies described above, including a planar electrical generator and a rotary electromagnetic pulse amplifier.

The diesel engine incorporated into the module is specifically designed to operate using either conventional diesel fuel or a water-fuel emulsion. The emulsion is prepared using water produced by the atmospheric water generation system, while the electrical energy required for the operation of the water production unit is supplied by the diesel generator itself, thereby forming an integrated autonomous energy and water production system.

The novelty of this comprehensive engineering solution lies in several innovative structural, functional, and system-integration aspects.

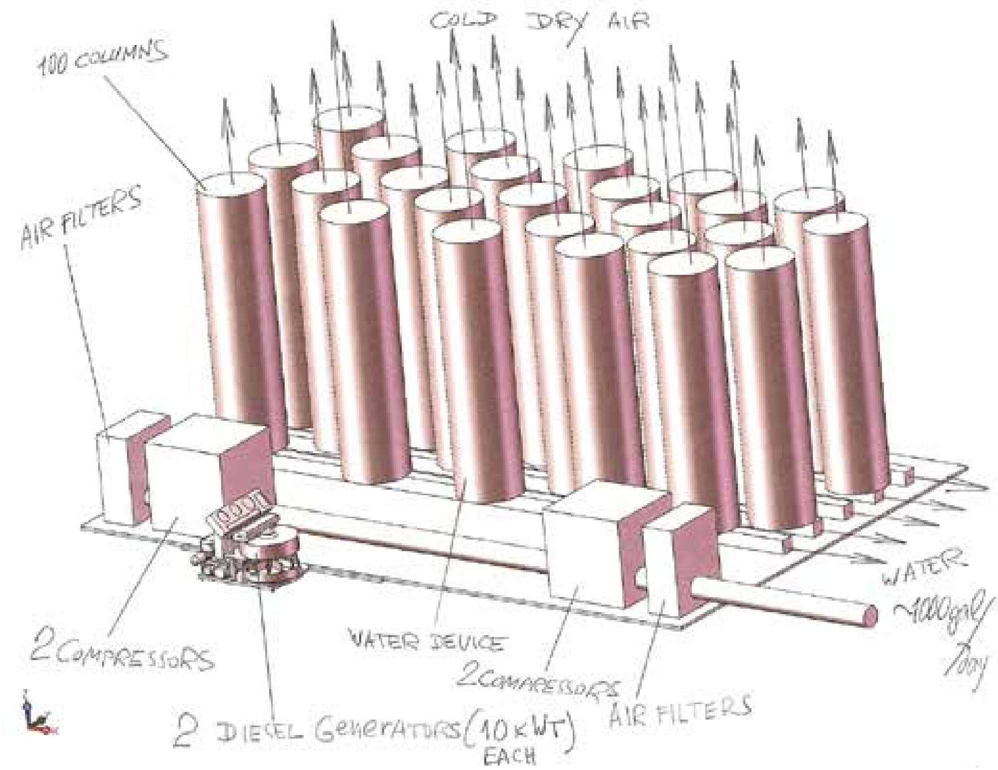
The intelligent characteristics of the proposed technology result from the synergistic combination of multiple independent engineering innovations. Each patented component provides specific technical advantages, while their integrated application creates a comprehensive package of innovative benefits that significantly exceed the performance of conventional technological solutions.

For example, the application of a rotary torque amplifier operating according to the Otto principle, in combination with a planar electrical generator capable of maintaining high efficiency even at relatively low rotational speeds, enables an increase in power generation of at least 10%.

Furthermore, the use of a water-fuel emulsion in the diesel engine substantially reduces exhaust emissions while simultaneously decreasing fuel consumption by at least 10%.

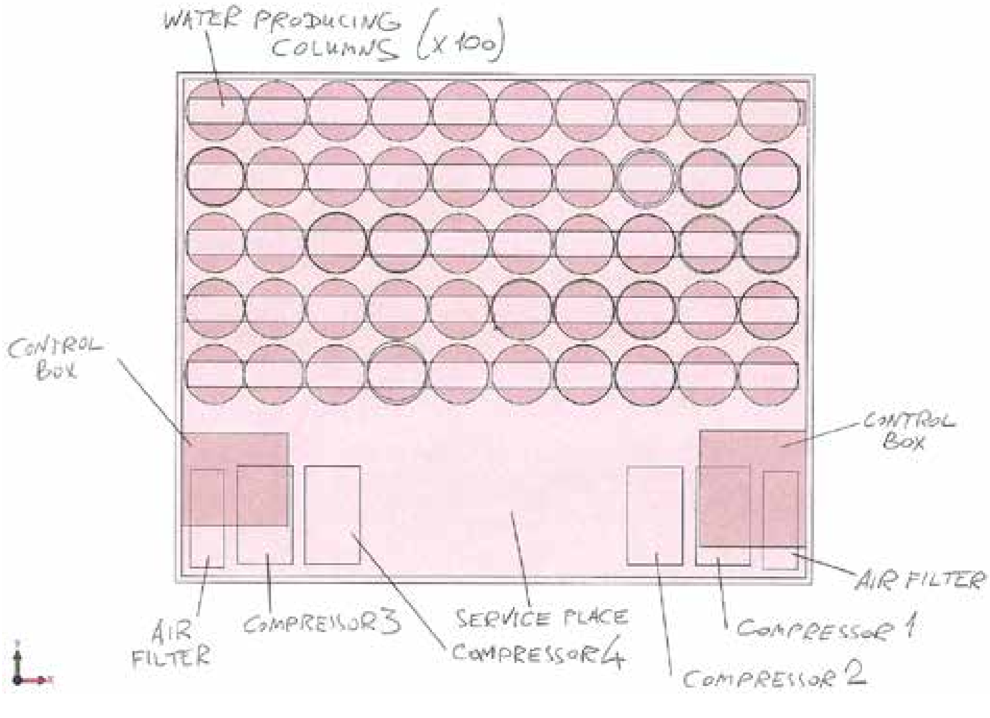
Further development of this integrated system may include the introduction of additional compressed air into the fuel emulsion preparation process, thereby transforming the conventional incompressible emulsion into a compressible air-fuel-water emulsion. This engineering approach offers additional improvements in combustion efficiency, further reductions in fuel consumption, and a significant decrease in nitrogen oxide (NO_x) emissions, resulting in enhanced environmental performance and overall operational efficiency of the power generation system.

Figure 5.



The figure presents a three-dimensional model of an industrial modular installation for water production by the condensation of atmospheric moisture.

Figure 6. *Figure 6 presents an industrial modular atmospheric water generation system based on the condensation of atmospheric moisture, shown in plan view*



The proposed installation is designed to utilize **universal diesel generator modules**, the operating principles and technical advantages of which have been described in the preceding sections.

Figure 7. *Illustrates a new system layout providing the possibility of vertical aggregation and a substantial reduction in the production floor area required for the installation of the complete equipment incorporated into the water production complex, while providing reserve capacity for supplying surplus electrical energy to external consumers*

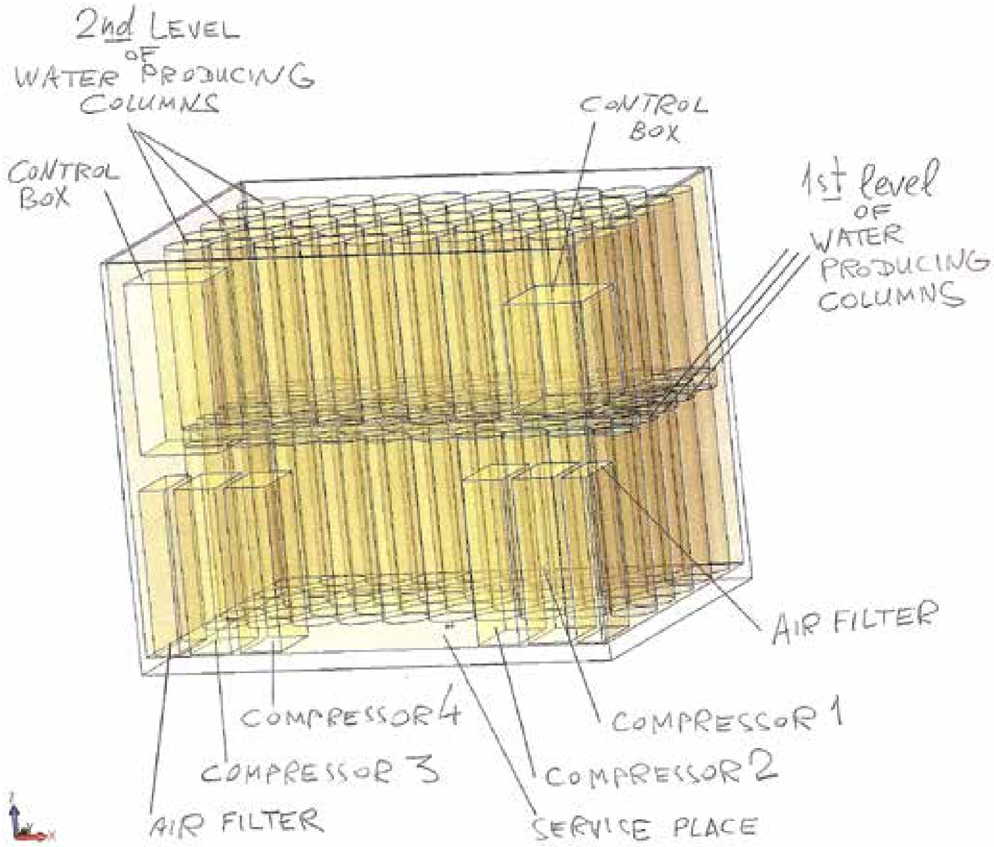
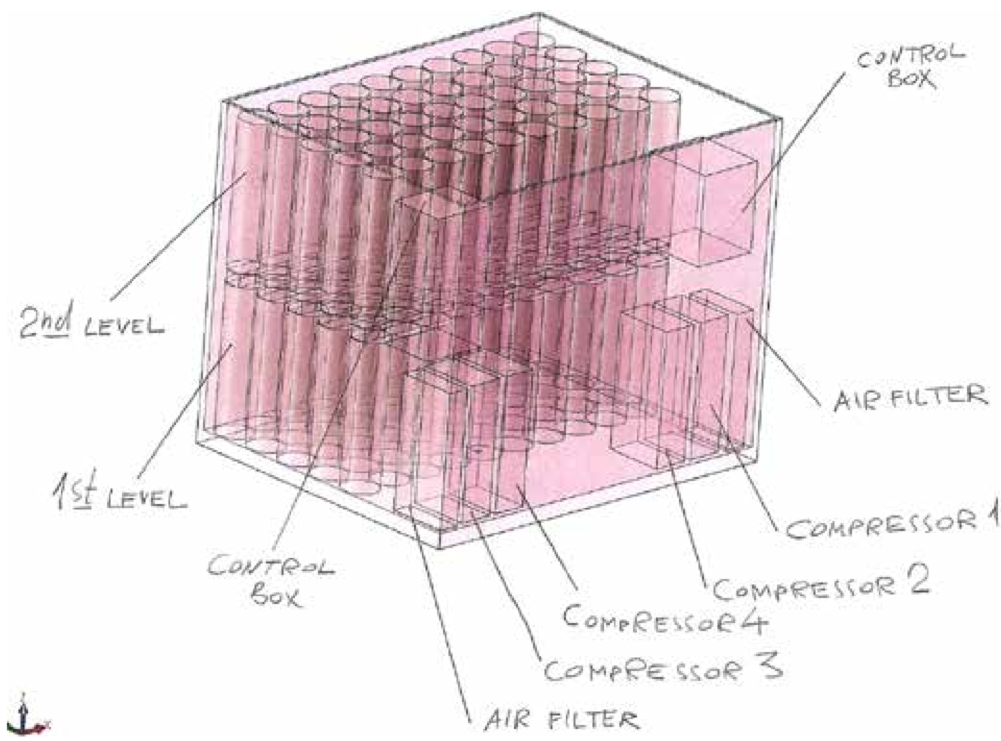


Figure 8. *Illustrates the architecture of a two-level atmospheric water generation system, identifying its principal structural and functional components*



As demonstrated by the system models, the application of **New Smart Manufacturing Technologies** makes it possible to develop industrial atmospheric water generation systems characterized by **minimum specific energy consumption** and **minimal environmental impact**.

Through the application of comprehensive computer-aided modeling, the proposed system can be designed with optimally selected engineering and operational parameters. Furthermore, these parameters may be automatically optimized in accordance with external operating conditions, including atmospheric pressure at the installation site, ambient air humidity, ambient temperature, and other environmental factors that influence system performance.

The range of simulated parameters and engineering configurations may be further expanded to include numerous additional operating variables and technical characteristics of the individual system components.

In addition to optimizing the principal operating parameters, digital modeling enables the development of highly accurate schedules for preventive maintenance, technical servicing, replacement of wear components and mechanical assemblies, as well as quality control procedures for the produced water, thereby improving the overall reliability, operational efficiency, and lifecycle management of the installation.

In conclusion, it should be emphasized that New Smart Manufacturing Technologies have a significant positive impact on the comprehensive development of virtually all manufacturing systems, industrial equipment, and integrated engineering solutions.

The practical implementation of these technologies demonstrates that the integration of intelligent engineering principles, digital manufacturing technologies, advanced composite materials, and automated control systems substantially expands the functional capabilities, operational efficiency, and technological flexibility of modern production facilities.

References

Device and Method for the Extraction of Metals from Liquids. United States Patent Application US 20100224497 A1, September 9, 2010.

Magnet Assembly with Reciprocating Core Member and Associated Method of Operation. United States Patent US 6,188,151 B1, February 13, 2001.

Rotary Valve Internal Combustion Engine. United States Patent US 9,951,685 B2, April 24, 2018.

Rotary Internal Combustion Engine with Exhaust Purge. United States Patent US 9,926,842 B2, March 27, 2018.

Power Transmission Device and Lock-Up Device for Torque Converter. United States Patent US 9,915,329 B2, March 13, 2018.

Naruoka, T., et al. *Rotary Unit of Supercharger for Engine and Balance Adjustment Method Thereof*. United States Patent US 9,945,288 B2, April 17, 2018.

Dedicated Exhaust Gas Recirculation System. United States Patent US 9,932,939 B2, April 3, 2018.

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