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NEW SMART MANUFACTURING TECHNOLOGIES. (Methods and devices for non-contact electromagnetic resonance testing; various high-efficiency electrochemical processing methods, including high-speed metallization technology and water extraction from air)

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Abstract

The article examines the development of New Smart Manufacturing Technologies based on the integration of digital solutions, innovative materials, and advanced production methods. It demonstrates how TRIZ principles and the pursuit of the Ideal Final Result can improve manufacturing systems and processes. Particular attention is given to intelligent technologies, including non-contact electromagnetic resonance monitoring of water and process solutions in real time.

The article also presents practical applications such as seawater desalination through high-speed electrochemical salt deposition and water production from atmospheric air. It concludes that the integration of digital modeling, intelligent sensor systems, and innovative engineering solutions enhances efficiency, sustainability, and automation while creating new opportunities for modern industrial development.

Keywords: *Technologies; Smart technologies; Smart manufacturing technologies; Current level of manufacturing process development; Classical methods of processing raw materials, digital technologies, and new composite materials; Non-contact electromagnetic resonance testing; High-speed metallization technology; The process of achieving the ideal final result; Auxiliary materials and tools whose combined use makes it possible to approach the achievement of an ideal final result; Globalization of manufacturing processes; The expansion of areas of application follows a fan-shaped pattern and gradually spreads to numerous related processes, including both manufacturing and all auxiliary operations and processes*

At the current stage of manufacturing process development, characterized by the extensive integration of digital technologies and new composite materials into traditional methods of raw material processing, it is extremely important to manage these additions properly and to fully utilize the advantages they provide in the pursuit of the Ideal Final Result.

As is well known from the classical Theory of Inventive Problem Solving (TRIZ) and its further development – the Algorithm for Inventive Problem Solving (ARIZ) – an innovative approach to the systematic development of manufacturing processes offers a number of tools whose combined application makes it possible to approach the achievement of an Ideal Final Result that is as close as possible to the ideal inherent in each technology or device.

The emergence of new components in process schemes and fundamentally innovative solutions has made it possible, through proper integration methods and carefully selected implementation options, first, to reformulate the very concept and criteria of the Ideal Final Result and, second, to refine the criteria and characteristics that define this concept.

Under the conditions of globalization of manufacturing processes and the transition of the world's most developed economies to innovation-driven models of development and operation, it must be acknowledged that, in order to navigate new and not always positive production trends correctly, it is necessary to reconsider both the principles governing the organization and formation of manufacturing processes and the declared goals and objectives of those processes.

In some countries, this new approach to production organization, which incorporates the latest achievements and opportunities for improving all stages of manufacturing as well as the requirements for the development of production equipment, has been termed **New Smart Manufacturing Technologies**.

As demonstrated by the first practical experiences in the formation, design, and, most importantly, implementation of so-called new smart manufacturing technologies in industrial complexes, this process tends to gradually expand the application of original innovative technical solutions to an increasing number of complex production tasks.

This expansion follows a fan-shaped pattern, gradually spreading to numerous related processes, including both manufacturing operations and all auxiliary operations and processes, such as quality control.

As an example, one may cite the gradual spread of real-time non-contact monitoring technologies and principles, which can confidently be classified as smart technical solutions that fundamentally transform monitoring techniques and technologies while continuously improving measurement accuracy.

The implementation of this technology began in agriculture, where the need for such monitoring was driven by new requirements and increasing demands on water quality, particularly in irrigation projects.

Due to its high relevance and demand, the implementation process initially focused on monitoring acidity levels.

1. Acidity level monitoring – the following key features were taken into account and considered:

The range of acidity level monitoring in water and aqueous solutions using non-contact resonance monitoring methods is unlimited.

The monitoring accuracy can be adjusted as required, but is no less than 0.1 acidity units in accordance with the accepted standard.

The monitoring accuracy does not depend on the concentration of organic substances in the water or aqueous solution, nor does it depend on the aggressiveness of the solution, since all monitoring operations are performed remotely without any contact with the monitored liquid.

Since the highest water consumption occurs in irrigation systems, where fertilizers and other chemical reagents are introduced into the water, the next expansion of the technology's application involved monitoring the concentration of nutrients and fertilizers in irrigation solutions.

If the substances to be introduced into the nutrient solution are known in advance, the integrated sensor includes a number of selective sensors corresponding to the number of components in the solution.

Each of these sensors is configured to monitor a single component.

The measurement accuracy is within 0.5 milligrams per liter.

Since the conductivity of water and aqueous solutions largely determines their quality, the next stage of technology deployment involved its application to the monitoring of water and aqueous solution conductivity.

2. Water and aqueous solution conductivity monitoring.

Conductivity monitoring is similar to acidity level monitoring.

For successful implementation, a measurement accuracy within 1 microSiemens is sufficient.

A logical continuation of the implementation process was the development of methods and techniques for comprehensive integrated quality monitoring of liquids and aqueous solutions.

3. Comprehensive integrated quality monitoring of liquids and aqueous solutions.

Two methods are proposed for comprehensive monitoring.

The first method involves the use of only one sensor, which provides an indication of an integrated water or liquid quality parameter.

The second method involves installing a number of sensors corresponding to the number of monitored parameters or materials, with each sensor monitoring the condition or concentration of only one specific material.

The success of the third stage of technology deployment determined the strategy for its further expansion into the field of monitoring heavy metal concentrations in liquids and aqueous solutions.

4. Monitoring of heavy metal concentrations in liquids and aqueous solutions.

Monitoring can be carried out in a general mode; in this case, the sensor provides an indication of the presence of all metals in the water or aqueous solution.

Monitoring can also be performed selectively; in this case, the integrated sensor module must include sensors configured to monitor the concentration of each individual metal separately.

The sensor module may also include sensors for comprehensive monitoring of the condition and quality of water or aqueous solutions, providing simultaneous monitoring of all quality parameters.

Since organic substances are currently used as components in many water-based process solutions, a logical continuation of the expansion of non-contact measurement technology has been its further implementation in monitoring the level or concentration of organic substances in water-based process solutions.

5. Monitoring of the level or concentration of organic substances in aqueous solutions.

Monitoring of organic substance concentrations may be performed in a general mode, for example by measuring the total concentration of all organic materials and compounds in water or an aqueous solution.

Monitoring may also be selective; in this case, the integrated sensor module must include selective sensors configured for each individual organic component.

The methodology for monitoring biological components in water or aqueous solutions, due to the complete absence of contact during measurement, eliminates the possibility of measurement distortion.

Although there are many instruments and technologies available for temperature monitoring, the non-contact monitoring method makes it possible to implement an active temperature monitoring system in production lines of any complexity. Most importantly, it does not require the insertion of a temperature sensor into equipment such as an electrochemical reactor or any other complex chemical reactor.

6. Temperature monitoring of aqueous solutions.

Temperature monitoring of aqueous solutions is analogous to conductivity monitoring.

For the use of water and aqueous solutions in advanced manufacturing processes, and especially in photolithography production lines, including those involving silicon wafers, the dielectric permittivity parameter is of critical importance, particularly for automated process quality monitoring. Therefore, this group of technologies has been further extended to systems and methods for monitoring the dielectric permittivity of water and aqueous solutions.

7. Monitoring of the dielectric permittivity level of water and aqueous solutions.

Monitoring of dielectric permittivity is analogous to monitoring the level or concentration of organic substances in water and aqueous solutions.

All monitoring options are implemented using selectively configured sensors or groups of sensors installed on the outer surface of a pipeline or supplied as part of a pipeline section integrated into an existing pipeline.

During project implementation, software will be developed to identify sensor signals and interpret the concentration of the monitored parameter in water or an aqueous solution.

During the project, a range of sensor sizes will be developed for installation on pipes with diameters ranging from 10 to 120 millimeters.

The sensor manufacturing technology will also be optimized to achieve an acceptable cost level for comprehensive water and aqueous solution quality monitoring systems used in agriculture.

Further development of sensor designs and monitoring methodologies has made it possible to consider the creation of applications for a specialized device intended for non-contact verification of drinking water compliance with environmental and public health standards.

8. Applications of a device for non-contact monitoring of drinking water compliance with standards.

The device is available in two main versions. The first version is intended for installation directly on a pipeline before a tap within residential premises. The second version is portable and is designed for taking a water sample from a tap into a section of pipeline on which the sensor is installed.

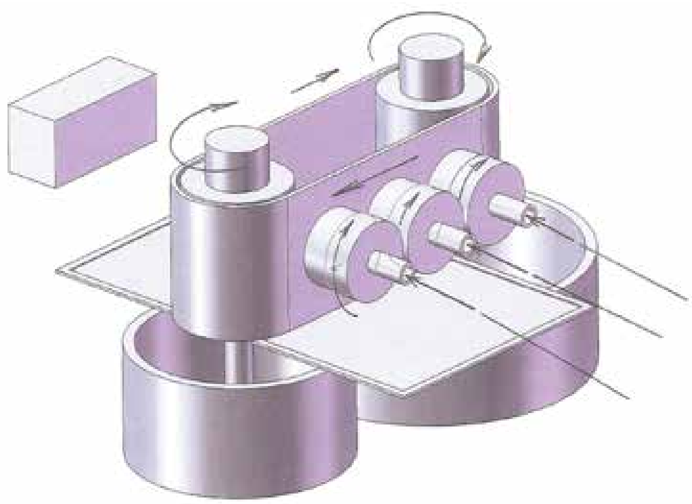
Both versions of the product feature a simple design, are manufactured from plastic, typically polyvinyl chloride (PVC), and are compact and easy to use.

The operating principle of both versions is based on comparing the reference signals of a resonance sensor with the signal obtained from a test measurement. The reference signal is obtained from water that fully complies with established standards. The sensor detects even the slightest deviations from the reference signal. The sensitivity threshold is 0.000000005 grams for metals, 0.000000000001 grams for radioactive isotopes, 0.000001 grams for hardness salts and silicates, and 0.0000001 grams for organic acids and compounds, including phenols, traces of surfactants, detergents, and mineral fertilizers. All specified concentrations are calculated per one liter of water.

The device does not selectively identify or record each individual contaminant or impurity. However, due to its high sensitivity, it can detect contamination levels corresponding to 50% of the threshold considered hazardous to human health in drinking water. This high level of accuracy allows continuous monitoring of water quality for domestic use and enables corrective measures to be taken before contamination reaches dangerous levels.

Public health standards in most developed countries recommend continuous water quality monitoring. The implementation of this requirement is often limited by the lack of reliable, user-friendly, and accurate devices available at a price suitable for widespread adoption.

Figure 1. *Block diagram of a seawater desalination module utilizing the method of high-speed electrical salt deposition onto a moving permeable cathode made of a composite carbon-carbon fabric*



The proposed versions of the device fully comply with applicable standards, both in terms of the safety of the materials used and the effectiveness of their operation.

Both versions are easy to manufacture, do not require any special production technologies, and can be produced under the conditions of small-scale enterprises while maintaining an optimal price level.

This makes it possible to localize production and assembly near the point of sale, reducing transportation costs and enabling direct distribution without the need for warehouse storage, thereby minimizing associated expenses.

The foregoing demonstrates that the implementation of so-called smart elements of manufacturing technologies in one area and within one group of technologies immediately creates demand for their application in other areas and technological fields.

To further illustrate this phenomenon, an example is presented of the application of an innovative smart high-speed metallization technology as a core technology for seawater desalination, replacing the conventional technology based on reverse osmosis membranes.

As can be seen from the three-dimensional model of the seawater desalination module, water is supplied to three rotating anodes, through which it is delivered to a moving cathode made of carbon-carbon fabric.

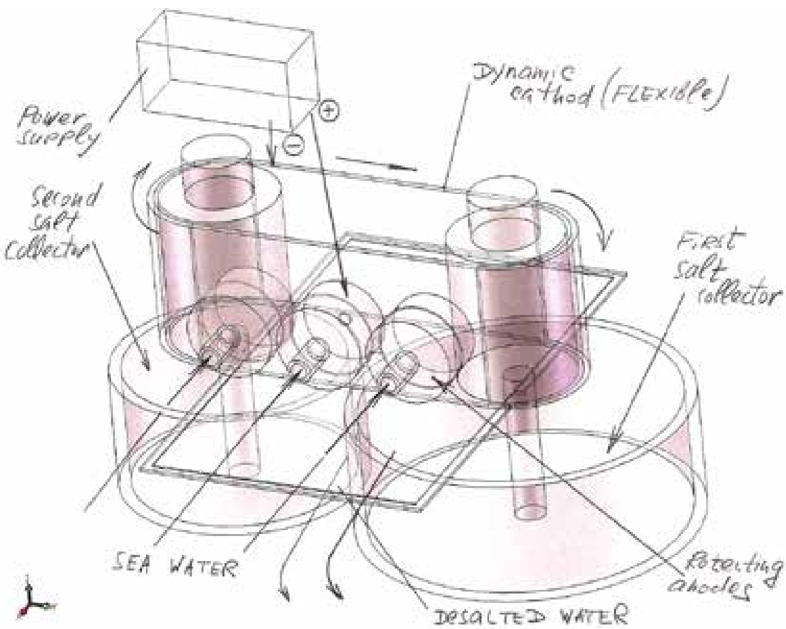
The module performs a complete cycle of high-speed electrical deposition of salt from seawater (a natural electrolyte) onto the conveyor-type cathode.

As the conveyor belt approaches the drums, the deposited salt falls from the cathode into a salt collection container.

This technology addresses one of the major challenges associated with reverse osmosis desalination, namely the discharge back into the sea of highly concentrated brine containing the salt removed from the desalinated water.

In addition, unlike membrane-based reverse osmosis technology, this approach makes it possible to construct an efficient and autonomous desalination module with a capacity of, for example, 50 cubic meters of desalinated water per hour.

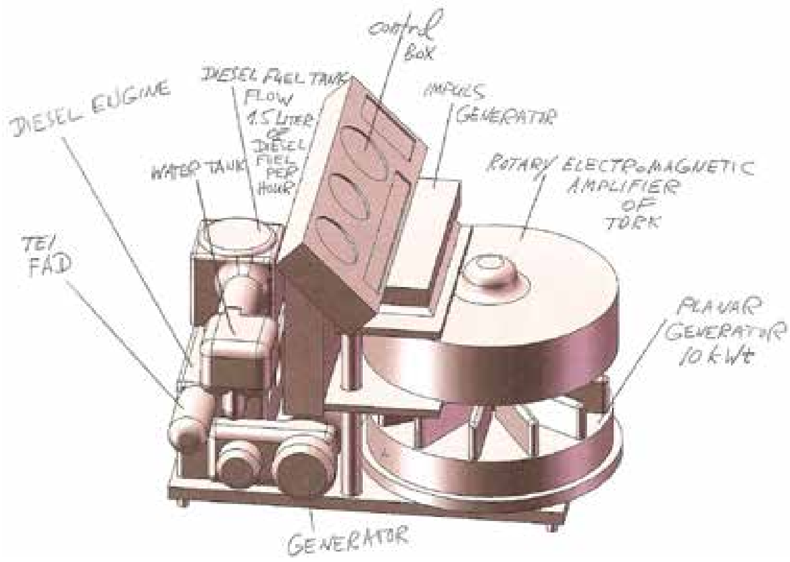
Figure 2. *The figure shows a model of a seawater desalination module employing the method of high-speed electrical deposition with complete recovery of the salt contained in seawater in dry form*



As noted above, the application of innovative high-speed electrolytic coating technology (characteristic of automated production lines and flexible automated manufacturing modules in microelectronics) makes it possible to create a new group of innovative products in a scale and size range previously unavailable to the market. This, in principle, confirms the validity of the concept advocating the widespread adoption of manufacturing system design principles based on the methods of New Smart Manufacturing Technologies.

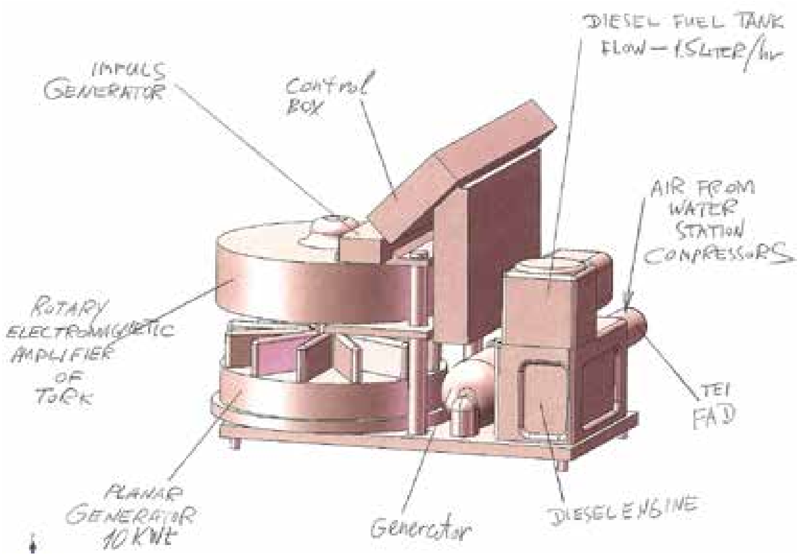
To further illustrate this concept, let us consider a sequence of developments in air-to-water production technology aimed at incorporating the characteristic features inherent in **New Smart Manufacturing Technologies**.

Figure 3. *The figure presents a three-dimensional model of an innovative diesel generator module containing several innovative components that create entirely new operating conditions and performance outcomes in water production systems based on atmospheric moisture condensation*



The diesel generator module is also adapted for use with an automatic emulsion preparation system and online fuel homogenization. In the presented configuration, this combination provides several important additional benefits, including reduced nitrogen oxide emissions in the exhaust gases, lower fuel consumption, increased torque output, improved vibration stability of the unit, and reduced aerodynamic noise levels.

Figure 4. *The figure presents a three-dimensional model of a diesel generator in which a number of the effective innovative technologies described above have been integrated, including a planar generator and a rotary electromagnetic pulse amplifier*



The diesel engine of such a module is adapted to operate on a fuel emulsion, with the emulsion being prepared using water produced by the installation itself, while the energy required for the installation is generated and supplied by this module.

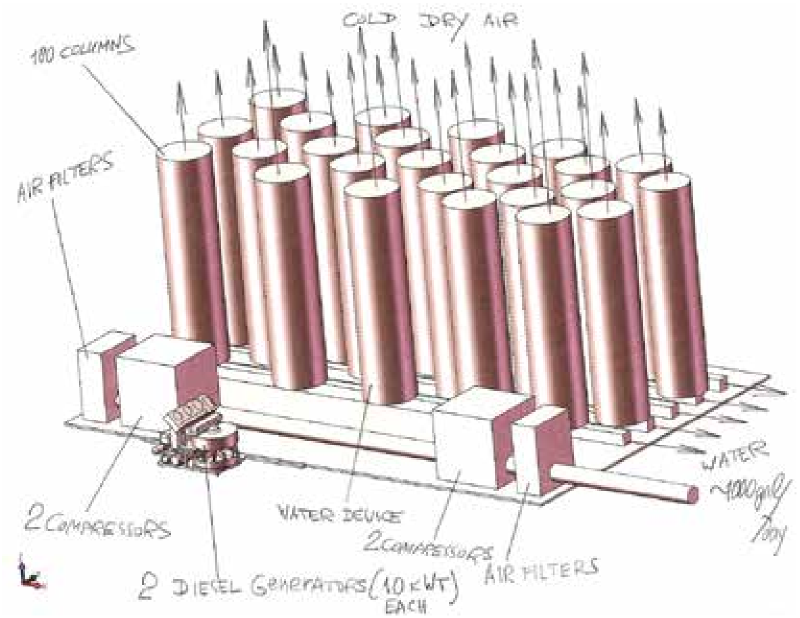
The novelty of this integrated technical solution lies in several design and configuration aspects.

The characteristics of the so-called smart technology are achieved through the combination of a number of diverse innovative elements. Their novelty is reflected in the application of multiple inventions, each of which individually, and all of which collectively, create a package of innovative advantages over conventional technologies.

For example, the use of a rotary torque amplifier operating according to the Otto principle in combination with a planar generator that maintains efficiency even at low rotational speeds makes it possible to increase power output by at least 10%. In addition, the use of a fuel emulsion in the diesel engine significantly reduces exhaust gas toxicity while also reducing fuel consumption by at least 10%.

As a further development of this system, additional air may be supplied to the emulsion preparation unit, transforming a conventional incompressible emulsion into a compressible emulsion. This provides additional fuel savings while significantly reducing the concentration of nitrogen oxides in the exhaust gases.

Figure 5. *The figure presents a three-dimensional model of an industrial modular installation for water production by means of condensation from atmospheric air*



The presented installation is intended to utilize universal diesel generators, the operating principles and advantages of which have been described above.

As can be seen from the system models, the application of so-called smart manufacturing technologies makes it possible to develop, for example, an industrial system for producing water from atmospheric air with minimal specific energy consumption and minimal environmental impact.

Thanks to the possibility of end-to-end computer modeling, such a system can be configured with optimal technical parameters and, when necessary, can optimally adapt these parameters to existing external factors such as atmospheric pressure at the installation site, ambient humidity, air temperature in the operating area, and similar conditions.

The list of modeled parameters and combinations of modeled objects may also include many additional characteristics and technical performance indicators of the system components.

In addition to the primary operating parameters of the system, modeling can provide the ability to develop highly accurate maintenance schedules, including preventive maintenance plans, replacement schedules for consumable parts and mechanisms, as well as quality control schedules for the water produced.

Figure 6. *The figure shows an industrial modular installation for water production by means of condensation from atmospheric air, plan view*

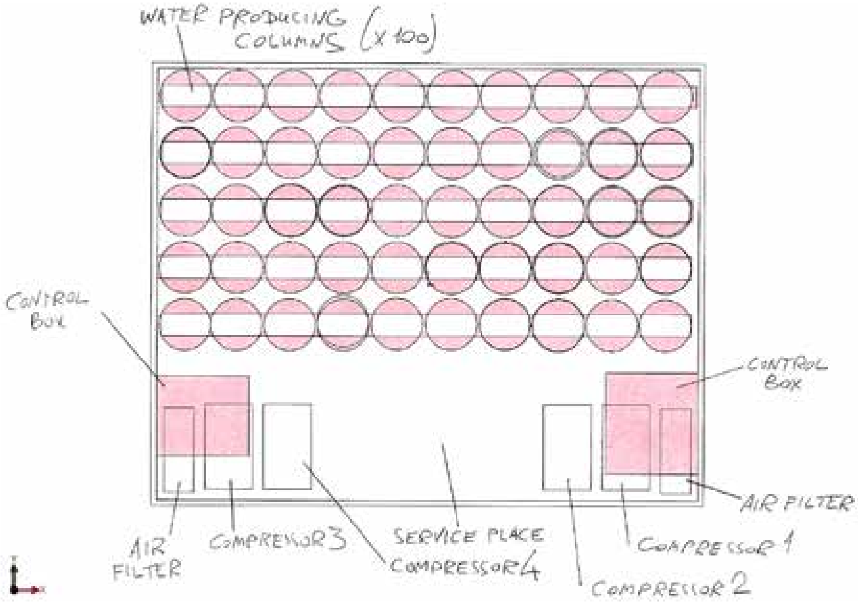
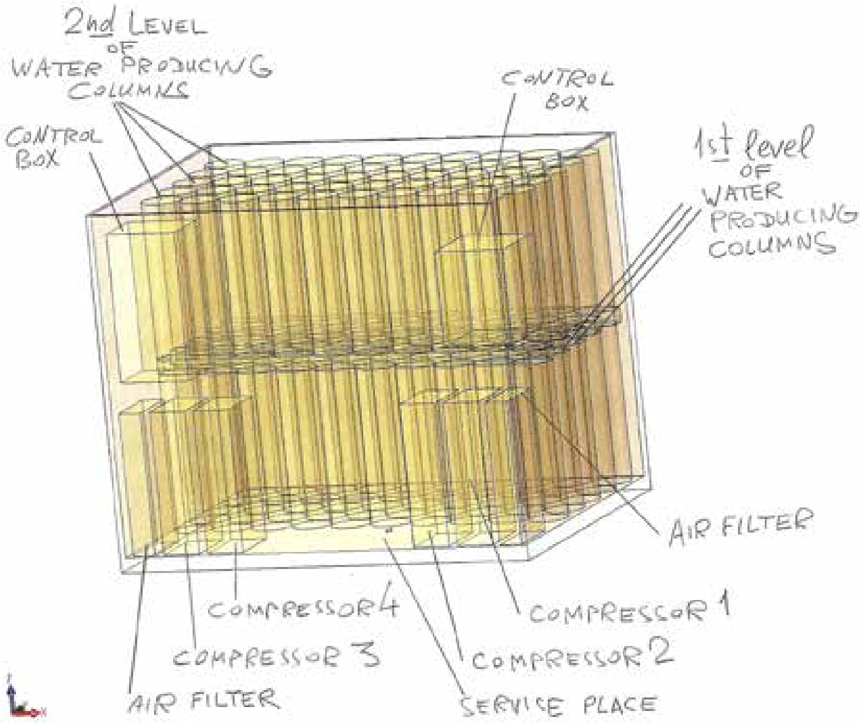
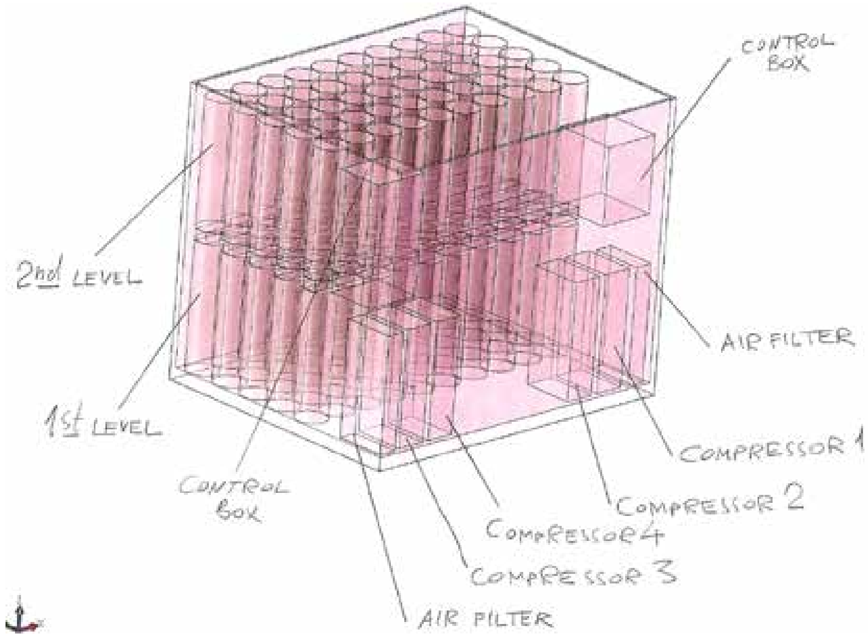


Figure 7. *The figure presents a new configuration option for vertical aggregation and a significant reduction in the production area required for the installation of this integrated equipment, which forms part of a water production complex and has reserve capacity for supplying surplus electrical energy to other consumers*



In conclusion, it can and should be noted that New Smart Manufacturing Technologies have a positive impact on the comprehensive development of virtually all manufacturing systems and equipment, as well as on their combinations and configurations developed through both vertical and horizontal integration.

Figure 8. *The figure shows the structure of a two-level system for producing water from atmospheric air, with the constituent components identified*



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