Device for automated magnetic pulse stimulation of plant production processes

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Abstract. Numerous studies of various physical factors show the promise of using pulsed magnetic fields in bioregulatory technologies to stimulate plant life and growth processes. As a result of exposure to garden strawberries with a low-frequency magnetic field, the quality of planting material improves, plant immunity increases, crop growth and development accelerates, the number and weight of berries increase. The article presents a developed automated device for magnetic pulse processing (MPP) of plants, considers the device, design and principle of its operation. The electrical circuit of the device and its technical characteristics are given. According to the results of a laboratory experiment, the magnetic field parameters of the working body of the device in the near zone of a flat spiral coil were established. The numerical value of the magnetic induction at a distance of 100 mm from the center of the coil is 8.3 mT.

1 Introduction

At present, in order to solve the problems of realizing the genetically potential productivity of crops, improving the environmental safety of products and the economic efficiency of agricultural production, high-precision, low-energy-intensive technologies based on the effects of various physical factors on living objects are becoming most urgent [1,2]. Physical factors such as electromagnetic fields, laser radiation, ultrasonic vibrations and others are widely used in various fields of science, including agricultural, in order to stimulate various biological processes of living organisms and activate plant production processes [3-5].

The most effective and less energy-intensive is to stimulate the development and growth of plants by changing the parameters of the magnetic field [6-9]. An analysis of the studies showed the high efficiency of external pulsed magnetic fields of low intensity (from 0.05 mT to 100 mT) during bioregulatory activation of production processes of garden strawberries [10-12]. Due to its high vitamin content, wild strawberry (Fragaria) is one of the most popular agricultural berry crops. Berries, in addition to sugars and organic acids, contain essential oils, tannins and dyes, salts of iron, phosphorus, calcium and trace elements. Strawberries are a valuable raw material for making jam, jam, syrups, juice, jelly, marmalade and dessert wines [13].

As a result of exposure to garden strawberries with a low-frequency magnetic field, the quality of planting material improves, plant immunity increases, crop growth and development accelerates, the number and weight of berries increase.

The effect of a magnetic field on a living organism is determined by such parameters as intensity (field strength, magnetic induction), gradient (rate of rise or fall of the field), vector (direction of field lines of force), exposure (duration of exposure), frequency (number of oscillations of the magnetic field per one second), the shape of the impulse (characteristic of the rise and fall of intensity), localization (spatial characteristic).

The practical application of magnetic pulse processing (MPP) technologies in crop production is constrained by the lack of technical solutions to ensure compliance with processing conditions in the field. To create specialized equipment and establish optimal exposure modes when implementing magnetic-pulse treatment of plants in industrial gardening, it is necessary to conduct scientific research and development work to substantiate the design, technical characteristics and operating modes of equipment for MPP plants.

2 Materials and Methods

As a result of the analysis of the instrument and hardware base and operating modes of various devices for magnetic pulse treatment of plants [14,15], an automated device was developed that allows controlled magnetic pulse treatment of garden plants in various modes (frequency, duty cycle, magnetic induction, exposure time etc.).

The main component of the MPP automated device is a microcontroller for controlling the supply of voltage to the working element (magnetic inductor - a flat spiral coil). Elements of the device's sensor system are connected to the microcontroller via pin connectors according to standard schemes: a laser distance sensor on one of the GPIO lines of the microcontroller, a touch screen to the GPIO line on the Uart protocol (Fig. 1).

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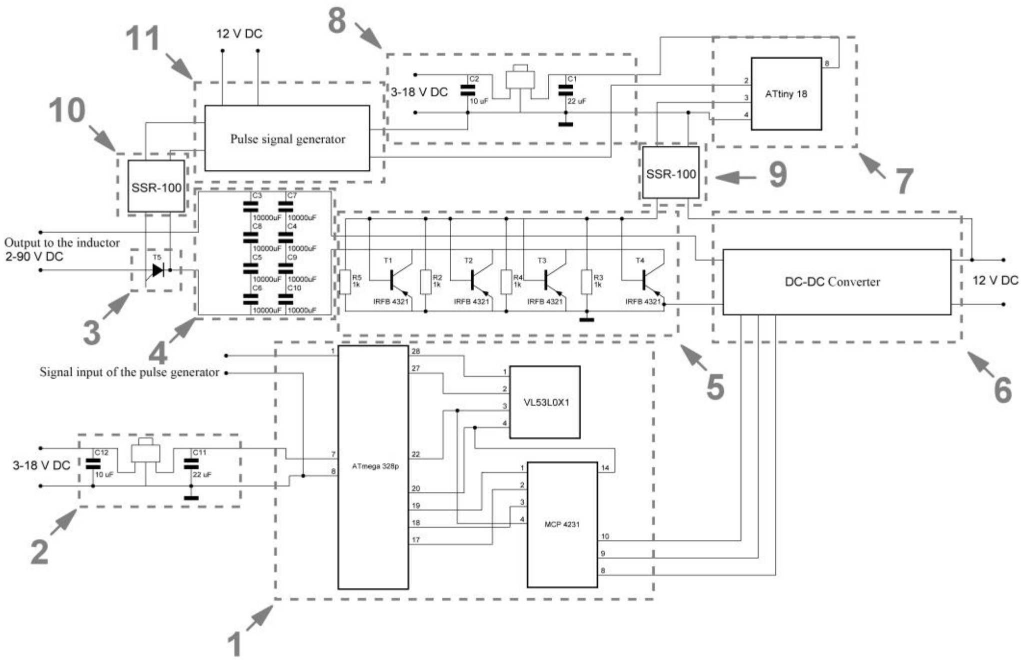

Fig. 1. Electrical diagram of an automated device for magnetic pulse processing of plants: 1 – voltage control unit, 2 – 5V voltage stabilizer, 3 – thyristor, 4 – block of capacitor botors, 5 – transistor block, 6 – block of DC-DC Converter, 7 – microcontroller, 8 – voltage stabilizer 3.3V, 9,10 – blocks of solid-state relays, 11 – pulse signal generator.

Power to the MPP automated device is supplied to the DC-DC converter from a 12V battery. The DC-DC converter converts the voltage from the battery from 12 to 12-90 V. The converted voltage is supplied to the transistor unit. The transistor block is used to turn on and off the power of capacitor banks. Capacitor batteries accumulate electrical energy and in a pulse mode through a frequency generator emit it on the working body of the device. The frequency generator allows you to change the frequency and duty cycle of a low-frequency pulsed magnetic field. A signal with a set frequency and duty cycle is supplied to a solid-state relay, which connects the control electrode to the cathode of the power thyristor. After opening the thyristor, the stored energy in the capacitor bank is supplied to the magnetic inductor. To close the thyristor, the method of changing the voltage between the cathode and the anode is used. When the thyristor is open, the microcontroller sends a signal to the transistor unit to close the power between the DC-DC converter and the capacitor bank. At this moment, the stored energy in the capacitor bank is discharged to the inductor and the voltage on the power thyristor is 0V, and it closes. When the thyristor is closed, the microcontroller sends a signal through the solid-state relay to the transistor unit to open the power between the capacitor bank and the DC-DC converter. The cycle of the described works is repeated depending on the set frequency and duty cycle on the pulse signal generator. The capacitor unit of the MPP automated device is a 10,000 μF 25V parallel-series connected capacitors. 4 capacitors are connected in series, as a result of which the total voltage of the capacitor bank rises to 100V. To increase the capacitance, one more capacitor is connected in parallel to each of the series-connected capacitors. The total voltage of the capacitor unit is 100V, the capacity is 50kF. The transistor unit of the MPP automated device consists of 4 parallel-connected P-N-P field-effect transistors mounted on a radiator. To close the transistors, the base and emitter are connected through a 1kΩ resistor. To open the transistor, a voltage (control signal) is applied to the base and emitter. For the transistor to fully open, 7-30V is required, and the signal voltage at the microcontroller is 5V, so the control signal is supplied to the solid-state relay, and it, in turn, supplies voltage to the base and emitter from the battery. The ATmega 328p microcontroller is responsible for automatically adjusting the magnetic field generated by magnetic inductors. For this, a laser sensor VL53L0X1 is installed on the magnetic inductor, which transmits data on the distance between the bush and the working body. Having received and processed the distance data, the microcontroller sends a signal to the electronic potentiometer MCP4231, which regulates the output voltage on the DC-DC converter. The higher the voltage on the capacitor bank, the greater the generated magnetic field on the magnetic inductor. The microcontroller is powered through a power converter from 12V to 3.3V.The main components of the device are located in a plastic box IP65, on six printed circuit boards that are rigidly connected to the housing. As the working bodies of the device MPP plants it is possible to use various options for inductors. Technical characteristics of the automated MPP device are presented in table 1.

The work of the automated device is based on the principle based on the sequential conversion of electrical energy stored in the capacitor unit into influencing factors - a limited sequence of one or multidirectional pulses of magnetic induction. The developed automated MPP device allows you to change the polarity of magnetic pulses (up/down), the exposure time in increments of 1 s, operate in a wide range of frequencies of pulsed magnetic radiation and duty cycle with the possibility of automatic adjustment.

Table 1. Technical characteristics of the automated device MPP

Characteristic	Value
Type of magnetic field:	Low-frequency, pulse
Number of connected working bodies, PCs.	8
Type of pulse frequency adjustment	smooth
Frequency range, Hz	1-100
Duty cycle range	1-100
AC power	50 Hz 220V via the power supply (12V, 1000 mA), as well as from external 12V power supplies
Adjustable exposure time, s	from 1 to 9999

3 Results and discussion

To create the required value of magnetic induction in the plant processing zone, the magnetic field structure of the magnetic inductor was measured and analyzed in the laboratory under the selected operating modes of the automated MPP device. The laboratory stand includes a test magnetic inductor mounted on a table with a coordinate grid, connected to an automated MPP device (Fig. 2).

Fig. 2. Laboratory stand for measuring the distribution of pulsed magnetic induction: 1 – automated MPP device, 2 – magnetic inductor, 3 – milliteslameter portable universal (TPU-01), 4 – digital oscilloscope AKIP 4122/1, 5 – battery.

Moving the milliteslameter measuring probe along the coordinate grid with a step of 1 cm, we measured the pulsed magnetic field in triplicate, at different operating modes of the MPP device, at frequencies of 8 Hz, 16 Hz, 32 Hz (Fig. 3).

The measuring probe was mounted so that the plane of the Hall transducer at the required point of the measured magnetic field was normal to the magnetic induction vector (Bio-Savard-Laplace law). To measure the shape of the IMP, the AKIP-4122/1 oscilloscope was connected to the TPU-01 analog input. The permissible relative measurement error of the pulsed magnetic field did not exceed the values calculated by the formula1:

$$\delta = \pm [0,5 + 0,5 \cdot (V_p / V_i - 1)] \quad (1)$$

where δ – is the permissible relative measurement error, %, V_p – is the limit of the milliteslameter measurement, mT, V_i – is the milliteslameter reading, mT. The results of measurements in the form of a diagram and an oscillogram are shown in figures 4,5.

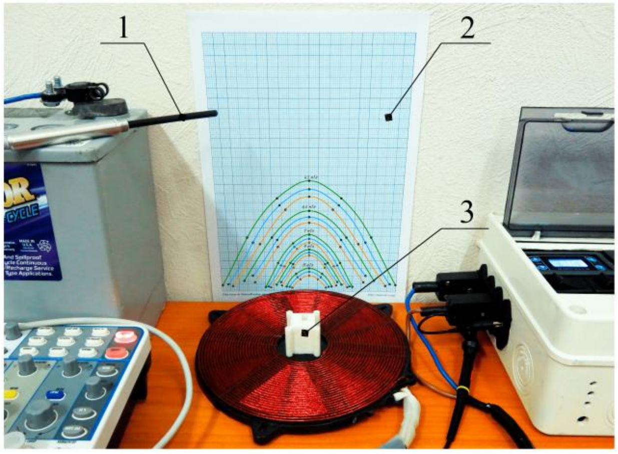

Fig. 3. Measurements of the distribution of pulsed magnetic induction of a flat spiral coil in various operating modes of the automated MPP device: 1 – milliteslameter measuring probe, 2 – coordinate grid, 3 – VL53L0X1 laser sensor housing.

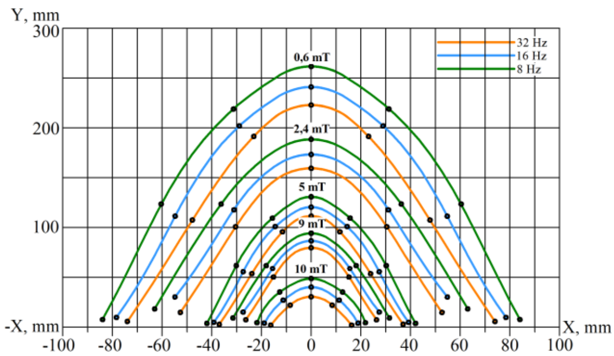

Fig. 4. Diagram of the distribution of the induction of the pulsed magnetic field created by the inductor in various operating modes of the MPP device, pulse repetition rate of 8, 16, 32 Hz.

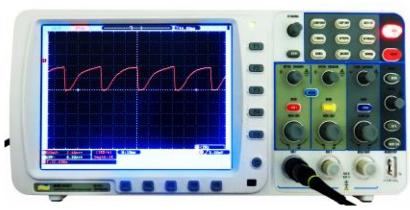

Fig. 5. Oscillogram of magnetic induction pulses emitted by the inductor.

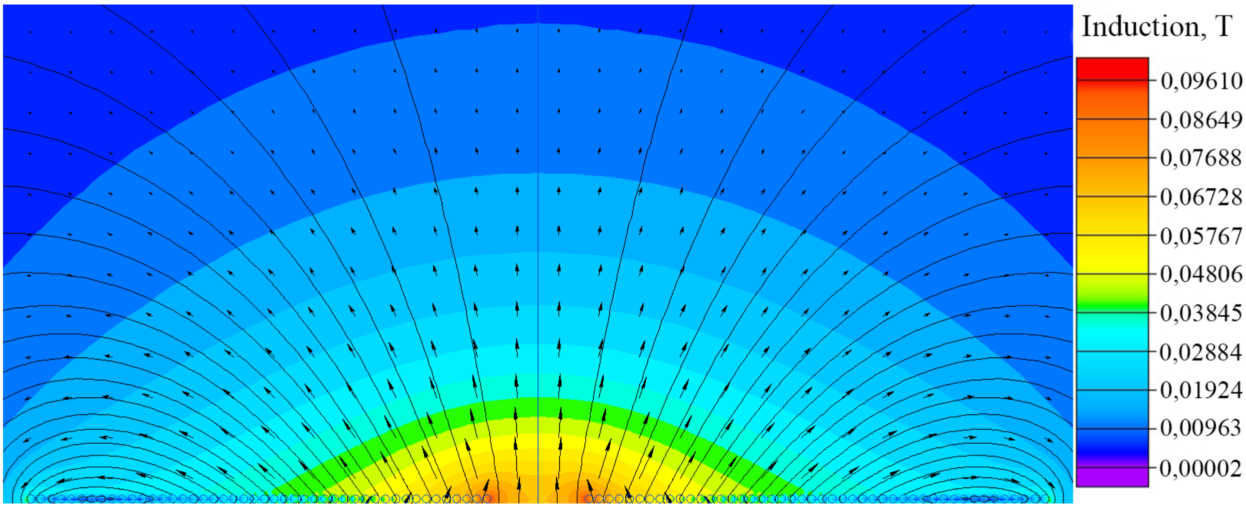

Fig. 6. Graph of the magnetic induction distribution of a flat spiral coil for finite element modeling in the Elcut 6.3 Professional program.

Analysis of the distribution of magnetic induction pulses showed that the most suitable for performing technological operations in the field is the use of working bodies in the form of a flat spiral coil. Coil parameters: 27 turns of a multi-core cable with a cross section of 6 mm^2 with an outer diameter of 190 mm, an inner diameter of 50 mm, an inter-turn distance of 3 mm, and an inductance of 27 μH (Fig.6).

The coil meets the requirements for the level of magnetic induction for processing garden plants in the field and laboratory conditions, simple in design and allows you to get a fairly uniform pulsed magnetic field using a minimum number of turns of the winding. As a result of the experiments, the magnetic field parameters in the near zone of the planar spiral coil were obtained. As you move away from the center of the turn, an increase in the value of the magnetic induction vector is observed. When leaving a coil with a radius of 210 mm, the magnetic field changes direction and weakens when moving away from the conductor. Closer to the edge of the spiral and outside its plane, the level of tension decreases to small values. An analysis of the diagrams from bench tests of an automated MPP device with magnetic inductors showed that in order to obtain the required value of magnetic induction in the treatment zone (pulse repetition rate from 1 to 64 Hz and magnetic induction 0.3 mT - 15 mT) for the treatment of garden plants, it is necessary to provide a distance between working bodies and plants 5 mm - 280 mm. The numerical value of the magnetic induction at a distance of 100 mm from the center of the coil is 8.3.

4 Conclusions

The proposed design of the device allows one to automate the MPP process of strawberries with the ability to customize to different agrotechnological parameters of the plantings, providing the required value of the magnetic induction of frequency and duty cycle in the processing zone and the accuracy of the new technological operation. For the successful implementation of this technology in industrial crop production, the establishment of optimal operating conditions for various agricultural enterprises. cultures and it is necessary to continue scientific research and the accumulation of experimental data on plant objects in the field. The use of the developed MPP device in agricultural production showed that with triple magnetic-pulse treatment of flowering plants of the Malvina cultivar under the conditions of an industrial plantation, an increase in the weight of berries compared to the control averaged from 16 to 58.7%. The most effective was the processing mode with a frequency of 32 Hz and a magnetic inductance of 6 mT.

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