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Operation Analysis of Automated Unit for Magnetic Pulse Treatment of Garden Strawberry

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Abstract. Federal Scientific Agroengineering Center VIM conducts research and development work on the determination of parameters, technical characteristics of machines and operating modes of magnetic pulse treatment (MPT) of plant material in field conditions. (*Research purpose*) To analyze systems of adaptation of the working elements of an automated unit in field conditions during the technological operation of magnetic pulse treatment of strawberry. (*Materials and methods*) To ensure the quality of the technological operation of irradiating plants with a low-frequency magnetic field, as well as to maintain the required value of magnetic induction in the working area, an automated system of adaptation of the working elements of the unit has been developed. The experiment has been carried out for three times on the plot of garden strawberry with a length of 140 m using an automatic system of adaptation of the working elements of the unit and without its use. To control the travel speed use has been made of an electronic GPS speedometer. Operating modes of pulse magnetic treatment (frequency, duty factor, exposure time) have been selected for the ВИМ-МИО device and the БСА-01 automated control unit. To control the distance between the object of magnetic pulse treatment and the working element, use has been made of a measuring tape, a laser rangefinder (Amtast AMF106) and a laser sensor (Laser sensor VL53L0X) mounted on the magnetic inductor of the automated unit. For monitoring and keeping the obtained experimental data, the authors have used the program Advanced Serial Port Monitor 4.4.9 (*Results and discussion*) As a result of the experiment, the authors have determined the dependence of the deviation of the working surface position of magnetic inductors from the required distance. The maximum and minimum values of distances between the plant and the working element of an automated mounted unit during the technological operation of magnetic pulse treatment have been found. (*Conclusions*) The analysis of the experimental data calculation results has shown that the variation scope of the data obtained by using an automated adaptation system of the working elements is 2.1 times less than in case with a disabled system. The coefficient of variation of the obtained values (a measure of deviation from the standard value) when using the adaptation system of the working elements is 2.35 times less than in case with a disabled system. The developed system of automated adaptation of the working elements provides a distance of 0.18-0.25 m between the working elements of the unit and plant objects, which allows to maintain the required value of magnetic induction of 5 MT in the treatment zone. The authors have established parameters of the working elements necessary for magnetic pulse treatment of garden strawberry in the field conditions: 48 turns of a cable of 1x2.5 mm with an outer diameter of 400 mm, an inner diameter of 30 mm, and an inductance of 373 µH.

Keywords: automated unit, magnetic pulse treatment, adaptation system, magnetic inductors, garden strawberry.

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Most of the equipment designed for the magnetic pulse treatment (MPT) of plants was developed without involving a scientific explanation of the magnetic and biological effects and studying the machines for their implementation, basing on empirical dependencies obtained exclusively in laboratory studies. To design specialized equipment and find out the optimal modes of magnetic impulse treatment of plants in industrial horticulture, it is necessary to conduct research and development projects to determine the parameters, technical characteristics of machines and operating modes of equipment to be used on plant objects in the field [1].

The research purpose is to analyze a system of adaptation of the working elements of an automated unit in field conditions when carrying out the technological operation of magnetic pulse treatment of garden strawberry.

Materials and methods. Analysis of the ongoing research on the bioregulatory activation of horticultural crops has shown the high efficiency of using a low-frequency pulsed magnetic field of low intensity modulated in amplitude and frequency, *Table 1* [2-4].

inductors changes, which leads to a change in the position of the working zone of interaction with the necessary modes [7-9]. In addition to irregularities, the working element also adapts to the change of agrotechnological parameters of plants, dimensional parameters of bushes and their structure [10].

To ensure high-quality technological operation of MPT on garden strawberry with a low-frequency magnetic field and maintain the required magnitude

Table 1

Effect of magnetic fields on garden plants

Name of plant	Part of the plant	Exposure parameters	Effect	Authors
Wild strawberry (Fragaria vesca)	Seedlings	0.096 Тл (T) 0.192 Тл (T) 0.384 Тл (T)	Increase in productivity (+) Increase in number of fruits (+)	Esitken A. и Turan M. (2004)
Fragaria "Ananasnaya"	Vegetative part	0.096 Тл (T) 50 Гц (Hz)	Increase of productivity (+) Content of Ca, Mg (+)	Esitken A. и Turan M. (2004)
		0.192 Тл (T) 0.384 Тл (T) 50 Гц (Hz)	Increase in the number of fruits (–) Increase in productivity (–)	
Apples, apricots	Seeds	60 мТл (mT)	Germination energy (+)	Chao и Walker (1967)
Strawberry, pear	Seeds, Vegetative part	5 мТл (mT) 16 Гц (Hz) 50-100 Гц (Hz)	Increase in productivity (+) Increase in the number of fruits (+) Increase in germination energy (+)	Donetskikh V.I. (2016)

The effect of MPT on horticultural crops improves the digestibility of substances and microelements, accelerates the growth and development of crops, increases the permeability of cell membranes and the quality of planting material and yield [5, 6]. As a result of field experiments, it has turned out that the mode of operation of the MPT unit, which meets the following parameters, has proved to be most effective for stimulating the life processes in the vegetative parts of horticultural crops:

- travel speed *V* of 2.5 km/h;
- frequency of magnetic field pulses of 15.325 Hz;
- duty cycle of 16,145;
- magnetic induction in the irradiation zone of 5.05 mT;
- a rectangular shape of magnetic pulses;
- the vector of magnetic induction directed vertically down.

These parameters can be obtained using the developed ВИМ-МИО device with a working element (the magnetic inductor) in the form of a flat spiral coil. When performing technological operations of MPT in field conditions, an automated unit with a tractor (the mobile unit - MU) moves along the plantation and hits irregularities that do not exceed the agricultural background requirements for the cultivated crop (*Fig. 1*). When the MU runs over unevenness, the position of magnetic

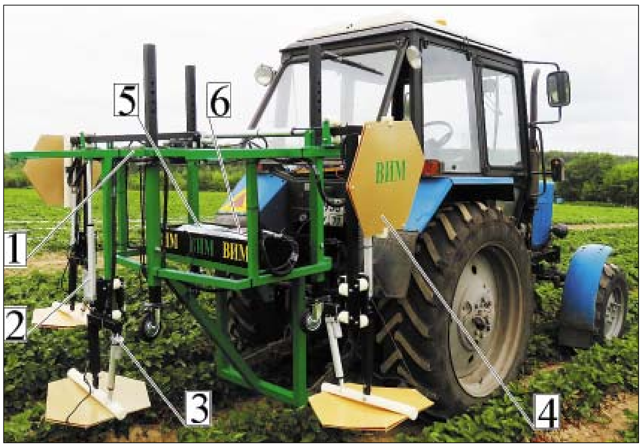

Fig. 1. Performance of technological operations of MPT on garden strawberry by an automated unit

1 – the frame of the automated MPT unit; 2,3 – actuators for changing the angle inclination of the working elements and maintaining a predetermined distance between plants and working elements; 4 – working elements of the automated unit (magnetic inductors); 5 – the ВИМ-МИО device of magnetic pulse treatment of plants; 6 – automated control unit for the adaptation system БСА-01

of magnetic induction in the working area, an automated system for the adaptation of the working parts of the unit has been developed (Certificate 2018614946) [11, 12].

Actuators (electric cylinders) adjust the magnetic inductors of the MPT unit to the agrotechnological parameters of plants automatically, depending on the distance of ultrasonic sensors to the MPT object and the selected mode of operation [7].

The analysis of the adaptation system performance of the working elements of the automated mounted MPT unit have been carried out for an industrial plantation of garden strawberry in the scientific and production test department of the VSTISP (Moscow region, Leninsky district, the village of Bulatnikovo), *Table 2*.

Table 2

Characteristics of the site for production testing of an MPT unit

Crop, variety	"Festivalnaya" strawberry variety
Planting pattern, cm	80×20
Age of plantations, years	2
Average height of a bush, cm	25.2
Average width of a bush, cm	30.4
Deviation of bushes from the center line of a row, cm	4.5
Average height of weed vegetation, cm	23.6

The experiment was conducted on a plot of 140 m long with a threefold repetition using an automatic system of adaptation of the working elements of the unit and without it. Magnetic inductors in the form of a flat spiral coil were used as the working elements of the automated MPT unit. The magnitude of the magnetic field at a distance of 100 mm from the center of the coil is 0.0050572 T [8].

To control the speed of motion use was made of a GPS-speedometer. The MPT modes (frequency, duty cycle, and exposure time) are set on the ВИМ-МИО device and the БСА-01 automated control unit (*Fig. 2*) [9].

When performing a MPT process operation using MU, the laser sensor transmitted the distance between the plant and the working unit to the laptop via the serial port (COM-port) in a real-time mode. The monitoring and saving of the experimental data were performed using the *Advanced Serial Port Monitor 4.4.9* app program (*Fig. 3*).

The average linear deviation from the arithmetic mean of the data obtained is determined by the formula:

$$a = \frac{\sum_{i=1}^{n} |X - \overline{X}|}{n}, \qquad (1)$$

where X is the analyzed indicator, cm; n is the number of values in the analyzed data set, pieces; $\overline{X}$ – is the mean value of indicators, cm:

$$\overline{X} = \frac{1}{n}\sum_{i-1}^{n} X_i. \qquad (2)$$

Fig. 2. Measuring distance from the working elements to the plant and the magnetic induction when performing the technological operation of MPT

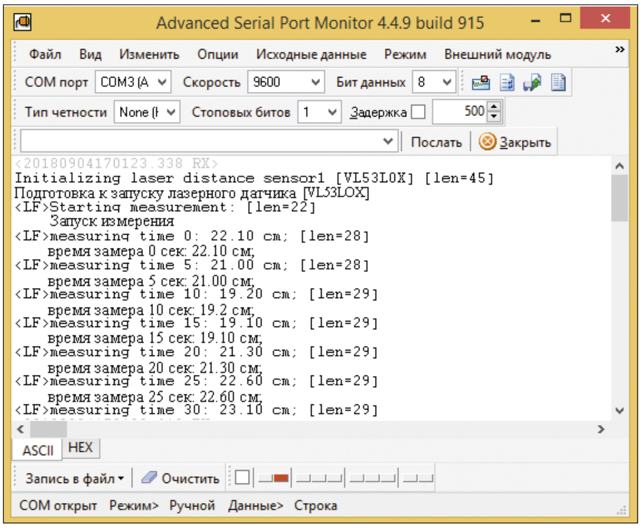

Fig. 3. COM-port monitoring while performing the technological operation of MPT

The variance s^2 of the obtained data is determined by the formula:

$$s^2 = \frac{\sum_{i=1}^{n} (X - \overline{X})^2}{n-1}. \qquad (3)$$

The standard deviation is calculated by the formula:

$$s = \sqrt{\frac{\sum_{i=1}^{n} (X - \overline{X})^2}{n-1}}. \qquad (4)$$

All the indicators discussed above are tied to the scale of the source data and do not allow to get a figurative idea of the variation of the analyzed set of obtained data. To obtain a relative measure of the data variation, the coefficient of variation V and the oscillation coefficient P were used:

$$V = \frac{s}{\overline{X}}, \quad (5)$$

$$P = \frac{R_x}{\overline{X}}, \quad (6)$$

where R_x – is the variation range of the random variable x, cm: $R_x = x_{max} - x_{min}$ [12].

Results and discussion. As a result of the experiment, a graph of the deviation of the position of the working surface of magnetic inductors from the required distance has been made (*Fig. 4*).

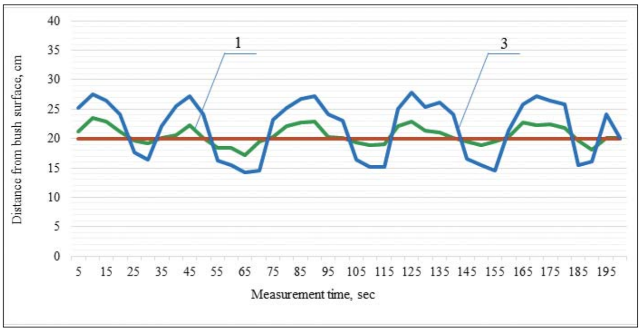

Fig. 4. Graphs of deviation in the position of the working surface of magnetic inductors from the required distance:
1 – the position of a magnetic inductor using the adaptation system, 2 – the required distance to a garden strawberry bush, 3 – the position of a magnetic inductor without using the adaptation system

Table 3

The analysis results of the data obtained in the field experiment

The rate of variation	Values obtained using an automatic adaptation system	Values obtained without using an automatic adaptation system
Maximum, cm	23.56	27.84
Minimum, cm	17.22	14.24
The range of variation, cm	6.34	13.6
Average linear deviation, cm	1.33	4.37
Variance based on the general population, cm^2	2.42	22.67
Variance based on a sample, cm^2	2.49	23.26
Standard general deviation, cm	1.56	4.76
Standard deviation of the sample, cm	1.58	4.82
Coefficient of variation, %	8	22
Coefficient of oscillation	0.31	0.63

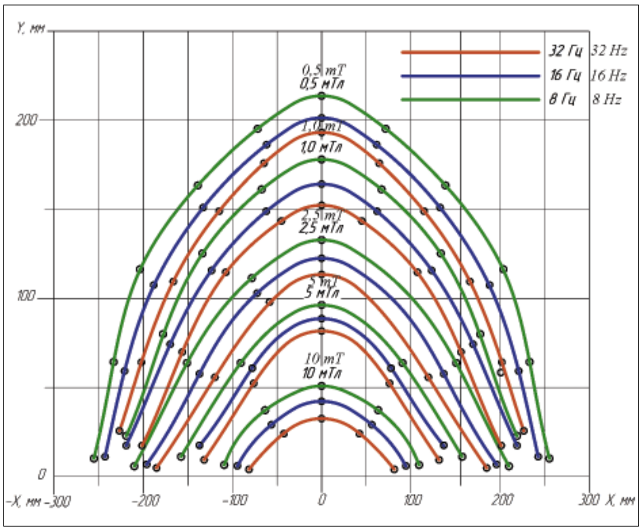

Fig. 5. Induction distribution of a pulsed magnetic field for various treatment modes, at a pulse repetition rate of 8, 16 and 32 Hz

According to the calculation results, the maximum and minimum distances between the working elements of the unit and the plants, the range of variation, the average linear deviation, the standard deviation, the variance, the coefficient of variation and oscillation have been determined, *Table 3*.

In the course of the field experiments, the parameters of the magnetic field in the near zone of a flat spiral coil have been obtained for various operating modes of the ВИМ-МИО unit. It has been established that the distribution of force lines in simulation and experiment are identical (*Fig. 5*).

As the distance from the center of the coil increases, the vector of magnetic induction increases. When going beyond the coil with a radius of 115 mm, the magnetic field changes direction and weakens, as it moves away from the conductor. Closer to the edge of the spiral and outside its plane, the level of tension decreases to small values.

Conclusions

1. An analysis of the experiment results has shown that the range of variation of the obtained data when using an automated system for adapting the working elements is 2.1 times smaller than with the turned-off system. The coefficient of variation when using the system of adaptation of the working elements is 8%, while with the turned-off system it amounts to 22%. Reducing the coefficient of variation leads to an increase in the uniformity of the magnetic induction distribution in the treatment area of up to 2.5 times. The use of an automatic system ensures the accuracy of the MPT technological operation with a general dispersion of 2.42.

2. The developed system of automated adaptation of the working elements ensures the distance between the working elements of the unit and plant objects

within 0.18-0.25 m, which allows maintaining the required magnetic induction in the treatment area of 5 mT.

3. The authors have determined the parameters of the working elements required for magnetic pulse treatment of garden strawberry in the field conditions: 48 cable turns 1×2.5 mm with an outer diameter of 400 mm, an inner diameter of 30 mm, and an inductance of 373 μH.

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