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MICROPROCESSOR CONTROL OF THE ELECTRIC DRIVE OF VARIABLE RADIATION INSTALLATION AND ENSURING OF OPERATION RELIABILITY

Introduction. *The introduction of energy-saving technologies has become particularly relevant in recent years, when energy prices have been constantly increasing. This is particularly important for greenhouse farms, where the main condition for growing plants indoors is the creation of artificial climatic conditions: temperature, humidity, and lighting.*

Problem Statement. *Given the light and the dark stages of photosynthesis, it becomes possible to use a variable light field in the plant-growing photoculture, which is created by light installations with variable radiation. The development of an energy-saving electric drive and automated control systems for the parameters of artificial climatic conditions when growing plants indoors results in reducing energy consumption and increasing the reliability of the technological process in greenhouses of agro-industrial complex.*

Purpose. *Implementation of energy-saving variable illumination irradiating systems with an automated control system for greenhouse farms.*

Materials and Methods. *A lighting installation with rotation of the irradiator in the vertical and horizontal planes with a discrete electric drive and microprocessor control has been used.*

Results. *The current state of variable irradiating systems with energy-saving radiation sources has been analyzed. The use of a discrete electric drive with an automated control system has been proposed. The installation with a DNAT-400 radiation source and a ZHO-01 reflector enables irradiating an area of up to 100 m^2. The maximum exposure to photosynthetically active radiation is 30 W/m^2, and the irradiation irregularity does not exceed 20%. At the same time, electricity savings reach about 10 thousand kWh per season. The yield and quality of products remain unchanged.*

Conclusions. *The results of the research have confirmed the feasibility of practical implementation of variable irradiation system for energy efficiency of greenhouse operations.*

Keywords: variable radiation, plant-growing photoculture with illumination, electric drive, stepping motor, microcontroller.

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The problem of electric drive in most cases concerns industrial production mechanisms [1]. This study deals with its application in the illumination industry, namely in irradiating systems/units emitting variable radiation. Growing plants indoors is an energy-intensive process, so finding ways to reduce energy costs is relevant at this time, when energy prices have been increasing dramatically [2]. In most greenhouse farms, during the period of short daylight hours, plants are additionally irradiated by artificial light sources that are permanently placed above the sowing area. On average, they operate 8 hours daily. Due to the peculiarity of photosynthesis processes, namely its light and dark phases, there is a prospect of using variable irradiation of plants [3, 4]. Variable radiation is one of the ways to reduce energy costs in agricultural production without reducing the yield and quality of vegetable crops grown indoors. This can be achieved with the help of mobile irradiating units, the design of the electric drive for which is the subject of this study.

The purpose of this study is to create technical means and systems for controlling the parameters of a variable light field and to conduct studies of plant growth and development in greenhouse conditions under variable radiation. To achieve this goal, the task is to develop a lighting device with rotational motion of the irradiator and a energy-efficient controlled electric drive.

Information on the development and improvement of electric drives and control systems is mainly related to industrial production [1]. For implementing variable irradiation of crop plots in greenhouses, an electric drive for mobile irradiating units needs to be designed [4—8]. This electric drive belongs to the class of mechanisms in which the static torque does not depend on the speed. The main source of its torque is friction. The peculiarity of the operating conditions of irradiating units used for growing plants in closed environments is the microclimate of the greenhouse: humidity and temperature of the air medium. To ensure the reliability of the motor in such conditions, it is necessary to comply with the requirements for its thermal operation and protection against moisture. Most irradiating systems are based on the reciprocating irradiator system that uses AC motors with a square-cage rotor and no additional control systems. Such systems have proven to be quite effective in greenhouses in the Netherlands and Norway [4, 5].

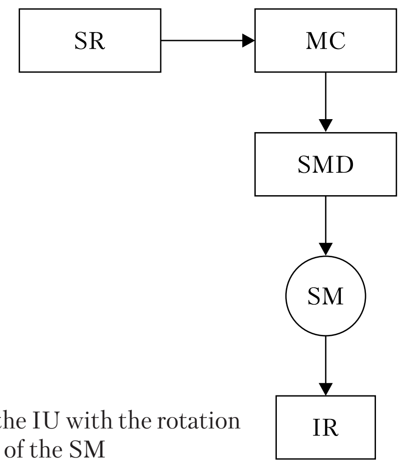

Fig. 1. Flowchart of the IU with the rotation of the IR and the use of the SM

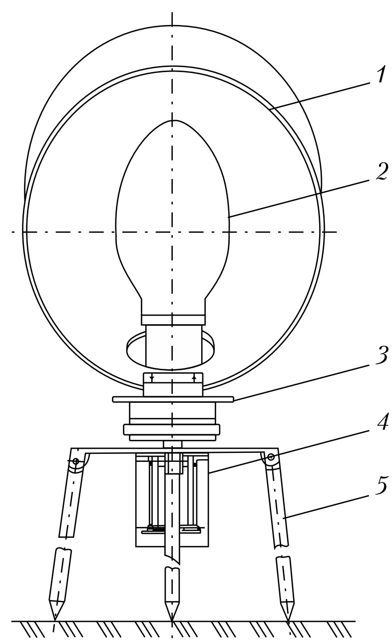

Fig. 2. General view of the irradiating unit with rotational motion of the irradiator

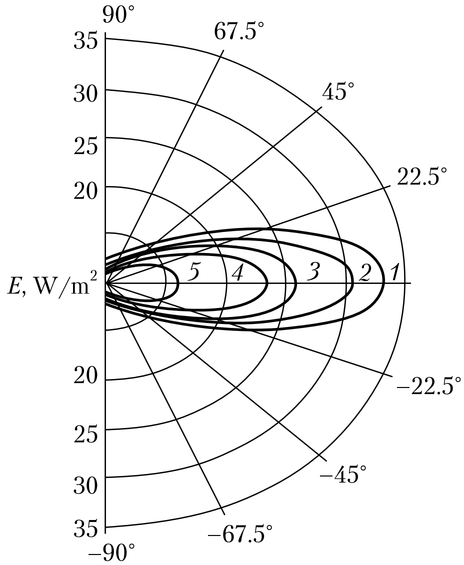

Fig. 3. Dependence of horizontal plane irradiation on the azimuthal angle β for the radiation source ZhO-01 with sodium lamp-400 positioned at a height of h = 3 m at different values of the angle of inclination ζ: *1* — 10°; *2* — 20°; *3* — 30°; *4* — 40°; *5* — 50°

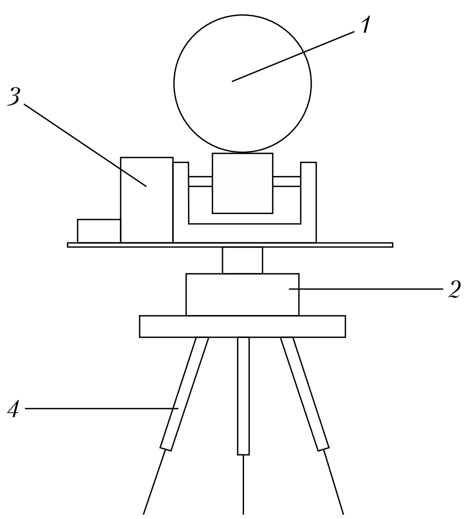

Fig. 4. General view of the irradiating unit with simultaneous rotation of the irradiator around the horizontal and the vertical axes

Study [9] describes industrial carousel-type variable irradiating systems with a DC electric drive based on the rotational motion of radiation sources.

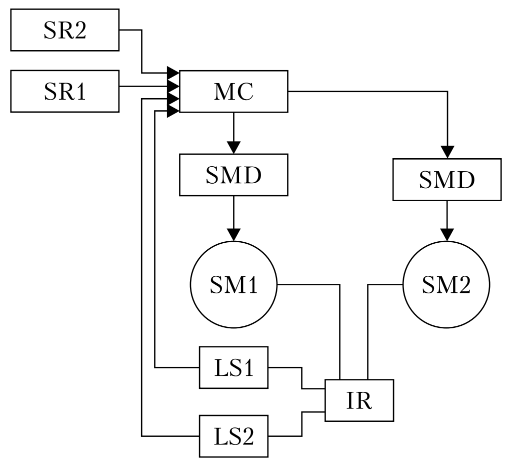

Fig. 5. Block diagram of the irradiating unit electric drive with rotation of the irradiator around the vertical and the horizontal axis

Variable irradiation, as described in [10], has been realized by moving the operating surface, that is irradiated by fixed light sources. Its motion is realized by means of a cable traction. This system uses an asynchronous motor with a square-cage rotor that ensures a constant speed of the sowing area motion relative to the light sources with different spacing intervals.

A variable irradiation system based on LEDs that stand out among other sources for their high energy efficiency and durability, has been described in [11]. The variable luminous flux is obtained by rotating a disk with LEDs, lenses of total internal reflection, and a diffuser. A DC motor is used for the electric drive, without additional speed control. This device provides a variable light field with a constant frequency of light and dark intervals.

In all the works involving variable irradiation used in greenhouse farms, a reduction in energy costs has been achieved without loss of yield and product quality.

For developing the experimental models of irradiating system, the following conditions are specified: ensuring the required level of irradiation of the crops, the ability to adjust the duration of light and dark intervals, efficiency, compactness,

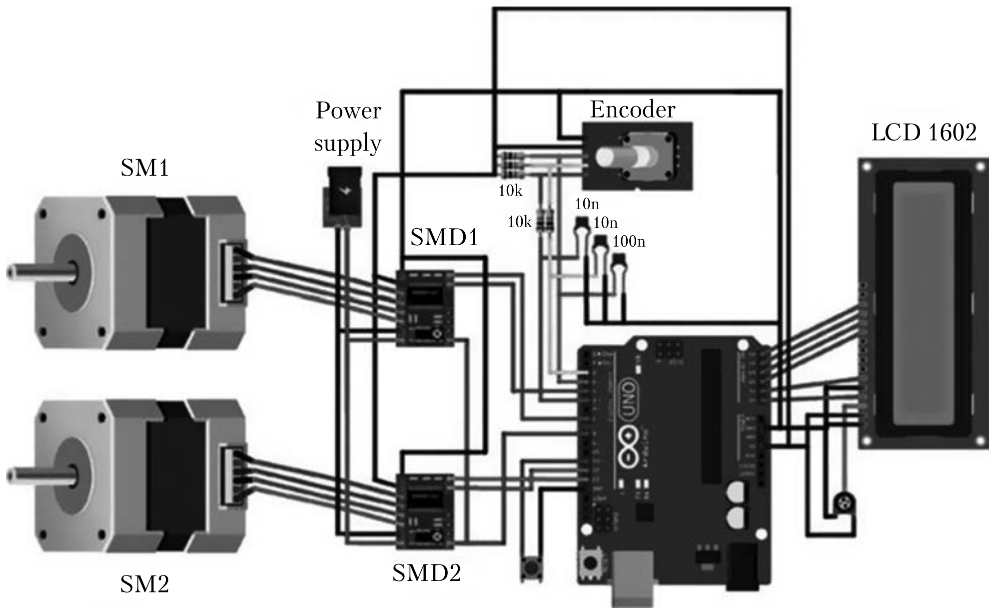

Fig. 6. Block diagram of the control unit for the rotary mechanism of the IU: SM1, SM2 are the stepper motors for rotation around the horizontal and the vertical axis; SMD is the stepper motor drive; KY-040 is the encoder; LCD 1602 is the display

ease of operation and mobility, and reliability of operation.

The reflectors of the ZhO-01 floodlight, the GSP-04 lamp, and the ZhSP-VOT-02 greenhouse irradiator, which have a wide-angle distribution of luminous flux and high efficiency (at least, 0.75), have been used for designing these lighting installations. These devices are equipped with the following gas discharge radiation sources: sodium lamp-400, metal halide lamp-400-5, metal halide lamp-1000-2. Each type of irradiator is used depending on the location of the sowing area, the structure of the plants and the peculiarities of their ontogeny. In the first prototypes, an asynchronous motor with a square-cage rotor AIP80A8 IM 2081, a gearbox mounted on the motor shaft and connected to the irradiator, and a motor speed frequency controller have been used to drive the installation with rotational motion of the irradiator [12]. Such electric drives are quite sophisticated and usually have a vector control system, which significantly complicates their electrical circuit.

To improve the energy efficiency and reliability of the IU, a stepper motor (SM) has been used to drive it. The advantages of such a motor are the absence of brushes and other parts with mechanical friction, a simplified and cheap control system with no feedback, the ability to achieve very low rotational speeds of the load connected directly to the motor shaft without an intermediate gearbox, and the absence of special position sensors. These factors increase its reliability and ensure a long service life.

Figure 1 shows the flowchart of the variable irradiating installation with rotational motion of the irradiator (IR). It consists of: stepper motor (SM); microcontroller (MC); stepper motor driver (SMD); irradiator (IR); and speed rate units (SR).

Figure 2 shows the design of this installation that is mounted on a tripod. Sodium lamp-400 that is a radiation source (*2*) is placed in parabolic-elliptical reflector ZHO-01 (*1*). The reflector is made of high-purity aluminum sheet with anodic-oxide or “alglas” coating. The reflector with the lamp (irradiator) is attached to platform (*3*) that

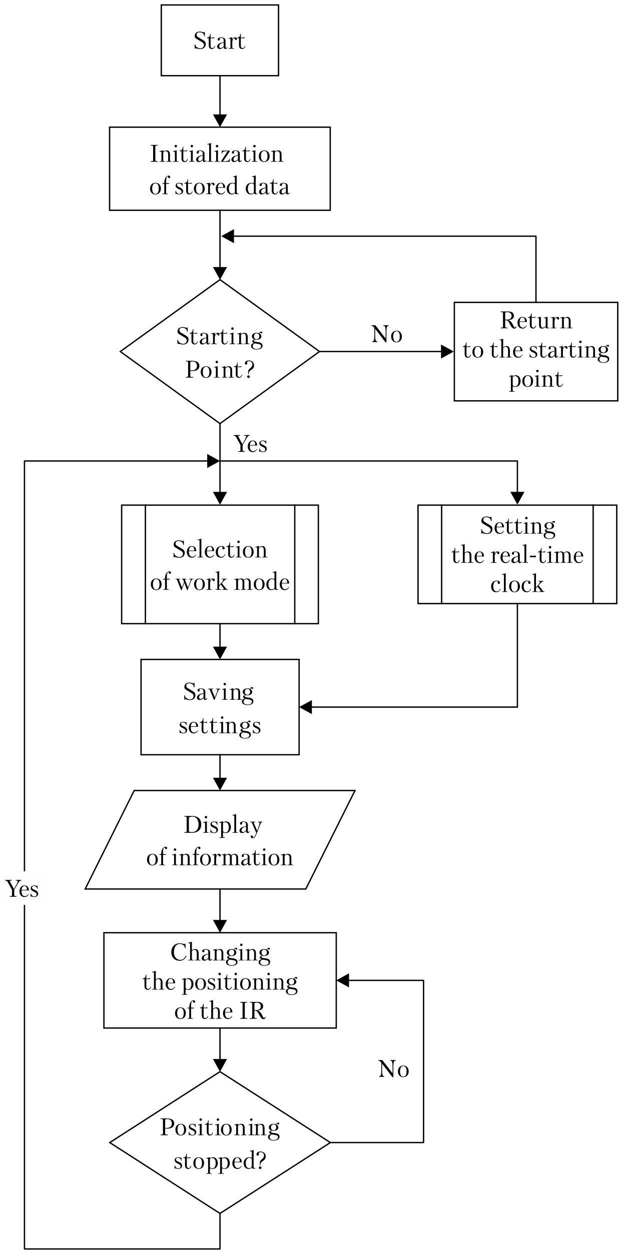

Fig. 7. Block diagram of the operation algorithm of the main program for controlling the rotary mechanism of the IU

is connected to the shaft of stepper motor (*4*). A nema 23 motor (23HS2410) and a DM556 driver are used to rotate the irradiator. The whole structure is placed on tripod (*5*) or can be attached to the greenhouse ceiling.

Figure 3 shows the dependence of the radiation falling onto the horizontal plane on the azimuthal angle β at different angles of inclination of the irradiator ζ to the vertical axis. For the irradiator placed at a height of $h = 3$ m and at an angle of $\zeta = 20°$, the optimal level of radiation falling on the horizontal surface from the photosynthetically active radiation (PAR), which is equal to 30 W/m^2 is achieved.

To increase the functionality of the irrading unit with rotational motion of the irradiator in the racked multilevel seedling growing system, an alterative installation in which the irradiator rotates around the vertical and the horizontal axes has been designed. This allows adjusting the level of irradiation of any part of the sowing area and thereby achieving a high homogeneity of radiation dose, to create the same conditions for illumination of the plants. Figure 4 shows the general view of the installation. Irradiator (*1*) is connected to electric motor (*2*) that rotates it around the vertical axis, changing the azimuthal angle β. Electric motor (*3*) moves the irradiator around the horizontal axis and changes the angle of inclination in the vertical plane ζ. Stepper motors nema 23 (23HS2410) and DM556 drivers are used to rotate the irradiator in both planes. This unit can be mounted on portable tripod (*4*) or attached to the greenhouse ceiling.

The irradiation frequency is set by the parameters of the electric drives and varies within 0.5—3 min. Also, to limit the motion of the irradiator in the vertical plane and to protect the electric drive from destruction, position switches PS1 and PS2 are additionally installed.

The block diagram of the electric drive of the irradiating unit with the rotation of the irradiator around the vertical and the horizontal axes is shown in Fig. 5. Here: MC is the microcontroller; SMD in the stepper motor drive; IR is the irradiator; SR1, SR2 are the speed rate units; SM1, SM2 are the stepper motors for rotation around the horizontal and the vertical axis; LS1, LS2 are the limit switches.

When designing an electric drive for irradiating units, it is important to choose not only a motor

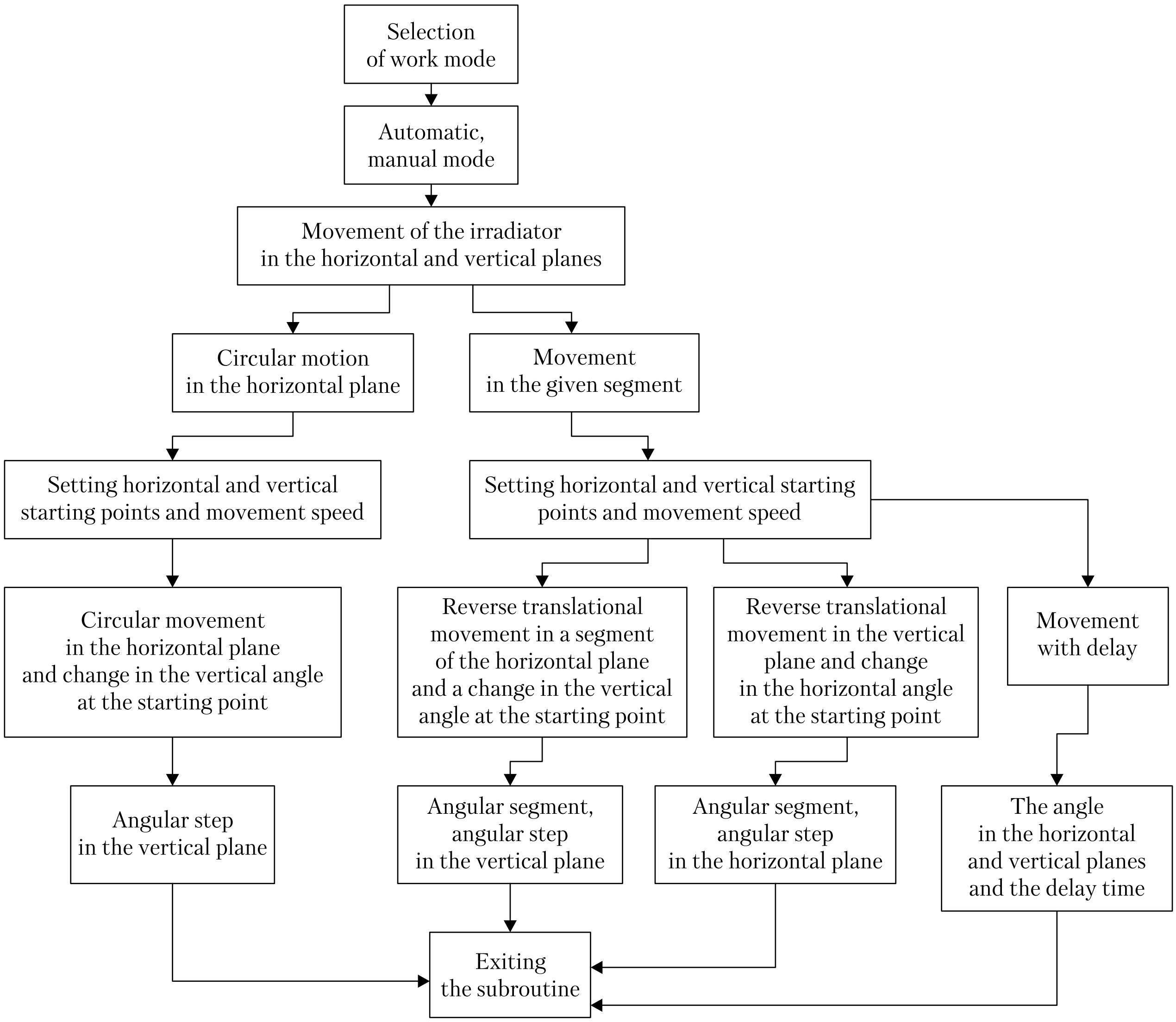

Fig. 8. The algorithm of the subroutine for selecting the operation mode to control the IU with a two-axis rotary mechanism

but also a correct drive circuit and its operation algorithm that is often determined by the microcontroller program. A simple and cheap stepper motor drive based on an AVR family microcontroller that ensures all the specified conditions for the operation of irradiating units has been chosen.

The block diagram of the control unit is shown in Fig. 6.

The control unit of the IU rotary mechanism includes:

- Arduino microcontroller that is designed to process input signals and to further control the operation of stepper motors;
- Encoder that is designed to change the operating conditions of the unit in manual or automatic (controlled by the MC) modes;
- Display to show all input data and to select the operating mode;
- stepper motor driver designed to amplify the output control pulses and to provide their

required frequency for normal operation of the stepper motor.

The motor is controlled by an Arduino microcontroller based on the Atmel ATMega microprocessor and a digital drive based on a signal processor using modern control algorithms. The DM556 is distinguished by smooth motor shaft motion, high torque, resonance suppression algorithms, and protection against short circuits and overvoltage. It can be easily configured via RS232 port. The use of this electric drive in combination with control microprocessor allows automating the operation of the motor unit. For this purpose, we have designed a program to control the rotary mechanism of the IU, the algorithm of which is shown in Fig. 7.

Let us analyze the program of the Arduino microcontroller. As can be seen from the block diagram, after the installation starts, the saved data is initialized. After that, the process returning the IU to the starting point takes place. During the return, the SM moves in the vertical plane, until it reaches the starting point or the point of operation of the position switch. The operator sets the starting point of the horizontal motion. After returning to the starting point, the subroutine selects the operating mode. The block diagram of the subroutine is shown in Fig. 8. This subroutine has two modes of operation: manual and automatic. In the manual mode, the IU moves using the encoder and the plant operator. In the automatic mode, the rotary mechanism of the unit is controlled according to with the set parameters. The program provides for circular motion of the irradiator both in the horizontal plane and in a given angular segment. In the vertical plane, the motion of the irradiator is set only within a selected angle. It is also possible to select the speed of the irradiator motion and the delay time at the specified angular coordinates. This program also allows us to set the position of the light field and the ratio between light and dark periods.

The calculations and experimental tests have shown that this irradiation device with a sodium lamp-400 radiation source and a reflector ZHO-01 allows irradiating a section of indoor soil with an area of up to 100 m^2. The maximum irradiation of the PAR is 30 W/m^2, the irradiation level irregularity does not exceed 20%. The duration and frequency of changes in light and dark irradiation levels using the automatic control system vary within the limits set by the control program.

The effectiveness of the use of a variable light field created by the proposed technical means in terms of increasing the productivity of photosynthesis and reducing energy consumption for plant irradiation has been proved by experimental work on growing plants in vegetation and climatic chambers with 8-hourly variable irradiation. It has been found that the annual energy savings as a result of using a variable irradiation unit with a sodium lamp-400 instead of a similar continuous irradiation unit are about 10 thousand kW · h [13].

ACKNOWLEDGMENTS

Stepper motors nema 23 (23HS2410) and DM556 drives have been used to drive variable irradiation units with rotational motion of the irradiator. The configurations of irradiating units with rotation of the irradiator in the horizontal plane and horizontal and vertical planes have been designed and presented. The operation of the units is controlled in manual and automatic mode by Arduino microcontroller (MC) based on Atmel ATMega microprocessor. The program of the Arduino microcontroller is designed to control the operation of the units in automatic mode, which allows setting the necessary conditions for plant-growing photoculture in variable light fields. In experimental work on growing plants in vegetation and climatic chambers with 8-hour variable irradiation, the energy savings of about 10 thousand kWh have been achieved without any loss of yield and product quality.

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МІКРОПРОЦЕСОРНЕ КЕРУВАННЯ ЕЛЕКТРОПРИВОДОМ УСТАНОВОК ЗМІННОГО ОПРОМІНЕННЯ ТА ЗАБЕЗПЕЧЕННЯ НАДІЙНОСТІ ЇХНЬОЇ РОБОТИ

Вступ. Питання впровадження енергоощадних технологій особливо гостро постало останнім часом, оскільки ціни на енергоносії постійно зростають. Це особливо відчутно економічно для тепличних господарств, де основною умовою вирощування рослин у закритому ґрунті є створення штучних кліматичних умови — температури, вологості, освітлення.

Проблематика. Враховуючи світлову та темнову стадії фотосинтезу, постає можливість застосовувати у світлокультурі рослин змінне світлове поле, яке створюється світлотехнічними установками змінного опромінення. Розробка енергоощадного електроприводу та автоматизованих систем керування параметрами штучних кліматичних умов при вирощуванні рослин у закриму ґрунті зменшить енергоспоживання та надійність технологічного процесу в тепличних господарствах агропромислового комплексу.

Мета. Впровадження енергоощадних опромінюючих установок змінного опромінення з автоматизованою системою керування для тепличних господарств.

Матеріали й методи. Використано освітлювальну установку з обертанням опромінювача у вертикальній та горизонтальній площинах з дискретним електроприводом та мікропроцесорним керуванням.

Результати. Проаналізовано поточний стан установок змінного опромінення із енергоощадними джерелами випромінювання. Запропоновано використання дискретного електроприводу з системою автоматизованого керування. Установка з джерелом випромінювання ДНаТ-400 та відбивачем ЖО-01 дозволяє опромінювати ділянку площею до 100 м^2. При цьому максимальне опромінення фотосинтезно-активної радіації складає 30 Вт/м^2, нерівномірність рівня опромінення не перевищує 20 %. При цьому економія електроенергії досягала близько 10 тис. кВт · год за сезон. Врожайність та якість продукції залишилася незмінною.

Висновки. Результати досліджень підтвердили доцільність практичного впровадження системи змінного опромінення для енергоефективності роботи тепличного господарства.

Ключові слова: змінне опромінення, світлокультура рослин, електропривід, кроковий двигун, мікроконтролер.