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ELABORATION AND RESEARCHES OF APPARATUS OF CONTROL FOR HYDROPONIC INSTALLATIONS

Introduction of hydroponic installations is a prospective direction of agriculture, while they allow to get all-the-year-round fresh vegetables, fruits and greenery, including their exotic kinds for some regions. For provision of high efficiency of this equipment (minimal expenses of energy, materials and time, maximal productivity of the plants) there is important to supply the plants with optimal quantity of nutrients (nitrogen, potassium, sulfur, calcium, magnesium, phosphorus, natrium), microelements (iron, boron, iodine, copper, zinc, cobalt, molybdenum, manganese), acids, salts. Herewith concentration of some from these additives can amount several milligrammes. So, an actual task is an accurate batching of the components of nutrients. There are several variants of an equipment for the accurate batching of liquid solutions: valves with electric control for feeding of fuel in jet engines (they have high price because of utilization of expensive materials in their construction), hydraulic engines with periodic turns of executive element for angle less than 360º (don't provide exact regulation of turning angle) and linear electric-hydraulic engines (have other designation and design that demands of improvement). Authors propose a scheme of improved apparatus for accurate batching of the components of nutrients hydroponic installations, created at the base of the linear electric-hydraulic engine. The apparatus has a simple and reliable design and provides a possibility of high accurate batching of the components of nutrients. There are cited equations and formulas for definition of main working parameters of the apparatus, that can be used for creation of its method of design calculation.

Kee words: *hydroponic installation, minimal expenses of energy, nutrients, accurate batching, linear electric-hydraulic engine.*

Problem formulation. Hydroponics is a prospective direction of agriculture, providing possibility of receipt of fresh vegetables, fruits and greenery in cold regions all-the-year-round and on small squares [1-3]. At present time a lot of attention is spared for elaboration of new more effective methods of hydroponics and equipment for their realization. But main parameters of efficiency of the methods (expenses of energy, materials and time, productivity of the plants, quality of products) significantly depends from content of utilized mixtures and their correct batching. Elements of these mixtures are: nutrients (nitrogen, potassium, sulfur, calcium, magnesium, phosphorus, natrium); microelements (iron, boron, iodine, copper, zinc, cobalt, molybdenum, manganese), acids, salts. Herewith concentration of some from these additives can amount several milligrammes. So, modern and efficient hydroponic equipment should provide automated control and support with high accuracy of content of additives depending from content in leaves of plants of potassium, calcium, phosphorus, natrium, nitrate nitrogen, magnesium and other important elements [4]. Therefore, an actual task is selection or elaboration of apparatuses for control and batching of nutrients, microelements, acids and salts.

Analysis of last researches and publications. Let us examine main kinds of known apparatuses for control of fluid's supply that can be

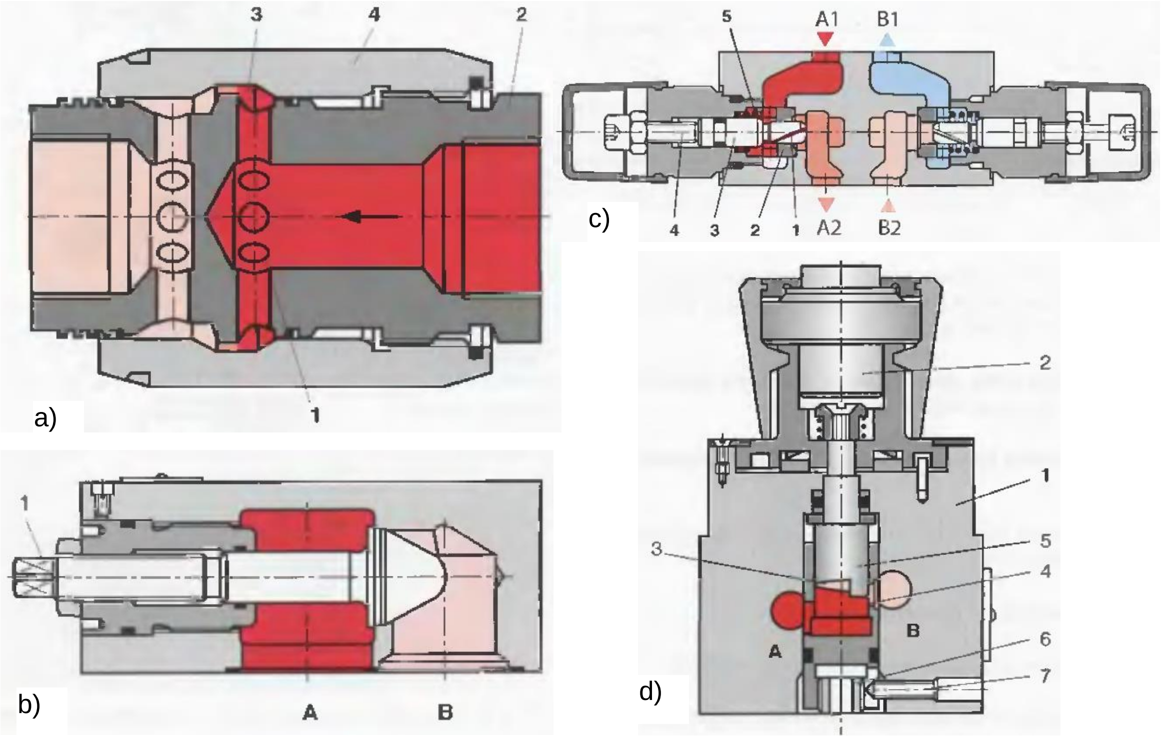

Fig. 1 Schemes of throttles: a) - throttle of thread mounting; b) - throttle of platen mounting; c) - double throttle with check valves of module mounting; d) – tweaking throttle

used in hydroponic installations.One of most simple variants of these apparatuses are throttles [5]. Their simplified schemes are presented at the fig. 1 [5]. The apparatuses have reliable design but provide only manual control of fluid's supply by change of an orifice size. That does not allow to realize an effective optimal support of nutrients batching for many kinds of crops. Besides, scales of these apparatuses have no sectoring for exact adjustment of certain orifice size or fluid's supply. Actually, for setting of an optimal mode of the functioning of these apparatuses one should use an experimental method of trials and mistakes [6]. This causes significant losses of time in case of adjustment of throttles of a hydroponic installation for supplying of several different crops. Besides, as we can see at the fig. 1, some of the throttles contain several details that are complex by form and should be made with high accuracy.

Flow governors are used for regulation and support of supply independently from change of pressure [5]. Unlike of throttles the flow governors provide more stable and accurate supply of working liquid, but they have more complex and expensive design (fig. 2) [5]. Actually, these devices contain besides of a throttle a pressure compensator. Adjustment of flow governors for realization of a necessary optimal supply of working liquid is realized manually, so this causes a decrease of

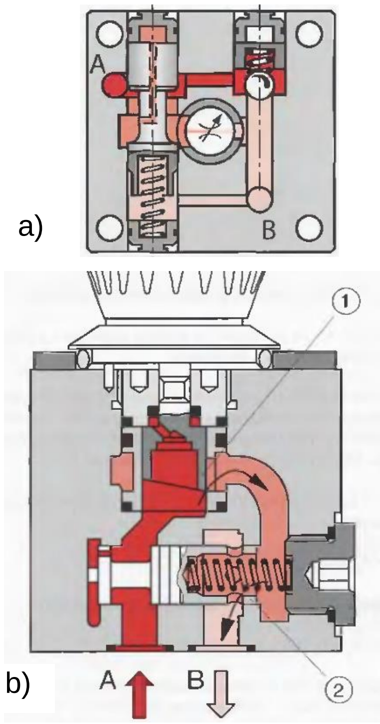

Fig. 2 Schemes of flow governors: a) – dual line with a pressure compensator at the input; b) - dual line with a pressure compensator at the output

efficiency of utilization of these apparatuses for supplying of many kinds of crops. Besides, there are no versatile formulas for calculation of necessary amount of scale divisions of the flow governors depending from a given supply of working liquid.

The principle of operation of a direct-acting flow regulator (fig. 3) is based on maintaining of a constant pressure drop across a throttling device with a constant hydraulic resistance. A constant differential pressure across the valve with a

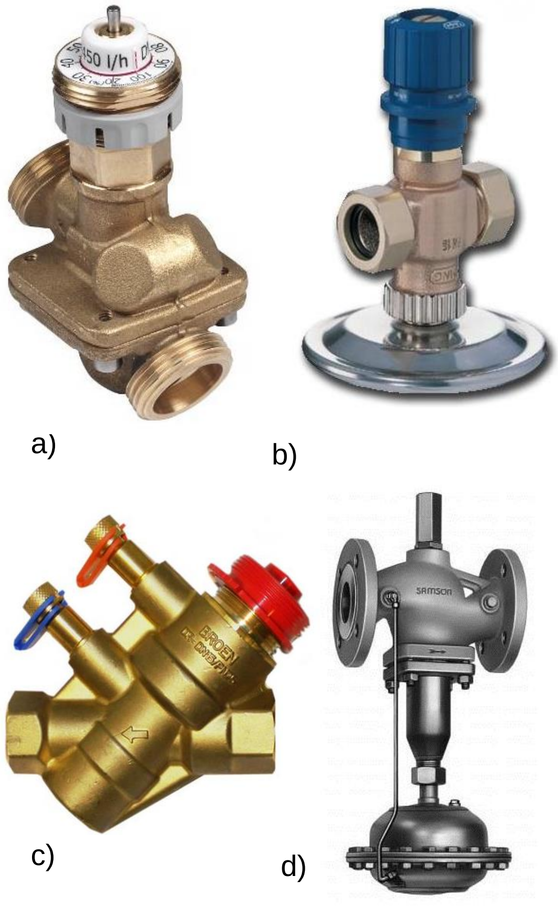

Fig. 3 Photos of direct-acting flow regulators: a) – AB-QM (Danfloss); b) – Kombi-FC (Honeywell); c) – Ballorex Dynamic (Broen); d) – 42-36 (Samson)

constant hydraulic resistance guarantees a constant flow through it. Water flow regulators provide maintaining of a range of flow rates at the expense of change of hydraulic resistance of the throttling element during the adjustment process. The throttling element's pressure difference is maintained constant. In fact, an automatic water flow regulator combines two devices - a balancing valve and a differential pressure regulator that closes with an increase in the maintained value. But these apparatuses intended for functioning with the continuous supply of working liquid because a principle of their operation is based on control of supply depending from pressure of working liquid and in case of unstable working or periodical turning on and turning out of a pump of the hydraulic system there is need some time for adjustment of its working parameters. All this will lead to decrease of functioning efficiency of a hydroponic installation in case of introduction of the direct-acting flow regulator.

The next type of apparatuses for supply control are distributors for fuel components of liquid-propellant engines (fig. 4). Their features are: functioning in course of short time and with high productivity, using in their design of heat and intensive loading resistant materials, high price. So, these apparatuses are not quite suitable for operation in structure of hydroponic complexes.

Therefore, as we can see available apparatuses for control of supply of working liquid

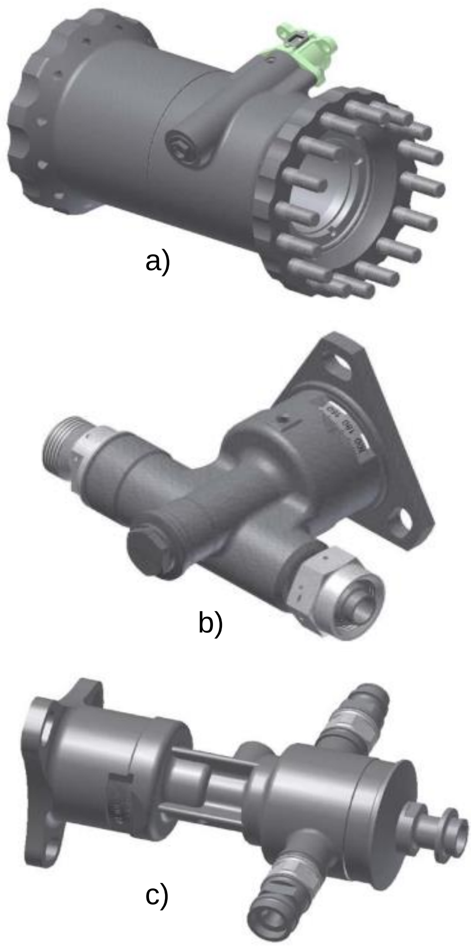

Fig. 4 Photos of control apparatuses for liquid-propellant engines: a, b) – hydraulic throttle for flow regulation with electric drive; c) – two-speed throttle of cam type for turning over from main engine's regime into a throttling regime

do not correspond to demands for their using in composition of hydroponic installations.

Purpose formulation. A purpose of the article there is elaboration and research of an apparatus for effective and accurate control of supply of nutrients for hydroponic installations in course of batching of different crops.

Presentation of main material. With examination of advantages and disadvantages of above analyzed known equipment here were elaborated demands for apparatuses for control of supply nutrients:

1. A possibility of control with help of one apparatus of open flow area of several throttles for supply of different nutrients.
2. A possibility of an automatic stepless and accurate change of the throttles open flow areas.
3. A possibility of previous determination of a necessary movement of an executive element of the throttle for provision of given supply of the corresponding nutrient.
4. A possibility of functioning in a continuous and in a periodical regime of supply, with a quick change of given supply in any moment of time.
5. A possibility of a change of supply regardless of pressure of nutrients in the hydraulic system.
6. A simple and reliable design of the apparatus, its creation on the base of standardized and normalized elements.

With consideration of these demands there was elaborated a scheme of an improved apparatus for control of supply of nutrients for hydroponic installations. Scheme of this apparatus is presented on fig. 5.

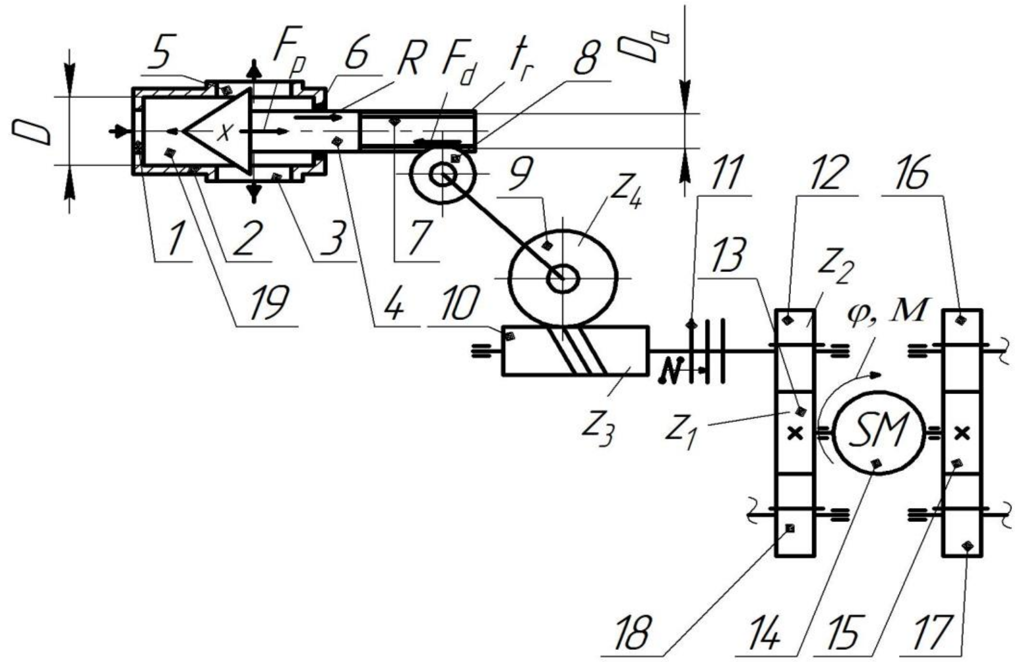

Fig. 5 Scheme of an improved apparatus for control of supply of nutrients for hydroponic installations: 1 – input cavity; 2 – case; 3, 5 – output cavities; 4 – throttle; 6 – sealing; 7 – rack; 8, 12, 13, 15, 16, 17, 18 – gears; 9 – worm gear; 10 – worm; 11 – electromagnetic coupling; 14 – stepper motor; 19 – control cavity

A nutrient moves from the cavity 1 of the apparatus, through the cavities 19, 5 and further in the hydroponic installation. An orifice size between the cavities 19 and 5 is regulated with help of the throttle 4, that can moved in the case 2 in an axial direction. The movement of the throttle 4 and at once change of the nutrient's supply are adjusted with help of the stepper motor 14. In case of necessity of supply regulation, there is turned on the motor 14 and the friction coupling 11 with an electromagnetic control. As a result a rotation from the stepper motor 14 is transmitted through gears 13, 12 (the gear 12 is movable), worm gearing 10, 9 and rack transmission 8, 7. Actually the rack 7 connected directly with the throttle 4. The step of a standardized stepper motor can amount 0,5 – 2,0^{o} [7]. This rotation is provided with high precision and with frequency up to 1000 – 2000 Hz [8], so we have a possibility of accurate and quick regulation of nutrient's supply. From the same stepper motor 14 and through gears 13, 18, 15, 16, 17 (the gears 18, 16, 17 can be introduced in engagement with gears 13 and 15 with help of electromagnetic couplings, that are analogous to coupling 11). Rotation from the gears 16, 17, 18 is transmitted to an analogous throttle (see position No 11 at the fig. 5) and through analogous cinematic chains. As a result, from one stepper motor 14 can be realized an independent control of supply for up to eight various nutrients. So, this apparatus corresponds to above formulated demands.

Movement *x* of the throttle 4 depending from turning angle φ of stepper motor's shaft can be found by formula

$$x = \varphi \frac{z_1}{z_2}\frac{z_3}{z_4} t_p, \quad (1)$$

where z_1, z_2 – amounts of teeth of gears 13, 12; z_3, z_4 – amounts of worm entry 10 and teeth of the worm gear 9; t_p – step of the rack 7.

The speed *v* of the throttle's movement can calculate as

$$v = n \frac{z_1}{z_2}\frac{z_3}{z_4} t_p, \quad (2)$$

where *n* – linear rotation frequency of the stepper motor's shaft.

Then, change of nutrient's supply *ΔQ* corresponding to the movement *x* we can define

$$\Delta Q = \pi \cdot D \cdot x \cdot v_l, \quad (3)$$

where *D* – diameter of the cavity 19; v_l - middle speed of nutrient in this cavity.

Value of ΔQ we can also determine depending from a maximal nutrient's supply – Q_{max} in case of full opening of the throttle's orifice size (its corresponds to the nominal supply of a pump of the hydroponic installation). In this case we use the formula

$$\Delta Q = \frac{\pi \cdot D \cdot x \cdot Q_{max}}{\pi \cdot D \cdot x_{max}}, \quad (4)$$

where· x_{max} – a maximal opening of the throttle's orifice size.

Equation of movement of the throttle 4 in course of change of supply and relatively axle *x* (see fig. 5) can be presented as

$$-m\ddot{x} = F_d - F_p - R;\ 0 \le t \le t_r, \quad (5)$$

where *m* – mass of the executive element of the throttle 4; F_d – driving force, that makes an impact at the executive element 4 from the rack transmission (see below); F_p – a force, created by difference of pressures of nutrient at the executive element 4; *R* – force of friction in the sealing 6 of the throttle 4; t_r – time of regulation of the throttle's orifice size.

The driving force F_d we can find by the formula

$$F_d = M \cdot \eta_e \eta_c \eta_b^3 \eta_g \eta_w \eta_r \frac{z_1}{z_2}\frac{z_3}{z_4}\frac{1}{D_a}, \quad (6)$$

where *M* – a turning moment at the shaft of the stepper motor 14; $\eta_e, \eta_c, \eta_b, \eta_g, \eta_w, \eta_r$ – coefficients of efficiency of stepper motor 14, electromagnetic coupling 11; ball-bearings in the drive (three pairs), gearing 13, 12, worm gearing 10, 9, rack transmission 8, 7 [8, 10]; D_a – dividing diameter of the gear 8 [8]

A formula for definition of the force F_p we can get from the known dependence [9]

$$Q_n = \mu \frac{\pi \cdot D^2}{4} \sqrt{\frac{2\Delta p}{\rho}}, \quad (7)$$

where Q_n – nominal supply of nutrient; μ – a coefficient of supply at the throttle 4 [11]; Δp – difference of pressures, that creates the force F_p; ρ – a density of nutrient.

So, from the formula (7) we can determine

$$F_p = \Delta p \frac{\pi \cdot D^2}{4} = \frac{\rho}{2}\left(\frac{4 \cdot Q_n}{\mu \cdot \pi \cdot D^2}\right)^2 \frac{\pi \cdot D^2}{4} = \frac{2 \cdot {Q_n}^2 \rho}{\mu^2 \cdot \pi \cdot D^2}. \quad (8)$$

The force R one can calculate as [11]

$$R = 0{,}1 \cdot F_d. \quad (9)$$

Conclusions. 1. For wide and effective introduction of hydroponic installations there is need to provide separate and accurate regulation in wide range of supply of main nutrients (nitrogen, potassium, sulfur, calcium, magnesium, phosphorus, natrium), and also microelements, acids, salts depending from kinds of crops and from actual content of the nutrients in their leaves.

2. Known apparatuses for change of supply of working liquids (throttles and flow governors with manual control, direct-acting flow regulators, control apparatuses for liquid-propellant engines) are not correspond to main demands for an efficient control equipment of hydroponic installations: a possibility of automatic control of supply of several nutrients with help of one apparatus; functioning in a continuous and in a periodical regime of supply, with quick change of supply's value in any moment of time; a possibility of supply change regardless of pressure of nutrients in the hydraulic system; simple and reliable design of the apparatus, its creation on the base of standardized and normalized elements.

3. With consideration of these demands there was elaborated a scheme of an improved apparatus for control of supply of eight various nutrients for hydroponic installations.

4. There are presented formulas and equations for determination of basic parameters of the improved apparatus: movement and speed of its executive element in course of regulation' process, change of nutrient's supply, loading at the executive element. These dependencies can be used for creation of a method of design calculation of automatic high efficient control equipment for optimal nutrients supply of hydroponic installations.

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РОЗРОБКА ТА ДОСЛІДЖЕННЯ АПАРАТУРИ УПРАВЛІННЯ ГІДРОПОННИХ УСТАНОВОК

Впровадження гідропонних установок є перспективним напрямом сільського господарства, оскільки вони дозволяють отримувати цілий рік свіжі овочі, фрукти та зелень, у тому числі їх екзотичні для деяких регіонів види. Для досягнення високої ефективності цього обладнання (мінімальних витрат енергії, матеріалів та часу, максимальної продуктивності рослин) важливо забезпечити рослини оптимальною кількістю елементів живлення (азотом, калієм, сіркою, кальцієм, магнієм, фосфором, натрієм), мікроелементами (залізом, бором, йодом, міддю, цинком, кобальтом, молібденом, марганцем), кислотами, солями. При цьому концентрація деяких із цих добавок може становити кілька міліграмів. Таким чином, актуальним завданням є дозування компонентів поживних речовин. Існує кілька варіантів обладнання для точного дозування рідких розчинів: клапани з електроуправлінням для подачі палива в реактивні двигуни (мають високу вартість через використання в їхній конструкції дорогих матеріалів), гідродвигуни з періодичними поворотами виконавчого елемента на кут менше 360° (не забезпечують точного регулювання кута повороту) та лінійні електрогідравлічні приводи (мають інше призначення та конструкцію, що потребує доопрацювання). Автори пропонують схему вдосконаленого апарату для точного дозування компонентів поживних речовин гідропонної установки, створеного на базі лінійного електрогідравлічного двигуна. Апарат має просту та надійну конструкцію та забезпечує можливість високоточного дозування компонентів поживних речовин. Наведено рівняння та формули для визначення основних робочих параметрів апарату, які можуть бути використані для створення методики його проектного розрахунку.

Ключові слова: гідропонна установка, мінімальні витрати енергії, поживні речовини, точне дозування, лінійний електрогідравлічний привод.

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