DESIGN AND TESTING OF ELECTRONIC CIRCUITS TO IMPROVE PERFORMANCE OF AUTOMATIC ADJUSTMENT SYSTEMS WHICH EQUIP SPRINKLING MACHINERY

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Abstract. The use of electronic regulators, in order to correlate the working parameters at sprinkling machines, requires a study to assess the performances of the regulation process in working conditions. Given that the parameters to be correlated are physical sizes, the equipment must be fitted with appropriate sensors to perform the conversion into electrical sizes. Processing the input information, present in the form of electrical voltages, can be achieved only by a specialized circuit of comparator type. To operate properly the liquid flow control valve, this circuit will have to generate different commands in the form of electrical signals. Having low values, these signals are not at the required level to operate the electric motor used for actuating the control valve. Therefore, it is necessary to amplify them to an appropriate level by a power amplifier. The amplifier must be able to put the motor rotor in short-circuit mode with the cancellation of each adjustment command. This mode of operation ensures strong braking and stoppage almost instantaneously of the rotor. This fact has favourable consequences on accuracy of flow adjustment. For optimum operation of the equipment, the design of these circuits was done so as to ensure a maximum sensitivity by eliminating self-oscillating work regimes. Experiments were performed simulating on adequate stands the real working process of a sprayer, equipped with such a regulator. Testing in laboratory conditions has the following purposes: checking the functioning of some important electronic circuits, which are components of the adjusting system; establishing the performances of the adjustment system, from the point of the quality of the adjusting process. Analysis of the obtained results from the tests demonstrates that the hysteresis of the comparator circuit is10 mV, in accordance with the setting, ensuring a good sensitivity during operation and also the elimination of the over-adjustment phenomenon. Amplifying the signals at the 9 V value, the power amplifier ensures a proper reversal of the sense of rotation of the actuating electric motor and putting in short-circuit mode for its quick stop. Due to the correct operation of the designed circuits, the adjustment function is performed correctly, the deviation from the prescribed adjustment report being just 0.2 %.

Keywords: machines, system, circuits, adjustment, flow.

Introduction

The fact that the parameters which need to be correlated in the operation of the adjusting system are physical sizes (displacement velocity, liquid flow, work width), shows that it must be equipped with suitable transducers (which covert these physical sizes into electrical sizes). Thus, the transducers used for measuring the displacement velocity and liquid flow (which are digital type) ensure following the transfer function [1-3]:

$$f_V = v \cdot K_{1V}^{-1}; \; f_Q = Q \cdot K_{1Q}^{-1}, \tag{1}$$

where f_V, f_Q – frequencies of impulses generated by the transducers, Hz;
K_{1V}, K_{1Q} – coefficients of proportionality.

After the conversion of these signals into analogical sizes results [3-5]:

$$U_V = K_{2V} \cdot f_V, \tag{2}$$

$$U_Q = K_{2Q} \cdot f_Q, \tag{3}$$

where U_V – continuous voltage at the output of the displacement velocity transducer, mV;
U_Q – continuous voltage at the output of the liquid flow transducer, mV;
K_{2V}, K_{2Q} – coefficients of proportionality.

To determine the structure of electronic circuits of the equipment we will take into account the relationship of calculation the liquid rate (N) [4; 6]:

$$N = \frac{Q}{B \cdot v} = \frac{K_{1Q} \cdot K_{2V}}{K_{1V} \cdot K_{2Q}} \cdot \frac{U_Q}{U_V \cdot B}, \tag{4}$$

Concerning the relation (4), the following specifications are made [4].

It will be noted:

$$U_Q^{/} = \frac{U_Q}{N \cdot B}.$$

The coefficients of proportionality are chosen so that:

$$\frac{K_{1Q} \cdot K_{2V}}{K_{1V} \cdot K_{2Q}} = 1.$$

Given the notations made, relation (4) becomes:

$$U_Q^{/} = \frac{U_Q}{N \cdot B} = U_V. \quad (5)$$

The relationship (5) shows the following.

1. Voltage U_V (corresponding to displacement velocity) must be compared with a fraction of voltage U_Q (corresponding to the liquid flow), the division factor being ($N{\cdot}B$); liquid rate (N) and work width (B) are prescribed sizes.
2. For achieving the adjusting function the equipment must contain a comparator circuit, able to compare the two electrical signals.

Taking into account the theoretical considerations made, a block scheme was developed for the automatic adjustment system, used for correlating the two working parameters: displacement velocity and liquid flow (Fig. 1) [4; 7].

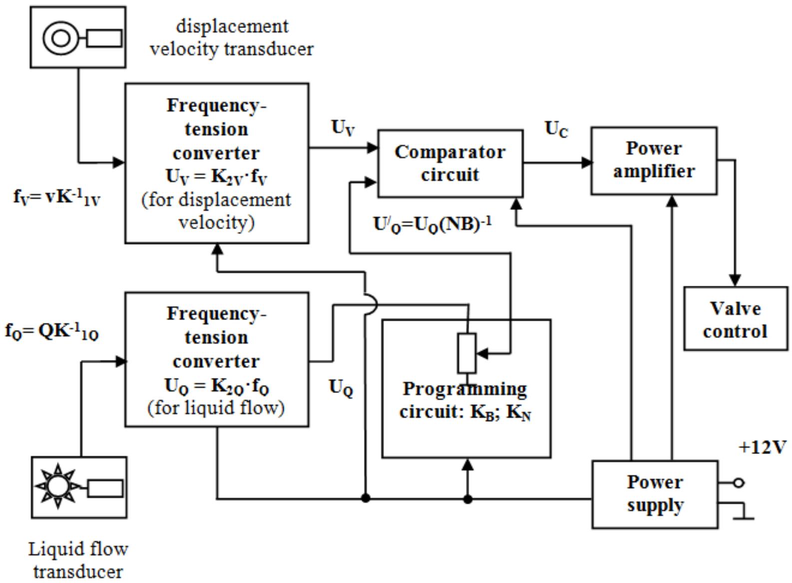

Fig. 1. **Block scheme of the automatic adjusting system of liquid flow with displacement velocity**

Materials and methods

In accordance with relations (2) and (5), the comparator circuit has the role of processing the input information, presented in the form of voltages (U_V, $U_Q^{/}$) and generating at the output commands that will be applied to the electric motor for actuating the liquid flow control valve (for the purpose of closing or opening). Therefore, the comparator circuit must generate these two distinct commands, in the form of electrical signals, which will be amplified by the power amplifier of the equipment (at an appropriate level for electric motor operation) [8; 9].

Considering that in the operation of the sprayer slight variations in speed and flow occur, it is necessary that the equipment does not react to these small changes. Too high sensitivity of a comparator circuit would also include these slight variations in the process of generating orders to the electric control valve (existing the risk of triggering self-oscillating work regimes).

Thus, for optimum operation of the equipment, the comparator circuit should combine the conservation of maximum sensitivity with the elimination of the possibility of occurrence of some self-oscillating work regimes [5; 10].

Taking into account the relationships (2-5), the design of the comparator circuit was based on the following transfer functions:

For stationary regime ($\Delta U_H \neq 0$): $|U_V - U'_Q| < \Delta U_H$; $U_C = U_{C0} = 0$;

For the command regime of the control valve (transitive regime, $\Delta U_H = 0$):

$$U_V > U'_Q \rightarrow U_C = U_C \, ,$$

$$U_V < U'_Q \rightarrow U_C = U_{C2},$$

$$U_V = U'_Q \rightarrow U_C = U_{C0},$$

where U_{C1} – the signal at the output of the comparator circuit, which controls the adjusting valve for increasing the liquid flow, mV;

U_{C2} – signal at the output of the comparator circuit, which controls the adjusting valve to decrease the liquid, mV;

U_{C0} – zero control voltage, at the output of the comparator circuit (0 volts);

$\Delta U_H = |U_V - U'_Q|$ – hysteresis voltage of the circuit, the difference between voltages U_V and U'_Q, for which the comparator circuit does not generate any commands, mV.

Functioning on the basis of these transfer functions ensures in the case of transitional regimes (when the equipment ensures the effective correlation of the liquid flow with displacement velocity) a maximum sensibility ($\Delta U_H = 0$). From the moment when $U_V = U'_Q$ (the programmed working regime), voltage is introduced ($\Delta U_H \neq 0$ – hysteresis of the circuit), which triggers the stationary working regime (in which slight variations of U_V or U'_Q voltages do not generate any commands over the adjusting valve). A new adjustment command will be triggered, if these variations exceed those permissible ($|U_V - U'_Q| > \Delta U_H$) [5].

Signal inputs of the comparator circuit are represented by the inputs of the integrated circuits IC_1 and IC_2, mounted as repeaters (to increase the input impedance and also to achieve small output impedances). The outputs of the circuit are made with IC_3 and IC_4 integrated circuits (marked with A and B). Depending on the states of the outputs, the following working regimes can be identified [8]:

1. stationary regime (not generated any command in the sense of changing the liquid flow value): $U_{output\ A} = 0$; $U_{output\ B} = 0$; in this case the transistor T_2 is blocked, transistor T_3 is open and the voltage ΔU_H is present (the constant current generator is active);
2. transitive regime ($\Delta U_H = 0$, situation in which the transistor T_2 is open and the transistor T_3 is blocked): $U_{output\ A} = U_{C1}$ (generated the command in the sense of increasing the value of the liquid flow); $U_{output\ B} = U_{C2}$ (generated the command in the sense of decreasing the value of the liquid flow).

This state exists until the control voltage in points A or B disappears ($U_V = U'_Q$); at this moment the integrated circuit IC_5 is activated (the constant current generator is active), which maintains ΔU_H voltage for a period of time. This way of working allows the elimination of some self-oscillations of the circuit, when switching on ΔU_H voltage.

If $|U_V - U'_Q| \geq \Delta U_H$, the ΔU_H voltage is cancelled (the comparator has maximum sensitivity). Voltages U_{C1} or U_{C2} appear at the circuit outputs, which determines the increase or decrease of the liquid flow to the prescribed value ($U_V = U'_Q$). At this point the ΔU_H voltage is generated again and the operation of the comparator circuit enters again in stationary regime (until a new flow correction) [5; 9].

We must take into account the fact that the control signals generated by the comparator circuit (voltages U_{C1} and U_{C2}) have low values and are not at the required level to operate the electric motor (used for actuating the control valve). Also, to make a precise correction, it is necessary to reverse the sense of rotation of the electric motor. To solve these two problems the presence of a power amplifier is required.

The power amplifier has two independent channels (for the two signals that must be amplified, U_{C1} and U_{C2}). Signal amplification is performed using transistors T_2, T_3 and the relays R_I, R_{II}. Diodes D_1, D_2 protect these transistors against self-induction currents (that appear when switching).

For reversing the sense of rotation of the electric motor the relays R_I, R_{II} have three pairs of contacts (K_{11}, K_{12}, K_{21}, K_{22}, K_{13}, K_{23}). The contacts K_{13} and K_{23} normally closed (connected in series) put into short circuit the motor rotor (for $U_{C1} = 0$, $U_{C2} = 0$) [11].

In accordance with the operating principle established, Fig. 2 shows the electronic scheme of the two important designed circuits, as well as how to interconnect with the other components of the adjusting system. For checking the operation of the designed circuits, the other connected components were:

1. the speed transducer, for which the frequency variation range of signal applied to the input is 16-60 Hz (corresponding for displacement velocities of 1.11 to 2.78 $m \cdot s^{-1}$); it was also considered that to ensure the linear operation of the converter, it is necessary that the maximum voltage at the output must be limited to 5 V (corresponding to a maximum displacement velocity of 2.78 $m \cdot s^{-1}$) [3; 10];
2. the liquid flow transducer (having a flow rate coefficient of 10 cm^3 per impulse); the range of variation of the generated frequencies is 16.6-166.6 Hz (for which the work domain of the transducer is in the range 10-100 $l \cdot min^{-1}$ [10; 12; 13];
3. the programming circuit of the liquid rate (N) and working width (B), consisting of two divisor circuits mounted in cascade; by dividing the function $U'_Q = f(f_Q)$, different values can be selected for the two working parameters.

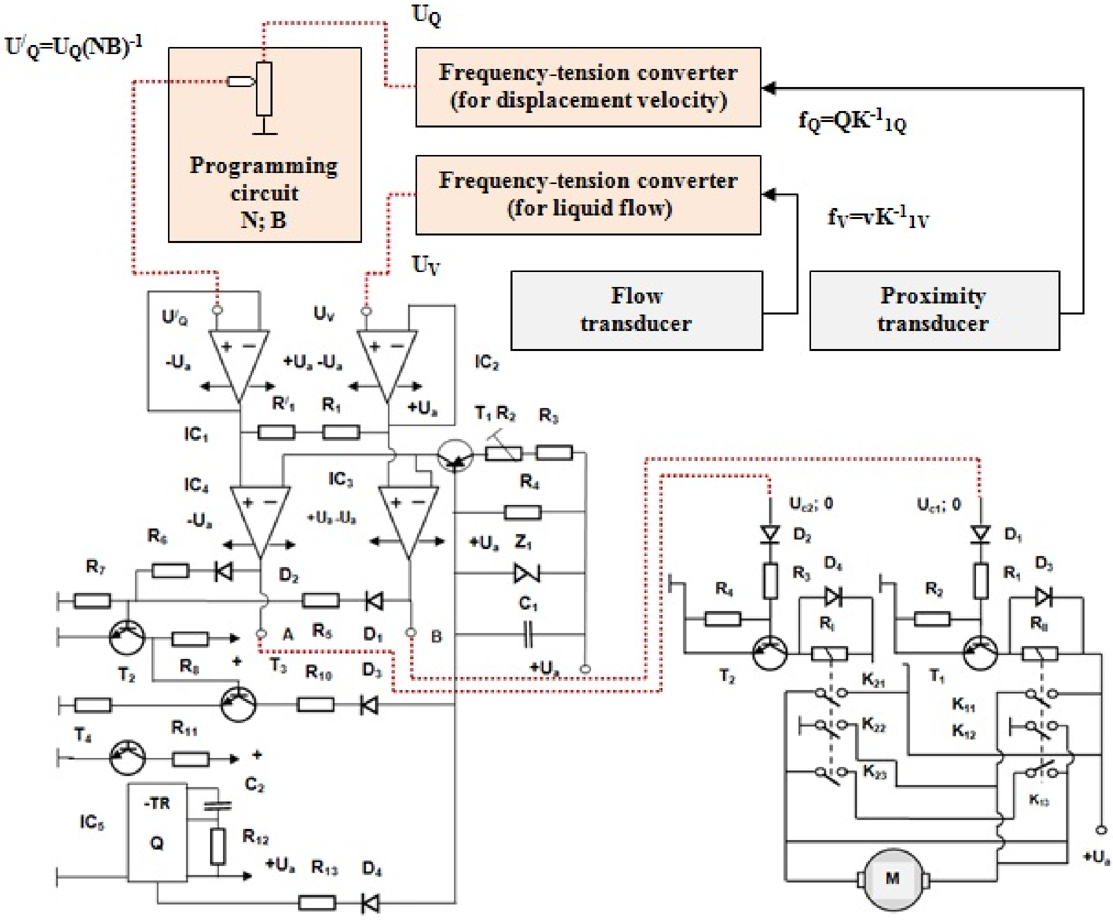

Fig. 2. **Electronic scheme of the comparator circuit, power amplifier and the connections with the other components of the adjusting system**

For checking the functioning of the designed circuits a test stand was used equipped with two signal generators, for which the signal output level was set to 200 mV (signal that was applied to the inputs of the speed and liquid flow transducers) (Fig. 3).

Using a digital voltmeter the status of the two outputs of the comparator was monitored (depending on the difference between the input voltages U_V and U'_Q) [5; 8]. The tests were performed for the following values from the range of working voltages of the transducers: $U_V = 700$ mV; $U_V = 4000$ mV; $U_V = 8000$ mV.

Checking the operation of the power amplifier consisted of the following:

- monitoring the operating mode of the electric motor to observe if the reversing sense of rotation is ensured;
- fast engine shutdown (by putting the rotor in short-circuit mode), when the adjustment command is cancelled ($U_V = U'_Q$), to avoid the phenomenon of over-regulation.

In the experiments also the adjustment feature of the automatic adjusting system of liquid flow with displacement velocity was verified (using the same stand). In this case, the adjustment function is carried out via a reaction circuit (which physically consists of the flow control valve and the flow transducer – by which the compliance with the prescribed value is controlled).

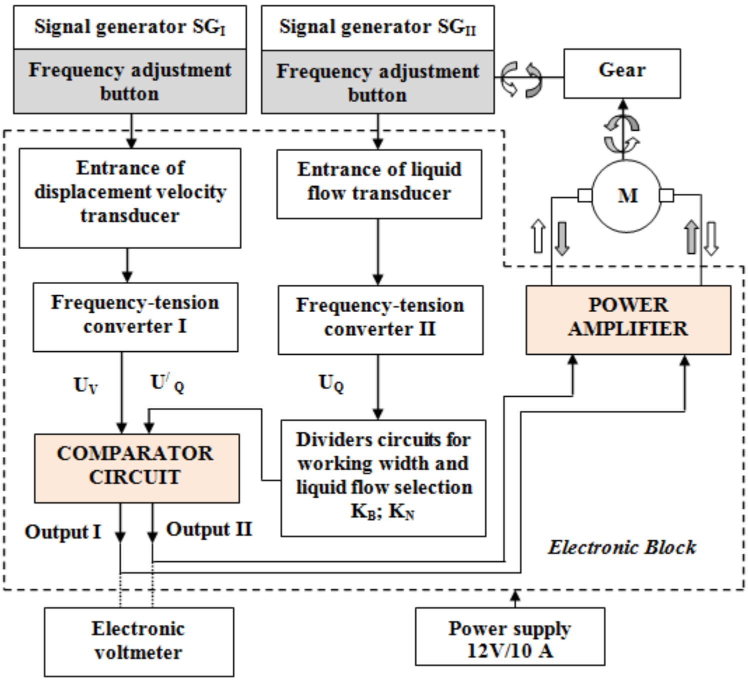

Fig. 3. **Stand for checking the operation of the comparator circuit, power amplifier and the entire adjusting system**

Results and discussion

Based on the results obtained, Fig. 4 shows the diagram of the voltages at different points of the comparator circuit.

From the analysis of the diagram it is observed that:

1. in stationary regime, hysteresis voltage (ΔU_H) is present and if $\Delta U = |U_V - U'_Q| < \Delta U_H$, the circuit does not generate any commands ($U_{C1} = 0$, $U_{C2} = 0$);
2. if $\Delta U = |U_V - U'_Q| \geq \Delta U_H$, the ΔU_H voltage is cancelled and the circuit commands the change of the liquid flow value up to the prescribed value ($U_V = U'_Q$); at this moment voltage ΔU_H is generated again, until a new correction will be required.

The operation of the comparator circuit was performed for the following values from the range of working voltages of the transducers: $U_V = 700$ mV (Fig. 5); $U_V = 4000$ mV (Fig. 6) and $U_V = 8000$ mV

(Fig. 7). In all three cases, the results of laboratory tests show that by changing the value of the frequency applied at the input of the flow transducer, the following can be observed:

1. if $U'_Q = U_V + 5$ mV: the output 1 passes into state UP (9 V), output 2 remains in DOWN state (0 V); if the frequency value is modified in the opposite way, the output 1 returns to the state DOWN (0 V), when $U_V = U'_Q$;
2. if $U'_Q = U_V - 5$ mV: the output 2 passes into state UP (9 V), output 1 remains in DOWN state (0 V); switching of the output 2 in DOWN state (0 V) occurs, if the frequency value is modified in the opposite way, also when $U_V = U'_Q$.
3. the circuit is working properly, hysteresis voltage being 10 mV.

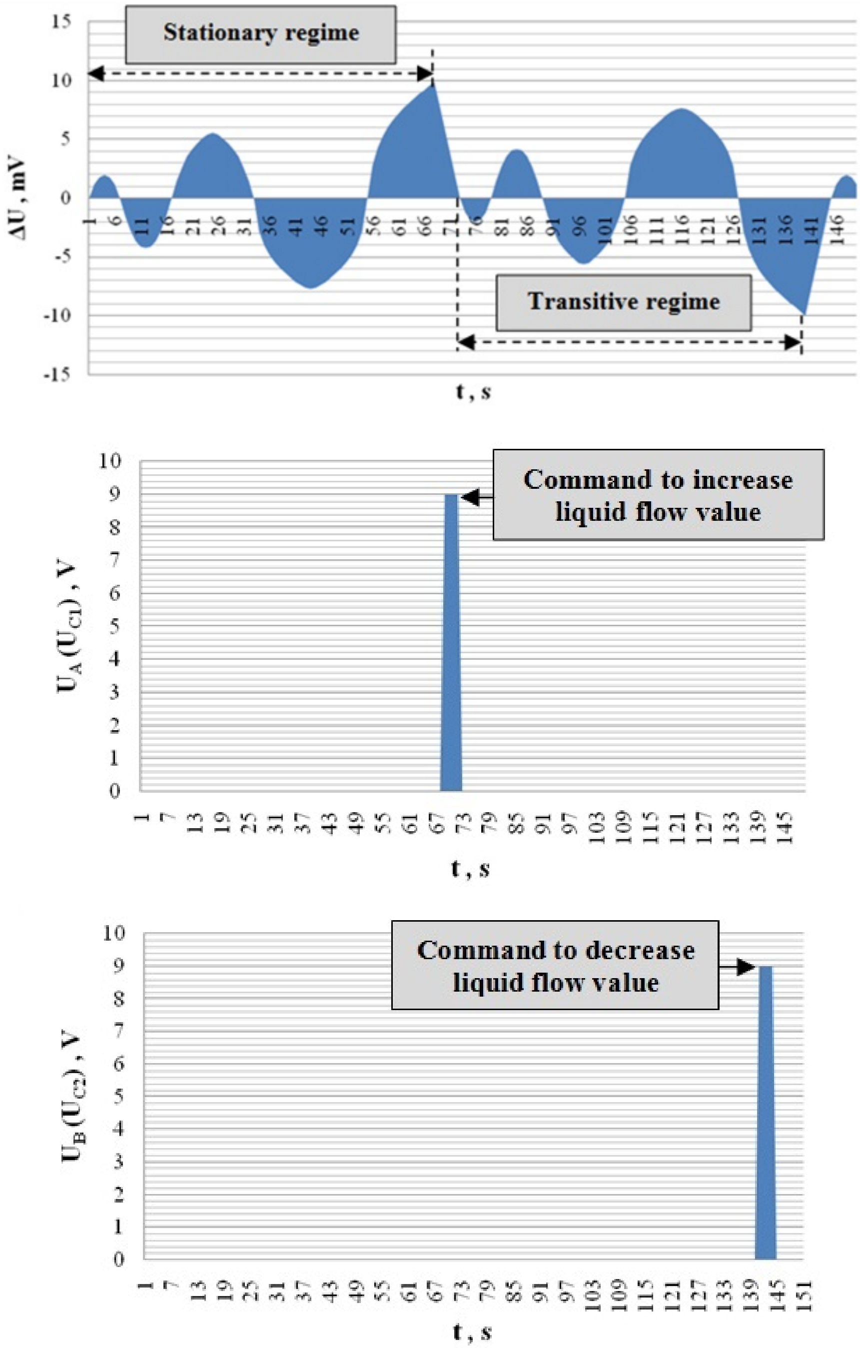

Fig. 4. **Diagram of the voltages at different points of the comparator circuit**

Checking the states of the power amplifier outputs highlighted its optimal functioning (Table 1). It demonstrates that the motor operation is accurate. The motor is stopped promptly, when the control command is cancelled.

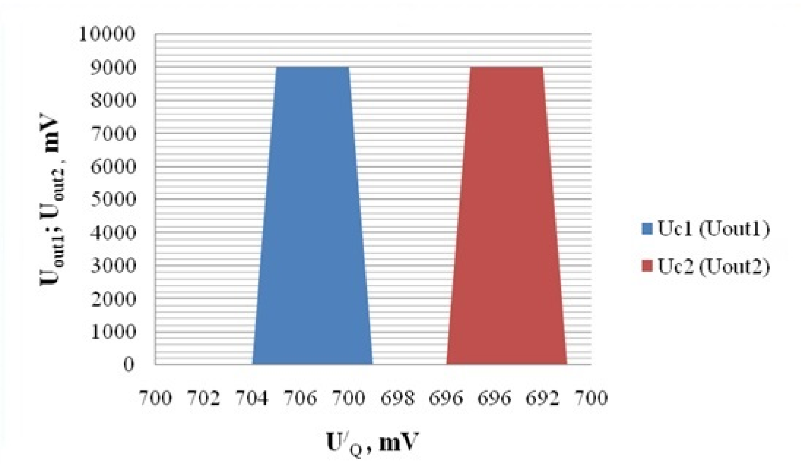

Fig. 5. **Sates of the outputs of the comparator circuit for U_V = 700 mV**

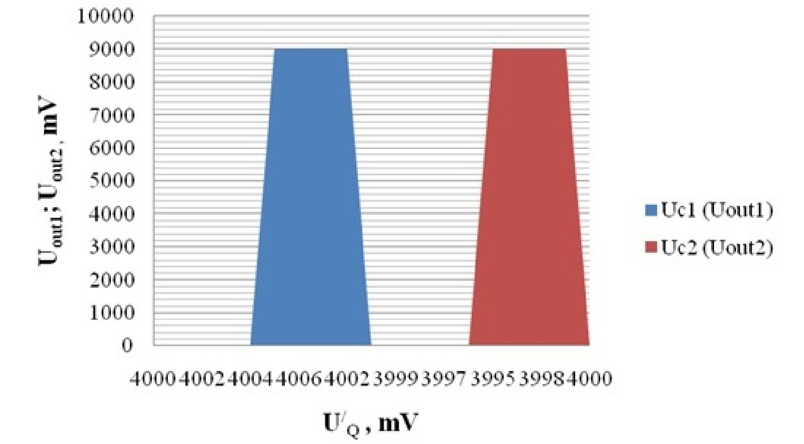

Fig. 6. **States of the outputs of the comparator circuit for U_V = 4000 mV**

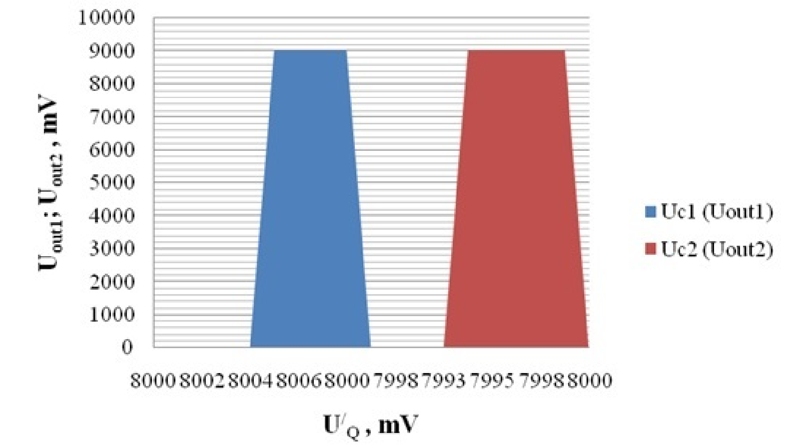

Fig. 7. **States of the outputs of the comparator circuit for U_V = 8000 mV**

Table 1

Results obtained for checking the functioning of the power amplifier

Output status of the comparator circuit		Electric motor	Value of the liquid flow
Output 1,V	**Output 2, V**		
DOWN (0 V)	DOWN (0 V)	not rotating	constant
UP (9 V)	DOWN (0 V)	rotating to the left	decrease
DOWN (0 V)	UP (9 V)	rotating to the right	increase

The test results concerning the adjusting characteristic ensured by the automatic adjusting system are shown in Table 2 and the graph of Fig. 8.

Table 2

Test results on stand of the automatic adjusting system

f_v, Hz	16.00	20.00	24.00	28.00	32.00	36.00	40.00
v, m·s^{-1}	1.11	1.39	1.67	1.95	2.23	2.51	2.78
f_Q, Hz	28.30	35.40	42.48	49.58	56.60	63.70	71.00
Q, l·min^{-1}	16.98	21.24	25.48	29.74	33.96	38.22	42.60
Q/v	**4.230**	**4.230**	**4.230**	**4.230**	**4.229**	**4.228**	**4.240**

Analysis of the results reveals that the report (*Q*/*v*) is approximately constant, deviation for the considered example being insignificant (0.2 %). This indicates that the adjustment function is ensured in good conditions.

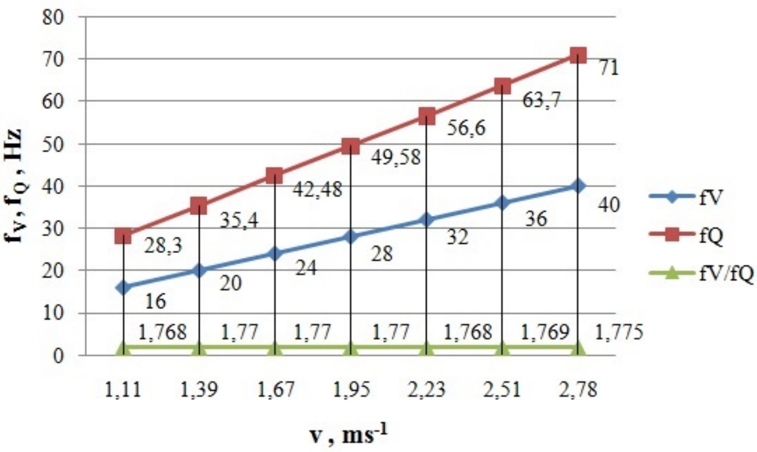

Fig. 8. **Adjusting characteristic ensured by the automatic adjusting system**

During the tests, it was found that: operating the button to adjust the frequency value corresponding to the displacement velocity (f_v), automatically determines the actuation of the knob for adjusting the frequency value, corresponding to the liquid flow (f_Q); thus, the ratio of the two working frequencies (f_v/f_Q) remains permanently constant; it means that the electronic block performs correctly the adjusting function, on the basis of information concerning the displacement velocity and liquid flow (signals provided by the two signal generators: SG_I and SG_{II}).

Conclusions

1. The comparator circuit ensures good sensitivity during operation and does not determine the appearance of self-oscillating operating regimes; also the size of the hysteresis of 10 mV (at which the circuit was adjusted) is respected during operation.
2. The tests performed for the three values of the working voltages of the transducers (U_V = 700 mV; U_V = 4000 mV; U_V = 8000 mV) showed that by changing the value of the frequency applied at the input of the flow transducer (with 5 mV), the two outputs of the comparator circuit pass into the corresponding states (9 V, 0 V respectively 0 V, 9 V) in order to adjust the flow value.
3. The power amplifier has a stable behavior during the adjustment process, ensuring: a proper amplification of the signals generated by the specific transducers; a proper reversal of the sense of rotation of the actuating electric motor, depending on the requirements imposed; putting in short-circuit the rotor motor with cancellation, once the adjustment command is cancelled (necessary to avoid the phenomenon of over-adjustment).
4. The performance of the adjusting system of the liquid flow with displacement velocity is primarily due to the linear operation of equipment components; thus, for usual frequency values corresponding to displacement velocity (in the range of 16-40 Hz), respectively liquid flow (in the range of 28-71 Hz), the report *Q*/*v* is approximate constant (≅4.23); the adjustment feature

highlights that the adjustment function is performed correctly, the deviation from the prescribed adjustment report (*Q*/*v*) being just 0.2 %.

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