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MODELLING AND AUTOMATION OF PROCESS OF WATER PURIFICATION BY MAGNETIC FILTER

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Abstract. *The model problem of type "convection-mass-transfer" is solved for the process of cleaning of water mediums in the grainy magnetized filter material. The mathematical analysis of parameters and model of process of the magnetic sediment of admixtures was done. The system of automation of process of permanent water purification from magnetic admixtures was worked out.*

Keywords: magnetic sediment, computer design, automation of process of filtration

MODELOWANIE I AUTOMATYZACJA PROCESÓW UZDATNIANIA WODY ZA POMOCĄ FILTRU MAGNETYCZNEGO

Streszczenie. *W artykule rozwiązywany jest model problemu typu „konwekcyjny transport masy” dla procesu oczyszczania w środowisku wodnym w ziarnistym magnetycznym materiale filtrowanym. Opisano matematyczną analizę parametrów i konstrukcję modelu procesu osadzania zanieczyszczeń magnetycznych. Opracowano system automatyzacji procesu ciągłego oczyszczania wody z domieszek magnetycznych.*

Słowa kluczowe: osady magnetyczne, modelowanie komputerowe, automatyzacja procesu filtracji

Introduction

Technological water systems of many industries of industry, as known, are soiled by different kind of admixtures. Pointedly this problem stands in thermal and nuclear power industry (heat electro power station, thermal power plant, and nuclear power generation station), chemical, metallurgical, glass, spirit, ceramic, aviation industries. Principal reason of presence of admixtures in the water technological systems is continuous corrosion of technological and of communication equipment. In circulating (sewer) waters of metallurgical productions the concentration of dispersed particles are at 100 mg/l, at a norm 10 mg/l. Such high concentration of particles causes the rapid wear of technological equipment, impairment of quality of products that is produced. For moving away of ferromagnetic admixtures from technological water systems it is offered to use the method of the magnetic sediment of admixtures in the magnetized grainy filter material. Advantages of this method are a possibility of purification of water environment with a temperature to 500°C, with speed of filtration to 1000 m/h, possibility to clear chemically aggressive mediums. The regeneration of grainy ferromagnetic filter materials does not need chemical reagents that make the method of the magnetic cleaning ecologically safe.

1. Statement of the problem and its relationship to important scientific and practical tasks

1.1. Analysis of recent research and publications, which discuss current issues

It is determined by numerous researches, that a great bulk of admixtures is ferriferous with ferromagnetic properties [1, 2, 5, 7]. Deposit of admixtures on the steam generating surfaces of caldrons of the thermal stations in an amount in all 200–300 g/m^2, that corresponds to the thickness of sedimentations 0,3–0,5 mm, stipulates the additional overheat of pipes on 50–120°C, that in special cases causes over flame and breaks of pipes.

Experimental researches are known with determination of influence of parameters of process of the magnetic cleaning on the coefficient of the magnetic sediment, concentration of ferriferous admixtures, period of filter cycle [1, 5, 7]. The actual problem is a mathematical analysis of parameters and design of process of the magnetic sediment of admixtures at cleaning of the both multiconcentrated and littleconcentrated water systems and automation of corresponding process of cleaning.

1.2. Highlight of the unsolved aspects of the problem

According to the above studies, the work shall be considered and resolved the model problem of type "convection–mass-transfer" for the process of cleaning of water mediums in the grainy magnetized filter material and developed The system of automation of process of permanent water purification from magnetic admixtures was.

1.3. Formulation of the problem

In this article we considered and resolved the model problem of type "convection–mass-transfer" for the process of cleaning of water mediums in the grainy magnetized filter material. The mathematical analysis of parameters and model of process of the magnetic sediment of admixtures was done. The system of automation of process of permanent water purification from magnetic admixtures was worked out.

2. Statement of main research data with full justification of scientific results

We will consider spatially the one-dimensional process of cleaning of liquid by filtration in the layer of grainy filter material with thickness L (what equates with the segment $[0;L]$ of axis $0x$). We assume [3, 4], that the particles of contamination (admixtures) can change from one state in other (processes of fascination-tearing away) and, here, reverse influence of corresponding concentrations takes place on characteristics of the considered layer. Corresponding process of filtration with taking into account reverse influence of characteristics of process (concentrations of contamination of liquid and trapped particles) on characteristics of medium (coefficients of porosity, filtration, mass-transfer, tension of magnetic-field) by analogy from [1–4]) will describe by the next model problem:

$$\begin{cases} \dfrac{\partial\left(\sigma(\rho)c(x,t)\right)}{\partial t}+\dfrac{\partial\rho(x,t)}{\partial t}+v\dfrac{\partial c(x,t)}{\partial x}=0, \\ \dfrac{\partial\rho(x,t)}{\partial t}=\beta(H,v,d)c(x,t)-\varepsilon\alpha(\rho)\rho(x,t), \end{cases} \quad (1)$$

$$c\big|_{x=0}=c_*^*(t),\ \ c\big|_{t=0}=0,\ \ r\big|_{x=0}=0,\ \ r\big|_{t=0}=0, \quad (2)$$

$$v=\kappa(\rho)\cdot grad\ p, \quad (3)$$

where $c(x,t)$ is a concentration of admixtures in a liquid medium that is filtered; $\rho(x,t)$ is a concentration of the admixtures precipitated in grainy filter material; β – a coefficient that characterizes the mass volumes of sediment of admixture particles for time ($\beta(H,v,d)=\frac{\beta_0 H^{0.75}}{vd^2}$ [7], where β_0 is a free parameter, H is tension of magnetic-field, v is speed of filtration, d is a diameter of granules of filtered material), $\alpha(\rho,H)$ is a coefficient that characterizes the mass volumes of torn off admixture particles for the same time from the granules of filtered material:

$$\alpha(\rho)=\alpha_0+\varepsilon\alpha_*\rho(x,t), \tag{4}$$

$c_*^*(t)$ is a concentration of admixture particles on the entrance of filter, $\sigma(\rho)$ is porosity of filtering material (σ_0 is starting porosity of filter material),

$$\sigma(\rho)=\sigma_0-\varepsilon\sigma_*\rho(x,t), \tag{5}$$

$\kappa(\rho)$ – coefficient of filtration, $\rho_0=\rho(L,\tau_з)$,

$$\kappa(\rho)=\begin{bmatrix}\kappa_0-\varepsilon\gamma\rho(x,t), & \rho<\rho_0,\\ \kappa_0-\varepsilon\gamma\rho(x,\tau_з), & \rho\ge\rho_0,\end{bmatrix} \tag{6}$$

$\alpha_0,\alpha_*,\sigma_*,\kappa_0,\gamma,\varepsilon$ – hard parameters (they characterize corresponding coefficients), $\alpha(\rho),\sigma(\rho),\kappa(\rho)$ are variable parameters (are founded by the experience method), ε is a small parameter, p is pressure. We will mark thus, that unlike [3, 4], in more general case pressure $p=p(x,t)$ rationally it would be to determine as a result of decision equalization $\frac{\partial}{\partial x}\left(\kappa(\rho)\frac{\partial p}{\partial x}\right)=\frac{\partial\sigma(\rho)p}{\partial t}$, that is got on the basis of written in higher equalization of motion and equalization of the state: $div\ v=\frac{\partial\sigma(\rho)p}{\partial t}$ at last $p(0,t)=p_*(t)$, $p(L,t)=p^*(t)$ ($0<t<\infty$) and initial $p(x,0)=p_*^*(x)$ ($0<x<L$) terms $p_*(t)$, $p^*(t)$, $p_*^*(x)$ – smooth enough and concerted in angular points areas $G=\{(x,t):0<x<L,0<t<\infty\}$ of function are set. Herewith, in the process of decision of task, we can determine a corresponding value $grad\ p$, in particular – the difference of pressures $\Delta P=p^*(t)-p_*(t)$ on an entrance and exit of filter.

The solutions of the system (1) at terms (2) search as asymptotic rows [2, 3]:

$$c(x,t)=c_0(x,t)+\sum_{i=1}^{n}\varepsilon^i c_i(x,t)+R_c(x,t,\varepsilon),$$

$$\rho(x,t)=\rho_0(x,t)+\sum_{i=1}^{n}\varepsilon^i\rho_i(x,t)+R_\rho(x,t,\varepsilon), \tag{7}$$

where R_c,R_ρ are remaining members, $c_i(x,t)$, $\rho_i(x,t)$ ($i=\overline{0,n}$) are members of regular parts of asymptote.

Like to [6], after a substitution (7) in (1) and application of standard "procedure of equating", for solving the functions c_i and ρ_i ($i=\overline{0,n}$) come to such tasks:

$$\begin{cases}\sigma_0\frac{\partial c_0}{\partial t}+v\frac{\partial c_0}{\partial x}+\frac{\partial\rho_0}{\partial t}=0, & \frac{\partial\rho_0}{\partial t}=\frac{\beta_0H^{0.75}}{vd^2}c_0,\\ c_0\big|_{x=0}=c_*^*(t),\ c_0\big|_{t=0}=0,\ \rho_0\big|_{x=0}=0,\ \rho_0\big|_{t=0}=0,\end{cases} \tag{8}$$

$$\begin{cases}\sigma_*\rho_{i-1}\frac{\partial c_i}{\partial t}+v\frac{\partial c_i}{\partial x}+\sigma_*\frac{\partial\rho_{i-1}}{\partial t}c_i+\frac{\partial\rho_i}{\partial t}=0, & \frac{\partial\rho_i}{\partial t}=\frac{\beta_0H^{0.75}}{vd^2}c_i-g_i,\\ c_i\big|_{x=0}=0,\ c_i\big|_{t=0}=0,\ \rho_i\big|_{x=0}=0,\ \rho_i\big|_{t=0}=0, i=\overline{1,n},\end{cases} \tag{9}$$

where $g_i(x,t)=\sum_{j=1}^{i}\rho_{j-1}\left(\alpha_0+I(i,j)\sum_{j=2}^{i}(\alpha_*\rho_{i-2})\right)$.

Conduct a design in the software environment of Matlab, in particular *M*-function of *pdepe*. For work with the given function will convert systems (8), (9) in an absolute code:

$$\begin{cases}\sigma_0\frac{\partial c_0}{\partial t}+v\frac{\partial c_0}{\partial x}+\frac{\partial\rho_0}{\partial t}=0,\\ \frac{\partial\rho_0}{\partial t}=\beta\cdot c_0.\end{cases}\Leftrightarrow c(x,t,u,\frac{\partial u}{\partial x})\cdot\frac{\partial u}{\partial t}=$$

$$=x^{-m}\frac{\partial}{\partial x}(x^m f(x,t,u,\frac{\partial u}{\partial x}))+s(x,t,u,\frac{\partial u}{\partial x}),$$

Commands in Matlab:

```
function [c, f, s] = pdex2pde (x, t, u, DuDx)
S=200;
V=200;
B=6.1;
c =[S; 1];
f =[0; 0];
s =[- V*DuDx (1) - u (2); B*of u (1)];
```

Initial conditions

$$\begin{cases}c_0(x,t_0)=2,\\ \rho_0(x,t_0)=0.\end{cases}\Leftrightarrow u(x,t_0)=u_0(x)$$

Commands in Matlab:

```
function u0 = pdex2ic (x)
u0 =[2;0];
```

Limited terms

$$\begin{cases}c_0(x_L,t)=2, & \frac{\partial c_0(x_R,t)}{dx}=0,\\ \frac{\partial\rho_0(x_L,t)}{dx}=0, & \rho_0(x_R,t)=0.\end{cases}\Leftrightarrow$$

$$\Leftrightarrow p(x,t,u)+q(x,t)\cdot f(x,t,u,\frac{\partial u}{\partial x})=0$$

Commands in Matlab:

```
function [pl,ql,pr,qr] = pdex2bc(xl,ul,xr,ur,t)
pl = [0; 0];
ql = [1; 1];
pr = [0; 0];
qr = [1; 1];
```

For the call of function of pdepe have a next code:

```
m = 0;
sol = pdepe(m,@pdex2pde,@pdex2ic,@pdex2bc,x,t);
u1 = sol(:,:,1);
u2 = sol(:,:,2);
figure
surf(x,t,u1)
title('c0(x,t)')
xlabel('Distance x')
ylabel('Time t')
shading flat
figure
surf(x,t,u2)
title('p0(x,t)')
xlabel('Distance x')
ylabel('Time t')
shading flat
```

As a result of computer design (at next starting points: $c_*^*(t) = 2$ mg/l, $L = 1$ m, $v = 200$ m/h, $\beta_0 = 0.9 \cdot 10^{-9}$ m²/s, $H = 80$ kA/m, $d = 5$ mm, coefficients $\alpha_0 = 0.28 \cdot 10^{-13}$ m²/s, $\alpha_* = 0.65$, $\varepsilon = 0.01$, $\sigma_0 = 0.5$, $k_0 = 1$) we got next results (see Fig. 1–4).

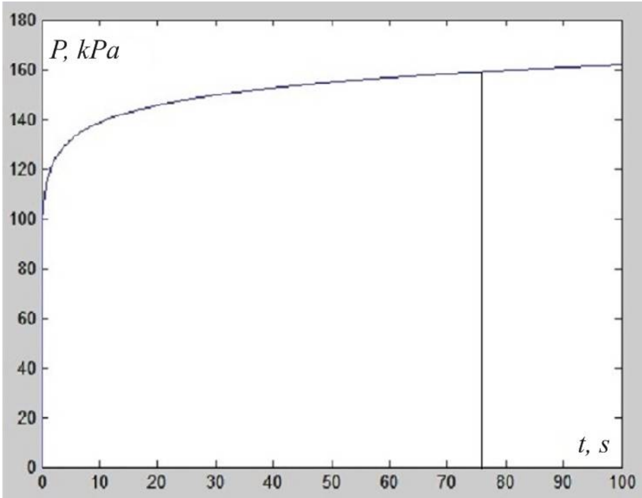

Fig. 1. Change of difference of pressures

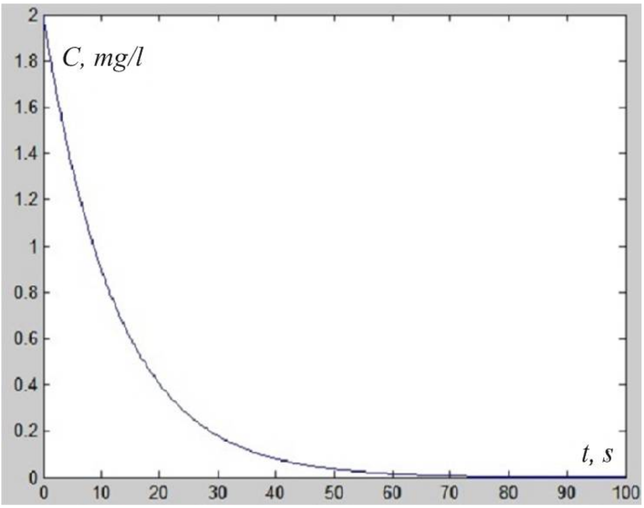

Fig. 2. A change of concentration of particles in solution

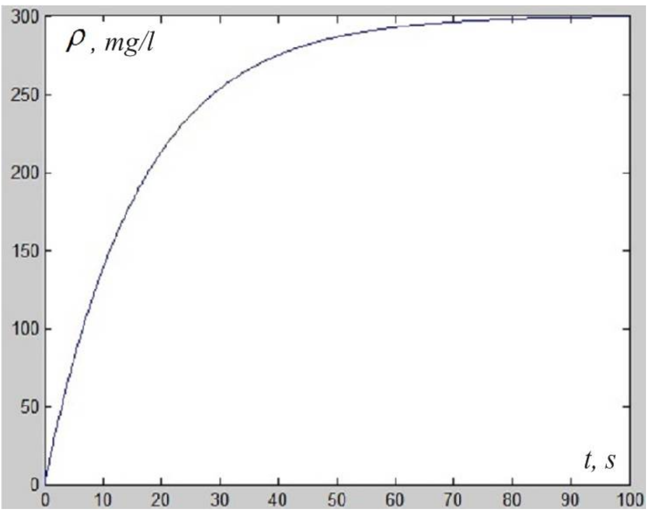

Fig. 3. Change of concentration of particles that admired in a filter

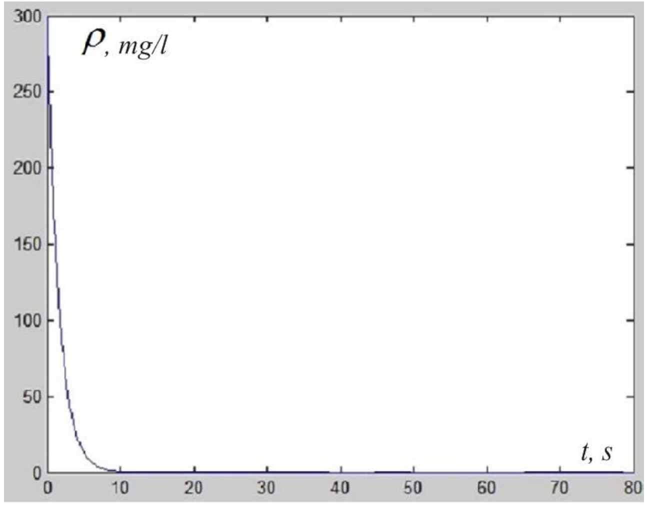

Fig. 4. A change of concentration of particles during cleaning of the filter

Time of protective action of filter is determined in the moment of minimum rejection of pressure (see Fig. 1) for the considered process it equals 76 hours.

From Fig. 3 it is evidently, that a filter takes particles during set time, and farther its efficiency is very small and concentration of parts on the exit of filter falls in course of time, that confirms efficiency of this filter as shown on Fig. 2.

According to Fig. 4, time of cleaning of filter is considerably exceeded by time of work of filter that is why for effective automation it is enough to have a system with 2 filters.

For automation of process of magnetic water purification the functional diagram of automation is worked out. It is presented on Fig. 5, accordingly to that a management the system occurs transferring of stream of filtering liquid between two filters. During filtration is by the working filter, other is "muddy" automatically conducts a regeneration.

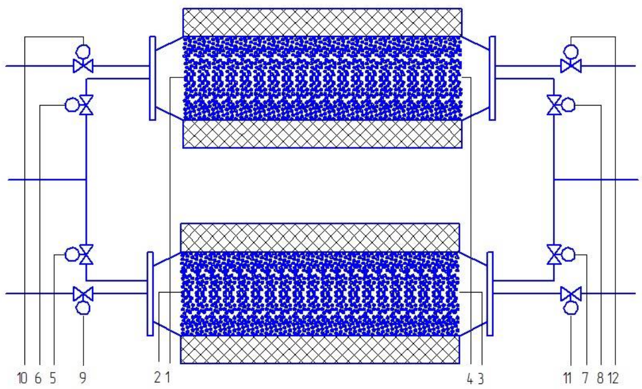

Fig. 5. Functional diagram of automation

All functions of adjusting and control of basic parameters in the designed system of automation are executed by programmable logical inspector MIK - 51 of native enterprise "Microl" with the module of expansion of MP - 07, that during this configuration has four analog entrances, three discrete entrances and four analog exits, five discrete exits that are sufficiently enough for a management this system.

The system is used for adjusting of concentration of admixtures in liquid medium that consists of 2 filters, 4 sensors of pressure, programmable logical inspector MIK - 51 with the module of expansion of MP - 07 and 8 regulative valves.

The management program works as follows: signals from analog entrances (AIN - 1, AIN - 2) come on the adder (SUMM - 6) where from a value 1 of analog entrance a value 2 of analog entrance is subtracted and this difference comes on the block of comparison (CMP - 7), where it compared to the set value.

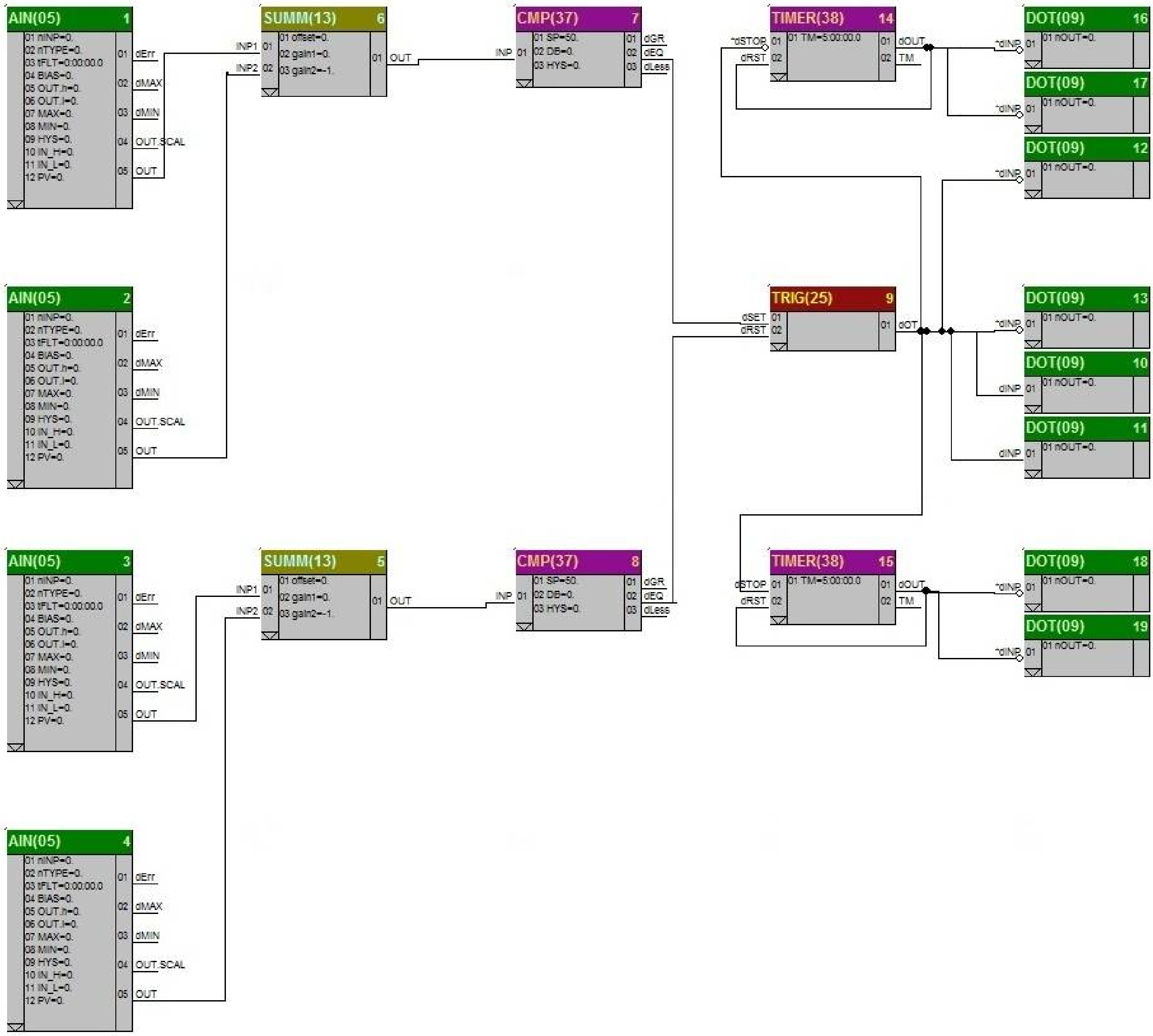

Fig. 6. Program of management the system

When difference of values 1 and 2 of analog entrances achieved set value on the exit of block of comparison, the logical "1" appears, that comes on RS - trigger (TRIG - 9), sets its exit in "1" and changes the states of discrete exits (DOT - 10, DOT - 11, DOT - 12, DOT - 13) that carry out stopping of serve of water through a 1 filter and transferring of stream of liquid on 2 filter. A signal from the exit of RS - trigger in parallel comes on a timer (TIMER - 14) that is started, when on an entrance is logical "1" and at once on its exit the logical "0"appears, that sets discrete exits (DOT - 16, DOT - 17) in "1", as their entrances are inverted, then cleaning of filter carries out 1. After the achievement of the set time (about 2 hours) on the exit of the timer (TIMER - 14) the logical "1" appears, that changes the states of discrete exits (DOT - 16, DOT - 17), that stops cleaning of 1 filter.

An inspector in accordingly to the program manages the supply of water through one or other filter, in particular switching takes place as follows: signals from givers of pressure 1, 2 and 3, 4 after previous transformation come on inspector, where are subtracted between each other and compared to the set value, after that filter does not detain particles (it is attained corresponding value of difference of pressures), a closing signal is given on regulative valves 6 and 8, and also in parallel signal on opening on regulative valves 5 and 7 or the other way round. As a result of that is the transferring of stream of liquid from one filter to another. For the further use of previous filter it is necessary to clean it, that is why after transferring of stream of liquid a signal is given on opening on regulative valves 10 and 12, as a result a filter clears up by the stream of liquid, like for cleaning of other filter after transferring of stream of liquid a signal is given on opening on regulative valves 11 and 9. In the system also blocking of supply of stream of liquid is present, that takes place, when pressure before a filter exceeds an admissible value that can take place for different reasons: increase of pressure of liquid in a pipeline, getting into of the things of large diameter, that do not pass through a filter, thus "contaminate" it, that increases pressure in the system. The system of blocking is used only for givers of pressure; those are before a filter, as pressure naturally is bigger in them. This system works as the following: signals from analog entrances (AIN - 1, AIN - 3) are compared to the set value and if pressure is in possible limits, then the system works until then while pressure will not attain set value. If pressure attained a set value, then an inspector sends signals on closing for regulative valves 5, 6 and signal on opening for 7, 8, that stops the supply of stream of liquid in a filter and pours out the remain water from the filter.

2 part of the program works analogously: signals from analog entrances (AIN - 3, AIN - 4) come on the adder (SUMM - 5) where from the value 1 of the analog entrance a value 2 of analog

entrance is subtracted and this difference comes on the block of comparison (CMP - 8), where it is compared to the set value. When difference of values 3 and 4 of analog entrances attained set value, then on the exit of block of comparison appears the logical "1", that comes on RS-trigger (TRIG - 9) and sets his exit in "0" and changes the states of discrete exits (DOT - 10, DOT - 11, DOT - 12, DOT - 13) that carry out stopping of supply of water through 2 filter and transferring of stream of liquid on a 1 filter. A signal from the exit of RS - of trigger in parallel comes on a timer (TIMER - 15) that is started, when on an entrance there is a logical "0" and at once on its exit the logical "1" appears, that sets discrete exits (DOT - 18, DOT - 19) in "1", as their entrances are inverted, that carry out cleaning of 2 filter. When this time reaches at set, then on the exit of timer (TIMER - 15) the logical "1" appears, that changes the states of discrete exits (DOT - 18, DOT - 19), that stops cleaning of 2 filter. For that during every new transferring of stream a timer would deduct new time again, and would not continue to count, the timer throws down itself. It is realized as follows: on the entrance of dRST timer the exit of dOUT is connected. For that a timer would begin the new counting out it is necessary on the entrance of dRST to give logical "1", that on the exit of dOUT appears at the achievement of time that deducts the timer.

3. Conclusions

As a result of work the decision of model problem of process of cleaning of water mediums was got in the grainy magnetized filter material, automation of the system was conducted for permanent water purification taking into account the change of parameters of stream, that manages two filters with permanent transferring of stream of liquid and regeneration of previous filter, and also times of the effective cleaning and regeneration of filter are determined.

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