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Computer Simulation of a Magnetic Separator for Iron Ore Dressing under Conditions of Uncontrolled Disturbances

Nina Osipova*

University of Science and Technology MISIS, Moscow, Russia

Financial University under the Government of the Russian Federation, Moscow, Russia

Abstract: The article presents a theoretical material about the principle of operation, design and advantages of the magnetic iron ore separator. A review of researches is given, where special attention is paid to the study of factors that affect the quality of concentrate and the loss of a valuable component in the tailings. The specification of the PDM-SC-120/300 magnetic separator is given. Regression models are obtained that reflect the relationship between the content of the class -0.074 mm and the solid phase flow rate in the separator feed with a high coefficient of determination. The statistical significance of this coefficient was verified using the Fisher criterion. A mathematical description of the object elements such as governing valve, motor, and magnetic separator is given. These models are simplified by dropping small time constants and linearization in the vicinity of nominal modes using Taylor series expansion. The main disturbances that cause the deviation of the dressing indicators from the optimal values are highlighted. A computer model of the magnetic separator was constructed using the Simulink Matlab application. The simulation results showed that with the specified control actions, an increase in the content of the class -0.074 mm in the feed to 94-95 % brings the mass fraction of iron in the concentrate to the acceptable limits but reduces the productivity of the separator.

Keywords: magnetic separator, concentrate, tails, Matlab, MS Excel, regression model, Fisher criterion, correlation, coefficient of determination, Taylor series.

1. INTRODUCTION

Over the past century, the constant growth of human needs for iron has led to the development and improvement of new technologies for ore dressing. The most widespread process is the magnetic separation. Its main purpose is to separate ore material particles into two phases: concentrate with a high iron content and tailings with a small fraction of the valuable component. By design the magnetic separator is made in the form of a drum that rotates at the given speed and a stationary magnetic system located in its inner part. Separation of the ore stream is based on the magnetic susceptibility of its constituent particles. If this parameter has a high value, then the particles stick to the drum and enter the concentrate compartment, and the rest, without attracting, are immediately washed off into the tailings compartment.

The advantage of the magnetic dressing method is the ability to create a high force of attraction to the drum, which is hundreds of times higher than the particles weight, as well as safety during maintenance of the separator and harmlessness to the environment [5].

There are dry and wet magnetic dressing. In the first case, the ore is fed to the separator after preliminary crushing and screening. In the second case, after grinding in the mill and classification by size, the ore enters the magnetic separator in a mixture with a liquid (pulp). The above processes are multi-stage.

* Corresponding author: nvo86@mail.ru

The iron ore raw material coming to the metallurgical plant in the form of agglomerate or pellets must be of the specified quality with permissible deviations from the norm established by technical conditions and regulations. Otherwise, you have to adjust the modes of melting units or spend more additional materials, which increases the cost of steel production. It is also necessary to ensure that iron losses in the tailings that do not exceed the permissible value.

2. REVIEW OF THE RESEARCH

The main purpose of the research in the study of mineral processing is to identify the main factors that affect the iron content in the products of the magnetic separator, including controlling and disturbing influences. Control actions can be changed by a human operator or by an automatic system. Disturbing influences are random changes in the physical and mechanical properties of the ore or pulp.

Several researches have been devoted to the study of the influence of controlling and disturbing influences on the magnetic separation process.

In [1], multiple regression equations for a specific type of ore are obtained. One of them relates the iron content in the concentrate and the control variables: the filling level of the mill at the second stage of grinding, the density of the hydrocyclone discharge. Another is the association of loss of iron in the tails of the first stage of dressing and fill level of the mill, the water flow into the mill the first stage of grinding, drain density classifier.

The coursebook [10] describes the principle of creating a regression model based on experimental planning, which can predict the mass fraction of iron in the concentrate for a predetermined step forward in time. This model is based on the calculated average iron content for a certain period, the deviation of the current value of the iron content from the average, and changes in the load on the ore section.

The paper [4] presents a regression model, in which the dependent variable is the iron mass fraction in the enrichment products, and the factors are the load on the industrial product of dry magnetic separation, water flow into the classifying apparatus and magnetic separators at the 1st, 2nd, 4th stages of dressing.

The disadvantage of these methods is a large delay between obtaining of input and output variables, which makes it difficult to quickly update the coefficients of the regression model and calculate the control variables. The above papers do not specify what specific disturbances can cause deviations of the dressing indicators from the set ones.

In [6], static characteristics of magnetic separators are given, reflecting the dependence of the iron content in the concentrate and its losses in the tailings on the drum rotation speed and pulp density, which can be controlled by supplying additional water to the separator bath. However, the graphs do not indicate the numerical values on the axes and the equations that they were based on. It is only known that in a wide range of parameters, the dependencies are nonlinear, close to the second-order polynomial.

Therefore, it is necessary to solve the following problems: to select the control and disturbing effects that affect the content of the useful component in the concentrate and in the tailings, so that there is no lag between the input and output of the object; to develop a computer model of the magnetic separator, which allows to study its operation of the separator under nominal control effects under conditions of uncontrolled disturbances.

3. OBJECT OF RESEARCH

The object of research is the drum semi-countercurrent magnetic separator PDM-SC-120/300, which is used in many iron ore mining and processing plants to separate particles of less than 1 mm in size at the final stages of dressing. It’s required for simulation specification is given in Table 3.1 [2].

Table 3.1. Specification of the PDM-SC-120/300 magnetic separator

Feed option	Drum rotation speed, min^{-1}		Permissible productivity for solid phase, tons/h
	Content in the feed separator, %		
	Class -0.074 mm	Solid phase of the pulp	
1	60-70	30	140-180
2		20	80-120
3	75-85	30	100-140
4		20	70-100
5	94-96	30	60-80
6		20	40-60

As you can see from the table, there are six separator feed options. In this case, the disturbing effects are the content in the feed of the class -0.074 mm and the of solid phase flow rate (productivity) at two limit values of the solid phase content in the pulp. Before finding the degree of influence of factors on the dressing indicators, it is necessary to check their correlation. For this purpose, MS Excel generated samples of random variables with a normal distribution law that characterize the content of the class -0.074 mm and the corresponding solid phase flow rate for two values of the solid phase content in the separator feed (Table 3.2).

Table 3.2. Characteristics of random values of disturbances for simulation in MS Excel

Solid phase content in pulp, %	Mathematical expectation		Maximum deviation (3σ)		Standard deviation (σ)	
	Performance, tons/h	The content of the class -0.074 mm, %	Performance, tons/h	The content of the class -0.074 mm, %	Performance, tons/h	The content of the class -0.074 mm, %
20	100	65	20	5	20/3	5/3
30	160					
20	85	80	15		15/3	
30	120		20		20/3	
20	50	95	10	1	10/3	1/3
30	70					

For each of the above six options, the sample consists of 10 values, i.e. 30 positions for the solid phase content in the feed, equal to 20 % and 30 %. The diagram with the trend line based on the linear dependence is presented and the coefficient of determination is calculated (Fig. 3.1).

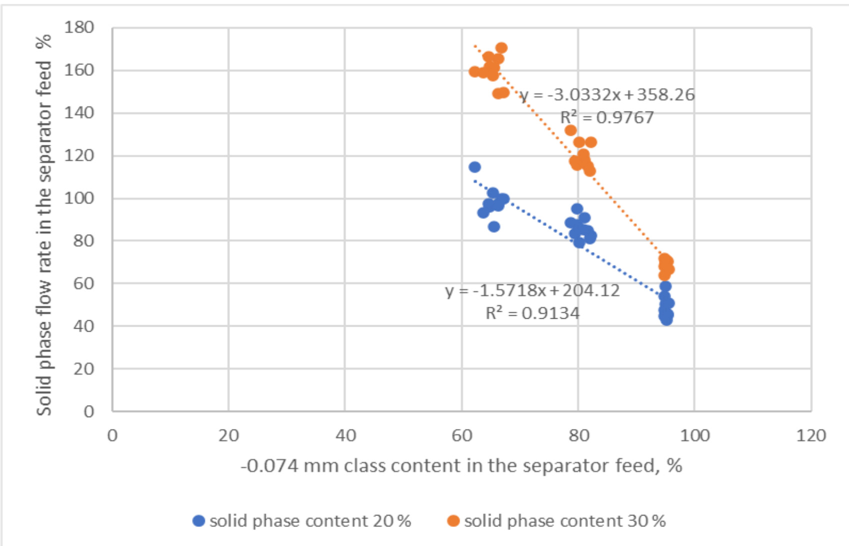

Fig. 3.1. Correlation diagram of solid phase flow rate and -0.074 mm class content in the separator feed

The high determination coefficients R_1^2 = 0,9134 и R_2^2 = 0,9767 indicate a strong dependence of the solid phase flow rate on the content of the class -0.074 mm in the separator feed. Let's evaluate the statistical significance of the coefficients using the Fischer criterion. In the first case, we find the observed F-value for two dependencies:

$$F_1 = \frac{R_1^2}{1-R_1^2}\frac{f}{m} = \frac{0.9134}{1-0.9134}\frac{28}{1} = 38.55,$$
$$F_2 = \frac{R_2^2}{1-R_2^2}\frac{f}{m} = \frac{0.9767}{1-0.9767}\frac{28}{1} = 1173.72, \qquad (3.1)$$

where n = 30 is the number of experimental points; m = 1 is the number of factors; $f = n\text{-}m\text{-}1$ is the number of degrees of freedom; $\alpha = 0.05$ is the level of significance.

It turns out that the found value is greater than the critical value indicated in the table $F_{cr} = 4.2$ ($F_1 > 4.2$; $F_2 > 4.2$), which confirms the statistical significance of R^2 with a probability $P = 1 - \alpha = 0.95$.

Therefore, if there is a correlation in the mathematical model, it is sufficient to use just one of the disturbances: the solid flow rate or the content of the class -0.074 mm in the feed of the separator.

4. COMPUTER MODEL OF A MAGNETIC SEPARATOR

4.1 Nonlinear Dynamic Model of a Magnetic Separator

As control variables, we will use the water flow rate into the separator bath and the rotation speed of its drum. This choice is justified by the absence of a lag between these impacts and the output indicators, as well as the fact that there is no need to change the separator design. The model block diagram is shown in Figure 4.1. When controlling the degree of the valve opening and the motor shaft rotation speed by setting different values ε_s and ω_s, the water flow rate into the bath W_b and the rotation speed of the drum ω, respectively, are regulated. It causes a change in the content of magnetite iron in the concentrate β and tailings ν monitored by analyzers. The parameter ξ is a disturbance that characterizes the instability of the physical and mechanical properties of the pulp, which also causes fluctuations in the dressing indicators β and ν.

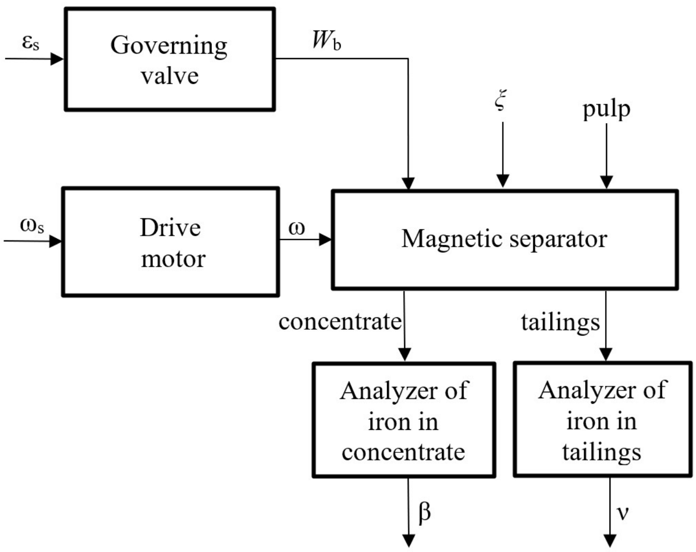

Fig. 4.1. Block diagram of the magnetic separator model

Let's look at the individual components of the model in detail. The model of the governing valve is described by the following differential equation:

$$T_v \frac{d\varepsilon_v(t)}{dt} + \varepsilon_v(t) = \varepsilon_s, \qquad (4.1)$$

ε_s is the set value for the degree of opening of the valve, %;
ε_v is the current value of the valve opening degree, %;
T_v is the time constant of the controlled valve, sec.

For the most valves, T_v is approximately 0.3 sec [7].

The water flow rate in the separator bath is related to the value ε_v and the ratio [9]:

$$W_b(t) = 11\varepsilon_v(t). \quad (4.2)$$

The model of an asynchronous drive motor has a very complex mathematical description in the form of a system of nonlinear equations. However, in the case of operation in a small neighborhood of the point that corresponds to the rated mode, it is allowed to consider a linearized system equivalent to the DC motor model:

$$T_m \frac{d\omega_m(t)}{dt} + \omega_m(t) = \omega_s, \quad (4.3)$$

ω_s is the set value of the motor drive shaft rotation speed, $\min^{-1}$;
ω_m is the current value of the motor drive shaft rotation speed, $\min^{-1}$;
T_m is the time constant of the drive motor, s.

The model of the gearbox is determined based on the ratio of the nominal rotation speed of the separator drum $\omega_{s.nom} = 19 \min^{-1}$ and the motor $\omega_{m.nom} = 1000 \min^{-1}$:

$$k_g = \frac{\omega_{s.nom}}{\omega_{m.nom}} = \frac{19}{1000} \approx 0.02. \quad (4.4)$$

The rotation speed of the separator drum ω_g using a reducer is equal to:

$$\omega_g(t) = 0.02\omega_m(t). \quad (4.5)$$

According to the simulation of asynchronous motors the value of T_m can be assumed to be equal to 0.03 sec [9].

The models must have "dead zones" Δ_v and Δ_m for the valve and drive, respectively. This means that if the input signal is $|\varepsilon_v| \le \Delta_v$ or $|\omega_g| \le \Delta_m$, then the output signal is $\varepsilon = 0$, $\omega = 0$, otherwise $\varepsilon = \varepsilon_v - \Delta_v$ or $\omega = \omega_g - \Delta_m$. Let's take $\Delta_v = 3$ %, $\Delta_m = 0,1$ %.

The dynamics of the content of magnetite iron in the concentrate and tailings is governed by the following system of differential equations:

$$\begin{aligned} \frac{d\beta}{dt} &= \frac{1}{T_\beta}\beta + \frac{1}{T_\beta} f_\beta(W,\omega) + \frac{1}{T_\beta} f_{\beta\xi}(\xi), \\ \frac{d\nu}{dt} &= \frac{1}{T_\nu}\nu + \frac{1}{T_\nu} f_\nu(W,\omega) + \frac{1}{T_\nu} f_{\nu\xi}(\xi), \end{aligned} \quad (4.6)$$

where $W = W_l + W_b$ is the sum of the liquid phase consumption in the pulp and the water consumption in the separator bath, $f_\beta(W, \omega)$ и $f_\nu(W, \omega)$ describe the relationship of the dressing indices β, ν and the control variables W, ω and the control variables W, ω in steady state when $\frac{d\beta}{dt} = 0$ и $\frac{d\nu}{dt} = 0$:

$$\begin{aligned} f_\beta(W, \omega) &= -0.0000042W^2 + 0.0082W - 0.023\omega^2 + 1.21\omega + 46.5, \\ f_\nu(W, \omega) &= -0.0000025W^2 + 0.0087W + 0.035\omega^2 - 1.3\omega + 10.2, \end{aligned} \quad (4.7)$$

where T_β, T_ν are the time constants of magnetic separator (sec), $T_\beta = 1\ldots10$ sec, $T_\nu = 1...10$ sec [7]; $f_{\beta\xi}(\xi)$, $f_{\nu\xi}(\xi)$ are the functions on uncontrolled disturbances ξ.

To simplify the simulation, we put $T_\beta = T_\nu = 1$ sec.

The system (4.7) is obtained in [9] based on the reference data of the average concentration of iron ore mining and processing plants, provided that $f_{\beta\xi}(\xi)$ = const, $f_{\nu\xi}(\xi)$ = const. The units of measurement for W and ω are m^3/h and $\min^{-1}$ respectively.

4.2 Linearization of the Magnetic Separator Model

For the convenience of research, simulation and automation of the magnetic separator, we linearize equations (4.6). The most of automatic systems are designed and configured under the assumption that the object under control is linear. Using the rule for calculating the function increment $\Delta y = y'\Delta x$, we perform the system linearization by expanding the Taylor series of equations (4.6) in the vicinity of the nominal modes (W_{nom}, ω_{nom}) with respect to $\Delta\beta$ and $\Delta\nu$ with the rejection of nonlinear terms. Given that $T_\beta = T_\nu = 1$ sec and that $f_\beta(W, \omega)$, $f_\nu(W, \omega)$ are found by equation (4.7), we obtain:

$$\begin{aligned}
&\Delta\dot{\beta} = -\Delta\beta - 2\cdot 0.0000042W_{\text{nom}}\Delta W + 0.0082\Delta W - 2\cdot 0.023\omega_{\text{nom}}\Delta\omega + 1.21\Delta\omega = \\
&= -\Delta\beta - 0.0000084W_{\text{nom}}\Delta W + 0.0082\Delta W - 0.046\omega_{\text{nom}}\Delta\omega + 1.21\Delta\omega, \\
&\Delta\dot{\nu} = -\Delta\nu - 2\cdot 0.0000025W_{\text{nom}}\Delta W + 0.0087\Delta W + 2\cdot 0.035\omega_{\text{nom}}\Delta\omega - 1.3\Delta\omega = \\
&= -\Delta\nu - 0.000005W_{\text{nom}}\Delta W + 0.0087\Delta W + 0.07\omega_{\text{nom}}\Delta\omega - 1.3\Delta\omega.
\end{aligned} \tag{4.8}$$

For simulation, we assume that the required content of magnetite iron in the concentrate $\beta_s = 63.8$ %, which is the average for many iron ore mining and processing plants [2]. Substituting $\omega_{\text{nom}} = 19$ min^{-1} in the first equation in (4.7) for $f_\beta(W_{\text{nom}}, \omega_{\text{nom}}) = \beta_s$, we get $W_{\text{nom}} = 400$ m^3/h. Then the loss of magnetite iron in the tailings at W_{nom}, ω_{nom} is $f_\nu(W_{\text{nom}}, \omega_{\text{nom}}) = \nu_s = 1.22$ %.

Assuming the time constants of the valve and motor are negligible in compare with the time constants of the magnetic separator, the water flow rate into the separator bath is associated with a given degree of opening of the valve as $W = 11\varepsilon_s$, and the rotation speed of the drum is determined by the equality $\omega = \omega_s$. We introduce new notation for the variables $\Delta\beta = x_1$, $\Delta\nu = x_2$, $\Delta W = u_1$, $\Delta\omega = u_2$. We assume that the change ΔW is due to the control of the valve. Is due to the control of the valve. Taking into account the above, substituting W_{nom}, ω_{nom} in equation (4.8), we get:

$$\begin{aligned}
&\dot{x}_1 = -x_1 + 0.00484u_1 + 0.336u_2, \\
&\dot{x}_2 = -x_2 + 0.0067u_1 + 0.03u_2
\end{aligned} \tag{4.9}$$

or in matrix form:

$$\dot{x}(t) = Ax(t) + Bu(t), \tag{4.10}$$

where:

$$A = \begin{pmatrix} -1 & 0 \\ 0 & -1 \end{pmatrix}, B = \begin{pmatrix} 0.0048 & 0.336 \\ 0.0067 & 0.03 \end{pmatrix}. \tag{4.11}$$

The linear representation of the system (4.7) in the interval (W_{nom}, ω_{nom}) has the form:

$$\begin{aligned}
&f_{\beta\text{lin}}(W, \omega) = f_\beta(W_{\text{nom}}, \omega_{\text{nom}}) + \frac{\partial f_\beta(W_{\text{nom}}, \omega_{\text{nom}})}{\partial W}(W - W_{\text{nom}}) + \\
&+ \frac{\partial f_\beta(W_{\text{nom}}, \omega_{\text{nom}})}{\partial \omega}(\omega - \omega_{\text{nom}}) = 55.48 + 0.00484W + 0.336\omega, \\
&f_{\nu\text{lin}}(W, \omega) = f_\nu(W_{\text{nom}}, \omega_{\text{nom}}) + \frac{\partial f_\nu(W_{\text{nom}}, \omega_{\text{nom}})}{\partial W}(W - W_{\text{nom}}) + \\
&+ \frac{\partial f_\nu(W_{\text{nom}}, \omega_{\text{nom}})}{\partial \omega}(\omega - \omega_{\text{nom}}) = -2.035 + 0.0067W + 0.03\omega.
\end{aligned} \tag{4.12}$$

As a disturbance, we will consider the change in the percentage q of solid and the solid phase flow rate in the feed q.

As can be seen from Table 4.1, the separator maximum performance is $Q = 180$ tons/h with a percentage of solid $q = 30$ %, and the minimum - $Q = 40$ tons/h with a solid $q = 20$ %. Let's calculate the minimum and maximum values of the liquid phase flow rate in the pulp, taking into account that the water density $\rho_w = 1$ ton/m^3:

$$W_l = \frac{(100\ \% - q)}{\rho_w \cdot q} \cdot Q,$$
$$W_{l.min} = \frac{(100\ \% - 30\ \%)}{1\ \text{ton/m}^3 \cdot 30\ \%} \cdot 40\ \text{tons/h} \approx 93.3\ \text{m}^3/\text{h}, \qquad (4.13)$$
$$W_{l.max} = \frac{(100\ \% - 20\ \%)}{1\ \text{ton/m}^3 \cdot 20\ \%} \cdot 180\ \text{tons/h} \approx 720\ \text{m}^3/\text{h}.$$

Substituting $W = W_b + W_l$ in (4.12) and replacing the liquid phase flow rate of the with the expression from equation (4.13), we get:

$$f_{\beta lin}(W,\ \omega) = 55.48 + 0.00484 W_b + 0.336\omega + f_{\beta\xi}(q, Q),$$
$$f_{v lin}(W,\ \omega) = -2.035 + 0.0067 W_b + 0.03\omega + f_{v\xi}(q, Q),$$
$$f_{\beta\xi}(q, Q) = 0.00484 \frac{(100 - q)}{\rho_w \cdot q} \cdot Q = 0.00484 W_l, \qquad (4.14)$$
$$f_{v\xi}(q, Q) = 0.0067 \frac{(100 - q)}{\rho_w \cdot q} \cdot Q = 0.0067 W_l.$$

According to the specifications, the permissible deviation for the content of magnetite in the concentrate $x_{1,2max} \leqslant 1\ \%$. Then $\beta_{min} = 63.8\ \% - 1\ \% = 62.8\ \%$, $\beta_{max} = 63.8\ \% + 1\ \% = 64.8\ \%$. Obviously, the minimum losses in the tailings are 0. Their limit is $\nu_{lim} = 1.22\ \% + 1\ \% = 2.22\ \%$. Then the deviation $x_{2max} = 1\ \%$.

Consider the procedure for determining the upper limits on control actions.

The main requirement for the linear representation of the model (4.7) is that at the boundary values of $\pm u_{1,2max}$, the absolute value of the difference in the dressing indicators calculated from the nonlinear and linearized models should be equal to the error of their measurement. According to Russian Standard, it is 0.9 % for magnetite iron in concentrate and 0.3 % for losses in tailings during laboratory research by chemical analysis [3]. Let the error of the analyzers also be equal to these values, then restrictions can be found from the solution of the system:

$$\begin{cases} \left| f_\beta(W_{nom} + u_{1max},\ \omega_{nom} + u_{2max}) - f_{\beta lin}(W_{nom} + u_{1max},\ \omega_{nom} + u_{2max}) \right| = 0.9, \\ \left| f_v(W_{nom} + u_{1max},\ \omega_{nom} + u_{2max}) - f_{v lin}(W_{nom} + u_{1max},\ \omega_{nom} + u_{2max}) \right| = 0.3. \end{cases} \qquad (4.15)$$

The expressions $f_{\beta lin}(W_{nom} + u_{1max},\ \omega_{nom} + u_{2max})$, $f_{v lin}(W_{nom} + u_{1max},\ \omega_{nom} + u_{2max})$ are found by substitution in (4.12) $W_{nom} + u_{1max}$, $\omega_{nom} + u_{2max}$ instead of W, ω:

$$f_{\beta lin}(W_{nom} + u_{1max},\ \omega_{nom} + u_{2max}) = f_\beta(W_{nom},\ \omega_{nom}) + \frac{\partial f_\beta(W_{nom},\ \omega_{nom})}{\partial W} u_{1max} + \frac{\partial f_\beta(W_{nom},\ \omega_{nom})}{\partial \omega} u_{2max},$$
$$f_{v lin}(W_{nom} + u_{1max},\ \omega_{nom} + u_{2max}) = f_v(W_{nom},\ \omega_{nom}) + \frac{\partial f_v(W_{nom},\ \omega_{nom})}{\partial W} u_{1max} + \frac{\partial f_v(W_{nom},\ \omega_{nom})}{\partial \omega} u_{2max}. \qquad (4.16)$$

The system (4.16) is easily solved using the Matlab computing package of the Optimization toolbox application. In this case, among the real roots, $u_{1max} = \pm\ 346.83$ m^3/h, $u_{2max} = \pm\ 4.14$ min^{-1}. So $W_{nmin} = 400$ m^3/h -346.83 m^3/h = 53.2 m^3/h, $W_{nmax} = 400$ m^3/h + 346.83 m^3/h = 746.8 m^3/h, $\omega_{nmin} = 19$ min^{-1} - 4.14 min^{-1} = 14.86 min^{-1}, $\omega_{nmax} = 19$ min^{-1} + 4.14 min^{-1} = 23.14 min^{-1}, the following restrictions must be met: $W_{nmin} \leqslant W \leqslant W_{nmax}$ and $\omega_{nmin} \leqslant \omega \leqslant \omega_{nmax}$. The nominal value of degree of opening of the valve $\varepsilon_{nom} = 36.36\ \%$, which corresponds to $W = 400$ m^3/h.

We will assume that the data from the analyzers is transmitted with a very small delay, the voltage at the output of their microchip is related to the physical value through a coefficient equal to one. Therefore, we will not take them into account in the model.

The diagram of the computer model of the magnetic separator is shown in Fig. 4.2. It was also built using the Matlab environment of the Simulink application based on the block diagram from Fig. 4.1.

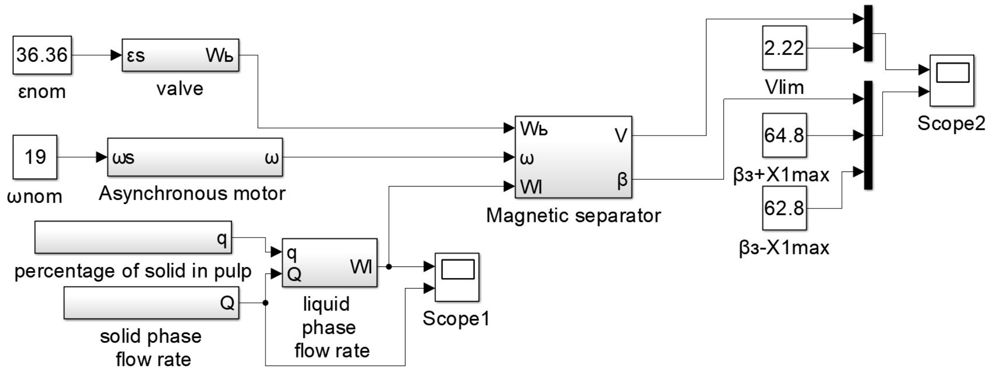

Fig. 4.2. Diagram of a computer model of a magnetic separator in Matlab Simulink

4.3 Simulation Result

The simulation was performed as follows. Disturbances were periodically fed to the input of the object at an interval equal to the end time of transients of the magnetic separator $t_{end} = 5$ sec [8]: the change in the percentage of solid in the feed and the solid phase flow rate, which was set using a random number generator in the range according to Table 4.1, i.e., six variants of pulp properties were modeled.

Let's take the first option as an example. When the solid content in the feed is 30 %, the solid phase flow rate increases to 120 tons/h. The model calculates the water consumption in the pulp using the equation (4.13), which becomes equal to $W_l = 280$ m^3/h, which is within the range of $W_{lmin} \le W_l \le W_{lmin}$. The change in this signal is fed to the magnetic separator model (4.14) and used in the functions $f_{\beta\xi}(q, Q)$, $f_{v\xi}(q, Q)$ (Fig. 4.3).

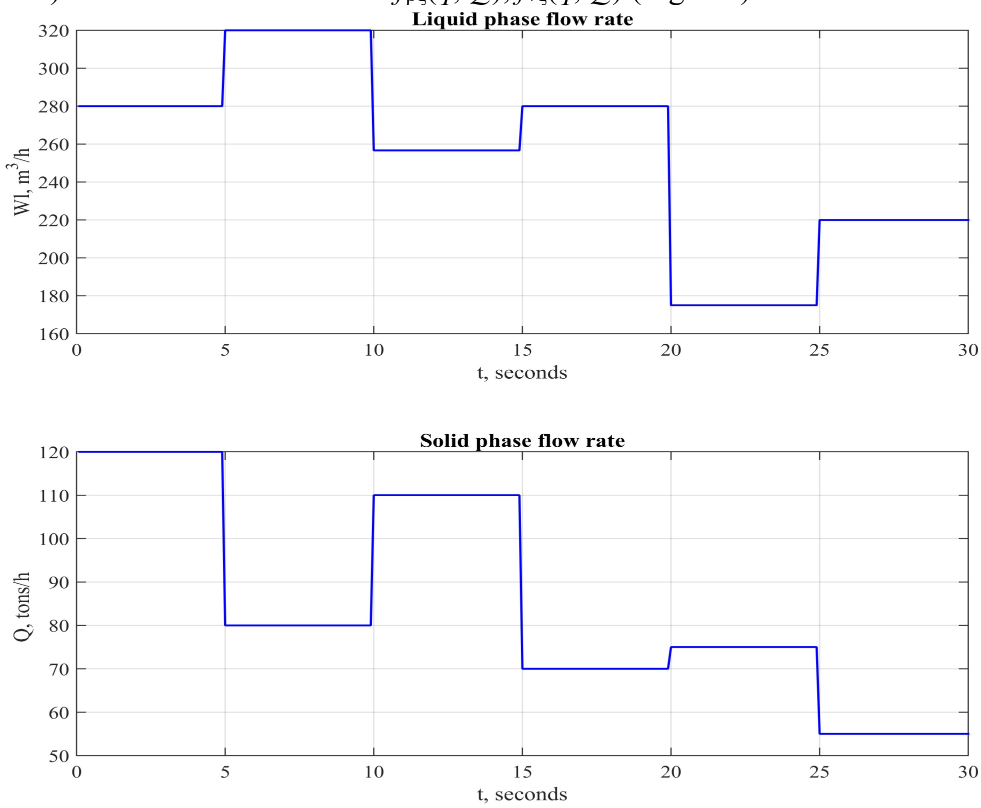

Fig. 4.3. Changing the liquid and solid phases flow rate in the pulp

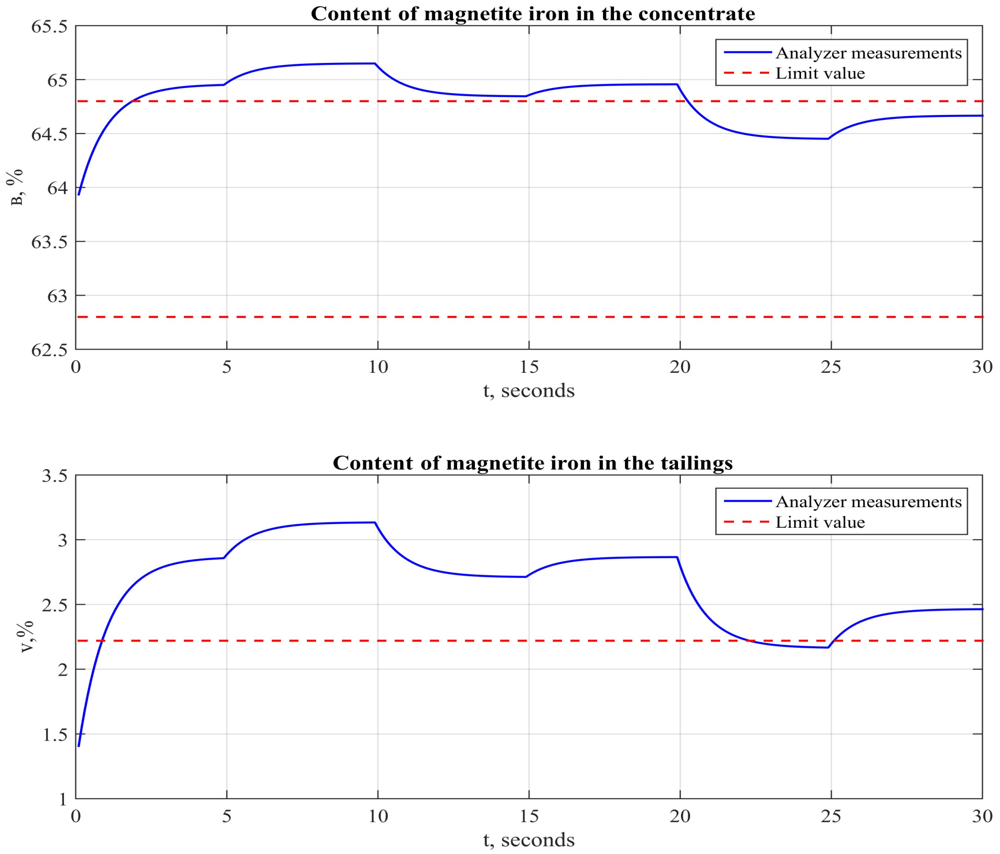

Fig. 4.4. The content of magnetite iron in the concentrate and tailings when the properties of the pulp are unstable

In the absence of automatic control of the separator, constant nominal values of water flow rate W_b = 400 m^3/h and rotation speed ω =19 min^{-1}. The following conditions are met: $W_{nmin} \leq W \leq W_{nmax}$. The content of magnetite iron in the concentrate in the time interval of 5-20 sec is greater than the value of β_{max}. The same can be said for tailings that are superior to the ν_{lim}. The largest of the bursts is β = 65.34 % и ν = 3.35 % (Fig. 4.4). This corresponds to the content of the class -0.074 mm in the feed of 60-70 %. Only after t = 20 sec, the iron content falls below β_{max}, when the pulp is 94-95 % of the class -0.074 mm, but there is a sharp decrease in the productivity of the separator, which becomes below 80 tons/h.

5. CONCLUSION

As control actions were selected the rotation speed of the magnetic separator drum and the water flow rate into its bath. The nominal operating modes corresponding to the specified dressing parameters in the absence of disturbances are determined by the content and the solid phase flow rate in the feed, which correlates with the content of the class -0.074 mm in the feed, are taken as the parameters. A computer linear dynamic model of the separator in the Matlab Simulink package is constructed. Based on the results of the simulation, the following conclusions can be drawn. Setting control actions with constant nominal values is not enough to stabilize the quality of iron ore concentrate. When changing the content of the class -0.074 mm in the feed in the range from 60 % to 85 %, the separator operates with a sufficiently high performance, but the iron content in the concentrate is higher than normal. The same can be said about tailings. Increasing the content of the class -0.074 mm in the feed to 94-95 % brings the mass fraction of iron in the concentrate to the acceptable limits but reduces the productivity of the separator.

Therefore, controlling the grinding and classification processes before magnetic separation in order to stabilize the granulometric composition is not promising.

A more rational approach is to create an optimal control system. It should be based on the formulated criterion for minimizing deviations of the iron content in the concentrate and tailings relative to the set values with restrictions on the control variables selected based on the permissible linearization error at the boundaries of their change intervals.

In the future, the model of optimal control of the magnetic separator will allow evaluating and predicting the possibility of maintaining the quality of iron ore concentrate with acceptable deviations. This will reduce the number of experiments in laboratory and industrial installations and thus increase their service life and reduce the number of consumables.

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