Noise Technology and System for Determining of Flow Rate of Oil Wells

Telman Aliev[1], Gambar Guluyev[2], Asif Rzayev[3], Fahrad Pashayev[4], Rauf Gadimov[5], Iltizam Yusifov[6], Ismat Sattarov[7]
[1-5,7]Cybernetics Institute of ANAS, [6]Shirvan OIL, Azerbaijan
[1,5]*telmancyber@rambler.ru*, [2]*scb_06@mail.ru*, [3]*asifrzayev48@gmail.com,*
[4]*pasha.farhad@gmail.com*, [6]*iltizam.yusifov@shirvanoil.com*, [7]*ismet.s@mail.ru*

***Abstract*— Algorithms have been developed for determining of the instantaneous flow rate of oil wells operated by rod deep-well pumping units with the use of noise technologies for analysis of dynamometer and wattmeter cards. Least-squares method has been used to determine coefficients of RNMT model.**

***Keywords*— instantaneous flow rate; robust noise monitoring technologies; least-squares method; analysis of dynamometer and wattmeter cards**

I. INTRODUCTION

Many known works are devoted to determining of instantaneous flow rate of oil wells operated by rod deep-well pumping units (RDPU) and many theoretical and empirical formulas have been created for this purpose [1-5].

For instance, V.M. Muravyev gives the following formula for determining of theoretical well production capacity [1, pp.264-265, 280-288]:

$$Q = 1440\frac{\pi \cdot d^2}{4} \cdot S_{pl} \cdot n \tag{1}$$

where 1440 is the amount of minutes per day, *d* is the diameter of pump plunger, S_{pl} is plunger stripping, *n* is the amount of pumpings per minutes. Formula (1) makes it possible to determine liquid flow rate per pumping cycle. A properly operating pump can have this production capacity with 100% filling and nondynamic operation mode. Plunger stripping being less than throw on the polished rod, plunger stripping for nondynamic modes is determined from the following formula:

$$S_{pl} = S - \frac{q_m \cdot L^2 g}{E}\left(\frac{1}{f_{st}} + \frac{1}{f_{tr}}\right) \tag{2}$$

where S is throw on polished rod, L is the length of the rod, q_m is weight of one meter of liquid column, E is elasticity modulus, f_{st} is cross sectional area of the rod, f_{tr} is cross sectional area of the oil pipe. If oil pipes are fixed and immovable, the second summand is taken out of the brackets.

For wells with pumped out operation mode, formula (1) has been modified by multiplying by a coefficient that equals to the filling rate [3], the filling rate being determined from dynamometer card.

In all operation modes of the well, especially in dynamic ones, determination of well production capacity by means of these methods is highly inaccurate. And besides technical difficulties, measuring of flow rate in metering units depends on the time of measuring and measuring period, which are quite difficult to determine [4, pp. 16-33].

Application of new information technologies, particularly Robust Noise Monitoring Technologies (RNMT), in analysis of dynamometer and *wattmeter* cards will undoubtedly ensure more precise determination of instantaneous flow rate [6-9].

II. MODEL OF DETERMINING OF INSTANTANEOUS FLOW RATE WITH APPLICATION OF RNMT

The paper offers to determine instantaneous flow rate of wells in the form of the following equalities:

$$Q_1 = a_{11}D_X + a_{12}D_\varepsilon + a_{13}D_g \tag{3}$$

$$Q_2 = a_{21}\frac{R_{\varepsilon X\varepsilon}}{D_\varepsilon} + a_{22}\frac{R_{X\varepsilon}}{D_\varepsilon} + a_{23}\frac{R_{\varepsilon X\varepsilon}}{R_{X\varepsilon}} \tag{4}$$

$$Q_3 = a_{31}\frac{D_\varepsilon}{D_g} + a_{32}\frac{D_X}{D_g} + a_{33}\frac{D_\varepsilon}{D_X} \tag{5}$$

The following symbols were used in equalities (3-5): g is the noisy signal that corresponds to the power consumed by the electric motor of the pump drive during wattmetry or polished rod force during dynamometry. It is assumed that $g = X + \varepsilon$, where X is the useful component of the signal; ε is the noise component of the signal, which carries useful information. Statistic characteristics ε change as the state of ground and underground equipment begins to change [6, pp.175-189]. The time of the noisy signal g is taken as multiple of an integer number of well cycles and centered. Signal is collected in the memory as readings of $g(i\Delta t)$, where $i = 1,2,3,...,N$, Δt is the requests period, N is the number of readings, D_g, D_X, D_ε are variances of the noisy signal g, the useful signal X and the noise ε, respectively.

$$D_\varepsilon \approx \frac{1}{N}\sum_{i=1}^{N}\left[g^2(i\Delta t) + g(i\Delta t)g((i+2)\Delta t) - 2g(i\Delta t)g((i+1)\Delta t)\right] \qquad (6)$$

D_g is calculated from the formula for signal variance calculation

$$D_X = D_g - D_\varepsilon \qquad (7)$$

$R_{X\varepsilon}$ is values of correlation function between the useful signal and the noise. It is calculated from formula [8-10]:

$$R_{X\varepsilon}(\mu=0) \approx \frac{1}{2}\left[R_{gg}(\mu=0) - \left[R_{gg}(\mu=1) + \left(R_{gg}(\mu=2) - R_{gg}(\mu=3)\right)\right] - R_{\varepsilon\varepsilon}(\mu=0)\right] \qquad (8)$$

$$R_{\varepsilon X\varepsilon} = R_{X\varepsilon} - D_\varepsilon \qquad (9)$$

In this expression, calculation of estimates $R_{gg}(\mu=0)$, $R_{gg}(\mu=1)$, $R_{gg}(\mu=2)$ is performed by means of the traditional algorithm, and estimate $R_{\varepsilon\varepsilon}(\mu=0) = D_\varepsilon$ is calculated from expression (6). Instantaneous flow rate is determined from the given formulas as the average value:

$$Q = \frac{1}{3}(Q_1 + Q_2 + Q_3) \qquad (10)$$

III. DETERMINATION OF COEFFICIENTS OF THE MODEL (3)-(6) WITH APPLICATION OF LEAST-SQUARES METHOD

To determine coefficients a_{ij}, *i=1,2,3, j=1,2,3,* it is necessary to build the training table from required amount of data:

TABLE I. TRAINING TABLE

NN	Q actual measurement	D_g	D_X	D_ε	$R_{X\varepsilon}$	$R_{\varepsilon X\varepsilon}$
1	Q_1	D_{g1}	D_{X1}	$D_{\varepsilon 1}$	$R_{X\varepsilon 1}$	$R_{\varepsilon X\varepsilon 1}$
2	Q_2	D_{g2}	D_{X2}	$D_{\varepsilon 2}$	$R_{X\varepsilon 2}$	$R_{\varepsilon X\varepsilon 2}$
...	…	…	...	…	…	…
N	Q_N	D_{gN}	D_{XN}	$D_{\varepsilon N}$	$R_{X\varepsilon N}$	$R_{\varepsilon X\varepsilon N}$

Coefficients a_{ij}, *i=1,2,3, j=1,2,3* for Q_1, Q_2, Q_3 are determined separately using least-squares method. After designating:

- for (3)

$$k_1 = a_{11}, k_2 = a_{12}, k_3 = a_{13}, X = D_X, Y = D_\varepsilon, Z = D_g$$

- for (4)

$$k_1 = a_{21}, k_2 = a_{22}, k_3 = a_{23}, X = \frac{R_{\varepsilon X\varepsilon}}{D_\varepsilon}, Y = \frac{R_{X\varepsilon}}{D_\varepsilon}, Z = \frac{R_{\varepsilon X\varepsilon}}{R_{X\varepsilon}}$$

- for (5)

$$k_1 = a_{31}, k_2 = a_{32}, k_3 = a_{33}, X = \frac{D_\varepsilon}{D_g}, Y = \frac{D_X}{D_g}, Z = \frac{D_\varepsilon}{D_X}$$

each of equalities (3), (4), (5) can be represented as follows:

$$q = k_1 X + k_2 Y + k_3 Z \qquad (11)$$

The following function is built by means of the table:

$$F(k_1,k_2,k_3) = \sum_{n=1}^{N}(k_1 X_n + k_2 Y_n + k_3 Z_n - q_n)^2 \qquad (12)$$

Values of coefficients k_1, k_2, k_3, giving minimum of the function, define the required coefficients a_{ij}, *i=1,2,3, j=1,2,3.* The set of equation is therefore solved relative to k_1, k_2, k_3:

$$\begin{cases} \dfrac{\partial F}{\partial k_1} = 2k_1\sum_{n=1}^{N}X_n^2 + 2k_2\sum_{n=1}^{N}X_nY_n + 2k_3\sum_{n=1}^{N}X_nZ_n - 2\sum_{n=1}^{N}q_nX_n = 0 \\ \dfrac{\partial F}{\partial k_2} = 2k_1\sum_{n=1}^{N}X_nY_n + 2k_2\sum_{n=1}^{N}Y_n^2 + 2k_3\sum_{n=1}^{N}Y_nZ_n - 2\sum_{n=1}^{N}q_nY_n = 0 \\ \dfrac{\partial F}{\partial k_3} = 2k_1\sum_{n=1}^{N}X_nZ_n + 2k_2\sum_{n=1}^{N}Y_nZ_n + 2k_3\sum_{n=1}^{N}Z_n^2 - 2\sum_{n=1}^{N}q_nZ_n = 0 \end{cases} \qquad (13)$$

After all equations have been bisected and absolute terms have been placed in the right part, the set of equations is solved by Cramer's rule:

$$\Delta = \begin{vmatrix} \sum_{n=1}^{N} X_n^2 & \sum_{n=1}^{N} X_n Y_n & \sum_{n=1}^{N} X_n Z_n \\ \sum_{n=1}^{N} X_n Y_n & \sum_{n=1}^{N} Y_n^2 & \sum_{n=1}^{N} Y_n Z_n \\ \sum_{n=1}^{N} X_n Z_n & \sum_{n=1}^{N} Y_n Z_n & \sum_{n=1}^{N} Z_n^2 \end{vmatrix}$$

$$\Delta_1 = \begin{vmatrix} \sum_{n=1}^{N} q_n X_n & \sum_{n=1}^{N} X_n Y_n & \sum_{n=1}^{N} X_n Z_n \\ \sum_{n=1}^{N} q_n Y_n & \sum_{n=1}^{N} Y_n^2 & \sum_{n=1}^{N} Y_n Z_n \\ \sum_{n=1}^{N} q_n Z_n & \sum_{n=1}^{N} Y_n Z_n & \sum_{n=1}^{N} Z_n^2 \end{vmatrix}$$

$$\Delta_2 = \begin{vmatrix} \sum_{n=1}^{N} X_n^2 & \sum_{n=1}^{N} q_n X_n & \sum_{n=1}^{N} X_n Z_n \\ \sum_{n=1}^{N} X_n Y_n & \sum_{n=1}^{N} q_n Y_n & \sum_{n=1}^{N} Y_n Z_n \\ \sum_{n=1}^{N} X_n Z_n & \sum_{n=1}^{N} q_n Z_n & \sum_{n=1}^{N} Z_n^2 \end{vmatrix}$$

$$\Delta_3 = \begin{vmatrix} \sum_{n=1}^{N} X_n^2 & \sum_{n=1}^{N} X_n Y_n & \sum_{n=1}^{N} q_n X_n \\ \sum_{n=1}^{N} X_n Y_n & \sum_{n=1}^{N} Y_n^2 & \sum_{n=1}^{N} q_n Y_n \\ \sum_{n=1}^{N} X_n Z_n & \sum_{n=1}^{N} Y_n Z_n & \sum_{n=1}^{N} q_n Z_n \end{vmatrix}$$

Thus,

$$k_1 = \frac{\Delta_1}{\Delta},\ k_2 = \frac{\Delta_2}{\Delta},\ k_3 = \frac{\Delta_3}{\Delta} \qquad (14)$$

So, (11)-(13) are repeated for each equality (3), (4), (5) and corresponding coefficients a_{ij} , *i=1,2,3, j=1,2,3* are found. Instantaneous flow rate determined from formula (10) holds true between two measurements in case of calculation by the traditional method by means of available measuring device.

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