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POSITION-BINARY RECOGNITION OF CYCLIC SIGNALS BY FUZZY TIMING ANALYSIS OF INFORMATION INDICATORS

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The positional-binary technology of cyclic signals (CS) recognition was considered in [1-3], where changes of duration of positional-binary constituent (PBC) of signals depending on change of their form are used as informative indicators, and the affinity estimation is made by calculation of numerical parameters of proximity by result of PBC covering of analyzed pairs signals according to expression $S_w = \sum_{k=0}^{n-1} (\chi_{qk} + \eta_{qk}) R^k$, where $\chi=\sum p_+$ is the sum of PBC-duration forming by positional-binary elements at the expense of $0\to1$ transitions; $\eta=\sum p_-$ is the sum forming by $1\to0$ transitions; R is the notation basis; n – quantity of positions in PBC-decomposition. Experience of use of PBC-technology at the decision of problems of the control and diagnostics of objects of oil extracting has shown that in some cases there are the errors are related to that at an quantitative estimation of affinity are not considered a interim order of of cyclic signals PBC (CSPBC). Therefore, for recognition CS it is offered to use the fuzzy interpretations of PBC considering both duration and the interim order of PBC.

In Figure 1 it is illustrated the etalon e_j and recognized r_j (j=1÷3) wattmetergram over period of one cycle of bottomhole pumping characterizing three kinds of its malfunctions. According to algorithm of positional-binary recognition [3] at Δt=50 and amplitude to 60 in each q_k-th position (k=0÷5) binary components of etalon e_j signals and recognized signals r_j are formed (Fig. 2). Thus, duration of PBC formed by singular constituent of binary codes are defined in each position.

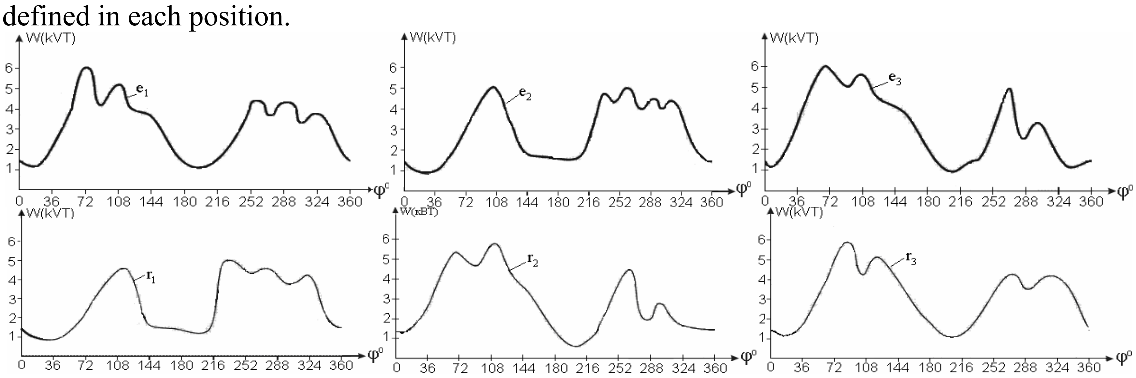

Fig. 1 Etalon and recognized wattmetergram over period of one cycle of bottomhole pumping

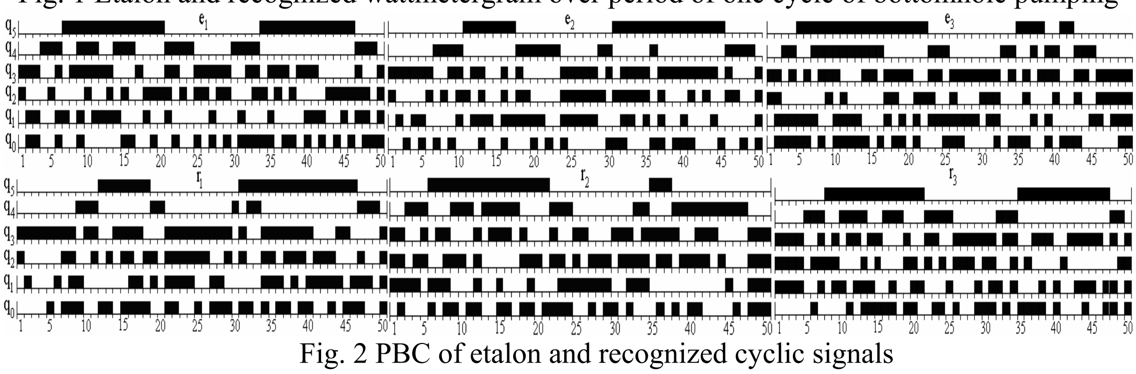

Fig. 2 PBC of etalon and recognized cyclic signals

For fuzzy interpretation of CSPBS we will take advantage of procedure of fuzzyfication with use of linear membership function $\mu_{\tilde{A}}(n)=1-n/51$ establishing the accessory degree of each impulse to fuzzy set «CLOSER TO THE BEGINNING»[1]. In particular, for the etalon signal e_1 (Fig. 2, position q_5), where binary impulses of PBC are located on 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20. 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46-th positions, the given membership function describes the fuzzy subset of the discrete universe {1,2, …., 50} in the following type:

$$\widetilde{E}(q_5(e_1)) = \frac{0}{1} + \frac{0}{2} + ... + \frac{0}{6} + \frac{0.8627}{7} + \frac{0.8431}{8} + \frac{0.8235}{9} + \frac{0.8039}{10} + \frac{0.7843}{11} + \frac{0.7647}{12} +$$
$$+ \frac{0.7451}{13} + \frac{0.7255}{14} + \frac{0.7059}{15} + \frac{0.6863}{16} + \frac{0.6667}{17} + \frac{0.6471}{18} + \frac{0.6275}{19} + \frac{0.6078}{20} + \frac{0}{21} +$$
$$+ ... + \frac{0}{33} + \frac{0.3333}{34} + \frac{0.3137}{35} + \frac{0.2941}{36} + \frac{0.2745}{37} + \frac{0.2549}{38} + \frac{0.2353}{39} + \frac{0.2157}{40} + \frac{0.1961}{41} +$$
$$+ \frac{0.1765}{42} + \frac{0.1569}{43} + \frac{0.1373}{44} + \frac{0.1176}{45} + \frac{0.0980}{46} + \frac{0}{47} + ... + \frac{0}{50}.$$

Thus, on this base PBC of etalon and recognized cyclic signals one can present in the form of fuzzy sets on corresponding basic vectors. The account of interim order of PBC is realized on the basis of point estimate of fuzzy sets describing them [4]. For this purpose in the beginning for fuzzy subset $\widetilde{C}$ of some discrete universe I it is necessary to construct α-level sets ($\alpha \in [0;1]$) in the form of $C_\alpha=\{i | \mu_C(i) \ge \alpha,\ i \in I\}$, for which corresponding cardinal numbers are defined: $M(C_\alpha) = \sum_{j=1}^{n} \frac{i_j}{n}$ ($i \in C_\alpha$). As a result, the point estimate of fuzzy sets is calculated from equality: $F(\widetilde{C}) = \frac{1}{\alpha_{\max}} \int_0^{\alpha_{\max}} M(C_\alpha) d\alpha,$ where $\alpha_{\max}$ is the maximum value on $\widetilde{C}$.

Being guided by this rule, one can find the point estimate to fuzzy interpretations of PBC of considered etalon and recognized cyclic signals. In particular, for a position q_5 of etalon signal e_1 (Fig. 2) we have:

- for $0<\alpha<0.0980$: $\Delta\alpha=0.0980$, E_α={7,8,9,10,11,12,13,14,15,16,17,18,19,20,34,35,36,37,38, 39,40,41,42,43,44,45,46}, $M(E_\alpha)=26.2593$;
- for $0.0980<\alpha<0.1176$: $\Delta\alpha=0.0196$, E_α={7,8,9,10,11,12,13,14,15,16,17,18,19,20,34,35,36, 37,38,39, 40,41,42,43,44,45}, $M(E_\alpha)=25.50$;
- for $0.1176<\alpha<0.1373$: $\Delta\alpha=0.0196$, E_α={7,8,9,10,11,12,13,14,15,16,17,18,19,20,34,35,36, 37,38,39, 40,41,42,43,44}, $M(E_\alpha)=24.72$;
- for $0.1373<\alpha<0.1569$: $\Delta\alpha=0.0196$, E_α={7,8,9,10,11,12,13,14,15,16,17,18,19,20,34,35,36, 37,38,39, 40,41,42,43}, $M(E_\alpha)=23.9167$;
- for $0.1569<\alpha<0.1765$: $\Delta\alpha=0.0196$, E_α={7,8,9,10,11,12,13,14,15,16,17,18,19,20,34,35,36, 37,38,39, 40,41,42}, $M(E_\alpha)=23.0870$;
- for $0.1765<\alpha<0.1961$: $\Delta\alpha=0.0196$, E_α={7,8,9,10,11,12,13,14,15,16,17,18,19,20,34,35,36, 37,38,39, 40,41}, $M(E_\alpha)=22.2273$;
- for $0.1961<\alpha<0.2157$: $\Delta\alpha=0.0196$, E_α={7,8,9,10,11,12,13,14,15,16,17,18,19,20,34,35,36, 37,38,39, 40}, $M(E_\alpha)=21.3333$;
- for $0.2157<\alpha<0.2353$: $\Delta\alpha=0.0196$, E_α={7,8,9,10,11,12,13,14,15,16,17,18,19,20,34,35,36, 37,38,39}, $M(E_\alpha)=20.40$;
- for $0.2353<\alpha<0.2549$: $\Delta\alpha=0.0196$, E_α={7,8,9,10,11,12,13,14,15,16,17,18,19,20,34,35,36, 37,38}, $M(E_\alpha)=19.4211$;

[1] With the same success it is possible to use, for example, fuzzy sets «CLOSER TO THE END». Thus, the choice of optimal membership function is not a matter of principle since it is considered only the question of comparison of signals.

- for $0.2549<\alpha<0.2745$: $\Delta\alpha=0.0196$, $E_\alpha=\{7,8,9,10,11,12,13,14,15,16,17,18,19,20,34,35,36, 37\}$, $M(E_\alpha)=18.3889$;
- for $0.2745<\alpha<0.2941$: $\Delta\alpha=0.0196$, $E_\alpha=\{7,8,9,10,11,12,13,14,15,16,17,18,19,20,34,35,36\}$, $M(E_\alpha)=17.2941$;
- for $0.2941<\alpha<0.3137$: $\Delta\alpha=0.0196$, $E_\alpha=\{7,8,9,10,11,12,13,14,15,16,17,18,19,20,34,35\}$, $M(E_\alpha)=16.1250$;
- for $0.3137<\alpha<0.3333$: $\Delta\alpha=0.0196$, $E_\alpha=\{7,8,9,10,11,12,13,14,15,16,17,18,19,20,34\}$, $M(E_\alpha)=14.8667$;
- for $0.3333<\alpha<0.6078$:$\Delta\alpha=0.2745$,$E_\alpha=\{7,8,9,10,11,12,13,14,15,16,17,18,19,20\}$,$M(E_\alpha)=13.50$;
- for $0.6078<\alpha<0.6275$: $\Delta\alpha=0.0196$, $E_\alpha=\{7,8,9,10,11,12,13,14,15,16,17,18,19\}$,$M(E_\alpha)=13.00$;
- for $0.6275<\alpha<0.6471$: $\Delta\alpha=0.0196$, $E_\alpha=\{7,8,9,10,11,12,13,14,15,16,17,18\}$, $M(E_\alpha)=12.50$;
- for $0.6471<\alpha<0.6667$: $\Delta\alpha=0.0196$, $E_\alpha=\{7,8,9,10,11,12,13,14,15,16,17\}$, $M(E_\alpha)=12.00$;
- for $0.6667<\alpha<0.6863$: $\Delta\alpha=0.0196$, $E_\alpha=\{7,8,9,10,11,12,13,14,15,16\}$, $M(E_\alpha)=11.50$;
- for $0.6863<\alpha<0.7059$: $\Delta\alpha=0.0196$, $E_\alpha=\{7,8,9,10,11,12,13,14,15\}$, $M(E_\alpha)=11.00$;
- for $0.7059<\alpha<0.7255$: $\Delta\alpha=0.0196$, $E_\alpha=\{7,8,9,10,11,12,13,14\}$, $M(E_\alpha)=10.50$;
- for $0.7255<\alpha<0.7451$: $\Delta\alpha=0.0196$, $E_\alpha=\{7,8,9,10,11,12,13\}$, $M(E_\alpha)=10.00$;
- for $0.7451<\alpha<0.7647$: $\Delta\alpha=0.0196$, $E_\alpha=\{7,8,9,10,11,12\}$, $M(E_\alpha)=9.50$;
- for $0.7647<\alpha<0.7843$: $\Delta\alpha=0.0196$, $E_\alpha=\{7,8,9,10,11\}$, $M(E_\alpha)=9.00$;
- for $0.7843<\alpha<0.8039$: $\Delta\alpha=0.0196$, $E_\alpha=\{7,8,9,10\}$, $M(E_\alpha)=8.50$;
- for $0.8039<\alpha<0.8235$: $\Delta\alpha=0.0196$, $E_\alpha=\{7,8,9\}$, $M(E_\alpha)=8.00$;
- for $0.8235<\alpha<0.8431$: $\Delta\alpha=0.0196$, $E_\alpha=\{7,8\}$, $M(E_\alpha)=7.50$;
- for $0.8431<\alpha<0.8627$: $\Delta\alpha=0.0196$, $E_\alpha=\{7\}$, $M(E_\alpha)=7.00$;

Thus, the point estimate of fuzzy set $\widetilde{E}(q_5(e_1))$ will be:

$$F\left(\widetilde{E}(q_5(e_1))\right)=\frac{1}{0.8627}[0.098\cdot 26.2593+0.0196\cdot 25.50+0.0196\cdot 24.72+0.0196\cdot 23.9167$$
$$+0.0196\cdot 23.087+0.0196\cdot 22.2273+0.0196\cdot 21.3333+0.0196\cdot 20.4+0.0196\cdot 19.4211+$$
$$+0.0196\cdot 18.3889+0.0196\cdot 17.2941+0.0196\cdot 16.125+0.0196\cdot 14.8667+0.0196\cdot 13.5+$$
$$+0.0196\cdot 13+0.0196\cdot 12.50+0.0196\cdot 12.00+0.0196\cdot 11.50+0.0196\cdot 11.00+0.0196\cdot 10.50$$
$$+0.0196\cdot 10.00+0.0196\cdot 9.50+0.0196\cdot 9.00+0.0196\cdot 8.50+0.0196\cdot 8.00+0.0196\cdot 7.50+$$
$$+0.0196\cdot 7.00]=15.85401.$$

Similarly one can define the point estimate of fuzzy set for other positions:
$F\left(\widetilde{E}(q_4(e_1))\right)=13.43813$, $F\left(\widetilde{E}(q_3(e_1))\right)=12.57224$, $F\left(\widetilde{E}(q_2(e_1))\right)=14.47692$,
$F\left(\widetilde{E}(q_1(e_1))\right)=11.95379$, $F\left(\widetilde{E}(q_0(e_1))\right)=14.3967$.

Thus, setting each position of binary decomposition of cyclic signals corresponding weight, for example, for position q_5-2^5, q_4-2^4, q_3-2^3, q_2-2^2, q_1-2^1 and q_0-2^0, total point estimation of the signal e_1 one can obtain in following type:

$TE(e_1)=2^5\cdot 15.8540+2^4\cdot 13.4381+2^3\cdot 12.5722+2^2\cdot 14.4769+2^1\cdot 11.9538+2^0\cdot 14.3967=919.1283.$

According to the considered technique the calculated total estimations for other signals are presented in Table 1.

On the basis of the data from the Table 1 it is possible to conclude that the closest to the etalon e_1 is the signal r_3, to the etalon e_2 – the signal r_1, and to the etalon e_3 – the signal r_2. At once, estimation of affinity of considered signals by results of the coverings [3] formed in each position of PBC of analyzed pairs of signals e_i-r_j (i, j=1÷3) according to expression S_w yields following total results (Table 2).

Table 1

Result of signals comparison with use of the point estimations of fuzzy interpretations of PBC

$\lvert E(r_i) - E(e_k)\rvert \, (i,k=\overline{1,3})$			The point estimations of fuzzy interpretations of PBC recognized signals		
			r_1	r_2	r_3
			1126.71	845.80	942.97
The point estimations of fuzzy interpretations of PBC of etalon signals	e_1	919.13	207.58	73.33	23.85
	e_2	1076.30	50.41	230.51	133.33
	e_3	839.10	287.61	6.70	103.87

Table 2

Result of recognition of signals on S_w-technology with coverings

S_w-technology	r_1	r_2	r_3
e_1	848	1101	777
e_2	614	1526	1117
e_3	1452	754	1019

Apparently from the obtained results, in both variants validity of recognition is provided. However, the analysis of numerical values of results of recognition shows that at use of the point estimation method of fuzzy interpretations of PBC the values of numerical characteristics of remoteness between adjacent classes are increased. For example, if at use of the point estimation method to PBC of the signal r_1 the closest is the etalon signal e_2 with the numerical characteristic 50.41. The following on affinity is the signal e_1 with the numerical characteristic of affinity 207.58 and, further, a signal e_3 – with the characteristic of affinity 287.61. Thus, if ratio of numerical estimations for e_2 and e_1 composes 4.12 (207.58/50.41), for e_2 and e_3 – 5.7 (207.58/50.41), then for the variant with coverings (S_w-technology) similar ratios of numerical estimations compose: for e_2 and e_1 – 1.38, and for e_2 and e_3 – 2.36.

Thus, at use of the method of point estimation of PBC the interclass distance for analyzed pairs of signals increases more than 2 times. It provides rather exact classification of cyclic signals. Besides, it is necessary to notice that if at application of the method of point estimation of PBC the closest to the signal e_1 is the signal r_3 with value 23.85 (Table 1) and further consecutively: r_2 – with value 73.33, r_1 – with value 207.58, then with application of the method of coverings the closest to e_1 is the signal r_3 (Table 2) with conventional value of affinity 777, however, further on degree of affinity instead of r_2 it is selected r_1 with value 848 and then the signal r_2 with value 1101.

The carried out analysis confirms that, despite some complication of recognition procedure, reliability of definition of relative degree of affinity of considered pairs of signals at use of the method of point estimations of CS PBC essentially improves.

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