NON-STANDARD SPESIMENS ULTRASOUND DEFECTOSCOPY OF PIPES

Klymenko S.M. (Poltava branch of Ukrainian Government Geological Research Institute, Poltava, Ukraine), Malaychyk V.P., Mozgovoy A.V. (Dnepropetrovsk National University, Dnepropetrovsk, Ukraine)

Introduction

Traditional ultrasound defectoscopy assumes the use of samples of controlled articles with applied standard defects to set the settings for the equipment. With this way of settings and followed by control, the influence of unstable acoustic contact with transformer and the surface of the pipe is not accounted for; and also the difference in reflective abilities of real and controlled (standard) defects. Aside from that, with control of real long measured articles, which are pipes, that approach does not allow to differentiate the variable measure of speed of ultrasound waves and their disbursement in one pipe, and also in the same pipes in one batch. Also, the companies-producers and companies-consumers, which use those pipes, in present time use the samples in which the defects are imitated by different ways: drill holes, creases, scratches and cuts. All this leads to great errors in making a decision on the quality of controlled pipe. In this case it is wise to apply statistical decision rules and methods of detecting patterns.

The influence of this deficiency can be greatly reduced, using the non-standard approach to defectoscopy, which is based on using limited quantity of priority information about the norms of defects and processing of a large quantity of data.

This article discusses the proposed non-standard information technologies of ultrasound control and monitoring of drilling pipes in the process of their exploitation.

Determining the task

Drilling pipes in exploitation are periodically checked in the process of accent-decent operations with the purpose of determining their condition. The purpose of control – determining the defects and changes in structure of metal by statistical treatment of recorded selections of measurements of parameters of reflected input signals in discrete points along the total length of the controlled pipes. The decision about the condition of each pipe of the drilling column should be made based on the measurement results not only of the last control, but all the previous measurements contained in the database. Information about the condition of the exploited pipe, received with double-channel ultrasound defectoscope, is contained in two selections of measurements: $x_1(j,k)$ – peek values of signals, reflected from the defects, or structural noises, and $x_2(j,k)$ – peek values of ground signals, where j – control number of given pipe, and k – number of measurement and point of probing on the surface. [1]. Knowing the numbers of measurements of signals reflected from defects, it is possible to determine the size and location coordinates of defect areas. Having processed the selection of measurements after each control, it is possible to evaluate the dynamics of condition of exploited drilling pipes. Determining and analyzing the change in statistical conformities of ultrasound signals consists of two tasks: 1) estimation of defects of controlled pipes; 2) estimation of changes in properties of metal to disburse ultrasonic vibrations. The first task is a part of statistical recognition of patterns, second task is non-parametrical statistic of comparative analysis of selections of measurements of random values. [2]

Initial processing of measurements

Measurements of the output of defective $x_1(k)=m(k)S_1(k)+n_1(k)$ and ground $x_2(k)=m(k)S_2(k)+n_2(k)$ channels of ultrasound defectoscope are distorted by contact *m(k)* and noise *n(k)* disruptions, thus influence of contact distractions on the effectiveness of control is greater then the influence of noise distractions. The values of measurements $x_1(k)$ and $x_2(k)$ depend on the settings of defectoscope, therefore the numeral values of two selections received with the second control can greatly differ from each other. To compare the selections of measurements, it is necessary to have the changing normality, which would not decrease the quantity of information about the control pipe, contained in two initial selections. For this purposes the summary-differentiation wave conversion is used

$$z_1(i) = \frac{x_1(2i-1) + x_1(2i)}{x_2(2i-1) + x_2(2i)}, \tag{1}$$

$$U_1(i) = \frac{x_1(2i-1) - x_1(2i)}{x_2(2i-1) + x_2(2i)}, \qquad U_2(i) = \frac{x_2(2i-1) - x2(2i)}{x_2(2i-1) + x_2(2i)}. \tag{2}$$

Summary selection $z_1(i)$ contains information about defects and with such norm the influence of modulating interferences, that distort measurements $S_1(k)$ and $S_2(k)$, is greatly reduced. The measurements $z_1(i)$ relate to class of low frequency discrete random values, and $U_1(i)$ and $U_2(i)$ – to high frequency noises (analog derivative from functions *x(t)*). The last contain information about inside remaining tension and structure of metal, in other words, are structural noises. The size of generated selections $z_1(i)$, $U_1(i)$ and $U_2(i)$ in comparison with selections $x_1(k)$ and $x_2(k)$ decrease by two times, but the whole number of measurements, containing information, does not change.

With dynamic control the minimal number of signal measurements, reflected from point defects, depends in linear size of gage and scanning speed. If their number equals *n*, and the total number of measurements is *N*, then the number of controlled areas of pipe equals to $M = N/n$. The pipe is considered a defective if one or several defective areas are discovered. Thus, the most undetermined task of pipe control with one defective area, and its coordinates unknown, then it is necessary to control and process all the measurements of all *M* parts. Measurement $z_1(i)$ is a norm sum of measurements $x_1(k)$ and $x_1(k+1)$, $i = 1,2,..., N/2$. The decision about the condition of each area of the pipe can be made based on mean vale of measurements selections $z_1(i)$ on this area. But with this division of selection size 0,5*N* measurement on *M* selections with 0,5*n* measurements it is possible to have a division of measurement selection from point defects in neighboring areas of pipe, which will bring to increase of mistakes in valuation of coordinates and sizes of defect areas. This can be avoided when valuation mean values by summary wave conversion $z_1(i)$, repeating it until two mean values for the each of *M* areas of pipe are received

$$\bar{z}_1\left(i/_{r+1}\right) = \frac{\bar{z}_1\left(r_i - 1/_r\right) + \bar{z}_1\left(r_i/_r\right)}{2}, \tag{3}$$

where *r* – number of wave-conversions.

The number of mean values on each of *M* areas of pipe depends on the number of conversions. If until the conversion the number equals to *n*, then after *r* conversions their number will be equal to $n/2^r$. Consequently, if to consequently conduct $\lg_2\left(n/2\right)$ conversions, then each of *M* areas of pipe will contain two mean values, based on which the decision should be made: to consider the area of the pipe defective, if there is two and more increases in the threshold of defect determination. This will decrease the number of false decisions of norm-defect.

Mathematical task of recognition of defect areas of pipe.

As a result of the initial processing of measurements, each elementary area of controlled pipe is assigned two random values – the mean measurement values of left and right half of selection on the given area. Mean values have distribution of probabilities close to normal, they are also independent on defect and non-defect areas and in any case differentiated by their mathematical expectations and dispersions. With control of pipe two errors are possible: 1) admission of pipe with defect areas; 2) exclusion of pipes without defects. The consequences of these errors are different. Obviously, consequences of admission of defective pipes are far more dangerous then exclusion of non-defective pipes. The effectiveness of control can be described by mathematical expectation of losses $M[C]$ due to errors of control. If quality of production or condition before control of pipes is characterized by the possibility of their defect $P(Б)$, the cost of making false control decision equals to $C_{БН}$ and $C_{НБ}$ (cost of error to count defect as norm and norm as a defect), and conditional probabilities of errors equal $P\left(H^*/Б\right)$ and $P\left(Б^*/H\right)$, then

$$M[C] = P(Б)C_{БН}\,P\left(H^*/Б\right) + [1 - P(Б)]C_{НБ}P\left(Б^*/H\right), \tag{4}$$

where $Б$ и H - symbols of condition defect, norm; symbols H^* and $Б^*$ - decision norm, defect. For pipes with one defect area conditional probabilities equal to

$$P\left(H^*/Б\right) = P^{M-1}\left(H^*/H\right)P\left(H^*/Б\right),\;\; P\left(Б^*/H\right) = P^{M-1}\left(H^*/H\right)P\left(D^*/H\right), \tag{5}$$

Where H and D, H^* and D^* - symbols of condition and decision about condition of the area. With consideration (5) expression (4) will be transformed into

$$M[C] = P(Б)C_{БН}\,P^{M-1}\left(H^*/H\right)\left[P\left(D^*/H\right) + l_0\,P\left(H^*/D^*\right)\right]. \tag{6}$$

The minimum rule of this expression is known [2]: it is necessary to calculate for each semi-area relationship of function of truth and compare it with the threshold l_0.

$$l(\bar{z}) = \frac{W\left(\bar{z}/D\right)}{W\left(\bar{z}/H\right)} >< l_0 = \frac{[1 - P(Б)]C_{НБ}}{P(Б)C_{БН}}. \tag{7}$$

If $l(\bar{z}) > l_0$, then decision should be made about the defect of controlled half-area, and area should be considered defective, if inequalities are present on two half-areas.

Research of effectives of recognition of defective area of pipe

Guided by known mathematical expectations and dispersions of mean values of measurements of defect a_{z1} and σ_{z1}^2 and non-defect a_{z2} and σ_{z2}^2 areas, for Gauss model the decision rule (7) is written as inequality

$$\left(\frac{\bar{z}-a_{z2}}{\sigma_{z2}}\right)^2-\left(\frac{\bar{z}-a_{z1}}{\sigma_{z1}}\right)^2 >< \ln\left(\frac{\sigma_{z1}^2}{\sigma_{z2}^2}l_0^2\right). \quad (8)$$

Convert this to inequality to be

$$\bar{z} >< a_{z2}+\sigma_{z2}\left(\frac{AB^2}{B^2-1}\sqrt{1+\frac{B^2-1}{A^2B^2}\ln\left(B^2 l_0\right)}-\frac{1}{B}\right). \quad (9)$$

From (9) it is seen that recognition of defectiveness of a half-areas comes down to check of inequality $\bar{z}>z_0$ on each area of the pipe and if inequalities are present two or more times in a row, then the decision of a defective area should be made. In (9) recognized values, which represent the differences in statistical laws of measurements on defective and non-defective areas of pipe

$$A=\frac{a_{z1}-a_{z2}}{\sigma_{z1}}, \quad B^2=\frac{\sigma_{z1}^2}{\sigma_{z2}^2}.$$

The right part of inequality (9) – threshold of comparison using the minimum criteria of cost of making false decision (minimum of middle risk). If the dispersion is $\sigma_{z1}^2=\sigma_{z2}^2=\sigma^2$, then the threshold is determined by this formula

$$z_0=a_{z2}+\sigma\left(\frac{A}{2}+\frac{\ln(l_0)}{A}\right)=\frac{a_{z1}+a_{z2}}{2}+\frac{\sigma^2\ln l_0}{a_{z1}-a_{z2}}. \quad (10)$$

If Neyman-Pearson criteria is applied assuming that conditional probability of exclusion of half-areas does not exceed $P_0\left(D^*/H\right)$, then the threshold equals to

$$z_0=a_{z2}+\sigma_{z2}\Psi\left[1-P_0\left(D^*/H\right)\right], \quad (11)$$

Where $\Psi(x)$ - function, reverse to integral of possibility of Gauss $\Phi(x)$.
If modified Neyman-Pearson criteria is applied, assuming that conditional probability of admission of defect half-area should not exceed $P_0\left(H^*/D\right)$, then the threshold should be chosen as follows

$$z_0=a_{z1}+\sigma_{z1}\Psi\left[1-P_0\left(H^*/D\right)\right]. \quad (12)$$

Conditional probabilities of admission of defective half-areas and probability of exclusion while using Gauss models are equal to

$$P\left(H^*/D\right) = \Phi\left(\frac{z_0 - a_{z1}}{\sigma_{z1}}\right), \quad P\left(D^*/H\right) = 1 - \Phi\left(\frac{z_0 - a_{z2}}{\sigma_{z2}}\right). \tag{13}$$

From (13) it follows that regardless of type of criteria for making the decision between possibility of errors of recognition of 1st and 2nd kind there is the same connection

$$P\left(H^*/D\right) = 1 - \Phi\left(\frac{a_{z1} - a_{z2}}{\sigma_{z1}} - \frac{\sigma_{z2}}{\sigma_{z1}}\Psi\left[1 - P\left(D^*/H\right)\right]\right). \tag{14}$$

To realize the program algorithm of finding defective areas of pipe, using the minimum average risk, it is necessary to know the parameters $(a_{z1}, a_{z2}, \sigma_{z1}, \sigma_{z2})$ of average values, the values $\bar{z}(i)$ of defect and non-defect semi-areas of pipe, the value of quality of pipe $P(Б)$ and the cost of making a false decision $C_{НБ}$ and $C_{БН}$. Using the results of control it is possible to evaluate only expected values a_{z2} и σ_{z2} and thus to perform only non-standard control using Neyman-Pearson criteria. [1, 3]. The cost of false decision should be chosen to reflect $C_{БН} >> C_{НБ}$. If their values will be chosen in reverse to proportional possibilities $P(Б)$ and $1 - P(Б) = P(H)$, then $l_0 = 1$. In this case the threshold z_0, according to formula (10), should be selected as a half sum a_{z1} и a_{z2}

$$z_0 = \frac{a_{z1} + a_{z2}}{2}, \qquad \sigma_{z1}^2 = \sigma_{z2}^2. \tag{15}$$

With this selection in accordance to (13) the conditional probabilities are the same, thus $P\left(D^*/H\right) = P\left(H^*/D\right)$. In this case the minimal cost of making a false decision depends only on their probability and according to (6) will be equal to

$$M[C] = 2P(Б)C_{БН}\left[1 - P\left(D^*/H\right)\right]^{M-1} P\left(D^*/H\right). \tag{16}$$

The determination of defect semi-areas of pipe could be realized using programming with minimum average conditional risk criteria (16) as follows.
Having the evaluation a_{z2} and σ_{z2}, and the decision rule threshold (15) and initial value (11) of admissible error possibility $P\left(D_0^*/H_0^*\right)$, thresholds of recognition z_{0k} of defective semi-area with expected values a_{zk} we choose equal to

$$z_{ok} = z_0 + k\Delta a = a_{z2} + \sigma\Psi\left(1 - P\left(D_0^*/H_0\right)\right) + k\Delta a, \tag{17}$$

Where *k*- number of discreet value a_{zk}, $k = 0,1,2,\ldots,k_m$.
Putting in (15) z_{ok} and solving it, we will receive the expected (potential) average values of measurements on possible defective semi-areas

$$a_{zk} = a_{z2} + 2\sigma\Psi\left(1 - P\left(D_0^* / H\right)\right) + 2k\Delta a\,.$$

In this case the possibilities of making a false decision will be equal to

$$P\left(H^* / D\right) = P\left(D_k^* / H\right) = 1 - \Phi\left(\Psi_0 + \frac{k\Delta a}{\sigma}\right). \qquad (18)$$

A relation $\Delta a / \sigma$ can be chose as follows. For example, if the possibility of exclusion of area of pipe should not exceed the threshold equal to 0,09, then $P\left(D_0^* / H\right) \le 0{,}3$ and in this case $\Psi_0\left[1 - P\left(D_0^* / H\right)\right] = \Psi_0(0{,}7) = 0{,}526$. If the possibility of finding minimal intensity signal, reflected from a defect, should be less then 0,64, then $P\left(H_1^* / D\right)$ should not exceed 0,2. Consequently, we will have $\Psi_1\left[1 - P\left(H_1^* / D\right)\right] = \Psi_1(0{,}8) = 0{,}846 = \Psi_0 + \frac{\Delta a}{\sigma}$ and $\frac{\Delta a}{\sigma} = 0{,}32$. For this case the results of valuation of possibility of finding potential defective semi-areas are presented in table 1.

Table 1

Criteria	k	1	2	3	4	5	6	7
MAR	$P\left(D_k^* / D\right)$	0,8	0,81	0,82	0,88	0,93	0,96	0,98
	$P\left(D_k^* / H\right)$	0,2	0,19	0,18	0,12	0,07	0,04	0,02
NP	$P\left(D_0^* / H\right)$	0,3	0,3	0,3	0,3	0,3	0,3	0,3
	$P\left(D^* / D\right)$	0,881	0,965	0,998	0,999	0,9995	0,9997	0,9998

From the analysis of table 1, it follows that using the minimum conditional average risk criteria (MAR) allows to substantially reduce the exclusion of pipes with comparison to Neyman-Pearson (NP) criteria with almost identical possibilities of discovery of defective areas of pipe.

Information support for decision making about defectiveness of controlled pipe

The result of treatment of selections $x_1(k)$ and $x_2(k)$ of measurements of ultrasound double-channel defectoscope of exploited drilling pipe – it is a sequence of average values of measurements on semi-areas of control $\bar{z}(m)$, $m = 1, 2, \ldots, 2M$. The decision about condition of *m* semi-area can be written as follows

$$r(m,k) = \mathrm{sgn}(\bar{z}(m) - z_{ok}), \qquad (19)$$

Where $\mathrm{sgn}(x)$ – function of single jump, taking on value of 1, if $x \geq 0$, and 0, if $x < 0$, k =0,1,2,…, k_m .

The decision about state of i defective area $R(i,k)$, $i = 1,2,\ldots,M$ is written as derivative of decisions on two neighboring semi-areas

$$R(i,k) = r[(2i-1),k]\ r(2i,k). \qquad (20)$$

Dual function of decisions $R(i,k)$ contains quantitative information about the degree if defectiveness of controlled pipe. The valuation of degree of defectiveness can be the average value of function of defectiveness on each of i area of pipe

$$\overline{R}(i) = \sum_{k=0}^{k_m} R(i,k). \qquad (21)$$

Function $\overline{R}(i)$ contains information about coordinates and sizes of defects and the degree of danger of defective areas (the greater $\overline{R}(i)$, the more dangerous is defective area). For integral valuation of defectiveness of pipe the sum of average values of function after j control $\overline{R}_j(i)$ can be used

$$\overline{R}_j = \sum_{i=1}^{M} \overline{R}_j(i), \qquad (22)$$

where j – control number (or pipe number).

The value $\overline{R}_j$ can be used for comparison valuation of changes in defectiveness of pipes during exploitation and comparison of pipes based on their defectiveness.

For non-defective pipes the inequality $\bar{z}(i) < z_{01}$ is present. This means that on non-defective areas because of error in measurements $\overline{R}(i)$ can be only 0 or 1. It is possible to select the noise constituents $R_ш(i)$ using formula

$$R_ш(i) = \mathrm{sgn}(R(i,0) + R(i,1) - 1). \qquad (23)$$

The probability of such event equals the probability of execution of two inequalities:

$$z_0 \leq \bar{z}(m) \leq z_{01} \text{ and } z_0 \leq \bar{z}(m+1) \leq z_{01}.$$

Their probabilities are identical and equal to

$$P_ш = \int_{z_0}^{z_{01}} W\left(\bar{z}/H\right) d\bar{z} = \Phi\left(\frac{z_{01} - a_{z2}}{\sigma}\right) - \Phi\left(\frac{z_0 - a_{z2}}{\sigma}\right).$$

The expected quantity of noise constituents equals to $MP_ш^2$ and knowing their number along the whole pipe

$$\overline{M}_0 = \sum_{i=1}^{M} R_ш(i) \approx MP_1^2 ,$$

we can control the effectiveness of algorithms of revealing the defects, controlling the probability of exclusion, changing Δa , z_{ok} и k_m .

Preparation of information for valuation of change in quality of exploited non-defective pipes. During drilling of the wells only non-defect pipes are used, as new and being in exploitation after planed control. Information about the quality of non-defective pipe is contained in selections of high-frequency structural noise $U_1(i)$ and $U_2(i)$. Lets look at another differentiated wavelet conversion

$$U_3(j) = z_1(2j-1) - z_1(2_j),$$

which contains information about the second derivative of initial signals $x_1(t)$ and $x_2(t)$. This is structural low-frequency noise of the second order. Selections of measurements $U_1(i)$, $U_2(i)$, $i = 1,2,\ldots, N/2$, and $U_3(j)$, $j = 1,2,\ldots, N/4$, received from results of control of a new pipe, can serve as empirical standards of norm for structural noises of given pipe. With this selections we can compare the selections of structural noises after the next pipe control in the process of accent-decent operations. The purpose of comparison – valuation of measurements of unknown statistical probabilities of measurements as a cause of change of internal residual tension and structure of pipe metal, effecting the dispersion of reflected ultrasonic vibrations. For a new non-defective pipe discrete selections of average values $\overline{z}(i)$ - stationary consequences (derivatives) almost normal independent random values. During exploitation pipes experience big pressure and we can expect the changes in metal properties to disperse ultrasound vibrations, which will lead to disruptions in structure on separate areas of pipe and changes in statistical conformities of structural noises. Thus, the selections of measurements $\overline{z}_1(i)$ and $U_3(j)$ contain information about the properties of metal that reflect ultrasound vibration in different parts of scanned pipe, and selections of measurements $U_1(i)$ and $U_2(i)$ - information about the properties of metal that disburse ultrasound vibrations on those points. The valuation of this properties can be the value of correlation bonds between selections $U_1(i)$ and $U_2(i)$. The numeral integral coefficients of the results of control of new pipe are the average value of selection $\overline{z}_1$, random dispersions of selections $D^*[z_1(i)]$, $D^*[U_1(i)]$, $D^*[U_2(i)]$ и $D^*[U_3(i)]$ and random coefficient of correlation bond between two selections $R_{12}^*[U_1(i)U_2(i)]$. To determine the value of correlation bond between two selections of random values with unknown conformities of assigning the probabilities we can use the rank correlation coefficients of Kendall and Spearman [4].

The comparison of results of control of exploited pipe with the results of its first control has a purpose of determining the differentiated values not only between integral indexes, but also between the indexes of all *M* elementary areas. For example, in a 12-meter pipe we have 120-130 areas, 60-65 measurements in each. Lets look at a pipe with 8192 measurements $x_1(i)$ and $x_2(i)$. It has 128 areas with 64 measurements in each. After first summary-differentiated wavelet conversion we will get $z_{11}(i)$, $U_{11}(i)$ and $U_{21}(i)$, $i = 1,2,\ldots,4096$ and $U_{31}(i)$, $i = 1,2,\ldots,42048$. After the successive wavelet conversion as

$$z(i)=z(2i-1)+z(2i),$$

we will get *M*=128 areas with average values $\bar{z}_{11}(m)$, $\bar{U}_{31}(m)$, $\bar{U}_{11}(m)$,$\bar{U}_{21}(m)$ on each area ($m=1, 2,\ldots, M$). Conducting the analogical wave-conversions of the results of new pipe control, we will get standard selections $z_1(m)$, $\bar{U}_3(m)$, $\bar{U}_1(m)$ и $\bar{U}_2(m)$. Given this information we can estimate the constant of metal properties along the whole length of the pipe by the method of hypothesis of presence or deficiency trend in averages and measurement dispersions by periodic pipe control and dynamics of change in statistical conformities of measurements of ultrasound signals.

Estimation of value of changes in results of control of exploited pipes.

This task is solved by comparison of standard indexes of control with indexes of current pipe control during accent-decent operations. For research of integral indexes the Cochrane-Cox criteria is used for comparison of averages with Fisher criteria for dispersion comparison [4]. Reliability of decision making and valuation of changes in statistical conformities *M*-selections can be estimated using non-parametrical criteria of change and scale, and presence of trends in averages and dispersions of empirical rows using Foster-Steward criteria and index-rank Hollin criteria. This explained by the fact that task of comparison of averages with unknown and unequal dispersion still does not have the exact decision (Behrens-Fisher problem).

To estimate the possible changes in averages and dispersion of two sequences $\bar{z}_1(m)$ and $\bar{z}_2(m)$ is possible by combining the Bush-Wind criteria of change and scale [3], which is calculated as follows. Ranks $R(\bar{z}_2(m))$ in the general index statistics are assigned $\xi(1)<\xi(2)<\ldots<\xi(2M)$ of two selections $\bar{z}_1(m)$ and $\bar{z}_2(m)$

$$R[\bar{z}_2(m)]=\sum_{i=1}^{2M}\operatorname{sgn}[\bar{z}_2(m)-\xi(i)]=R_2(m).$$

Then the analogs of Van Der Varden *S* and Klotz *T* criteria are calculated

$$S=\frac{\sqrt{2M-1}\sum_{m=1}^{M}\Psi\left(\frac{R_2(m)}{2M+1}\right)}{M\sqrt{D[\Psi]}},\quad T=\frac{\sqrt{2M-1}\left(\sum_{m=1}^{M}\Psi^2\left(\frac{R_2(m)}{2M+1}\right)-\sum_{m=1}^{M}\Psi^2\left(\frac{m}{2M+1}\right)\right)}{M\sqrt{D[\Psi^2]}},$$

where $D[\Psi]=\frac{1}{2M}\sum_{m=1}^{2M}\Psi^2\left[\frac{m}{2M+1}\right]$; $D[\Psi^2]=\frac{1}{2M}\sum_{m=1}^{2M}\Psi^4\left[\frac{m}{2M+1}\right]$.

Butt-Wind criteria is calculated according to formula

$$W=-2\ln[2(1-\Phi(|S|))-2\ln[2(1-\Phi(|T|))]\ ],$$

Where $\Phi(x)$ - Gauss probability integral, to calculate which the approximation can be used

$$\Phi(x)=1-0{,}852\exp\left[-\left(\frac{x+1{,}5774}{2{,}0637}\right)^{2,34}\right].$$

For approximation of reverse function can be used this formula

$$\Psi(B) = 4{,}91\left[B^{0,14} - (1-B)^{0.14}\right].$$

Hypothesis of absence in change (i.e. equality of mathematical expectations) and indistinctibility of dispersion (i.e. equality of dispersion) selections $\bar{z}_1(m)$ and $\bar{z}_2(m)$ with truth P accepted, if $W \le W_0$. The threshold of comparison W_0 with $m > 30$ has distribution close to χ square with 4 degrees of freedom. The values if thresholds are shown in table 2.

Table 2

P	0,9	0,95	0,98	0,99	0,995	0,998
W_0	7,8	9,5	11,7	13,3	14,9	16,9

For determining the changes in statistical conformities of selections we can use the Klotz criteria $\overline{W}_1(m)$, $\overline{W}_2(m)$ and $\overline{W}_3(m)$. For each pair of selections $\overline{W}_1(m)$ and $W_{12}(m)$ the ranks are assigned $R[W_{12}(m)]$ and the Klotz criteria is formed by the formula

$$L = \sum_{m=1}^{M} \Psi^2\left[\frac{R(m)}{2M+1}\right].$$

If $M > 10$, then the law of distribution of *L* criteria can be approximated by normal mathematical expectation and dispersion

$$M[L] = \frac{1}{2}\sum_{m=1}^{M} \Psi^2\left[\frac{m}{2M+1}\right],$$

$$D[L] = \frac{M}{2(2M-1)}\sum_{m=1}^{2M} \Psi^4\left[\frac{m}{2M+1}\right] - \frac{1}{2M-1}\left[\frac{1}{2}\sum_{m=1}^{2M} \Psi^2\left[\frac{m}{2M+1}\right]\right].$$

If $l = \frac{L - M[L]}{D[L]} \ge \Psi\left(\frac{1+P}{2}\right)$, then with probability *P* the decision can be made about the presence of changes in statistical conformities of selections $\overline{U}(m)$.

One of the reasons, influencing the meaning of Bush-Wind and Klotz criteria, can be presence of trends in selections $\bar{z}(m)$ and $\overline{U}(m)$. To check this assumption and valuation of meaning of changes due to trends, the Foster-Stuart and Hollin criteria can be used. At first the presence of trends in the selections is checked $\bar{z}_1(m)$, $\overline{U}_3(m)$, $\overline{U}_1(m)$ and $\overline{U}_2(m)$ in the new pipe. Their values can serve as a norm standard. Foster-Stuart criteria allows to evaluate average trends and dispersion trends. Criteria are formed as follows. Two sequences are calculated - $x(i) > x(i-1)$; $x(i-2); x(1)$, $i \ge 2$ and $x(i) < x(i-1)$; $x(i-2);\ldots; x(1)$, $i \ge 2$, first $U(i)$ – greater then all, second $V(i)$ – less then all

$$U(i) = \prod_{j=1}^{i} \operatorname{sgn}[x(i) - x(i-1)], \;\; V(i) = \prod_{j=1}^{i} \operatorname{sgn}[x(i-1) - x(i)].$$

First $U(i)$ - dual sequence “greater then”, second – “less then”. They take on the value of 0 or 1, i =2,3,…, M . Then the difference *D* and sum *S* are calculated

$$D = \sum_{i=2}^{M} (U(i) - V(i)), \qquad S = \sum_{i=2}^{M} (U(i) + V(i)).$$

The difference is used for discovering the trend in averages, the sum – for checking the trend in dispersions in probed sequences of random values. Criteria *D* and sum *S* – random values with intervals $-(M-1) \le D \le (M-1)$ and $0 \le S \le (M-1)$. The decision about absence of trend is made when ($M \ge 50$)

$$t_1 = \frac{D}{\sqrt{2\ln M - 0,8456}}, \quad t_2 = \frac{S - (2\ln M - 0,8456)}{\sqrt{2\ln M - 3,4253}}.$$

The values t_1 and t_2, with no trend present, have Student’s probability with M degrees of freedom. The decision about no presence of trend is made when $|t_{1.2}| \le \Psi_c\left(\frac{1-P}{2}\right)$, where $\Psi_c(x)$ - function, reverse to integral of Student’s probability (with M >30 Ψ_c(0,975)=2,3), $P = 1 - P_0$, P_0 - acceptable probability of making a false decision.

Hollin criteria, as a generalization of Wald-Wolfowitz rank criteria and numeral criteria of cumulative sums, can be used for comparison of stationary selections of measurements of pipe in exploitation, with its first measurements before exploitation. The Hollin criteria is based on calculating index of numeral rank autocorrelation of the probed selection x_1, x_2, …, x_m. At first, the median of initial selection is determined and a number of differentiation modules $z(m) = |x(m) - \tilde{x}|$ is formed. Median equals to half-sum of central values sorted by increase of probed selection $x(m)$. Then the sequence ranks are determined $z(m)$

$$R(m) = R[z(m)] = \sum_{i=1}^{M} \operatorname{sgn}[z(m) - \xi(m)],$$

where $\xi(1)$, $\xi(2)$,…,$\xi(M)$ increasing row of selection $z(m)$,

The Hollin index is determined by formula

$$\bar{x}_0 = \frac{1}{k(M-1)} \sum_{m=1}^{M} R(m-1)R(m)\,\delta[(x(i-1) - \tilde{x})]\,\delta[(x(i) - \tilde{x})],$$

Where *k*- Hollin coefficient (table 3).

Table 3

M	10	20	50	100	200	400
k	36	140	850	3370	13400	53480

For the evaluation of changes in statistical conformities of measurements of exploited popes, the sequence of relations of Hollin index $C_x(j) = x_0(j) / x_{01}$, is formed, where j – control number during accent-decent operations.

Conclusion

Theoretical bases of non-standard information technologies of ultrasound control and monitoring are developed for pipes being in exploitation. Proposed are the algorithms of forming the decision rule of determining and evaluation of defective areas of pipe based on conditional minimum criteria of expected cost of making a false decision (conditional average risk). For determination and evaluation of measurements of internal residual tensions and structure of metal in pipes being in exploitation, the algorithms of comparison of selections of measurements are proposed by summary-differentiation conversion and formation of deciding rules on the bases of nonparametric Bush-Wind criteria and Klotz criteria of change and scale, Foster-Stuart criteria for determining trends and Hollin criteria.

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