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E.B. Zavoichinskaya, B.I. Zavoichinskii

ESTIMATION OF STRUCTURE DURABILITY USING THE STATE DIAGNOSTIC AND SAFETY REQUIREMENTS

Here is presented the theoretical bases of a method of definition of extended structure service life on values of service life of their elements with defects which geometry is established by methods of technical diagnostics with results of the analysis of previous operation features, failure statistics for similar structures and requirements of industrial safety. There is submitted the algorithm of definition of recommended pipeline service life on a design stage, provided carrying- out of requirements of industrial safety.

The approach is illustrated by obtained relations for an estimation of a residual resource of the main pipelines taking into account the results of diagnostics of their technical condition.

1. There are considered the structures consisting of a significant amount of elements ($N \geq 10^3$), including welded connections of various types.

Structure elements contain the defects having a mechanical, technological and operational origin.

Methods an estimation of durability of such designs is based on the block-hierarchical approach according to which some hierarchical structural levels are selected, and service life is estimated consistently from the lowest to the maximum hierarchical constructive levels [1], [2].

The structure conditionally is segmented (sections, macrosegments, etc.) on the functional-design principle (the maximum hierarchical level).

Further macrosegments are represented as calculative segments on character of internal and external loadings and influences and design data (an average hierarchical level). The sizes of each segment are defined by the condition approximately homogeneity of internal and external loadings and influences. The calculated segment is determined as a certain set of structure elements (the lowest hierarchical level).

In the article for the first time the problem of determination of segment life (an average hierarchical level) on results of life calculation of its elements with defects (the lowest hierarchical level), established by carried out diagnostics, is formulated and solved, in view of requirements of social and ecological safety.

The calculation of element durability is carried out on the theory of failure processes of loading [1], [6] and fracture mechanics on the basis of results of diagnostics of technical condition of the element. Service life of a macrosegment at the top hierarchical level is determined as the least value from service life of calculated segments.

There is submitted the algorithm of definition of recommended pipeline service life on a design stage, provided carrying- out of requirements of industrial safety.

2. The present approach is illustrated by the example of diagnostics of a technical condition of main pipelines and an estimation of their service life.

Diagnostics of a sections or several sections of the pipeline (the top hierarchical level) is carried out passing through them the intrapipe intellectual shells (profile recorders, ultrasonic and magnetic flaw detectors). Electrometric and acoustical-issue diagnostics are applied for calculated sections (an average hierarchical level), and ultrasonic, magnetic, magnetic-powder and x-ray diagnostics are spent for structure elements in test pits (the lowest hierarchical level).

Large-scale pipeline destructions are caused by stochastic processes of evolution of cracks, geometrical defects, corrosion defeats of element metal. The matrix of defects contains the cracks in the basic metal of structure elements, cracks in ring and longitudinal welded connections, corrosion cracks, stress - corrosion cracks, corrosion loss of metal, stratification and inclusion in element metal, risks, dents, corrugations in an element wall. Defects can be found by means of intrapipe and external diagnostics with the certain reliability, and also be set by results of the previous section operation and failure statistics on the similar sections.

Each kind of the above-stated defects "x", $x = 1,...x_c$, leads to the destruction stream of element section.

Data files of each kind of defects "x", $x = 1,...x_c$, is associated with the data files of failure times $t_{y,x,i}$ for defects found out by means of intrapipe diagnostics ($t_{y,x,i}$ - failure times of reaching by defect of a kind "x" with a serial number "y" of the critical size $y = 1,...y_x$);

data files "x", $x = 1,\ldots x_c$, is associated with the data files of failure times $t_{z,x,e}$ ($t_{z,x,e}$ - failure times of reaching by defect of "x" with a serial number "z" of the critical size $z = 1,\ldots z_x$) for defects found out by means of external diagnostic inspection;

data files "x", $x = 1,\ldots x_c$, cause data files $t_{w,x}$ ($t_{w,x}$ - failure times of reaching by defect of a kind "x" with a serial number "w" of the critical size $w = 1,\ldots w_x$) for defects found out by means both intrapipe, and external diagnostics,

for defects which cannot be revealed by diagnostic inspection it is determined failure times $t_{x,ind}$ of achievement by defect "x" to the critical size.

To serial current numbers "y","z","w" there correspond the coordinates of defect arrangement on section length L_y, L_z, L_w accordingly.

The probability P_f of large-scale destruction of a calculated section is determined by the sum of probabilities of the large-scale destructions caused by occurrence and growth of defects, having mechanical, technological and operational origin, during the time (the theorem of an addition of probabilities for not joint events):

$$P_f(t_r) = \left\{ \sum_{x=1}^{x_c} \frac{Q_{x,f}(t_r)}{1 - Q_{x,f}(t_r)} \right\} \times \prod_{q=1}^{x_c} \left[1 - Q_{q,f}(t_r)\right], \quad (1)$$

where

$$Q_{x,f}(t_r) = \{ \sum_{y=1}^{y_x} \frac{P_{y,x,i}(t_r)}{1 - P_{y,x,i}(t_r)} + \sum_{z=1}^{z_x} \frac{P_{z,x,e}(t_{d,x}+t_r)\left[1 - P_{z,x,e}(t_{d,x})\right]}{1 - P_{z,x,e}(t_{d,x}+t_r)\left[1 - P_{z,x,e}(t_{d,x})\right]} + \sum_{w=1}^{w_x} \frac{P_{w,x}(t_r)}{1 - P_{w,x}(t_r)} +$$
$$+ P_{x,ind}(t_r) \} \times \prod_{y=1}^{y_x} \left[1 - P_{y,x,i}(t_r)\right] \prod_{z=1}^{z_x} \left[1 - P_{z,x,e}(t_{d,x}+t_r)\left[1 - P_{z,x,e}(t_{d,x})\right]\right] \prod_{w=1}^{w_x} \left[1 - P_{w,x,i}(t_r)\right] +$$
$$+ P_{x,3f}(t_{d,x}+t_r)\left[1 - P_{x,3f}(t_{d,x})\right] + P_{x,a}(t_{d,x}+t_r)\left[1 - P_{x,a}(t_{d,x})\right] q(y,z,w), \text{ here} \quad (2)$$

$P_f(t_r)$ - probability of destruction of a certain length pipeline section during residual time of its operation t_r after the end of diagnostic inspection or after the certain time of operation;

$P_{y,x,i}(t_r)$ - probability of destruction of the section having defects of a kind "x", $x = 1,\ldots x_c$, located on its length on the distance $L_y, y = 1,\ldots y_x$, and found out only means of intrapipe diagnostics during time t_r;

$P_{z,x,e}(t_{d,x} + t_r)$ - probability of destruction of the section having defects of a kind "x", $x = 1,\ldots x_c$, located on its length on the distance $L_z, z = 1,\ldots y_x, L_z \neq L_y$ and found out only by means of external diagnostic inspection during the operation time $t_{d,x} + t_r$;

$P_{w,x}(t_r)$ - probability of destruction of element section having defects of a kind "x", $x = 1,\ldots x_c$, ,which are located on its length on the distance $L_w, w = 1,\ldots w_x$, and are found out both intrapipe, and external diagnostics, during the residual time t_r;

$P_{x,ind}(t_r)$ - probability of destruction of the section having defects of a kind "x", $x = 1,\ldots x_c$, of which sizes isn't revealed of diagnostics;

$P_{x,a}(t_r)$ - probability of destruction of a section during the residual time t_r, estimated by results of indirect methods of external diagnostics (magnetic gradiometer; acoustical-issue and eddy methods, electrometric methods of technical condition monitoring for insulating cover and metal), the analysis design, executive and service documentations and statistics of destructions on defects of a kind "x", $x = 1,\ldots x_c$;

$P_{x,3f}(t_r)$ - probability of destruction of the section, estimated by results of the previous section operation in view of activity of the third parties and statistics of destructions while in service the similar sections of the area, during the time t_r;

t_r - residual time of operation from the ending of last diagnostics;

$t_{d,x}$ - the time of finding of defects "x" from the beginning of pipeline operation;

$q(y,z,w) = 1$ - if the results of intrapipe and external diagnostics are not presented;

$q(y,z,w) = 0.5$ - if it is not results either intrapipe, or external diagnostics;

$q(y,z,w) = 0$ - if we have the results of intrapipe and external diagnostics.

At $P_{y,x,i} << 1, P_{x,ind} << 1, P_{z,x,e} << 1, P_{w,x} << 1, P_{x,3f} << 1, P_{x,a} << 1$, the relations (1), (2) can be transformed to the following:

$$P_f(t_r) = P_e(t_r, t_{d,x}) + P_i(t_r) + P_w(t_r) +$$
$$+ P_{ind}(t_r) + P_{3f}(t_r, t_{d,x}) + P_a(t_r, t_{d,x}), \quad (3)$$

where $P_e(t_r, t_{d,x}) = \sum_{x=1}^{x_c} \sum_{z=1}^{z_x} P_{z,x,e}(t_{d,x}+t_r)\left[1 - P_{z,x,e}(t_{d,x})\right]$,

$$P_i(t_r) = \sum_{x=1}^{x_c} \sum_{y=1}^{y_x} P_{y,x,i}(t_r),$$

$$P_w(t_r) = \sum_{x=1}^{x_c} \sum_{w=1}^{w_x} P_{w,x}(t_r),$$

$$P_a(t_r,t_{d,x})=\sum_{x=1}^{x_c} P_{x,a}(t_{d,x}+t_r)\left[1-P_{x,a}(t_{d,x})\right]q(y,z,w),$$

$$P_{ind}(t_r)=\sum_{x=1}^{x_c}\sum_{y=1}^{y_x} P_{y,x,i}(t_r),$$

$$P_{3f}(t_r,t_{d,x})=\sum_{x=1}^{x_c} P_{x,3f}(t_{d,x}+t_r)\left[1-P_{x,3f}(t_{d,x})\right].$$

3. Damages of structure elements of a pipeline section $\pi_x=\pi_x(t)$ under operational loading are proportional to the relation of service life of a section t to failure time t_x of destruction of a section on the defect "x" (the linear theory of damage accumulation):

$$\pi_x \sim \frac{t}{t_x},\ \pi_x \sim \lambda_x L t, \qquad (4)$$

where t_x - failure time of achievement by the defect "x" of the critical sizes $l_{x,f}, x=1,...x_c$, under operational loading: $\sigma_{g,j}=\sigma_{g,j}(t), g,j=1,2;$ $l_{x,f}=l_0+f_x\left[\sigma_{g,j}(\tau)\right]_{\tau=0}^{\tau=t_x}$, f_x - time functional, describing the growth of the defect sizes in time $\frac{1}{t_x}\sim\lambda_x L$;

λ_x - coefficient of intensity of a stream of destructions "x"; L - length of a calculated section.

For definition of damage of constructive elements π_x it can be used the approaches [1] - [3]. It is assumed, that the probability of section destruction $P_x=P_x(t)$ on the defect "x" during the time t is univalent determined by damage $\pi_x=\pi_x(t)$:

$$P_x(t)=\varphi(\pi_x(t)),\quad \text{i.e.} \qquad (5)$$

$$P_{y,x,i}(t_r)=\varphi\left(\frac{t_r}{t_{y,x,i}}\right) P_{w,x}(t_r)=\varphi\left(\frac{t_r}{t_{w,x}}\right)$$

$$P_{x,ind}(t_r)=\varphi\left(\frac{t_r}{t_{x,ind}}\right),$$

$$P_{z,x,e}(t_r)=\varphi(\lambda_{x,e}t_r L)$$

$$P_{x,a}(t_r)=\varphi(\lambda_{x,a}t_r L)\ P_{x,3f}(t_r)=\varphi(\lambda_{x,3f}t_r L),$$

$$x=1,...x_c, y=1,...y_x, z=1,...z_x, w=1,...w_x,$$

where L - length of a calculated section;

$\lambda_{x,e},\lambda_{x,a},\lambda_{x,3f}$ -coefficients of intensity of a stream of the destructions "x";

$\varphi=\varphi(t)$ - function of distribution of section destruction;

$t_{y,1,i}, t_{w,1}, t_{1,ind}$ - time of reaching of critical sizes by longitudinal or cross-section cracks in the basic metal of elements on the distance L_y, L_w and in the most stress zone on the length of a calculated section accordingly;

$t_{y,2,i}, t_{w,2}, t_{2,ind}$ - time of reaching of the critical sizes of longitudinal or cross-section cracks in ring and longitudinal welded connections on distance L_y, L_w and in the most stress zone on length of a calculated section accordingly, and at displacement of their edges;

$t_{y,3,i}, t_{w,3}, t_{3,ind}$ - time of reaching of the critical sizes of element metal stratifications on distance L_y, L_w and in the most stress zone on length of the section accordingly;

$t_{y,4,i}, t_{w,4}, t_{4,ind}$ - time of reaching of the critical sizes of corrosion cracks and the volume of corrosion losses of metal on distance L_y, L_w and in the most stress zone on length of the section accordingly;

$t_{y,5,i}, t_{w,5}, t_{5,ind}$ - time of reaching of the critical sizes stress - corrosion cracks on distance L_y, L_w and in the most high stress zone on length of the section.

For the description of destruction during service life t_r there is chosen the function $\varphi=\varphi(t)$ as Pouasson distribution:

$$\varphi = k_x\frac{t_r}{t_x}\exp\left(-k_x\frac{t_r}{t_x}\right), \qquad (6)$$

$$\varphi = k_x\lambda_x t_r L\exp(-k_x\lambda_x t_r L),$$

where $k_x, x=1,...x_c$, - safety coefficients providing the conformity the valid and calculated failure times.

Calling all (3) and (6) the probability of destruction of a calculated section $P_f=P_f(t_r)$ can be determined on the following relation:

$$\begin{aligned}P_f(t_r)=\sum_{x=1}^{x_c} k_x[(t_{d,x}+t_r)L\{&H_{x,e}\lambda_{x,e}\exp(-k_x\lambda_{x,e}(t_{d,x}+t_r)L)\left[1-k_x\lambda_{x,e}t_{d,x}L\exp(-k_x\lambda_{x,e}t_{d,x}L)\right]+\\ &+H_{x,a}\lambda_{x,a}\exp(-k_x\lambda_{x,a}(t_{d,x}+t_r)L)\left[1-k_x\lambda_{x,a}t_{d,x}L\exp(-k_x\lambda_{x,a}t_{d,x}L)\right]+\\ &+H_{x,3f}\lambda_{x,3f}\exp(-k_x\lambda_{x,3f}(t_{d,x}+t_r)L)\left[1-k_x\lambda_{x,3f}t_{d,x}L\exp(-k_x\lambda_{x,3f}t_{d,x}L)\right]\}+\\ &+t_r S_{x,t}\left\{\frac{H_{x,ind}}{t_{x,ind}}\exp\left(-k_x\frac{t_r}{t_{x,ind}}\right)+\sum_{w=1}^{w_x}\frac{H_{x,w}}{t_{w,x}}\exp\left(-k_x\frac{t_r}{t_{w,x}}\right)+\sum_{y=1}^{y_x}\frac{H_{x,i}}{t_{y,x,i}}\exp\left(-k_x\frac{t_r}{t_{y,x,i}}\right)\right\}].\end{aligned} \qquad (7)$$

Under the condition of

$$k_x \frac{t_r}{t_{y,x,i}} < 1, k_x \frac{t_r}{t_{x,ind}} < 1, k_x \frac{t_r}{t_{w,x}} < 1, k_x \lambda_{x,3f} (t_{d,x} + t_r) L < 1, k_x \lambda_{x,e} (t_{d,x} + t_r) L < 1,$$

the relation (7) can be reformed by following:

$$P_f(t_r) = t_d L\lambda_f + t_r \left(L\lambda_f + \frac{1}{t_f} \right), \qquad (8)$$

$$\lambda_f t_d = \sum_{x=1}^{x_c} k_x t_{d,x} \{ H_{x,e}\lambda_{x,e} + H_{x,a} q(y,z,w) \lambda_{x,a} + H_{x,3f}\lambda_{x,3f} \}$$

where

$$\frac{1}{t_f} = \sum_{x=1}^{x_c} s_{x,t} k_x \left\{ \frac{H_{x,ind}}{t_{x,ind}} + \sum_{w=1}^{w_x} \frac{H_{x,w}}{t_{w,x}} + \sum_{y=1}^{y_x} \frac{H_{x,i}}{t_{y,x,i}} \right\},$$

t_d - time of the diagnostic end from the beginning of operation;

$\lambda_{1,e}, \lambda_{1,a}, \lambda_{1,3f}$ - coefficients of intensity of a destruction stream, characterized the distribution of probability of reaching of the critical sizes by longitudinal and cross-section cracks in the basic metal and in zones of geometrical concentrators (in dents, corrugations, risks);

$\lambda_{2,e}, \lambda_{2,a}, \lambda_{2,3f}$ - coefficients of intensity of a destruction stream, characterized the distribution of probability of reaching of the critical sizes by longitudinal and cross-section cracks in ring and longitudinal welded connections, and at displacement of their edges;

$\lambda_{3,e}, \lambda_{3,a}, \lambda_{3,3f}$ - coefficients of intensity of a destruction stream, characterized the distribution of probability of reaching of the critical sizes of metal stratifications in structure elements;

$\lambda_{4,e}, \lambda_{4,a}, \lambda_{4,3f}$ - coefficients of intensity of a stream of corrosion destructions of structure elements (taking into account the quality of insulating cover, duration and quality of a work of electrochemical protection devices, corrosion activity of spoils, the water environment);

$\lambda_{5,e}, \lambda_{5,a}, \lambda_{5,3f}$ - coefficients of intensity of a stream of stress-corrosion destructions of structure elements (taking into account the quality of an insulating cover, mark of steel and a level mechanical loading constructive elements, aggression of an environment);

$\lambda_{6,e}, \lambda_{6,a}, \lambda_{6,3f}$ - coefficients of intensity of a destruction stream caused by occurrence of mechanical influences on elements section as a result of activity of the third parties (acts of vandalism, mechanical influences of digging and transport equipments, explosions, impacts), depends on the depth of pipeline position, conditions of the conservation zone, frequency of patrolling;

$H_{x,ind}$ - probability of potential presence of defects "x" not detected by known means (the calculated maximal length of the defect is equal l_0 =50мм, the calculated maximal depth of the defect is equal h_0 =1,5 mm);

$H_{x,i}$ - probability of detection of defects "x" with the sizes (l, h), $(l>l_0, h>h_0)$, by known means at intrapipe diagnostics;

$H_{x,e}$ - probability of detection of defects "x" by known means at external diagnostics;

$H_{x,w}$ - probability of detection of defects of a kind "x" with the sizes $(l,h), (1>l_o, h>h_0)$, by known means at intrapipe and external operational joint diagnostics,

$$H_{x,w} = H_{x,i} + H_{x,e} - 2H_{x,i}H_{x,e};$$

$H_{x,a}$ - probability of a prediction of defects of a kind "x" by results of analysis of design, executive and the operational documentations and statistics of destructions on defects of a kind "x" while in service similar sections in similar nature-climatic conditions;

$H_{x,3f}$ - probability of a prediction of defects "x" caused by activity of the third parties, by results of the previous section operation and statistics of destructions while in service of similar sections at similar social and industrial conditions;

$S_{x,t}$ -probability of definition of non-failure operation of structure elements with "x" defects according to the accepted failure theory ($t_{x,ind}, t_{w,x}, t_{y,x,i}$).

5. According to the criterion of industrial safety of pipelines the probability of pipeline destruction during its service life (structural risk) should not exceed the acceptable risk determined on values of social risk, industrial risk and ecological risk (on flora and fauna) [3]-[5].

Residual time of socially and ecologically safe section operation should satisfy to the following inequality:

$$\left[\lambda_f L t_d + t_{sf} \left(\lambda_f L + \frac{1}{t_f} \right) \right] \le [I], \qquad (9)$$

where at $t_{d,x} = t_d$

$$\lambda_f = \sum_{x=1}^{x_c} k_x \left\{ H_{x,e}\lambda_{x,e} + H_{x,a} q(y,z,w)\lambda_{x,a} + H_{x,3f}\lambda_{x,3f} \right\},$$

$$\frac{1}{t_f} = \sum_{x=1}^{x_c} S_{x,t} k_x \left\{ \frac{H_{x,ind}}{t_{x,ind}} + \sum_{w=1}^{w_x} \frac{H_{x,w}}{t_{x,w}} + \sum_{y=1}^{y_x} \frac{H_{x,i}}{t_{y,x,i}} \right\};$$

t_{sf} - residual time socially and ecologically safe section operation;

$[I]$ - accepted relative risk [5,6].

It is possible to use the following inequality if service life is known on design stages (item 6)

$$\lambda_{pr} L k_r t_{pr} \le [I], \tag{10}$$

t_{pr} - recommended service life of a pipeline section, year;

k_r - coefficient of corresponding calculated and recommended pipeline service life;

λ_{pr} - design value of intensity coefficient of destruction stream (item 6).

The relation (9) can be transformed to the following kind:

$$t_{sf} = \left(\lambda_{pr} L k_r t_{pr} - \lambda_f L t_d\right) / \left(L\lambda_f + 1/t_f\right). \tag{11}$$

Thus, relations (9) or (11) allow to calculate the value of residual time t_{sf} in view of distribution of the defects determined by means of intrapipe and external diagnostic inspection, results of the previous section operation and requirements of social and ecological safety of pipeline operation.

6. The recommended section service life determined on a design stage can be found as a decision of the following transcendental equation:

$$P(t_{pr}) = Q(t_H), \ where$$

$$P(t_{pr}) = \sum_{i=1}^{5} P_i(t_{pr}) - \sum_{i \ne j; i,j=1}^{5} P_i(t_{pr}) P_j(t_{pr}) +$$

$$+5\prod_{i=1}^{5} P_i(t_{pr}) + P_{3f}(t_{pr}),$$

$$P_i(t_{pr}) = t_{pr} \times (t_H / t_i)\lambda_i L \exp(-\lambda_i L t_{pr} \times t_H / t_i),$$

$$i = 1,.,.,5, P_{3f} = \lambda_{3f} t_{pr} L \exp(-\lambda_{3f} L t_{pr}),$$

$$Q(t_H) = \sum_{i=1}^{5} Q_i(t_H) - \sum_{i \ne j; i,j=1}^{5} Q_i(t_H) Q_j(t_H) +$$

$$+5\prod_{i=1}^{5} Q_i(t_H) + Q_{3f}(t_H),$$

$$Q_i(t_H) = t_H \lambda_i L \exp(-\lambda_i L t_H), i = 1,.,.,5, Q_{3f}(t_H) =$$

$$= \lambda_{3f} t_H L \exp(-\lambda_{3f} L t_H); \ here \tag{12}$$

$P_i(t_{pr}), i = 1,.,.,5, P_{3f}$ - probability of destruction of pipeline section of certain length L during operation time t; components of the probability are caused by the destruction or assembly $(i=1)$, or factory welded connections $(i=2)$, or the basic pipe metal $(i=3)$, or taps $(i=4)$ or tee connectors $(i=5)$ and also as a result of activity of the third persons accordingly;

$Q_i(t_H)$, $i=1,.,.,5, Q_{3f}(t_H)$ - accepted value of probability of destruction of pipeline section of certain length L; components of the probability are caused by the destruction or assembly $(i=1)$, or factory welded connections $(i=2)$, or the basic pipe metal $(i=3)$, or taps $(i=4)$ or tee connectors $(i=5)$ and also as a result of activity of the third persons and which corresponds to statistics operation of the similar section during the appointed pipeline service life;

λ_1 - coefficient of intensity of a destruction stream, characterized the distribution of probability of reaching of the critical sizes by potential cracks and similar crack defects in ring welded connections of a section, including the displacement of their edges, $\lambda = 1/(km * year)$;

λ_2 - coefficient of intensity of a destruction stream, characterized the distribution of probability of reaching of the critical sizes by potential cracks and similar crack defects in longitudinal welded connections of a section, $\lambda = 1/(km * year)$;

λ_3 - coefficient of intensity of a destruction stream, characterized the distribution of probability of reaching of the critical sizes by potential longitudinal and cross-section cracks and similar crack defects in the basic metal, in the zones of geometrical concentrators (in the dents, corrugations, risks), and also in the zones of metal stratification, $\lambda = 1/(km * year)$;

λ_4 - coefficient of intensity of a destruction stream, characterized the distribution of probability of reaching of the critical sizes by potential cracks and similar crack defects in taps, including the cold air blast pieces, $\lambda = 1/(km * year)$;

λ_5 - coefficient of intensity of a destruction stream, characterized the distribution of probability of reaching of the critical sizes by potential cracks and similar crack defects in tee connectors, $\lambda = 1/(km * year)$;

λ_{3f} - coefficient of intensity of a destruction stream, caused by occurrence of mechanical influences on structure elements as a result of activity of the third parties (acts of vandalism, mechanical influences of digging and transport equipments, explosions, impacts), depends on the depth of pipeline position, conditions of the conservation zone, frequency of patrolling, $\lambda = 1/(km * year)$;

$t_i, i = 1,...5$ - failure time of operation of the generalized structure elements, namely: the ring welded section connections $(i = 1)$, longitudinal welded connections $(i = 2)$, the basic pipe metal $(i = 3)$, taps $(i = 4)$, tee connectors $(i=5)$, determined by accumulation of damages at operational loading in corrosion-active environments around of the pipeline;

$t_н$- the appointed pipeline service life: $t_н = k_e t_{p.b.d.}$; k_e- a parameter of total efficiency of a project (including the public and commercial effectiveness, taking into account the rates of predicted inflation, uncertainty and risks); $t_{p.b.d}$- a time of pipeline payback in view of discounting;

λ_{pr} - design value of destruction stream intensity coefficient: $\lambda_{pr} = \sum_{i=1}^{5} \lambda_i + \lambda_{3f}$.

7. Here is chosen a nominal circular stress in the section beginning and an axial stress maximal on all length of a section in the compressed zone on element section as components of calculated nominal stress - strain state of generalized constructive elements:

$$\sigma_\theta(t) = \sigma_{\theta,m} + \sum_{k=1}^{K} \sigma^a_{\theta,k} \sin \omega_k t, \qquad (13)$$

where $\sigma_z = \mu\sigma_{\theta,m} - E[\alpha\Delta t + D_н(R_1^{-2} + R_2^{-2})^{1/2}/2]$,

$\varepsilon_{усл} = (0.002 + \sigma_s / E)(\sigma_t / \sigma_s)[1 + (\sigma_z/\sigma_t)^2 + |\sigma_z|/\sigma_t]^{1/2}$,

here $\sigma_{\theta,m} \sigma^a_{\theta,k} \omega_k, k = 1,..K$ - the calculated amplitude-frequency characteristic of circular stress, caused by the characteristic of internal pressure of product transmission;

R_1, R_2 - the radiuses of a technological bend of an pipeline axis at its stacking in horizontal and vertical plane accordingly;

α - coefficient of linear expansion of element metal;

E- Young's module of structure element;

μ - Pousson's cross-section reduction coefficient;

Δt - the calculated temperature difference at "short circuit" of a section;

σ_s, σ_t - the relative yield stress of steel and circular stress in the structure elements at hydraulic tests accordingly.

The service life of basic structure elements of pipeline section is determined as the decision of the following transcendental equation:

$$\varepsilon_{усл}/\varepsilon_b + \sigma_{\theta,m}/\sigma_{дл}(t_i, \alpha_{t,i}, n) + \sum_{k=1}^{K} \sigma^a_{\theta,k}/\sigma_{-1}(\omega_k, \omega_k t_i, \alpha_{t,i}, n) = 1,$$

$i = 1, 2, 3$,

where $\sigma_{дл}(t_i, \alpha_{t,i}, n)/\sigma_b = \psi_1(t_i, \alpha_{t,i}, n) + \psi_2(t_i, n)$,

$$\sigma_{-1}(\omega_k, \omega_k t_i, \alpha_{t,i}, n)/\sigma_b = \phi_1(\omega_k, \omega_k t_i, \alpha_{t,i}, n)\phi_2(\omega_k t_i) + \phi_3(\omega_k, \omega_k t_i, n); \qquad (14)$$

$\sigma_{дл} = \sigma_{дл}(t_i, \alpha_{t,i}, n)$, i-1,.,5-q – the quantile curve of long-term strength of generalized structure elements of a calculated section namely: the ring welded section connections $(i = 1)$, longitudinal welded connections $(i = 2)$, the basic pipe metal $(i = 3)$, taps $(i = 4)$, tee connectors $(i = 5)$, taking into account processes of ageing and corrosion, $\sigma_{-1} = \sigma_{-1}(\omega_k, \omega_k t_i, \alpha_{t,i}, n), i = 1,2,3$ q - the quantile curve of fatigue strength of generalized structure elements of a calculated section namely: the ring welded section connections $(i = 1)$, longitudinal welded connections $(i = 2)$, the basic pipe metal $(i = 3)$, taps $(i = 4)$, tee connectors $(i = 5)$, taking into account processes of ageing and corrosion,

q - the quantile curve of strength is the strength curve corresponding to probability of failure-free operation of an element, equal q:

$q = 1 - 1/N$, $N = N_1 L$, where N_1 - the quantity of pipes for one-km pipeline;

L - the length of a section, km;

$\alpha_{t,1}, \alpha_{t,2}, \alpha_{t,3}, \alpha_{t,4}, \alpha_{t,5}$ - calculated values of theoretical coefficients of stress concentration in assembly and factory welded connections, in the basic pipe metal, taps and tee connectors accordingly;

n - the number of group describing the corrosion and stress - corrosion intensity in the generalized structure elements.

Function $\sigma_{дл}(t_i, \alpha_{t,i}, n)/\sigma_b$ is submitted as the sum of two functions $\psi_1(t_i, \alpha_{t,i}, n)$ and $\psi_2(t_i, n)$, and function $\sigma_{-1}(\omega_k, \omega_k t_i, \alpha_{t,i}, n)/\sigma_b$ is represented as the sum of two functions $\phi_1(\omega_k, \omega_k t_i, \alpha_{t,i}, n)\phi_2(\omega_k t_i)$ and $\phi_3(\omega_k, \omega_k t_i, n)$, the first of which is product of two functions $\phi_1(\omega_k, \omega_k t_i, \alpha_{t,i}, n)$ and $\phi_2(\omega_k t_i)$. That representation of determining strength curves has allowed to approximate of significant number of curves describing interrelation of basic parameters on numerous experimental data of processes of steel failure [1] - [3] . The basic hypotheses of suggested methods are listed further.

The method of definition of residual service section life on a design stage is based on three hypotheses. At first, the expression for definition of probability of section destruction on values of probability of destruction of elements with defects of a various origin revealing by methods of an intrapipe and external diagnostics, is presented. Secondly, the regularity of probability distribution of element destruction is written down depending on their damages which determined on kinematic or other durability hypotheses. Thirdly, the criterion of definition of socially and ecologically safe operation times is formulated.

The method of definition of recommended service pipeline life on a design stage also is based on three assumptions. At first, it is written the condition according to the probability of the section destruction during recommended service life doesn't exceed the probability of its destruction during the appointed service life according to the requirement of industrial safety. Secondly, the criterion for determination of operation service life of the generalized constructive section elements is offered. Thirdly, approximations of relations between the determining functions and loading parameters and mechanical material properties are offered.

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Э.Б. Завойчинская, Б.И. Завойчинский

ПРОГНОЗИРОВАНИЕ ДОЛГОВЕЧНОСТИ КОНСТРУКЦИЙ С УЧЕТОМ РЕЗУЛЬТАТОВ ДИАГНОСТИКИ ИХ ТЕХНИЧЕСКОГО СОСТОЯНИЯ И ТРЕБОВАНИЙ БЕЗОПАСНОСТИ

1. Рассматриваются конструкции, состоящие из значительного количества конструктивных элементов ($N \geq 10^3$), в том числе сварных соединений различного типа.

Конструктивные элементы содержат дефекты, имеющие механическое, технологическое и эксплуатационное происхождение.

Методика оценка долговечности таких конструкций базируется на блочно-иерархическом подходе, согласно которому выделяется несколько иерархических конструктивных уровней, и оценка сроков службы начинается последовательно от низшего к высшему иерархическим конструктивным уровням [1], [2].

Конструкцию условно разбивают на крупные макросегменты (участки, фрагменты и т.п.) по функционально-конструкторскому принципу (высший иерархический уровень).

Макросегменты в свою очередь представляют в виде расчетных сегментов по характеру внутренних и внешних нагрузок и воздействий и конструктивным параметрам (средний иерархический уровень). Размеры каждого расчетного сегмента таковы, что для него внутренние и внешние нагрузки и воздействия приближенно могут рассматриваться как однородные. Расчетный сегмент формируется из определенного набора конструктивных элементов (низший иерархический уровень).

В настоящей статье впервые поставлена и решена задача об определении срока службы расчетного сегмента (средний иерархический уровень) по результатам расчета срока службы его конструктивных элементов с дефектами (низший иерархический уровень), установленными проведенной диагностикой, с учетом требований социальной и экологической безопасности.

Расчет долговечности конструктивных элементов на основе результатов диагностики их технического состояния выполняют по теории предельных процессов нагружения [1], [4] и механики разрушения. Срок службы макросегмента на верхнем иерархическом уровне определяется как наименьшее значение из сроков службы расчетных сегментов.