Analysis and evaluation of technogenic risk of technological equipment of metallurgical enterprises

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Abstract. The results of the theoretical review and research for the evaluation of technogenic risk of technological equipment of metallurgical enterprises are presented. The hazards and the risk of accidents or catastrophes of the bearing structure of a bridge crane are considered. A well-known technique based on the theory of random functions and processes is used. Theoretical calculations are based on known methods of probability theory. A relatively new numerical (test) calculation of the evaluation of technogenic risk for elements of technological equipment of metallurgical enterprises is made. The analysis and evaluation of technogenic risk will allow one to make correct management decisions.

1. Introduction
The technological equipment of various degrees of responsibility is used at metallurgical enterprises. Analysis and evaluation of technogenic risk on such equipment is quite a crucial task [1-21]. The analytical test solution to the problem on the basis of specifying dangerous factors in the form of random functions (processes) is important.

It is necessary to express analytically the joint effect of dangerous factors on safety and risks in each operational process for evaluation and analysis of the technogenic risk of technological equipment of metallurgical enterprises.

The technological equipment of metallurgical enterprises is characterized by a whole set of very dangerous factors. These are moving of large loads, liquid molten metal, high temperatures, a wide range of vibration frequencies and many others.

The developed system of such a complex of equipment, a large number of different units are dangerous for production and for personnel (mechanical damage, falls from height).

2. Materials and methods
It is necessary to have quantitative values of the parameters of dangerous factors for evaluation of safety and risk of any element or set of elements of technological equipment of metallurgical enterprises. We use the well-known technique [2,9,10,13]. The dangerous factor is determined by one or more parameters, each of which can be specified in various forms [1]:

- deterministic, when the values are considered as non-random variables set of practical reasons;
the parameter is a random variable which makes it possible to give probabilistic estimates of hazards and risks;
• the expression of a dangerous factor as a random n-dimensional vector;
• description of the function Z of random variables, when the functional dependence is deterministic, but it includes random variables with known distribution laws.

The fifth, most complete, but also complex form of specifying dangerous factors is their representation in the form of random functions (processes) [2,4].

The most convenient form is the canonical decomposition:

\[ X(t) = m_x(t) + \sum_{i=1}^{\infty} V_i \phi_i(t), \]  

where \( X(t) \) is the random function; \( m_x(t) \) is the non-random function of the expected value; \( V_i \) are random uncorrelated centered variables; \( \phi_i(t) \) are non-random coordinate functions.

The canonical decomposition replaces the random function by a set of random variables and non-random functions. The total characteristic of a random function is the multidimensional distribution law at each point of the process. For the canonical decomposition (1) it is sufficient to know variance \( \Delta(V_i) \) of random variables and coordinate functions.

If a random process in the interval \((0; t)\) is differentiable, we can find the probability \( P_o(t) \) of lack of its emissions (accidents) for non-random limits \( X_B, X_H \) during time \( t \). It is particularly important for evaluation of risk and assessment of safety. We will assume that random emissions, as rare events, are distributed according to Poisson's law:

\[ P(X = x) = \frac{\alpha^x}{x!} e^{-\alpha}, \]

for \( x = 0, 1, 2, \ldots; m_x = \alpha; \sigma = \sqrt{\alpha}. \)

We also assume that the emissions of the lower and upper limits are independent:

\[ P_o(t) = 1 - \int_0^t \left( \int_0^\infty f\left(X_B, \frac{v}{t}\right) + f\left(X_H, \frac{v}{t}\right) \right) dv \, dt, \]

We also assume that the emissions of the lower and upper limits are independent:

\[ \frac{v}{t} = \frac{dX(t)}{dt}. \]

For a stationary random function in a more strict sense, all its probabilistic characteristics do not change at any shift along the \( t \) axis.

\[ K_x(t, t) = K_x(0) \rho(t) \]

where \( K_x(0) = \sigma_x^2 \) is the process variance; \( \rho(t) \) is the normalized correlation function.

In the stationary centered random process on the interval \((0; t)\) the canonical decomposition (1) takes the form:

\[ X_0(t) = \sum_{i=1}^{\infty} (V_i \cos \omega t + v_i \sin \omega t) = \sum_{i=1}^{\infty} (V_i \cos \omega t + V_i \sin \omega t), \]

where \( V_i, v_i \) are random centered non-correlated variables with variances \( \sigma_i^2 \);
\[
\omega = \frac{i \pi}{T}; \sigma_i^2 = \frac{2}{T} \int_0^T K_0(\tau) \cos \omega \tau d\tau (i \neq 0); \sigma_v^2 = \frac{1}{T} \int_0^T K_v(\tau) \cos \omega \tau d\tau.
\]

\[
S(\omega) = \frac{2}{\pi} \int_0^\infty K_v(\tau) \cos \omega \tau d\tau.
\]

The variance process is constant by definition and is associated with spectral density

\[
\sigma_v^2 = \int_0^\infty S(\omega) d\omega.
\]

Expression (3) is simplified for stationary differentiable process:

\[
P_v(t) = \exp \left\{-t \int_0^T f\left(\frac{B_1}{t}, \frac{v}{t} \right) + f\left(\frac{B_2}{t}, \frac{v}{t} \right) \right\} dv.
\]

For stationary differentiable process normally distributed,

\[
P_v(t) = \exp \left\{-t \sqrt{\frac{-d^2K_v(0)}{K_v(0)}} \left[ \frac{\left(X_B - m_x\right)^2}{2\sigma_v^2} + \frac{\left(X_H - m_x\right)^2}{2\sigma_v^2} \right] \right\},
\]

where \( K_v(0) = -\frac{d^2K_v(0)}{dt^2} = -\sigma_v^2 \) the process speed variance has a negative sign.

3. Results

Let us calculate according to the formulas (3), (4), (8) and (9) for the technological equipment element - load-bearing structure of bridge crane with lifting capacity of 50 tons.

Let the operation of the load-carrying structure of the crane during lifting, moving and lowering the load (changing the operating bending stresses) is a random stationary differentiable process with a normal distribution. The constant expected value \( m_x \) is equal to 165 MPa, the variance \( \sigma_v^2 \) is approximately equal to 8300 MPa\(^2\), the correlation function of the process has the form

\[
K_v(\tau) = \sigma_v^2 e^{-\alpha \tau^2},
\]

where \( \alpha = 0.035 \text{ s}^{-1} \).

The normalized correlation function \( \rho(\tau) = e^{-\alpha \tau^2} \) is shown in figure 1.
Suppose that non-random limits are also established - the upper $\sigma_u = 256$ MPa and the lower limit $\sigma_h = 74$ MPa, going beyond these limits leads to an accident. It is necessary to find the probability that within 100 seconds there will not be a single emission (accident) beyond the established limits if the upward and downward emissions are independent.

The analysis of the function (figure 1) shows that the random deviations of the operating stresses occurring at an arbitrary moment of time, on average, do not attenuate long enough. Even after 100 seconds of operation, the deviation that occurred at the initial moment will still have a noticeable effect on the deviations during $t = 100$ seconds.

We find the second derivative of the correlation function for calculation of the probability according to formula (9):

\[
K_\sigma (\tau) = \sigma^2 e^{-\alpha^2 \tau^2},
\]

\[
K_\alpha (\tau) = -2\alpha^2 \tau \sigma^2 e^{-\alpha^2 \tau^2},
\]

\[
K_\alpha (\tau) = -2\alpha^2 \sigma^2 e^{-\alpha^2 \tau^2} + 4\alpha^2 \tau^2 \sigma^2 e^{-\alpha^2 \tau^2},
\]

\[
\tau = 0:
K_\sigma (0) = \sigma^2, K_\alpha (0) = 0, K_\alpha (0) = -2\alpha^2 \sigma^2.
\]

We substitute these values into a formula (9):

\[
P_0 (t) = \exp \left\{ -\frac{100}{2\pi} \sqrt{2 \cdot (0.035)^2} \left[ e^{\frac{(256-165)^2}{28300}} + e^{\frac{(74-165)^2}{28300}} \right] \right\} = e^{-0.956632} = 0.3842.
\]

The probability of technogenic risk in this case is equal to:

\[
R = 1 - P_0 (t) = 1 - 0.3842 = 0.6158.
\]
If we take the basic technological equipment of the metallurgical enterprises, for example, 10 bridge cranes of carrying capacity of 50 tons, than $M$ accidents or catastrophes are possible because of the possible overrun of operating stresses in load-bearing structures:

$$M = n \cdot R = 10 \cdot 0.6158 = 6.158.$$ 

It is certainly unacceptable under the given conditions.

This calculation is test and at the same time new, it is made to show the work of such a technique for the metallurgical industry. It can help not only the operators, but also the project designers when choosing the permissible limits $\sigma_y$, $\sigma_b$, the stress output where going beyond which leads to an accident. It should be noted the importance of value of coefficient $\alpha$ in calculations.

Different versions of describing dangerous factors from a deterministic value to a non-stationary random process give different information about the factor. Thus, the analytical description is more complex, the information on possible accident or catastrophe is more complete.

4. Conclusion

Only the representation of dangerous factors in the form of random variables and random functions reveals the way to determine the characteristics of technogenic risk and safety while operating technological equipment at metallurgical enterprises.

The groups of dangerous factors considered are characterized by parameters that change during the life cycle of the equipment are considered.

One of the reasons for changing the parameters is modifications that reduce the risk of accidents and catastrophes.

Another reason for changing the parameters of dangerous factors is aging, equipment deterioration, resource depletion - all this reduces safety and increases the risk.

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