Numerical calculation of durability and reliability using correlation method

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Abstract. The article describes numerical calculation and analysis of the use of the correlation method for predicting durability of a mechanical system – the bearing structure of a metallurgic crane bridge. Studied input parameters of the system are maximum stresses in the cross-section of the bridge bearing construction, and output parameters are residual strain and deflections caused by operation of the bridge crane. A well known mathematical tool of correlation function is used with derived formula of probabilistic relationship between the input and output parameters. The article will help to make appropriate management decisions for ensuring technological safety of metallurgical bridge cranes, and it is an essential complement to the theory of mechanical systems design probabilistic risk analysis.

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Introduction

In the problem of determining reliability and predicting durability of complex mechanical systems, probability of an event, correlation function and mathematical expectation can completely determine the distribution law for a random function. Knowing the distribution law for durability and reliability of a mechanical system, one can control technogenic safety of certain mechanical systems [1-11, 13, 14].

The correlation function is a universal characteristic of a stationary random process, as it makes it possible to find all statistical characteristics in the probabilistic synthesis of mechanical systems [1, 2, 4, 5, 12, 14]. It is a mixed dispersion and characterizes the relation between a random function X(t) at moments t1, t1+τ and depends only on the time interval τ:

$$K_x(t) = \lim_{T\to\infty} \frac{1}{T}\int_0^T x(t)x(t+\tau)dt.$$

With τ=0, we get standard deviation of the random function X (t) (energy of a random process), while with $\tau \to \infty$, the correlation function of a stationary process is equal to a random variable square mean value, $K_x(\infty) = \left(\overline{X}\right)^2$.

Then the process dispersion

$$D_x = K_x(0) - K_x(\infty).$$

Methodology

Numerical mathematical modeling and calculation of reliability and durability of a load bearing structure, main beam of a metallurgical bridge crane with 50 tons lifting capacity, was made on the basis of correlation method.

Main part

Let us formulate the problem of numerical calculation of mechanical system reliability as follows: having the known correlation functions of process input parameters, to determine type and value of correlation function of output parameters. We will study the bearing structure of a metallurgical crane bridge beam as a mechanical system. Chose of this mechanical system is caused by drawbacks of existing guidelines for inspection of metallurgical cranes and the so-called "principle of reasonable reliability" enforced by some business managers, namely, taking no actions before the structure failure. This approach has the right to exist, taking into account many tasks, including longevity prediction using correlation method [1, 12]. (1)

Sequence of the nonlinear problem of determining the correlation function of system output parameter, if the joint density of input parameter is known at moments t and t+τ, is sufficiently described in [12].

In metallurgical cranes during operation random processes of fatigue and deformation occur simultaneously. Correlation function of the output parameter is determined under the condition that the normalized (2) correlation function of the system input and the function of relation between the output and input parameters are already known, research and calculation of which are given in [1, 2, 12, 15].

Let us define the normalized correlation function ax(τ):

$$r_x(\tau) = e^{-c_\rho|\tau|}, \qquad (3)$$

where c_ρ is the constant coefficient characterizing oscillation of function damping.

The formula of relation between the output parameter that limits performance of the mechanical system and determines its longevity - plastic deformation and deflections, and the input parameter - load (maximum bending stress in the cross-section of the bridge) is expressed by the formula [13, 14]:

$$\Delta\varepsilon = \left(\frac{\sigma}{E}\right)^n . \qquad (4)$$

Let us determine values of several Chebyshev-Hermite polynomials [12]:

$$H_{m+1}(x) = xH_m(x) - mH_{m-1}(x). \qquad (5)$$

Since $H_0(x)=1$, $H_1(x)=x$, let us obtain $H_2(x)=x^2-1$; $H_2(x)=x^3-3x$ and so on, and insert it into the formula:

$$C_m(m_x, s_x) = \frac{1}{\sqrt{2\pi}}\int_0 y(x) H_m\left[\frac{x-m_x(t)}{s_x(t)}\right] exp\left[-0,5\cdot\left(\frac{x-m_x(t)}{s_x(t)}\right)^2\right]dx, \qquad (6)$$

where σd0, σdp are stresses that correspond to the limit and boundary state of stress of bearing structures in the mechanical system. C1, C2, C3, etc. are found in a similar way.

Let us find the correlation function of system response:

$$K_y(\tau) = C_0^2 + C_1^2\frac{r_x(\tau)}{1!} + C_2^2\frac{r_x(\tau)}{2!} + C_3^2\frac{r_x(\tau)}{3!} + \dots \qquad (8)$$

Basing on the above theoretical method, let us perform numerical calculation of the correlation function.

So, the mechanical system in question is a 50-ton crane working in the oxygen-converter plant of a metallurgical company 260 days a year. The average number of crane cycles in a two shift operation mode is 600. Standard service life of the crane is 15 years. The total number of crane cycles during its entire service life will be 2,340,000 [1, 14]. Such load distribution corresponds to loading modes Q3 – heavy and Q4 - extra heavy.

Let us calculate the fatigue resistance of structural elements using the condition:

$$\sigma \le [\sigma_{Rk}] = \frac{\sigma_{Rk}}{n_1}, \qquad (9)$$

where σ_{Rk} is the longevity limit calculated by taking into account asymmetry R, effective strength reduction factor k, dimensions and heat treatment of the component; $[\sigma_{Rk}]$ is the allowable stress; and n_1 is the fatigue resistance factor.

Let us numerically define correlation function (in logarithmic units) using the aforementioned method.

Let us present calculation results as a graph of changes of correlation function of mechanical system input parameters in Figure 1 by years.

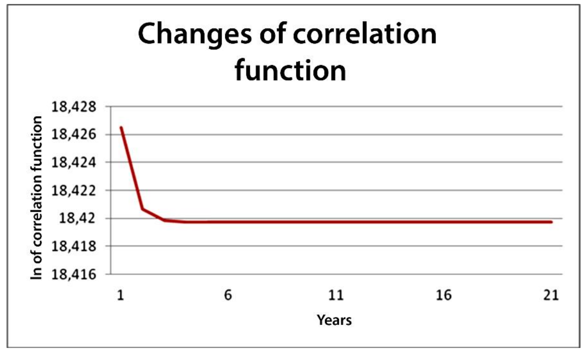

Fig. 1. Changes in the correlation function by years

When obtaining data in relative terms $\varepsilon_{max} = 1{,}276$, and $\sigma = 165$ MPa, $\varepsilon =$ 0.786.

Conclusion

Knowing the correlation function of a random process at the output of a mechanical system, we can determine all statistical characteristics of the distribution and solve the problem of service life of the mechanical system in question, i.e., the supporting structure of a metallurgical crane bridge. We can see that with the standard crane life of 15 years, even if it is operated in heavy and extra heavy conditions, calculations make it possible to make positive decisions about prolongation of its service life. Although, technological safety should, in each case, be ensured with consideration and prudence.

Summary

Thus, having numerically determined the correlation function of residual strain and deflection of metallurgical crane load-bearing structure and having determined its permissible value, one can evaluate longevity of the structure and its service life till next maintenance or failure.

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References

1. Izvekov, Y.A. Risk analysis for equipment of metallurgical industries. Deutschland,

Saarbrucken: LAP LAMBERT Academic Publishing, pp: 56.
2. Izvekov, Y.A., V.V. Dubrovsky and E.Y. Hamutskikh, 2014. Mathematical Modeling and Calculation of Accuracy and Durability of Mechanical Systems' Elements. World Applied Sciences Journal, 30(1): 32-34.
3. Barkhotkin, V.V., Y.A. Izvekov and S.R. Minikaev, 2013. Review of Crashes Involving Crane Equipment at Metallurgical Productions. International Journal of Applied and Fundamental Research, 10(1): 9-11. Date Views: 13.12.2013 www.rae.ru/upfs/?section=content&op=show_article&article_id=4040.
4. Izvekov, Y.A., 2012. Analysis of Anthropogenic Safety of Crane Facilities in Russia. Modern High Technology, 12: 18-19. Date Views: 13.12.2013 www.rae.ru/snt/?section=content&op=show_article&article_id=10000338.
5. Krylova, E.A. and Y.A. Izvekov, 2012. About the Approach to Evaluation of Anthropogenic Safety of Metallurgical Production. Achievements of Contemporary Natural History, 6: 32-33. Date Views: 01.11.2013 www.rae.ru/use/?section=content&op=show_article&article_id=9999573.
6. Kumamoto, H. and E.J. Henley, 1996. Probabilistic Risk Assessment and Management for Engineers and Scientists. Second Edition. New York: IEEE Press, pp: 598.
7. Anon, 1993. Risk Analysis, Perception, Management. London: The Royal Society, pp: 28.
8. Anon, 1989. Risk Criteria for Land Use Planning in the Vicinity of Major Industrial Hazards, U.K. Health and Safety Executive. London: Her Majestys Stationary Office, pp: 14.
9. Taguchi, G., 1985. Quality Engineering in Japan. Bulletin of the Japan Society of Precision Engineering, Vol. 19, 4: 237-242.
10. Boulding, K.E., 1956. General Systems Theory – The Skeleton of Science. Management Science, 2: 197-208.
11. Brushlinsky, N.N., J.R. Hall, S.V. Sokolov and P. Wagner, 2003. Fire Statistics, June 2003. Moscow: Academy of State Fire Service, pp: 62.
12. Birukov, M.P., 1980. Dynamics and Forecast Calculation of Mechanical Systems. Minsk: Vysheishaya Shkola, pp: 192.
13. Izvekov, Y.A., E.V. Kobelkova and N.A. Loseva, 2013. Analysis of Dynamics and Issues of Optimization of Metallurgical Traveling Cranes. Fundamental Research, 6(2): 263-266. Date Views: 01.11.2013 www.rae.ru/fs/?section=content&op=show_article&article_id=10000704.
14. Izvekov, Y.A. and T.G. Kuzina, 2013. Evaluation of Elastoplastic Distortion Based on the Probability Transformation Method. Contemporary Issues of Science and Education, 6. Date Views: 13.12.2013 www.science-education.ru/113-10810.

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