UDC 621.317

Dr. O. Vasilevskyi

ASSESSMENT OF THE DURABILITY OF ELECTRICAL MACHINE STRUCTURES

University College Cork, Ireland

Abstract. *A technique for evaluating the durability of structures of power electrical machines is proposed, which is implemented on the basis of the simultaneous use of the functions of the instantaneous amplitude and the module of the instantaneous frequency.*

Keywords: structural durability, vibration loads, oscillatory process of loads, frequency, amplitude.

When assessing the durability of structures of power electrical machines (EM) under the action of random vibration loads, an important task is to schematize the oscillatory processes of the load [1-3]. To effectively solve this problem, a method based on the use of the instantaneous frequency and instantaneous amplitude of a random loading process is proposed.

Traditionally, in durability problems, an integer number of closed cycles of the loading process is considered, $n = f*t$, where n is the number of cycles of the harmonic process with frequency f and duration t. Damage that accumulates gradually and continuously during even the shortest duration of each cycle can be described by the expression

$$dn = module[f(t)]dt, \tag{1}$$

where dn - increase in the number of cycles; *module*[$f(t)$] - module of instantaneous frequency; dt - increase in the duration of the process.

The modulo sign for the instantaneous frequency means that damage can only increase (accumulate) over time. The expression for the instantaneously limiting number of cycles $N(t)$ before the appearance of damage using the power-law approximation of the fatigue curve can be written as

$$N(t) = \frac{\sigma_{-1}^{z}}{A(t)} N_0 \ , \tag{2}$$

where σ_{-1}^{z} is endurance limit; z is the slope of the fatigue curve; N_0 is the number of cycles corresponding to endurance limits; A(t) is instantaneous amplitude (envelope).

To estimate the durability of the structure, we will accept the hypothesis of adding tiresome damage. Tiresome destruction at a continuously changing frequency and amplitude occurs at the time $t = T$. Then the integral of the instantaneous relative damage $dn/N(t)$ in the range from 0 to T reaches unity: $\int_0^T \frac{dn}{N(t)} = 1$. Expanding the integrand, taking into account formulas (1) and (2), we obtain:

$$\sigma_{-1}^{-z} N_0^{-1} \int_0^T A^z(t)|f(t)|dt = 1. \tag{3}$$

Denoting by $k_{A,f}$ the mixed moment of two random processes $A^z(t)$ and $|f(t)|$, we obtain:

$$k_{A,f} = \lim_{T\to\infty} T^{-1} \int_0^T A^z(t)|f(t)|dt = 1. \tag{4}$$

From expression (3) we obtain a formula for estimating the value of durability: $T = \sigma_{-1}^{z} N_0 \, k_{A,f}$, which includes the theoretically mixed moment. In the case of replacing the theoretical moment by its estimate, we obtain a sample estimate for the value of durability in a general form:

$$\overline{T}(t) = \sigma_{-1}^{z} N_0 \ t \left[\int_0^T A^z(t)|f(t)|dt\right]^{-1}. \tag{5}$$

If there are no deterministic components in the original random process, that is, there is a statistical independence of the instantaneous amplitude and frequency of the process, then the formula for estimating the durability is greatly simplified:

$$\overline{T}(t) = \sigma_{-1}^{z} N_0 \ \left[\overline{A}^z(t)\left|\overline{f(t)}\right|\right]^{-1}. \tag{6}$$

In expression (6), $\overline{A}$ and $\overline{f(t)}$ denote the average sample values. Thus, in order to obtain an estimate of the durability of a structure under random stationary random loads, it is necessary, in addition to the characteristics of the fatigue curve, to have the statistical characteristics of the functions of the instantaneous amplitude and the modulus of the instantaneous frequency. To assess the durability at various loads, we describe the process of changing loads by the sum of two oscillations $X(t) = A_1\cos(2\pi f_1 t) + A_2\cos(2\pi f_2 t)$. Then the Gilbert-adjoint process takes the form: $X_G(t) =$

$A_1 \sin(2\pi f_1 t) + A_2 \sin(2\pi f_2 t)$. And the instantaneous amplitude and instantaneous frequency will be described by the formulas:

$$A(t) = A_1\left[1 + k^2 + 2k\cos\left(2\pi(f_2 - f_1)t\right)\right]^{0.5}; \tag{7}$$

$$f(t) = f_1 + \frac{k(f_2 - f_1)[k + \cos\left(2\pi(f_2 - f_1)t\right)]}{1 + k^2 + 2k\cos\left(2\pi(f_2 - f_1)t\right)}, \tag{8}$$

where $k=A_2/A_1<1$, $(f_2-f_1)>0$.

For the most common normal random loads, the instantaneous amplitude will be distributed according to the Rayleigh law [4 - 6], and at a high level of loads on the power EM structures, an expression for the mathematical expectation can be written:

$$\overline{A}^z(t) = \sigma_x^z 2^{\frac{z}{2}} G\left(1 + \frac{z}{2}\right), \tag{9}$$

where σ_x is standard deviation of the initial process; G(·) — Gamma function.

For the initial process as a sum of two statistically independent stationary narrow-band normal center processes $x(t) = x_1(t)+x_2(t)$ with different center frequencies f_1 and f_2, the mathematical expectation of the instantaneous amplitude of the total process will be determined by expression (9), in to which $(\sigma_x)^2 = (\sigma_1)^2 + (\sigma_2)^2$ is the variance of the total process [7 - 12]; $(\sigma_1)^2$, $(\sigma_1)^2$ are the variance of the response of one and the other narrowband process. Using formulas (6) and (9), we obtain an expression for the durability of the design of power EM:

$$T = 2^{-z/2}\sigma_{-1}^z N_0 \left[\sigma_1^2 f_1^2 + \sigma_2^2 f_2^2\right]^{-0.5}\left(\sigma_1^2 + \sigma_2^2\right)^{\frac{1-z}{2}} G\left(1 + \frac{z}{2}\right). \tag{10}$$

It can be seen from formula (10) that the durability depends on the ratio of dispersions and the central parts of narrow-band oscillatory processes.

REFERENCES

1. Wang, H., Liu, Z., Peng, D., & Zuo, M. J. Interpretable convolutional neural network with multilayer wavelet for Noise-Robust Machinery fault diagnosis // *Mechanical Systems and Signal Processing*. – 2023. – T. 195. – p. 110314.
2. Cunha, B., Droz, C., Zine, A., Foulard, S., & Ichchou, M. A review of machine learning methods applied to structural dynamics and vibroacoustic // arXiv preprint arXiv:2204.06362. – 2022.
3. Shuai, Z., Huang, W., Shen, Z. J., Luo, A., & Tian, Z. Active power oscillation and suppression techniques between two parallel synchronverters during load fluctuations // IEEE Transactions on Power Electronics. – 2019. – T. 35. – №. 4. – P. 4127-4142.
4. Vasilevskyi, O.M., Ignatenko, O.G. Rationing of indicators of reliability of technical means : [training manual]. - VNTU. – 2013. – 160 p.
5. Vasilevskyi O. M. Means for measuring the dynamic torque electric motors and an analysis of its accuracy // Vymiriuvalna tekhnika ta metrolohiia. – 2012. – T. 73. – P. 52-56.
6. Vasilevskyi O. M. et al. Vibration diagnostic system for evaluation of state interconnected electrical motors mechanical parameters // Photonics Applications in Astronomy, Communications, Industry, and High Energy Physics Experiments 2017. – SPIE, 2017. – T. 10445. – P. 1883-1888.
7. Vasilevskyi O. M. Algorithm for Estimating Uncertainty in Measurements When Performing Metrological Works // Information technology and computer engineering. – 2006. - № 3. – P. 147-151.
8. Vasilevskyi, O. M., Kulakov, P. I., Ovchynnykov, K. V., Didych, V. M. Evaluation of dynamic measurement uncertainty in the time domain in the application to high speed rotating machinery // International Journal of Metrology and Quality Engineering. – 2017. – 8. – P. 25.
9. Vasilevskyi O. M. Rationing of indicators of metrological reliability // Bulletin of the Vinnitsa Polytechnic Institute. – 2011. - №4. – pp. 9-13.
10. Soprunuk, P.M., Vasilevskyi, O.M., Chabanuk, Y.A. Uncertainty of measurement results in the control of asynchronous rotation of electromechanical converters // Information processing systems. – 2006. - №7. – pp. 72-75.
11. Vasilevskyi O. M. Method for assessing the durability of structures of power electrical machines under random vibration load // Bulletin of the Vinnitsa Polytechnic Institute. – 2010. - № 5. – pp. 58 - 61.
12. Vasilevskyi O. M. Metrological characteristics of the torque measurement of electric motors // International Journal of Metrology and Quality Engineering. – 2017. – 8. – P. 7.

Vasilevskyi Oleksandr, DSc., prof., University College Cork, Cork, Ireland, ovasilevskyi@ucc.ie

ОЦІНКА ДОВГОВІЧНОСТІ КОНСТРУКЦІЙ ЕЛЕКТРИЧНИХ МАШИН

Анотація. *Запропоновано методику оцінки довговічності конструкцій електричних машин, що реалізована на основі одночасного використання функцій миттєвої амплітуди і модуля миттєвої частоти.*

Ключові слова: міцність конструкції, вібраційні навантаження, коливальний процес навантажень.

Васілевський Олександр, д.т.н., проф., Національний університет Ірландії, м. Корк, Ірландія, ovasilevskyi@ucc.ie