УДК 620:178.3

O.M. Shumylo, O.M. Kononova

ASSESSMENT OF AVERAGE RESOURCE OF SHIP'S SHAFTING

Запропоновано новий підхід щодо прогнозуванню ресурсу суднових валів, що враховує вплив і значимість максимальних напружень спектру навантажень, і ґрунтується на ймовірнісних закономірностях втомного руйнування.
Ключові слова: *судновий валопровід, опір втомі, режим навантажування, довговічність.*

Предложен новый подход по прогнозированию ресурса судовых валов, который учитывает влияние и значимость максимальных напряжений спектра нагрузок, и базируется вероятностных закономерностях усталостного разрушения.
Ключовые слова: *судовой валопровод, сопротивление усталости, режим нагружения долговечность.*

New approach to prediction resource ship's shafting was proposed. It take into account the impact and importance of maximum stress load range and based on the regularities of probability fatigue fracture.
Keywords**:** *ship shaft, fatigue resistance, load mode, longevity.*

Problem statement. The service life of the ship shafting is calculated by decades but the total number of loads (resource) – billions of cycles. Therefore accepted to consider that criterion of operability is strength and it characteristic is fatigue limit. Nevertheless ruptures of ship shafts, especially in a fastening zone of propeller (the loss of the propeller) were observed and after of operating time billion cycles. For large steel structures fatigue limit σ_R is determined on the basis of no more $2{\cdot}10^7$ cycles. It could seem, that as abscissa N_G of point of fracture of fatigue curve no longer of base $N_б$ ($N_G \le N_б$), that the shafts for operating without rupture N_Σ cycles, well above the longe-vity N_G, generally must not is ruptured. In other words, if it turned $N_\Sigma >> N_G$, that stress in dangerous section of the shaft was less fatigue limit and a shaft can continue to work indefinitely long.

Aim of the paper. The article considers fundamentally different approach predicting longevity of the ship shafting.

Main text. Ship shafts operate in regime of complex stressed state and continuous change of the amplitudes of all of its components. Let us assume that complex stressed state can transform to equivalent of uniaxial stressed state with stress τ which change reflects the change of all components.

© **Shumylo O.M., Kononova O.M., 2016**

Let the change in time stress τ will discrete and block which replace with some approximation with some approximation operational regime. The question of the methods of schematization has independent value [1]. Here he is not affected.

As is known, with the help of the ship shafting is carried transmission of torque from the engine to the propeller and the it thrust that creates propeller passed the ship's hull. Herewith shafting in operation is constantly under the action of a number of loads. depending on the operating conditions of the ship (in ballast, loaded, in stormy weather and so on) changes working conditions shafting − amplifies the action of some types of loads is reduced or disappears completely other action one.

The ships shafting works in difficult conditions which are characterized variety of operating conditions and loads that appear in this case. To the main loads and arising under the it influence of stresses can include – bend, buckling, torsion, transversal longitudinal and tensional vibrations.

The maximum normal stresses on circular cross section due to bending moment and axial force

$$\sigma = \frac{M_b D}{2 I_y} + \frac{F}{A},$$

where M_b – bending moment;
D – shaft diameter;
Iy – moment of inertia;
F – axial force (propeller thrust);
A – cross-sectional area.

The maximum shear stress due to torsion is similarly given

$$\tau = \frac{T D}{2 I_p},$$

where T – torsion moment;
D – shaft diameter;
I_p – polar moment of inertia.

The equivalent combined stress according to maximum distortional energy is

$$\sigma_{eq} = \sqrt{\sigma + 3\tau}\ .$$

Hereinafter equivalent stress σ_{eq} will be denoted by σ.

Let the number of stages levels in the block will be k and stresses a block arranged in the order decreasing from τ_1 till τ_k, so that in variation series $\sigma_1, \ldots, \sigma_i, \ldots, \sigma_k$ stress σ_1 is highest. Then we can talk about the decreasing series $\sigma_i/\sigma_1 = \alpha_i$ as the a series of proper fractions with a maximum value $\alpha_1 = 1$. If the duration of the block – n_b cycles, that $n_{бi}$ the duration of the action stress σ_i within the block and the ratio of $n_{бi} \ /n_б = \beta_i$ – the relative duration of it. Obviously, $\sum_{i=1}^{k} \beta_i = 1$. It can be assumed that at schematization of operational regimes of loading shaftings and transformation their to discrete volumes of block of stresses do not exceed $5 \cdot 10^5$ cycles. In these volumes blocks and the actual number of cycles $N_\sum$ for all service life ratio $N_\sum / n_б = \lambda$, is sufficiently large that allows consider $N_\sum$ multiple volume of block (λ – the whole). The total operating time n_i at stresses σ_i – multiple operating time $n_{бi}$ in block i.e. $n_i = \lambda n_{бi}$ and $N_\sum = \lambda n_б$.

Spectrum of stresses in block can be wide enough. In this case the maximum stress σ_1 even with a very large project resources (which is typical for marine shafting) can significantly exceed the fatigue limit if it will be s rarely and short-term action.

In calculation practice is accepted such stresses be disregarded the summation of damages from other stresses. This is a mistake which can significantly distort the resource assessment. In fact, each overload stress cycle does not pass in vain for material0f parts. It is equally important to know and the total operating time at this stress for the entire service life.

In real life terms ship's shafting the number of cycles n_1 can become comparable with the abscissa N_G, point of fracture of Wohler's curve. And only by the fact how to relate n_1 and N_G, and should be classified shaft calculation [2]. It is clear that when $n_1 \ \geq N_G$ it should be strength analysis leads on the maximum stress τ_1 as stress of regular regime, i.e. according to the strength of the condition $\sigma_1 \leq \sigma_R$ (all other stress of the spectrum undoubtedly will be less σ_R). In contrast, when $n_1 \ < N_G$ stress σ_1 can exceed fatigue limit σ_R and then within the meaning of calculation becomes calculation on longevity: breakage is possible at the further operation in area a very long life.

Calculation machine elements on fatigue life in the nature of things is to connect with the choice of a particular model of fatigue damage accumulation. The most widely used in the calculation practice gained linear hypothesis of fatigue damage accumulation (it often calls linear rule of fatigue damage accumulation)

$$\sum_{i=1}^{k} \frac{n_i}{N_i} = a , \tag{1}$$

where a – the sum of accumulated fatigue damage;

n_i – operating time on stress level σ_i in the actual load spectrum;

N_i – longevity was determined by Wohler's curve (Fig. 1) on the stress level σ_i .

According to this hypothesis rupture will come if the cumulative sum a of damage reaches a unit i.e. $a = 1$.

As fatigue curve model will use the curve of fatigue subordinate degree function which describes the experimental data with a high correlation coefficient and thus it is widely used in design practice

$$\sigma_i^m N_i = 10^C = \sigma_R^m N_G, \qquad (2)$$

where σ_i, N_i – current stress and longevity (Fig.)

m, C – the parameters of the power equation

$m = 0,027\sigma_R + 1,04$, $C = 0,997(m+1)\lg\sigma_R + 4,25$ [1; 2; 6],

σ_R – fatigue limit MPa, in this equation it is also a parameter;

N_G – abscissa of the inflection point of the fatigue curve.

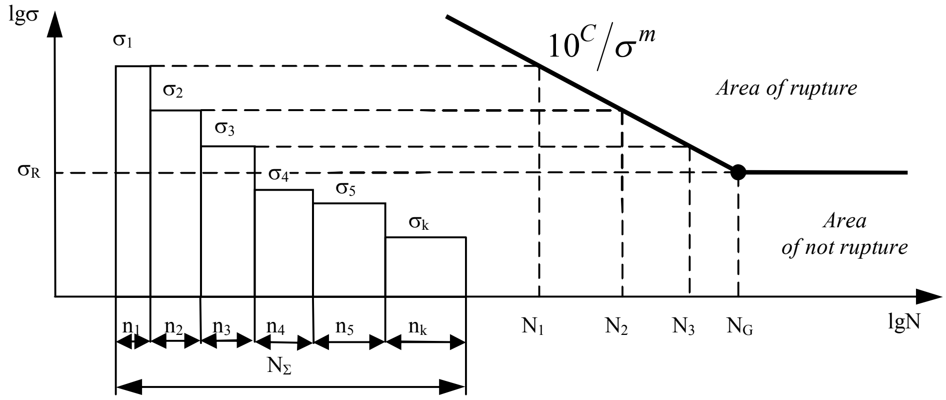

Fig. Scheme for determining the longevity parts regime of loading and Wohler's curve

Application of the linear hypothesis in the calculation of longevity is often disputed.

Substantially these sum – random quantities [3; 5]. Previously, it was found that it can be distributed according to a normal or lognormal distribution law of random variables although it is not excluded and other distributions [5]. Then it was discovered that a more appropriate distribution is Johnson distribution with mode, a less unit [3]. The average or modal values amounts of the relative longevity can be considered as the fundamental characteristics of the parts [3; 5]. They are close to unity. If they are be taken equal unity, and the sum of damage a to spread extended to part of the spectrum, which lies below the fatigue limit that error by use of the linear hypothesis in its original form It will be acceptable, though undesirable by sign.

Longevity calculation is traditionally held by the formula

$$N_\Sigma = \frac{1}{\sum_{i=1}^{k} \frac{\beta_i}{N_i}}, \qquad (3)$$

which follows from linear hypothesis of fatigue damage accumulation according to which

$$\sum_{i=1}^{k} n_i / N_i = \sum_{i=1}^{k} \beta_i \, N_\Sigma / N_i = 1 \cdot$$

This formula can be transformed into

$$N_\Sigma = \frac{1}{\frac{1}{N_1}\sum_{i=1}^{k} \beta_i \frac{N}{N_i}} = \frac{1}{\frac{1}{N_1}\sum_{i=1}^{k} \beta_i \frac{10^C}{\sigma_1^m} \div \frac{10^C}{\sigma_i^m}} = \frac{N_1}{\sum_{i=1}^{k} \beta_i \frac{\sigma_i^m}{\sigma_1^m}} \; ,$$

taking into account ratio $\sigma_i / \sigma_1 = \alpha_i$ we get

$$N_\Sigma = \frac{N_1}{\sum_{i=1}^{k} \beta_i \alpha_i^m} \; . \tag{4}$$

In continuation of the above should indicate other more weighty reason for the error which mainly affects the determination of longevity N_Σ. The random longevity N_Σ according to the function is connected with the random longevity N_i, nonlinear dependence. If a longevity N_i to understand the average value, the longevity N_Σ not the average value because the expectation of the function of random arguments in this case are not the equal function of the expectations of these arguments [5].

To get the average value of longevity N_Σ, you can use the delta method [5]. Assuming dispersions longevity N_i equal in stress levels are equal expanding the function $N_\Sigma = f\,(N)$ in the formula (1) in a multi-dimensional Taylor series, after transformations we obtain [3]

$$\overline{N}_\Sigma = \frac{N_1}{\sum_{i=1}^{k} \beta_i \alpha_i^m} - \frac{N_1}{\left(\sum_{i=1}^{k} \beta_i \alpha_i^m\right)^3} \sum_{i=1}^{k} \beta_i \alpha_i^m \left(\sum_{i=1}^{k} \beta_i \alpha_i^m - \beta_i \alpha_i^m\right) V_i^2 \; . \tag{5}$$

where V_i^2 – coefficients of variation of longevity N_i.

In the expression (5) is showed, that the average longevity $\overline{N}_\Sigma$ less longevity N_Σ , given by the formula (4), and it depends on scattering of longevity N_i of the at levels σ_i of regular loading. And only in the absence of the scattering longevity N_i at levels σ_i regular loading, i.e. at $V_1 = 0$, equation (2) would have coincided with the formula (1) that is naturally, as a function of random arguments would become an ordinary function.

As is known, to eliminate scattering characteristics of fatigue resistance is impossible therefore it is impossible do not reckon with a decrease in longevity $\overline{N}_\Sigma$ compared with the longevity N_Σ . This fact is explained by the difference between the calculated and experimental average longevities which when sharp fluctuations of quality of products in the party and the heavy modes of loading can be quite significant [3].

Using Formula (2) reduce the error estimation of the average resource of shafting. significantly. It was previously thought that resource estimation error entirely determined by the hypothesis of damage accumulation, its unsatisfactory conformity the experimental data. It follows from the above mentioned that these representations are illegal and that the error caused actual damage accumulation hypothesis can be detected only by applying formula (2).

To determine the factor of safety and longevity shafting at reassigned average resource and loading mode of the formula (2), we find the need longevity N_1 that corresponding to the maximum stress of spectrum σ_1

$$N_1 = \frac{\overline{N}_{\Sigma}}{\dfrac{1}{\sum\limits_{i=1}^{k}\beta_i\alpha_i^m} - \dfrac{1}{\left(\sum\limits_{i=1}^{k}\beta_i\alpha_i^m\right)^3}\sum\limits_{i=1}^{k}\beta_i\alpha_i^m\left(\sum\limits_{i}^{k}\beta_i\alpha_i^m - \beta_i\alpha_i^m\right)V_i^2} 1 \qquad (6)$$

This longevity by fatigue curve corresponds to stress σ_{1red} which is regarded as the limiting

$$\sigma_{1red} = \sigma_R \sqrt[m]{\frac{N_G}{N_1}} \qquad (7)$$

From fatigue curve equation can be found and longevity which is the limit according to the actual stress σ_1

$$N_{1red} = \left(\frac{\sigma_R}{\sigma_1}\right)^m N_G \qquad (8)$$

Then the ratio σ_{1red} of formula (7) to the actual stress σ_1 and the ratio of N_{1red} of formula (7) to the longevity N_1 of formula (5) will determine factor of safety and longevity on average values

$$S_\sigma = \frac{\sigma_{1red}}{\sigma_1} \qquad (9)$$

$$S_N = \frac{N_{1red}}{N_1} \qquad (10)$$

Providing factor of safety and longevity $S_\sigma > 1$ and $S_N > 1$ according to equations (10) assumes that the inclined segments of fatigue curves of shafts (within its real change) parallel to each other. For the design of a particular type is quite acceptable. However, if necessary, easy to take into account the and changing the slope of the curves of fatigue to change the limit of endurance shaft [2].

Conclusions. Thus, to refine estimates of the average a resource of ship shafting you must take into account the effect of the maximum short-term loads and proceed from the ideas considered in the calculation formula (2).

REFERENCES

1. *Гусев А.С., Файнберг М.С. Метод постепенного исключения промежуточны циклов в расчетах ресурса конструкций при случайных процессах нагружения сложной структуры // Машиноведение. – 1987. – № 2. – С. 74-80.*
2. *Олейник Н.В. Выносливость деталей машин. – К.: Техніка, 1979. – 200 с.*
3. *Олейник Н.В., Пахомова Н.И. Вероятностная оценка усталостной долговечности деталей строительных и дорожных машин при нерегулярном нагружении // Строительные и дорожные машины. – 1987. – № 10. – С. 27-28.*
4. *Хан Г., Шапиро С. Статистические модели в инженерных задачах. – М.: Мир, 1969. – 396 с.*
5. *Johnser S., Doner M. A statistical simulation model of Miner's rule // Trans. ASME. J. Eng. Mater and Technol. – 1981. – Vol. 103. – № 2. – P. 112-117.*
6. *Шумило О.М. Обґрунтований вибір матеріалу для деталей, підлягають циклічному навантаженню // Вісник Одеського державного морського університету. – 1999. – Вип.4. – С. 35-43.*

Стаття надійшла до редакції 20.10.2016

Рецензенти:

доктор технічних наук, професор, завідувач кафедри «Суднові енергетичні установки та технічна експлуатація» Одеського національного морського університету **Р.А. Варбанець**

доктор технічних наук, професор, завідувач кафедри «Теорія механізмів і машин і деталі машин» Одеського національного морського університету **А.В. Коноплёв**