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THE CALCULATION OF THE MAXIMUM RATED VOLTAGE FOR DIFFERENT TYPES OF LOADING

Vladimir DUKOV [1]
[1]Student, Odessa National Maritime University

Abstract: *In the first part of this work, we examined the determination of the stresses in the cross sections with a closed fracture. This placement of fracture is typical for objects with stress concentrator. In the second part we consider the possibility of determining the maximum rated voltage for various configurations of the location of the test sample zone, which has a closed fracture.*
The maximum rated voltage σ_{imax} is also proposed to determine within fraktographical analysis result, and therefore the method of finding these voltages is valid for objects with a clearly defined zone. Features of this technique are mainly related to the configuration of breaks for different types of loading. Given the lack of such solutions in reference books we are about to review in details the nature of methods for determining the maximum rated voltage at the example of the two most common types of loading: tension with a coefficient of asymmetry of the cycle R> 0 and cyclic bending / 9 /.
Keywords*: tension; fatigue fracture; crack form*

THE MAXIMUM NOMINAL VOLTAGE IN TENSION

Under cyclic tension, crack front Lo break is usually a non-closed form /5,7,8,14,15,18,19/. The maximum rated voltage at the time of the destruction of the area because of the fatigue crack will differ from the initial stress of $\sigma_i = P / F_0$, where P is external load applied at the gravity center of O cross-section of the object, F_0 is sectional area of the object. The figure shows a fracture of the object of arbitrary shape under cyclic tension. With the development of a fatigue crack gravity center of the object sections is shifting, reaching the point A at the time of the destruction. If we draw x_0 and y_0 axes through the center O, the position of point A is defined by coordinates

$$X_{OA} = S_{y0}/F \quad (2.1)$$

$$y_{OA} = S_{x0} / F \quad (2.2)$$

Where S_{y0} and S_{x0} are static moments of zone (without regard to fatigue crack spreading) related to axes y_0 and x_0, F is an area of the zone. Using the formula axes transfer / 4 /, we can write the coordinates of the point O (point of application of force P) relative xAy coordinates (the central axes of the zone)

$$x_A = -x_{OA}, \quad (2.3)$$

$$y_A = -y_{OA}, \quad (2.4)$$

Due to mismatch of center of gravity A of this zone with the point of application of force P (point O), there is eccentric stretching / 2, 10, 11 /, which appears to act in the cross section details the tensile force P (applied in point A) and bending moments $M_y = P\,x_A$ and $M_x = P\,y_A$, and the direction of the moments is such that they tend to reveal the fatigue crack. With the destruction of the object σ_{imax} voltage is in the plastic deformation diagram (the relation between stress σ and strain ε), which leads to disruption of the linear relationship between σ and ε. The figure shows the true strain diagrams in tension for brittle and ductile metals and their schematization / 2,10,12 / in the form of Hooke's law σ = Eε and Prandtl diagram with hardening

$$\sigma = E\varepsilon, \text{ if } \varepsilon \le \varepsilon T,$$

$$\sigma = \sigma T + El(\varepsilon - \varepsilon T), \text{ if } \varepsilon > \varepsilon T,$$

where E is a modulus of elasticity of the first kind;

εT is strain corresponding to yield strength σ T;

E1 - hardening modulus.

The study of fatigue fracture of machine parts, destroyed in the high-cycle fatigue, showed that the final destruction of the area is not very different from the brittle fracture even for parts made of ductile metals / 3, 5, 37.11, 13, 15, 16, 17, 18, 19 /. From this we can assume that at the time of the fatigue destroying of the object its diagram of deformation can be described by the equation of Hooke, i.e., determination of stress σ_{imax} news from the assumption of a linear relationship between stress σ and strain ε.

Then the maximum rated voltage in the area is defined by the formula of materials resisting for eccentric tension rod / 2,11 /.

$$\sigma_{nmax} = P / F + My\,xv / Iy + Mx\,yv / Ix \quad (2.5)$$

where Iy and Ix are the moments of inertia zone, respectively, relative to the axes y and x, and xv yv - coordinates of point B, the farthest from the neutral line n-n, position of which is determined by the intercepts on the coordinate axes x and y
/11, 12/.

$$x_H = -i_y^2 / x_A \quad (2.6)$$

$$y_H = -i_x^2 / y_A \quad (2.7)$$

where $i_y = \sqrt{I_y / F}$ $i_x = \sqrt{I_x / F}$ - inertia radiuses related to the axes y and x respectively.

If we draw perpendicular from point A onto the neutral line, the position of point B is determined by the maximum interval length received by projection of points of the zone profile onto perpendicular and measured from the line n-n. Expressions (2.5) - (2.7) will get considerably simplified for parts having a symmetrical cross section.

Let us apply formula (2.5) for circular objects most often encountered in practice. Depending on the level of existing nominal voltages and the nature of the voltage concentration, fatigue fracture of objects of that form is shown in figure (a and b are objects without voltage concentrator at high and low loading, the v and g are objects with a significant concentration of stress under high and low level of loading, d and e are objects with low stress concentration at high and low load) / 5, 7, 14, 15, 18, 19 /. The cross section of the object with diameter d at break has a concave crack of length L and depth H. Center of gravity of the cross section is located at point O, and the zone is at the point A. The coordinates of the latter is defined by formulas (2.1) - (2.4), and because of the symmetry of the zone $x_A = 0$ (the coordinate axis is chosen so that it is symmetrically located on zone of crack propagation) and, therefore,

My = 0, so formula (2.5) will get simpler and will look like

$$\sigma_{imax} = P/F + PyA\,umax / 1x \quad (2.8)$$

Here is the coordinate of the most distant point from the central axis equals: for the concave crack front (Figure 2.6)

$$ymax = yA + 0{,}5d - H + K \quad (2.9)$$

for a convex crack front (Figure 2.7)

$$ymax = yA + 0{,}5d - H \quad (2.10)$$

where the distance from the crack tip to the straight line connecting the points of intersection of the crack front with a circle of area cross-section

$$K = (H - 0{,}5d + 0{,}5\,j\sqrt{d^2 - L^2})i, \quad 2.11)$$

where j = -1 for the case where the distance from point E to the line B-B is more than 0,5 d, in other cases, j = 1, i = 1 - for concave, i = -1-a convex crack front.

Let us represent the zone in the form of two segments BCB and BMB, the area where F1 and F2 (hereafter the subscript 1 refers to the geometrical characteristics BCB segment, and the index 2 – to those of segment BMB), are respectively equal

$F_1 = 0{,}25d^2(0{,}57\pi + \varphi + 0{,}5\sin 2\varphi)$ (2.12)

$F_2 = \rho^2 (0{,}5\,\pi - \gamma + 0{,}5\sin 2\gamma)$ (2.13)

Where

φ = arcsin[(0,5d-H+Ki)/0,5d];

ρ is radius of the crack front curvature,

$\rho = 0{,}5(K^2 + 0{,}25L^2) / K$;

angle γ = arcsin[(ρ - K) / ρ].

These equations are obtained due to the following considerations:

Let us express the area of BCB segment:

$F_{BCB} = F_{окд} - F_{BBE}$

Under the reference book:

$$F_{BDB} = \frac{d^2}{4}\left(\frac{\alpha}{2} - \frac{\sin\alpha}{2}\right)$$

We transform

$$F_{BDB} = \frac{d^2}{4}\left(\frac{\alpha}{2} - \frac{\sin\alpha}{2}\right) = [\alpha = 180є\ -2\varphi = \pi - 2\varphi] =$$

$$= \frac{d^2}{4}\left[\frac{\pi}{2} - \varphi - \frac{\sin(180^\circ - 2\varphi)}{2}\right] = \frac{d^2}{4}(0{,}5\pi - \varphi - 0{,}5\sin 2\varphi)$$

Then on substituting into the formula for the area:

$$F_{BCB} = \frac{\pi d^2}{4} - \frac{d^2}{4}(0{,}5\pi - \varphi - 0{,}5\sin 2\varphi) = \frac{d^2}{4}(0{,}5\pi + \varphi + 0{,}5\sin 2\varphi)$$

Then the area of the zone

F=F1-F2i

Presentation of the area segment in the form (2.12) and (2.13) differs from the conventional in engineering / 1,11 /, but it is convenient for calculations. Using the formulas of materials resisting /11, 12 / as well as the solution of definite integrals by means of tables by G.B. Dwight / 6 / we define the geometric characteristics of the segments of a circle with diameter d (area F, the static moment Sx and moment of inertia Ix, relatively to the x-axis). The figure shows segments 3 and 4, defined by the angle α. Let us select an element of area

dF = dxdy, therefore

$$F_3 = 2\int_{F_3} dF_3 = 2\int_{0{,}5d\sin\alpha}^{0{,}5d} dy \int_0^{\sqrt{0{,}5d^2 - y^2}} dx = 2\int_{0{,}5d\sin\alpha}^{0{,}5d} \sqrt{0{,}25d^2 - y^2}\,dy$$

The final result is

$F_3 = 0{,}25d^2(0{,}57\pi - \alpha - 0{,}5\sin 2\alpha)$, (2.15)

$F_4 = \pi d^2 / 4 - F_3 = 0{,}25d^2(0{,}5\,\pi + \alpha - 0{,}5\sin 2\alpha)$, (2.16)

$$S_{3x} = 2\int_{F_3} y\,dF_3 = 2\int_{0{,}5d\sin\alpha}^{0{,}5d} y\sqrt{0{,}25d^2 - y^2}\,dy\ \text{o}$$

$S_{3x} = (d\cos\alpha)^3 / 12$ (2.17)

$S_{4x} = -(d\cos\alpha)^3$ (2.18)

$$I_{3x} = 2\int_{F_3} y^2 dF_3 = 2\int_{0{,}5d\sin\alpha}^{0{,}5d} \sqrt{0{,}25d^2 - y^2}\,dy$$

On having submitted the integration limits, we get

$I_{3x} = d^4(0{,}5\,\pi - \alpha + 0{,}25\sin 4\alpha)/64$, (2.19)

$I_{4x} = \pi d^4 / 64 - I_{3x} = d^4(0{,}5\,\pi + \alpha - 0{,}25\sin 4\alpha)/64$, (2.20)

Using formulas (2.15) - (2.20), we define the geometric characteristics needed to calculate the maximum rated voltage of σ_{imax}. The position of the central axis Ax of the zone, defined by the coordinate y_A is to be found by (2.2) and (2.4), on having presenting a static point on the central axes of the cross section as

$S_{xo} = S_{xo1} - S_{xo2}i$, (2.21)

where

$S_{xo1} = -(d\cos\varphi)^3/12$;

$S_{xo21} = y_2 F_2$.

The distance from gravity center of BMB segment to axis Ox_0

$y_2 = y_{c2} + Ti$ (2.22)

где y_{c2} is the distance from gravity center of BMB segment to axis O'x',

$$y_{c2} = \left[-\frac{2}{3}(\rho\cos\gamma)^3 / F_2\right] i$$

This a distance between axes Ox_0 and O'x',

T = ρ + (0,5*d*-H)i.

Inertia moment I_x related to axis Ox equals

$I_x = I_{x1} - I_{x2}i$, (2.23)

where I_{x1} and I_{x2} are inertia moments related to axis Ax,

$I_{x1} = I_{c1} + (y_a + y_1)^2 F_1$;

$I_{x2} = I_{c2} + (y_a + y_2)^2 F_2$.

We find exact moments of inertia I_{c1} and I_{c2}, with the help of formulas (2.19) and (2.20) and formulas for the transfer of inertia moments to parallel axes

/11, 12/. This is what we have for the exact inertia moment I_{c1}

$I_{c1} = I_{xo1} - y_1^2 F_1$ (2.24)

where I_{x01} is inertia moment of BCB segment related to axis Ox_0,

$I_{x01} = d^4(0{,}5\,\pi + \varphi - 0{,}25\sin 4\varphi) / 64$,

yl, is distance from segment BCB gravity center to axis Ox_0,

$y_1 = S_{x01}/F_1$.

This is what we have for the exact I_{c2} inertia moment

$I_{c2} = I'_{x2} - y^2_{c2} F_2$, (2.25)

where I'_{x2} is a BMB segment inertia moment related to axis O'x',

$I'_{x2} = 0{,}25\rho^4 (0{,}5\,\pi - \gamma + 0{,}25\sin 4\gamma)$.

To calculate the voltage σ_{imax} by formulas (2.8) - (2.25), the algorithm developed can quickly determine the desired values. According to the results of calculation on the charts for concave and convex crack fronts, the relative maximum rated voltage σ_{imax} / σ_i the relative length L / d crack within different values of its relative H / d depth are presented. Such a presentation of the calculation results pursuant to formula (2.8) makes it possible to quickly determine the voltage σ_{imax} if you know the size and location of the zone.

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