Determination of metallurgical equipment components life

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Abstract
Metallurgical equipment components service life evaluation, when fatigue failure, is presented; one of the main reliability indexes determination of resource distribution function for failure-free operation specified probability is provided.
Developed evaluation workability is shown by the specific example and can be used for life prediction of any metallurgical equipment component under repeated loading.
Key words: FAULTS, LOADS, STRESS, DISTRIBUTION LAW, EQUIPMENT, (OPERATING) LIFE, FAILURE-FREE OPERATION PROBABILITY, SERVICE LIFE.

There are three main reasons of metallurgical equipment components breakdown: wear-out failure, unexpected failure, formation and growth of fatigue cracks, which finally cause the component breakdown [1].

In the present paper, the problems of metallurgical equipment components life valuation, when fatigue failure, are considered.

One of the main conditions, which metallurgical equipment must fulfill, is its failure-free operation with the required reliability in accordance with the operating specifications within predetermined period.

Hence, operating life evaluation of metallurgical equipment components, when fatigue failure, provides determination of one of the main reliability indexes. This index is failure-free operation probability within predetermined period R(t) or the inverse solution - finding the life distribution function for specified probability R.

The equipment components life evaluation methods in probability formulation [1,3] are known. These methods allow determining the failure-free operation probability or life distribution function and they are found the use in practice of predictions.

The failure-free operation probability may be determined from the well-known formula [1]

$$R(t) = e^{-\int_0^t \lambda(t)dt}, \qquad (1)$$

where λ(t) - fault rate.

At that, fault rate determination difficulty arises, since this value behavior in steady-state operational mode can vary according to the kind of fracture process (wear-out, fatigue, unexpected failure).

For the components fatigue failure accumulation process, the fault rate in steady-state operational mode for the first approximation is accepted as a constant value and introduced in the form of [1]

$$\lambda(t) = \frac{1}{T_g} = const, \qquad (2)$$

where T_g - component life.

The component life for continuum working stress spectrum may be determined on the basis of [1, 2] as

$$T_g = \frac{\bar{N}_{og} \cdot 10^{\frac{\bar{\sigma}_{-1g}}{\bar{K}_g}}}{n_t \int_{\sigma_{min}}^{\sigma_{max}} f(\sigma) \cdot 10^{\frac{\sigma}{\bar{K}_g}} \cdot d\sigma}, \qquad (3)$$

where $\bar{N}_{og}$, $\bar{\sigma}_{-1g}$, $\bar{K}_g$ – average abscissa values of culminating point, endurance limit and angular coefficient of fatigue curve respectively; $f(\sigma)$ -

working stresses distribution density truncate on sections $\sigma_{min}\dots\sigma_{max}$; σ_{min}, σ_{max} – minimum and maximum stress of spectrum of working stresses respectively; n_t - number of cycles accumulated by the component in a unit time.

Solution of integral $I=\int_{\sigma_{min}}^{\sigma_{max}} f(\sigma)d\sigma$ is introduced in formulas (1, 2) for various stress distribution law including normal distribution.

Solving equations (1)…(3) simultaneously, we obtain the formulas for life determination depending on component failure-free operation probability when $t=T_g$,

$$T_{g(R)}=\frac{\bar{N}_{og}\cdot 10^{\frac{\bar{\sigma}_{-1g}}{\bar{K}_g}}}{n_t\int_{\sigma_{min}}^{\sigma_{max}} f(\sigma)d\sigma}\cdot ln\frac{1}{R}, \quad (4)$$

or

$$(T_g)_R=\bar{T}_g\cdot ln\frac{1}{R}, \quad (5)$$

Fixing the failure-free operation probability R, the component life distribution function may be obtained by formula (5).

As an example, let us calculate the life distribution function of working roll of tubes cold rolling mill.

The roll failure under observation is of fatigue nature. For the roll made of 40CrNi steel the following fatigue characteristics were obtained: $\bar{\sigma}_{-1g}=128$ MPa; $\bar{K}_g=55$ MPa; $\bar{N}_{og}=4{,}45\cdot 10^6$ MPa. Per year, the roll loading cycles number obtained by processing of experimental data is $n_t=2{,}43\cdot 10^6$.

After processing of experimental data on the roll loading conditions, the frequency diagram and stresses distribution curve $f(\sigma)$ were obtained [4] (they are shown in Fig. 1). The correspondence of obtained curve to normal distribution law was established [4]. Minimum and maximum stress values are $\bar{\sigma}_{min}=131$ MPa; $\bar{\sigma}_{max}=175$ MPa respectively.

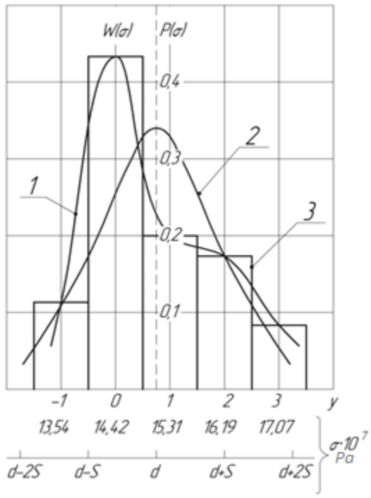

Figure 1. Roll stresses distribution curve: 1 –true; 2 – normal; 3 - frequency diagram.

Average stresses value and roof-mean-square deviation obtained from statistical processing of experimental data are [4] $d=150{,}5$ MPa; $s_\sigma=10$ MPa respectively.

For the integral I solution let us determine the values

$$b=d+\frac{s_\sigma^2\cdot\ln(10)}{\bar{K}_g}=150{,}5+\frac{10^2\cdot\ln(10)}{55}=154{,}7$$
MPa

$$z_1=\frac{\sigma_{min}-b}{s_\sigma}=\frac{131-154{,}7}{10}=-2{,}37 \text{ MPa}$$

$$z_2=\frac{\sigma_{max}-b}{s_\sigma}=\frac{175-154{,}7}{10}=-2{,}04 \text{ MPa}$$

Let us evaluate the integral I for normal stresses distribution law:

$$I=e^{-\frac{d^2-b^2}{2\cdot s_\sigma^2}}[F_0(z_2)-F_0(z_1)]=e^{-\frac{150{,}5^2-154{,}7^2}{2\cdot 10^2}}[0{,}4911+0{,}4793]=583{,}8$$

By the formula (3) $\bar{T}_g=8{,}1$ mo

Using the formula (5), we find the roll service life fixing the value of failure-free operation probability (Table 1).

Practical interpretation of calculation results is introduced in Fig. 2. The obtained operating life conforms well to life of rolls under operation. As it was noticed in the paper [5], the interval 80-20% of failure-free operation probability is enough for metallurgical equipment.

Table 1. The roll service life value of mill HPT-55 for various failure-free operation probability

Failure-free operation probability, R, %	Service life $T_{g(R)}$, mo.	Failure-free operation probability, R, %	Service life $T_{g(R)}$, mo.	Failure-free operation probability, R, %	Service life $T_{g(R)}$, mo.

5	24,3	40	7,4	75	2,3
10	18,7	45	6,5	80	1,8
15	15,4	50	5,6	85	1,3
20	13,3	55	4,8	90	0,9
25	11,2	60	4,1	95	0,4
30	9,8	65	3,5		
35	8,5	70	2,9		

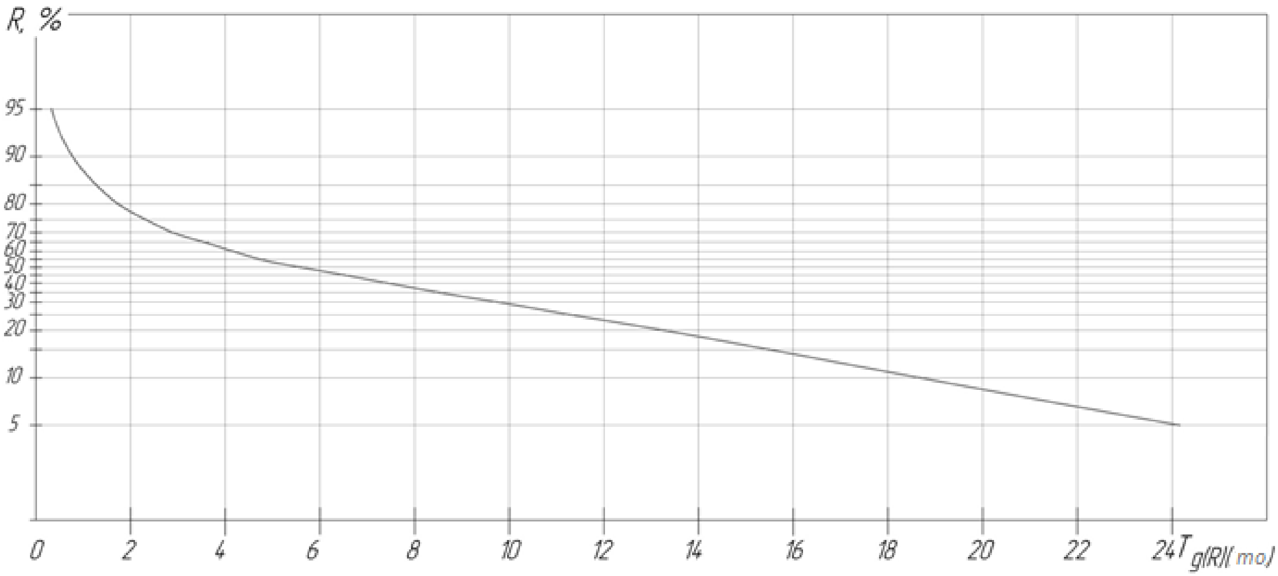

Figure 2. Roll life distribution function of mill HPT-55

Conclusions

1. The developed method for component life determination allows determining the operating life depending on failure-free operation specified probability.

2. The introduced method can be used for life prediction of any metallurgical equipment component under repeated loading.

3. The operating life function of working roll made of 40CrNi steel of tubes cold rolling mill is determined.

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