Theoretical Foundation for Mechanical Products Service Life Prediction

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Abstract. The article presents theoretical foundations for prediction of service life of mechanical products, based on the fatigue theory and fatigue limit. Ultimate amplitude and ultimate stress diagrams are presented. Wohler curve, characterizing material durability, is constructed on the results of the tests.

Analytical studies show that about a half of the agricultural machinery failures occur for production reasons. This rate has been maintaining at the same level for the past 15 years. Operation life of complex mechanisms is usually determined by durability of the weakest components and parts.

For example, life of high pressure hoses, composed of high-pressure sleeves and nozzles is determined by durability of sleeve screening braid if careful embedding of nozzles. The service life of internal combustion engines depends on durability of valve springs, specifying the output parameters of engines, namely fuel consumption and capacity.

1. Timeliness of the research

Service life of suspensions is determined by durability of the spring main plates, life of carbide cutting tools - by durability of carbide plates if a reliable connection to holders, life of working bodies of feed mills and tillage machines - by durability of their working bodies, etc.

Thus, to predict service life of machines, a method is to be developed for prediction of durability of components or parts, which are the weakest components in the whole machine.

Durability of any machine element is characterized by the number of load cycles before failure. The problem of determining the durability of components or parts, and hence a service life of machines and mechanisms is being studied constantly; but it has not been resolved definitively.

For components of agricultural machinery, exposed to extreme stresses (in areas of stress concentration, locales of high temperatures and residual stresses) strength calculations (strength of materials) are traditionally used, which can be inadequate and sometimes inappropriate. As a result, for example, cables, having a tenfold safety margin, collapse under loads which are significantly lower than the design loads.

Modern computational methods allow determining durability (safety factor of durability) of components or parts, under certain magnitude and nature of stress [1], which does not guarantee their uptime.

Therefore, development of methods of forecasting of safety and durability under multiple-cycle fatigue is an urgent task. New techniques of engineering calculations bring about fundamentally new opportunities for lifetime assessment of agricultural machinery at the design stage and during their operation.

Methods of research, authenticity and validity of the results:

Stresses, variable in time, occur in structural elements under load, variable in magnitude or direction. For example, the car axle is bent under the weight load of the car. In the upper part of each axis cross section normal tensile stresses occur. During the motion the wheel and the axis, rigidly connected to the wheel, rotate, and each point of the axis alternately moves from the top (extended) of the half-section, to the bottom (compressed), and vice versa.

Variable stresses arise in shafts of machines, in braided sleeves of high-pressure hoses, in valve springs of internal combustion engines, in spring plates, in suspensions, in working bodies, etc.

Time-scale stress variations can be represented by a graph; time t or the number of cycles of a certain frequency N is plotted on the abscissa axis, a value of normal σ stress or tangential τ stress - on the ordinate axis. It is usually assumed, that time-scale stress variations are characterized by a sine curve (see Figure 1).

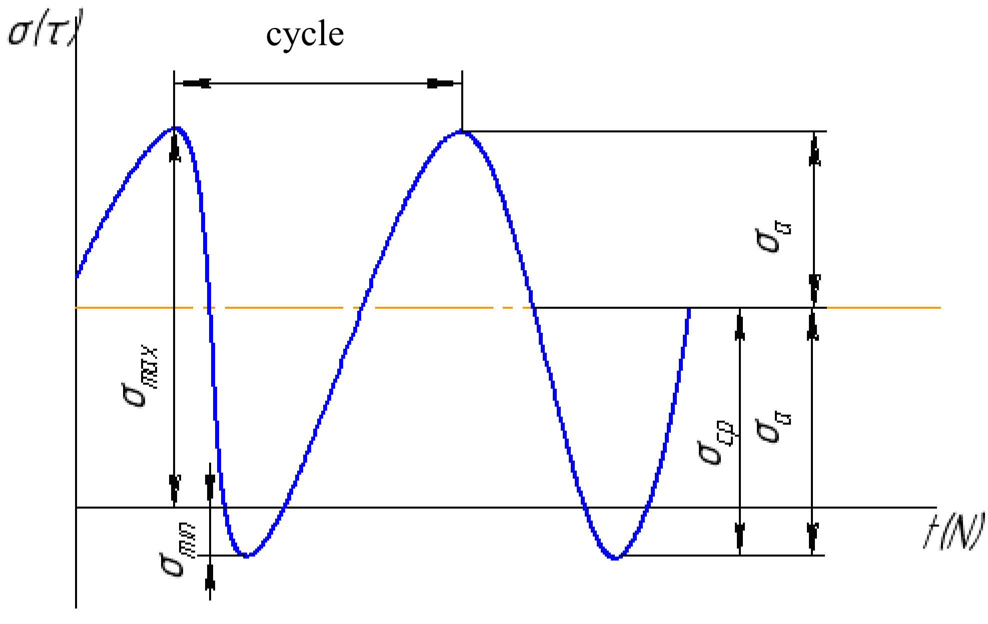

Figure 1. Time-scale stress variations

In fact, as shown by numerous experiments [2], the type of the curve is irrelevant; material strength at variable stresses depends mainly on stress values: σmax and σmin. Population of all successive values of stress variations for one period of change is called the stress cycle. The largest (algebraically) stress of the cycle is called maximum and is denoted σmax (or τmax for tangential stresses). We principally consider normal stresses. For tangential stresses similar conclusions, formulas and calculation procedures are applicable.

Algebraic half-sum of maximum and minimum stress of the cycle is called the average stress.

$$\sigma_{cp} = \frac{\sigma_{max} + \sigma_{min}}{2} \quad (1)$$

Algebraic half-difference of maximum and minimum stresses is called the cycle amplitude.

$$\sigma_{a} = \frac{\sigma_{max} - \sigma_{min}}{2} \quad (2)$$

Average stress of the cycle can be either positive or negative. The amplitude of the cycle is always positive. If stresses σmax and σmin are equal in magnitude and opposite in sign, then the cycle is called reversed. In the reversed cycle $\sigma av = 0$, and $\sigma a=\sigma max=-\sigma min$

If stress σmax and σmin are not equal in absolute values, the cycle is called irregular. Irregular cycle can be alternating (where σmax is positive and σmin is negative) or constant (when both σmax and σmin have the same sign). In particular cases, when σmin or σmax is equal to 0, the cycle is called fluctuated. Ratio of σmin stress to σmax stress is called ratio R of cycle irregularity.

$$R = \frac{\sigma_{min}}{\sigma_{max}} \quad (3)$$

Stress cycles with the same values of irregularity ratio are called alike. For a reversed cycle R = -1, for fluctuated cycle R = 0, if stresses have positive values.

Results of the research

To determine durability, a special testing of material mechanical properties (fatigue) is carried out. For these tests, a series of identical samples (at least 10) are produced. Pure bending tests with a reversed cycle of stress variations are the most common. They are carried out in the following order.

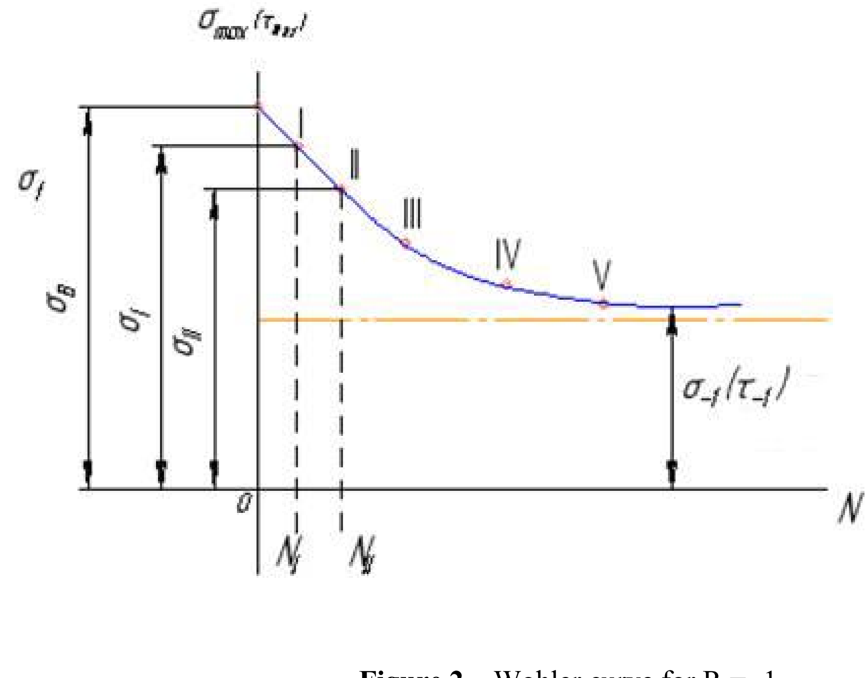

Figure 2. Wohler curve for R = -1

In the first sample a special device produces stress cycles characterized by the values σmax=σI and σmin. Stress value σI is set near to ultimate tensile strength σв of the material so as to obtain a fatigue failure of the sample after a relatively small number of cycles NI. The test result is plotted (in the adopted scale) as a point I, the abscissa is equal to the number of cycles NI, that caused the sample failure, and the ordinate shows the stress value σI (Figure 2). Then, the next sample is bended to failure, if stresses σmax =σII<σI and σmin=–σII. The test result is plotted as a point II.

In the test series, points III, IV, V and etc. are obtained. Joining the points, we plot a so-called fatigue curve or the Wohler curve (A.Wöhler first studied the phenomenon of fatigue in 1852 - 1869.), corresponding to reversed cycles (R = -1) (see Figure 2). By this method, fatigue curves, corresponding to cycles with other values of R, can be obtained.

Limiting stress diagram (LSD) shows the relationship between the limit cycle parameters σ'av-σ'max. LSD is used for functional connections that are used in durability analysis under varying stresses. For a single point of the diagram, a series of identical samples (at least 10) should be tested, and the Wohler curve should be constructed; the latter shows the value of fatigue limit for the cycle with a given R.

For example, tests were conducted at irregular stress cycle. As a result, a value of fatigue limit σ-I is found. The coordinates of this limit cycle are: σ'a =σ'max=σ-1, σ'av=0 (see Eq. (1) - (3)). That is, the point is on the ordinate (point A) (Figure 3).

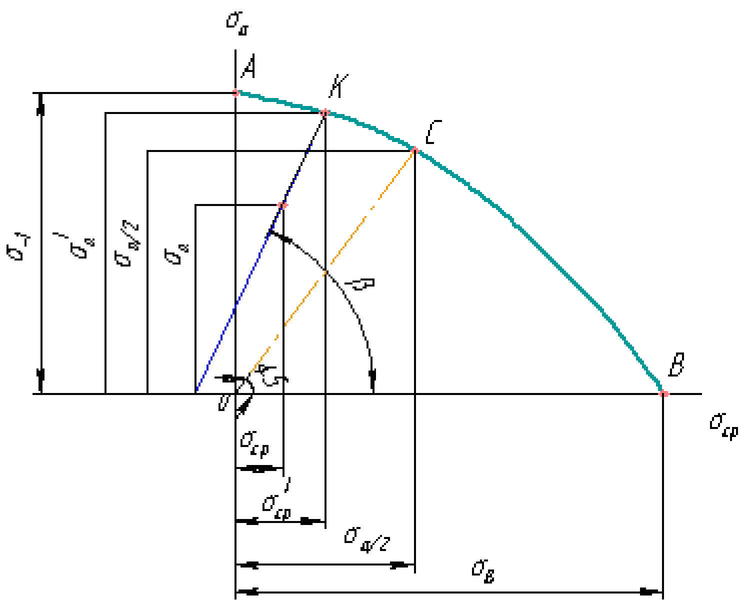

Figure 3. Diagram of limit amplitudes along σ_B

For any irregular cycle, according to the durability limit $\sigma'_{\max} = \sigma_R$, determined by tests, it is easy to find σ'_a and σ'_{cp}.

According to the formula (3), $\sigma'_{\max} = \sigma'_{cp} + \sigma'_a$, but $\sigma'_a = \rho \cdot \sigma'_{cp}$, where ρ – is characteristic of a stress cycle, determined by ratio σ'_a / σ'_{cp}. Consequently,

$$\sigma'_{\max} = \sigma'_{cp} + \rho \cdot \sigma'_{cp} = \sigma'_{cp}(1+\rho)$$

or $\sigma'_{cp} = \frac{\sigma'_{\max}}{1+\rho}$ and $\sigma'_{a} = \frac{\rho \cdot \sigma'_{\max}}{(1+\rho)}$ (4), (5)

In particular, for a fluctuated cycle (R=0, $\rho = 1$) at durability limit equal to σ_0

$$\sigma'_{cp} = \sigma'_{a} = \frac{\sigma_0}{2}$$

This cycle corresponds to point C in the diagram shown in Fig. 3.

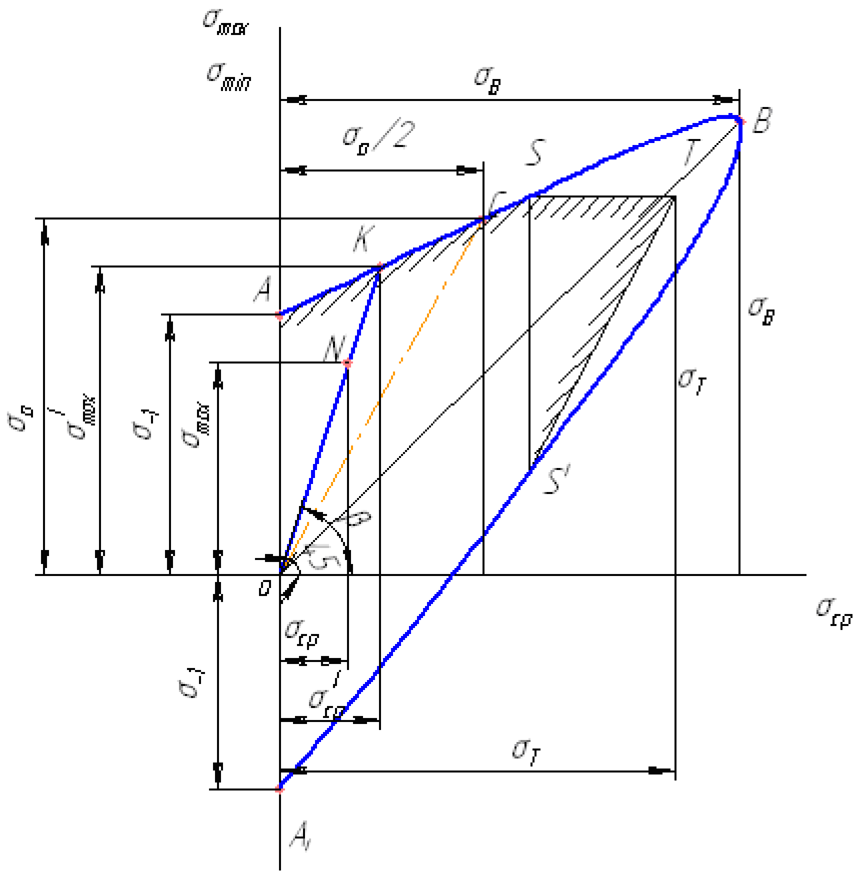

Figure 4. Diagram of limit stresses along σ_B

This diagram shows each cycle with two points. For example, limit reverse cycle is shown with points A and A1: point B corresponds to a limit constant stress $(\sigma'_{\max} = \sigma'_{cp} = \sigma_B)$, limit fluctuated cycle $\sigma'_{\max} = \sigma_0; \sigma'_{\max} = \sigma'_{cp} = \frac{\sigma_0}{2}$ is shown with points C and F.

To determine fatigue limit for the cycle with ratio R we draw a half-line at angle β to the x-axis from zero [7]. Tangent of the angle is determined by the formula:

$$tg\beta = \frac{\sigma_{\max}}{\sigma_{cp}} = \frac{2\sigma_{\max}}{\sigma_{\max} + \sigma_{\min}} = \frac{2}{1+R} \quad (6)$$

K-ordinate of crossing between the half-line and limit stress line gives a value σR= σ'max. To determine areas of cycles safe from fatigue and flow, on the half-line 0B (points of the half-line correspond to time-constant stresses: σmax=σcp, σa=0) we plot a point that corresponds to the cycle with σmax=σcp= σт and draw from this point two straight lines as shown in Fig. 2.5.

Area of safety life cycle is limited by the segment AA1, axes are limited by the curves AS, A1S1 and the broken curve STS1. According to numerous studies [3,4,5,6,7], LSD from Fig. 4 can be simplified as it is represented in Fig. 5,6.

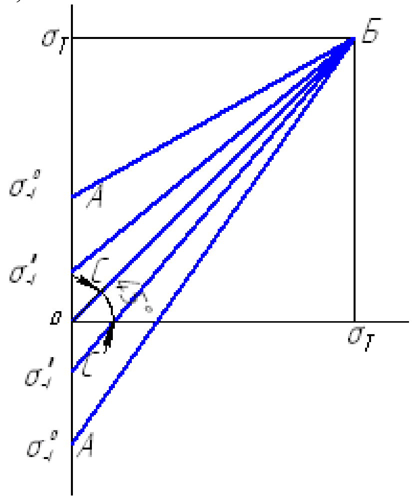

Figure 5. Simplified diagram of the limit stresses along σ_T

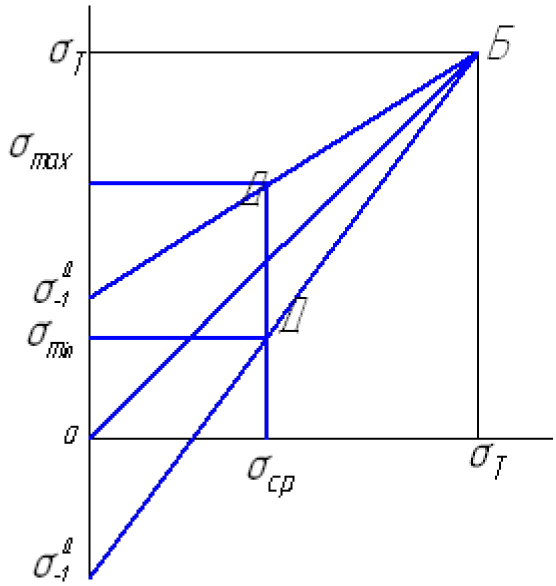

Figure 6. Real diagram of limit stresses

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Conclusions

The proposed method is universal. For example, based on testing of a certain helical spring, made of certain steel, LSD can be plotted for any helical springs made from this steel. In tests it is important to find a point of the Wohler curve inflection that characterizes springs durability equal to Nб; that is, to find point Д (see Fig. 6) experimentally, but not by standard specifications.

References

[1] Darkov A.V. Strength of Materials /A.V. Darkov, G.S. Spiro. - M .: Higher School, 1975. - 654 p.

[2] Lasukov, A.A., Mokhovikov, A.A. Influence of tool modified layer on stress - Strain state of cutting wedge, Proceedings - 2012 7th International Forum on Strategic Technology, IFOST 2012

[3] Chernukhin R.V. Reliability of steering gears of truck vehicles// Applied Mechanics and Materials. - 2013 - Vol. 379. - p. 36-42.

[4] Putilova U.S., Nekrasov Yu.I., Lasukov A.A. Loading of Manufacturing System Elements at Unsteady Cutting and the Models of their Arrangement Deviations, Applied Mechanics and Materials, Vol. 682 (2014), pp. 192-196

[5] Retyunsky O.Y. Method of making performs for composite reversible cutting plates // Applied Mechanics and Materials. - 2013 - Vol. 379. - p. 24-27.

[6] Valentov A.V., Retyunsky O.Yu. Use of tungsten carbide cutting tools in processing of mining machinery parts, recovered by surfacing / Mining informational and analytical bulletin (scientific and technical journal). 2012. № S3. Pp 245-249.

[7] Valentov A.V. Retyunsky O.Yu., Konovodov V.V. Increased durability and performance of cutting tools at processing of weld surfaces // Mechanics XXI 2012. № 11. C. 395-399