Computer analysis to determine service life criteria for special elements and applications

Miroslav Kopecky[1] and Marian Kopecky[2]

[1]*Full professor of Applied Mechanics, Dept.of Material*
ROZTEKA,Ltd.
. SK-010 01 Zilina , Slovak Republic
e-mail: mirkopecky @ inmail.sk

[2]*Post-graduate student VŠB-TU Ostrava,CZ.*
CZ-736 01 Havirov, Czech Republic
e-mail: marian.kopecky.st@vsb.cz

Abstract

A characteristic feature of new trends in development of new aggregates of mobile machinery is a continuous increase in manufacturing and operating costs. Simultaneously, transmitted outputs are also higher and a sufficient reliability has to be maintained. There is a tendency towards a higher use of materials, i.e. a relatively higher stress on particular parts of the aggregate. At the same time, a real safety of operation against the maximum admissible stress decreases. This all requires a further improvement of the method of designing and strength checking of a construction.
The problem of fatigue strength and service-life, as the most important phenomena of strength reliability under those conditions, is connected more or less with a certain degree of uncertainty.
The methods described in this paper are the ways to reach the solution goals by means of a characteristic curve of fatigue strength and reduced fatigue curve with the maximum use of computer technology.

Keywords: Dynamic Failure, Fatigue, Non Linear Dynamic Systems, Numerical Method and Validation.

1. Introduction

In some mobile machinery and equipment, or their elements, the problem of fatigue strength is conditioned by a fatigue process and by knowledge of a fatigue curve.

The problem of fatigue strength and service-life, as the most important phenomena of strength reliability under those conditions, is connected more or less with a certain degree of uncertainty.

It is probable that the most significant cause of this unfortunate situation is the fact that so far there has not been a single universal theoretically and experimentally proved fatigue theory which would consider all the factor that have an influence on the phenomena. Apart from this, there are not a generally accepted methodology of fatigue tests.

The methods described in this paper are the ways to reach the solution goals by means of a characteristic curve of fatigue strength and reduced fatigue curve with the maximum use of computer technology. It has to be said, in the very beginning that insufficient information about the values of the fatigue curve can lead to errors sometimes higher than 100%. Also, because of economic and other reasons, it is impossible to carry out sufficient number of fatigue tests on a finished product in the laboratory in order to get reliable information about the fatigue curve. It is further connected with a choice of a suitable cumulating of a fatigue failure, which can also lead to different results.

In spite of the above limitations it is necessary to pay attention to this area, as it comprises significant components or units of transportation machinery and equipment.

2. The computing system

If we know the probability density of occurrence of decisive loading quantity, esq. a moment on the inlet of a transportation machine and we also know the fatigue curve for a given constructional element of unit, we can determine the total strength reliability from the point of view of fatigue strength.

Let us suppose that the probability density of a moment parameter occurrence on the inlet is f(M). The following relation can be generally written for stress:

$$\sigma_{(M)} = \varphi(M) \text{ x } M \tag{1}$$

where φ (M) can be generally also a stochastic function.

In this way the probability density of stress $\varphi(\sigma)$ can be achieved. As we also know the fatigue curve for a particular component we can, with the help of a hypothesis of failure, determine the total service of a part Lc corresponding to a domain of loadings f(M) and functions φ(M).

With regard to a probability character of the fatigue curve, where its exponents p, q, have a character of a random quantity, a total service life is also a random quantity characterized by a probability density. The probability that a failure might occur before a required service life Lp ends is given by a hatched surface in Fig. 1.

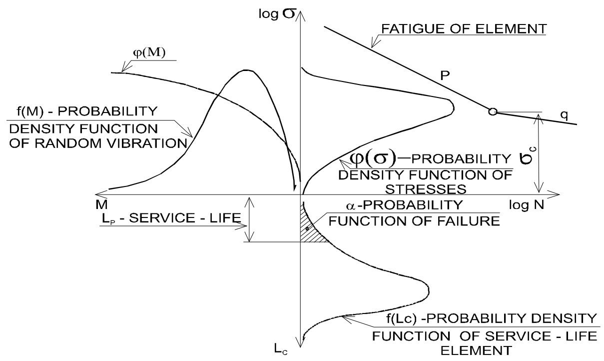


Figure 1:The dependence of a component service life on loading

The basic scheme is based on an assumed dependence of a failure on he intensity of damage. We define the basic fatigue curve for a basic material completed with further information. The method is based on a maximum use of computers.

The basic scheme of a development diagram can be seen in Fig. 3. It is based on an assumed dependence of a failure on he intensity of damage. We define the basic fatigue curve for a basic material completed with further information.

2.1 In dependence on the fatigue curve

In spite of the fact that a shape of the fatigue curve is idealized to a great extent, it was chosen because of its simplicity and possible application of a majority of calculation procedures.

According to the theory of fatigue failure we determine a new fatigue curve, the reduced course of which would correspond to the result of the experimental test, so that a failure would occur at a failure intensity *CDC = 1,* as shown in Fig. 2.

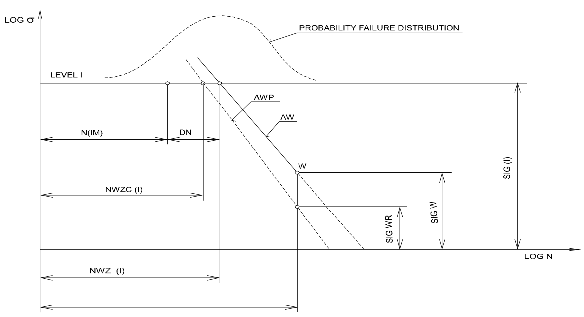


Figure 2:An estimation of a fatigue curve and its reduction

The parameters of the fatigue curve reduced in this way are: *NWO, AWP, SIGWR* .

We determined the probability for a given course of the fatigue curve. It is the probability of a failure occurrence for a deviation *SR* of a group of parts according to the relation:

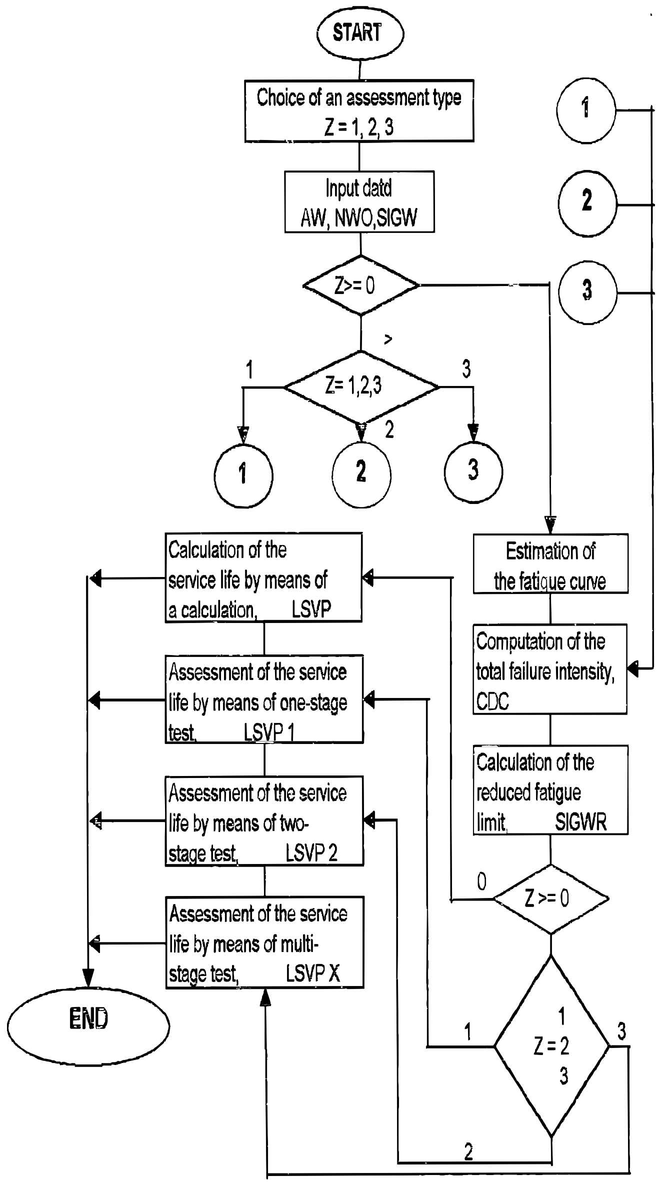
$$R_{(\%)} = 100\,(0{,}5 - \phi_{(x)}) \qquad (2)$$

where : $x = DN/SR$, and $DN = |\log DC|$

In order to determine a failure probability we use Laplace integral:

$$\phi_{(x)} = 1 / (2\pi)^{1/2} \cdot \int_{0}^{x} e^{-((T)/2)^{2}} \, . \, dT \qquad (3)$$

Having acquired the courses of a failure intensity of all major components of a construction, we can proceed to a determination of a test procedure and programme.



Figuree 3: A basic scheme of the development diagram

2.2 On a simulated programmer of an experimental test

If an assessment of some properties of constructional units on the basic of experimental destructive test is to be reliable, it requires mathematical statistics to be used.

It is impossible to carry out 100% assessment of investigated properties. It would lead to a total destruction of an investigated series of components or units and it would also prevent them from being used in practice. Also another extreme, i. e. verification of service life with one specimen only is useless, especially when we realize e. q. a distribution of service life.

The length of service life of one component or unit is conditioned by a series of factors, as e.g. inner microscopic defects of material, manufacture irregularities, ways of use, impact of the environment, etc.

A range and occurrence of such factors is incidental and, therefore, individual service lives generally differ and it is impossible to determine exactly a service life for a given component. If we use N as a symbol for the service life, then individual service lives which are the results of the test will have the values of $N_1, N_2, \ldots N_n$.

In order to describe the service life, the following functions can be used:

1. a distribution function F(N) given by the relation:

$$F(N) = 1 - \exp\left[- \int_0^N Z(N)\, dN \right] \qquad (4)$$

which gives a probability that a service life of a test element will not exceed a predetermined value of service life N,

2. a probability density f(N) determined by the relation:

$$f(N) = Z(N) \cdot \exp\left[- \int^N Z(N)\, dN \right] \qquad (5)$$

which gives a probability that a test element will be damaged at an interval dN beginning in N_i . The function Z(N) in the equations (4) and (5) is derived from the relation:

$$Z(N) = f(N) / (1 - F(N))$$

and means that when multiplied by dN, it expresses a probability that the element reaching the service life N will be damaged before the nearest time interval dN ends.

For a practical processing of the results of tests it is better to use, instead of the function Z(N), its integral which is in the exponent of the distribution function:

$$\varphi(N) = \int_0^N Z(N)\, dN \qquad (6)$$

Weibull’s model or regressive model can be chosen as a starting point for further solution. When solving the problems of strength reliability of transportation components and units, Weibull’s model is more exact than the regressive model. Its use, however, requires more profound experimental information.

For the used Weibull’s model, the function in (6) can be sufficiently approximated by the function:

$$\varphi(N) = [(N_i - a)^k] / b$$

where $a, b, k,$ are parameters determined from the experimental results.

where a, b, k, are parameters determined from the experimental results.

The dependence between an operating process of a constructional component and its service life N_i must be extended by a variable R(N) **,** which offers a numerical guarantee in a probability form.

In more complex units, where one component is repeated several times, an analysis of service life will not be sufficient enough, even if the relation (4) and (5) are implemented.

Let us consider that it consists of the components y_1 , y_2 , y_i , and it can be n_1 pieces of the component y_1, n_2 pieces **...** , n_j pieces of the component y_j .

The test can show that the component y_1 will be damaged with a probability $F_1(N)$, before reaching the service life N, the component y_2 will be damaged with a probability $F_2(N)$, etc. Then the probability that the whole complex unit will not be damaged before reaching the service life N**,** is given by the relation:

$$R(N) = [1 - F_1(N)]^{n_1} \cdot [1 - F_2(N)]^{n_2} \ldots [1 - F_i(N)]^{n_j}$$

The most general form of the probable function of service life is:

$$R(N) = 1 - [1 - \exp\{-(N_i - a)^k / b \}] = \exp\{-[(N_i - a) / b^{1/k}]^k \} \qquad (7)$$

The function in the equation (7) specifies the probability that the service life of the component will be higher than the chosen value N.

The function of the probability density to the function in the equation (7) is:

$$f(N) = k/b^{1/k}[(N_i - a)/b^{1/k}]^{k-1} \exp\{-[(N_i - a)/b^{1/k}]^k\} \qquad (8)$$

The determination of the distribution parameters in the equation (8) is carried out numerically.

The equation (7) can be written in the form:

$$\ln (-\ln R(N)) = k [\ln (N_i - a) - \ln b + \ln\ln e] \qquad (9)$$

which is the equation of characteristic curve of the strength reliability found for a tested constructional component.

2.3 A sequence of computation

In order to determine the distribution parameters in the equation (2) the values from Tab. 1 are to be used:

VALUES OF FUNCTIONS

1/k	A (k)	B (k)	C (k)	D (k)	1/k	A (k)	B (k)	C (k)	D (k)
0,01	0,4481	-1,0813	0,9944	78,5536	0,65	0,1673	1,0279	0,9001	1,5075
0,05	0,4392	-0,8680	0,9735	16,1952	0,70	0,1416	1,1604	0,9086	1,4078
0,10	0,4250	-0,6376	0,9514	8,3119	0,75	0,1163	1,2941	0,9190	1,3201
0,15	0,4082	-0,4357	0,9331	5,6883	0,80	0,0915	1,4295	0,9314	1,2423
0,20	0,3891	-0,2541	0,9181	4,3658	0,85	0,0674	0,5674	0,9456	1,1725
0,25	0,3681	-0,0872	0,9064	3,5645	0,90	0,0441	1,7080	0,9618	1,1095
0,30	0,3455	0,0687	0,8975	3,0243	0,95	0,0216	1,8521	0,9799	1,0522
0,35	0,3217	0,2167	0,8912	2,6337	1,00	0,00	2,00	0,00	1,00
0,40	0,2669	0,3586	0,8873	2,3370	1,50	-0,1585	3,8196	1,3317	0,6454
0,45	0,2715	0,4963	0,8857	2,1040	2,00	-0,2236	6,6188	2,00	0,4472
0,50	0,2456	0,6311	0,8862	1,9131	3,00	-0,1912	10,5849	6,00	0,2294
0,55	0,2195	0,7640	0,8889	1,7554	4,00	-0,1154	60,0917	23,9880	0,1204
0,60	0,1933	0,8960	0,8935	1,6221	5,00	-0,0626	190,113	119,113	0,0068

Table 1: Values of functions

Let *n* constructional components or units be tested, and the results of service life tests be $N_1, N_2, ..N_j$.

We calculate the mean value of service life N_S.

We calculate a standard deviation of service life S_N .

We determine a degree of slope by means of the relation:

$$b^{1/2} = n^2 / [(n-1) (n-2)]. [N_S^3 - (3 N_S^2).N_S + 2N_S^3] / S_N^3$$

For the parameters *a*, *b*, holds by means of the moments of the function from the equation (8) :

$b^{1/2} = B(k)$, from which *1/k* is determined,

$S_N . D(k) = b^{1/2}$, from which *b* is determined,

$N_S - [S_N . D(k)]. C(k) = a$, from which *a* is determined.

The functions B(*k*), C(*k*), D(*k*) are determined numerically from a general *k*-th moment for the variable

$$(N_i - a) / b^{1/2} , \quad [1],$$

$$m_n = \Gamma (1 + n/k).$$

3. Application

The applications of this methology shorten knowledge of the time to failure of mobile machines components and contribute to the safety and economy of mechanical systems.

The results of its application would be presented to mobile facility elements with the maximum use of computer technology.

For illustration are shown the results of tests for load-carrying part of tower crane construction. The principle measurement of random signals is make by the special measuring instrument, as shown in Fig. 4.

The substance of construction makes up the mechanical gauge connected with the indicator. The instrument works together with photo-cell, which take effect to star of the recording equipment. The instrument can be installed on the critical points of the tower cranes, as shown in Fig. 4.

Use up of special measuring instrument in operating state is continually and directly. Long-time tests can be runned independently from climatic conditions. Very valuable results of experimental tests of the tower cranes make for recording of signals of random loads under long-time operating state to render possible the special measuring instrument.

The application of the fatigue curve reduced method, as shown in Fig. 2 for special type tower crane and results are shown in Fig. 5.

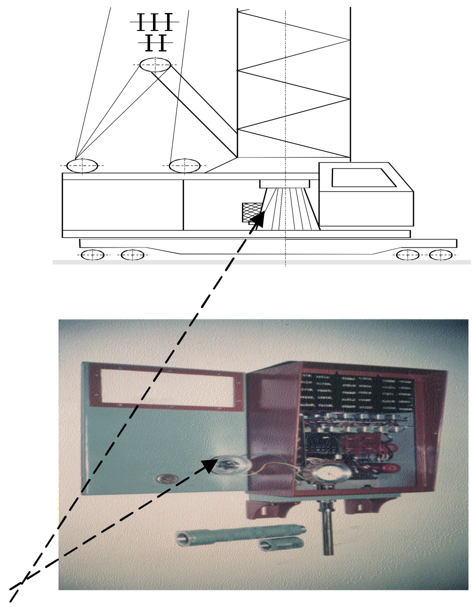


Figure 4: The detail view of the tower crane with special measurement instrument

4. Conclusions

Measurement and assessment of random operating processes are, neither technically nor theoretically, simple problems. The expansion of computers and measuring tape recorders and high-quality apparatus together with more profound information about an application of theory of random processes have caused that the problem of random processes have penetrated to the area of design and manufacture of construction.

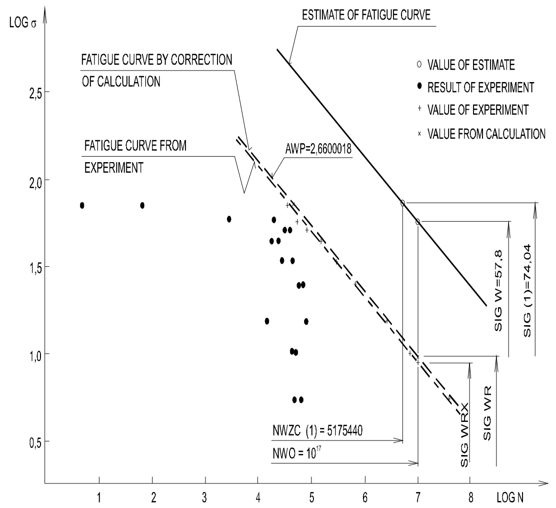


Figure 5: Fatigue curve reduced for tower crane

A completely different is a situation with a laboratory simulation of the obtained operating processes. In general, there are not any known methods of creation of processes and there are different approaches to the ways of reproduction.

Mechanical systems of transportation machinery and equipment differ considerably from the point of view of a possibility of simulation procedures. When assessing properties of a construction model in the stage of its design and prototype test, or innovation and experiment verification, the question of economy is also important.

Acknowledgments

The author expresses his thanks to Slovak Agency for Research and Science for its support of this work. (grant 4/2010/08).

References

[1]. Kopecky, M. and Peslova. F.. Assessment Methodology of elements and constructions reliability criteria for mobile machines and equipment. In: *ISTLI special publication 2: Teaching and Education in Fracture and Fatigue,* Imprint: E & FN SPON , London, England, pp.325-330, 1996.

[2] Cuth, V., Tvaruzek, J., Vavro, J., Husar, S., and Varkolyova. B. The stress analysis and the service life prediction on the low-power motorcycle. In: *4th Mini Conf. on Vehicle System Dynamics, Identification and Anomalies,* Budapest, Hungary, pp.171-177,1994.

[3] Letko, I., Bokuvka, O., Nicoletto, G., Janousek, M., and Palcek, P., Fatigue resistance of two tool steels. In: *11th Danubia-Adria Symposium on Experimental Methods in Solid Mechanics,* Baden, Austria, pp.139-140, 1994.

[4] Vavro, J., Optimisation of the Design of Cross-Sectional Quantities in Transport Machines and Equipments. In: *Studia i materialy,* Technika, Zelena Gora, Poland, pp.187-194, 1998.

[5] Weibull, W., A statistical distribution function of wide applicability.In: *Journal of Appl.Mechanics, No.3*. 1951.