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AUTOMATIC DIAGNOSING OF FATIGUE LIFE OF MACHINE PARTS

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Abstract.

In the paper one of crucial point in the condition assessment strategy-fatigue life diagnosis has been discussed. The non-linear cumulative fatigue model has been presented.

1.Introduction

There is a strong trend for machine parts to move towards the conditioned based maintenance strategy. There are a number of reasons for this, all of them essentially economic, but mention in the paper will be made of one - diagnosing of fatigue life. For reason such that, maintenance activities planned and scheduled only when machine symptoms indicate that they are necessary. If economically justified, condition based maintenance must be founded upon reliable and accurate machine symptom diagnosis. "Condition assessment" (CA) is the term we prefer to the more commonly used term "condition monitoring", either of the terms implying an evaluation of the fitness of machine or system to perform its design function. Condition monitoring implies an evaluation of the current state of machine of system, condition assessment implies in addition the prediction of its probable state at some time in the future [3,5,6,7].

The role of conditioned assessment is to provide input so that condition based maintenance planning can make sound economic decisions. To achieve this, CA must be ultimately be quantitatively predictive. In the paper a part of CA evaluating of remaining fatigue life will be presented.

2.Condition assessment

"Condition assessment" of any existing machine beyond the originally design demands a number of theoretical and experimental analysis to be done. Due to a generally limited information regarding loading history and low availability for specimens, sampled from plant components in the actual damage state a number of analytical as well experimental problems arises. One of the prospective sources of investigation or/and recalculations is cumulative fatigue damage area.

A large amount and variety of materials data, specific for components in the actual damage state, are required to evaluate and predict the extent of damage. The problem of fatigue damage is one of the most important aspect affecting the residual life. On the other hand it is recognised that the creep damage, environmental effects in a material can also considerably reduce other mechanical characteristics of the material with respect to virgin state. The problem of the identification the critical locations of fatigue or fracture damage relies at a preliminary level on life estimation derived from nominal fatigue life curves and damage theories.

Despite a long time effort, designing against fatigue still remains one of the most difficult problems. This is mainly due to vast numbers of factors conditioning the operating fatigue life such as random cyclic loads, materials properties, environmental effects etc. Thus in practical design procedures and mainly in complex CAD design, generally three stages are to be considered simultaneously:

-typical operating random loads (or their statistical characteristics),

-material fatigue characteristics,

-design procedures - cumulative damage rule

3.Design against cumulative fatigue damage

Since the fatigue damage is generally caused by plastic strain, the dissipated plastic strain energy density plays an important role in fatigue phenomena. However, when the number of cycles tends to infinity, the value of plastic strain range as well as plastic strain energy density tends to zero. Therefore in high-cycle fatigue the calculations based only on the plastic strain range or plastic strain energy density may not be accurate.

To unify description of fatigue life in low- and high-cycle fatigue the strain energy density equal to the sum of plastic strain energy density and elastic strain energy density in tensile half-cycle as a damage parameter has been proposed (Fig.1) [1,2].

Let the controlling damage parameter will be total strain energy density designated by ΔW^t. The damage variable in the relation to number of cycles to failure can be expressed through life curve as :

$$\Delta W^t = kN_f^{\alpha} + C \qquad (1)$$

where k, g , C are material parameters and N_f is the number of cycles to failure. It is assumed that the above mention relation can be expressed by two equations

$$\Delta W^t = kN_f^{\alpha} \qquad \text{for } N_f < N_o$$

$$\Delta W^t = C \qquad \text{for } N_f > N_o$$

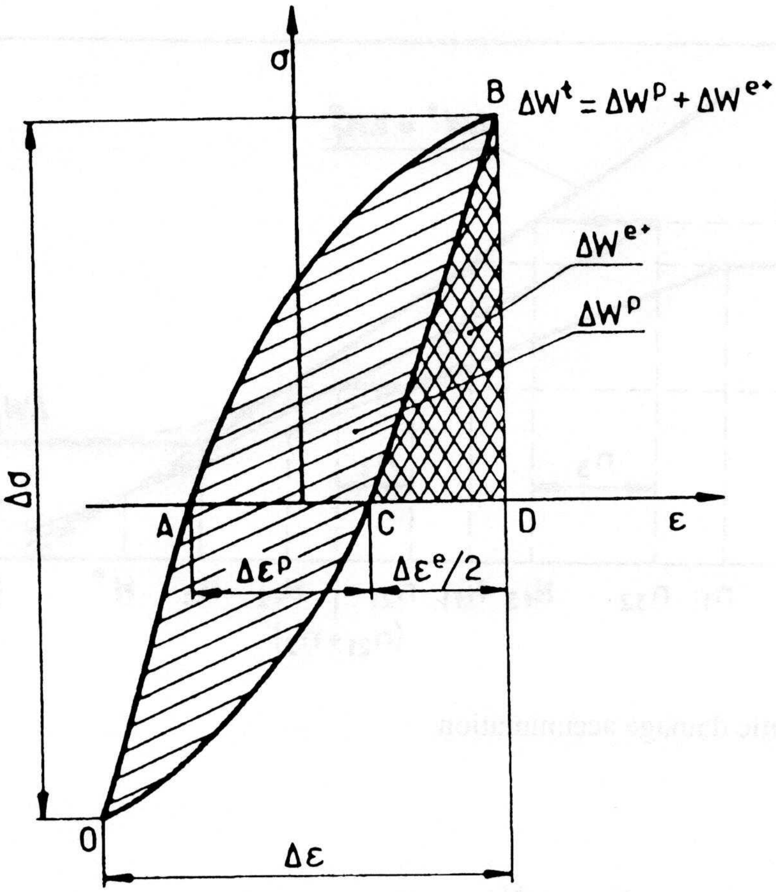

Fig.1 Damage parameter

Now let us consider a specimen which is subjected to two-block cyclic loading. Let damage parameter associated with the first loading block be denoted by $\Delta W^t{}_1$ at which is applied n cycles. The damage curve can be expressed as:

$$\frac{\Delta W_1^t}{\Delta W^*} = \left(\frac{n_i}{N_{fi}}\right)^{\varsigma} \qquad (3)$$

where z is a parameter which is constant for a specific damage curve. Changing the applied load and denoting the associated damage parameter $\Delta W_2{}^t$ we continue cycling until failure occurs. Application of n_1 cycles at $\Delta W_1{}^t$ level will cause same damage in material which can be determined from the damage curve. We could find an equivalent number of cycles n_{21} applied at the level $\Delta W_2{}^t$ which would cause the same amount of damage as the first loading block

$$n_{21} = N^* \left(\frac{n_1}{N^*}\right)^{\frac{\log\left(\Delta W_2^t/\Delta W^*\right)}{\log\left(\Delta W^t/\Delta W_1^*\right)}} \qquad (4)$$

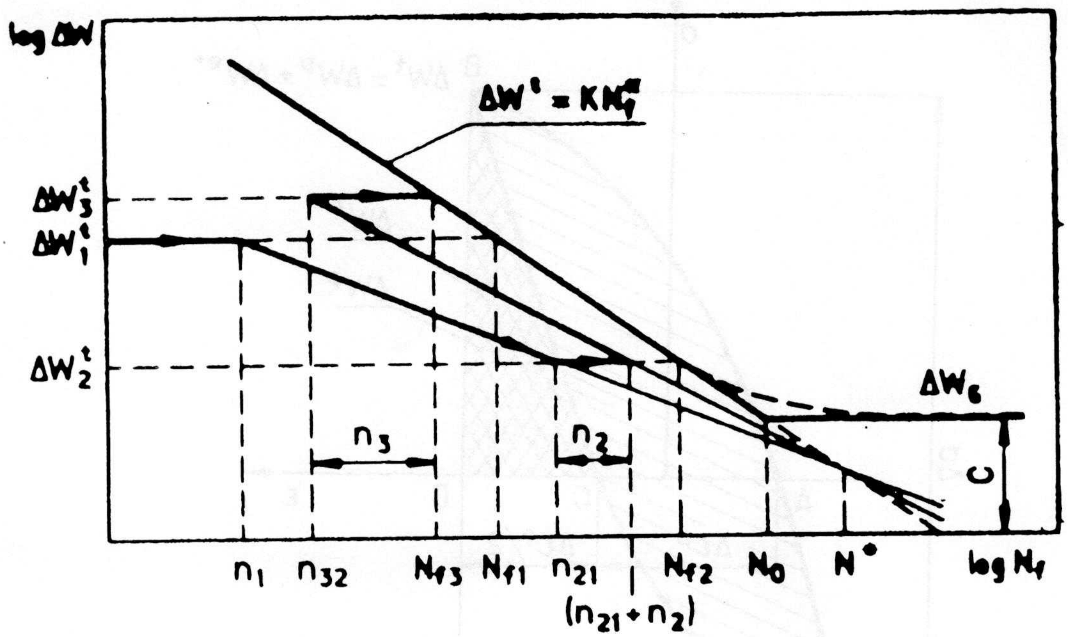

Figure 2. Schematic damage accumulation.

Noting that

$$n_{21}+n_2=N_{f2},\tag{5}$$

we get the cumulative damage hypothesis for the two-stage loading in the form of

$$\left(\frac{n_1}{N_{f1}}\right)^{\frac{\log\left(\Delta W_2^t/\Delta W^*\right)}{\log\left(\Delta W_1^t/\Delta W^*\right)}}+\frac{n_2}{N_{f2}}=1\tag{6}$$

The method described for two stage loading can be easily generalised to multilevel loading blocks. We observe from the above that for the increasing value of "reduced" fatigue limit the equation (8) is the same as the linear Palmagren and Miner rule. Also in the case when the slope of the damage line is constant to that of the life curve we obtained the Palmgren-Miner rule.

4.Comparison with experimental data

In the analysis the data presented by Miller and Zachariah [4] for En3A steel have been used. Tests have been performed for both low-high and high-low sequences. The corresponding number of cycles to failure at the analysed stages ranges from $N_f = 720$ to $N_f = 700000$. All results in the investigated model correctly predicts the trends of experimental results for analysed strain amplitudes and given sequences.

5.Summary and conclusions

1.Fatigue life prediction is one of the crucial elements in condition assessment.

2.Machine manufactures and operators should be prepared to supply complete information on the proper instrumentation (for example - collection of applied loads, environmental conditions).

3.A new hypothesis of cumulative fatigue damage has been presented.

4.The final responsibility for the extent of any machine parts, and hence the reliability of condition assessment, must rest with the plant operator, but the manufacturer (researcher) should be in a position to give guidelines for this decision.

References

[1] Golos, K., Energetistic formulation of fatigue strength criterion, Archiwum Budowy Maszyn, Vol.25, No 1/2, 1988, 5-16.

[2] Golos, K., Effect of sequence of loading on fatigue in St5 steel, Proc. of the 10th Congress on Material `Tesing, E.Czoboly ed., Budapest, Vol.II, 1991, 472-477.

[3] Hubka, V, Theorie der Konstruktionsprozesse, Berlin-SpringerVerlag, 1976.

[4] Miller, K.J., Zachariach, K.P., Cumulative damage laws for fatigue crack initiation and propagation, J.Strain Analysis, Vol.12, 262-271, 1977.

[5] Oziemski, S.,Niezowodnosc i bezpieczenstwo maszyn, Przeglad Mechaniczny , Nr 8 (25-31), Nr 9 (5-9), Nr 10 (12-15), Nr 11 (5-8,17), 1985.

[6] Oziemski, S., Zaganienia wyboru modelu odnowy maszyny. Zaloxenia techniczne i ekonomiczne., VI Kon. Sterowanie Naped, Wytrzymalosc zmeczeniowa i Projektowanie Maszyn Budowlanych, WAT, 1-8, 1994.

[7] VDI 2221, Systematic Approach to the Design of Technical Systems and Products, Dusseldorf, 1987.