Cycle Counting Technique For Variable Amplitude Loading

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Abstract

This paper deals with the cycle counting technique involved in fatigue life prediction for variable amplitude (VA) loading. The cycle counting techniques have now gained tremendous importance due to the generalized acceptance of the damage accumulation theories, which have been given by many researchers since the past 70 years starting with the Palmgren-Miner theories. The cycle-by-cycle approach predicts growth of the crack associated with each load cycle, thus predicting the overall fatigue life of a structure. This paper discusses a simple fatigue code for the analysis of structures with known stress time history. It describes numerical algorithms that have peen incorporated in the code. The code uses a simple range counting algorithm to describe the cyclic stress imposed on a structure. The counting algorithm is a two parameter statistical representation of a load history. Fatigue life is predicted using the Miner's Rule. The results obtained match with those obtained from standard cycle counting software's available.

Keywords: VA loading, cycle counting, stress time history, Miner's Rule

1. Introduction

The most widely used method for fatigue analysis is that which uses the Miner's Rule in conjunction with the S-N (Wöhler) curves. The basic requirements for this method are as given below:

1. The S-N curves for the materials used, which are determined by experimental methods.
2. Physical load decomposed into elementary cycles characterized by their mean value and amplitude. The loading can be determined in terms of stress or strain with the help of strain / stress gauges, which are installed at critical points in the structure.

This paper deals with the cycle counting technique involved in fatigue life prediction for variable amplitude (VA) loading. Several methods have been proposed by researcher's viz. Rainflow cycle counting[1,2] method, Range counting method. Rainflow method is a cycle-counting technique that makes it possible to store service measurements in a form suitable for fatigue analysis of structures. Rainflow counting results can give level crossing counting results and allow a reconstruction of a possibly different sequence, which contains exactly the same cycles as the original sequence. This paper proposes to give a method of cycle counting for any representative loading pattern, which may not contain successive peaks and valleys.

2. Methodology

The aim of this program is to program the combination of Rainflow method and Range count method algorithms so as to obtain the advantages of both these proven methods. The representative stress data may not contain only peaks or valleys. Intermediate points will be detected by the program and thus will not be taken into consideration when giving the final cycle count. The algorithm used in this program does not take care of the load sequence, which means that there is no difference between a high stress range cycle followed by low stress cycle and vice versa. The steps followed by this program can be effectively depicted by the flowchart, which has been given below. The stress values are input in the program through a file named 'stress.dat'. Program functions are used to analyze the data and to determine the maximum, minimum amplitudes, mean and average values.

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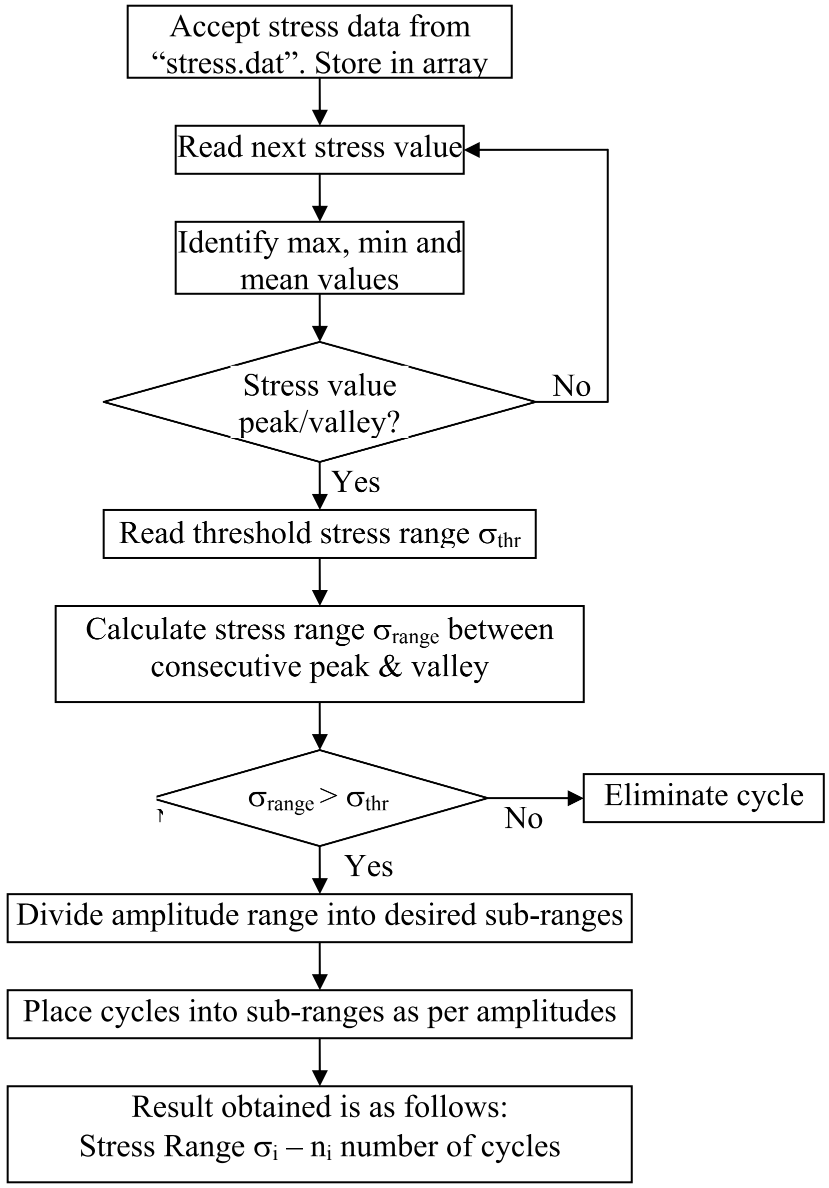

Fig. 1. Flowchart representing the cycle counting algorithm

If the peaks and valleys follow alternately, as in an ideal stress data, the difference between consecutive peak and valley gives the stress range σ_{range}. This σ_{range} is what is compared with the minimum threshold range σ_{thr} given by the user. In absence of σ_{thr}, all the cycles are counted. If a stress point is not either the peak or the valley, then such points need to be identified by the program automatically and eliminated from the data so that they do not contribute to the cycle count. This is effectively done by calculating the slopes of the straight segments joining the consecutive stress points. If 2 consecutive segments have the same slope, then the intermediate point needs to be eliminated. This has been depicted in the Fig. 2.

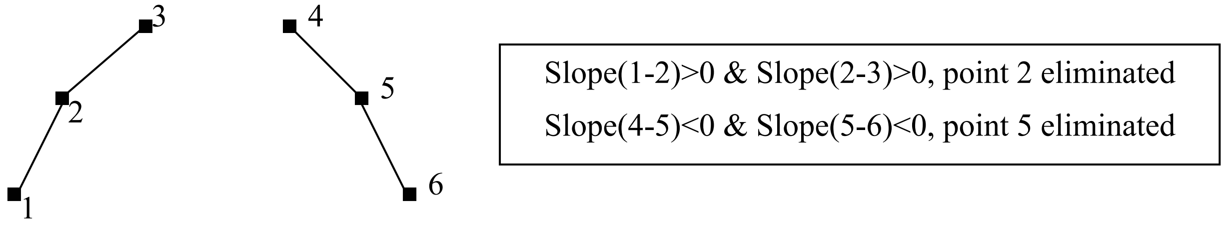

Fig. 2. Elimination of non peak / non valley points

3. Example problem

A simple representative data sample for a low Carbon steel component has been illustrated to show the effectiveness of the cycle counting program developed. The plot of the stress data is shown in Fig. 3.

Table 1. Representative stress readings

Stress (σ)	-26.4	22.3	0	6	-3.6	15	-5	7	0	7	-24	5E-04	-4	37	2
Pt. No.	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14

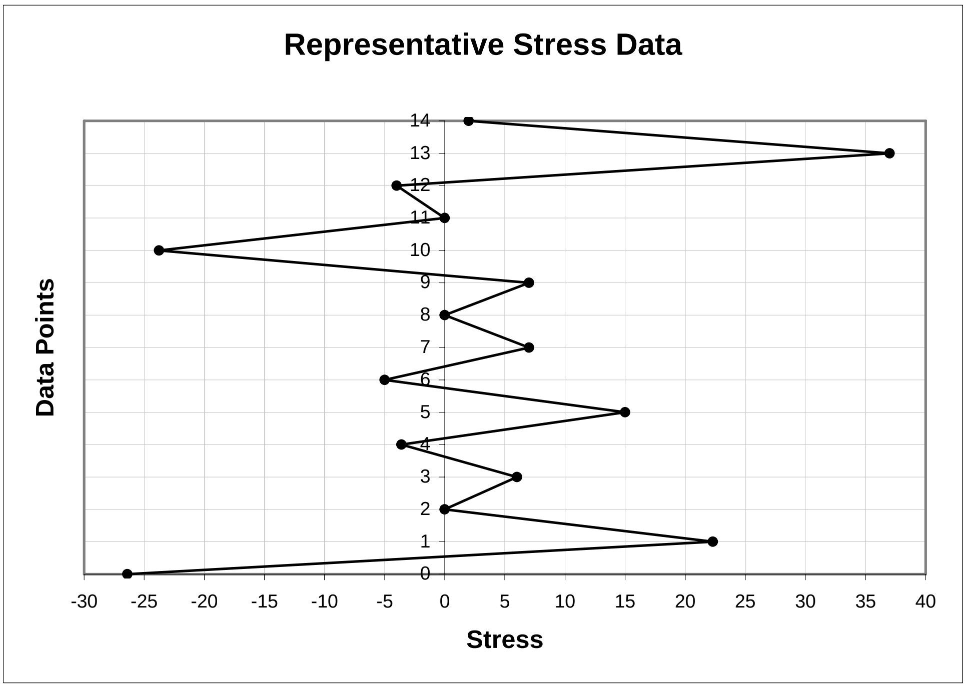

Fig. 3. Plot of representative stress points

In this problem the stress cycles have been counted in ranges of 10 N/mm^2. The results of the numbers of cycles falling in the data ranges have been given by the program and are depicted in Fig. 4.

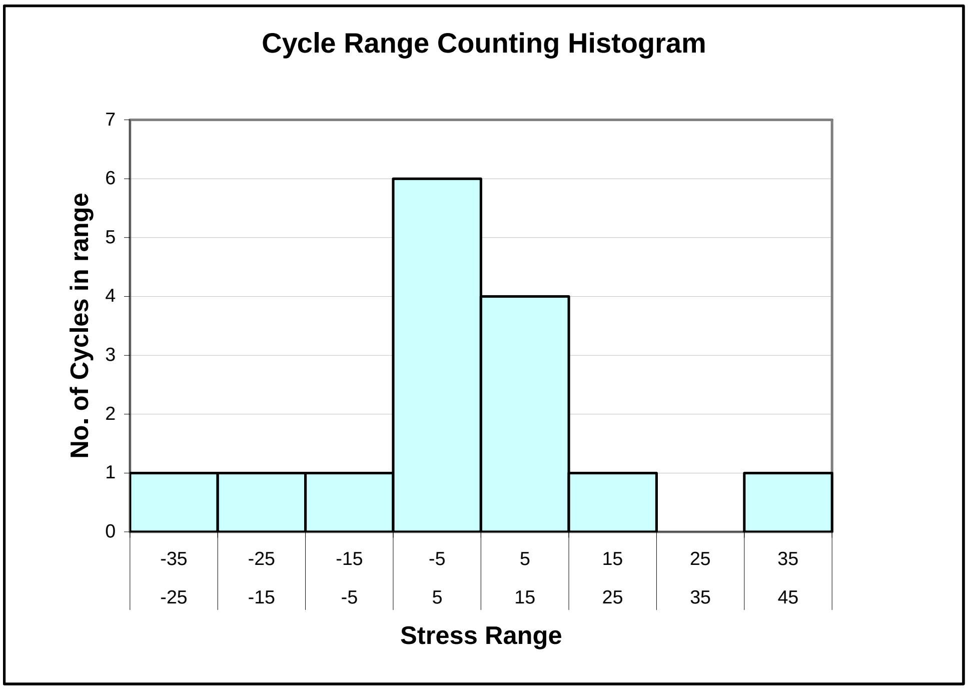

Fig. 4. Histogram showing number of cycles in ranges given.

The above histogram indicates the 15 half cycles falling in the amplitude ranges given. To get the total cycle count, the program checks if both the half cycles, which make up one complete cycle are greater than the threshold stress value set by the user. In the above stress data, if the user sets the threshold stress range as 10 N/mm^2, then the cycles counted are 6, whereas 1 cycle is eliminated. The ranges in which the cycles fit is given by the maximum range of the two half cycles which form the cycle.

3. Fatigue life estimation

The cycles counted using the program are now used in the next part of the algorithm, which use the standard fatigue *S-N* curves[4] of the material, of which the structure/component under observation is made of. A library of material *S-N* equations is under preparation. The user of the program needs to give the choice of material, whereby the material specific S-N equation would be used in the Miner's Rule equation to calculate the damage index and the fatigue life.

In the example problem, since we have considered the material to be of low Carbon steel, we can use the material specific S-N curve under axial tension, which is given in Fig. 5.

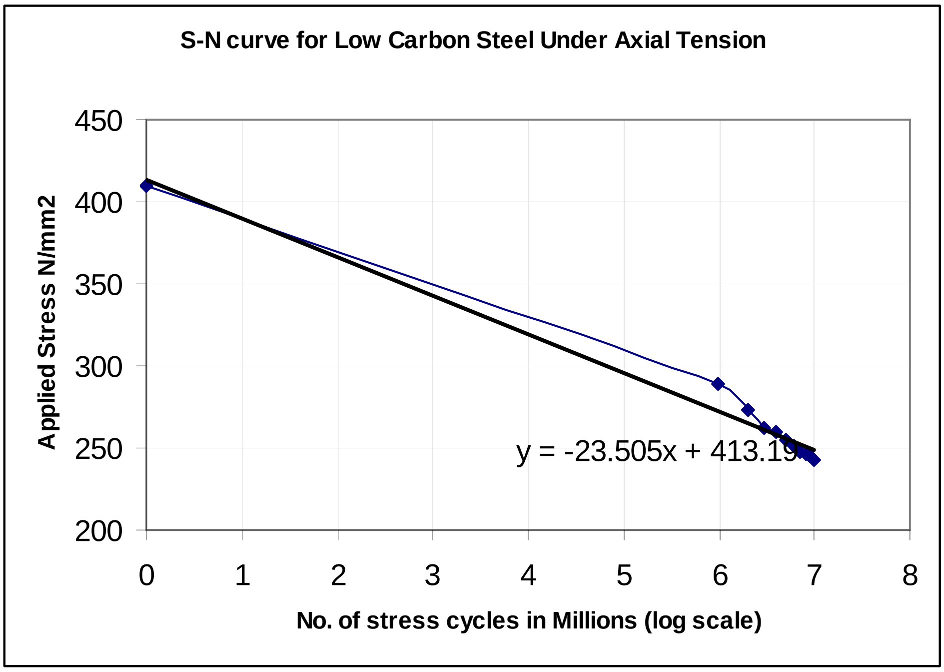

Fig. 5. Typical *S-N* curve for low Carbon steel under axial tension.

Now, the linear fit of the data points has been used to get the fatigue life of the component under observation. The user has the option to choose the material type and also the polynomial fit of the data points. As of now, the program allows the user to enter either the linear or the quadratic fit of the S-N curve. In the example problem, the life predicted using the linear fit of the *S-N* data, which is given by the equation $y = -25.505x + 413.19$ and Miner's Rule. The life in terms of number of cycles is found to be more than $8x10^6$ stress cycles. The component can therefore be assumed to have infinite life in this case. The program is still under development and more material S-N equations are to be added in order to make the program more user-friendly and state-of-the-art.

4. Summary

A simple counting algorithm for processing field data has been presented. This algorithm gives us the combined advantages of the Rainflow counting and the Range counting methods, which have been in use in the aircraft and land vehicle industry for quite sometime now. Outputs of the program show that results are in conjunction with the results obtained from standard cycle counting software. The results obtained from this program can be directly input to the fatigue models, which use the Miner's Rule for fatigue life prediction, which is given by the equation:

$$\sum_{i-1}^{k} \frac{n_i}{N_i} = C \qquad (1)$$

Where C gives us the damage index and k is the number of stress ranges or magnitudes. In the above example problem, k=8.When $C \geq 1.0$, damage index indicates fatigue failure. The results of the program give the value of n_i and k and the magnitudes of stress range. The N_i value is obtained from the loading calculated over the design life of the structure.

It can be further stated that the program has a lot of scope for improvement, after which it can be directly used on live problems with continuous stress data. Load sequencing effects, which have not been taken into consideration in this algorithm need to be incorporated, such that this program can become the state-of-the-art cycle counting method.

Acknowledgements

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