Materials Science and Engineering A 505 (2009) 163–168

Contents lists available at ScienceDirect

Materials Science and Engineering A

journal homepage: www.elsevier.com/locate/msea

Noise reduction for fatigue crack growth test data under random loading

Jae-Man Choi[a], Chung-Youb Kim[b,*], Ji-Ho Song[a]

[a] Department of Mechanical Engineering, Korea Advanced Institute of Science and Technology, 373-1 Guseong-dong, Yuseong-gu, Daejeon 305-701, Republic of Korea
[b] Division of Mechanical and Automotive Engineering, Chonnam National University, San 96-1, Dunduck-dong, Yosu, Chonnam 550-749, Republic of Korea

ARTICLE INFO

Article history:
Received 8 July 2008
Received in revised form 5 November 2008
Accepted 6 November 2008

Keywords:
Fatigue crack growth
Random loading
Noise reduction
Load-based averaging

ABSTRACT

The noise included in electrical signal significantly influences on the estimating results of crack length and crack opening point. The noise can be effectively reduced by averaging some consecutive loading cycles without distortion of the signal for constant amplitude loading tests, whereas the averaging technique cannot be applied to random loading tests due to the variation of load. In this study, a noise reduction technique was developed by using a load-based averaging technique, which can be applied to fatigue crack growth test data under random loading. Additionally, the developed noise reduction method was applied to random loading test data to verify the effectiveness of the method.

1. Introduction

Generally, fatigue crack length and crack opening load are measured by using compliance or unloading elastic compliance method and calculated from load vs. displacement or load vs. differential displacement curves. The noise included in electrical signal significantly influences on the calculation results of crack length and crack opening point. Especially, since the compliance around the crack opening point changes very gradually, the presence of noise causes significant error in the crack opening estimates. Accordingly, several noise reduction techniques have been used to reduce the effect of noise in determining the crack opening load.

The common noise reduction technique usually used in determining a crack opening point is a curve fitting approach. The ASTM standard method [1] employs a sequence of linear regressions to model the load vs. displacement data and compute compliance. Carman et al. [2] fitted the nonlinear portion of load vs. displacement data with a quadratic polynomial. For the region in which the crack was fully open, a linear curve fit was used. Kujawski and Stoychev [3] also proposed a curve fitting approach. Line, parabola, and line were used to fit load vs. displacement curve to the lower, middle, and upper regions, respectively. Another useful method to reduce the problem of noise in experimental data is a low-pass filter. The authors [4] used a low-pass filter to reduce the noise of differential displacement data obtained from random loading test. Daniewicz [5] also used a low-pass smoothing filter to smooth and differentiate the load vs. displacement data. The low-pass filter can effectively reduce the noise of experimental data, but might introduce the distortion of the original signal especially for the data of low signal to noise (S/N) ratio.

The most effective method to reduce the noise is an averaging technique over consecutive loading cycles. This method can effectively reduce the noise without distortion of the signal for stable crack growth region where crack opening loads do not fluctuate widely with loading cycles so that can successfully apply to constant amplitude loading test. However, in case of fatigue crack growth test under random loading, since the magnitudes of loads vary irregularly, this averaging technique cannot be applied.

The authors have been extensively studied crack growth and closure behavior under random loading. In this study, a noise reduction technique for the experimental data obtained from fatigue crack growth tests under random loading was developed based on the results of the previous work [6–8]. Additionally, the noise reduction method developed was applied to random loading test data to verify the effectiveness of the method.

2. Noise reduction method

2.1. Time-based averaging technique

Since the noise included in the electrical signals is generally a stationary random process and has a Gaussian probability density function, averaging n_c consecutive cycles reduces stationary random noise to $1/\sqrt{n_c}$ by the central limit theorem. For constant amplitude loading tests where the magnitude of load is constant, crack grows stably and there is no sudden change of crack opening

* Corresponding author. Tel.: +82 61 659 3222; fax: +82 61 659 3229.
E-mail address: kimcy@chonnam.ac.kr (C.-Y. Kim).

0921-5093/$ – see front matter © 2008 Elsevier B.V. All rights reserved.
doi:10.1016/j.msea.2008.11.005

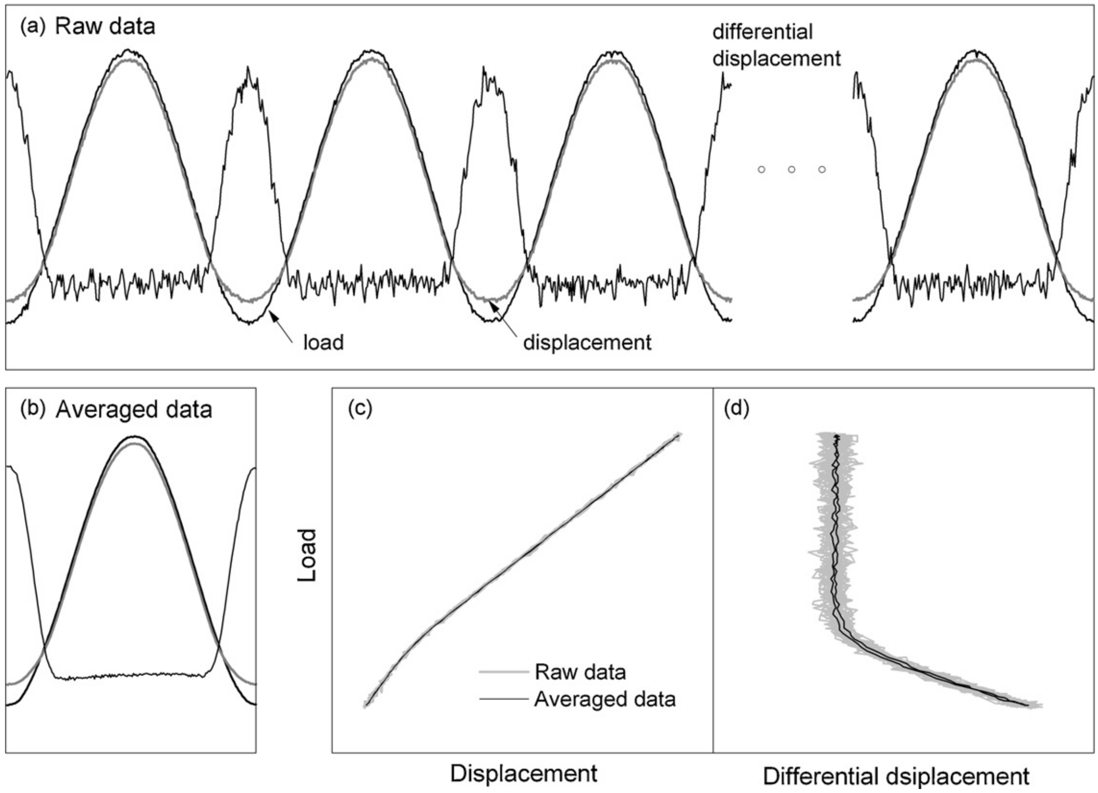

Fig. 1. Time-based averaging for constant amplitude loading data.

load with load cycling in most region of fatigue crack growth. In this case, a fatigue loading cycle with same shape is repeated for some consecutive cycles, so that by averaging some consecutive cycles, the noise included in the electrical signals can be reduced without distortion of the signal.

Fig. 1 shows the noise reduction results for experimental data by using the time-based averaging (TA) technique described above. The experimental data shown in Fig. 1 were obtained from the tests on M(T) specimens of 2024-T351 aluminum alloy under constant amplitude loading for a stress ratio of $R = 0$. The experimental details employed in this work are nearly same as in the previous work [6], so only the important aspects are outlined below. The M(T) specimen is 20% side-grooved one of length 184 mm, width 70 mm, and thickness 10 mm. The crack opening displacement was measured by using the clip gage attached at the center of the specimen, and differential displacement signal was obtained by using an electrical subtraction circuit. The tests were conducted using a servo-hydraulic testing machine at a frequency of 7 Hz, and the load signal from the load cell, the crack opening displacement signal from the clip gage, and the differential displacement signal from the electrical subtraction circuit were acquired. Each acquired fatigue cycle consists of 200 data points, spaced at equal time intervals.

Fig. 1(a) shows variations of raw experimental data of load, displacement, and differential displacement signals. As can be seen in the figure, the S/N ratio of the differential displacement signal is much lower than the others. This results from amplifying the load and displacement signals to obtain the differential displacement signal. Fig. 1(b) shows the averaged cycle for 20 consecutive loading cycles. The number of averaging cycles, n_c, is determined referring to the S/N ratio of the signals. The number of averaging cycles employed in this study ranges from 100 to 30. For the initial stage of a crack growth test, where crack growth rate and the S/N ratio of the displacement signal are low because of small deformation, large n_c is required to reduce sufficiently the noise. On the other hand, since crack growth rate and S/N ratio increase with increasing crack length, the value of n_c required is also reduced. Fig. 1(c) and (d) shows the load vs. displacement and load vs. differential displacement curves, respectively, where the gray and black lines represent the raw and averaged data curve, respectively. It can be seen from these figures that the TA method can effectively reduce the noise for constant amplitude loading test.

2.2. Load-based averaging technique

In analyzing fatigue crack growth under random loading based on the crack closure model, determining precisely the crack opening load is more difficult compared with constant amplitude loading, because the signal random noise included in the load vs. displacement or load vs. differential displacement curves cannot be reduced under random loading so easily as under constant amplitude loading. If the crack opening load under random loading can be assumed to be constant and represented by the averaged one during a random loading block, the signal noise can be reduced by averaging the signal data included within sufficiently small load intervals (load-based averaging, LA). The authors have studied the effects of random loading spectrum, history length of the random loading, and stress ratio on the crack growth and closure behavior under random loading [6–8]. Some important conclusions obtained from the previous works, related to the crack opening behavior under random loading, are summarized as:

The crack opening load fluctuates through a random loading block, but the range of fluctuation is not so great to introduce significant error in crack growth, irrespective of random loading spectrum, random loading block length, or crack length. Therefore, the crack opening loads under random loading can be regarded as nearly constant during a random loading block.