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Improving of acoustic emission signal detection for fatigue fracture monitoring

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Abstract

Identifying growing cracks in running machinery and industrial facilities is challenging, particularly at the nucleation stage in "hard-to-reach" places and in harsh environment. The method of acoustic emission is a popular non-destructive means for inspecting and monitoring the behavior of loaded materials and active internal defects. One of the key problems which impedes a wider application of the AE technique is associated with detectability of low amplitude signals hidden on a background of laboratory or industrial noise. A recently proposed continuous threshold-less mode of AE data acquisition offers an advantage in analyzing AE random time series on different time scales, thus providing information otherwise inaccessible by a conventional threshold-based acquisition mode. The evaluation criteria concerning the activity of internal defects depend strongly on the AE detectability in the selected time interval. In the present work we compare performance of two signal detection algorithms: conventional amplitude threshold discrimination and innovative «phase picker» based on a wavelet transform. In observing the characteristic accumulation of AE signals over long periods of hundreds time and opposite in a single loading cycle can provide a difference at signal estimation.

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Keywords: *acoustic emission; spectral analysis; fatigue; welded joints; wavelet analysis; signals detection;*

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1. Introduction

Continuous integrity monitoring of dynamically loaded infrastructure and industrial facilities is of vital importance for their safe operation. A broad variety of methods has been developed in Non-Destructive Testing (NDT) practice for diagnostics of defects emerging in structural materials during exploitation of industrial facilities. These inluce, but not limited to, visual inspection (VT), radiographic testing (RT), penetrant testing (PT), ultrasonic testing (UT), vibro-acoustic testing (VA), acoustic emission testing (AET) etc. However very few of them can be used for on-line monitoring of dynamically loaded unit. VA and AET methods are admittedly the most popular among others for this purpose. The VA technique provides invaluable information for diagnostics of rotating machinery at frequencies over several Herz. The low frequencies are however can be hardly used in VA because of limited sensitivity of piezoelectric transducers in that frequency range. On the other hand, the AET technique does not have such limitations. Although the acoustic emission (AE) signal itself is a high frequency transient by origin, the periodicity of operating (generating) sources can be arbitrarily low. Fatigue is the phenomenon of materials degradation under cyclic load, which is the root cause of a vast majority of technological failures and manmade catastrophes nowadays. Fatigue cracks initiate and propagate inside material under cyclic loading and/or vibration. The behavior of fatigue cracks has well distinguish stages: (1) nucleation; (2) stable growth and (3) unstable propagation and failure [1]. The fact, which makes it extremely challenging to identify a growing fatigue crack, is a small increment of the crack length per loading cycle. The problem is particularly acquit in ductile structural materials, where fatigue crack behavior is dominated by plastic deformation ahead of its tip. The available NDT methods often cease to detect early stages of crack initiation and stable crack propagation even in static conditions. It is virtually impossible to use a vast majority of the NDT techniques for running industrial equipment. The acoustic emission (AE) technique is unique in this respect as its permits the remote access to the information regarding dynamically developing defects in solids under load. AE reflects local structural transformation caused by stress relaxations in solids and the AE response is directly related to the size and velocity of the emitting defect, e.g. crack [2]. However, the above mentioned issues arising from the small size of the fatigue crack nuclei and slow speed of their propagation extend to the AE method since the signals generated by such cracks are of low amplitude and are hard to detect on a background of the surrounding electric and mechanical noise [3,4]. The conventionally used signal detection schemes based on the amplitude threshold crossing by well separated AE transients experiences substantial difficulties in this case. Thus, the consensus exists that the most difficult task for the on-line diagnostics is the identification of early fatigue cracks in ductile structural steels and alloys. Aiming at addressing this challenging problem, we propose a novel approach for AET, which is based on the threshold-less mode of data acquisition followed by detection of low level individual AE signals corresponding to accumulating fatigue damage in every deformation cycle. This offers new possibilities to investigate fine details of AE waveforms which are not accessible in “classic” amplitude threshold based AE signal detection schemes. This allowed us to increase significantly the sensitivity of the AE technique to small fatigue cracks.

The use of commercial AE diagnostic equipment and software, is restricted nowadays by standards and regulations formulated in early 70s of the past century. According to these standard requirements, any AE device must provide an amplitude resolution threshold 1dB and the count rate of AE signals should be not less than one thousand counts per second per channel [5]. Commonly, the AE equipment fails to meet these requirements in actual situations when the system tuning requires numerous hardware and software settings including (but not limited to) sampling rate, the frame size, peak definition time, hit definition time, hit lockout time, etc., depending on the manufacturer. Real recording systems have typically a limit of less 2000 signals per second. That means that the system receives not more than 200 signals per loading period if a 10 Hz frequency fatigue load is applied. In actual situation, the acquisition rate is even less being close to of 15 - 20 signals per period due to the equipment "dead time" and artificial presets, which cannot be optimized and adaptively tuned since they are not data drive. This fact sets a challenge to an operator to make a justified decision about the material state. The differences in the signal detection algorithms implemented by different makers are minute and therefore the performance of different AE systems is similar and is unsatisfactory to practitioners when low-amplitude signals are of concern. Particularly, the use of commercial equipment is difficult for fatigue tests which are often performed and 10-20 Hz frequency.

Facing this apparent difficulty when testing cyclically the popular structural steels, particularly those weakened by welding joints has prompted us to revisit the classic topic of AE signal detection with a new idea based