Proceedings of 15th World Conference on Non-Destructive Testing, Roma, 15-21 October 2000, Paper IDN_553

ACOUSTIC EMISSION MONITORING FROM WIND TURBINE BLADES UNDERGOING STATIC AND FATIGUE TESTING

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ABSTRACT

The ever increasing size (and hence cost) of wind turbine blades and the desire of developers to start siting their machines offshore place an ever higher premium on the need for effective condition monitoring of the blades. A current EC-funded research project is looking at the possibility of using acoustic emission (AE) monitoring for proof-testing of glass-polyester and glass-epoxy blades. Results are presented from three static blade tests and one dynamic fatigue test conducted to failure in the laboratory. The test methodology is presented and discussed in the context of the blade certification procedure followed by the manufacturers. In order to be acceptable, the test procedure must enable maximum benefit to be gained from the AE readings, but at the same time not inflict additional damage to the blade to that which occurs during the normal certification test. Results using zonal and linear location techniques are presented progressively through the tests until the final failure of the blades. The location of the failure is clearly indicated by the AE emissions during the later static load steps and fatigue cycles.

1 INTRODUCTION

Operational wind turbine blades see a complex, stochastic load distribution. This load history must be represented as well as possible in certification tests. Also, as blades get larger and turbines are sited in more inaccessible places, particularly offshore, there is an increasing premium for effective condition monitoring.

Static and fatigue tests are routinely conducted as part of the certification process for wind turbine blades. These tests are designed to ensure that all parts of the blade can withstand extreme load cases as defined in the wind turbine design and testing standards [1,2]. It is usual practice to conduct one or more static tests up to an extreme load value, which typically may represent the 1 in 50 years gust, and then to use the same blade for an accelerated 20 years fatigue lifetime test. It is common for there to be sudden, audible acoustic emission during the static phase of the test, but without proper equipment it is impossible to locate the source. It is clearly important to discover the location and severity of any damage which occurs during the static test in order to be able to improve blade design and also to monitor such areas during the ensuing fatigue test.

The blades for the tests described in this paper were designed for the project and comprise an outer, load-bearing skin with a pair of internal shear webs.

2 STATIC STRENGTH BLADE TEST

2.1 Test procedure

Initially, two blades were tested under static load conditions using a load profile common for AE tests (see, for example, FRP fan blades [3]). The sequence was based around two characteristic load levels: the nominal operating load (OL) and the maximum test load (MTL). Normally, the blade should not undergo critical damage when loaded up to OL and so multiple tests can be performed at this

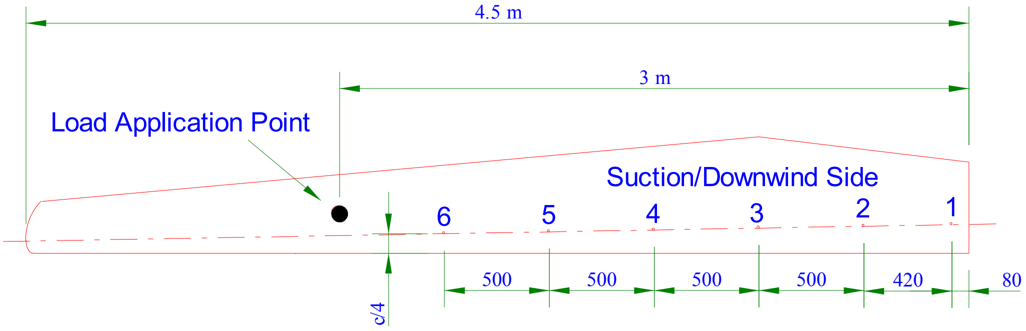


Figure 1: AE sensor and load application points along blade quarter chord line for static and fatigue tests

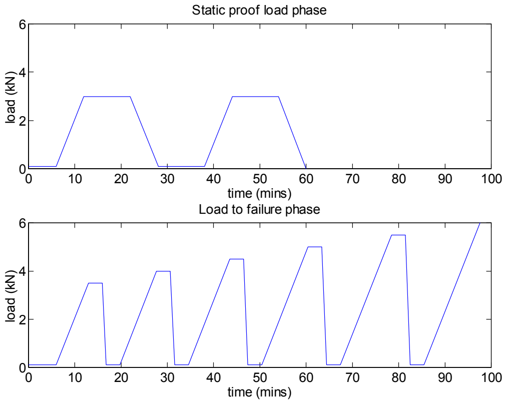


Figure 2 : Load profile for static AE strength test

level before the final strength test. However, it is known that composite structures emit when they are first loaded to a given level, so it is necessary to repeat the initial application of the OL. During this second loading, it is expected that there will be no AE if no damage is propagated. In common with many standardised AE tests it was desired to have load-holds of up to 10 minutes duration in order to establish stability criteria. Following the two load-holds at OL the load was increased by successive increments, each with a three minute load hold, until the blade failed. For the second blade the load was removed between increments.

The load application point and the sensor locations for the tests discussed herein are shown in figure 1. The blade is 4.5 m long and is attached to a reaction frame at the root. The complete load envelope to failure at 5.9 kN is presented in figure 2.

2.2 Results

The results showing AE events v. time for each channel are presented in figure 3. The applied load is superimposed on the figure in green. The blade was loaded up to a final peak of 5.9 kN, at which point it failed catastrophically due to a buckling instability which initiated at a point 2.4 m from the blade root (between sensors 5 and 6).

At the third load peak (4.5 kN) all the signals are seen to stabilise during the load-hold period, as witnessed by the convex curvature of the events v. time graph for all channels. During the fourth load peak (5.0 kN), the trace for sensor 5 (and to a lesser extent sensor 4) already exhibits a different curvature and does not properly stabilise during the hold period. At the fifth load peak (5.5 kN), there is a steep rise in the number of events recorded at sensor 5 and sensors 4 to 6 are all still strongly emitting at the end of the load-hold period. The shape of the signal from channel 5, in particular, suggests that the blade damage has reached a critical level.

Information about the type of damage taking place can be obtained from the amplitude of the AE signals. The amplitude distribution indicates a concentration of high amplitude events, usually associated with fibre breakage, at sensor 4 during the load-hold at 5.0 kN and at sensors 4 and 6 during the load-hold at 5.5 kN. During final failure practically all the high amplitude events are concentrated close to sensor 6. A remarkably similar distribution was obtained from both blade tests with this load profile.

3 STATIC CERTIFICATION BLADE TEST

3.1 Test procedure

As discussed in section 1, the MTL for the blade under consideration is estimated based on a single event, namely the 1 in 50 years gust. This event is generally modelled as a rapid load "spike" with a duration of no more than 10 seconds. Pass/fail certification criteria are based on the blade successfully surviving this load. Load-holds of up to 3 minutes at sizeable fractions of the MTL were not acceptable to the blade manufacturers since these were perceived to be unrealistic loads that would

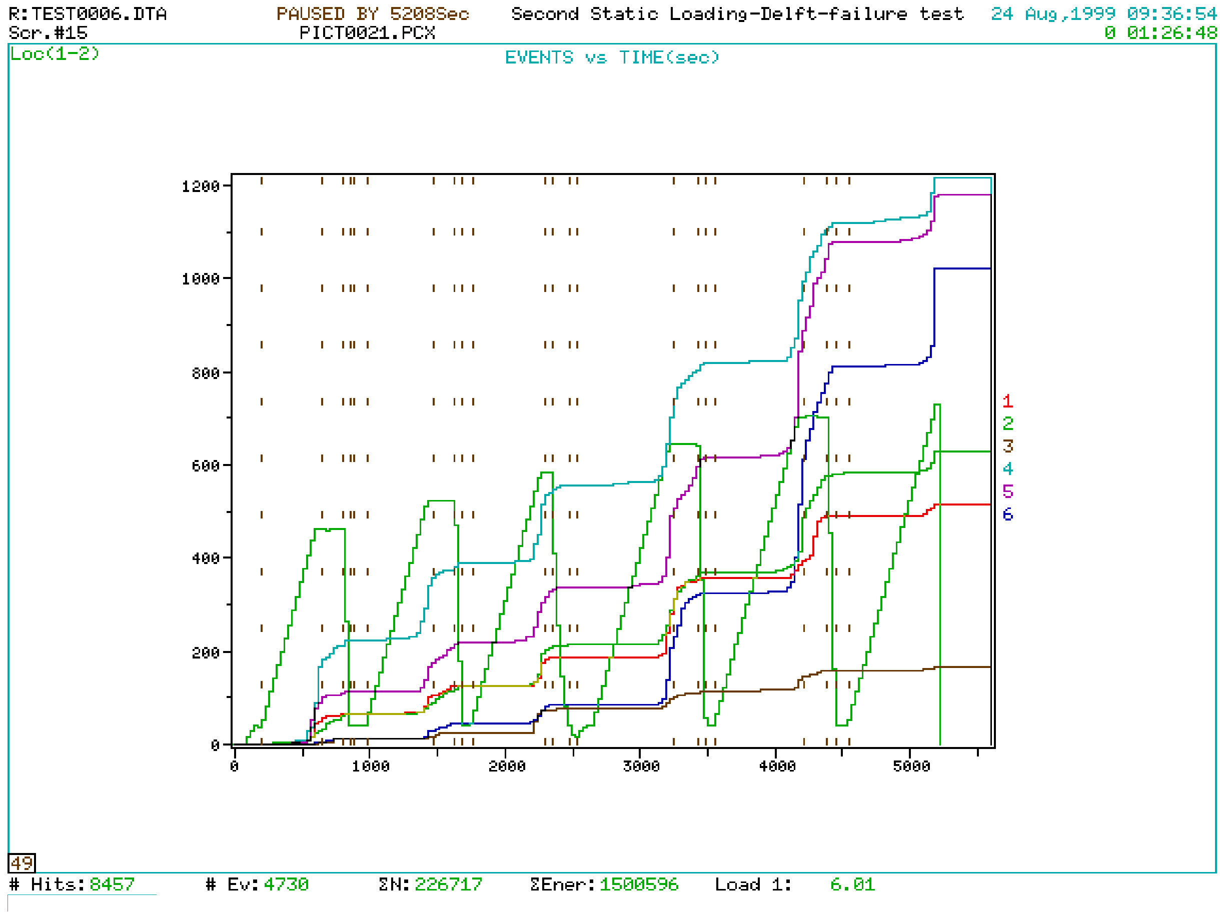


Figure 3 : Static blade test 2 - AE events v. time for each sensor channel (test load superimposed in green)

not be seen in service and which might cause premature failure during the certification test.

It was necessary therefore to develop a load profile which incorporated the standard certification loading and to base the AE evaluation criteria on such tests. At the same time, it was recognised that the certification loading was designed to mimic the extreme load the blade might experience in service and it was necessary to be able to determine after the event whether such a loading had caused damage within the blade. Thus, it was specified that a sequence of so-called examination loadings (AEL) should be applied to the blade after the MTL to determine the minimum load level at which AE could be detected. The resulting load profile is shown in figure 4 and was applied to a third test blade. To avoid initiating the same buckling failure mode, the load on this third blade was applied just 2m from the blade root. Final failure was again from buckling around the saddle point.

3.2 Results

Since the load history effectively combines two different test strategies, the data was first divided into two sections, which were analysed separately. Results are presented here from the sequence of standard (increasing) MTL tests only. Analysis is still continuing on data from the intermediate AEL loading.

A graph showing the distribution of linearly located events along the blade v. time from the sequence of MTL loads is presented in figure 5. This shows a progression of event clusters starting from the root and moving outwards to the loading saddle as the test progressed. Arbitrary placement location was used to identify particular clusters of activity in 2-D space and identified notable concentrations around the inner end of the shear web and the maximum chord area of the blade. However, without longer load-hold periods it is not possible to make any judgement about the criticality of damage at any stage during the test. This task is made more difficult by the nature of the final failure - buckling instability - which may well not have been preceded by significant material failure.

It is hoped that future tests on blades which have been designed to avoid the buckling instability will give clearer results in this respect.

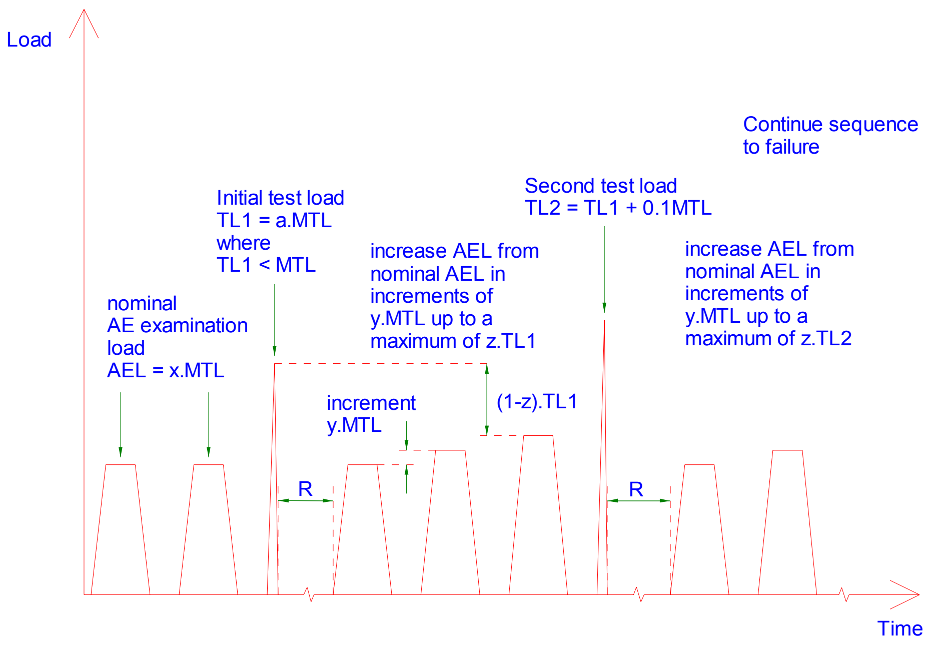
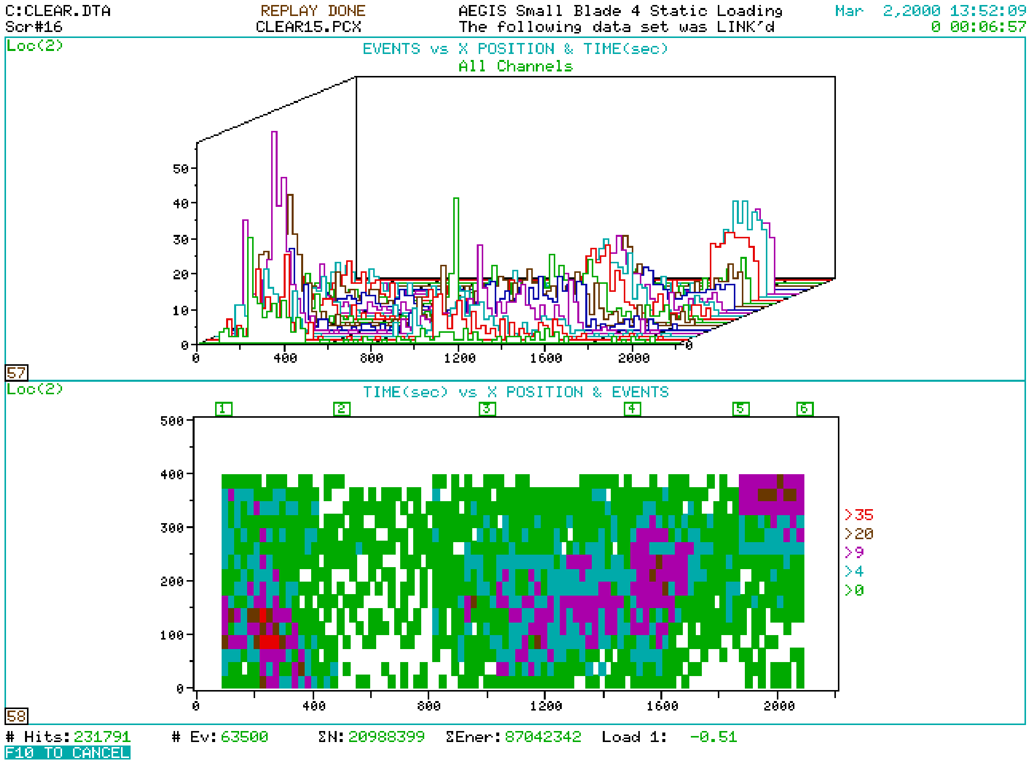


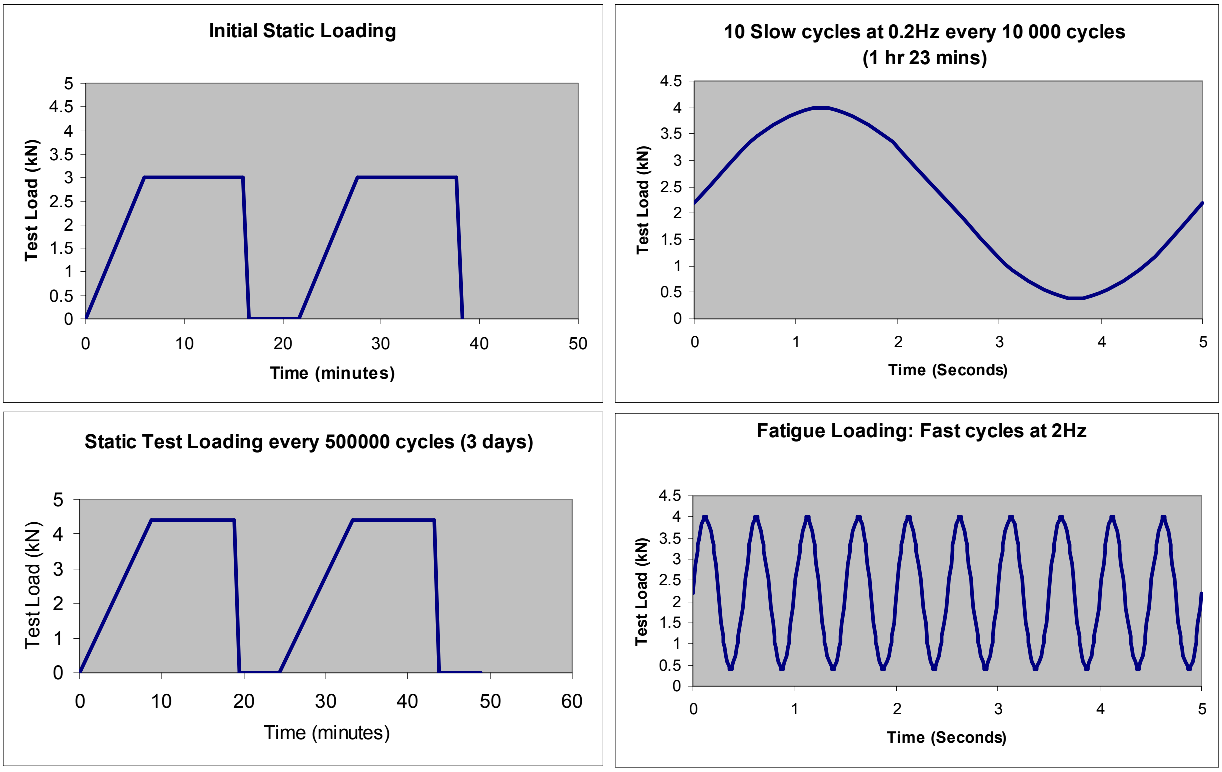
Figure 4 : Static load profile for blade certification test with AE monitoring



```
C:CLEAR.DTA          REPLAY DONE       AEGIS Small Blade 4 Static Loading      Mar  2,2000 13:52:09
Scr#16               CLEAR15.PCX       The following data set was LINK'd                0 00:06:57
```

```
# Hits:231791     # Ev:63500     ΣN:20988399   ΣEner:87042342   Load 1:   -0.51
F10 TO CANCEL
```

Figure 5: Static certification blade test - linear location of events v. x-position v. time


Initial Static Loading

10 Slow cycles at 0.2Hz every 10 000 cycles (1 hr 23 mins)

Static Test Loading every 500000 cycles (3 days)

Fatigue Loading: Fast cycles at 2Hz

Figure 6: Fatigue loading

4 FATIGUE TEST PROCEDURE

4.1 Test procedure

For a long test (the fatigue test was expected to take about 2 months) the quantity of non-critical AE data becomes the main problem. To keep the data to a manageable amount, only time driven data (i.e. parametrics, number of cycles, average AE signal level, absolute energy) was continuously recorded, then for 10 slow cycles every 10000 cycles the recording of hits was initiated. The sensor positions remain the same as for the static test and the threshold is set higher at 55 dB. In all, the fatigue test consisted of four load stages (see figure 6):

I : initial static loading to OL (AE hits data recorded).

II : static test loading at start and after every 500000 cycles to 10% above the peak fatigue load (AE hits data recorded).

III : fast cycles at 2 Hz sinusoidal fatigue load (R-ratio = 0.1) to the peak fatigue load (parametrics only - no AE hits data).

IV : after every 10000 cycles, the load application rate is reduced to give ten slower cycles at 0.2 Hz and during this interval the load-strain characteristic and the AE activity is monitored.

4.2 Results

Due to the limitation on overall load that could be applied due to the likelihood of causing the static buckling instability it proved quite difficult to achieve a fatigue failure of the blade. Several load increases were applied to the blade in tension-tension loading, but then, as very little appeared to be happening, it was decided to extend the loading into the compression regime. The final breakage of the blade occurred soon after the change of loading but was not recorded by AE because it occurred between two low speed cycles.

A 2-parameter filter was designed and applied to all the data files from the low speed cycles. This filter is designed to separate out events due to fibre breakage or propagating damage in the blade. It accepts only events with amplitude greater than 70 dB and counts less than 100. (A second filter that has been devised to detect signals due to impending buckling failure will also be applied to the data.)

The combined results from the data collection during all the low speed cycles are presented in figure 7. The graph shows the energy (red high) v. x-position progressively through the test. The scale maximum is indicated on the right hand side since auto-scaling within the software has resulted in a change of scale for some of the later tests. It is

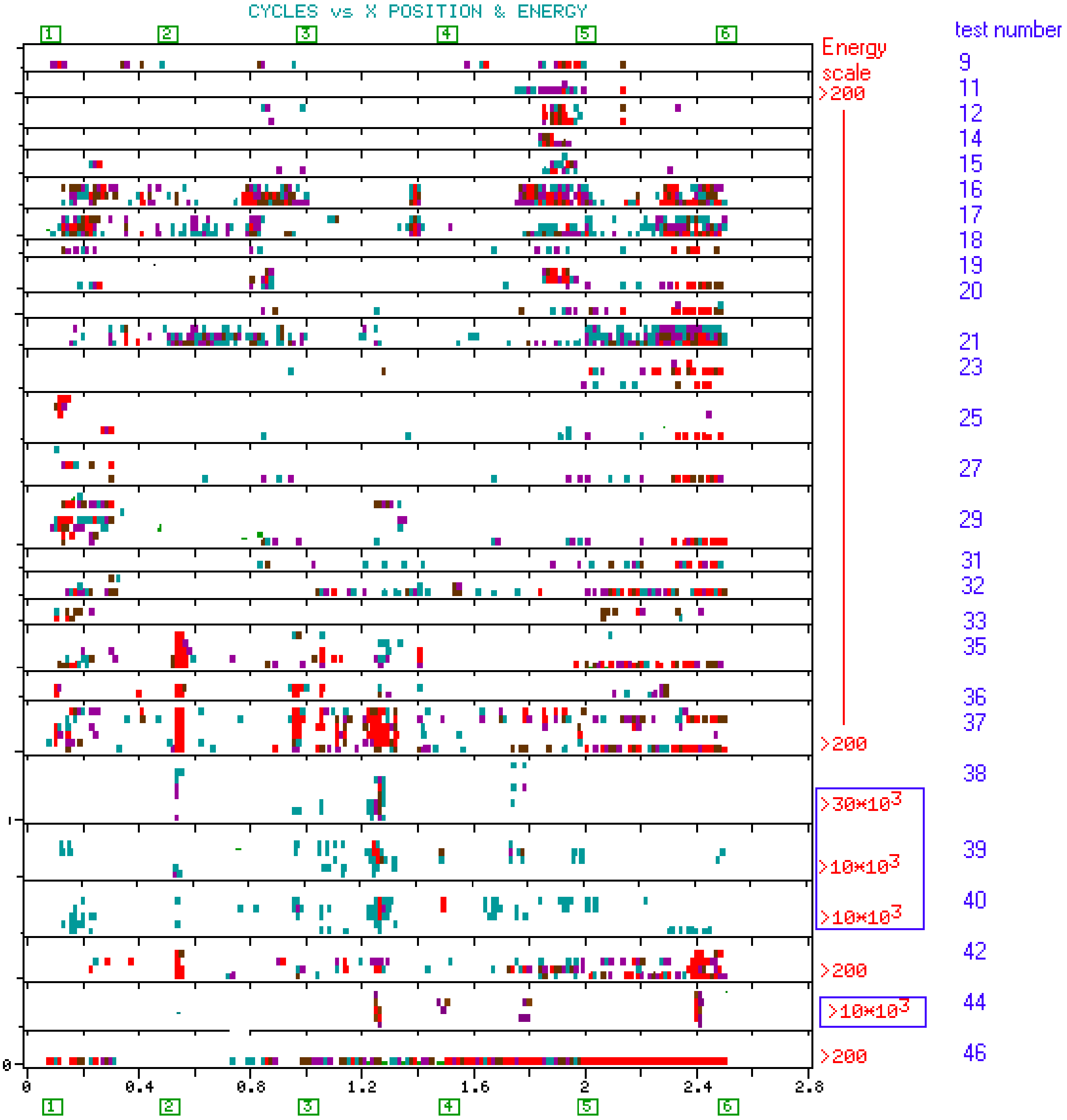


Figure 7: Fatigue test loading - plot of combined slow cycle loads showing energy v. x-position v. test number

interesting that initially there are two concentrations of activity, one in the blade root and at the start of the shear web located 0.8m along the blade (sensors 1-3) and the other between sensors 5 and 6 where the buckling instability set in to cause final failure of the blade. In the intermediate part of the test there is a relatively quiet period (test numbers 23-32), followed by another burst of activity at the root and now slightly outboard from the end of the shear web. Following the introduction of load reversal at test number 45, a wide spread of high energy signals were recorded between sensors 4 to 6, immediately prior to blade failure, which initiated in this area.

5 DISCUSSION

The work reported here has sought to combine classical AE testing and analysis methodologies with the requirements of wind turbine blade certification testing. Although the AE data and analysis was able to correctly identify critical damage prior to the onset of the buckling stability in the static strength blade tests 1 and 2, this occurred at unrealistically high load levels. Using a loading more representative of the gust loading a blade might be expected to experience in the field, significant AE activity was obtained, confirming the potential to locate damage and make a preliminary assessment of damage type. However, the loading is such that the ability to determine damage criticality appears to have been lost and work is continuing to identify the lowest loads at which this can be achieved.

The fatigue test has indicated that collecting data during periodic high load cycles can, with suitable filtering, indicate where potential damage sites are located. This finding will be verified using other inspection techniques during later tests.

The results to date are very promising, but it is recognised that new criteria and analysis methods need to be developed in order to be able to determine criticality.

6 CONCLUSIONS

Acoustic emission monitoring during static and fatigue wind turbine blade certification tests can give information about the location and type of damage events. The test differs markedly from conventional applications of AE and so it is difficult at present to make judgement over damage criticality from these tests. Damage criticality can be determined from the emission level during relatively long duration load-hold periods during an ultimate strength test, but such a loading is unrepresentative of blade loads in the field. Work is continuing to establish the lowest level of AE examination load at which significant emission can be expected in a seriously damaged blade.

7 REFERENCES

[1] IEC 61400-1, *Wind turbine generator systems - part 1: safety requirements*, 1998
[2] IEC 61400-23 TS Ed.1: *Wind turbine generator systems - part 23: Full scale structural testing of rotor blades for WTGS's*, draft 1999
[3] ASTM E07.04.03-98/1 draft standard, FRP pressure vessels per ASME Code Section V, Art. 11

ACKNOWLEDGEMENTS

This research was supported by the EC Non-nuclear energy programme under contract number JOR3-CT98-0283.