

Acoustic Emission Monitoring of Field Tests of an operating Wind Turbine

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Abstract

Acoustic Emission (AE) testing procedures developed during a laboratory blade testing programme have been applied to an in-service wind turbine blade. AE monitoring can both locate and characterise damage processes in blades, starting with non-audible signals occurring due to damage propagation at relatively low loads. The results of this assessment of the potential of blade in-service monitoring are sufficiently encouraging to justify further development.

Introduction

Wind turbines now have diameters in excess of 110 m and are being located out at sea. Both their increased power production and their inaccessibility drive the need to monitor their blade's condition. This paper examines whether AE monitoring can achieve this. The application of an Acoustic Emission Examination Load (AEL) test to a stationary in-service blade is presented followed by the more difficult collection of AE data while the turbine is operating. All tests were conducted on LM 8.5m blades fitted on the Windharvester wind turbine at RAL. As far as possible, the tests were conducted in compliance with static and fatigue guidelines specified for laboratory testing [1, 2]. A Physical Acoustics Corporation MISTRAS system with R6I sensors was used.

AE Monitoring Laboratory Blade Test Procedures

The concept of an AE examination load (AEL) has been developed. It comprises a trapezium-shaped load envelope with a 10 minute load-hold period to evaluate the damage imposed on the blade and its capability to withstand a particular load level for long term operation. The AEL test can be applied equally well to a new, previously unloaded blade, a blade undergoing static certification testing (before and after the test), a blade undergoing fatigue testing (before, at intervals during, and/or after the fatigue test), and an in-service blade on a wind turbine as reported here.

The first AEL test applied to a blade should be repeated since a high level of emission can be expected when a composite structure is initially loaded to a given level. Emission from subsequent applications of the same AEL will then yield information on the true condition of the blade.

The appropriate load value to be used for an AEL test depends on the goal of the test, as defined by the owner in consultation with the designer of the blade. From the acoustic emission practitioner's point of view the AEL should be at least 5% higher than the maximum continuous load that the blade will see in service, but it is recognized that this will normally be too severe for a wind turbine application. It is suggested that the AEL should correspond to the maximum design load of the normal operating load cases without fault situations (i.e. Design Load Case 1.2 as described in [3]), but, in any case, should not exceed 65% of the expected 50 year gust load. It is likely that the value will be site-specific, depending on the local wind regime that the blade must withstand. For a field test, where it is essential not to impose any damage on an otherwise sound blade as a consequence of the AE loading, it may be appropriate to apply the load-holds at progressively increasing load values, performing an intermediate evaluation prior to each increase in load, in order to be able to stop the test following any significant indications of load criticality.

The AEGIS Pattern Recognition software [4, 5, 6] was developed to assess a blade's condition during the AEL test and hence grade the its condition. This software was also used to assess the AE monitored during dynamic load events (e.g. the 50 year gust loading, or during dynamic operation).

Adapting Laboratory Test Procedures to a Stationary In-Service Blade

It was considered that a "load and hold" test similar to the AEL test incorporated in the laboratory AE test procedure could be applied to the testing of a blade mounted on a wind turbine. If this was to be adopted as a regular maintenance procedure then the loading mechanism would need to be specifically designed into the blades and tower. For the purposes of this demonstration, however, the load was applied using a system of ropes and pulleys slung from the tower and connected to a rubber-lined, airfoil-shaped saddle that mated with the blade.

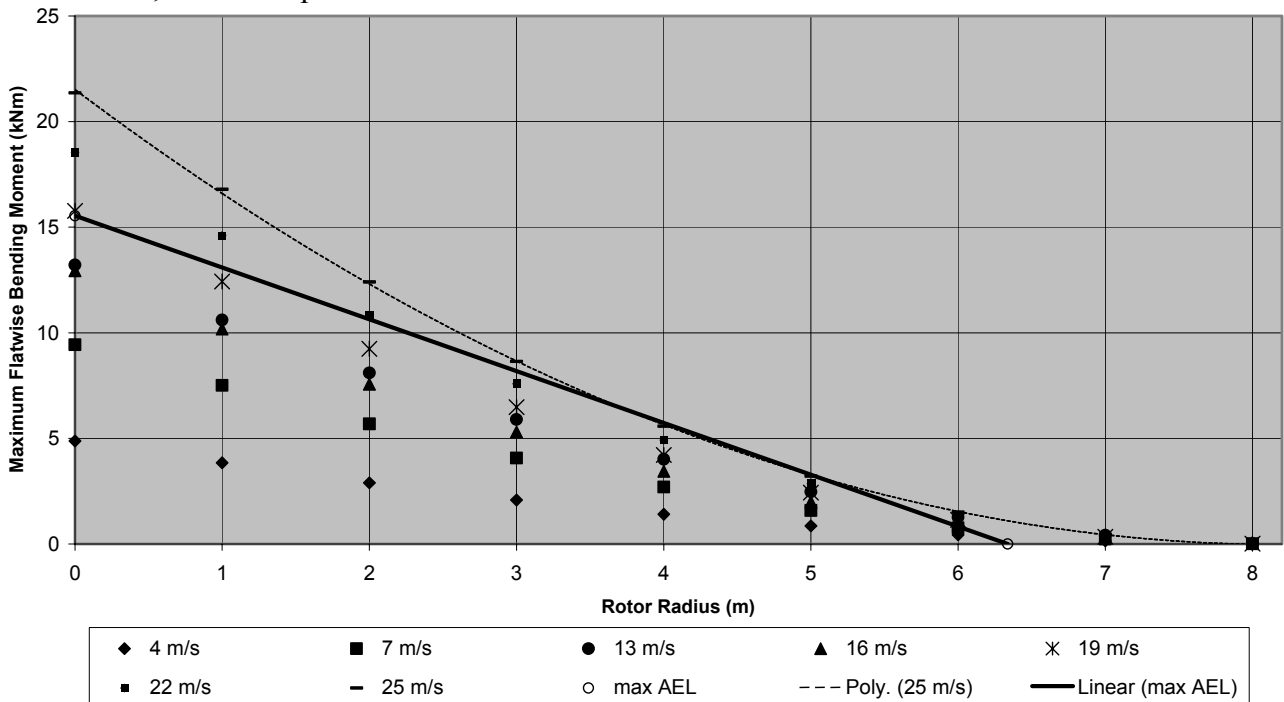


Figure 1: Maximum flapwise bending moments calculated for selected radii at different wind speeds with the bending moments from the 2450 N field test AEL as the solid line.

Ideally, the applied load should slightly exceed the maximum service load experienced in the regions of the blade which it is desired to test (likely to be the blade root and other critically loaded areas); at the same time, the load should not result in overloading of any other part of the structure (e.g. shear loading of the blade section at the load application point, bending loading rootwise of the load application point or excess load on the tower structure). In this case, the blade shear load effectively limited the maximum blade root bending moment achievable. The calculated flapwise bending moment at different blade sections are shown in Figure 1. From the assumption that no part of the blade should exceed the calculated bending moment at peak loading (25 m/s wind speed) it can be seen that applying the 2.45 kN AEL at 6.3 m only tests the blade properly between 3.5 m and 5.5 m, the root section being less fully tested (maximum root bending moment of 15 kNm, compared to the expected 21.5 kNm peak loading). Wider coverage would require a second load application point.

The sensor lay-out used is presented in Figure 2. The maximum load applied was 2.45 kN @ 6.30 m radius which was reached after three intermediate steps of 1.68, 1.95 and 2.2 kN. The loading rate was approximately 1 kN/minute and each load step was held for a nominal 10 minutes and then released and the blade allowed to relax. Figure 3 a) & b) are photographs of the test arrangement.

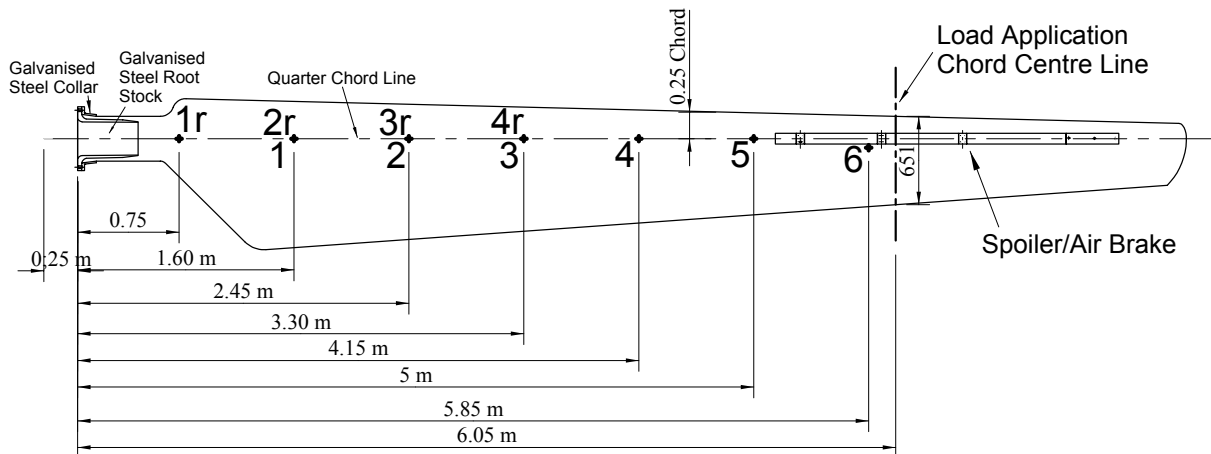


Figure 2: AEGIS blade field tests sensors (r = running test) and load application location

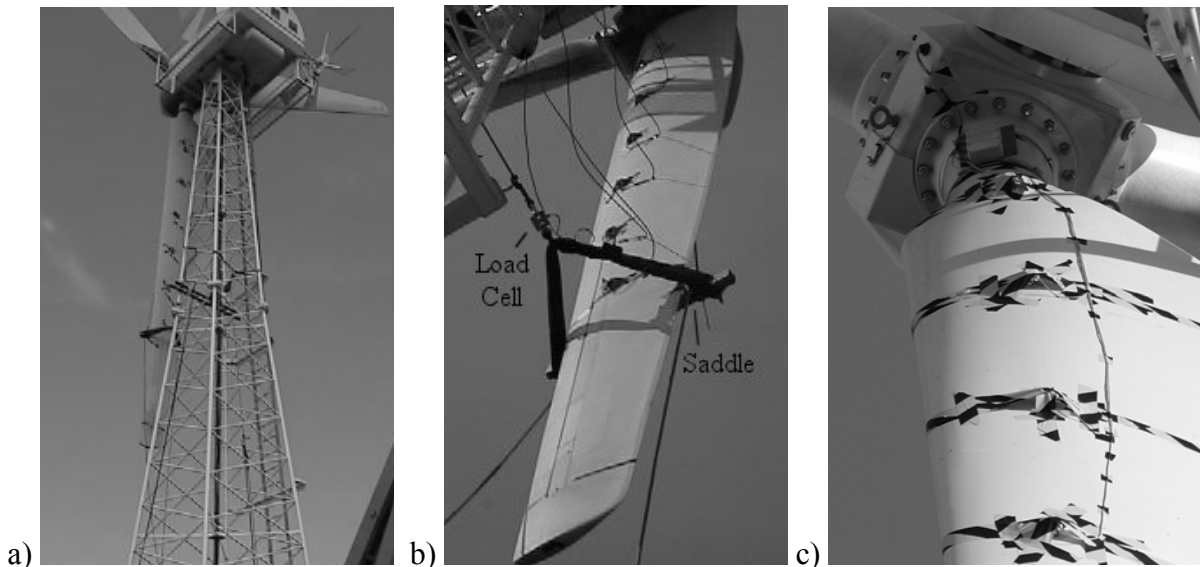


Figure 3: AE Sensors on the Windharvester wind turbine at RAL for stationary tests with load cell and loading gear a) & b), and operating tests with root mounted the radio transmitters c)

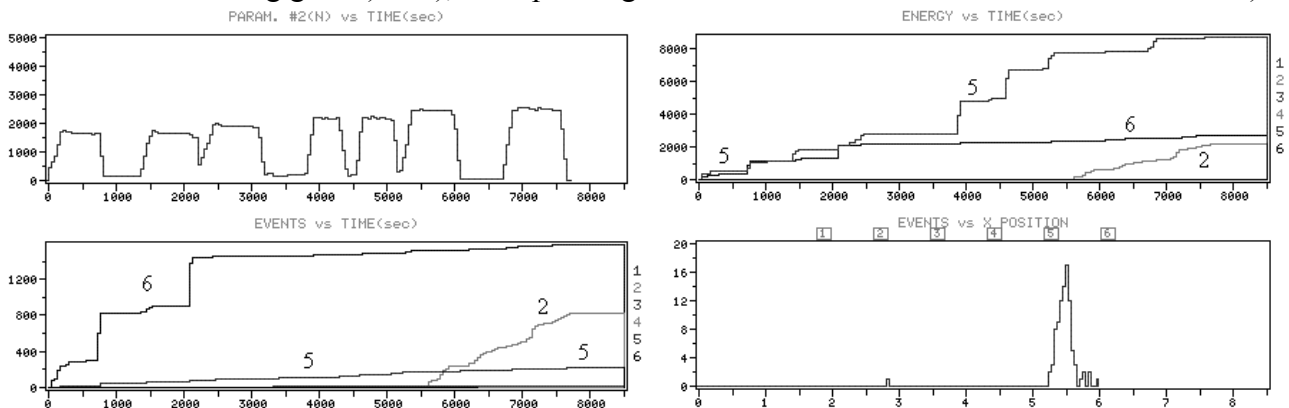


Figure 4: Blade AEL tests showing load profile, events and energy with time and linear location.

Figure 4 shows the overall load envelope and the resulting Hits profile per channel, with associated Energy and Amplitude. The burst of emission at the end of the first load-hold (1.68 kN) is due to the release of the ratchet loading mechanism, which was not used in subsequent tests. In the first load-hold, the majority of activity occurs at channels 5 and 6 (at least in part due to “noise” from the loading mechanism). The AEL tests at 1.95 kN and 2.2 kN are very quiet, but, at the start of the final pair of load-holds, channel 2 starts to emit, apparently independent of load. This activity at

channel 2 is also not located by the location algorithm (i.e. it does not register as a Hit at another sensor). However, close examination of the data did not justify dismissing it as noise. It is possible that this signal was connected with damage existing (but, at the time, unknown) in the wind turbine's main shaft, which failed some months after the test. Unfortunately, sensor 1, which might have been expected to register a signal from the shaft as well, was a less sensitive type of sensor.

Apart from a single event located at 2.8 m, the only AE activity located by the linear location algorithm (Figure 4) was centred on 5.5 m, which is just inboard of the blade's spoiler casing at the first screw joint. A steel-GRP interface of this kind is often the source of AE. The distribution shown in the Counts-Amplitude characteristic (Figure 7a) is typical of AE from GRP materials.

Real-Time Monitoring of a Rotating In-Service Blade

The real-time data monitoring was carried out using a radio telemetry system developed in-house at RAL (Figure 5). Each of the four transmitter/receiver pairs was engineered to have zero gain so that the MISTRAS system would record the signal at the same level as if were directly connected to a sensor. A drawback of the current system is that a break of the radio telemetry link is interpreted as a genuine signal by the MISTRAS system, even on occasions resulting in located "damage". Fortunately these spurious signals generally have very high Counts (above 1×10^4) and can clearly be separated out in the Amplitude-Counts characteristic. Several manufacturers and research organisations have expressed an interest in obtaining similar systems from RAL.

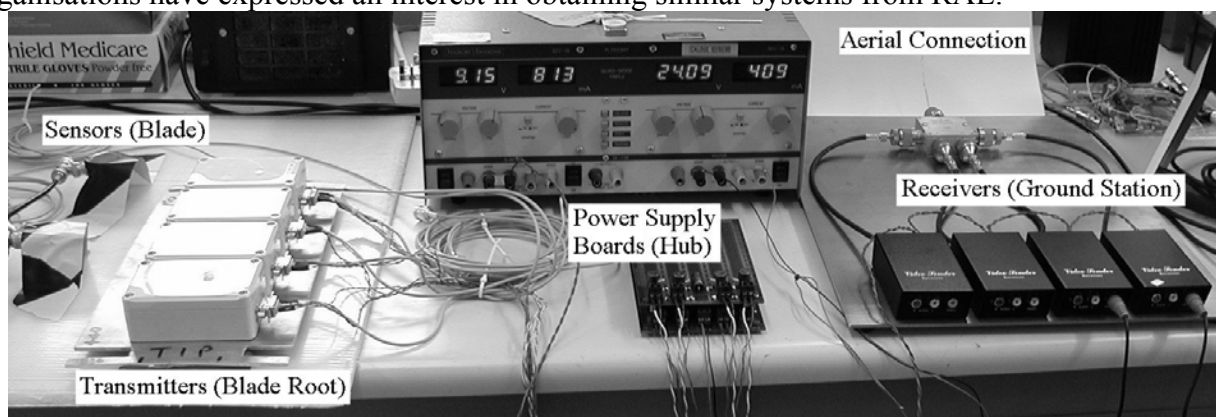


Figure 5: Bench testing of AEGIS RT system - basic components

On the turbine, power was supplied to the sensors via a slip-ring arrangement on the main shaft and the radio transmitters were attached to a fixture at the blade root. The four sensors were mounted spanwise along the blade between 750 mm and 3300 mm from the blade root (see 'r' sensor positions in Figure 2). The mounting of the high profile (28 mm diameter x 39 mm tall) sensors on the external surface of the blade was problematic since the tape used to fully secure the glued on sensors could have fretted or vibrated during the operation of the turbine, thereby giving rise to spurious signals, and there was some evidence of this in the collected data. The ultimate application of the technique would require low profile, low mass sensors, preferably mounted on the inside of the blade or even integrated into its structure during manufacture. Any sensor integration in to the structure would need to ensure that no stress raisers are formed.

Figure 3c shows the sensors and transmitters mounted on the blade. Data was collected for the parked, start-up, synchronised, and shut down operating modes. Figure 6 shows 135 minutes of data collected whilst the turbine was synchronised and operating in wind speeds above 9 m/s. The measurements for sensors 1 to 3 show remarkably consistent low Amplitude data. Sensor 4 appears to have detected some high Amplitude hits, although the periods of abruptly reduced signal level suggest that some of this might be an artefact caused by fretting of the tape or aerodynamic noise.

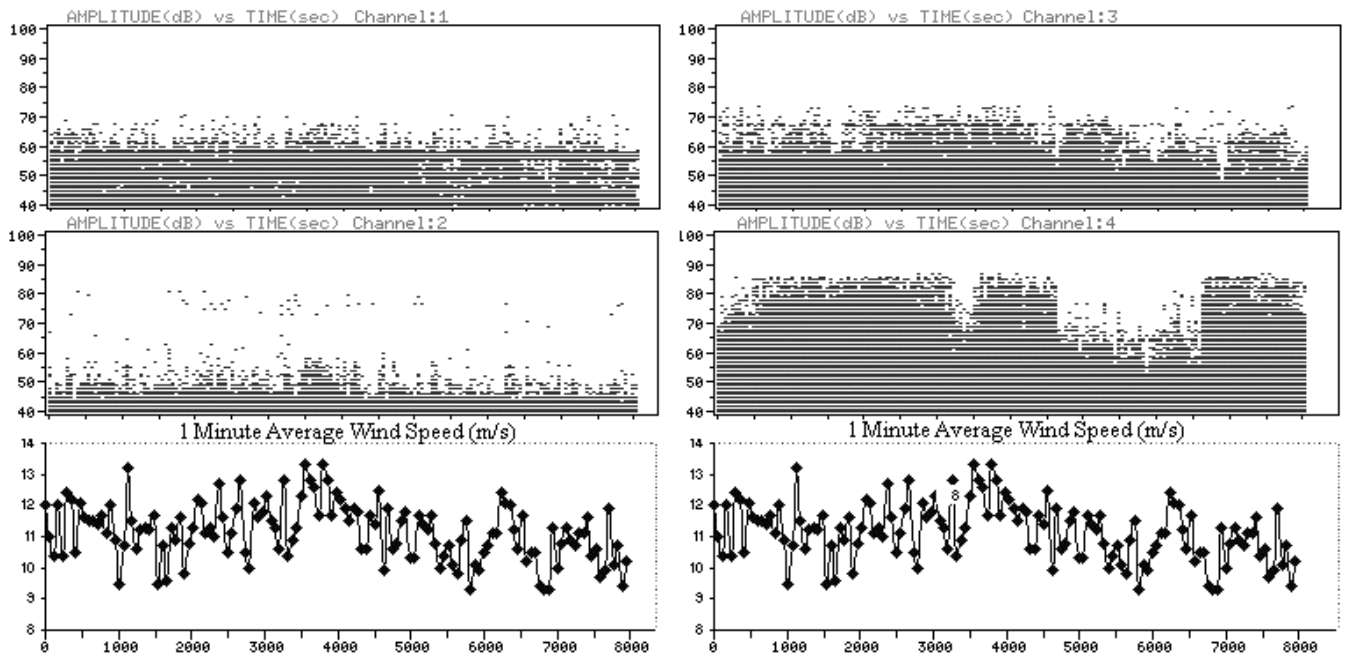


Figure 6: Amplitude (by channel) v time and 1-minute average wind speed during synchronised operation of the Windharvester wind turbine (39 r/min)

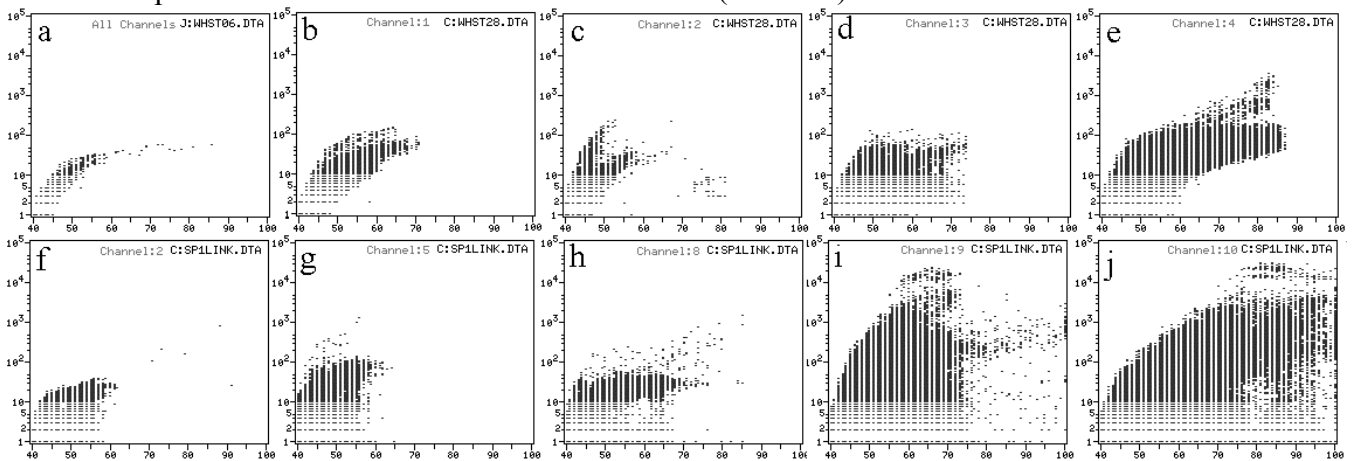


Figure 7: Comparison of Counts v Amplitude characteristic from AEL test on the stationary blade (all channels) a), during real-time operation for 135 minutes channels 1 to 4 b) to e), and from a laboratory fatigue test to failure of a similar blade channels 2, 5, 8 to 10 f) to j).

Comparison of Stationary, Operating, and Blade Failure Data

The relative severity of the stationary and real-time operating loads is well captured by comparing their Counts v Amplitude plots with the equivalent characteristic from a laboratory fatigue test on a similar blade (Figure 7). Assuming that both field-operating blades were undamaged, it must be concluded that the static test (Figure 7a) represented a relatively moderate loading, emphasising the difficulty of performing such a single point test at sufficiently high load for the test to be meaningful. The higher level of activity (on a hopefully healthy blade) during the real-time test at moderate wind speed (Figure 7e) gives some cause for concern, but the Amplitude/Counts envelope does not have as much spread as the highly damaged laboratory tested blade (Figure 7i & j).

Conclusions

A static “load and hold” Acoustic Emission Examination Load (AEL) test has been demonstrated in principle for a wind turbine blade mounted on a wind turbine, using a pulley mechanism to load the blade. The retro-fitted loading device was able only to fully test the mid-span of the blade and not

the more critical blade root area. Any widespread application of the technique would require the loading system to be built in to the tower and suitable load application points sited on the blade.

Since comparatively high loads are required to indicate damage criticality and the test is quite complex to perform, it is probable that a test of this kind will not be adopted by the wind turbine manufacturers. However, intermittent monitoring of AE sensors mounted on the blade during periods of high loading is likely to result in a valid “health check” for the blade. This could be conducted with the turbine operating and/or using the loading on the blade in high wind conditions when the turbine has shut down.

The principles of such a real-time system have also been demonstrated on the Windharvester wind turbine at RAL. A broadband radio transmission system was developed to transmit the AE data from the rotating frame to the ground without losing any signal resolution. Minor problems remain to be solved concerned with temporary loss of signal and attachment of sensors. The effectiveness of such a system can probably only be demonstrated by large scale demonstration on many machines (in which case, AE data from “problem” blades would be expected to stand out from their structurally sound neighbours). A demonstration of this kind would require the development of a low cost sensor network for deployment on a blade set, with low cost, on-board processing.

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