

Combination of vibration analysis and Acoustic Emission measurements to better characterize damage and mechanical behaviour of aerospace high speed rolling bearing

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Abstract

Designed to break the paradigm for efficiency, the new generation of engines promises double-digit reductions in fuel burn, as well as an unparalleled single-leap improvement in emissions and lower noise to fulfil societal environmental objectives for a more sustainable future. The end-use consumer and environmental policy requirements for aircrafts of the next generation translate into components with higher temperature and speed. Furthermore, new monitoring technics are needed to closely monitor rolling contact during testing of the next generation of aero engine bearing to check its behavior under the new application condition. Vibration analysis for condition assessment and fault diagnostics is widely used nevertheless interpretation and correlation of collected data is often cumbersome.

That is why combination of vibration analysis and acoustic emission techniques giving different types information in different frequency band can help to understand the behavior of new rolling bearing. This paper presents an experimental testing campaign on bearings with seeded defects. Correlation between low and high frequency signals with different strategy of signal acquisition are presented from signal processing step.

Real time transient analysis with feature extraction was done in parallel with streaming acquisition on both signals. Pattern recognition of individual AE signal is possible and were correlated with more traditional analysis based on signal enveloping vibration analysis. Continuous monitoring on finished duration were done to provide information on no stationary regime and also time of stabilization. Comparison between features extraction is done on damaged and defect free rolling bearing at several rotating speed and loading level.

Keywords: Rolling contact monitoring, vibration monitoring, EHL conditions

1 Introduction

Many studies are dealing about the use of vibration to detect fault in gear box and rolling bearings. Some of them are focusing on the use of Acoustic Emission (AE) and vibration for better characterization of the gear box default type. Based on vibration technology the acquisition of raw signal is done by a partial acquisition of the signal at random. AE technology is more focusing on the detection of transient above a predefined threshold in a narrow bandwidth [1,2]. According the progress of the acquisition system this study proposes a combination of all these types of acquisition with wide band sensors in parallel to offer richer bunch of data that allow us to investigate new method of processing and default characterization. The fault Characterization we propose will be more than a statistic acquisition but a continuous monitoring.

Acoustic emissions (AE) are defined as transient elastic waves generated from a rapid release of strain energy caused by a deformation or damage within or on the surface of a material [4]. This technique is widely used as a non-destructive testing technique for fitness for service evaluation in industrial field. AE is also a powerful tool to characterize and understand damage initiation and propagation. Most of all microscopic mechanisms has been studied and correlated with AE signals as fretting [3]. Many developments in AE technology, mainly developments in AE instrumentation, have occurred in the past ten years.

In this investigation, AE's are defined as the transient elastic waves generated by the interaction of two surfaces in relative motion. The interaction of surface asperities and impingement of the bearing rolling elements over the seeded defect on the outer race will generate AE's. Due to the high frequency content of the AE signatures typical mechanical noise (less than 20kHz) is eliminated.

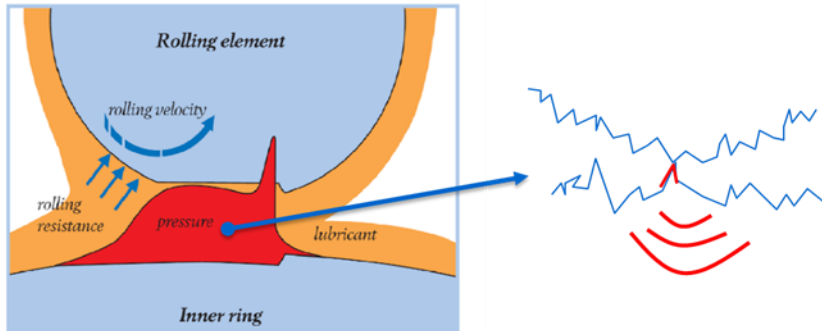


Figure 1. AE signal from asperity in rolling contact

There have been numerous investigations reported on applying AE to bearing defect diagnosis. Roger [5] utilised the AE technique for monitoring slow rotating anti-friction slew bearings on cranes employed for gas production. In addition, successful applications of AE to bearing diagnosis for extremely slow rotational speeds have been reported [6, 7]. Yoshioka and Fujiwara [8, 9] have shown that selected AE parameters identified bearing defects before they appeared in the vibration acceleration range. Hawman et al [10] reinforced Yoshioka's observation and noted that diagnosis of defect bearings was accomplished due to modulation of high frequency AE bursts at the outer race defect frequency. The modulation of AE signatures at bearing defect frequencies has also been observed by other researchers [11, 12, 13]. Morhain et al [14] showed successful application of AE to monitoring split bearings with seeded defects on the inner and outer races.

This paper investigates the relationship between AE signal for a range of defect conditions, offering a more comparative study than is presently available in the public domain. Moreover, comparisons with vibration analysis are presented. The source of AE from seeded defects on bearings, which has not been investigated to date, is presented showing conclusively that the dominant AE source mechanism for defect conditions is asperity contact.

2 Experimental setup

2.1 General

The bearing test rig employed for this study had an operational speed range of 5000 to 15000 rpm with a maximum load capability of 50kN via a hydraulic ram. The test bearing employed was 3 points contact ball bearing. This bearing type was selected as it allowed defects to be seeded onto the races, furthermore, assembly and disassembly of the bearing was accomplished with minimum disruption to the test sequence. Five calibrated dents were done on the bearing inner ring (rotating). Pure axial loading is applied to the rolling bearing. The defects are located along the predicted rolling raceway path inside the hertz contact zone. Dent length against the rolling velocity are around 200 μ m. The acquisition is performed via a multichannel last generation Mistras AE acquisition system: Express 8.

All capability of this system was used to record the maximum of information. First, we use continuous energy summation without threshold is much accurate than traditional RMS or ASL integration. Then, acquisition of transients based on smart threshold allows us to avoid triggering on continuous signal and can guaranty a significant hits rate whatever the level of background continuous is without any manual change all along the monitoring. Transient is characterized by hit and waveform, it can be feed in Noesis our pattern recognition software for multiparametric evaluation. Express offer also the capability to record streaming

(acquisition of raw signal at very rate and with quasi unlimited buffer) to apply more traditional signal processing often use in vibration.

Accelerometer + Enveloping Acoustic emission sensor

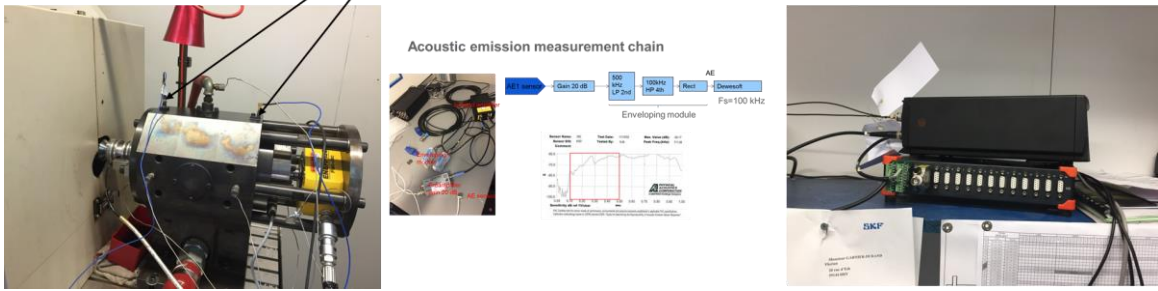


Figure 2 Experimental set-up

In parallel, vibration and AE enveloped signals were acquired on Dewesoft Sirius acquisition station. The next table presents the acquisition characteristics. FFT was computed from the enveloped signal.

Sensor type	Sampling frequency	Enveloped bandwidth
B&K	200 kHz	5-40 kHz
Mistras WD AE sensor	2 gHz	100-500 kHz

Table 1 Acquisition characteristics

2.2 Acoustic emission acquisition setting

Mystras Express8 system also offers the capability to record streaming (acquisition of raw signal at very rate and with quasi unlimited buffer) to apply more traditional signal processing often use in vibration.

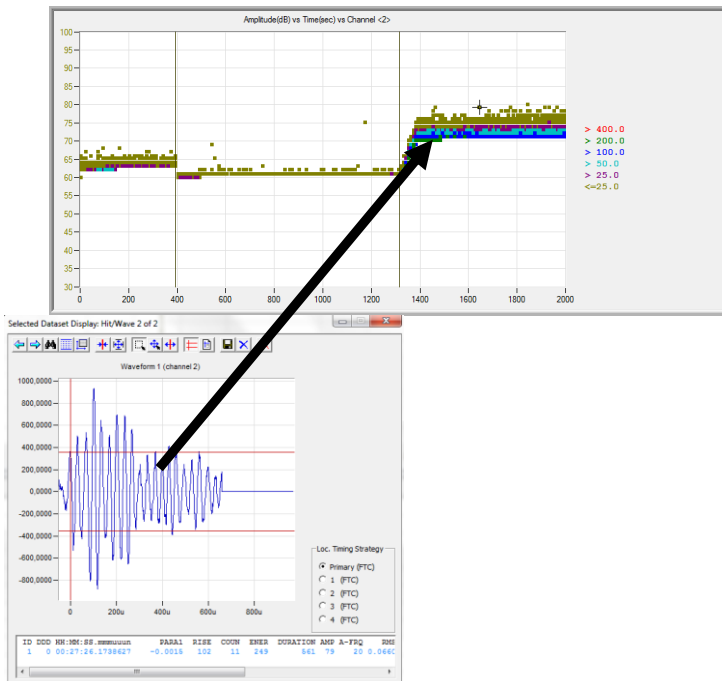


Figure 3 acquisition with smart threshold (above graph) and waveform and hit correspondence (graph below).

The streaming has been also used it parallel without any reduction of performance of traditional AE acquisition. Streaming is a synchronized acquisition the 4 channels without threshold, the windows length can be arbitrary of defined like shown in figure 5.

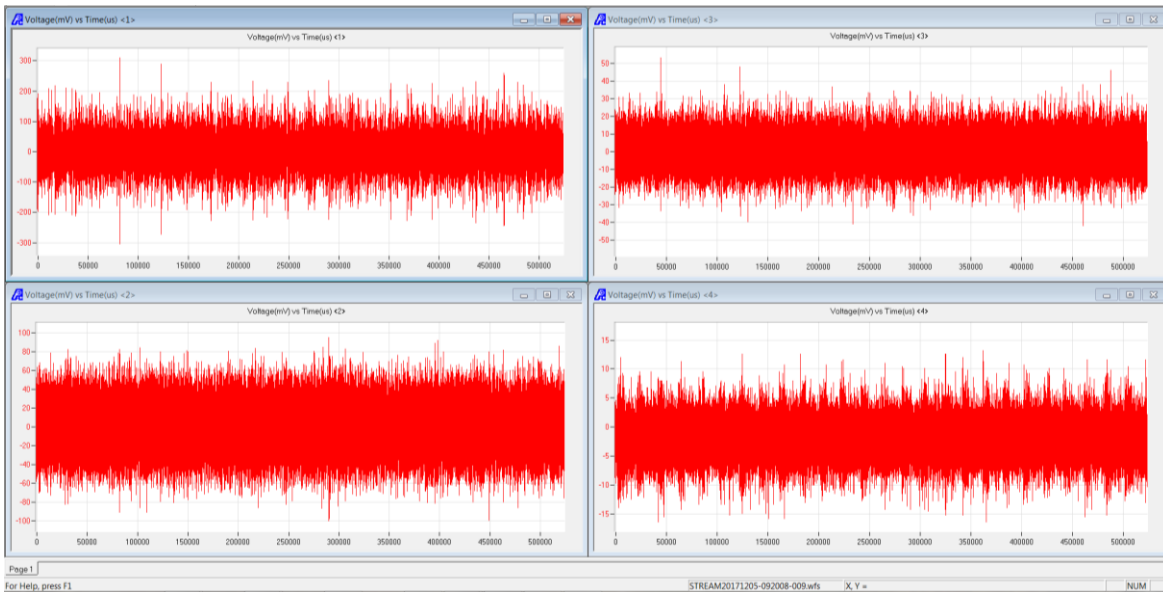
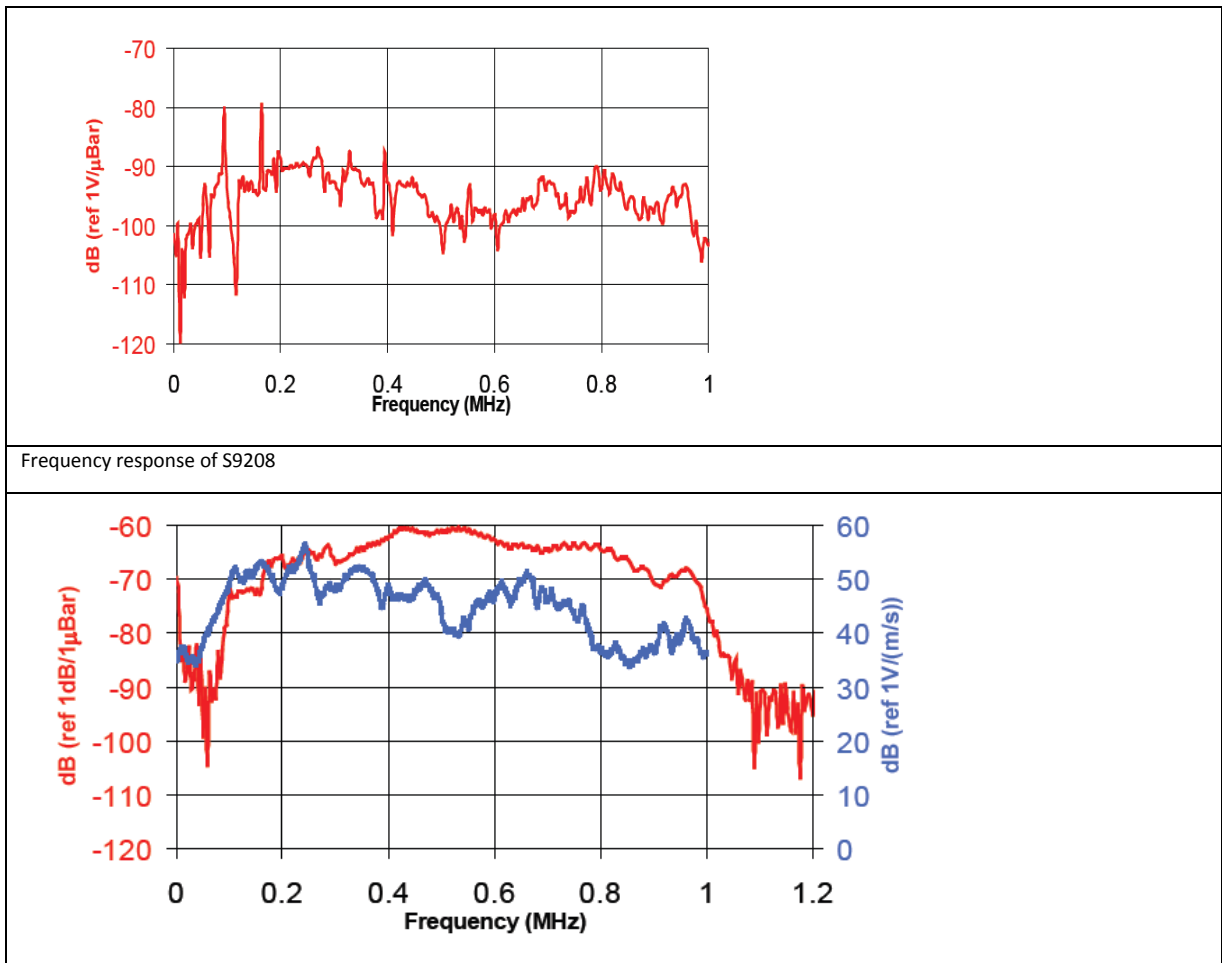


Figure 4 streaming acquisition during 5 sec at 2 Mega sample per second on the four channels.

Three different wideband AE sensors (WD, S9208 and micro 80) are used in parallel with a standard accelerometer Bruel et Kjaer type 4374 (bandwidth 1 to 26KHz 0,5 pC ms⁻²). The calibration curve of the sensors are given in figure 5.



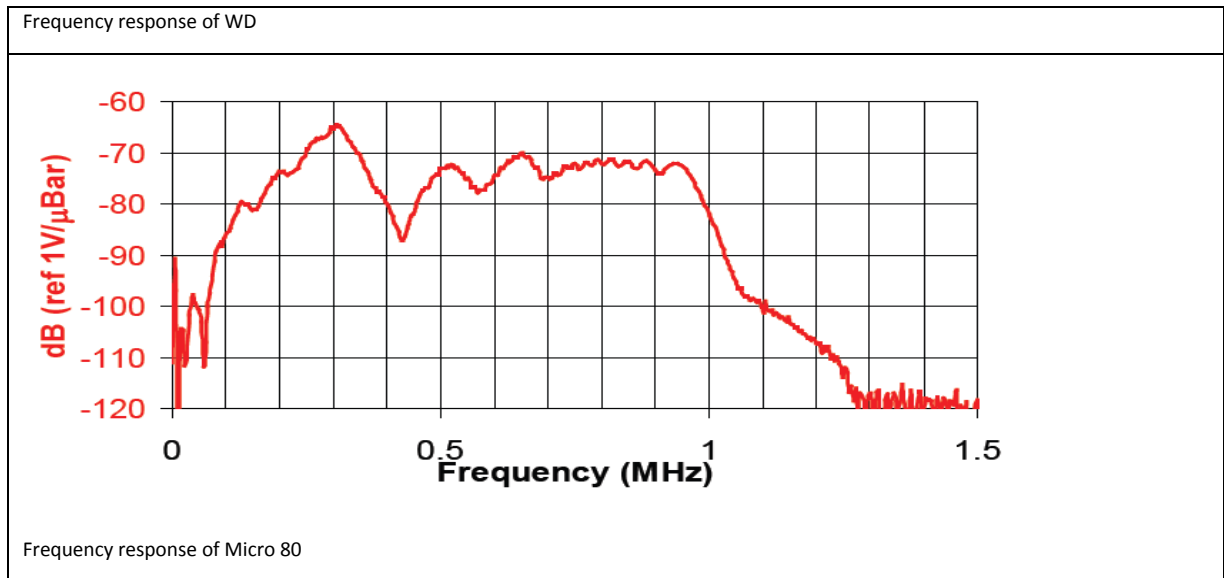


Figure 5 calibration curve of sensors S9203, WD and micro 80.

The sensor must be held in place for the duration of the test. Dry contact between the sensor and the structure does not meet the goal for appropriate wave transmission. For the AE sensors coupling, we used an adhesive tape developed for aerospace industry called “KAPTON” on which the sensor is glued with cyanoacrylate or cement glue. (figure 3). This solution has been tested with success with cyanoacrylate glue for test space telescope for Astrium under high energetic vibration [15]. The reduction of measured amplitude compare to a traditional grease coupling is less than one dB for Hsu Nielsen source (NFEN1330-9).

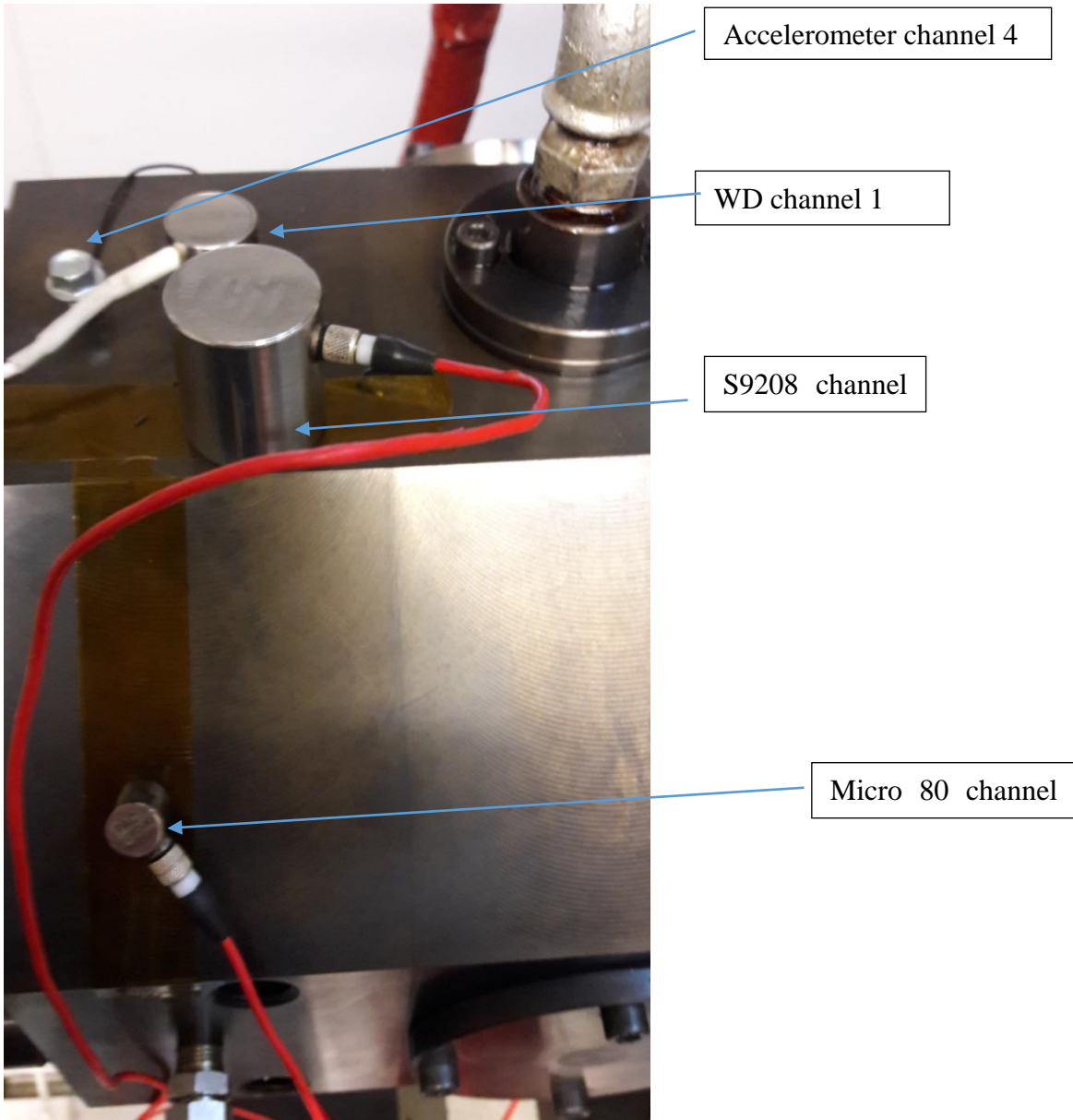


Figure 6 picture of the different sensors used for the monitoring and coupling mode.

3 Introduction

We performed the same loading sequence for all bearings, see table 2.

Speed (Rpm)	Load (kN)
3000	5
6000	5
11500	5
11500	10
11500	15
11500	20
11500	25
6000	23,5

Table 2 loading sequence for bearing the colors are used to separate the loading sequences.

The four sensors are compared and the WD (channel 1) and micro 80 (channel 2) are giving better results than accelerometer and S9209.

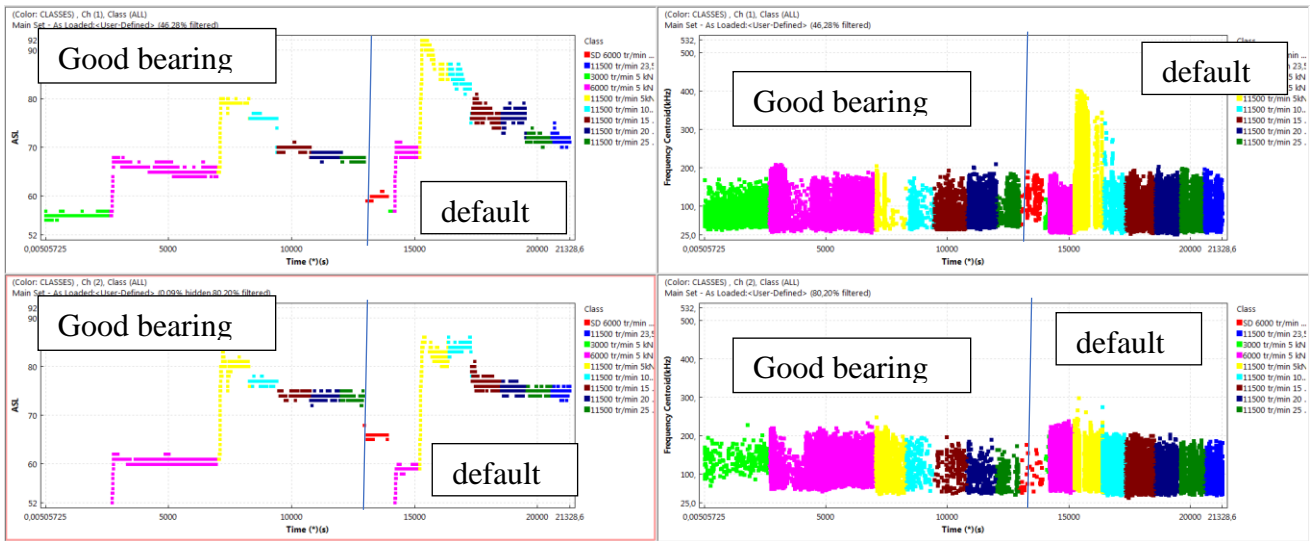


Figure 7 evolution of ASL and frequency centroid versus time with and without default. On the top graph channel 1 (WD) at the bottom channel 2 (Micro 80).

A clear difference of behavior can be seen above 6000 rpm at 5 kN and it enhances at 11 kN on the energy of the AE signal on transients. Also, the center mass of the frequency spectrum (called frequency centroid) increases a lot for the bearing with default; it exhibits the best power of discrimination using our pattern recognition software. The stabilization of the AE signal takes at least 2 minutes after the loading condition change.

Considering a more standard acquisition mode for channel 1 (WD), on the bearing with default, it can be seen a new pic at 27 kHz at 11500 tr/min and above speed. For another side, the width of the FFT increases as the load increases (fig. 8).

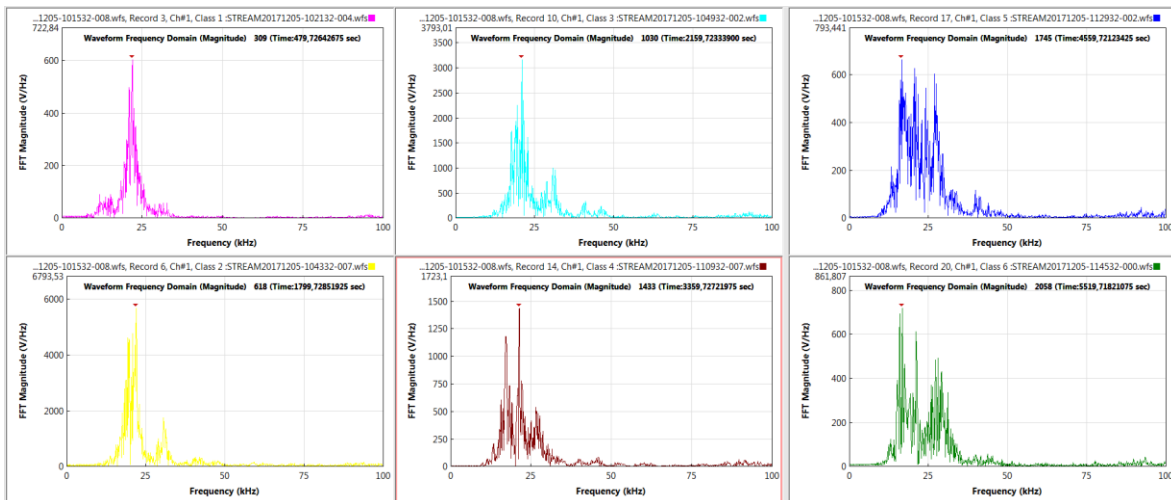


Figure 8 Fourier transform on 5s files on channel 1 for different cases of load levels and rotating speed.

Fourier Transform from Enveloped Spectrum from enveloped AE and vibration Signal were computed in real time from the Sirius acquisition station. Bearing and shaft frequencies were identified from the signal.

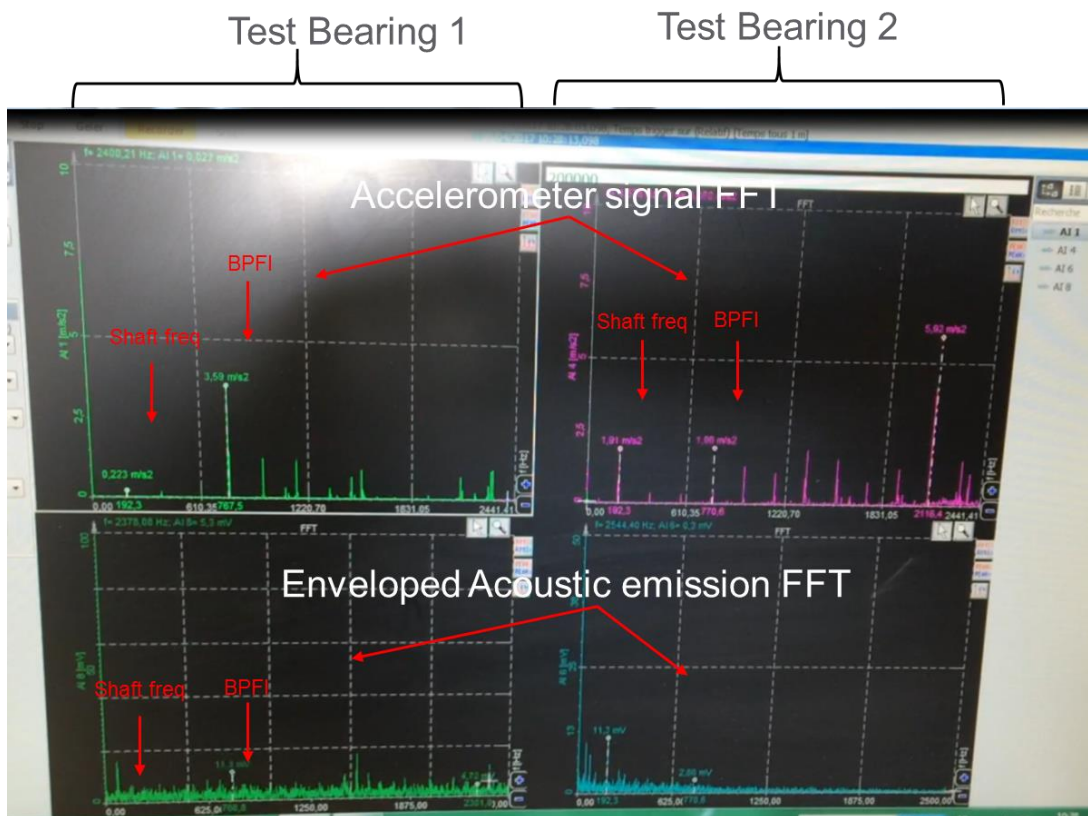


Figure 9 Enveloped spectrum with bearing frequencies identified

4 Discussion

The source of AE for seeded defects is attributed to material protrusions above the surface roughness of the outer race. This was established as the smooth defect could not be distinguished from the no-defect condition. However, for all other defects where the material protruded above the surface roughness, AE transients associated with the defect frequency were observed. As the defect size increased, AE r.m.s, maximum amplitude and kurtosis values increased, however, observations of corresponding parameters from vibration measurements were disappointing. Although the vibration r.m.s and maximum amplitude values did show changes with defect condition, the rate of such changes highlighted the greater sensitivity of the AE technique to early defect detection.

Again, unlike vibration measurements, the AE transient bursts could be related to the defect source whilst the frequency spectrum of vibration readings failed in the majority of cases to identify the defect frequency or source. Also evident from this investigation is that AE levels increase with increasing speed and load. It should be noted that further signal processing could be applied to the vibration data in an attempt to enhance defect detection.

Techniques such as demodulation, band pass filtering, etc, could be applied though these were not employed for this particular investigation. The main reason for not applying further signal processing to the vibration data was to allow a direct comparison between the acquired AE and vibration signature. From the results presented two important features were noted:

- firstly, AE was more sensitive than vibration to variation in defect size
- secondly, that no further analysis of the AE response was required in relating the defect source to the AE response, which was not the case for vibration signatures.

The relationship between defect size and AE burst duration is a significant finding. In the longer term, and with further research, this offers opportunities for prognosis. AE burst duration was directly correlated to the seeded defect length (along the race in the direction of the rolling action) whilst the ratio of burst amplitude to the underlying operational noise levels was directly proportional to the seeded defect width.

5 Conclusion

It has been shown that the fundamental source of AE in seeded defect tests was due to material protrusions above the mean surface roughness. Also, AE maximum amplitude has been shown to be more sensitive to the onset and growth of defects than vibration measurements.

A relationship between the AE burst duration and the defect length will be established in further posttreatment.

6 References

- [1] Raad. A. Sidahmed, B; Early detection of the gear fault – advantage of the acoustic emission technique 25th European conference, Acoustic emission testing; EWGAE; 2002; Prague; 2; II/125-II/130
- [2] Lekou, D.J., Mouzakis, F., Anastasopoulos, A. A., Kourousis, D., Fused Acoustic Emission and Vibration Techniques for Health Monitoring of Wind Turbine Gearboxes and Bearings; Scientific Proceedings of EWEC 2009, pp. 78-82., At Marseille
- [3] Boinet, M. Proust, A., Lenain, J.C., Yantio Njankeu Sabeya, G.R., Paris, J.-Y., Denape, J., Analyse par Emission Acoustique de la dégradation d'un contact sollicité en fretting, Journées Francophone de Tribologie Poitiers, 22–23 mai 2007.
- [4] Mathews, J. R. Acoustic emission, Gordon and Breach Science Publishers Inc., New York. 1983, ISSN 0730-7152.
- [5] Roger, L. M., The application of vibration analysis and acoustic emission source location to on-line condition monitoring of anti-friction bearings. Tribology International, 1979; 51-59.
- [6] Mba, D., Bannister, R.H., and Findlay, G.E. Condition monitoring of low-speed rotating machinery using stress waves: Part's I and II. Proceedings of the Instn Mech Engr 1999; 213(E): 153-185
- [7] N. Jamaludin, Dr. D. Mba, Dr. R. H. Bannister Condition monitoring of slow-speed rolling element bearings using stress waves. Journal of Process Mechanical Engineering, I Mech E. Pro. Inst. Mech Eng., 2001, 215(E):, Issue E4, 245-271.
- [8] Yoshioka T, Fujiwara T. New acoustic emission source locating system for the study of rolling contact fatigue, Wear, 81(1), 183-186.
- [9] Yoshioka T, Fujiwara T. Application of acoustic emission technique to detection of rolling bearing failure, American Society of Mechanical Engineers, Production Engineering Division publication PED, 1984, 14, 55-76.
- [10] Hawman, M. W., Galinaitis, W. S, Acoustic Emission monitoring of rolling element bearings, Proceedings of the IEEE, Ultrasonics symposium, 1988, 885-889
- [11] Holroyd, T.J. and Randall, N., (1993), Use of Acoustic Emission for Machine Condition Monitoring, British Journal of Non-Destructive Testing, 1993, 35(2), 75-78.
- [12] Holroyd, T. Condition monitoring of very slowly rotating machinery using AE techniques. 14th International congress on Condition monitoring and Diagnostic engineering management (COMADEM'2001), Manchester, UK, 4-6 September 2001, 29, ISBN 0080440363
- [13] Bagnoli, S., Capitani, R. and Citti, P. Comparison of accelerometer and acoustic emission signals as diagnostic tools in assessing bearing. Proceedings of 2nd International Conference on Condition Monitoring, London, UK, May 1988, 117-125.
- [14] Morhain, A, Mba, D, Bearing defect diagnosis and acoustic emission Journal of Engineering Tribology, I Mech E, Vol 217, No. 4, Part J, p 257-272, 2003. ISSN 1350-6501.
- [15] Levallois, F., Sobeczko, A., Proust, A., Marlot, D., Lenain J.C. Non-destructive testing of GAIA frame by means of acoustic emission monitoring during launch simulation tests., 30th European Conference

on Acoustic Emission Testing & 7th International Conference on Acoustic Emission University of Granada,
12-15 September 2012.