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CONDITION MONITORING OF VERY SLOWLY ROTATING MACHINERY USING AE TECHNIQUES

Dr. Trevor J. Holroyd

Holroyd Instruments Ltd
Via Gellia Mills, Bonsall, MATLOCK, DE4 2AJ, UK
tel : +44 (0)1629 822060, email : trevor@holroyd-instruments.com

ABSTRACT

In industry it is often very slowly rotating machinery which is the most critical to the production process as well as being the largest and the highest value. These factors combine to increase the economic requirement for Condition Based Maintenance and hence the importance of suitable means of Condition Monitoring. However slow rotational speeds result in reduced energy loss rates from damage related processes and because of this Condition Monitoring techniques which detect energy loss tend to be more difficult if not impossible to apply. Perhaps surprisingly this is not the case for the Acoustic Emission (AE) technique which is well suited to detecting very small energy release rates. As a result AE is able to detect subtle defect related activity from machinery, even when it is rotating very slowly. In this paper a new AE based signal processing approach is introduced which can provide simple but sensitive means of detecting the presence and evolution of faults in very slowly rotating machinery. These developments have further led to the creation of what is believed to be the first easily retro-fitted and affordable on-line monitoring module for very slowly rotating machinery.

KEYWORDS

AE, Acoustic Emission, Bearings, CM, Condition Monitoring, Rotating Machinery, Slow Speed.

INTRODUCTION

It is well known that the application of traditional Vibration monitoring techniques becomes progressively more difficult to apply as the speed of rotation of a machine decreases. The reasons for this are fourfold :

a) the energy release rates from defects reduces as speed reduces.
b) the associated defect repetition frequencies become very low and difficult to detect amongst background noise.
c) very long time records need to be digitised and further processed.
d) slowly moving structures are often very massive and stiff

However it is often the case that the most critical aspect of an industrial process operates at the slowest speed and under the highest loads. Examples are mills (eg sugar, paper and steel), rotating kilns, settlement tank scrapers etc.. The associated machinery is usually highly specialised and represents a high capital investment. Because of this such machinery is a prime candidate to benefit from Condition Monitoring. In particular this has provided a strong impetus for researchers and product developers to devise innovative signal processing methods in an attempt to apply vibration based CM [eg Ratcliffe (1990), Murphy T., Strackeljan et. al (1999)]. Whilst it is not possible to comment on the practicality, range of applicability or effectiveness of all such methods it is fair to say that at the present time end users in industry who work in the field of Condition Monitoring with slowly rotating machinery know that there is currently no simple way for them to apply vibration techniques.

Although it may be that newer and more complex vibration based techniques can be widely effective on slowly rotating machinery this has yet to be adequately demonstrated to end users and because of this we have concluded that an unsatisfied requirement exists in industry which we have sought to address. Instead of pursuing an ever more complex approach to overcoming the low signal to noise ratios of the vibration technique our long term aim has been to create an easy to install, easy to interpret and low cost approach to monitoring such slow speed machinery. This paper describes the development of an AE based instrument to achieve these objectives for everyday use in industry by shop-floor personnel.

BACKGROUND TO AE FROM SLOWLY ROTATING MACHINERY

For both impact and frictional source processes the signal strength at source reduces with increasing frequency. Because of this it is usual for AE sensors to be of a resonant design so that their output is magnified by the mechanical Q of the piezoelectric detection element. Typically reported detection frequencies for such AE sensors fall somewhere within the range 50 kHz to 500 kHz. By contrast vibration measurements usually use broadband accelerometers which are typically used in their region of flat frequency response well below the accelerometer resonance.

Using appropriate AE instrumentation higher speed machinery gives rise to a readily detectable continuous AE signal with transient variations superimposed upon it due to such processes as momentary rubbing, slip-stick and discrete impacts from defects in surfaces which make contact in the loaded zone. In particular the high signal to noise ratio (SNR) of defect activity for AE compared with vibration is a recurrent theme very widely reported in the literature and is the principal reason why AE monitoring can be so successfully carried out in the time domain [Holroyd (1999), Holroyd (2000)].

For the case of very slowly rotating machinery the continuous AE signal typically drops below the limit of detectability and defect presence manifests itself as isolated bursts of AE activity as shown in the example in Figure 1. For very slowly rotating machinery the 'mark to space' ratio of the presence of detectable AE activity can be extremely low making some forms of signal processing inappropriate. However since each individual burst of activity is observable directly in the time domain signal it follows that defect detection need not necessarily be hindered by such low mark to space ratios.

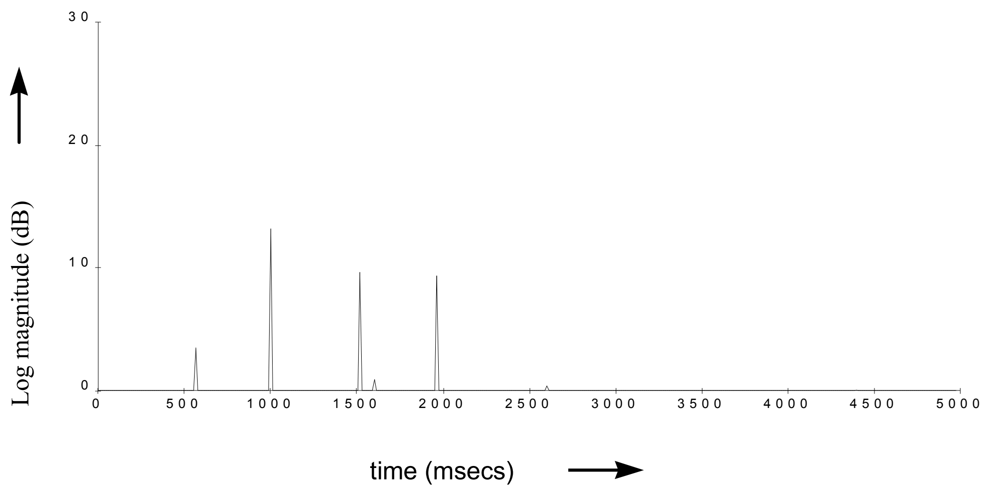

Figure 1 : AE envelope waveform from a defective slowly rotating bearing.

When monitoring slowly rotating machinery it is important not to overlook the need to include a statistically significant sample of the waveform in the analysis. At very slow speeds this means very long time records. Although in principle it would be possible to digitally store very long samples of the AE waveform and post process the signals, in practice such an approach would (with current technology) be too costly and impractical for widespread use. Instead some form of on-line processing is required to autonomously reduce the information content of the signal whilst retaining that part of the information which is of principal interest.

A wide variety of signal processing methods are commonly used in AE monitoring including distributions of AE parameters (eg peak amplitude in an amplitude distribution), locations plots (essentially distributions as a function of time difference of wavefront arrivals at an array of AE transducers) and trend plots of a processed AE parameter (such as AE count rate, energy etc.). For example Rogers [Rogers (1979)] positioned two AE sensors diametrically opposite each other on the inside face of a crane slew ring. The detected activity was presented in the form of an amplitude distribution and in the form of a linear location of its source position. In contrast

Miettinen & Pataniitty [Miettinen & Pataniitty (1999)] used a trend of AE count rate as a means of providing long term monitoring of the AE activity from 16 wheel bearings rotating at 8 rpm and supporting a kiln. A quite different approach has been reported by Mba et. al. [Mba et. al. (1999), Mba et. al. (1999)] who has published extensive work describing the in-depth analysis of AE signals from Rotating Biological Contactor bearings rotating at speeds as slow speed as 0.6 rpm in terms of their Auto Regressive Coefficients.

As a result of the lack of comparative data in the literature it is difficult to rank the relative merits of the different approaches that have been reported (and it will be seen that this paper is similarly deficient in this regard). Consequently it is difficult from an end-users perspective to know what method(s) to choose for particular applications. On the one hand it is self evident that no single signal processing approach can comprehensively describe all aspects of the AE activity from a slowly rotating bearing whilst on the other hand economics will dictate that all techniques cannot be simultaneously applied.

In addition it is also apparent to the AE practitioner that the signal processing techniques described above generally involve a degree of operator dependency in setting up the signal processing as well as significant expertise in the interpretation of the output. Such techniques are good for the investigative or diagnostic stage of a monitoring exercise since an experienced operator will then be at hand. As an alternative approach our aim in the work reported in this paper was to try and be more pragmatic, accepting the limitations of a simpler signal processing procedure, yet providing a more direct and readily understandable output. In this way we hoped to develop an affordable front-line condition monitoring tool for slowly rotating machinery which removed the need for an experienced operator but nevertheless was able to clearly identify when a machine had problems and enable a simple trend indicative of its deterioration to be generated.

A NEW APPROACH

Back in 1997 at Holroyd Instruments we considered the nature of the AE signals generated by slowly rotating machinery and developed new signal processing algorithms which we believed would be of relevance to monitoring very slowly rotating machinery. Although specific details of these algorithms are not made available for commercial reasons part of the external functionality of one of the parameters, 'Extent®', can be described as being to characterise the detectable AE activity in terms of the percentage of the rotational cycle where activity of concern is detected.

In particular the software algorithm for Extent® was intentionally developed so that it does not require a once per rev signal from the machine since this facilitates easier application and retrofitting to existing machinery installations. The only information which needs to be inputted into this algorithm is the approximate period of rotation which is essential in order to ensure that a statistically significant length of signal is processed during the measurement.

APPLICATION EXAMPLES

Initially the software algorithm for Extent® was incorporated within special versions of the MHC-Memo portable CM instrument in order to allow third parties to evaluate its effectiveness on their slowly rotating industrial machinery. Some of the results of this 'beta-trialling' by third parties are described below :

Turntable bearings

This application is based in a foundry where there are a series of turntables which rotate at 6 rpm. Of the many readings taken on a large number of bearings it was found that measurements had been made at various stages in advance of 10 catastrophic bearing failures.

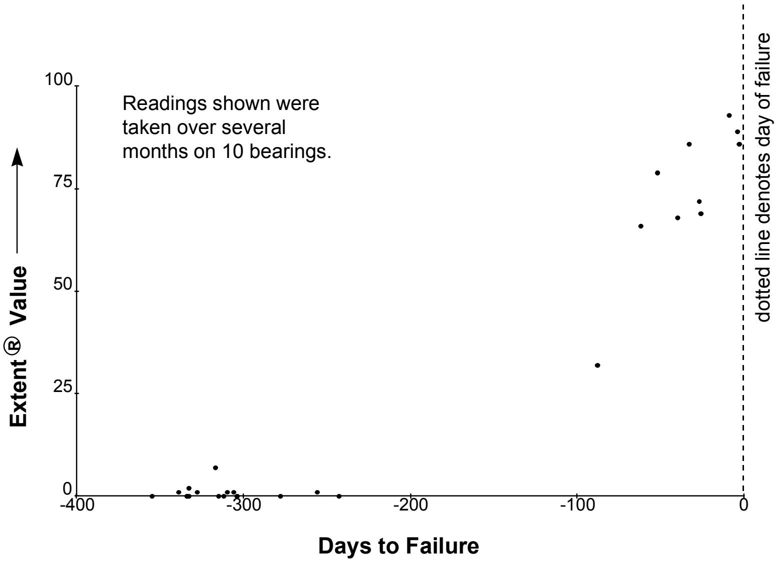

Figure 2 : Sensitivity of ' Extent® ' to proximity of failure in turntable bearings.

Figure 1 shows a composite plot for all the Extent® readings leading up to the failure of these 10 bearings. It is clear from this plot that Extent® provides a simple instant means of recognising the difference between a good and a defective bearing and is trendable up to the point of failure. Figure 2 also suggests that advanced warning of around 100 days might be expected for this particular application.

Rotating Kiln support wheels

This application is also based in heavy industry and concerns measurements made at the 8 wheel bearing positions of the 4 wheels supporting a rotating kiln. These wheels rotate at 7.5 rpm. Figure 3 shows three sets of readings for the Extent® value for measurements at each of the bearing positions. From the first two sets of readings, which were taken on the same day before and after greasing, it is clear that the reading at bearing #7 is noticeably higher. Simultaneous vibration diagnostics suggested (correctly as it turned out) there was no problem with this bearing and so it was decided to continue running. However 10 weeks after these measurements the wheel supported by bearings #7 and #8 catastrophically collapsed as a result of a fatigue crack growing in the axle shaft adjacent to bearing #7. The third set of readings were taken after the kiln assembly was rebuilt with a new axle. The previously high E value measured at bearing #7 has dramatically reduced to a more normal value. The reading at bearing #8 also shows a reduction.

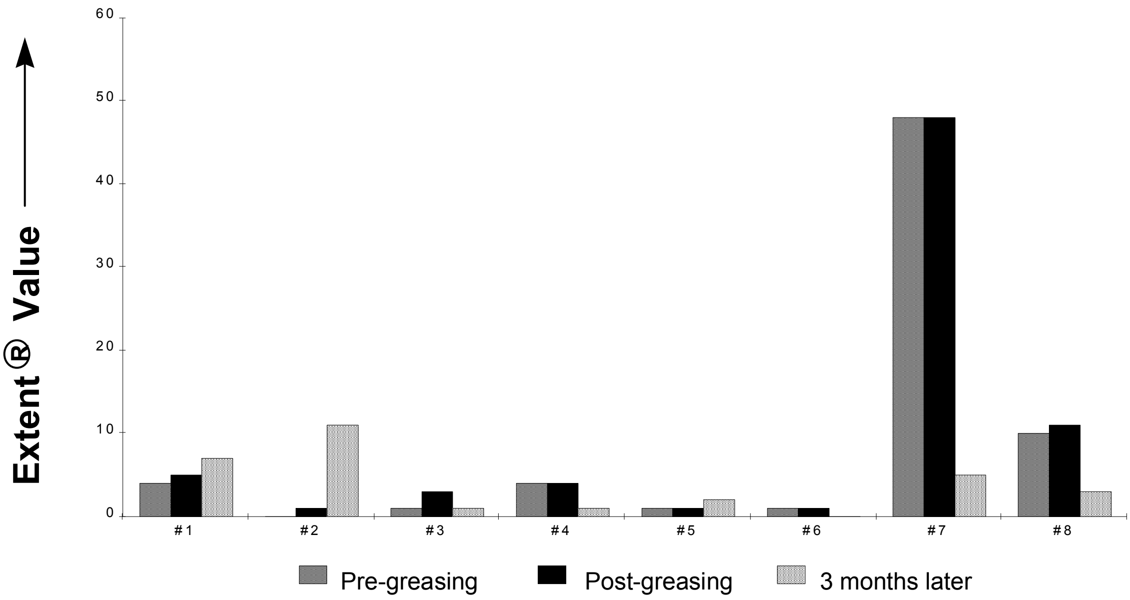

Figure 3 : Sensitivity of ' Extent®' to shaft cracking in a wheel axle.

In this application it is likely that the AE monitoring was picking up the crack closure and crack opening noise caused by rubbing of the interlocking fatigue crack faces. It is fully understandable why such activity would not be detected by vibration monitoring and illustrates well the benefits of signal detection methods that are not reliant upon pre-calculated defect repetition frequencies.

Other applications

Over the 4 year period in which this new slow mode of AE monitoring has been beta-trialled a number of other successes have been reported including sprocket bearings rotating at 2 rpm (detection of bearing damage and water ingress into the grease) and support bearings on cylinder dryers rotating at approximately 10 rpm (a worn bearing was immediately picked out from a one-off set of measurements on 10 bearings during a sales demonstration).

To date our experience is that bearings running normally and in good condition typically have Extent® values of less than 5. With this knowledge we have had good success in carrying out one-off measurements (ie sales demonstrations) and finding rogue bearings on a wide range of very slowly rotating machines. In the light of our experiences and those of our customers who have been evaluating it, we have finally developed our first commercial product incorporating slow mode monitoring.

IMPLEMENTATION AS A STANDARD SYSTEM

Although the demonstration trials described above were carried out with the analysis software implanted in a portable instrument it is clear that monitoring very slowly rotating bearings can be a time consuming and tedious task for the operator if a portable instrument is used. For this reason it was decided that the first product incorporating the new slow mode should be an on-line monitoring system which has the product name MHC-SloPoint™. This is a compact DIN rail mounting module which forms a complete monitoring system requiring only an external DC power supply and an external AE sensor. It has built in dual intelligent alarms and data logging. The data logging feature enables trends to be instantly observed whenever an alarm is triggered. In keeping with the concept of an easy to retrofit instrument the unit is able to be simply wired using screw terminals and takes a similar form to industry standard process monitoring and control modules.

DISCUSSION

Clearly the currently reported signal processing approach deals with only one aspect of the AE signal and can be supplemented by or supplemental to other signal processing methods (such as those Referenced in this paper). This is because the work reported here has not been aimed at producing the most sophisticated AE instrument possible for monitoring slowly rotating bearings, nor producing a diagnostic tool for use by Condition Monitoring specialists. Instead the path has been deliberately chosen to investigate simpler to use and easier to interpret signal processing methods than those which have been previously adopted when applying either AE or Vibration techniques to slowly rotating machinery.

An obvious concern when using the AE technique to monitor slowly rotating bearings is that background noise will mask the detection of defects. So far our experience is that defects are able to be readily detected even in heavy industry under noisy (and dirty) site conditions. Although it would be wrong to suggest that the monitoring system described here has total immunity to such noise we are confident that it is applicable in the majority of industrial uses for which it will be required. We further note that the measurements described were all spot readings (ie single measurements) and it is self evident that the use of more averaging over longer time periods would give a further improvement in signal to noise ratio.

Different signal characterisations are likely to be of greater or lesser importance for different fault modes. In the examples to date the ' Extent® ' value has been the most widely relevant AE signal characterisation we have evaluated. However it is noted that on its own this parameter may well be inappropriate in the case of, say, a bearing race with an isolated crack in it. It is for this reason that a selection of different AE signal characteristics are required and a strategy should be adopted whereby alarms are set on each of them. The system that has been created, the MHC-SloPoint™, performs four such signal characterisations. Importantly its design pays great attention to consistency and long term stability of these signal characterisations since this is very relevant to measurement integrity over the long periods it often takes for very slowly rotating machinery to degrade.

CONCLUSIONS

1 AE techniques can be successfully applied to monitoring the condition of very slowly rotating machinery.

2 A wide range of signal processing methods can be employed to detect the presence and amount of damage although cost and complexity limit their application.

3 A new signal processing method which is both simple to use and easy to interpret has been devised and tested over a 4 year period on numerous machines at a large number of test sites.

4 Indications are that such simple methods can be both effective and widely applicable for detecting the presence and amount of damage.

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Patents Pending on signal processing methods and means described in this paper.