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## SPINDLE BEARING MONITORING USING ACOUSTIC EMISSION

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**Abstract** – A premature failure of machine tool spindle bearings is a major problem in production and can result in enormous loss in the production and spindle rehabilitation cost. This paper describes a condition monitoring system applied to the spindle of a NC machining centre. During idle run the acoustic emission and vibrations were measured using sensors installed in prepared places. A large number of tests were carried out with varying sensor location, spindle rotating speed and spindle load. Measurements were performed in real industrial environment nine times with six weeks intervals in order to obtain trends. The spindle run out was determined at every measurement time as well.

Keywords: Bearing, monitoring, acoustic emission.

### 1. INTRODUCTION

Intermittent or continuous monitoring of machines during operation is an attractive opportunity for maintenance based on the actual condition of a machine rather than a pre-defined, fixed schedule. If the condition of components can be determined during operation, maintenance can be performed only when needed.

Machine monitoring is now a well-understood term. There are many techniques based upon lubricant analysis and vibration measurements. These are aimed at the main elements of machines such as bearings, gears and pumps but the list does not cover all items on the machine tool that can cause halts [1,2]. This paper is focusing on one particular subsystem of the machine tool; the spindle bearing of a NC machining centre. In some cases, the spindle bearings can fail in several months instead of their designed lifetime of several years.

Many factors can contribute to premature failures of bearings. These include poor lubrication, excessive vibration, contamination, faulty installation, improper loading and cooling conditions. Regardless of the types of failures that occur in bearings, e.g. contact staining, corrosion, surface damage, fracture, raceway distress and thermal instability, they are all closely related to the contact force between the rolling elements and the bearing rings [1,3].

Acoustic emission sensors have many desirable characteristics for machine monitoring, e.g. high sensitivity, durability and ease of mounting on bearing cases. Also, the wide bandwidth of signals implies the possibility of monitoring several machine elements [4,5]. However,

acoustic emission sensors are not typically used for bearing condition monitoring.

### 2. RESEARCH SET-UP

#### 2.1. Research equipment

The aim of the research was to develop easily adaptable condition monitoring systems for existing machining centres. The experiments were carried out in a FM-system with four horizontal Burkhardt&Weber machining centres. In the measurements three different spindle speeds, 50, 500 and 2000 rpm were used. The spindle transmission comprised two gears and both could be used at 500 rpm. The measurements were performed in order to clear up the influence of gearing on the signals.

Different sensor locations were tested, without disassembling more than a few covers of the machine. The production was not to be interfered in large extent.

AE signals were measured with three different piezoelectric AE sensors (Kistler, Holroyd) installed on the surface of the spindle (fig. 1.). The amplifier used in the research provided filtered Root Mean Square (RMS) signal output. One of the acoustic emission sensors used was connected to a portable advanced processing unit (APU by Holroyd Instruments). This equipment produces readings of Distress® and dB Level, which is a logarithmically scaled mean signal level.

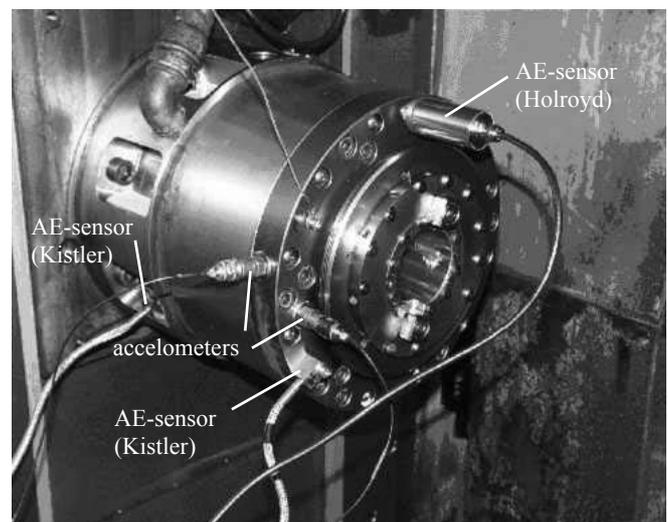


Fig. 1. Spindle with acoustic emission sensors and accelerometers.

For additional information the accelerometers (fig. 1.) were placed to measure in axial and radial directions. The signals from the accelerometers were high pass filtered at 50 Hz and low pass filtered at 15 kHz. All the data from the sensors was sampled and analysed using multi-channel data acquisition card. The Data Translation Fulcrum DT 3818 data acquisition card is equipped with an onboard integrated DSP-processor. The DSP-processor enables on-line analysing of the collected data, for example FFT-transform.

2.2. *Analysing methods*

The measured acoustic emission signals were analysed in time domain. Most of the calculations were performed online on the data acquisition board. From the RMS-signal maximum values, sum of squares and standard deviation were calculated.

The signals from the accelerometers were analysed in a frequency domain by means of power spectral density (PSD) technique. The PSD-signal was calculated by first converting the signal to frequency domain. Thereafter the intensity of the entire frequency range (50...15000 Hz) was calculated. The sampling rate used was 30 kHz.

3. RESULTS

3.1. *Introduction*

The bearing material is subject to both compressive and shear stresses and as fatigue cycles build up, cracks develop on or near the metal surface. Due to a hard impact on the bearing raceway surface minor cracks will form. Consequently, the surface is exposed to strain corrosion and a small part of the surface will break off leaving a small pit as shown in figure 2.



Fig. 2. The damaged outer raceway of the bearing

3.2. *Spindle Run Out*

As presented in figure 3 the spindle run have considerably higher values in machines No. 1 and No. 2 than in machine No. 3. The spindle as well as the spindle cone had been replaced 18 months earlier in machine No. 3. Again, they have not been replaced for several years in machines 1 and 2. Thus, the measurement of the spindle run out can be considered as a sensitive method to detect the

condition of a spindle cone. On the other hand, the measurement of the spindle run out is not an applicable method to detect failures described in the chapter 3.1.

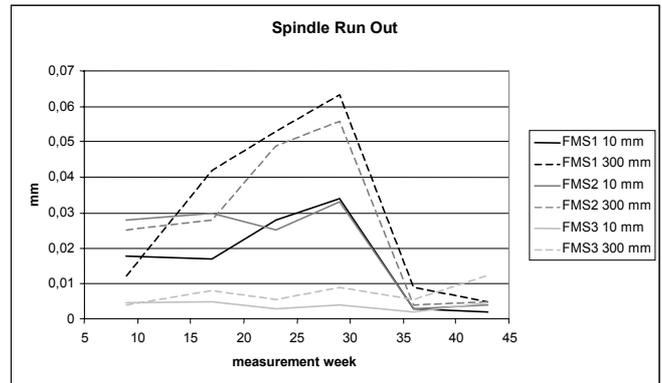


Fig 3. Spindle run out measured in the three machining centres. Results at distances of 10 mm and 300 mm from the spindle face.

3.3. *Acoustic emission*

Defects can be predicted by means of acoustic emission if information from former empirical studies is available. The curve in fig. 4. presents the increase of Distress® caused by the wear of bearings. The points present the Distress® values when the bearings have been replaced. In this research the Distress® values showed to be location sensitive and the spindle rotating speed used. The results of the best combination are presented in fig. 4.

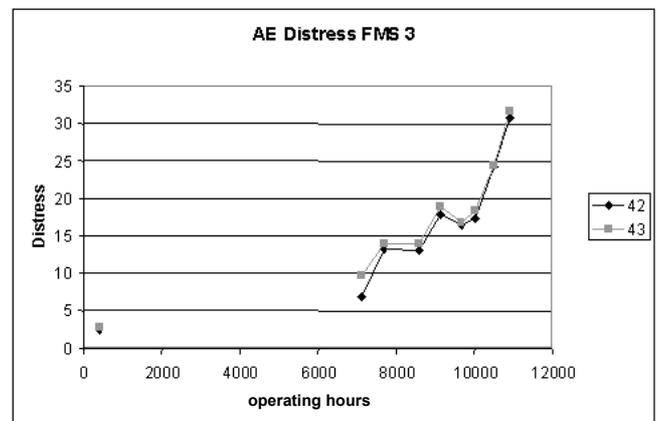


Fig. 4. AE Distress® vs. operating hours. Two different gears used (42= 1. gear, 43=2. gear), spindle rotating speed: 500 rpm.

Fig. 5. presents the influence of the bearing wear on the AE RMS values. Because of the settable parameters, including amplification factor, filtering and time constant, RMS was proved to be less sensitive than Distress® to the location of the sensor and the used spindle rotating speed.

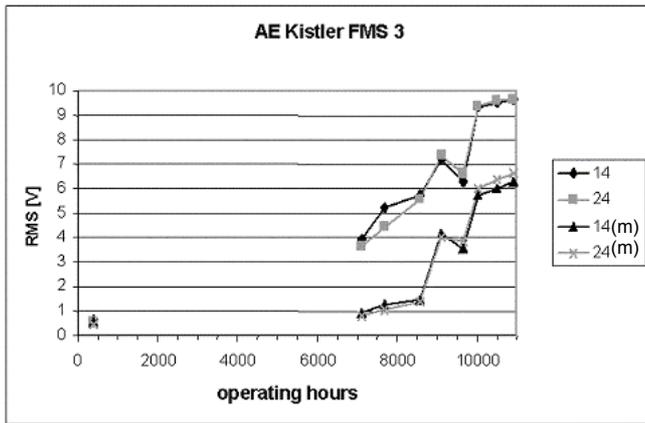


Fig. 5. AE RMS vs. operating hours. With (24) and without (14) unbalanced tool, spindle rotating speed: 2000 rpm. (m = mean)

Figure 6 shows an abnormal situation, where the bearing itself has rotated in its housing. This can be seen as extraordinary high RMS-signal peaks. The bearing was measured with CMM and showed no signs of damage. This kind of fault is easiest to detect with an AE-sensor at low rotational speeds, because then the base level of noise is low. As the rotation, speed increases the noise level increases as well, but the peaks remain at the same level.

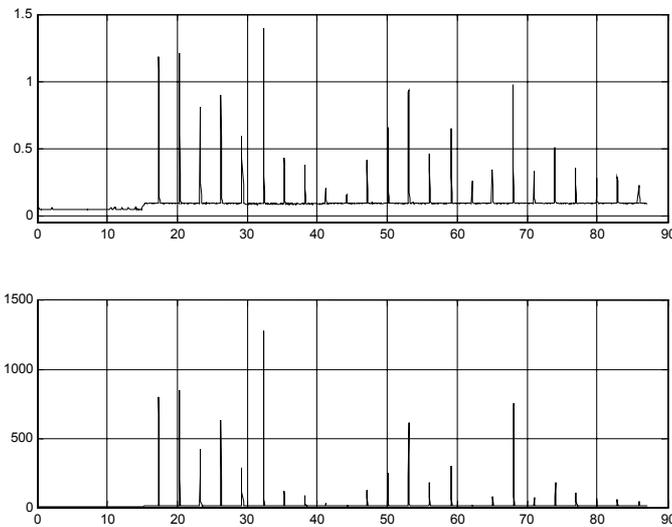


Fig. 6. Upper graph presents AE RMS maximum values of FMS 1 at 20 rpm. The lower graph presents the square sum of the same signal.

### 3.4. Vibration measurements

An accidental collision had most likely taken place before measurements at operating hours 9100 as shown in figure 7. The conclusion is that due to continued running, the collision deformed bearing surface is smoothed and the vibrations are restored close to the base level before the collision. Still vibrations in measurements from radial direction remain at a slightly higher level afterwards. This

theory is supported by the fact that the forming of surfaces emits high levels of acoustic emission, which was measured at the same time. The signal acquisition was also carried out with spindle rotation speeds at 20 and 500 rpm but no defects couldn't be detected.

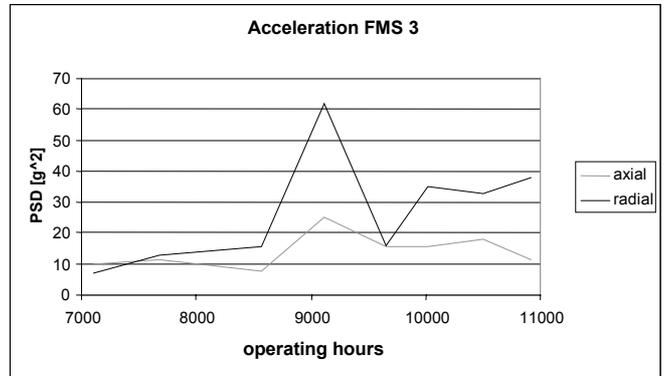


Fig. 7. Acceleration measured from axial and radial direction with spindle rotating speed 2000 rpm.

The used analysing methods for vibration measurements couldn't predict bearing defects reliably, since the level of vibration signals decreased considerably after 1000 operating hours in the survey.

## 4. CONCLUSIONS

A bearing condition monitoring technique based on processing the acoustic emission RMS signal of the monitored bearing system was investigated. The development and application of the monitoring technique was carried out in the real industrial environment. The results showed that the AE method is more applicable to predict bearing defects than traditional vibration bearing condition monitoring. The method described can be easily implemented with micro-processor hardware for on-line operation.

The results of the research are most likely also applicable to other machine tools, like turning lathes and grinding machines. The condition monitoring of guide ways and ball screws are a potential object to utilise this kind of approach as well.

The results showed that the spindle run out measurement was not a reliable condition monitoring method for bearings but can be used for the detection of the cone wear. The bearing defects are detected earlier in the quality assurance than by the maintenance department, if only run out is used follow the condition of bearings.

According to the research made, it is recommended to use a permanently installed automatic monitoring system. This system enabled to set the acoustic emission's measuring- and collection parameters in such a way that only the building up of cracks and micro cracks causes a system alarm. Cracks developed prior to measuring are not necessarily detected during normal operation with a portable system if the cracks don't proceed, especially when the cracks are located under the surface.

The location of the sensors is critical for the reliability of the acoustic emissions Distress<sup>®</sup> values. To ensure the reliability there must be historical data on trends of Distress<sup>®</sup> values.

It is possible to follow the wear and the progression of a bearing defect with the RMS –values of acoustic emission, but its difficult to determine the location and type of the defect. These could be determined by collecting the original unprocessed acoustic emission signal to the data acquisition card and analyse the data in the frequency domain.

#### REFERENCES

- [1] Katter, J. G. & Jay, F. T. 1996. Bearing Condition Monitoring for Preventative Maintenance in a Production Environment. Tribology Transactions, Vol. 39, 4, pp. 936-942
- [2] Thorpe, P. J. & Martin K. F. 1991. Milling machine bearing monitoring. Proc. I. Mech. E. Conf. Eurotech Direct '91, Paper C414/030, pp. 151-157
- [3] Miettinen, J. 2000. Condition Monitoring of Grease Lubricated Rolling Bearings by Acoustic Emission Measurements. Doctoral Thesis. Tampere, Tampere University of Technology Publications 307, 140 p., ISBN 952-15-0477-3
- [4] Yoshioka, T., Korenaga, A., Mano, H., Yamamoto, T. 1998. Diagnosis of Rolling Bearing by Measuring Time Interval of AE Generation. ASME/STLE Joint Tribology Conference, Tronto, Canada, Paper No. 98-Trib-40, 5 p.
- [5] Li, C. J. & Li, S. Y. 1995. Acoustic Emission Analysis for Bearing Condition Monitoring. Wear, Vol. 185, pp. 67-75

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