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# Fracture Detection of Bearings in Long-Term Measurements Using a Feature-Based CUSUM Algorithm

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**Abstract:**

In this paper, a new approach for fracture detection on tapered roller bearings is presented, which is based on a feature-based CUSUM algorithm. For this purpose, experimental investigations are presented in which fractures in bearings are generated by overload. The vibration signals are recorded throughout the entire bearing lifetime in the test, from which features are later extracted and used for fracture detection. More specifically highlighted as features in this paper are the standard deviation and the clearance factor, which are often used in the context of detecting damage to rotating machinery.

**Keywords:** Damage Detection, Condition Monitoring, Predictive Maintenance, Vibration Analysis, CUSUM Algorithm

## Introduction

In the field of condition monitoring, a large number of machine components are already monitored in order to optimize processes or detect damage. However, many areas have not yet been sufficiently investigated, so avoidable machine failures still occur. This includes undetected bearing damage, which often result in further machine damage. One solution to avoid this consequential damage in the future could be the detection of initial damage by analysing vibration data.

Previous approaches of detecting faults in rotating machine elements were largely based on envelope analysis of vibration signals, in which damage is detected on the basis of previously calculated damage frequencies [1]. A further approach of the detection of bearing damage uses feature extraction, followed by a classification [2]. Furthermore, with regard to long-term measurements, wear was generated by loading of deep groove ball bearings and estimates of remaining useful lifetime were investigated [3].

This publication presents a study of long-term measurements on tapered roller bearings, and the detection of fractures in the vibration signal via the application of the CUSUM algorithm to previously extracted features. This calculates and compares the cumulative sum of a measured value if this exceeds a threshold value [4].

## Experimental Setup

In order to investigate the vibration behavior of bearings in long-term tests, a laboratory test rig was set up, shown in Fig. 1. A bearing socket has been manufactured which can hold different bearing sizes. Piezoelectric vibration transducers can be attached by means of screw connections. A defined radial force can be applied to the bearing's outer ring by means of a screw attached to the bearing socket as shown in Fig. 1 (a). The bearing, which is set in the socket, is connected with an electrical motor via a low-vibration coupling.

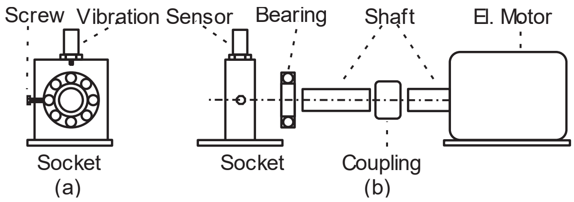


*Fig. 1. Experimental setup for the investigation of bearings in frontview (a) and sideview (b).*

During the measurement the vibration transducer was sampled with a sampling rate of 20 kHz and a resolution of 24 bits.

## Experimental Results

The damage pattern occurring due to the outer ring fractures is shown in Fig. 2.

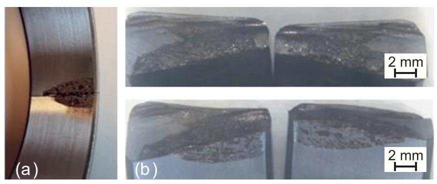


*Fig. 2. Occurred fracture on the outer ring with pitting (a). Close-up view of the fracture in the scanning electron microscope (b).*

In addition to the actual fracture of the outer ring, significant pitting can be seen at the edge of the fracture. Furthermore, material fatigue effects can be seen inside the material due to the dark discoloration of the material.

For the investigation of the long-term measurements, characteristics from time windows of 2000 samples each were first extracted and standardized. For closer examination the standard deviation $\sigma$ and the clearance factor $\mathrm{CF}$, calculated as shown in Eq. 1 [5], are considered.

$$\mathrm{CF} = \frac{x_{\max}}{\left(\frac{1}{N}\sum_{i=1}^{N}\sqrt{|x[i]|}\right)^2} \quad (1)$$

The statistically occurring feature values before and after fracture of the bearing's outer ring are compared. Fig. 3 shows the probability density function and the fitted normal distribution for both standardized features $\widehat{\mathrm{CF}}$ and $\hat{\sigma}$ before and after the fracture.

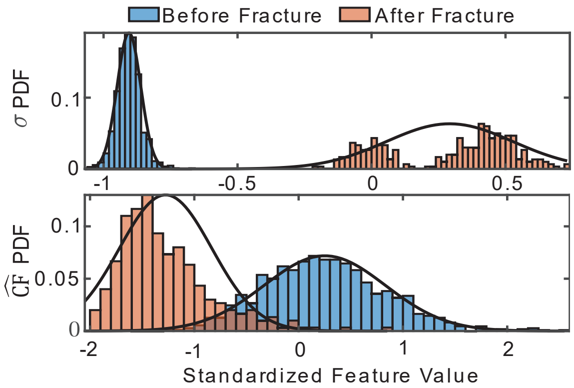


*Fig. 3. Probability density function (PDF) of standard deviation and clearance factor with fitted normal distribution before and after fracture of the outer ring.*

The PDF shows that both characteristics follow a normal distribution before the fracture. After the fracture there is a deviation of the mean value of both features. The curves of the PDF no longer follow a normal distribution after the fracture. Furthermore, it can be seen that the distribution of $\hat{\sigma}$ results in a bimodal distribution after the fracture. The standard deviations and mean values of both features over the range before fracture (1100 time windows) and after (300 time windows) are listed in Tab. 1.

*Tab. 1: Mean value and standard deviation of the considered features before (BF) and after fracture (AF).*

| | $\mu_{\mathrm{BF}}$ | $\sigma_{\mathrm{BF}}$ | $\mu_{\mathrm{AF}}$ | $\sigma_{\mathrm{AF}}$ |
|---|---|---|---|---|
| $\hat{\sigma}$ | -0.905 | 0.045 | 0.292 | 0.236 |
| $\widehat{\mathrm{CF}}$ | 0.250 | 0.582 | -1.275 | 0.444 |

The CUSUM algorithm is applied to the extracted features to realise a change detection. Fig. 4 shows the calculated cumulative sum for the two features previously considered, as well as the standardized feature value itself over time.

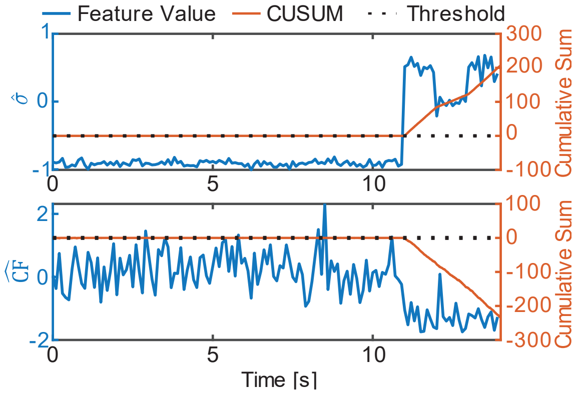


*Fig. 4. Standard deviation and clearance factor plotted over time with associated cumulative sum.*

At the point where the cumulative total exceeds a threshold value of $3\sigma$ of the characteristic value, the fracture is detected. In both features a fracture is detected after 11 hours which corresponds to the real fracture time. Both features can therefore be assumed to be suitable for bearing fracture detection.

## Conclusion

In this paper a detection of experimentally generated fractures in tapered roller bearings was presented. For this purpose, bearing fractures due to overload were generated in a laboratory setup and the vibration signal was recorded. Subsequently, the standard deviation and the clearance factor were determined as features to detect fractures based on the CUSUM algorithm. On the results obtained, it can be assumed that both characteristics used are suitable for breakage detection.

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