Estimating Lubrication conditions in Ball Bearings using low a cost MEMS Microphone

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Overview

In the industry, 40–80% of bearing defects [1,2] in rotating machines is believed to be initiated by improper lubrication. Traditional condition monitoring equipment relies on accelerometers with limited bandwidth (<20kHz) that fail to capture the subtle changes during infant defects, initiated by lack of lubrication.

Here we show an experiment where varying lubrication conditions are emulated by adjusting speed and temperature. The emitted vibrations are captured with an ultrasound microphone sampled at 100kHz and subsequently processed to estimate the measure reference viscosity ratio κ.

[1] FAG, Rolling Bearing Damage Recognition of damage and bearing inspection (20).
[2] SKF, Bearing Damage and Failure Analysis

Experiment

Four grease lubricated bearings (NSK6208) are subjected to a radial load of 4kN, and run through a alternating Speed sequence from 3000 rpm downto 500 rpm, with temperature increasing from 30˚C to 120˚C in steps of 10˚C, as outlined in figure 1. Reference viscosity ratio κ is calculated from Speed and Temperature. Audible vibrations are captured using an Ultrasound MEMS microphone (SPH641UL).

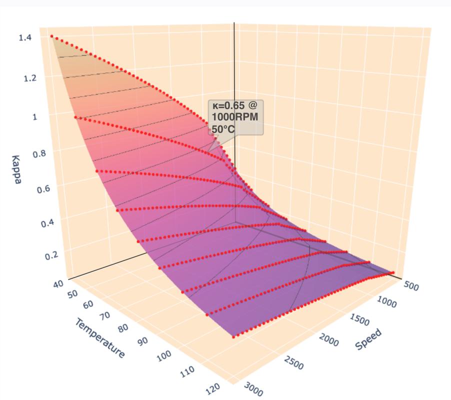
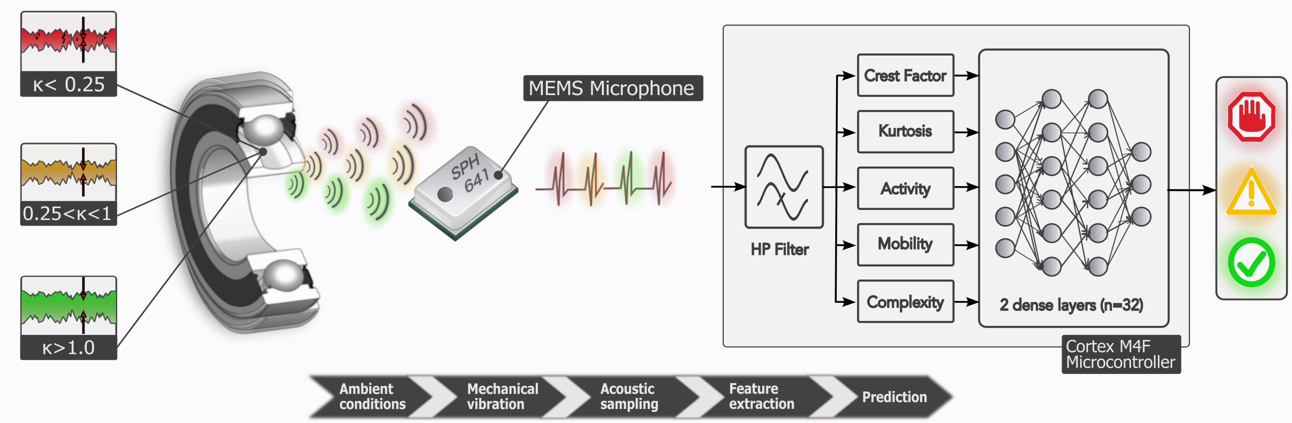


Figure1 – Obtained values of k during the experiment

Data collection & Signal processing



Sensor Node & Lubrication test rig

The sensor node is built around an ARM Cortex M4F CPU (Ambiq Apollo3 Blue) running at 48MHz. On the node accelerometers, magnetic and temperature sensors are availible in addition to the SPH641UL ultrasound microphone. The microphone signal is highpass filtered using a 6th order butterworth with Fc=5kHz and 5 time domain features are extracted: Crest Factor, Kurtosis, Variance, Hjorts Mobility and Hjorts Complexity. A NeuralNetwork is built with two hidden dense layers (n=32), ReLu activation and FP32 percistion, in order to combine and linearize the features. The sensor (**S**) is installed on a four bearing testrig, with radial load and heat applied.

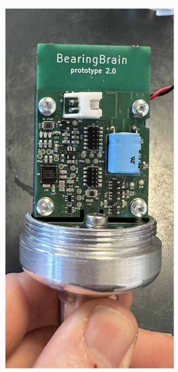


Figure2 – Sensor node for capturing vibration signals

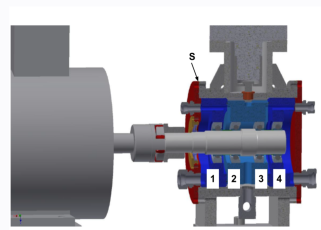


Figure3 – Testrig, bearing block radial load cylinder and drive motor. Heating elements fitted externally.

Feature	Formula
Crest factor	$\mathrm{Crf} = \frac{\text{max value}}{\text{RMS}}$
Kurtosis	$\mathrm{K} = \frac{1}{N}\sum_{i=1}^{N}\frac{(x_i-\overline{x})^4}{\sigma^4}$
Activity	$\mathrm{Act} = \frac{\sum_{i=1}^{N}(x_i-\bar{x})^2}{(N-1)}$
Mobility	$\mathrm{Mob} = \sqrt{\frac{Act(dx(t)/dt)}{Act(x(t))}}$
Complexity	$\mathrm{Com} = \frac{mobility(dx(t)/dt)}{mobility(x(t))}$

Figure4 – Preprocessing features: Crest factor, Kurtosis, Activity, Mobility and Complexity.

Results

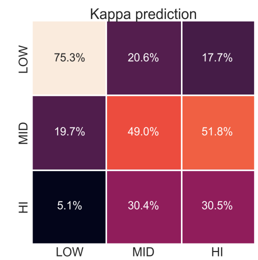
For poor lubrication conditions with κ<0.25 the proposed model shows good ability to detect to detect metal to metal contact.

Latency :

- 650 ms HP digital filter
- 150 ms Hjorts parameters
- 95 ms Neural network

Memory usage:

- 1.6 kB RAM – NN
- 20 kB RAM – Sample buffer
- 12 kB Flash



Conclusions

- An increase in amplitude of broadband signals during poor lubrication conditions is observed
- Hjorts parametes, Activity, Mobility and Complexity are low compute efficient features for detecting the prescence of broadband signals
- Crest and Kurtosis are capable of detecting mechanical asperity impacts in the bearing
- A small neural network is capable of removing non linearities and combining features into a usefull prediction of viscosity ratio κ

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Let's Connect: