# Acoustic Emission in Grease-Lubricated Helicopter Drivetrain Bearings

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## Abstract

Vibration-based diagnostic techniques have been successfully applied to bearings, gears and other mechanical components, with extensive use in helicopter propulsion systems over the past decade. Although signal processing techniques have been developed to extract features corresponding to various failure modes of these mechanical systems, challenges remain in early robust fault detection. Interpretation of diagnostic vibration features can be challenging in the complex noise and vibration environment of a helicopter propulsion system.

Over the past several decades, acoustic emission (AE) sensing has been commonly applied to the monitoring of damage initiation and progression in static structures, as well as in leak detection of pressure vessels. In recent years, AE sensing has also been applied to the detection of damage in rolling element bearings and to asperity interaction in tribological contacts. While the noise and vibration environment of helicopter propulsion systems is expected to remain a challenge for AE, the rapid attenuation of AE away from their sources allows a sensor positioned close to a source to more clearly measure only locally generated AE. In this study, we explore acoustic emission characteristics of grease lubricated viscous damper bearings from the UH-60 Blackhawk helicopter tailrotor drivetrain.

**Keywords:** bearings, acoustic emission, mechanical diagnostics, health monitoring, grease degradation

## Introduction

Helicopters have increasingly adopted vibration-based diagnostics in Health and Usage Monitoring Systems (HUMS) to monitor the health of dynamic components and early detection of critical flaws. Bearing and gear diagnostics based on analysis of vibration data have been reported extensively over the past several decades [1, 2], with many of the signal processing techniques derived from the physics-based dynamic behaviour.

An increasing amount of attention has been devoted to the study of acoustic emission (AE) characteristics of dynamic components, especially bearings [3-7]. Since acoustic emission sensing is well suited to the measurement and quantification of asperity contact in bearing contacts, it may provide improved and early detection of lubrication failure in grease-packed helicopter drivetrain bearings. Whether this detection ability can surpass that currently achievable using vibration-based techniques.

A previous study of the tailshaft viscous damper bearing from the UH-60 Blackhawk has shown a grease aging mechanism dominated by base oil consumption and a resulting increasing fraction of thickener to oil [8]. Interest in the detection of distributed damage such as corrosion in a nearly identical bearing in the Royal Australian Navy SH-70B Seahawk helicopters [9] provides further motivation for the investigation of AE in helicopter bearings. In this series of experiments, we apply techniques developed in earlier work [9] to the UH-60 viscous damper bearing to characterize the acoustic emission generated at speeds, loads, and lubrication conditions expected in that application. This establishes signal characteristics for longer duration experiments that will investigate trending over many thousands of hours of operation.

## Methods

### Test Rig

The test rig for this experimental study mounts up to eight test bearings on a rotating shaft within a thermal chamber, applying radial load to the outer race of the test bearings via pneumatic load cylinders. Two additional bearings support the test shaft at either end of the chamber, and for this study the rig bearings were identical to the test bearings. Fig. 1 provides an overhead view of the test rig.

A 7.5 hp, 7500 rpm AC motor and variable frequency drive are used to drive the test shaft through a flexible coupling. A once-per-revolution tachometer signal is provided using a fiber optic sensor. Early characterization of the signals found that the power switching from the drive could introduce considerable high frequency noise into the measurements, but additional precautions were taken to isolate the data acquisition system from this noise and later experiments showed that a noise floor of a few millivolts or less was achievable.

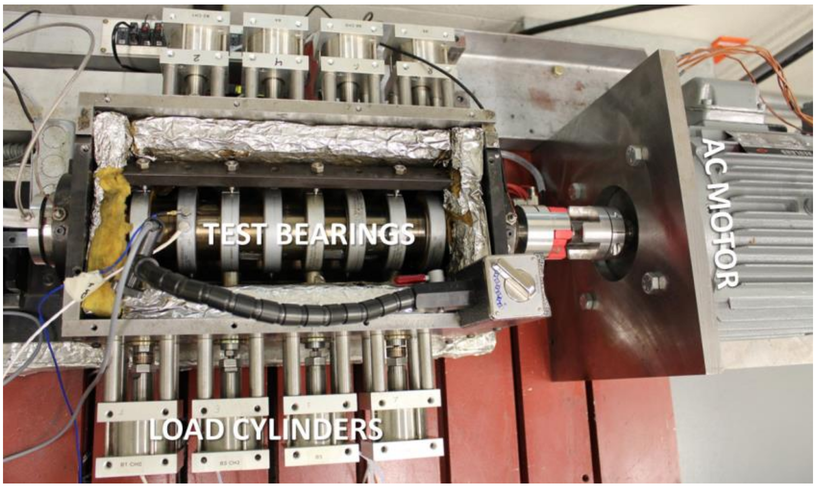


*Fig. 1: Test rig with bearings installed*

### Bearing Specimens

The UH-60 tail rotor driveshaft viscous damper bearing is a sealed deep groove ball bearing with AISI 52100 steel races, with a riveted two piece stamped cage. The bearing is housed within a viscous damper, loaded primarily in the radial direction with approximately 100 N (22 lb) of load. Table 1 gives an overview of the technical specification of the test bearings. These operational conditions can be characterized as light load with a moderate DN≈200,000 (mm·rpm) using a bore diameter of 50 mm (1.968 in) and a nominal tail shaft speed of 4115 rpm. DN is defined here as the product of bore diameter in millimetres and the speed in rpm, and gives a measure of the speed severity of a bearing, taking into account its size.

The test bearings are lubricated with grease conforming to the MIL-PRF-81322G standard, a high performance grease able to operate in a wide temperature range from -54 to 177 °C. The specific grease chosen for this study is a commercially available formulation consisting of a polyalphaolefin synthetic base oil with an organo-clay (non-soap) thickener, which gives the grease a high dropping point over 300 °C.

*Table 1*: *Test article specification, as described in its NSN technical listing*

| | |
|---|---|
| NATO Stock Number (NSN) | 3110-01-329-8573 |
| Bore Diameter | 50 mm |
| Bore Shape | Straight |
| Load Direction | Radial |
| Material | All steel |
| Overall Outside Diameter | 80 mm |
| Overall Width | 16 mm |
| Style Designator | 40A 4 Point Ball Contact, Solid Inner and Outer Rings, Non-Separable |
| Surface Finish | Ground |

Four test bearings were run in this study which included a newly lubricated bearing, two bearings with heavily aged grease from a previous study [8], and a nearly dry bearing prepared by subjecting a bearing with aged grease to ultrasonic cleaning in hexane for approximately ten minutes. This dry bearing had only one seal removed, so a small amount of grease residue remained after cleaning. The newly lubricated bearing had a smaller charge than normal to reduce the excess initial heat generation that often occurs in newly greased bearings as the grease is worked and distributed. These specimens are listed in Table 2.

*Table 2*: *Test specimens*

| Bearing designation | Description |
|---|---|
| B626-92877 “NG1” | New grease - newly greased bearing with a reduced initial charge of grease (3 cc) |
| B626-47134, “DG1” | Degraded grease - over 5800 hours of accelerated aging at outer race temperature of 114 °C with notably rough operation and perceived clearance due to wear when turned by hand |
| B626-56197 “DG2” | Degraded grease - over 5800 hours of accelerated aging at outer race temperature of 128 °C |
| B626-40571 “Dry” | Nearly dry bearing, most grease removed by ultrasonication in hexane |

## Instrumentation

This study was primarily concerned with the response of a Physical Acoustics Corporation Micro30D passive miniature sensor with a rated frequency range of 150 – 450 kHz. The sensor is connected to a PAC 2/4/6C preamplifier with integral analog bandpass filter from 100-400 kHz and a selectable gain of +20, +40 or +60 dB. The AE sensor was bonded to the outer race of the test bearings using cyanoacrylate adhesive.

In addition to the acoustic emission sensor, a PCB Piezotronics 320C-15 accelerometer and a Bruel & Kjaer Model 4939-A-011 high frequency microphone were also positioned at the test bearing to monitor structural vibrations of the outer race and airborne noise, respectively, but only limited results from those sensors are presented here for brevity. Fig. 2 shows the instrumentation configuration installed with one of the test bearings.

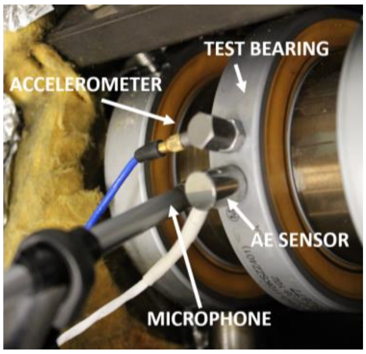


*Fig. 2: Instrumentation installed at the test bearing*

## Results

Measurements were made of all test bearings from 500-5000 rpm in increments of 500 rpm, and at loads of approximately 100 N and 200 N. The test was run initially with the lower load held constant while speed was traversed in steps, followed by a reduction in speed to 500 rpm, with the load increased and the sequence of speeds traversed again at the second load.

Fig. 3 shows the trends in the RMS of all sensors over the course of a test, where these values all increased substantially with speed. With the baseline radial load of 100 N, AE generally increased monotonically with a roughly linear response to speed, especially above 1000 rpm. Signal amplitudes from the microphone and accelerometer also generally increased with speed for all test bearings, but these trends were not always smooth or monotonic. Similar trends with increasing speed were likewise observed for the elevated load case of 200 N. This doubling of the applied radial load on the bearings had a weaker effect on signal amplitudes than the effect of increasing speed, and the AE signal power was usually slight less at the higher load.

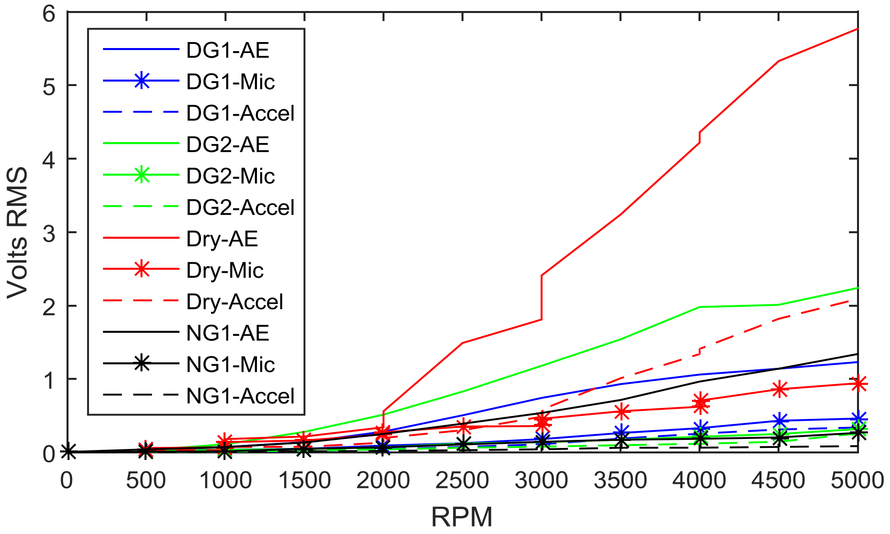
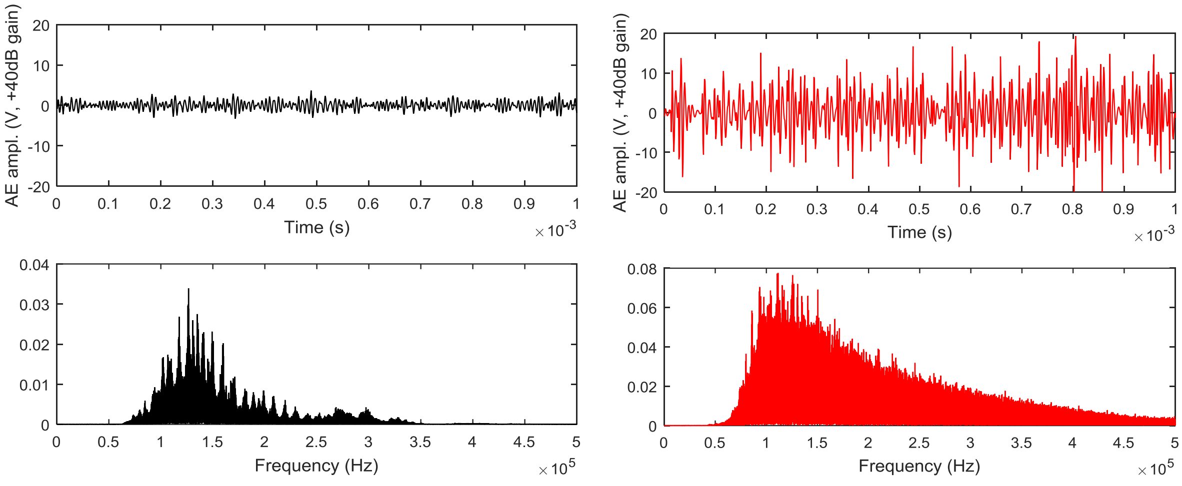


*Fig. 3: Sensor RMS dependence on RPM at Load of 100 N.*
*(Bandpass filtered, AE: 100-500kHz, Mic: 10Hz-100kHz, Accel: 10Hz-100kHz)*

It is significant that some reduction in the RMS AE was observed with time at a given condition, while at the same time bearing temperatures increased steadily throughout the experiments. With this observed effect, the lower measured AE at higher loads may be partly attributed to this running in effect. Upon observing this, a steady speed was held while load was toggled between the two cases to verify that the increase in load always resulted in a slight decrease in AE, even as the overall RMS AE signal drifted somewhat with time and as the temperature increased as well.

Figure 4 shows a comparison of the acoustic emission signal of the dry bearing and the newly greased bearing, zoomed to show just 0.001 s of the time domain data. This signal is consistent with continuous mode AE where individual bursts are generally not distinguishable. The increased AE in the dry condition is clearly seen in the time domain plot, and in the frequency domain this signal also shows a richer spectrum with increased broadband content above 175 kHz when compared with the newly greased bearing.



(a) (b)

*Fig. 4: Acoustic emission signals in time and frequency domains for (a) the newly greased bearing, and (b) the dry bearing*

To quantify the signal attributes at a given condition, Table 3 provides tabular metrics for the AE signal including the RMS signal value as well as dimensionless kurtosis and crest factor metrics typical in vibration based diagnostics. Count rates were calculated by counting positive threshold crossings of four- and five-times the signal RMS, giving normalized threshold crossings intended to distinguish more impulsive signals, and absolute counts when the signal crossed 5 V. These metrics showed mixed results, but both absolute counts and signal RMS were able to distinguish the extreme cases of a dry bearing from a newly greased bearing.

*Table 3 – Signal metrics for the AE sensor at 4500 rpm and 100 N load*

| | **New Grease** | **Dry** | **Deg. Grease 1** | **Deg. Grease 2** |
|---|---|---|---|---|
| Crest Factor | 4.39 | 6.00 | 6.08 | 4.53 |
| Kurtosis | 3.01 | 3.17 | 4.02 | 3.09 |
| RMS (V+40dB) | 1.13 | 4.88 | 1.09 | 2.13 |
| Count rate (>4*RMS) | 12 | 91 | 199 | 17 |
| Count rate (>5*RMS) | 0 | 2 | 14 | 0 |
| Count rate (>5V) | 0 | 67481 | 42 | 5085 |

## Concluding Remarks

In this series of experiments, we have focused mainly on measuring the acoustic emission on the outer race of several grease lubricated bearings

1. Acoustic emission increased strongly with speed from 500-5000 rpm and had a weaker dependence on load, with acoustic emission lessened at the higher load. This effect is consistent with increased chatter and noise at the lightly loaded condition.
2. Acoustic emission tended to decrease as the test progressed at a given condition and temperature increased. Increased oil mobility within the heated thickener is thought to improve lubrication of the contact and reduce asperity contact as the bearing heats with time.
3. The accelerometer and microphone also showed increased RMS signal power with lubricant distress, and the microphone showed a shift of signal power to higher frequencies similar to that reported in [9].
4. RMS and count rates based on absolute thresholds in the AE signal distinguished the most severe case of a dry bearing from one with fresh grease, with degraded grease specimens exhibiting less clear indications of distress in these metrics. Additional experiments to trend these metrics over time and multiple specimens are needed to establish diagnostic ability.

This preliminary study has characterized acoustic emission in a bearing of interest in preparation for longer duration experiments that will trend these signals over the life of a bearing. This provides initial data to compare whether acoustic emission signals can be used to reliably indicate the degradation and failure of the lubricant, particularly in comparison with vibration-based diagnostics. Further parametric study will quantify statistical significance and trends over time, and experiments with a more realistic outer race mounting are needed to measure the effect of structural restraints.

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