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HUMS2027 Data Challenge Dataset

Dr. Wenyi Wang and Dr. Nader Sawalhi

Power and Dynamics Branch
Platforms Division
Defence Science and Technology Group (DSTG)
Australia

A Description of the Dataset for HUMS2027 Data Challenge

Summary

Planet bearing faults in helicopter main rotor gearboxes (MRGs) are among the most difficult failure modes to detect and trend. In 2004, the Defence Science and Technology Group (DSTG) conducted an overload endurance test on a Bell-206B (4-planet) MRG at the Helicopter Transmission Test Facility (HTTF). After roughly 80 hours of accelerated testing, one planet bearing inner race developed extensive naturally occurring spalling damage.

A previous blind analysis of this dataset showed that conventional diagnostic techniques struggled to detect the fault or track its progression. Given the significant advances in analysis methods over the past two decades, we have prepared this legacy dataset as the basis for the HUMS2027 Data Challenge. Awards will be presented to teams that demonstrate the earliest convincing detection with an accurate trending of the fault. This document describes the test and the dataset provided to HUMS2027 Data Challenge.

The Background

Detecting and trending planet bearing faults in planetary gearboxes is inherently challenging. Jain *et al* [1] studied the detection of planet bearing faults in wind turbine planetary gearboxes theoretically and experimentally. The study showed that a simulated inner race fault in the planet bearing is readily detectable using vibration data from a planetary gearbox text rig. The analysis was conducted using the envelope analysis on signals high pass filtered with a high cut-off frequency of 30 kHz. Interestingly, their results revealed that the inner race defect frequency and its harmonics were surrounded by two sets of modulation sidebands at the carrier frequency and the planet bearing cage frequency relative to the carrier. They attributed the unexpected cage frequency modulation to a possible slight variation in the rolling-element diameters.

The characteristic defect frequency of a spalled planet bearing inner or outer raceway can be calculated by the formulae in [1], which are given below:

$$\omega_{di} = \frac{Z_b}{2}\left(\omega_p - \omega_c\right)\left(1 + \frac{r_b}{R_b}\right) \tag{1}$$

$$\omega_{do} = \frac{Z_b}{2}\left(\omega_p - \omega_c\right)\left(1 - \frac{r_b}{R_b}\right) \tag{2}$$

where Z_b is the number of rolling-elements in the planet bearing, r_b is the rolling-element radius, and R_b is the planet bearing pitch radius. ω_{di} and ω_{do} are defect frequencies for the inner and outer race, ω_p and ω_c are the planet and the carrier rotational speeds, respectively. So, ($\omega_p - \omega_c$) is the planet speed *relative* to the carrier rotation.

In 2019, Zhou *et al* [2] analysed a set of data from a real helicopter (SA330 Puma) main gearbox seeded fault test. They claimed to have successfully detected the seeded planetary bearing outer race defect in multiple test cases using a combination of self-adaptive noise cancellation (SANC), kurtogram and the envelope analysis techniques. They also showed that kurtogram alone struggled to identify the demodulation band in the spectrum of the SANC-filtered signal.

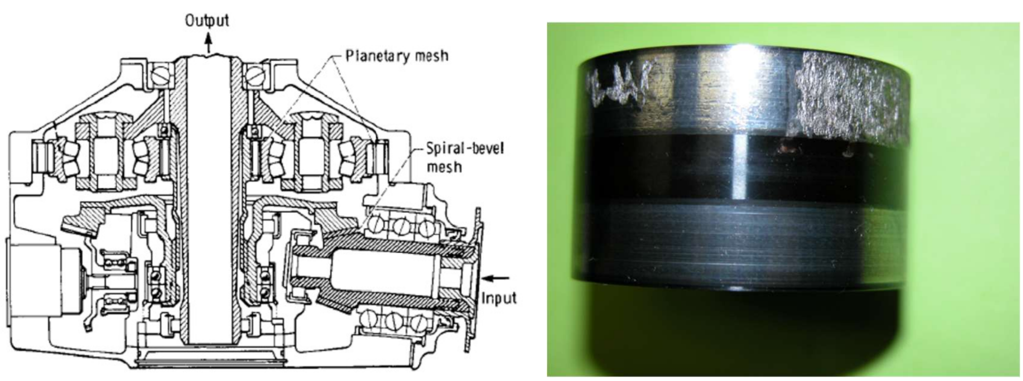
The DSTG Test

In 2004, DSTG conducted an overload endurance test on a full-scale helicopter (Bell-206B) main rotor gearbox (4-planet MRG) in their Helicopter Transmission Test Facility (HTTF).

The test article was a Bell Kiowa 206B-1 (OH-58) main rotor gearbox (4-planet version). A cross-sectional view of the gearbox is shown in Figure 1(*a*) and an exploded-view diagram of the gearbox with sensor locations is shown in Figure 2. Although these figures show the 3-planet version of the gearbox, the 4-planet configuration is mechanically similar aside from differences in the carrier, gears, and bearings. The planet gears in the 4-planet version are not evenly spaced due to kinematic constraints within the 99-tooth ring gear. This gearbox includes two speed reduction stages: a spiral pinion/bevel gear stage, and a planetary stage. With a nominal input speed of 6000 RPM, the output shaft speed was 344 RPM. The gear details and mesh frequencies are given in Table 1.

Table 1. Gear teeth and mesh frequencies for 6000 RPM nominal input speed

Component	No. of Gear Teeth	Gear Mesh Freq. (Hz)
Input pinion	19	1900
Bevel gear	71	1900
Sun gear	27	568
Planet gear x 4	35	568
Ring gear	99	568



(*a*) (*b*)

*Figure 1. (**a**) the Bell-206B MRG cross-section view showing the 3-planet version with spherical rolls whereas the 4-planet version has cylindrical rollers, and (**b**) the damaged inner race of one planet bearing inside the MRG.*

The test was conducted in repeated 30-minute cycles at 150% rated load. At the end of each cycle, vibration data was recorded on a Metrum RSR digital tape recorder for approximately 60 seconds at 150%, 120%, 100%, and 80% loads. After a sudden increase in wear debris mass at 56.97 test hours, the maximum load was reduced to 100% for the remainder of the test.

For the calculation of the plane bearing defect frequencies, there are 12 rollers, and the planet relative speed to the carrier is $(\omega_p - \omega_c) = 100/(71/19\times(99/27+1)\times 35/99) = 16.2202$Hz, the carrier speed is 5.73441 Hz, roller diameter is 12.97 mm, inner & outer raceway diameters are estimated as 48.97 and 61.94 mm, respectively. So, using Eqs. (1) and (2), we can calculate the plane bearing defect frequencies as:

- **Inner race defect:** $\omega_{di} = \frac{12}{2} \times 16.2202 \times \left(1 + \frac{12.97}{0.5\times(48.97+61.94)}\right) = 120.0828\ \text{Hz}$ (or 20.9408 carrier shaft order).
- **Outer race defect:** $\omega_{do} = \frac{12}{2} \times 16.2202 \times \left(1 - \frac{12.97}{0.5\times(48.97+61.94)}\right) = 74.5593\ \text{Hz}$ (or 13.0021 carrier shaft order).

The test concluded at 80.21 test hours due to an exponential growth in wear debris cumulative mass. In conjunction with the wear debris mass (WDM) data, one tachometer channel and four accelerometer channels (RR-1, IP-2, RF-3, RL-4) were collected from the test and stored in a legacy Metrum digital tape recorder. Post-test visual examination revealed that the inner raceway of one of the four planet bearings suffered extensive spalling damage as shown in Figure 1(*b*). The accelerometer locations are shown in Figure 2 and their descriptions are listed in Table . The sensitive axes of the ring gear accelerometers were radially aligned to the planetary stage, and the input gear accelerometer was radially aligned to the input shaft. A once-per-rev tachometer reference signal from the input shaft was used in the synchronous averaging process.

Table 2 Accelerometer locations (see Figure 2)

Sensor	Location Description
RR-1	• Ring-Rear of the gearbox (upper housing flange near ring gear)
IP-2	• Input-pinion flange
RF-3	• Ring-Front of the gearbox (upper housing flange near ring gear)
RL-4	• Ring-Left side (when facing front) of the gearbox (upper housing flange near ring gear)

In a previous blind analysis, we applied a range of traditional fault detection and diagnostic techniques to diagnose the fault at the earliest stage. These techniques included order tracking, discrete/random signal separation, minimum entropy deconvolution (MED), spectral kurtosis (SK) and cyclostationary analysis. The blind analysis results showed that these techniques failed to detect the planet bearing defect frequency or to reveal a convincing trend for damage progression. This has motivated the release of this dataset to the wider HUMS community for the HUMS2027 Data Challenge.

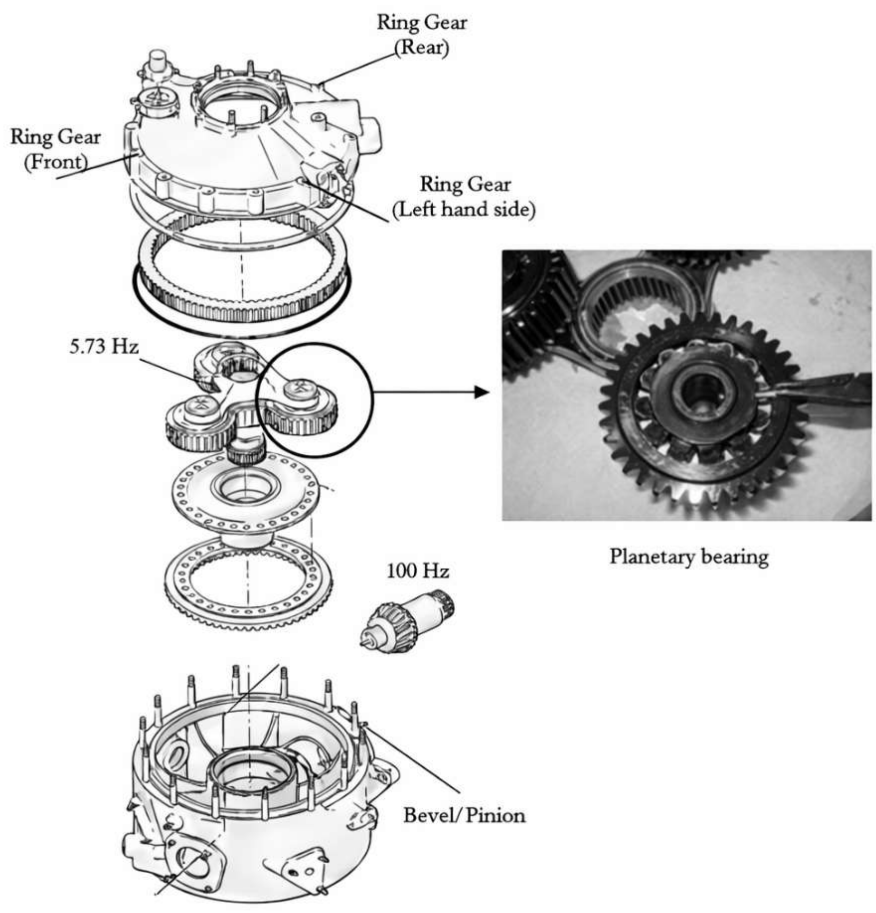


Figure 2. Bell-206B-1 (OH-58) main rotor gearbox (three-planet version). The four-planet version was used in the test. Four sensor locations are indicated in the figure.

The Dataset for HUMS2027

With the belief that the challenging failure mode, i.e. the planet bearing inner race spalling damage, should become detectable after the tremendous technological advancement in the last 20 years, we now derive a dataset from this legacy test for the HUMS2027 Data Challenge. The 323MB dataset in Matlab format consists of:

- one file containing wear debris cumulative mass (Fe_Cum_mg), oil temperature (Oil_Temp in ^{o}C), and the test hours (Test_Hours).
- 20 vibration data files, each 15-second long, sampled at 51200 Hz, recorded under 100% rated load at the corresponding test hours as indicated by variable "Test_Hours"

Each vibration file contains six channels of { Tach1, RR-1, IP-2, Tach2, RF-3, RL-4 }. Due to limitations of the legacy Metrum tape recorder only having a 3-channel data exporting capacity, the five channels were exported in two passes, resulting in two tachometer channels that are not aligned with each other. However, Tach1 aligns with RR-1 and IP-2 vibration signals and Tach2 aligns with RF-3 and RL-4. Therefore, Tach1 can be used for order tracking (or shaft angle-domain resampling) and synchronous averaging of RR-1 and IP-2, and Tach2 for RF-3 and RL-4.

The Data Challenge

The Data Challenge is open to all participants of HUMS2027. Competing teams can come from one single institution or across multiple institutions. The dataset will only be accessible to HUMS2027 participants. Interested people should show their intention of participating in the Data Challenge at the HUMS2027 website and agree to the terms and conditions for the data release. The committee will then send out a personalised link for participants to download the dataset.

Analysis results should be submitted by the final due date for HUMS2027 conference papers. The HUMS2027 committee will award the winning and runner-up teams that make the earliest convincing detection with an accurate trending of the fault progression. There is a cash prize of AUD$2000 to the winning team and AUD$1000 to the runner-up team. The results will need to be presented in Data Challenge designated sessions of the HUMS2027 conference. The competition result will be announced at the end of the last session of the HUMS2027 conference.

Any analysis methodology may be used. It can be physics-based, signal processing based, purely data-based, or use hybrid or any other techniques. At least one team member is required to attend the HUMS2027 conference and present their results, and all teams are encouraged to submit a paper.

Key Information

1. The HUMS2027 Data Challenge

KEYWORDS	DESCRIPTIONS
OBJECTIVE	• Competing for earliest fault detection with an accurate trending capability
TEAMS	• One team one entry, from a single or multiple institutes • At least one team member must participate in the conference and present results
METHODS	• No limitation on analysis methodology
AWARDS	• A cash prize of AU$2000 to the winning team • A cash prize of AU$1000 to the runner-up team • A certificate to the winner and runner-up
DATA ACCESS	• Access granted only to HUMS2027 participants • To download the data, show your interest at HUMS2027 website. On agreeing to the terms and conditions of the data release, you will receive an email from HUMS2027 Committee with the download link
QUESTIONS	• If there are questions about the test and dataset, please post the questions on the Q/A section of HUMS2027 Data Challenge website so they are visible to everyone.

2. The Dataset

KEYWORDS	DESCRIPTIONS
GEARBOX	• 4 planet gears in the planetary gearbox • The tooth numbers are: [Z_{pinion}, Z_{bevel}, Z_{sun}, Z_{planet}, Z_{ring}] = [19, 71, 27, 35, 99] respectively
DATA SIZE & FORMAT	• The dataset size: 323MB • in Matlab format, a double array per data file
ONE FILE: WD+TEMP+ HOURS	• one file consisting of the wear debris cumulative mass (Fe_Cum_mg), oil temperature measurement (Oil_Temp in oC) vs the test hours (Test_Hours).
VIBRATION DATA FILES	• 20 vibration data files, each of 15-second long, sampled at 51200 Hz, and acquired under 100% rated load • Each vibration file contains a 6-channel/column, {Tach1, RR-1, IP-2, Tach2, RF-3, RL-4}, array of 768000 × 6

3. The Endurance Test

KEYWORDS	DESCRIPTIONS
SPEED	• Nominally input pinion speed: 100 Hz • the output carrier shaft speed: 5.73 Hz • Gearbox reduction ratio: 17.44
LOAD CYCLE	• 30-minute load cycles: 150% load (27-min) – 120% (1-min) – 100% (1-min) – 80% (1-min) • Vibration data recorded at 150%, 120%, 100%, 80% at the end of each cycle on a Metrum RSR digital tape recorder
REDUCED LOAD	• The maximum load reduced to 100% after a sudden jump of wear debris cumulative mass from 42mg to 105mg at 56.97 test hours, indicating an accelerating damage progression
STOP	• The test concluded at 80.21 test hours due to an exponential growth in wear debris cumulative mass

REFERENCES

1. S. Jain, P.E. Whiteley, H.E.M. Hunt 2012, Detection of planet bearing faults in wind turbine gearboxes. The Proceedings of ISMA2012-USD2012, Leuven, Belgium, 17-19 September 2012, pp. 4351–4362.
2. L. Zhou, F. Duan, M. Corsar, F. Elasha, D. Mba 2019. A study on helicopter main gearbox planetary bearing fault diagnosis. Applied Acoustics 147, April 2019, pp. 4-14 (https://doi.org/10.1016/j.apacoust.2017.12.004).