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Helicopter Main Gearbox Planet Gear Crack Propagation Test Dataset

A description of the dataset for HUMS2023 Data Challenge

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Summary

The Defence Science and Technology Group (DSTG) has prepared a Data Challenge for the upcoming HUMS2023 conference. The vibration data come from a planet gear fatigue crack propagation test that was completed in January 2022. The Data Challenge will make two awards: one for the team that makes the earliest convincing detection of the planet gear crack, and one for the team that most accurately tracks the crack progression. Details about the test and the dataset for the HUMS2023 Data Challenge are presented below.

The Test

This test was designed to explore the phenomenon of fatigue cracking in thin-rim helicopter planet gears where the gear body incorporates the planet bearing outer raceway and the crack initiates at or near the raceway surface and propagates through the gear body. This type of fault is challenging to detect reliably, and it can lead to the catastrophic failure of the main rotor gearbox. Two helicopter accidents were attributed to similar types of fault (AS-332L2 Super Puma in 2009 [1] and H-225 Super Puma in 2016 [2]).

The seeded-fault test generated a vibration dataset from a propagating planet gear fatigue crack in a helicopter main rotor gearbox test under controlled conditions. The test was run in the Helicopter Transmission Test Facility (HTTF) at DSTG – Melbourne. The test article was a Bell Kiowa 206B-1 (OH-58) main rotor gearbox (four-planet version). This gearbox has two speed reduction stages: a spiral pinion/bevel gear stage, and a planetary stage. The test was run with a nominal input speed of 6000 RPM, giving an output speed of 344 RPM. The gear details and mesh frequencies are given in Table 1.

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

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

An exploded-view diagram of the gearbox with sensor locations is shown in Figure 1. A cross-sectional view of the gearbox is shown in Figure 2. These figures actually show the three-planet version of the gearbox, but the configuration is essentially the same for the four-planet gearbox apart from detail differences in the planet carrier, planet gears and bearings. Note that the spacing of the planet gears in the four-planet version is not quite equal due to kinematic constraints.

The cracked planet gear is shown in Figure 3. There are two notches in the gear, one on each side. This is because the first (smaller) notch did not initiate a crack in the first 146 load cycles. The gearbox was then disassembled and a second (larger) notch was added on the opposite side. A fatigue crack was successfully initiated and propagated from the second notch over load cycles 147 – 241. The dimensions of the notches are shown in Figure 4.

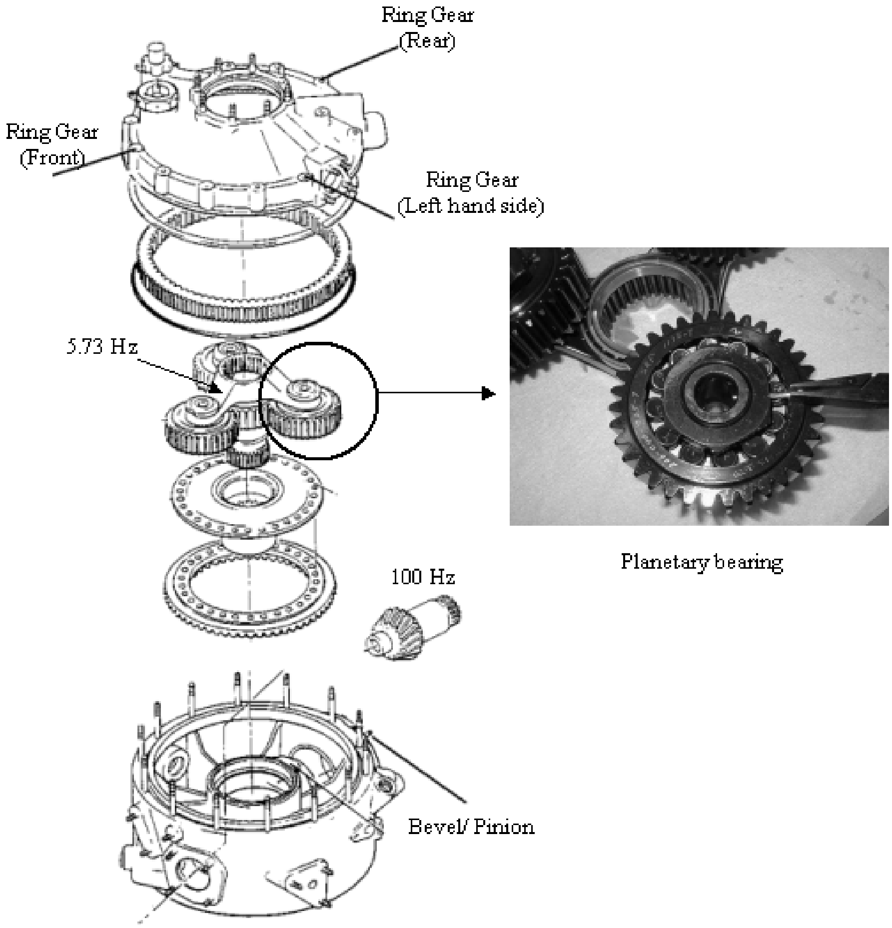

Figure 1 Bell 206B-1 (OH-58) main rotor gearbox (three-planet version). The four-planet version was used in the test. Four sensor locations are indicated in the figure.

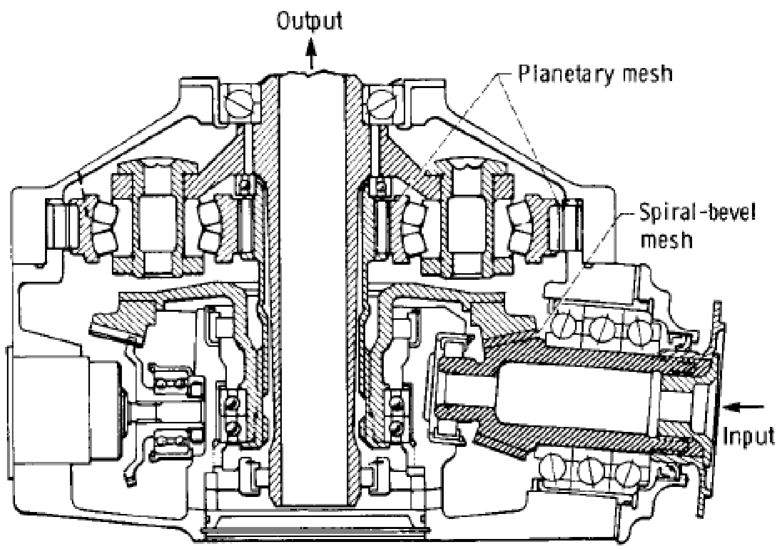

Figure 2 Bell 206B-1 (OH-58) main rotor gearbox (three-planet version) [from Lewicki & Coy (1987) https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19870011122.pdf].

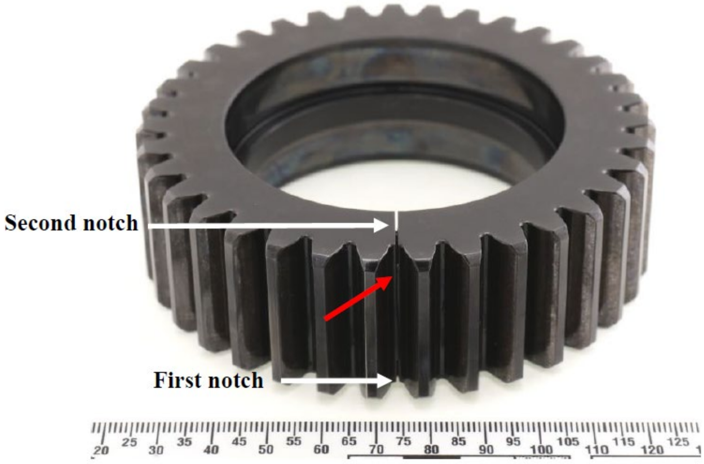

Figure 3 The cracked planet gear. The crack path is indicated by the red arrow.

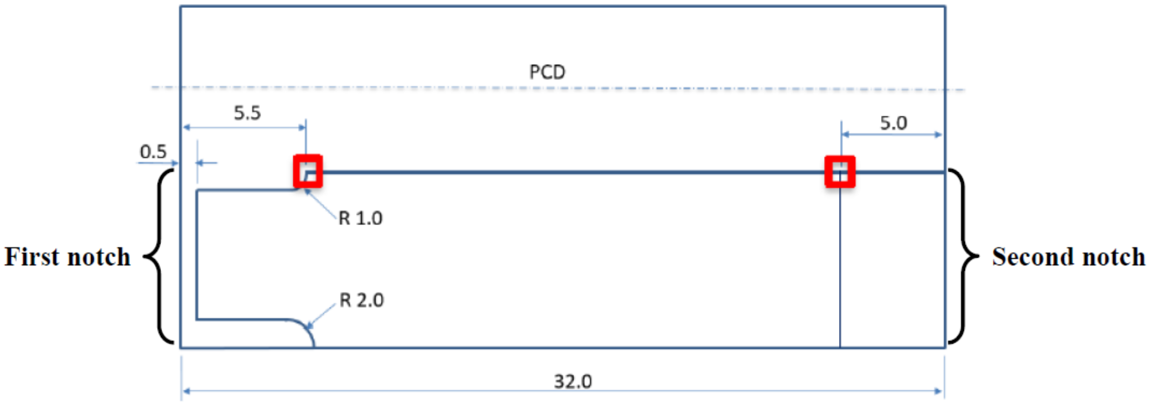

Figure 4 The notches in the planet gear (dimensions are in millimeters).

The test was undertaken using the loading cycle shown in Table 2. Most of the cycle is spent in an overload condition to accelerate the crack propagation. It is not meant to represent a typical flight profile. The lower torque values were incorporated to collect data at those torques (although data at these lower torques will not be provided in this dataset) and add markers into the fracture surface of the propagating crack. The load percentage is an estimate of the nominal rated load.

Table 2 Loading cycle

#	Load	Input Torque (Nm)	Input speed	Duration
A	50%	152	6000 RPM	2 minutes
B	75%	227	6000 RPM	2 minutes
C	100%	303	6000 RPM	2 minutes
D	125%	379	6000 RPM	24 minutes

Two close-up views of the cracked gear are shown in Figure 5 and Figure 6. These figures show the final state of the crack, where it had propagated through the full width of gear body in the valley between the gear teeth. The planet gear was subsequently sectioned for a post-test analysis of the fracture surface to estimate the crack propagation versus load cycle.

Figure 5 The complete crack viewed from the tooth top of the planet gear. The crack was propagated from the EDM notch at the bottom of the picture.

Figure 6 The complete crack viewed from the inner bore of the planet gear (the outer raceways of the double planet bearing). The crack was propagated from the EDM notch on the left.

The Dataset

To keep the size of the dataset modest (individual raw data files exceed 84 MB), only the hunting-tooth synchronous averages of the planet/ring gears (at 125% torque) from four vibration channels for the last 7 days of testing will be released for this challenge. The hunting tooth average is designed such that both the planet gear synchronous average and the planet carrier synchronous average can be derived from it (see details in a note for the dataset). The dataset incorporates the final 60 load cycles of the test where the gearbox was running at more stable operating conditions. There are 526 four-channel planet/ring hunting tooth average (TSA-hunting) data files in the dataset, with a total size of 6.1 GB.

The accelerometer locations are listed in Table 3 (also refer to Figure 1). 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 3 Accelerometer locations (also ref to Figure 1)

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

The Data Challenge

The Data Challenge is open to all participants of HUMS2023. Competing teams can come from one single institution or across multiple institutions. The dataset will only be accessible to HUMS2023 participants at this stage. Interested people should show their intention of participating in the Data Challenge at the HUMS2023 website and agree to the terms and conditions for the data release. The committee will then send to each registered person a link for participants to download the dataset.

Analysis results should be submitted by 01 November 2022, which coincides with the due date for HUMS 2023 conference papers. The HUMS2023 committee will award winners in two categories: one for the team that makes the earliest convincing detection of the planet gear crack, and one for the team that most accurately tracks the crack progression. There is a cash prize of AUD$1000 in each category. The results will be presented in Data Challenge designated sessions of the HUMS2023 conference. The winners will be announced at the end of Day 2 of the HUMS2023 conference, during the AIAC Dinner.

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 HUMS2023 conference and present their results, and all teams are encouraged to submit a paper.

Key Information

- One team one entry
- At least one team member must participate in the conference and present results
- No limitation on analysis methodology
- Two categories of winners – earliest detection and the best trending capability
- A cash prize of AU$1000 to the winners of each category
- A certificate to the winner and runner-up of each category
- To download the data, show your interest at HUMS2023 website before the end of September 2022. On agreeing to the terms and conditions of the data release, you will receive a download link.

- You may email with questions about the dataset or data challenge. Answers will be posted on the Q/A section of HUMS2023 Data Challenge website so they are visible to everyone
- The planet/ring hunting-tooth averaged signals in the last 60 load cycles are available
- All 526 hunting-tooth average signals are at 125% load. Other factors, such as lubrication oil temperature, could be different due to environmental conditions
- The input pinion speed is 100Hz nominally, the output shaft speed is 5.73Hz
- Gearbox reduction ratio is 17.44
- 4 planet gears in the planetary gearbox
- The tooth numbers are: $[Z_{pi}, Z_b, Z_s, Z_{pl}, Z_r] = [19, 71, 27, 35, 99]$ respectively
- Two EDM notches inserted separately; the 1st (smaller) notch didn't initiate a crack in first 146 load cycles; the 2nd (larger) notch initiated a crack that propagated over 95 load cycles (only the last 60 cycles available for the Data Challenge)

REFERENCES

[1] United Kingdom Air Accidents Investigation Branch (AAIB), Report on the accident to Aero-spatiale (Eurocopter) AS-332 L2 Super Puma registration G-REDL 11 NM NE of Peterhead Scotland on 1 April 2009, AAIB Aircraft Accident Report 2/2011.

[2] Accident Investigation Board Norway (AIBN), Report on the Air Accident Near Turøy, Øygarden Municipality Hordaland County Norway 29 April 2016 With Airbus Helicopters EC-225-LP LN-OJF Operated by CHC Helikopter Service, AIBN Report SL 2018/04, July 2018.