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DETECTING PLANETARY GEAR BORE CRACK

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Abstract

Since 2009 there have been two fatal crashes of the Super Puma helicopter caused by fatigue cracks propagated from the bore of the planetary gear in the main transmission gearbox. The bore crack propagated through the gear rim causing the planet gear to breakup, which consequently destroyed the integrity of the transmission gearbox. For helicopter safety, it is imperative to develop methodologies for detecting such faults and to implement this capability into helicopter Health and Usage Monitoring Systems (HUMS). In this paper, a method is proposed to detect and track the propagation of a planetary gear bore-crack based on planet gear Synchronous Signal Averaging (SSA) and residual signal enveloping. The method has been initially validated using the vibration data generated from a small industrial planetary gearbox test rig with a notch inserted in the bore of one of its planetary gears. Results from this test show that the planetary gear bore notch is detectable with two different notch sizes using the residual signal of the composite planet SSA signal under three different load conditions. Furthermore, the diagnostic capability may be achievable using the squared envelope of the SSA residual signal, where the respective meshing of the defective section in the planet gear with the ring and sun gears are individually identifiable. Further bench testing will be conducted in the small test gearbox and in a full-scale Bell-206B helicopter main rotor gearbox with a very fine spark-eroded initial notch defect inserted in the bore of the planetary gear. The objective is to initiate a real fatigue crack from the bore notch and propagate the crack. The vibration data generated in this test will be used to further validate the proposed method.

1. INTRODUCTION

There is a particularly challenging type of fault in the helicopter planetary gearbox – the planet gear bore cracking that has caused two fatal crashes of the Super Puma helicopter since 2009. The fatigue crack originated from bearing outer raceway spalls and propagated into the gear rim causing the planet gear to disintegrate, which consequently destroyed the integrity of the main rotor gearbox [1, 2]. To enhance safety, it is imperative to develop techniques to detect this type of fault and to implement this capability into helicopter health and usage monitoring systems. In this paper, a method is proposed to detect and track the progression of a planetary gear bore crack based on planet gear synchronous signal averaging and residual signal enveloping.

For the Super Puma helicopter accidents, both accident investigation reports [1, 2] mentioned that the existing HUMS on the Super Puma did not detect any anomaly prior to the failure. In a YouTube video uploaded on 07 October 2017 (https://www.youtube.com/watch?v=KvBLadpVscY), Airbus Helicopters claimed that there is currently no vibration means of detecting the particular type of fault that caused the crashes of an AS-332L2 Super Puma in 2009 and an EC-225 Super Puma in 2016. After the 2009 accident, the European Aviation Safety Agency (EASA) funded Cranfield University in the United Kingdom to conduct a research project on vibration and alternative monitoring techniques for helicopters, and for planetary gear trains in particular. The study had an emphasis on planet gear bearing outer race damage (i.e. the origin of the problem) detection using Acoustic Emission (AE) and a wireless sensor mounted inside the planetary gearbox. The final report [3] of this project concluded that the range of available and effective technologies is limited for real-time monitoring of rotating components using sensors inside the main rotor gearbox. However, despite apparent saturation of the sensor due to harsh vibration environment, the study did show some promise that it is feasible to clearly identify the bearing fault frequencies using a wireless AE sensor mounted on the planet gear of an operational gearbox. The report has given a thorough

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technology review of the fault diagnosis problem for helicopter planetary gearboxes.

The vibration detection of planet gear faults, mainly planet gear tooth cracking, has been studied extensively by many researchers since 1990's. Significant progress has been reported by McFadden [4] and Forrester [5]. However, these techniques are not validated in their studies using data from real helicopter gearbox failures because of the rarity of such failures, and a lack of any captured raw vibration data from a failure event. Lewicki et al. [6] carried out an investigation into detecting planetary gearbox faults using vibration separation algorithms including those developed by McFadden [4] and Forrester [5]. Using NASA's test facility based on an OH-58C helicopter planetary system with healthy and several seeded-fault components, they evaluated the effectiveness of various planetary fault detection algorithms based on vibration analysis. The results showed that planet gear tooth cracks and spalls were detectable using the vibration separation techniques, and envelope analysis provided an effective method for detecting planet bearing inner- and outer-race spalling faults.

A study conducted by Wang et al. [7] employed a method based on the Spectral Kurtosis (SK) ratio to identify the optimal frequency band for envelope demodulation analysis to detect planet bearing faults. The SK ratio is obtained by calculating the ratio between the SK matrix of raw faulty-state signal and the baseline healthy-state signal. A study on planet bearing diagnostics under variable speed conducted by Wade et al. [8] showed the importance of processing the signal in both the time and angle domains, e.g. removing deterministic gear mesh signal components in the angle domain and bandpass filtering in the time domain, for planet bearing fault diagnosis. The study also showed some promise of cyclo-stationary processing tools over the widely-used kurtogram for demodulation band selection. Recently, Zhou et al. [9] examined a number of frequency domain analysis techniques for diagnosing corrosion damage in a planet bearing of the CH-46E Sea Knight helicopter with the well-known Westland dataset. They concluded that the kurtogram gives the most reliable diagnosis results as a benchmark technique in comparison to the Self-Adaptive Noise Cancellation (SANC), Discrete-Random Separation (DRS), and the cepstrum editing techniques.

There is no literature found on detecting planetary gear bore cracking, which is the topic of this paper. The proposed method focuses on using composite Synchronous Signal Averaging (SSA) with respect to the rotation of the planet gear rather than the planet carrier. The word 'composite' is used here in the sense that we are not trying to separate the vibration from the individual planet gears, which will all be producing similar vibration at the same frequencies. The SSA with planet carrier is commonly used in helicopter health and usage monitoring systems (HUMS) to detect faults in planetary gearboxes, but the SSA with planet gears is less commonly employed. The detection is based on the assumption that planet gear deformation caused by a bore crack would distort its mesh with the ring and sun gears, and thus distort the planet gear mesh signature derived from the SSA, i.e. planet-SSA. The distortion is assumed to be represented by the extra modulations to the normal gear mesh signature, which should appear as modulation sidebands in the SSA spectra. With the Composite Planet-SSA (CP-SSA), we first remove the planet gear mesh harmonics to form the so-called residual signal for the planet gear. For fault detection, the RMS energy of the planet gear residual signal can be trended against time to detect any exceedance to any pre-defined threshold. For fault diagnosis, a squared envelope operation is then applied to the residual signal. In the envelope signal, we expect to observe peaks when the defective section in the planet gear is in mesh with either the ring gear or the sun gear. To further enhance the diagnosis, we can obtain the CP-SSA over multiple revolutions of the planet gear.

This method has been initially validated using the vibration data generated from a small industrial planetary gearbox test rig with a notch inserted in the bore of one of its planetary gears. Results from this test show that the planetary gear bore notch is detectable using the residual signal of the CP-SSA signal under three different load conditions. With two different notch sizes, a monotonic trend is also clearly observed. Furthermore, the diagnostic capability may be achievable using the squared envelope of the SSA residual signal, where the respective meshing of the defective section in the planet gear with the ring and sun gears are individually identifiable. Further bench testing will be conducted in this small test gearbox and in a full-scale Bell-206B helicopter main rotor gearbox with a very fine spark-eroded initial notch defect inserted in the bore of a planetary gear. The objective is to initiate a real fatigue crack from the bore notch and propagate the crack. The vibration data generated in this test will be used to further validate the proposed method. Other types of sensors such as the wear debris and wireless vibration sensors will also be installed in this test for a comparative study.

2. FAULTS IN PLANET GEAR-BEARING

It is common for helicopter main rotor gearboxes to have integral planet gear and bearing components, where the planet bearing outer raceway and the planet gear body (or rim) is an integral part. Therefore, faults originating from the planet bearing, e.g. outer raceway spalls, can significantly impact the integrity of the planet gear. Planet gear-bearing configurations may be different for industrial and wind turbine planetary gearboxes, e.g. the outer race of the planet bearing may be a separate component from the planet gear body or rim, which is the case in this paper.

2.1. Planet bearing fault detection

The detection of planet bearing faults is extremely difficult using Vibration Analysis (VA). This is mainly because the planetary motion of the bearing can significantly weaken the measured vibration signal by a transducer mounted at a fixed position on the ring gear. The moving transmission paths, and multiple planet gears producing near identical vibrations, complicate the detection of the fault buried in one planet gear/bearing. Over the last few decades, various VA techniques have been proposed for detecting planet bearing faults. The representational ones are summarised in the EASA Research Report on Vibration Health Monitoring [3].

Because of the difficulty in planet bearing fault detection using vibration-based methods, current helicopter HUMS often rely on wear debris analysis to detect bearing materials in the lubrication system of the gearbox. However, in both Super Puma accidents, the magnetic chip detection was unsuccessful at preventing the accidents due to either an insufficient amount of debris (i.e. only 1 or 2 pieces) being detected [1] and/or the debris was trapped by the oil filter and not completing the journey to the chip detector [2].

2.2. Planet gear fault detection

Common planet gear faults include tooth cracks and spalls, which have been studied extensively over the last 40 years. In this paper, our focus is on planet gear bore cracking, which is an unusual type of fault and has reportedly only occurred on the two failures of the Super Puma helicopter. As an example of the planet gear bore crack propagation, the 2016 H225 planet gear failure case is shown in *Figure 1*, which shows that the crack [2] was initially formed on left side of the picture from a spall on the bearing outer raceway.

Figure 1. H225 Super Puma planet gear bore crack propagation [2, Fig. 31] – Photo from AIBN/QinetiQ

To date, no VA method has been reported in the literature that is capable of detecting this rare type of failure for planet gears. As a general expectation, the planet gear bore cracking may have some unique vibrational characteristics compared to those from planet gear tooth cracking. For example, the effect of a bore crack on the planet gear mesh patterns might cover a larger shaft angle than that of a tooth crack. In other words, the effect of tooth cracking on gear mesh vibration may be more localised (i.e. it will occur more suddenly when the cracked tooth comes to mesh) than bore cracking, which may be more gradual and affect multiple teeth either side of the bore crack location. As a result, we would expect that bore cracking would produce features in a lower frequency band than those with tooth cracking. Because it is a fault on the planet gear, the first approach one tends to employ is the synchronous signal averaging process with respect to the rotation of the planet gear, i.e. CP-SSA.

3. METHOD OF DETECTING PLANET GEAR BORE CRACK

To detect a fault in any of the planet gears, we first need to isolate the vibration generated by the planet gears from other vibration sources. This isolation is normally achieved by SSA. In this paper, we take the composite planet SSA (CP-SSA) over 1000 revolutions of planet gear shaft using 5^{th} order spline interpolation [10] to resample the raw data in the shaft-angle domain. The CP-SSA represents the combined vibration produced by all the planet gears, which is not able to further isolate the vibration from the individual planet gears. Further isolation can be achieved using planet separation algorithms [4, 5]. In this paper, we do not employ a planet separation algorithm since the planet pass modulation patterns typically used by these algorithms are not clearly defined.

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As the planet gear mesh harmonics would normally dominate the CP-SSA spectrum, we then remove the planet gear mesh harmonics (i.e. harmonics of the ×23 shaft-order component) to obtain the residual signal with low pass filtering at 305 shaft orders. The low pass filtration is important to the detection of the fault of interest in this paper, i.e. the planet gear bore cracking. This is because the changes induced by the bore crack are expected to be less localised than those by tooth cracking and to contain features mostly in the lower frequency region.

With the residual signals from CP-SSA, we can extract the RMS values and trend them for fault detection, and we can obtain the squared envelope signals for further fault diagnosis. One approach to diagnose the fault is to calculate the CP-SSA over multiple revolutions of the planet gear and to observe the repetitive meshes of planet gear with the ring and sun gears.

4. EXPERIMENTATION WITH PLANET GEAR BORE CRACK

The vibration data analysed in this paper were acquired from a planetary gear test rig at the University of New South Wales (UNSW) in Australia. *Figure 2* shows the respective gear tooth numbers and the configuration of the test gearbox that has 3 planet gears. More details about the rig can be found in [8].
Figure *3* shows a diagram with dimensions and a picture of the notched test planet gear. The gear has an electric discharge machined (EDM) notch through the outer race ring of the planet bearing and into the rim of the planet gear. This type of planet gear-bearing, often found in industrial machinery, is different from those in most helicopter main gearboxes as described in the previous section. The thickness of the gear rim is 3.5 mm (i.e. 9.5 – 6) and we had two sizes (1 mm and 1.5 mm) of EDM notches into the rim.

During the test, the gearbox was running under three different torques on the output shaft, i.e. 45 Nm, 65 Nm and 85 Nm, where 85 Nm is the rated load for the test rig. Altogether there were 9 runs with 3 health conditions, i.e. baseline healthy condition and 2 faulty (EDM notched) conditions, and 3 operation conditions at 3 different loads with a fixed speed of 293 rpm at the input drive shaft. A vibration transducer was mounted on the ring gear housing and a tachometer sensor was placed on the free end of the drive shaft. Raw vibration and tachometer data were recorded for 100 seconds at the sampling rate of 131072 Hz.

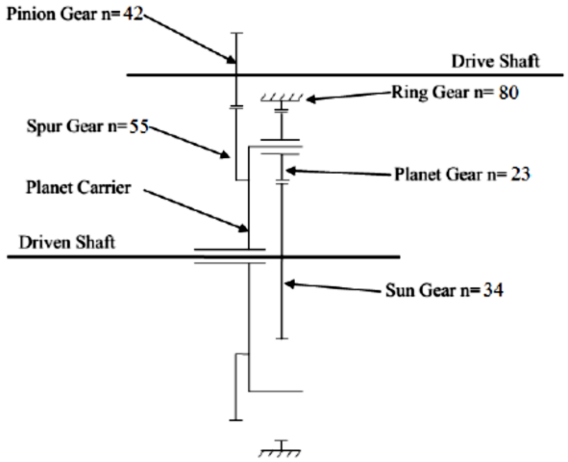

Figure 2. Test planetary gearbox configuration (Courtesy of UNSW [8])

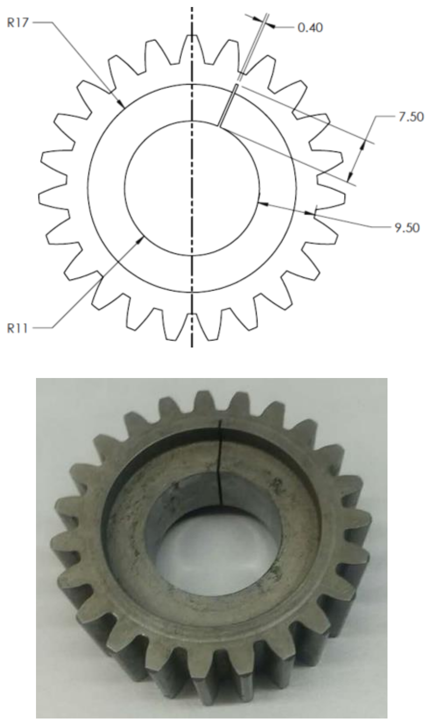

Figure 3. Test planet gear with an EDM notch (Courtesy of UNSW)

5. VIBRATION ANALYSIS RESULTS

A commonly used VA method in helicopter HUMS is the SSA with respect to the rotation of the planet carrier (or ring gear, denoted as carrier-SSA). The spectra of the resampled raw vibration signal and carrier-SSA are shown in *Figure 4*. As can be seen, the dominant spectral components are the planetary gear mesh harmonics indicated by multiples of 81 (ring gear tooth number) and the drive gear mesh harmonics by multiples of 55 (tooth number of the spur gear which meshes with the drive gear with 42 teeth).

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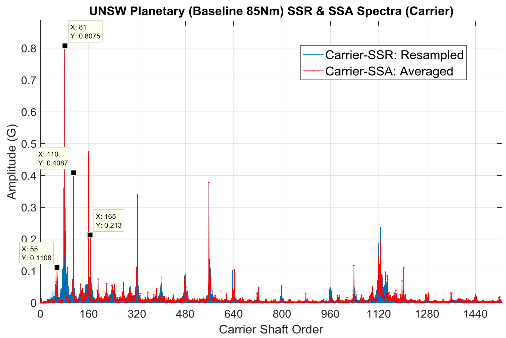

Figure 4. Spectra of the resampled raw vibration signal and carrier-SSA

In order to examine the planet gear vibration characteristics induced by a bore crack, we will need to remove the two sets of dominant gear mesh harmonics at ×81 and ×55 as shown in *Figure 4*. However, the removal of ×81 and ×55 harmonics from the carrier-SSA spectrum will still not be able to obtain the bore crack induced characteristics because the spectral content synchronous to planet gear rotation is averaged out in the carrier-SSA. This is why it is crucial to employ the SSA of the planet gears, denoted by planet-SSA, to detect a fault in any of the 3 planet gears. The planet-SSA used in this paper is the so-called composite planet-SSA (CP-SSA) which does not separate vibration from individual planet gears. Studies conducted by McFadden [4] and Forrester [5] allow planet separation provided there is a well-defined modulation pattern associated with the planet gear passing through the transducer at a fixed location on the ring gear. *Figure 5* shows the baseline CP-SSA at 85 Nm torque for the test gearbox, which is a typical 23rd (planet gear tooth number) order sinusoidal harmonic signal. Obviously, there are 23 spikes in the CP-SSA.

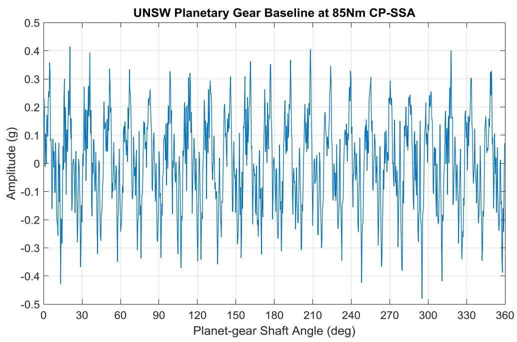

Figure 5. Baseline CP-SSA at 85 NM torque for the test gearbox

5.1. Fault detection and trending

Using raw vibration data acquired in the 9 test runs, we calculated the CP-SSA's and removed the planet gear mesh harmonics at ×23 and obtained the residual signals as shown in *Figure 6* to *Figure 13*. Note that data acquired at the baseline condition with 65 Nm torque was corrupted so no result is shown for this run. The number of averages used in these calculations was 1000, which means that at least 1000 revolutions of the planet gear worth of data were needed to calculate the CP-SSA.

From the baseline conditions shown in *Figure 6* and *Figure 7*, we can see a flat pattern with the planet gear residual signal across the whole revolution of the planet gear. However, both the RMS and kurtosis values under heavy load were increased slightly. For the 1 mm EDM notch, see *Figure 8* to *Figure 10*, there are some obvious spikes in the residual signals at certain rotation angles of the planet gear, and there is a monotonic increase of RMS values with the increasing load. The kurtosis values, however, do not follow a monotonical trend with load. It is worthwhile to note that the spikes may have occurred at different shaft angle locations at the different loads. This is because there is no absolute planet gear angular reference; hence the planet gear SSA can start at a different planet gear shaft angle in each case.

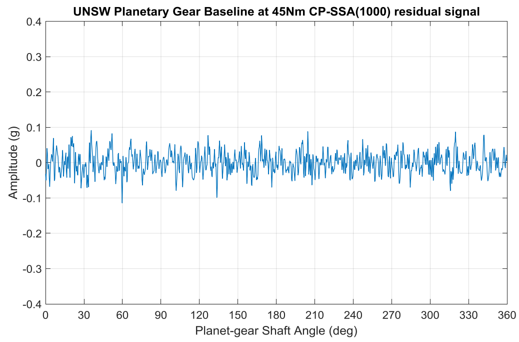

Figure 6. Planet gear residual signal for baseline condition at 45 Nm torque where RMS = 0.032(g), Kurt = 2.88

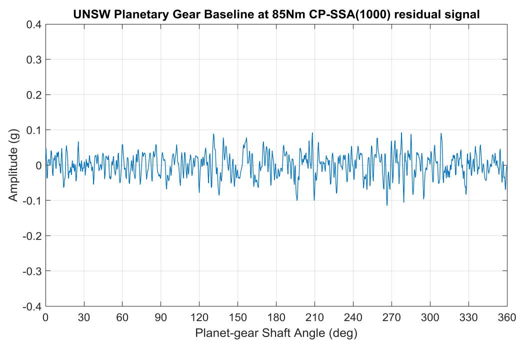

Figure 7. Planet gear residual signal for baseline condition at 85 Nm torque where RMS = 0.035(g), Kurt = 3.056

The observations with the 1 mm notch are

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reinforced by the result with the 1.5 mm notch shown in *Figure 11* to *Figure 13*. Of particular interest is the monotonic increase of the RMS values with the notch size. Therefore, it appears that the RMS values of the planet gear residual signals are changing monotonically with both notch size and the load level. On the other hand, the kurtosis values do not follow this monotonic trend.

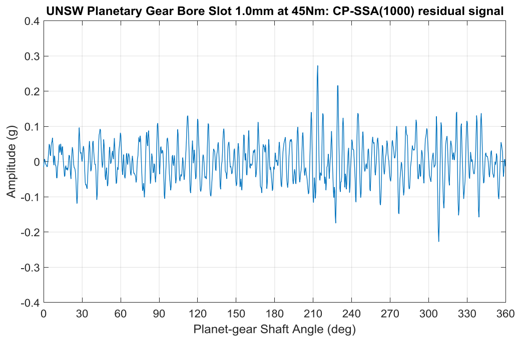

Figure 8. Planet gear residual signal for 1.0mm notch at 45Nm torque where RMS = 0.0576(g), Kurt = 4.1

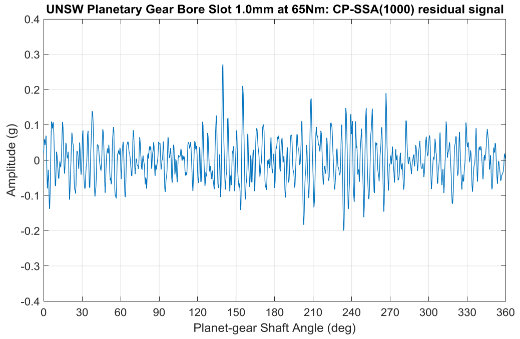

Figure 9. Planet gear residual signal for 1.0mm notch at 65Nm torque where RMS = 0.0614(g), Kurt = 3.72

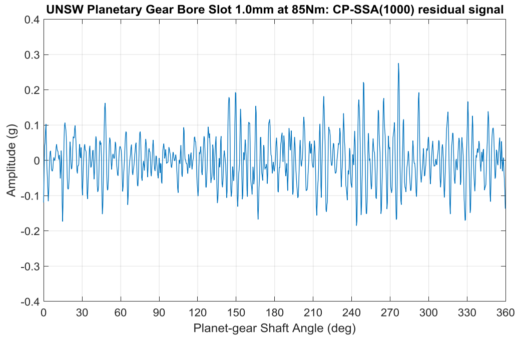

Figure 10. Planet gear residual signal for 1.0mm notch at 85Nm torque where RMS = 0.067(g), Kurt = 3.66

Table 1 summarises the results of the RMS values from the residual signals derived from the CP-SSA's shown in *Figure 6* to *Figure 13*. As a comparison, the RMS values of the corresponding CP-SSA's are also listed in the table. The indices in Table 1 are plotted in *Figure 14* and *Figure 15*, where the monotonic trend of residual signal RMS values is apparent in *Figure 15*. Potentially, with further validation using data from real cracks the residual signal RMS value may be employed as the health condition indicator (CI) for detecting planet gear bore cracking.

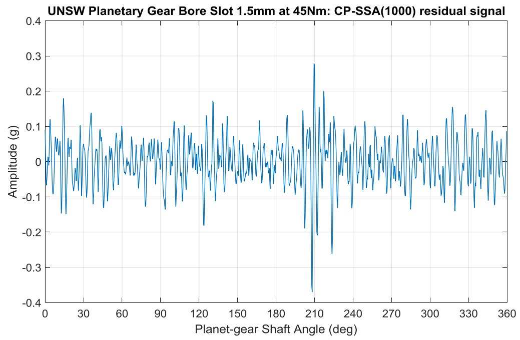

Figure 11. Planet gear residual signal for 1.5mm notch at 45Nm torque where RMS = 0.0676(g), Kurt = 4.999

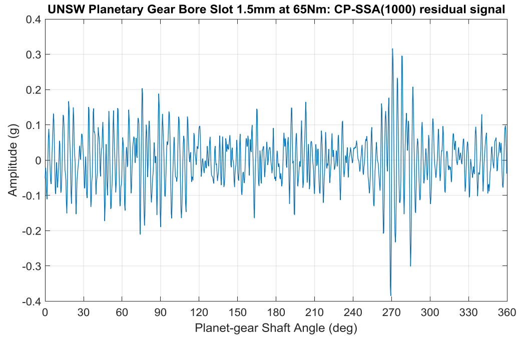

Figure 12. Planet gear residual signal for 1.5mm notch at 65Nm torque where RMS = 0.0767(g), Kurt = 4.788

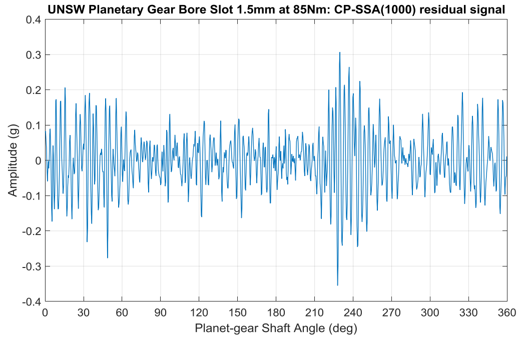

Figure 13. Planet gear residual signal for 1.5mm notch at 85Nm torque where RMS = 0.0809(g), Kurt = 4.115

The EDM notch lengths of 1.0 mm and 1.5 mm into the rim of planet gear is equivalent to 28.57% (i.e. 1 / 3.5) and 42.86% (i.e. 1.5 / 3.5) of the gear

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rim being cracked from the bore, respectively. It appears that the planet gear bore cracking is detectable using the residual signal of the CP-SSA. The two abnormalities or fault features (separated by roughly 180 degrees of shaft angle) are obviously identifiable in *Figure 12* and *Figure 13* for cases of 1.5 mm at 65 Nm and 85 Nm torques, respectively. These are presumably associated with the meshing of the planet teeth adjacent to the bore notch with the ring and sun gears. The RMS value of the residual signal seems to be a good index for trending the crack length (severity) development, as shown in *Figure 15*.

Table 1. RMS values of CP-SSA(1000) and their residual signals

Torque (Nm)	**Baseline (healthy condition)**		**1.0mm bore notch (faulty condition I)**		**1.5mm bore notch (faulty condition II)**	
	CP-SSA (y_a)	Residual (y_r)	CP-SSA (y_a)	Residual (y_r)	CP-SSA (y_a)	Residual (y_r)
45	0.1041	0.0319	0.1997	0.0576	0.1822	0.0676
65	*	*	0.2320	0.0614	0.2044	0.0767
85	0.1631	0.0353	0.2435	0.0670	0.2181	0.0809

* data file corrupted

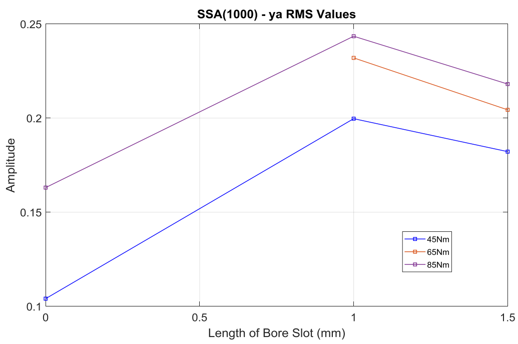

Figure 14. Trending of RMS values of CP-SSA signals

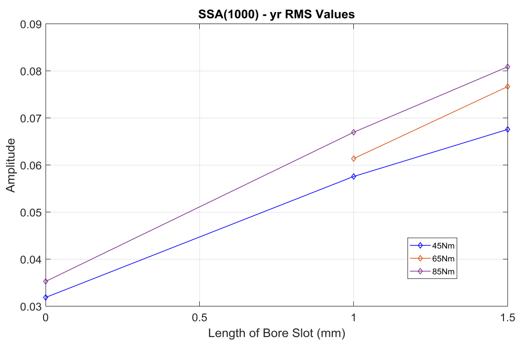

Figure 15. Trending of RMS values of residual signals derived from CP-SSA.

5.2. Fault diagnosis

To enhance diagnosis, we took the CP-SSA with respect to 3 revolutions of the planet gear shaft using the 5th order spline interpolation. Then we removed the ×23 gear mesh harmonics with low pass filtering at 305 shaft orders to obtain the residual signal. Lastly, we obtained the squared envelope from the residual signal. The resulting envelope signal for the 1.5 mm notch at 85 Nm torque is shown in *Figure 16*, where the changes (spikes) produced by the meshes of planet gear faulted section with the ring and sun gears are clearly identifiable.

When comparing *Figure 16* to *Figure 13*, it can be seen that the fault features are more clearly identifiable in the squared envelope signals of CP-SSA over 3 revolutions of the planet gear, than those in the residual signals over one revolution of the planet gear. It is assumed that the larger spikes in *Figure 16* are associated with the planet-ring meshing, and the smaller spikes are associated with the planet-sun meshing because of the differences in the vibration transmission paths between these two meshes to the transducer on the gearbox housing. In addition, we can overlay the scaled (with a factor of 5) squared envelope signals with the CP-SSA residual signals for more direct comparison in terms of visualisation for fault diagnosis. These plots are shown in *Figure 17* to *Figure 22*.

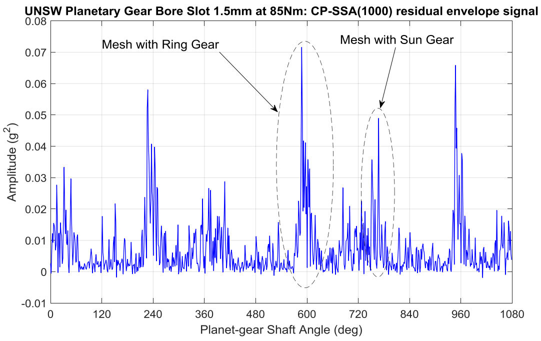

Figure 16. Feature signal (in 3 revolutions) for the detection of planet gear bore cracking. It is assumed that the larger spike is the mesh with the ring gear, and the smaller one is with the sun gear

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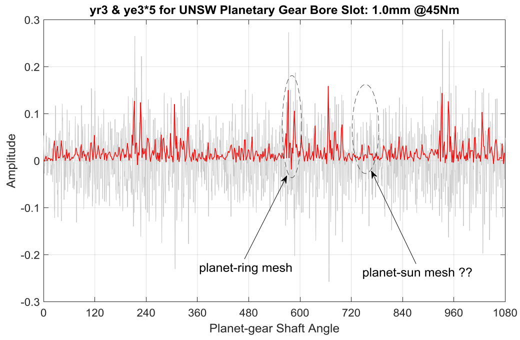

Figure 17. Residual (grey) and scaled envelope (red) signals for 1.0 mm notch at 45 Nm torque

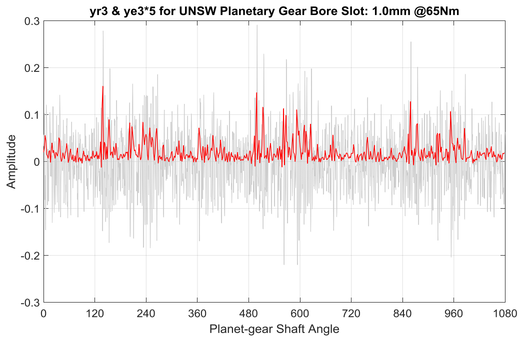

Figure 18. Residual (grey) and scaled envelope (red) signals for 1.0 mm notch at 65 Nm torque

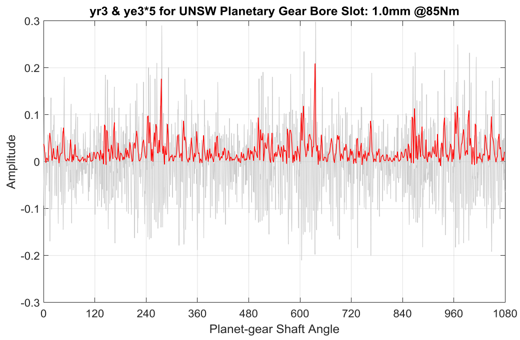

Figure 19. Residual (grey) and scaled envelope (red) signals for 1.0 mm notch at 85 Nm torque

Comparing the results for 1.0 mm notch (in *Figure 17* to *Figure 19*) to the 1.5 mm notch (in *Figure 20* to *Figure 22*) at different torques, we found the following:

- With the 1.5 mm notch, there are two main features associated with the planet-ring mesh and planet-sun mesh (roughly 180 degrees apart), and other smaller features can be seen in between the two main features;
- With the 1.0 mm notch, the features with planet-sun mesh appear to be quite weak and the in-between feature is stronger, for which we do not have an immediate explanation;
- The main features are much weaker for the smaller notch length;
- With lighter load, the feature associated with the planet-ring mesh is still comparable to heavier load, but the feature with associated with the planet-sun mesh is certainly weaker;
- With heavier load, the feature with planet-ring mesh seems to occupy a broader shaft angle, which is obvious in the case of 1.5 mm notch.

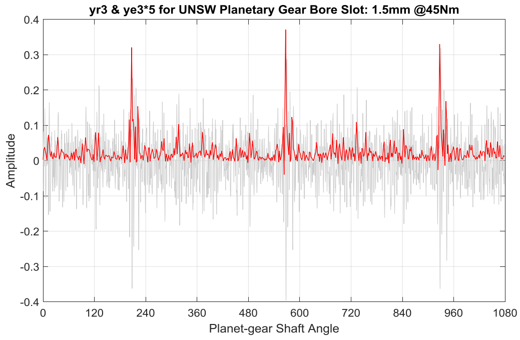

Figure 20. Residual (grey) and scaled envelope (red) signals for 1.5 mm notch at 45 Nm torque

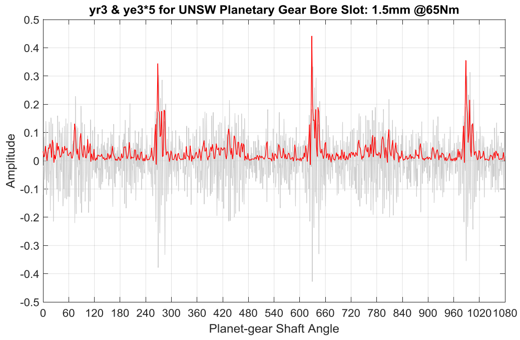

Figure 21. Residual (grey) and scaled envelope (red) signals for 1.5 mm notch at 65 Nm torque

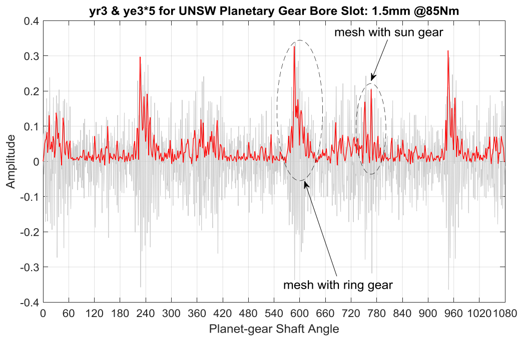

Figure 22. Residual (grey) and scaled envelope (red) signals for 1.5 mm notch at 85 Nm torque

Intuitively, we tend to attribute the spikes to the planet-ring and planet-sun gear meshes. This is because the planet gear with a bore crack is more deformed when the crack is aligned with radial load from gear mesh, i.e. the crack opens up in the tensile stress zone, than the planet gear without a bore crack. When the crack is not aligned with radial load of gear mesh, i.e. the crack closes down in the compressive stress zone, the deformation of the cracked gear is similar to the un-cracked gear. This explanation may be better illustrated by the diagram in *Figure 23*.

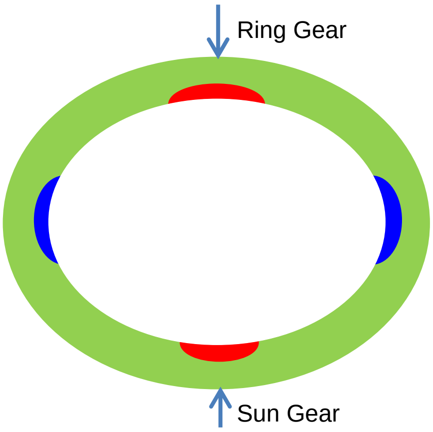

Figure 23. A diagram showing the opening on tensile stress (red) and the closing on compressive stress (blue) of the bore crack of a planet gear in mesh with the ring and sun gears, respectively.

6. CONCLUSION

In this paper, we propose a technique to detect and diagnose a very challenging type of fault – planet gear bore cracking. The fault detection can be achieved by trending the RMS values of the residual signal derived from the composite planet-gear SSA (CP-SSA) signal. When the RMS value exceeds a certain threshold, an anomaly of the planet gears is claimed to be detected. The diagnostic capability may be achievable using the squared envelope of the CP-SSA residual signal over multiple revolutions of planet gear. The meshing of the defective section in the planet gear with the ring and sun gears are individually identifiable by the local spikes in the envelope of the residual signal, especially under high-load conditions. The technique has been validated using test data acquired from a small industrial planet gearbox test rig.

To further validate the proposed technique for detecting planet gear bore cracking, a full-scale Bell-206B helicopter main rotor gearbox will be tested with a very fine EDM notch defect inserted into the rim of the planetary gear. The test will be conducted in the Helicopter Transmission Test Facility (HTTF) at DST Group in Melbourne, Australia. We will endeavour to initiate a real fatigue crack from the EDM notch and propagate it for a certain length with sufficient margin of safety to avoid catastrophic failure. There will be multiple types of sensors used during this test, such as an in-line oil wear debris sensor, a wireless vibration sensor placed on the planet carrier inside the planetary gearbox, and traditional accelerometers externally placed on the gearbox housing. The data from the various sensors will be compared to improve on the proposed technique and advance it to the stage where it could be potentially be implemented in a real helicopter HUMS.

BIOGRAPHY

Dr. Wenyi Wang is a Senior Scientist in machine dynamics and diagnostics within the Defence Science and Technology (DST) Group in the Department of Defence, Australia. He has over 80 technical publications and 25 years of extensive experience in machine fault diagnostics. In 2010 to 2016, Wenyi was the leader and chief investigator of a research and development project of vibration-based prognostics and health monitoring for the F135 engine, which was funded by the Joint Strike Fighter Program Office (JPO) in USA.

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