School of Mechanical and Manufacturing Engineering

Faculty of Engineering

The University of New South Wales

Vibration Diagnosis of Planetary Gearbox under Variable Speed Condition

by

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Thesis submitted as a requirement for the degree of

Master of Engineering in Mechanical Engineering

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Abstract

This document describes the requirements to theses submitted for the Master of Engineering in Mechanical Engineering degree at the School of Mechanical and Manufacturing Engineering. Requirements described are that of both of context and layout of the theses. The document is written using the LaTeX template provided by the school.

Acknowledgements

This work has been inspired by the labours of numerous academics in the Faculty of Engineering at UNSW who have endeavoured, over the years, to encourage students to present beautiful concepts using beautiful typography.

Further inspiration has come from Donald Knuth who designed TEX, for typesetting technical (and non-technical) material with elegance and clarity; and from Leslie Lamport who contributed LATEX, which makes TEX usable by mortal engineers.

John Zaitseff, an honours student in CSE at the time, created the first version of the UNSW Thesis LATEX class and the author of the current version is indebted to his work.

Abbreviations

BE Bachelor of Engineering

LaTeX A document preparation computer program

PhD Doctor of Philosophy

Contents

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Chapter 1

Introduction

The aim of this article is to investigate a method to identify planetary gearbox fault by vibration analysis. The planetary gearbox is

Chapter 2 explains the background for this document. Chapter 3 states the style and submission related requirements to theses submitted at the school. Chapter 4 explains content related requirements to theses. Chapter 5 evaluates the thesis requirements template. Finally, Chapter 6 draws up conclusions and suggest ways to further improve the thesis requirements template.

Chapter 2

Literature Review

In this chapter, some basic concepts and important knowledge are provided. These concepts are

2.1 Planetary gearbox

Planetary gearing or epicyclic gearing is a gear system typically consisting of four parts: sun gear, planet gear, ring gear and the planet carrier.

There are several ways of input-output method such as stationary ring gear, fixed carrier or no stationary part. The gear ratio of the planetary gearbox could be calculated as:

$$N_s\omega_s + N_p\omega_p - (N_s + N_p)\omega_c = 0 \tag{2.1}$$

$$N_r\omega_r - N_p\omega_p - (N_r - N_p)\omega_c = 0 \tag{2.2}$$

The following figure shows a typical planetary gearing system, which contains 3 planet gears.

The characters of planetary gearbox make it suitable for large transmission ratio, high load and split input or output circumstances. So it is widely used in wind turbines,

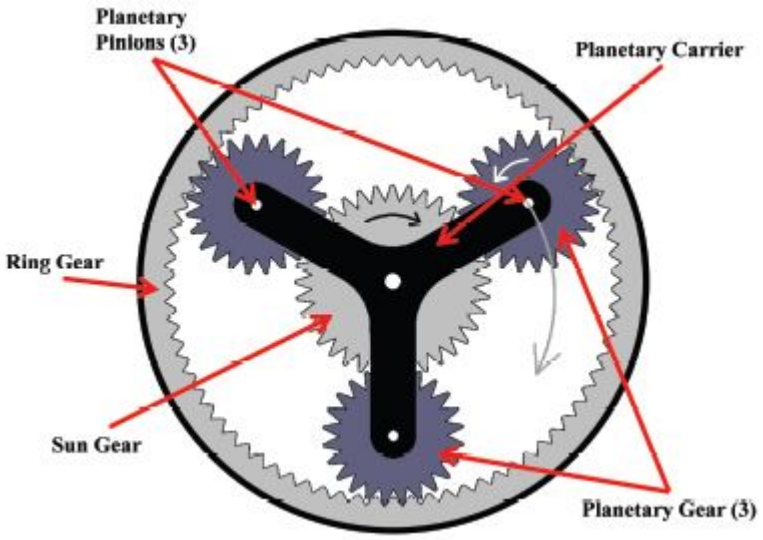

Figure 2.1: Planetary Gearbox Layout[2]

lathes, automobiles and helicopters. The widely appliance and tough working environment of planetary gearbox require it to be highly dependable. Failures of planetary gearbox may lead to huge economic losses as well as safety incidents. But the compact and complex structure on the other hand make it difficult to monitor its condition. Especially when the load and operating speed are varying. This project focuses on the varying speed conditions.

2.2 Planetary Gearbox fault diagnosis

Vibration of gear is caused by the geometric deviation of gears and teeth deformation under load. These two effects introduce a 'meshing error' or 'transmission error' (TE). [3]The transmission error could be divided into three types: unloaded static TE, loaded static TE and dynamic TE. The unloaded static TE could be measured under a very light load, and it is realised to be caused by the geometric deviation. The load static TE is introduced by the tooth deflection under a constant load torque. Dynamic TE is caused by the fluctuation of torque and transmission speed.

2.2.1 Vibration generated by gear

Based on the understanding of transmission error, vibration generated by gears is classified as follows: [3]

1) Mean effects for all tooth pairs

The mean effects here are the same for all tooth pairs. Torque varies when each pair of teeth mesh and cause vibration. Therefore it is dominated by harmonics of tooth-mesh frequencies. It could be sub divided into tree parts:

- Tooth deflection due to mean torque.

- The mean part of initial profile errors resulting from manufacturing.

- Uniform wear over all teeth.

Uniform wear of teeth could increase friction force, which would results in higher harmonics of the gearmesh frequency.

2) Variation from the mean.

Variation from the mean could give rise to side bands of harmonics and maybe caused by:

- Slow variations, such as distortion and runout.
- Local faults, such as tooth spalls and root cracks.
- Random errors.
- Systematic erros.

Sidebands around the harmonics of gearmesh frequencies contain the gear fault information. The spaces between sidebands and harmonics shows which gear has fault, while the form of sidebands identify the type of fault. For example, local faults may give rise to a flat sideband spectrum, while distributed fault may inspire higher level

but narrowly grouped sidebands. Due to limitation of time and resource, the main fault investigated in this project is Local fault, including tooth spalls and root cracks. Separation of spalls and cracks is another important topic due to the reason that cracks could cause a much more rapid failure. Endo[6] developed a finite element analysis method to investigate their difference. It was found that cracks at tooth root give a two-stage deviation of transmission error due to the reason that at first stage, faulty tooth together with a healthy tooth share the load and at the second stage, faulty tooth stands the load alone. Spalls on the other hand inspire one deviation of TE when mating tooth pass the spall.

Comparing to fixed-axis gearbox, in which each gear rotates around a fixed centre, planetary gearbox has planet gears which rotate around not only their own centres but also the centre of sun gear. The transmission structure of planetary gearbox bring unique behaviours. [4]

1. The planet gears are meshing simultaneously with sun gear and the ring gear. Part of the vibrations exited by different component and their different meshing phases could be neutralized or cancelled by each other.

2. The multiple vibration transmission paths are time-varing and load effected in planetary gearbox.It could attenuate the vibration signal of defective part and weaken the fault characteristics.

3. Differ from fixed-axis gear box, side bands apear in spectrum for both healthy and faulty planetary gearboxes and asymmetric about the tooth-mesh frequency. It may caused by multiple planet gears meshing with different phases.

4. Vibrations of low speed faulty components are easily masked and difficult to discover.

2.2.2 Diagnosis techniques

As discussed in the former section, when gears are operating in good condition, the vibration signal tend to be stationary, containing gearmesh frequency and shafts rotating frequencies. When fault happens, the amplitude or frequency components change according to the fault types. Plenty of diagnosis techniques are developed to seperate the faulty information from the original signal. [7]

Statistic Indicators

Time domain statistical indicators are carried out directly from the vibration signal. Some of them are scaled including peak value, peak to peak value, mean value, root mean squared value and variance. Among which RMS (root mean squared) value, as its name suggests, is the root of the mean of the squared signal values. It represents the overall vibration level. It is calculated as:

$$RMS = \sqrt{\frac{1}{N}\sum_{i=1}^{n} x_i^2} \tag{2.3}$$

Variance indicates the power of the vibration, and its formula is:

$$\sigma^2 = \frac{1}{N}\sum_{i=1}^{n}(x_i - \overline{x})^2 \tag{2.4}$$

There are also some useful unscaled indicators, including kurtosis, crest factor

1) Standard Indicators

2) wavelet

3) Cepstrum

4) TSA

5) Order tracking

6) Machine learning method

2.3 Variable Speed

Chapter 3

Methodology

Requirements for other parts of the thesis work can be found on the school web-pages [**?**]. The requirements below are for the written thesis only.

3.1 Format

The following format specifications must be adhered to for your thesis (the LaTeX template available from the school ensures this):

1. The thesis must be written on *A4 size paper*.
2. The thesis must be typed or prepared using a *word-processor*.
    - For Undergraduate theses, you are encouraged to use both sides of the paper.
    - For Higher Degree Research theses, your submitted thesis must be printed single-sided.
3. *Margins* on all sides must be no less than 20 mm (before binding).
4. *1.5 line spacing* (about 8 mm per line) must be used.

5. All sheets must be *numbered*. The main body of the thesis must be numbered consecutively from beginning to end. Other sections must either be included or have their own logical numbering system.

6. The *title page* must contain the following information:

   (a) University and School names.

   (b) Title of Thesis/Project.

   (c) Name of Author and student ID.

   (d) The degree the thesis is submitted for.

   (e) Submission date (month and year).

   (f) Supervisor's name (for undergraduate theses).

7. After the body of the thesis, the thesis *must* contain a Bibliography or References list as appropriate.

   Authors should confer with their supervisors and School about the style of their bibliography, as this varies between disciplines.

3.2 Other physical appearance

Other requirements to the physical appearance of your theses are:

1. *Graphs, diagrams and photographs* should be inserted as close as possible to their *first reference* in the text. Rotated graphs etc are to be arranged so as to be conveniently read, with the bottom edge to the outside of the page. *Graphs and diagrams must be legible!*

2. *Supplementary material (for example CFD animations)* may be submitted either online or via external drive, and must be referred to within the text. The text should make sense without the supplementary material available.

3.3 Submission

Finally, here are some requirements to the submission procedure.

1. The *author* of the thesis is *responsible* for the preparation of the thesis before the deadline, proofreading the typescript and having corrections made as necessary.
2. For undergraduate theses, there is a *page limit* of 50 pages for the main body of the thesis.

Chapter 4

Content Requirements

Students should consult the literature (e.g. [**?**, **?**, **?**, **?**]) and other resources for material on how to write a good thesis. The present document is only a very brief introduction as to what is expected.

4.1 Structure

Most theses are structured very much like the present document. The main part of the thesis can be structured in many different ways, however, but must contain: a *problem definition*; *theory* and *considerations* on how to solve the problem; a description of the *solution method* (dimensioning, construction, etc.); presentation of *results* (measurements, simulations, etc.); a *discussion* of the results (validity, deviations, comparison with previous solutions, etc.); and finally the *conclusions*.

4.2 Style of writing

1. Audience: The thesis must be addressed to engineers at the same level as the student but without the special knowledge gained during the thesis work. Such

a third-person must be able to reconstruct the results on the basis of the thesis alone.

2. Every used concept/symbol/abbreviation which is not widely know must be *defined*. The wording should be *short* and *concise*. Readable(!) *figures* and *graphs* enhances comprehensibility.

3. Units. *SI units* must be used.

4.3 Documentation

1. The work must be well documented; i.e. enclosed must be the *complete schematics* of designed electronic circuits/test set-ups and/or a *program listing*, and/or etc. Documentation of *simulation results* and/or *measurement results* likewise.

2. References: For every declaration/equation/method/etc., which is not widely known, a *reference to the literature* must be given (or a 'proof' if it is the authors own work). In case material is copied verbatim, quotes must be used. This is also the case when referring to partners work in the case of a Group Thesis.

3. Plagiarism: Failure to give proper references to the literature is *plagiarism*. Plagiarism is considered serious offence and severe penalties may apply.

Chapter 5

Evaluation

This chapter is mainly provided for the purpose of showing a typical thesis structure. There are no more thesis requirements described.

5.1 Results

The result of this work is the present document, being both a LaTeX template and a thesis requirement specification.

5.2 Discussion

The Dual function of this document somewhat de-emphasises the primary purpose of the document, namely the thesis requirements. It would be better, if these could be stated on a few concise pages (cf Appendix 1, p15).

Chapter 6

Conclusion

A thesis requirements/template document has been created. This serves the dual purposes of giving students specific requirements to their theses — both style and content related — while providing a typical thesis structure in a LaTeX template.

6.1 Future Work

Extract the requirements from the template in order to have very concise requirements.

Bibliography

[1] H. Partl: *German TEX*,TUGboat Volume 9, Issue 1 (1988)

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[5] P.D.McFadden, I.M.Howard, *The detection of seeded faults in an epicyclic gearbox by signal averaging the vibration*, Aeronautical Research Labs Melbourne, 1990

[6] Endo, H. Randall, R.B. *Differential diagnosis of spalls vs. cracks in the gear tooth fillet region* Journal of Failure Analysis and Prevention, 4(5), 57-65

[7] K. Ding, *Practical Fault Diagnosis Techniques for Gears and Gearboxes* , 2005

Appendix 1

This section contains the options for the UNSW thesis class; and layout specifications used by this thesis.

A.1 Options

The standard thesis class options provided are:

undergrad	default
hdr	
11pt	default
12pt	
oneside	default for HDR theses
twoside	default for undergraduate theses
draft	(prints DRAFT on title page and in footer and omits pictures)
final	default
doublespacing	default
singlespacing	(only for use while drafting)

A.2 Margins

The standard margins for theses in Engineering are as follows:

	U'grad	HDR
`\oddsidemargin`	40 mm	40 mm
`\evensidemargin`	25 mm	20 mm
`\topmargin`	25 mm	30 mm
`\headheight`	40 mm	40 mm
`\headsep`	40 mm	40 mm
`\footskip`	15 mm	15 mm
`\botmargin`	20 mm	20 mm

A.3 Page Headers

A.3.1 Undergraduate Theses

For undergraduate theses, the page header for odd numbers pages in the body of the document is:

Author's Name	*The title of the thesis*

and on even pages is:

The title of the thesis	Author's Name

These headers are printed on all mainmatter and backmatter pages, including the first page of chapters or appendices.

A.3.2 Higher Degree Research Theses

For postgraduate theses, the page header for the body of the document is:

The title of the chapter or appendix

This header is printed on all mainmatter and backmatter pages, except for the first page of chapters or appendices.

A.4 Page Footers

For all theses, the page footer consists of a centred page number. In the frontmatter, the page number is in roman numerals. In the mainmatter and backmatter sections, the page number is in arabic numerals. Page numbers restart from 1 at the start of the mainmatter section.

If the **draft** document option has been selected, then a "Draft" message is also inserted into the footer, as in:

	14	**Draft:** September 27, 2017

or, on even numbered pages in two-sided mode:

Draft: September 27, 2017	14	

A.5 Double Spacing

Double spacing (actualy 1.5 spacing) is used for the mainmatter section, except for footnotes and the text for figures and table.

Single spacing is used in the frontmatter and backmatter sections.

If it is necessary to switch between single-spacing and double-spacing, the commands `\ssp` and `\dsp` can be used; or there is a `sspacing` environment to invoke single spacing and a `spacing` environment to invoke double spacing if double spacing is used for the document (otherwise it leaves it in single spacing). Note that switching to single spacing should only be done within the spirit of this thesis class, otherwise it may breach UNSW thesis format guidelines.

A.6 Files

This description and sample of the UNSW Thesis LaTeX class consists of a number of files:

unswthesis.cls	the thesis class file itself
crest.pdf	the UNSW coat of arms, used by `pdflatex`
crest.eps	the UNSW coat of arms, used by `latex` + `dvips`
dissertation-sheet.tex	formal information required by HDR theses
pubs.bib	reference details for use in the bibliography
sample-thesis.tex	the main file for the thesis

The file sample-thesis.tex is the main file for the current document (in use, its name should be changed to something more meaningful). It presents the structure of the thesis, then includes a number of separate files for the various content sections. While including separate files is not essential (it could all be in one file), using multiple files is useful for organising complex work.

This sample thesis is typical of many theses; however, new authors should consult with their supervisors and exercise judgement.

The included files used by this sample thesis are:

definitions.tex	mywork.tex
abstract.tex	evaluation.tex
acknowledgements.tex	conclusion.tex
abbreviations.tex	appendix1.tex
introduction.tex	appendix2.tex
background.tex	

These are typical; however the concepts and names (and obviously content) of the files making up the matter of the thesis will differ between theses.

Appendix 2

This section contains scads of supplimentary data.

B.1 Data

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