CONTENTS

TITLE PAGE	i
CERTIFICATE OF APPROVAL	ii
CERTIFICATE FROM SUPERVISORS	iii
ACKNOWLEGMENTS	iv
DECLARATION	v
DEDICATION	vi
LIST OF FIGURES	vii
LIST OF TABLES	xiii
NOMENCLATURE	xiv
ABBREVIATIONS	xxi
ABSTRACT	xxii
CHAPTER 1. INTRODUCTION	1
1.1 Background and Motivation	1
1.1.1 Importance of Condition Monitoring	2
1.1.2 Importance in a Gearbox System	2
1.1.3 Importance in an Internal Combustion Engine	4
1.2 Analysis of Gearbox System with Fault	5
1.2.1 Geometric Error	5
1.2.2 Wear	5
1.2.3 Pitting	5
1.2.4 Spall	6
1.2.5 Tooth Broken	6
1.3 Organization of the Thesis	6
CHAPTER 2. LITERATURE REVIEW	9
2.1 Introduction	9
2.2 Instantaneous Angular Speed (IAS) Signal	9
2.2.1 Introduction	9
2.2.2 Theory behind Rotational Speed Measurement	10

2.2.3 IAS Signal Based Signal Processing for Gearbox 12
2.2.4 IAS Signal Based Signal Processing for Rotor 12
2.2.5 IAS Signal Based Signal Processing for Internal Combustion Engine 13
2.2.6 IAS Signal Based Signal Processing for Other Mechanical System 14
2.3 Vibration Signal Analysis 14
2.3.1 Vibration Signal Based Signal Processing for Gearbox 14
2.3.2 Vibration Signal Based Signal Processing for Rotor 15
2.3.3 Vibration Signal Based Signal Processing for Internal Combustion Engine 16
2.4 Signal Processing Techniques 17
2.4.1 Importance of Signal Processing 17
2.4.2 Time domain Analysis 17
2.4.3 Fast Fourier Transform 18
2.4.4 Short Time Fourier Transform 19
2.4.5 Wigner Ville Distribution 20
2.4.6 Continuous Wavelet transform 20
2.4.7 Discrete Wavelet transform 22
2.4.8 Wavelet Packet Transform 22
2.4.9 Cepstrum Analysis 25
2.4.10 Empirical Mode Decomposition 26
2.4.11 Demodulation 29
2.4.12 Time Synchronous Averaging 30
2.5 Summary of Literature Review 31
2.6 Scope of Work 32
2.7 Objectives of the Research 33

CHAPTER 3. INSTANTANEOUS ANGULAR SPEED (IAS) ESTIMATION 35
3.1 Introduction 35
3.2 Theory of Speed Measuring Device 36
3.2.1 Incremental Rotary Encoder 36

3.3 Analysis of Encoder Signal 37
3.4 IAS Estimation 39
3.4.1 Timer/counter Technique 39
3.4.2 Measurable speed by Timer/ counter technique 41
3.4.3 Analog to Digital Converter Technique 43
3.4.4 Zeros Cross Detection Technique 44
3.4.5 Frequency Domain Technique 46
3.4.6 Zeros Cross Time Modeling with Fourier Series 51
3.4.7 Time Frequency Domain Technique 53
3.4.8 Short Time Scale Transform 55
3.5 Sampling Frequency 58
3.5 Summary of Estimated IAS Signal from Various Techniques 59

CHAPTER 4. EXPERIMENTAL SETUP 63
4.1 Introduction 63
4.2 Test Facility 1 63
4.2.1 Induction Motor with Control Panel 64
4.2.2 Multistage Gearbox 65
4.2.3 Artificial Defect 68
4.2.4 DC Generator with Resistance Loading Unit 69
4.2.5 Incremental Rotary Encoder 69
4.2.6 Application of load 70
4.3 Test Facility 2 71
4.4 Data Acquisition System 74
4.4.1 Laser Vibrometer 74
4.4.2 Data Acquisition (DAQ) Devices 75
4.4.3 Accelerometer 75
4.4.4 DL 850 ScopeCorder 76

CHAPTER 5. IAS SIGNAL ANALYSIS FOR FAULT DETECTION IN MULTISTAGE GEARBOX 77

5.1 Introduction 77
5.2 Gearbox Fault Detection by Analysis of IAS 77
5.2.1 Introduction 77
5.2.2 IAS Signal under Different Defect Severity Conditions 77
5.2.3 Time-domain Analysis of IAS Signal 79
5.2.4 Frequency Domain Analysis of IAS signal 80
5.2.5 A Comparative Study between Vibration signal and IAS signal 84
5.3 Modeling of an IAS Signal 86
5.4 Demodulation of IAS Signal 88
5.4.1 Amplitude Demodulation of IAS Signal 89
5.4.2 Frequency Demodulation of IAS Signal 92
5.5 Cepstrum Analysis of IAS Signal 94
5.6 Wavelet Decomposition and Fault Detection 97
5.7 Complementary Ensemble Empirical Mode Decomposition of IAS Signal 101
5.8 Summary 104

CHAPTER 6. FAULT DETECTION IN GEARBOX BY TIME SYNCHRONOUS AVERAGING 105
6.1 Introduction 105
6.2 Time Synchronous Averaging(TSA) of IAS Signal 105
6.2.1 Output Shaft TSA of IAS Signal 106
6.2.2 Fault Detection under Different Load Conditions 108
6.3 Arbitrary Shaft TSA of IAS Signal 111
6.3.1 Modeling of IAS Signal 111
6.3.2 Estimation of Angular Position 111
6.3.3 Estimation of Angular Position of Output shaft 115
6.3.4 Estimation of Angular Position of Lay Shaft 117
6.3.5 Lay Shaft TSA of IAS Signal 118
6.3.6 Fault Detection under Different Load Conditions 120
6.3.7 Lay Shaft TSA of Amplitude Demodulated IAS Signal 122

6.4 Comparison of the Amplitude Variation around Important Frequencies 125
6.5 Selection of Number of Averaging 128
6.6 Summary 129

CHAPTER 7. SIGNAL ANALYSIS FROM SPARK IGNITION ENGINE 131
7.1 Introduction 131
7.2 SI Engine Responses 132
7.2.1 IAS Signal from SI Engine 132
7.2.2 Laser Vibrometer Signal 133
7.3 Engine Firing Detection 134
7.3.1 Time-domain Firing Detection 134
7.3.2 Time Frequency Based Firing Detection 135
7.4 Response Surface Methodology 138
7.4.1 Linear Regression Based Surface Plotting 138
7.4.2 Behavior of SI Engine Responses 139
7.5 Summary 140

CHAPTER 8. SUMMARY AND CONCLUDING REMARKS 141
8.1 Summary of IAS Signal Estimation 141
8.2 Summary of IAS signal Analysis for Multistage Gearbox 143
8.2.1 Time-domain Analysis 143
8.2.2 Frequency Domain Analysis 143
8.2.3 Demodulation 144
8.2.4 Cepstrum Analysis 146
8.2.5 WPT Analysis 147
8.2.6 CEEMD Analysis 147
8.3 Summary of Output Shaft TSA 148
8.4 Summary of Lay Shaft TSA 149
8.4.1 Lay shaft TSA of IAS Signal 149
8.4.2 Lay Shaft TSA of Amplitude Demodulated IAS Signal 149
8.5 Summary of Studies on SI Engine 151

8.6 Conclusions 152
8.7 Contributions made in the Thesis 153
8.8 Future Scopes 153

REFERENCES 155
Appendix 171
Publications 179
Vitae 181