

Contents

Preface	xi
About the Author	xv
Notation	xvii
Part A: The Exercises	1
1 Introduction	3
Overview	3
The Exercises	3
<i>Exercise 1.1</i>	3
<i>Exercise 1.2</i>	5
Solutions and Summaries	7
2 Signals	11
Overview	11
The Exercises	11
<i>Exercise 2.1</i>	11
<i>Exercise 2.2</i>	13
<i>Exercise 2.3</i>	14
<i>Exercise 2.4</i>	16
Solutions and Summaries	18
3 Fourier Methods	23
Overview	23
The Exercises	23
<i>Exercise 3.1</i>	23
<i>Exercise 3.2</i>	25
<i>Exercise 3.3</i>	26
<i>Exercise 3.4</i>	28
<i>Exercise 3.5</i>	29
<i>Exercise 3.6</i>	30
<i>Exercise 3.7</i>	32
<i>Exercise 3.8</i>	33
<i>Exercise 3.9</i>	35
<i>Exercise 3.10</i>	36

<i>Exercise 3.11</i>	38
<i>Exercise 3.12</i>	39
Solutions and Summaries	41
4 Linear Systems	53
Overview	53
The Exercises	53
<i>Exercise 4.1</i>	53
<i>Exercise 4.2</i>	55
<i>Exercise 4.3</i>	57
Solutions and Summaries	59
5 Filters	65
Overview	65
The Exercises	65
<i>Exercise 5.1</i>	65
<i>Exercise 5.2</i>	66
<i>Exercise 5.3</i>	68
<i>Exercise 5.4</i>	70
Solutions and Summaries	73
6 Time Domain Averaging (TDA)	83
Overview	83
The Exercises	83
<i>Exercise 6.1</i>	83
<i>Exercise 6.2</i>	84
<i>Exercise 6.3</i>	86
<i>Exercise 6.4</i>	87
Solutions and Summaries	89
7 Spectral Analysis	97
Overview	97
The Exercises	97
<i>Exercise 7.1(a)</i>	97
<i>Exercise 7.1(b)</i>	98
<i>Exercise 7.2</i>	100
<i>Exercise 7.3</i>	101
<i>Exercise 7.4</i>	103
<i>Exercise 7.5</i>	104
<i>Exercise 7.6</i>	106
<i>Exercise 7.7</i>	108
<i>Exercise 7.8</i>	109
<i>Exercise 7.9</i>	111
Solutions and Summaries	113
8 Envelope Detection	129
Overview	129
The Exercises	129
<i>Exercise 8.1</i>	129
Solutions and Summaries	131

9 The Spectrogram	135
Overview	135
The Exercises	135
<i>Exercise 9.1</i>	135
<i>Exercise 9.2</i>	136
Solutions and Summaries	139
10 Sampling	145
Overview	145
The Exercises	145
<i>Exercise 10.1</i>	145
<i>Exercise 10.2</i>	146
<i>Exercise 10.3</i>	148
<i>Exercise 10.4</i>	149
Solutions and Summaries	152
11 Identification – Transfer Functions	161
Overview	161
The Exercises	161
<i>Exercise 11.1</i>	161
<i>Exercise 11.2</i>	163
<i>Exercise 11.3</i>	164
<i>Exercise 11.4</i>	165
Solutions and Summaries	167
12 Model-based Signal Processing	177
Overview	177
The Exercises	177
<i>Exercise 12.1</i>	177
<i>Exercise 12.2</i>	179
<i>Exercise 12.3</i>	180
Solutions and Summaries	182
13 Diagnostic Applications for Rotating Machines	189
Overview	189
The Exercises	189
<i>Exercise 13.1</i>	189
<i>Exercise 13.2</i>	191
<i>Exercise 13.3</i>	192
<i>Exercise 13.4</i>	194
<i>Exercise 13.5</i>	196
Solutions and Summaries	198
14 Systems with Delays	211
Overview	211
The Exercises	211
<i>Exercise 14.1</i>	211
<i>Exercise 14.2</i>	213
<i>Exercise 14.3</i>	215
Solutions and Summaries	217

Part B	225
1 Introduction	227
1.1 General Objectives	227
1.2 Basic Processing	227
1.3 Why the Frequency Domain?	228
1.4 An Introductory Example	229
2 Introduction to Signals	231
2.1 Signal Classification	231
2.2 Signal Descriptions	231
2.3 Correlation Functions	234
2.4 Estimation and Errors	235
3 Fourier Methods	237
3.1 Fourier Series	237
3.2 Fourier (Integral) Transform	240
3.3 The Uncertainty Principle	241
3.4 The Discrete Fourier Transform (DFT)	242
3.5 The DFT and the Fast Fourier Transform (FFT)	244
3.6 Discontinuities and Windows	246
4 Linear Systems	247
4.1 Continuous Systems	247
4.2 Discrete Systems	248
4.3 A Specific Case of a Continuous Linear Systems – Accelerometers	250
Appendix 4.A The Lightly Damped SDOF System	251
5 Filters	253
5.1 Preliminaries	253
5.2 Analog and Digital Filters	253
5.3 Filter Classification and Specifications	257
5.4 IIR Filters	260
5.5 FIR Filters	260
5.6 The Importance of Linear Phase Filters	263
5.7 Design Tools	264
6 Time Domain Averaging (Synchronous Averaging)	265
6.1 Principle	265
6.2 Rejection of Nonsynchronous Components	268
6.3 TDA with Decaying Memory Process	269
7 Spectral Analysis	271
7.1 Introduction	271
7.2 Representation of Signals in the Frequency Domain	272
7.3 Errors and their Control	278
7.4 Spectral Analysis: Practical Considerations	288
8 Envelopes	291
8.1 Introduction	291

8.2 The Hilbert Transform (HT)	291
8.3 Analytic Signals	292
8.4 Narrow Band (NB) Signals and their Envelope	292
9 The Spectrogram	295
9.1 Introduction	295
9.2 Time Frequency Methods	295
9.3 The Short Time Fourier Transform (STFT) and the Spectrogram	296
10 Data Acquisition	299
10.1 Data Acquisition and Signal Processing Systems	299
10.2 Amplitude Quantization	299
10.3 Quantization in Time: The Sampling Theorem	301
10.4 Antialiasing Filters	303
11 Input/Output Identification	305
11.1 Objectives and Overview	305
11.2 Frequency Domain Identification: The Noiseless Case	306
11.3 Identification with Noise Corrupted Signals	307
11.4 Error Mechanisms and their Control in the Identification Process	311
11.5 Estimation Errors for the Coherence Function	314
12 Model-based Signal Processing	315
12.1 General	315
12.2 Signal Models	315
12.3 Modeling of Signals	317
12.4 Model-based Spectral Analysis	321
12.5 Model or Selection	322
12.6 Model-based Diagnostics	324
Appendix 12.A The Correlation Matrix	324
13 Machinery Diagnostics: Bearings and Gears	327
13.1 Diagnostics and Rotating Machinery	327
13.2 Structural Effects	327
13.3 Rotating Imbalance	328
13.4 Modeling of Roller Bearing Vibration Signals	328
13.5 Bearing Vibrations: Structural Effects and Envelopes	330
13.6 Modeling of Gear Vibration Signals	334
14 Delays and Echoes	337
14.1 System with Pure Delays	337
14.2 Correlation Functions	338
14.3 Cepstral Analysis	338
References	341
Index	345