

Contents

Summary	7
Streszczenie	9
Acknowledgements	11
1. Introduction	12
1.1. SHM and similar research fields	12
1.2. Effects of varying environmental and operational conditions on SHM.....	13
1.3. Why cointegration has been applied to SHM	16
1.4. A review of cointegration-based approaches for SHM	20
1.5. Motivation and scope of this monograph.....	24
2. Stationarity and nonstationarity	27
2.1. Definitions and basic concepts.....	27
2.2. Time series and stationarity	29
2.3. Unit root tests	32
2.4. The Dickey-Fuller (DF) and augmented Dickey-Fuller (ADF) tests.....	35
3. Cointegration method	39
3.1. Introduction to cointegration.....	39
3.2. Cointegration and common trends	40
3.3. Testing for cointegration	42
3.4. Johansen's cointegration procedure	43
3.5. Testing for stationarity	45
3.6. Example using the Weierstrass–Mandelbrot cosine fractal function	46
3.7. Summary and discussion.....	49
4. Lag length selection in cointegration analysis used for SHM	52
4.1. Background	52
4.2. Conventional selection methods from econometrics	53
4.2.1. Methods based on the information criteria.....	53
4.2.2. Methods based on the likelihood ratio test.....	54
4.2.3. Methods based on the sequential modified likelihood ratio test	55
4.2.4. Sample size and lag length selection.....	56
4.3. Optimal lag length selection based on stationarity analysis used for structural damage detection.....	57
4.4. Summary and conclusions	59

5. Cointegration-based approach to SHM applications	60
5.1. Damage detection scenarios.....	60
5.1.1. Using geometrical features of cointegration residuals	61
5.1.2. Using wavelet variance characteristics of cointegration residuals.....	61
5.1.2.1. Fractal-based signal processing using wavelets.....	61
5.1.2.2. Wavelet-based fractal analysis of cointegration residuals.....	63
5.1.3. Using stationary statistical characteristics of cointegration residuals....	63
5.2. Case study 1: Structural damage detection in aluminium plates using lamb waves under temperature variations.....	64
5.2.1. Lamb wave data contaminated by temperature.....	64
5.2.2. Lag length selection results.....	66
5.2.3. Damage detection results using cointegration residuals	67
5.2.4. Damage detection results using wavelet variance characteristics of cointegration residuals	70
5.2.5. Damage detection results using stationary statistical characteristics of cointegration residuals	76
5.3. Case study 2: Impact damage detection in composite plates using nonlinear acoustics under load changes	77
5.3.1. Principle of nonlinear vibro-acoustic wave modulation technique.....	77
5.3.2. Vibro-acoustic data for different frequencies of modal excitations	78
5.3.3. Lag length selection results.....	80
5.3.4. Damage detection results using stationary statistical characteristics of cointegration residuals	81
5.4. Summary and conclusions	84
6. Cointegration-based approach to condition monitoring of wind turbines	86
6.1. Introduction.....	86
6.2. Condition monitoring and fault diagnosis of wind turbines using SCADA data.....	87
6.2.1. Review of previous work	88
6.2.2. Discussion	90
6.3. Cointegration-based approach to condition monitoring of wind turbines	91
6.4. Experimental wind turbine data	93
6.5. Case study 1: Using various process parameters of the wind turbine.....	99
6.5.1. Optimal cointegrating vectors	99
6.5.2. Condition monitoring and fault detection using cointegration residuals	100
6.5.3. Discussion	104
6.6. Case study 2: Using only the temperature data of gearbox and generator.....	105
6.7. Summary and conclusions	109
7. Summary and conclusions.....	110
7.1. Summary	110
7.2. Conclusions	112
References	114