

Contents

Notation	1
1 Introduction	5
1.1 Structural Vibrations	5
1.2 Application Examples	7
1.3 Main Objective	9
1.4 Modeling and Analysis	10
1.4.1 Motivation	10
1.4.2 Related Work	10
1.5 Active Vibration Control under Parametric Resonance	12
1.5.1 Motivation	12
1.5.2 Related Work	13
1.6 Outline and Contributions	17
1.7 Publications	22
I Modeling and Analysis	25
2 Modeling and Validation of Stacker Crane	27
2.1 Modeling using the Hamilton's Principle	27
2.2 Control-Oriented Dynamical Model	31
2.2.1 Assumed-Modes Method	32
2.2.2 Admissible Functions Properties	34
2.3 Model Extension	35
2.4 Multibody Modeling	37
2.5 Experimental Setup	41
2.6 Parameter Identification	44
2.7 Model Validation	46
2.7.1 Drive Unit and Friction Model	46
2.7.2 Stacker Crane	47
2.8 Summary	49
3 Vibration Analysis	51
3.1 Approximate Solution	51
3.2 Analytical Solution	52
3.2.1 Discussion of the Solution	54
3.3 Impact of the Lift Speed on Modal Analysis	59

3.4	Summary	60
II Active Vibration Control under Parametric Resonance		61
4	Active Vibration Control Challenges	63
4.1	Feedforward Control using Input Shaping	63
4.2	Feedback Control	65
4.3	Challenges and Discussions	66
5	Vibration Damping Using a Soft-Constrained NMPC	71
5.1	Frequency Prediction and Determination	71
5.1.1	Frequency Prediction	72
5.1.2	Parametric Resonances Determination	73
5.2	Soft-Constrained NMPC Problem Formulation	74
5.3	Case Study: Stacker Crane	76
5.4	Summary	77
6	Vibration Damping Using a Time-Optimal NMPC	79
6.1	Time-Optimal Control Problem	80
6.2	Time-Optimal Model Predictive Control	82
6.2.1	Quasi Time-Optimal NMPC	82
6.2.2	Quasi Time-Optimal NMPC with Free Final Time	84
6.2.3	Stability and Recursive Feasibility	85
6.3	Case Study: Stacker Crane	86
6.4	Summary	88
7	Vibration Damping Using a Frequency-based NMPC	89
7.1	Brief Review	89
7.2	Frequency-Based Optimal Control Problem	91
7.2.1	Optimal Control Problem Design	91
7.2.2	Design Specifications	93
7.2.3	Feedforward Control	94
7.3	Frequency-Based NMPC	96
7.3.1	Dual-Mode Paradigm	96
7.3.2	Feedback Control	97
7.3.3	Terminal Set Design	98
7.3.4	Parametric Resonance Impact	99
7.4	Feasibility and Stability Discussion	100
7.5	Experimental Validation	102
7.6	Frequency-based Optimization using DM	106
7.7	Further Discussions	108
7.7.1	Lyapunov-based NMPC	108
7.7.2	Case Study: Nonlinear Oscillator	109

7.8 Summary	112
8 Conclusions and Outlook	115
8.1 Conclusions	115
8.2 Outlook	117
III Supplementary Material	121
A Preliminaries	123
A.1 Mathematical Preliminaries	123
A.2 Optimization Preliminaries	125
A.3 Distributed-Parameter System Modeling Preliminaries	127
B Additional Appendix	131
B.1 Implementation	131
B.2 Nonlinear Algebraic Equation (NAE)	131
C Proofs	135
Bibliography	135
Curriculum Vitae	155