

Contents

I Thesis overview	1
1 Introduction	3
1.1 Background	3
1.2 Engine emissions and control	7
1.2.1 After-treatment systems	9
1.2.2 After-treatment monitoring	10
1.3 Scope of the work	10
1.4 Objectives	11
1.5 Thesis organization	12
References	13
2 State of the art: Emissions control and monitoring	17
2.1 Introduction	17
2.2 Selective catalytic reduction	19
2.3 Ammonia slip catalyst	24
2.4 After-treatment control and diagnosis	25
2.5 On-board monitoring	27
2.5.1 Reductant agent monitoring	28
2.5.2 NOx sensors	28
2.5.2.1 NOx sensor cross-sensitivity	30
2.5.3 NH ₃ sensor	33
2.6 Conclusion	34
References	35
II Experimental set-up and performed tests	41
3 Experimental set-up	43

3.1	Engine	43
3.2	After-treatment structure and monitoring	45
3.3	Control environment	46
4	Engine test procedure	49
4.1	Test procedure	49
4.2	Preconditioning	50
4.2.1	Method 1 – Performed to aged and new catalyst	51
4.2.2	Method 2 – New catalyst	51
4.3	Ammonia injection strategy	52
4.3.1	Standard injection	52
4.3.2	Off-line optimisation	53
4.3.3	Real-time optimisation	54
4.3.4	Injection failure simulation	54
4.4	Engine test	55
4.4.1	Steady-state cycles	55
4.4.2	Driving cycles	56
III	Control-oriented modelling	59
5	NOx and NH₃ slip prediction models	61
5.1	Introduction	62
5.2	Zero-dimensional model	62
5.2.1	SCR Zero-dimensional model	63
5.2.2	Model results	67
5.2.3	SCR+ASC Zero-dimensional model with reduced states	70
5.3	Cross-sensitivity models	72
5.3.1	Cross-sensitivity cell temperature model	73
5.3.2	Model results	76
5.3.3	NH ₃ -dependent and constant cross-sensitivity	77
5.3.4	Model results	79
5.3.5	Comparison between cross-sensitivity estimation methods	80
5.4	Control-oriented models	83
5.4.1	Artificial neural networks	84
5.4.1.1	Model results	88
5.4.2	Sensor signal analysis model	91
5.4.2.1	Model results	94

5.4.3	Data fusion – Kalman filter	95
5.4.4	Extended Kalman filter applied to the models	97
5.4.4.1	Model results	99
5.5	Slip prediction based on different sensitivities of NOx sensors to ammonia	103
5.5.1	Model results	104
	References	105
6	After-treatment control and diagnosis	109
6.1	Introduction	110
6.2	Impact of the ammonia injection strategy and the catalyst ageing on the NOx and NH ₃ slip	111
6.3	Ammonia injection fault observation	112
6.4	Ammonia injection fault diagnosis	117
6.4.1	Proposed methodology extended to control-oriented models and observer	126
6.5	Results and discussion	129
6.5.1	Real-time strategy application for constant failure in ammonia injection	129
6.5.2	Real-time strategy application for ammonia injection system degradation	130
6.6	Emissions assessment under ammonia injection failure and catalyst ageing	135
6.7	Proposed methodology extended to the ASC catalyst and simultaneous diagnosis of ammonia injection failure and catalyst ageing	137
6.7.1	Real-time diagnosis for constant ammonia injection failure .	140
6.7.2	Real-time diagnosis for ammonia injection degradation .	143
6.7.3	Unknown ageing state diagnosis	146
	References	148
7	Optimisation of dynamic systems	151
7.1	Introduction	151
7.2	Optimal control problem	153
7.3	Mathematical methods for dynamic optimisation	154
7.3.1	Dynamic programming	154
7.3.2	Direct methods	155
7.4	Off-line Optimisation	156
7.4.1	Optimisation results	158

7.5 On-line optimisation	163
7.5.1 MPC methodology for SCR+ASC system	164
7.5.2 Optimisation results	168
References	172
IV Conclusions and future work	175
8 Conclusions and future work	177
8.1 Main contributions	178
8.1.1 Control-oriented models	178
8.1.1.1 Data-driven models	178
8.1.1.2 Zero-dimensional physical models	179
8.1.1.3 Extended Kalman filter	179
8.1.2 After-treatment system monitoring and diagnostics	180
8.1.2.1 Ammonia injection failure	180
8.1.2.2 Catalyst ageing state	180
8.1.3 Optimisation of dynamic systems	181
8.1.3.1 Off-line optimisation	181
8.1.3.2 On-line optimisation	181
8.2 Future work	181
8.2.1 Stochastic models embedded in the on-line optimisation approach	182
8.2.2 Integration of after-treatment system models into a hybrid vehicle design	182
References	182
References	183