# Contents

Abstract iii

Resum iv

Resumen vii

Contents xiii

List of acronyms xvii

List of symbols xix

1 Introduction 1

1.1 Motivation and background . . . . . 1

1.2 Objectives. . . . . 2

1.3 Organization and development of the Thesis . . . . . 3

2 Acoustic characterization of wheel and track rolling noise 5

2.1 Introduction . . . 5

2.2 State of the art . . . 6

2.2.1 Rolling noise . . . 6

2.2.1.1 Studying wheel behaviour in rolling noise . . . 8

2.2.1.2 Studying track behaviour in rolling noise . . . 11

2.2.1.3 Wheel/track interaction and contact . . . 15

2.2.1.4 Rolling noise comprehensive modelling: TWINS . . . 18

2.2.1.5 Rolling noise distribution among sources . . . 20

2.2.2 Tackling rolling noise: mitigation measures . . . 21

2.2.3 Tackling rolling noise: optimization techniques in the search for quieter trains . 28

2.2.4 Beyond rolling noise: additional noise sources . . . 30

2.2.4.1 Squeal noise . . . 30

2.2.4.2 Aerodynamic noise . . . 31

2.2.4.3 Bridge noise . . . 31

2.3 Wheel dynamic model . . . 32

2.3.1 Railway wheel characterization . . . 32

2.3.2 Wheel receptance function . . . 33

2.3.3 Wheel response in the frequency domain . . . 34

2.3.4 Wheel response in the time domain: simplified formulation . . . 37

2.4 Track dynamic model . . . 38

2.4.1 Timoshenko beam . . . 39

2.4.2 Rail receptance function . . . 42

2.4.3 Deformable track cross-section model . . . 44

2.4.4 Rail response . . . 51

2.5 Wheel/track interaction model . . . 52

2.5.1 The contact patch . . . 52

2.5.2 Contact receptance function . . . 55

2.5.3 Roughness filter . . . 57

2.6 Sound power radiation . . . 57

2.6.1 Wheel sound power . . . 58

2.6.1.1 Wheel radiation efficiencies . . . 60

2.6.1.2 Wheel noise in the three-dimensional case . . . 62

2.6.2 Track sound power . . . 63
2.6.2.1 Contribution of the rail . . . 63
2.6.2.2 Contribution of the sleeper . . . 66
2.6.2.3 Equivalent Sources Model . . . 66

3 Wheel shape optimization procedures for rolling noise minimization 71

3.1 Introduction . . . 71
3.2 Genetic Algorithms . . . 72
3.2.1 Theoretical foundations . . . 73
3.2.2 GA operators . . . 75
3.2.3 Constraint-handling in GAs . . . 76
3.3 Optimization algorithms: from the general methodology to the specificities of each procedure . . . 78
3.3.1 Perforation scheme optimization algorithm . . . 80
3.3.2 Wheel shape optimization algorithm . . . 81
3.3.3 Preliminary approach to the track shape influence on rolling noise . . . 82
3.4 High-cycle fatigue analysis . . . 83
3.5 Geometry parametrization of wheel shapes . . . 86
3.5.1 Finite Element model for the perforation scheme . . . 87
3.5.2 Finite Element model for the railway wheel cross-section . . . 88
3.5.2.1 Geometry parametrization . . . 89
3.5.2.2 Axisymmetric elements . . . 90
3.6 Modal identification and modeshape characterization . . . 92
3.6.1 Nodal diameters and modal amplitudes . . . 93
3.6.2 Displacement of the contact point . . . 96
3.6.3 Nodal circumferences . . . 97
3.6.4 Modal damping . . . 98
3.7 Objective functions . . . 98
3.7.1 $L_{A,W}$-min . . . 99
3.7.2 NF-max . . . 100

4 Results 103

4.1 Introduction . . . 103

4.2 Methodology validation . . . 104
4.3 Optimization of wheel perforated schemes . . . 113
4.3.1 Straight web . . . 113
4.3.2 Curved web . . . 117
4.3.3 Response Surfaces . . . 122
4.3.4 Accuracy assessment of the acoustic model . . . 124
4.4 Cross-sectional wheel shape optimization . . . 128
4.4.1 Optimization with fixed radius . . . 128
4.4.2 Optimization with all the geometric parameters . . . 135
4.4.3 Response Surfaces . . . 138
4.4.4 Studies on the correlation between natural frequencies and radiated noise . . . 142
4.5 Preliminary studies of the track shape influence on rolling noise . . . 143

5 Conclusions and future work 149
5.1 Conclusions . . . 149
5.2 Future work . . . 152

Bibliography 155

List of Publications 185
International journals (JCR) . . . 185
International congresses . . . 185
National congresses . . . 186