

Contents

Abstract	v
Contents	xvii
List of Figures	xxiii
List of Tables	xxix
1 Introduction	1
1.1 Research context	1
1.1.1 Characteristics of acoustic noise in electric drives and challenges	2
1.1.2 Objectives of the thesis	5
1.2 Original contributions	6
1.3 Dissertation outline	7
2 General notions behind magnetic noise	9
2.1 Fundamentals of rotating electric machines	9
2.1.1 Basic electromagnetic formulations	10
2.1.2 Fundamental principle of rotating electric motors	11
2.1.3 Common motor types in EVs	13

2.1.4	Force production calculation	16
2.2	Fundamentals of structural dynamics	17
2.2.1	Introduction to modal analysis	18
2.2.2	Calculation of the modal characteristics	19
2.2.3	Calculation of the forced response	23
2.3	Fundamentals of acoustic transfer systems	23
2.4	Typical measured acoustic noise from a rotating electric machine	25
3	The multi-physical nature of magnetic noise	29
3.1	Simulation of magnetic noise during run-up	29
3.1.1	FE Models	30
3.1.2	Analytical models	36
3.2	Reference experimental data	40
3.3	Result comparisons	42
3.3.1	Input currents	42
3.3.2	Force wave distribution	43
3.3.3	Structural vibrations and acoustic radiation	43
3.3.4	Computational time considerations	50
3.4	Intermediate conclusions	51
4	Rotor influences on the electric machine vibro-acoustic behavior	53
4.1	Common rotor design changes	54
4.2	Effects on the radiated magnetic noise	54
4.2.1	Case study definition	55
4.2.2	Electromagnetic model and torque ripple assessment . .	56
4.2.3	Structural and acoustic model	59
4.2.4	Results	60
4.3	Effects on the assembly structural dynamics	64

4.3.1	FE identification of RHC mode	65
4.3.2	Experimental validations of the RHC mode occurrence .	69
4.3.3	Experimental evaluation of the rotor structural dynamics responsibilities	73
4.3.4	Mathematical validation of the hypothesis	76
4.4	Intermediate conclusions	82
4.4.1	Conclusions on the effects on the radiated magnetic noise	82
4.4.2	Conclusions on the effects on the assembly structural dynamics	83
5	The laminated cores structural dynamics	85
5.1	Typical modes related to laminated cylindrical cores	85
5.2	1D Analytical models (Ring)	87
5.3	2D FE model	90
5.4	3D FE model with homogenized material properties	91
5.4.1	Isotropic behavior	92
5.4.2	Orthotropy and Transverse isotropy	93
5.5	Model comparison and validation: A case study	101
5.5.1	Reference experimental tests	101
5.5.2	Stator core models	103
5.5.3	Comparisons	107
5.5.4	Material parameter sweep and optimization	109
5.6	Effects of the number of laminations	114
5.6.1	Experimental setup and validation	114
5.6.2	Results	118
5.7	Effects of the stacking technology	119
5.7.1	Experimental setup	123
5.7.2	Results	124

5.8	Intermediate conclusions	126
5.8.1	Final remarks on stator model comparisons	126
5.8.2	Conclusions on the effects of the number of laminations	128
5.8.3	Conclusions on the effects of the stacking technology	129
6	On a novel attachment method of the laminations of the stator core for improved NV performances	131
6.1	Vibration reduction techniques	132
6.2	Conceptualization	133
6.2.1	Motivation	133
6.2.2	On forcing transversal asymmetry	137
6.3	Experimental validations	139
6.3.1	Manufacturing procedure	139
6.3.2	Testing procedure	141
6.3.3	Significance evaluation	143
6.4	Results	145
6.4.1	The effects on axial, shearing and anti-symmetric modes	145
6.4.2	The effects on pure radial modes $A(n_r, 0)$	150
6.4.3	Hypotheses validations	156
6.5	Intermediate conclusions	161
7	Conclusions	165
7.1	Multi-physical nature of magnetic noise	165
7.2	The laminated cores structural dynamics	166
7.3	Original lamination stacking for vibration damping purposes	168
7.4	Future work	170
A	Cylindrical symmetries formulation	173

B Steady-state versus Transient responses	177
Bibliography	181
Curriculum Vitae	195