

















Contents

Abstract	iii
Kurzfassung	v
1. Introduction and Literature	1
1.1. Design Process of Drive System	2
1.2. Objective	3
1.3. Structure of the Work	4
1.4. Pulsating Torque Minimization Rules- Literature Discussion	5
1.4.1. Minimization Method - Design Parameters	6
1.4.2. Minimization Method - Active Control	7
2. High Torque PMSM Application	11
2.1. Paper-Mill	11
2.2. Drive System of Paper-mill	12
2.2.1. Drive with Gears	14
2.2.2. Direct Drive	15
2.2.3. Comparison with and without Gears	16
2.2.4. Economical and Ecological Aspects	20
2.3. Application of PMSM in Paper-Mill	21
2.4. Generic Design and Working Principle of PMSM	22
2.4.1. Physical Description of PMSM	23
2.4.2. Selection of Ferromagnetic Materials	26
2.5. Considered Geometry of PMSM Stator/Rotor	27



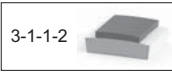



3. General Derivation of Force in PMSM		31
3.1. Classification of Parasitic Torque		31
3.2. Components of Air Gap Flux Density and Permeances		32
3.2.1. No-load Flux Density		32
3.2.2. Solution of the PDE (Method of Separation of Variables)		36
3.2.3. Magnet Leakage/Magnet Utilization		39
3.2.4. Armature Current Sheet		40
3.2.5. Permeance due to Slotting		44
3.2.6. Permeance due to Saturation		49
3.2.7. Permeance due to Magnets		50
3.2.8. No-load Flux Density with Slot		51
3.3. Torque Derivation		53
3.3.1. Mathematical Formulation of Cogging Torque		56
3.3.2. Cogging Torque Result Comparison		59
3.3.3. Mathematical Formulation of Torque Ripple		61
3.3.4. Torque Ripple Result Comparison		63
3.3.5. Torque with Saturation Permeance		65
3.4. Torque pulsation of Geometries		67
3.4.1. Cogging Torque		67
3.4.2. Torque Ripple		68
3.4.3. Relative Torque Pulsation Comparison		70
3.4.4. THD from Surface Mounted to Pole-Cap		70
4. Torque Analysis		73
4.1. Pulsating Torque for Considered Geometries		73
4.1.1. Cogging Torque from D1		74
4.1.2. Cogging Torque from D2		75
4.1.3. Cogging Torque from D4		75
4.1.4. Cogging Torque from D5		76
4.1.5. Torque Ripple from D1		77



4.1.6.	Torque Ripple from D2		78
4.1.7.	Torque Ripple from D4		78
4.1.8.	Torque Ripple from D5		79
4.2.	2D Harmonics Analysis of Numerical Calculations		80
4.2.1.	Step 1		80
4.2.2.	Step 2		80
4.2.3.	Step 3		82
4.2.4.	Step 4		83
4.3.	Torque Analysis for D1		85
4.4.	Torque Analysis for D2		93
4.5.	Torque Analysis for D3		101
4.6.	Intermediate Summary		103
4.7.	Torque Analysis for D4		104
4.8.	Torque Analysis for D5		109
4.9.	Torque Analysis for D6		113
4.10.	Summary		115

5. Measurement Results and Parasitic Torque Special Study 117

5.1.	Measurement Set-up	117
5.1.1.	Pulsating Torque	118
5.2.	Special Study	121
5.2.1.	Introduction to Optimization Methods	122
5.2.2.	Optimization Methods and Model Parameters	122
5.2.3.	Optimized Geometry	124
5.2.4.	Torque Analysis Optimized Geometry	125
5.3.	Torque Ripple under Field Weakening	127
5.4.	Torque Ripple under Alternative Field Weakening	128

5.5. Torque Ripple under Half Load Nominal Operating Point	132
5.5.1. Torque Analysis at Half Load D1 	132
5.5.2. Torque Analysis at Half Load D3 	134
5.5.3. Torque Analysis at Half Load D4 	135
5.5.4. Torque Analysis at Half Load D6 	137
5.6. Summary	138
6. Generic Design Rules for Tooth Coil Winding Arrangement	141
6.1. Design Guidelines	141
6.1.1. Design Rules based on Geometrical Parameters.	143
6.1.1.1. No-load Case.	143
6.1.1.2. Load Case	146
6.1.2. Simplified Design Rules	148
6.1.3. Design Rules from Manufacturing View Point	148
7. Conclusion and Outlook	151
A. Schwartz-Christoffel Transformation	153
B. Field equation of current sheet	155
C. Modal analysis of rotors D2 and D3	157
D. FEM mesh and post processing figures	159
Symbols und Acronyms	169