

Contents

0	Abbreviations and symbols	III
1	Introduction.....	1
2	State of the art.....	4
2.1	Project model V-Modell XT	4
2.2	Requirements engineering.....	5
2.3	Software verification and validation methodologies	5
2.3.1	Introduction	5
2.3.2	Finite state machines and model-based testing.....	6
2.4	Process quality concepts.....	13
2.4.1	Definitions	13
2.4.2	Failure modes and effect analysis	15
2.4.3	Design of experiments	18
2.5	Selective laser melting manufacturing technology	21
2.5.1	Basic concepts.....	21
2.5.2	Designs of machine tools	22
3	Objectives and approach.....	27
4	Test conditions and materials	29
4.1	Selective laser melting machine tool.....	29
4.2	Process parameters	30
4.2.1	Laser.....	30
4.2.2	Recoater device	31
4.2.3	Platform	31
4.3	Material and workpiece.....	32
4.3.1	Aluminum alloy AlSi10Mg.....	32
4.3.2	Geometry	32
4.4	Industrial computed tomograph	33
4.5	Platform for development of software tools.....	33
4.6	Hardware for a data acquisition device and server	33
4.7	Test procedure	34
5	Selective Laser Melting machine tool system	37
5.1	Process map	37
5.2	Key performance indicators	39
5.3	Requirements of the customer.....	44
5.4	Parameters visualization software	45
5.5	Concept of a database and data management	47
6	Methodology for in-process evaluation	51
6.1	Conformance timed automata effect analysis (ConTEA)	51
6.1.1	Models	51
6.1.2	Validation through model checking.....	56
6.1.3	Events evaluation.....	58
6.1.4	Events prioritization and choice of specific scenarios	59
6.1.5	Model revalidation	59
6.1.6	Tests generation	60
6.1.7	Reachable quality indicator	60

6.1.8	Reached quality indicator	62
6.2	Software tool	64
7	Practical application.....	69
7.1	V-Model level and testing guidelines	69
7.2	Machine tool subsystems prioritization	69
7.3	System integration requirements	71
7.4	Events and responses of the machine tool	72
7.5	Reference manufacturing process	73
7.5.1	Workpieces and key performance indicators	73
7.5.2	Tolerances	76
7.6	Conformance timed automata and effect analysis tests.....	77
7.6.1	Scenarios.....	77
7.6.2	Application	85
7.6.3	Final quality percentage	89
7.6.4	Key performance indicators and parameters	90
7.7	Taguchi tests.....	95
7.7.1	Parameter settings	95
7.7.2	Application	96
7.7.3	Key performance indicators and parameters	97
7.8	Comparison between ConTEA and Taguchi testing methodologies.....	102
7.8.1	Key performance indicators.....	102
7.8.2	Tests	104
7.8.3	Workpieces	105
8	Recommendation for the practice towards Industrie 4.0	109
9	Conclusions.....	111
10	References.....	114
11	Appendix A – System requirements.....	123
12	Appendix B – ConTEA variables.....	125
13	Appendix C – ConTEA models and properties.....	126
14	Appendix D – Sneak paths table and transitions prioritization tables	143
15	Appendix E – Test cases	147