Content

Content

1	Introduction	1
2 2.1 2.1.1 2.1.2 2.1.3 2.2 2.2.1 2.2.2 2.3 2.3.1 2.3.2 2.3.3 2.3.4 2.3.5	State of the art Process and machine subsystems Process fundamentals Optical system Shielding gas flow system Machine accuracy and calibration Linear axes Scanner systems Machine concepts for large build volumes Fundamentals of build volume enlargement Machines with multiple scanners Machines with movable processing head Machines with movable build volume Summary of the machine concepts	3 3 6 8 11 12 14 26 27 32 38 43 43
3 3.1 3.2 3.3	Research questions and approach Preliminary considerations Problem and research questions Approach	49 49 49 50
4 4.1 4.1.1 4.1.2 4.1.3 4.1.4 4.1.5 4.2 4.2.1 4.2.2 4.2.3 4.2.4	Prototype machine development and characterization Machine development Prototype machine Mechanical system Optical system Shielding gas system Control system Machine characterization Mechanical system Optical system Shielding gas system Conclusion	55 55 59 60 62 64 66 66 66 72 78 88
5 5.1 5.1.1	Modeling and calibration of the machine accuracy Geometric error models Fundamentals of the geometric error models	91 91 91

L

5.1.2 5.1.3 5.2 5.2.1 5.2.2 5.2.3 5.2.4 5.2.5 5.2.6 5.2.7	Analytical geometric error model Metrological geometric error model Conclusion Scanner calibration method Overall approach Camera system for scan field calibration Exposure strategies for generating markers Image processing for marker position detection Investigation of the repeatability Application for scan field alignment Conclusion	98 106 114 115 118 120 126 129 136 140
6 6.1 6.1.2 6.1.3 6.1.4 6.1.5 6.2 6.2.1 6.2.2 6.2.3 6.2.4 6.2.5	CAM development Multi-scanner workload balancing Overall approach Calculation of processing time Allocation of processing time Assignment of blocks to scanners Conclusion CAM for movable processing head Overall approach Determination of processing head positions Path planning Assignment of blocks to processing head positions Conclusion	143 143 145 146 149 154 154 155 156 159 161
7 7.1 7.2	Demonstration Part quality Demonstrator parts	165 165 168
8 8.1 8.2	Summary and outlook Summary Outlook	173 173 176
9	Bibliography	179
10	Abbreviations and symbols	197
11 11.1 11.2 11.3 11.4 11.5 11.5.1	Annex Errors of galvanometer scanner systems Assessment of approaches for scan field calibration Prototype machine Characterization of the linear axis system Characterization of the optical system Laser beam properties	205 206 209 210 213 213

215
217
222
222
224
230
230
233
236
236
236
237
239
240
242
242
243
245
246
246
246