

Contents

Abstract	v
Kurzfassung	vii
Nomenclature, Symbols & Abbreviations	xi
1 Introduction	1
1.1 The Cost of Manufacturing Variability	2
1.2 Estimating Geometric Uncertainty for Robust Design	4
1.3 Problem Statement and Thesis Outline	9
2 CAD Surface Parametrization and Measurement	11
2.1 CAD Surface Parametrization	11
2.2 Geometric Properties of B-Spline Surfaces	16
2.3 Parametric Construction of CAD Parts	19
2.4 Surface Measurement with Structured Light	20
3 CAD Representation of Manufacturing Deviations	29
3.1 Re-Parametrization as B-Spline Surface	30
3.2 Selection of Relevant Surface Positions	32
3.3 Selection of Relevant Control Points	34
3.4 B-Spline Morphing to Surface Measurements	38
3.5 Noise Elimination from Morphed Surfaces	41
3.6 Application to HPT Blade Casting Faces	45
3.6.1 Suction-Side Shank Face	45
3.6.2 Hot-Gas Faces	48
4 Probabilistic Representation of Manufacturing Deviations	51
4.1 Manufacturing Modes	51
4.2 Coupled Manufacturing Modes	55
4.3 Representation Capacity of Manufacturing Modes	58
4.4 Probabilistic Description of Surface Deviations	62

4.5	Application to HPT Blade Structural Uncertainty Quantification	66
4.6	Application to Manufacturing Variability of Diverse Shank Designs	73
5	Deviation Estimation for New Geometric Designs	79
5.1	Strategies for Deviation Estimation	80
5.2	Deviation Model Using Convolution Operators	84
5.3	Learning of Deviation Laws	90
5.4	Minimization of Deviation Prediction Divergence	98
5.5	Application to Estimation of HPT Blade Casting Deviations	102
5.6	Integration of Deviation Laws into Robust Design	112
6	Conclusions	117
	Appendix A: Convolutional Neural Networks	121
A.1	Basic Mathematical Background	121
A.2	Pooling, Interpolation and Filtering Operations	124
	List of Figures	125
	References	129