CONTENTS

Pre	face		page ix		
1	INTROD	1			
2	MECHA	MECHANICS OF METAL CUTTING			
	2.1 Int	roduction	4		
	2.2 Me	chanics of Orthogonal Cutting	4		
	2.3 Me	chanistic Modeling of Cutting Forces	15		
	2.4 Th	eoretical Prediction of Shear Angle	18		
	2.5 Me	chanics of Oblique Cutting	19		
	2.5.1	Oblique Cutting Geometry	19		
	2.5.2	Solution of Oblique Cutting Parameters	21		
	2.5.3	Prediction of Cutting Forces	25		
	2.6 Me	chanics of Turning Processes	27		
	2.7 Me	chanics of Milling Processes	35		
		Mechanics of Helical End Mills	41		
	2.8 An	alytical Modeling of End Milling Forces	43		
	2.8.1	Mechanistic Identification of Cutting Constants			
		Ailling	46		
		chanics of Drilling	47		
		ool Wear and Tool Breakage	54		
	2.10.1	Tool Wear	56		
		2 Tool Breakage	61		
	2.11 P	roblems	62		
3	STRUC	TURAL DYNAMICS OF MACHINES	66		
	3.1 Int	roduction	66		
	3.2 Ma	achine Tool Structures	66		
	3.3 Dir	mensional Form Errors in Machining	68		
	3.3.1	Form Errors in Cylindrical Turning	68		
	3.3.2	Boring Bar	70		
	3.3.3	Form Errors in End Milling	71		
	3.4 Str	ructural Vibrations in Machining	74		
	3.4.1	Fundamentals of Free and Forced Vibrations	75		
	3.4.2	Oriented Frequency Response Function	82		

۷

	3.4.3	Design and Measurement Coordinate Systems	83
	3.4.4	Analytical Modal Analysis for Multi–Degree-of-Freedom	
	Sys	tems	85
	3.4.5	Relative Frequency Response Function between Tool and	
	Wor	rkpiece	90
	3.5 Mo	dal Testing of Machine Structures	92
	3.5.1	Theory of Frequency Response Testing	92
	3.5.2	Experimental Procedures in Modal Testing	97
	3.6 Ex	perimental Modal Analysis for Multi–Degree-of-Freedom	
		tems	98
	3.7 Ide	entification of Modal Parameters	109
	3.7.1		
		ntification	113
		ceptance Coupling of End Mills to Spindle-Tool Holder	
		embly	115
		Experimental Procedure	118
	3.9 Pro	oblems	120
4	масни	NE TOOL VIBRATIONS	125
		roduction	125
		ability of Regenerative Chatter Vibrations in Orthogonal	196
	4.2.1	ting Stability of Orthogonal Cutting	126 126
	4.2.1 4.2.2	Dimensionless Analysis of Stability Lobes in Orthogonal	120
		ting	132
	4.2.3	Chatter Stability of Orthogonal Cutting with Process	102
		nping	135
		atter Stability of Turning Operations	139
		atter Stability of Turning Systems with Process Damping	142
	4.4.1	Metal Cutting Forces	144
		Process Damping Gains Contributed by Flank Wear	145
		Stability Analysis	147
		perimental Validation	148
		alytical Prediction of Chatter Vibrations in Milling	149
		Dynamic Milling Model	149
	4.6.2	Zero-Order Solution of Chatter Stability in Milling	154
	4.6.3	Multi-Frequency Solution of Chatter Stability in Milling	160
		atter Stability of Drilling Operations	172
	4.7.1	Dynamic Drilling Force Model	173
	4.8 Fre	equency Domain Solution of Drilling Stability	176
		midiscrete Time Domain Solution of Chatter Stability	178
	4.9.1	Orthogonal Cutting	178
	4.9.2	Discrete Time Domain Stability Solution in Milling	182
	4.10 P	roblems	186

vi

CONTENTS

TECHNOLOGY OF MANUFACTURING AUTOMATION						
5.1 Int	roduction	191				
5.2 Co	mputer Numerically Controlled Unit	191				
5.2.1	Organization of a CNC Unit	191				
5.2.2	CNC Executive	193				
5.2.3	CNC Machine Tool Axis Conventions	193				
5.2.4	NC Part Program Structure	193				
5.2.5	Main Preparatory Functions	196				
5.3 Co	mputer-Assisted NC Part Programming	201				
5.3.1	Basics of Analytical Geometry	201				
5.3.2	APT Part Programming Language	206				
5.4 Trajectory Generation for Computer-Controlled						
Ma	chines	211				
5.4.1	Interpolation with Constant Displacement	212				
5.4.2	Acceleration-Limited Velocity Profile Generation					
with	h Constant Interpolation Period	216				
5.4.3	Jerk-Limited Velocity Profile Generation	220				
5.5 Re	al-Time Interpolation Methods	229				
5.5.1	Linear Interpolation Algorithm	230				
5.5.2	Circular Interpolation Algorithm	234				
5.5.3	Quintic Spline Interpolation within CNC Systems	239				
5.6 Pro	oblems	245				
	에너 방법을 하는 것을 수 있는 것이 아니는 것이 같아. 이 것이 가지 않는 것이 같아.					
DESIGN	AND ANALYSIS OF CNC SYSTEMS	250				
6.1 Int	roduction	250				
0111 1.10	achine Tool Drives	250				
6.2.1	Mechanical Components and Torque Requirements	251				
6.2.2	Feedback Devices	256				
6.2.3	Electrical Drives	257				
6.2.4	8	258				
6.2.5		263				
6.3 Tra	ansfer Function of the Position Loop	264				
	ate Space Model of Feed Drive Control Systems	268				
	ding Mode Controller	281				
	tive Damping of Feed Drives	285				
	sign of an Electrohydraulic CNC Press Brake	293				
6.7.1	Hydraulic Press Brake System	293				
6.7.2	Dynamic Model of Hydraulic Actuator Module	296				
6.7.3 Identification of Electrohydraulic Drive Dynamics						
for	Computer Control	299				
	Digital Position Control System Design	301				
6.8 Pro	oblems	307				

5

6

vii

7	SEN	SOR-A	SSISTED MACHINING	313
	7.1	Introd	uction	313
	7.2	Intellig	gent Machining Module	313
	7.2	.1 Ha	rdware Architecture	314
	7.2	.2 So	ftware Architecture	315
	7.2	.3 Int	telligent Machining Application	316
	7.3	Adapti	ve Control of Peak Forces in Milling	317
	7.3	.1 Int	troduction	317
	7.3	.2 Di	screte Transfer Function of the Milling Process	
	\$	System		319
	7.3	.3 Po	le-Placement Control Algorithm	321
	7.8	.4 Ad	aptive Generalized Predictive Control of Milling	
]	Process		325
	7.3	.5 In-	Process Detection of Tool Breakage	330
	7.3	.6 Ch	atter Detection and Suppression	333
	7.4	Intelli	gent Pocketing with the IMM System	334
	7.5	Proble	ms	336
AP	PEND	IX A:	LAPLACE AND z TRANSFORMS	341
	A.1	Introd	uction	341
	A.2	Basic	Definitions	343
	A.3	Partia	l Fraction Expansion Method	347
	A.4	Partia	l Fraction Expansion Method to Determine Inverse	
]	Laplace	a and z Transforms	349
AP	PEND	IX B:	OFF-LINE AND ON-LINE PARAMETER	
	ESTI	MATIC	ON WITH LEAST SQUARES	353
	B.1	Off-Li	ne Least-Squares Estimation	353
	B.2	Recur	sive Parameter Estimation Algorithm	355
Bibliography			357	
Inde	Index			363