

# Contents

Thomas Paton Goodman . . . . .	v
A Word From The Author and Translators . . . . .	vii
Foreword . . . . .	xi
Introduction . . . . .	xi
The Current Status of the Development of Kinematics . . . . .	xiii
Reviews of Literature . . . . .	xiv
Research on Mechanisms . . . . .	xv
Aims of Kinematics . . . . .	xviii
Literature on Mechanisms . . . . .	

## Part I—Kinematic Analysis

1. Fundamental Concepts of Kinematics . . . . .	3
1.01 Basic Definitions . . . . .	3
1.02 Representation of Mechanisms . . . . .	5
1.03 Classification of Mechanisms . . . . .	6
1.04 Kinematic Pairs . . . . .	7
1.05 Kinematic Chains . . . . .	10
1.06 Symbolic Representation of Mechanisms . . . . .	12
1.07 Kinematic Models . . . . .	14
1.08 Kinematic Films . . . . .	14
2. Degrees of Freedom in Mechanisms . . . . .	15
2.01 What is Constrained Motion? . . . . .	15
2.02 Degrees of Freedom in General . . . . .	15
2.03 Constrained Motion in Turning-Pair Chains . . . . .	17
2.04 Constrained Motion in Sliding-Pair Chains . . . . .	19
2.05 Constrained Motion in Chains with Higher Kinematic Pairs . . . . .	20
2.06 Kutzbach's Theory of Multiple Drives . . . . .	21
2.07 Chains with Redundant Constraints . . . . .	23
3. Systematics of Mechanisms . . . . .	27
3.01 Meaning of Systematics . . . . .	27
3.02 Groups of Link Mechanisms with Turning Pairs . . . . .	28
3.03 Groups of Link Mechanisms Having Sliding Pairs . . . . .	32
3.04 Eight-Link Kinematic Chains . . . . .	39
3.05 Belt Mechanisms . . . . .	40
3.06 Spring Mechanisms . . . . .	42

3.07	Gear-Crank Mechanisms .....	43
3.08	Chain-Crank Mechanisms .....	44
3.09	Mechanisms with More Than One Degree of Freedom .....	44
4.	The State of Motion in a Planar Mechanism .....	47
4.01	Measurement in Mechanisms .....	47
4.02	The Forms of Motion .....	49
4.03	Determining Positions in Mechanisms .....	53
4.04	Polodes .....	56
4.05	Envelopes and Their Generating Curves .....	61
4.06	Relative Motion of Several Planar Systems .....	62
4.07	Instant Centers in Kinematic Chains and Mechanisms .....	63
4.08	Curvature Relationships .....	66
4.09	Bobillier's Construction .....	69
4.10	Inflection Circle and Cuspidal Circle .....	70
4.11	The Curvature of Traction Curves .....	73
4.12	Curvature Relationships in Crank Mechanisms ...	80
4.13	Graphical Representation of Curvature Relationships .....	85
4.14	Quadratic Relationships .....	86
	Velocity Vectors in a Planar System .....	87
5.01	Definition of Velocity .....	87
5.02	Velocities in Planar Motion .....	89
5.03	Velocities and Path Curvature .....	94
5.04	Determination of Velocities in Mechanisms .....	96
5.05	Determination of Velocities by Superposition of Motion .....	98
5.06	Method of Equivalent Mechanisms .....	101
5.07	Other Methods of Determining Velocities .....	109
5.08	The Transmission Ratio .....	110
5.09	Radius of Transmission .....	134
5.10	Six-Link Single-Piston Mechanisms .....	139
5.11	Maximum and Minimum Velocities in Motion ...	145
6.	Acceleration in Planar Mechanisms .....	148
6.01	Representation of Acceleration .....	148
6.02	Analysis of Acceleration .....	149
6.03	The Bresse Circles .....	152
6.04	The Acceleration Poles .....	155
6.05	Finding Accelerations in Planar Mechanisms ...	158
6.06	Acceleration States of Mechanisms with Sliding Components .....	166
6.07	Angular and Higher-Order Accelerations .....	170
6.08	Scale Factors .....	171
6.09	Kinematic Diagrams .....	172

7.	Force Analysis in Mechanisms . . . . .	178
7.01	Graphical Statics and Mechanism Design . . . . .	178
7.02	Simple Methods for Finding Static Forces . . . . .	178
7.03	Practical Examples of Forces Solutions by Graphical Statics . . . . .	184
7.04	The General Pole Force Method . . . . .	199
7.05	Simplified Pole Force Method . . . . .	215
7.06	Forces in Differential Mechanisms with Varying Velocity Ratios . . . . .	222
7.07	Other Effects of Forces . . . . .	232
8.	Dynamics of Mechanisms . . . . .	234
8.01	Dynamic Forces . . . . .	234
8.02	Dynamic Analysis of Mechanisms . . . . .	234
8.03	Resultant Inertia Force . . . . .	236
8.04	Dynamic Synthesis of Mechanisms . . . . .	237
8.05	Pendulum Linkages . . . . .	240
9.	The Quality of Motion Transmission . . . . .	241
9.01	Transmission Angle . . . . .	241
9.02	Location of the Transmission Angle . . . . .	242
9.03	Important Values of the Transmission Angle . . . . .	246
9.04	Possible Motions when the Transmission Angle is Zero . . . . .	
9.05	Quality of Transmission of Motion in the Presence of Forces . . . . .	250

**Part II—Mechanism Synthesis**

10.	Cam Mechanisms . . . . .	253
10.01	Comparison Between Cam and Link Mechanisms . . . . .	253
10.02	Transmission of Motion From Cam to Follower . . . . .	257
10.03	Analysis and Manufacture of Cams . . . . .	260
10.04	Guiding a Point Along a Given Path . . . . .	263
10.05	Guiding a Plane . . . . .	269
10.06	Revolving Cams with Oscillating Followers . . . . .	272
10.07	Revolving Roller Cranks with Oscillating Cams . . . . .	280
10.08	Cam Mechanisms for Various Applications . . . . .	282
10.09	Direct Contact (Rolling Lever) Mechanisms . . . . .	283
11.	Crank Mechanisms . . . . .	291
11.01	The Four-Bar Linkage . . . . .	291
11.02	Slider Crank Mechanisms . . . . .	300
11.03	Inverted Slider-Crank Mechanisms . . . . .	302
11.04	Scotch Yoke Mechanism and Inclined-Slip Mechanism . . . . .	306
11.05	Crank Mechanisms for Straight Line Paths . . . . .	307
11.06	Dead-Center Positions of Crank Mechanisms . . . . .	314

12.	Indirect Mechanism Synthesis . . . . .	322
12.01	Survey of Coupler Curves . . . . .	322
12.02	Use of Coupler Curves . . . . .	324
12.03	The Selection of Coupler Curves for Prescribed Conditions . . . . .	325
12.04	Cardan Motion and Coupler Motion . . . . .	326
12.05	Approximated Crank Circle . . . . .	328
12.06	Reduction of Mechanisms . . . . .	329
12.07	Double Point for Given Crank Positions . . . . .	329
12.08	Double Point for a Given Point . . . . .	331
12.09	General Observations on Double Points . . . . .	332
12.10	Coupler Curve Through Two Given Fixed Points . . . . .	333
12.11	Coupler Points for Curves of Constant Curvature . . . . .	336
12.12	Coupler Points for Curves with Changing Curvature . . . . .	337
12.13	Coupler Curves with Cusps . . . . .	339
12.14	Approximated Compound Mechanism . . . . .	346
12.15	Addition of Motions . . . . .	347
13.	Selection of a Mechanism from Design Curves . . . . .	350
13.01	General . . . . .	350
13.02	Design Curves for Crank-Lever Mechanisms . . . . .	351
13.03	Design Curves for Inverted Slider-Cranks . . . . .	357
13.04	Design Curves for Conventional Slider-Cranks . . . . .	357
13.05	Design Curves for Drag-Link Mechanisms . . . . .	358
13.06	Design Curves for Coupler Drives . . . . .	360
13.07	Design Curves for Converting Angular Motion . . . . .	361
13.08	Design Curves for Approximate Dwells by Using Charts . . . . .	370
13.09	Design Charts for Mechanisms Relating Linear and Rotary Motion . . . . .	373
13.10	Design for More than Two Positions of a Mechanism . . . . .	375
13.11	Applications of Computers to Mechanism Design . . . . .	379
14.	Synthesis Using Equivalent Mechanisms . . . . .	381
14.01	Application to Multibar Linkages . . . . .	381
14.02	Equivalent Cam Mechanisms for Coupler Mechanisms . . . . .	382
14.03	Motion Relationships in Coupler Mechanisms . . . . .	383
14.03.1	Coupler-Lever Mechanisms . . . . .	383
14.03.2	Coupler-Crank Mechanisms . . . . .	385
14.03.3	Revolving Coupler Mechanisms . . . . .	386
14.03.4	Oscillating Coupler Mechanisms . . . . .	389
14.04	Dead-Points in a Coupler Mechanism . . . . .	389
14.05	Coupler Dwell Mechanisms . . . . .	394
14.06	Equivalent Cam Mechanisms for Linkages with only Two Fixed Pivots . . . . .	396

14.07	Motion Relationships in Two-Pivot Mechanisms . . . . .	400
14.07.1	Two-Pivot Lever Mechanisms . . . . .	401
14.07.2	Two-Pivot Crank Mechanisms . . . . .	402
14.07.3	Revolving Two-Pivot Mechanisms . . . . .	403
14.07.4	Oscillating Two-Pivot Mechanisms . . . . .	404
14.07.5	Two-Pivot Slider Mechanisms . . . . .	405
14.07.6	Two-Pivot Mechanisms with Two Sliders . . . . .	410
14.08	Comparison of Motion Relationships in Coupler Mechanisms and in Two-Pivot Mechanisms . . . . .	412
14.09	Dead-Points in Two-Pivot Mechanisms . . . . .	413
14.10	Two-Pivot Dwell Mechanisms . . . . .	419
14.11	The Double Coupler Mechanism . . . . .	426
15.	Dimensional Synthesis . . . . .	432
15.01	Introduction . . . . .	432
15.02	Rotopoles and the Pole Triangles . . . . .	434
15.03	Matching of Point Positions . . . . .	440
15.04	Coordination of Point Positions with Angular Positions . . . . .	445
15.05	Coordination of Angular Rotations . . . . .	453
15.06	Coordination of Angles with Linear Displacements . . . . .	463
15.07	Coordination of Velocities and Accelerations . . . . .	464
15.08	Coordination of Angular Velocities, Torques, and Forces . . . . .	468
15.09	Coordination of Forces in Clamping Mechanisms . . . . .	474
16.	The Special Curves of Dimensional Synthesis . . . . .	478
16.01	The Circle-Point and Center Point Curves . . . . .	478
16.02	The $R_1$ , $R_M$ and $s_1$ Curves . . . . .	492
16.03	The Circling-Point Curve and the Centering Curve . . . . .	498
16.04	The $\rho$ , $\rho_m$ and $q$ Curves . . . . .	502
16.05	The $C_1$ Curve . . . . .	506
16.06	Some Special Cases of the Synthesizing Curves . . . . .	508
17.	Point Position Reduction . . . . .	524
17.01	The Meaning of Point Position Reduction . . . . .	524
17.02	Point Position Correlation in The Four-Bar Linkage . . . . .	
17.03	Point Position Correlation Using Multiple-Member Crank Mechanisms . . . . .	560
17.04	Correlation of Point Positions and Angles . . . . .	568
17.05	Correlation of Coupler Positions . . . . .	574
17.06	Correlation of Angle and Path in Four-Bar Linkages . . . . .	
17.07	Angle and Path Correlation Using Multiplink Crank Mechanisms . . . . .	594

17.08	Mechanism Synthesis for Given Transmission Ratio and for Given Sliding Distances . . . . .	608
18.	Symmetry as an Aid in Advanced Design Requirements . . . . .	619
18.01	General . . . . .	619
18.02	Corresponding Rotations . . . . .	619
18.03	Symmetrical Positions and Dwell Mechanisms . . . . .	621
19.	Special Types of Mechanisms . . . . .	634
19.01	Mechanisms with More than One Degree of Freedom . . . . .	634
19.02	Belt Mechanisms . . . . .	635
19.03	Spring Mechanisms . . . . .	635
19.04	Wheel Crank Mechanisms . . . . .	636
19.05	Ratchet Mechanisms . . . . .	636
19.06	Space Mechanisms . . . . .	637
	Bibliography . . . . .	639
	Publications of Kurt Hain, 1961-1966 . . . . .	703
	Index . . . . .	705