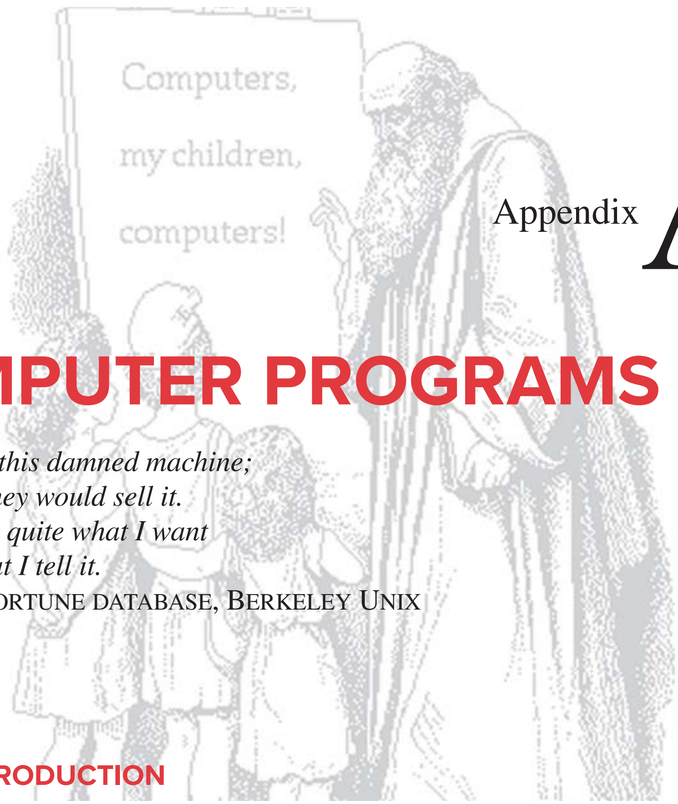


Appendix A

COMPUTER PROGRAMS

I really hate this damned machine;
I wish that they would sell it.
It never does quite what I want
But only what I tell it.
FROM THE FORTUNE DATABASE, BERKELEY UNIX

A.0 INTRODUCTION

In addition to the downloadable version of the commercial simulation program Working Model, there are three computer programs, written by the author, downloadable with this text: programs LINKAGES, MATRIX, and DYNACAM. These are student editions of the professional versions of these programs for educational use only. For commercial applications, professional versions with extended capabilities are available at **http://www.designofmachinery.com**. Program LINKAGES is based on the mathematics derived in Chapters 4 to 7 and 10 to 14 and use the equations presented therein to solve for position, velocity, acceleration, forces, and torques in fourbar, fivebar, sixbar, and slider linkages and IC engines. Program DYNACAM is a cam design program based on the mathematics derived in Chapters 8 and 15. Program MATRIX is a general linear simultaneous equation solver. All have similar choices for the display of output data in the form of tables and plots. All the programs are designed to be user friendly and reasonably "crashproof." The author encourages users to email reports of any "bugs" or problems encountered in their use to him at norton@wpi.edu.

To obtain these programs and the other videos and files provided with the book, you need to register as a **student using the book** on the website shown above. Note that I personally review all applications for access to this protected site, and if a student does not fill out the application completely and correctly according to the instructions, then they will be denied access.

Learning Tools

All the custom programs provided with this text are designed to be learning tools to aid in the understanding of the relevant subject matter and *are specifically not intended to be used for commercial purposes in the design of hardware* **and must not be so used**. It is quite possible to obtain inappropriate (but mathematically correct) results to any problem solved with these programs, due to incorrect or inappropriate input of data. The user is expected to understand the kinematic and dynamic theory underlying the program's structure and to also understand the mathematics on which the program's algorithms are based. This information on the underlying theory and mathematics is derived and described in the noted chapters of this text. Most equations used in the programs are derived or presented in this textbook.

Disclaimer and Limitations on Use

Student editions of these programs are made available with this book and carry a limited-term license restricted to educational use in course work for up to 2 years. If you wish to use the program for the benefit of a company or for any commercial purpose, then you must obtain the professional edition of the same program. **The student editions may not be used commercially**! The professional editions typically offer more features and better accuracy than the student editions. Commercial software for use in design or analysis needs to have built-in safeguards against the possibility of the user providing incorrect, inappropriate, or ridiculous values for input variables, in order to guard against erroneous results due to user ignorance or inexperience. **The student editions of the custom programs provided with this text are not commercial software and deliberately do not contain such safeguards against improper input data**, on the premise that to do so would "short-circuit" the student's learning process. We learn most from our failures. These programs provide an educational environment to explore failure of your designs "on paper" and in the process to come to a more thorough and complete understanding of the subject matter. **The author and publisher are not responsible for any damages which may result from the use or misuse of these programs.**

A.1 GENERAL INFORMATION

Hardware/System Requirements

These programs will run in Windows 2000/NT/XP/Vista/Windows7/8/10, but settings changes are needed in Vista as described in the installation instructions. All programs will operate properly in both 32- and 64-bit operating systems. In Windows 10, you may have to run them as Windows 7 applications.

Installing the Software

The install.exe files contain the executable program files plus all necessary Dynamic Link Library (DLL) and other ancillary files needed to run the programs. Run the Install file for each program to install all of its files on your hard drive. The program name will appear in the list under the *Start/Program/Design of Machinery* menu after installation and can be run from there. DYNACAM and LINKAGES can be updated from that menu also. Use the Check for Updates link within the program's folder in the Start menu

User Manual

User manuals are accessible from the programs' help menus. Tutorial videos are also in some programs. Instructional videos are also accessible from the help menus within the programs when the computer is connected to the Internet.

Appendix B

MATERIAL PROPERTIES

These tables are for selected engineering materials. Many other alloys are available.

The following tables contain approximate values for strengths and other specifications of a variety of engineering materials compiled from various sources. In some cases, the data are minimum recommended values, and in other cases data are from a single test specimen. These data are suitable for use in the engineering exercises contained in this text but should not be considered as statistically valid representations of specifications for any particular alloy or material. The designer should consult the materials' manufacturers for more accurate and up-to-date strength information on materials used in engineering applications or conduct independent tests of the selected materials to determine their ultimate suitability to any application.

Table No.	Description
B-1	Physical Properties of Some Engineering Materials
B-2	Mechanical Properties of Some Wrought-Aluminum Alloys
B-3	Mechanical Properties of Some Carbon Steels
B-4	Mechanical Properties of Some Cast-Iron Alloys
B-5	Properties of Some Engineering Plastics

TABLE B-1 Physical Properties of Some Engineering Materials

Data from Various Sources.* These Properties are Essentially Similar for All Alloys of the Particular Material

Material	Modulus of Elasticity E		Modulus of Rigidity G		Poisson's Ratio ν	Weight Density γ	Mass Density ρ	Specific Gravity
	Mpsi	GPa	Mpsi	GPa		lb/in^3	Mg/m^3	
Aluminum alloys	10.4	71.7	3.9	26.8	0.34	0.10	2.8	2.8
Beryllium copper	18.5	127.6	7.2	49.4	0.29	0.30	8.3	8.3
Brass, bronze	16.0	110.3	6.0	41.5	0.33	0.31	8.6	8.6
Copper	17.5	120.7	6.5	44.7	0.35	0.32	8.9	8.9
Iron, cast, gray	15.0	103.4	5.9	40.4	0.28	0.26	7.2	7.2
Iron, cast, ductile	24.5	168.9	9.4	65.0	0.30	0.25	6.9	6.9
Iron, cast, malleable	25.0	172.4	9.6	66.3	0.30	0.26	7.3	7.3
Magnesium alloys	6.5	44.8	2.4	16.8	0.33	0.07	1.8	1.8
Nickel alloys	30.0	206.8	11.5	79.6	0.30	0.30	8.3	8.3
Steel, carbon	30.0	206.8	11.7	80.8	0.28	0.28	7.8	7.8
Steel, alloys	30.0	206.8	11.7	80.8	0.28	0.28	7.8	7.8
Steel, stainless	27.5	189.6	10.7	74.1	0.28	0.28	7.8	7.8
Titanium alloys	16.5	113.8	6.2	42.4	0.34	0.16	4.4	4.4
Zinc alloys	12.0	82.7	4.5	31.1	0.33	0.24	6.6	6.6

* *Properties of Some Metals and Alloys*, International Nickel Co., Inc., NY; *Metals Handbook*, American Society for Metals, Materials Park, OH.

TABLE B-2 Mechanical Properties of Some Wrought-Aluminum Alloys

Data from Various Sources.* Approximate Values. Consult Manufacturers for More Accurate Information

Wrought-Aluminum Alloy	Condition	Tensile Yield Strength (2% Offset)		Ultimate Tensile Strength		Fatigue Strength at 5E8 Cycles		Elongation over 2 in	Brinell Hardness
		kpsi	MPa	kpsi	MPa	kpsi	MPa	%	HB
1100	Sheet annealed	5	34	13	90			35	23
	Cold rolled	22	152	24	165			5	44
2024	Sheet annealed	11	76	26	179			20	—
	Heat treated	42	290	64	441	20	138	19	—
3003	Sheet annealed	6	41	16	110			30	28
	Cold rolled	27	186	29	200			4	55
5052	Sheet annealed	13	90	28	193			25	47
	Cold rolled	37	255	42	290			7	77
6061	Sheet annealed	8	55	18	124			25	30
	Heat treated	40	276	45	310	14	97	12	95
7075	Bar annealed	15	103	33	228			16	60
	Heat treated	73	503	83	572	14	97	11	150

* *Properties of Some Metals and Alloys*, International Nickel Co., Inc., NY; *Metals Handbook*, American Society for Metals, Materials Park, OH.

TABLE B-3 Mechanical Properties of Some Carbon Steels

Data from Various Sources.* Approximate Values. Consult Manufacturers for More Accurate Information

SAE / AISI Number	Condition	Tensile Yield Strength (2% Offset)		Ultimate Tensile Strength		Elongation over 2 in	Brinell Hardness
		kpsi	MPa	kpsi	MPa	%	HB
1010	Hot rolled	26	179	47	324	28	95
	Cold rolled	44	303	53	365	20	105
1020	Hot rolled	30	207	55	379	25	111
	Cold rolled	57	393	68	469	15	131
1030	Hot rolled	38	259	68	469	20	137
	Normalized @ 1650°F	50	345	75	517	32	149
	Cold rolled	64	441	76	524	12	149
	Q&T @ 1000°F	75	517	97	669	28	255
	Q&T @ 800°F	84	579	106	731	23	302
	Q&T @ 400°F	94	648	123	848	17	495
1035	Hot rolled	40	276	72	496	18	143
	Cold rolled	67	462	80	552	12	163
1040	Hot rolled	42	290	76	524	18	149
	Normalized @ 1650°F	54	372	86	593	28	170
	Cold rolled	71	490	85	586	12	170
	Q&T @ 1200°F	63	434	92	634	29	192
	Q&T @ 800°F	80	552	110	758	21	241
	Q&T @ 400°F	86	593	113	779	19	262
1045	Hot rolled	45	310	82	565	16	163
	Cold rolled	77	531	91	627	12	179
1050	Hot rolled	50	345	90	621	15	179
	Normalized @ 1650°F	62	427	108	745	20	217
	Cold rolled	84	579	100	689	10	197
	Q&T @ 1200°F	78	538	104	717	28	235
	Q&T @ 800°F	115	793	158	1089	13	444
	Q&T @ 400°F	117	807	163	1 124	9	514
1060	Hot rolled	54	372	98	676	12	200
	Normalized @ 1650°F	61	421	112	772	18	229
	Q&T @ 1200°F	76	524	116	800	23	229
	Q&T @ 1000°F	97	669	140	965	17	277
	Q&T @ 800°F	111	765	156	1076	14	311
1095	Hot rolled	66	455	120	827	10	248
	Normalized @ 1650°F	72	496	147	1014	9	13
	Q&T @ 1200°F	80	552	130	896	21	269
	Q&T @ 800°F	112	772	176	1213	12	363
	Q&T @ 600°F	118	814	183	1262	10	375

* *SAE Handbook*, Society of Automotive Engineers, Warrendale, PA; *Metals Handbook*, American Society for Metals, Materials Park, OH.

B

TABLE B-4 Mechanical Properties of Some Cast-Iron Alloys

Data from Various Sources.* Approximate Values. Consult Manufacturers for More Accurate Information

Cast-Iron Alloy	Condition	Tensile Yield Strength (2% Offset)		Ultimate Tensile Strength		Compressive Strength		Brinell Hardness
		kpsi	MPa	kpsi	MPa	kpsi	MPa	HB
Gray cast iron—Class 20	As cast	–	–	22	152	83	572	156
Gray cast iron—Class 30	As cast	–	–	32	221	109	752	210
Gray cast iron—Class 40	As cast	–	–	42	290	140	965	235
Gray cast iron—Class 50	As cast	–	–	52	359	164	1131	262
Gray cast iron—Class 60	As cast	–	–	62	427	187	1289	302
Ductile iron 60-40-18	Annealed	47	324	65	448	52	359	160
Ductile iron 65-45-12	Annealed	48	331	67	462	53	365	174
Ductile iron 80-55-06	Annealed	53	365	82	565	56	386	228
Ductile iron 120-90-02	Q & T	120	827	140	965	134	924	325

* *Properties of Some Metals and Alloys*, International Nickel Co., Inc., NY; *Metals Handbook*, American Society for Metals, Materials Park, OH.

TABLE B-5 Properties of Some Engineering Plastics

Data from Various Sources.* Approximate Values. Consult Manufacturers for More Accurate Information

Material	Approximate Modulus of Elasticity *E* †		Ultimate Tensile Strength		Ultimate Compressive Strength		Elongation over 2 in	Max Temp	Specific Gravity
	Mpsi	GPa	kpsi	MPa	kpsi	MPa	%	°F	
ABS	0.3	2.1	6.0	41.4	10.0	68.9	5–25	160–200	1.05
20–40% glass filled	0.6	4.1	10.0	68.9	12.0	82.7	3	200–230	1.30
Acetal	0.5	3.4	8.8	60.7	18.0	124.1	60	220	1.41
20–30% glass filled	1.0	6.9	10.0	68.9	18.0	124.1	7	185–220	1.56
Acrylic	0.4	2.8	10.0	68.9	15.0	103.4	5	140–190	1.18
Fluoroplastic (PTFE)	0.2	1.4	5.0	34.5	6.0	41.4	100	330–350	2.10
Nylon 6/6	0.2	1.4	10.0	68.9	10.0	68.9	60	180–300	1.14
Nylon 11	0.2	1.3	8.0	55.2	8.0	55.2	300	180–300	1.04
20–30% glass filled	0.4	2.5	12.8	88.3	12.8	88.3	4	250–340	1.26
Polycarbonate	0.4	2.4	9.0	62.1	12.0	82.7	100	250	1.20
10–40% glass filled	1.0	6.9	17.0	117.2	17.0	117.2	2	275	1.35
HMW polyethylene	0.1	0.7	2.5	17.2	–	–	525	–	0.94
Polyphenylene oxide	0.4	2.4	9.6	66.2	16.4	113.1	20	212	1.06
20–30% glass filled	1.1	7.8	15.5	106.9	17.5	120.7	5	260	1.23
Polypropylene	0.2	1.4	5.0	34.5	7.0	48.3	500	250–320	0.90
20–30% glass filled	0.7	4.8	7.5	51.7	6.2	42.7	2	300–320	1.10
Impact polystyrene	0.3	2.1	4.0	27.6	6.0	41.4	2–80	140–175	1.07
20–30% glass filled	0.1	0.7	12.0	82.7	16.0	110.3	1	180–200	1.25
Polysulfone	0.4	2.5	10.2	70.3	13.9	95.8	50	300–345	1.24

* *Modern Plastics Encyclopedia*, McGraw-Hill, New York; *Machine Design Materials Reference Issue*, Penton Publishing, Cleveland, OH.

† Most plastics do not obey Hooke's law. These apparent moduli of elasticity vary with time and temperature.

B

Appendix C

GEOMETRIC PROPERTIES

DIAGRAMS AND FORMULAS TO CALCULATE THE FOLLOWING PARAMETERS FOR SEVERAL COMMON GEOMETRIC SOLIDS

V = volume

m = mass

C_g = location of center of mass

I_x = second moment of mass about x axis = $\int \left(y^2 + z^2\right) dm$

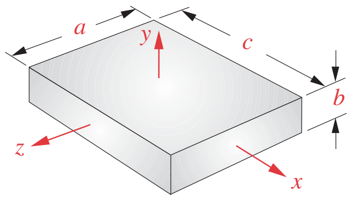
I_y = second moment of mass about y axis = $\int \left(x^2 + z^2\right) dm$

I_z = second moment of mass about z axis = $\int \left(x^2 + y^2\right) dm$

k_x = radius of gyration about x axis

k_y = radius of gyration about y axis

k_z = radius of gyration about z axis



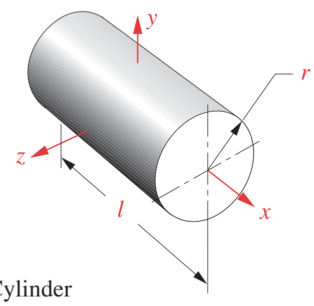
$V = abc$ $\quad m = V \cdot \text{mass density}$

$x_{CG} @ \dfrac{c}{2}$ $\quad y_{CG} @ \dfrac{b}{2}$ $\quad z_{CG} @ \dfrac{a}{2}$

$I_x = \dfrac{m\left(a^2 + b^2\right)}{12}$ $\quad I_y = \dfrac{m\left(a^2 + c^2\right)}{12}$ $\quad I_z = \dfrac{m\left(b^2 + c^2\right)}{12}$

$k_x = \sqrt{\dfrac{I_x}{m}}$ $\quad k_y = \sqrt{\dfrac{I_y}{m}}$ $\quad k_z = \sqrt{\dfrac{I_z}{m}}$

(*a*) Rectangular prism



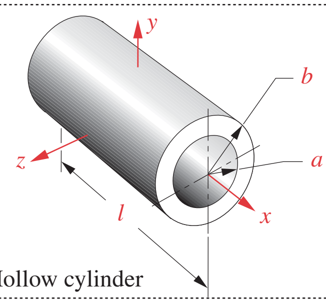
$V = \pi r^2 l$ $\quad m = V \cdot \text{mass density}$

$x_{CG} @ \dfrac{l}{2}$ $\quad y_{CG}$ on axis $\quad z_{CG}$ on axis

$I_x = \dfrac{mr^2}{2}$ $\quad I_y = I_z = \dfrac{m\left(3r^2 + l^2\right)}{12}$

$k_x = \sqrt{\dfrac{I_x}{m}}$ $\quad k_y = k_z = \sqrt{\dfrac{I_y}{m}}$

(*b*) Cylinder



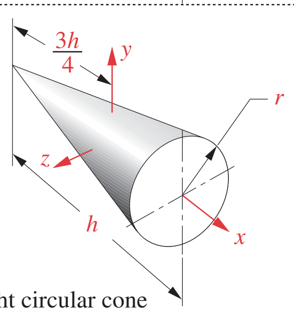
$V = \pi\left(b^2 - a^2\right)l$ $\quad m = V \cdot \text{mass density}$

$x_{CG} @ \dfrac{l}{2}$ $\quad y_{CG}$ on axis $\quad z_{CG}$ on axis

$I_x = \dfrac{m\left(a^2 + b^2\right)}{2}$ $\quad I_y = I_z = \dfrac{m\left(3a^2 + 3b^2 + l^2\right)}{12}$

$k_x = \sqrt{\dfrac{I_x}{m}}$ $\quad k_y = k_z = \sqrt{\dfrac{I_y}{m}}$

(*c*) Hollow cylinder



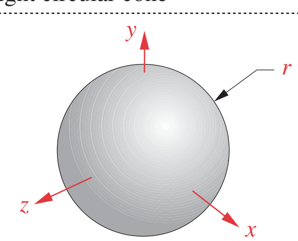
$V = \pi \dfrac{r^2 h}{3}$ $\quad m = V \cdot \text{mass density}$

$x_{CG} @ \dfrac{3h}{4}$ $\quad y_{CG}$ on axis $\quad z_{CG}$ on axis

$I_x = \dfrac{3}{10} mr^2$ $\quad I_y = I_z = \dfrac{m\left(12r^2 + 3h^2\right)}{80}$

$k_x = \sqrt{\dfrac{I_x}{m}}$ $\quad k_y = k_z = \sqrt{\dfrac{I_y}{m}}$

(*d*) Right circular cone



$V = \dfrac{4}{3}\pi r^3$ $\quad m = V \cdot \text{mass density}$

x_{CG} at center $\quad y_{CG}$ at center $\quad z_{CG}$ at center

$I_x = I_y = I_z = \dfrac{2}{5} mr^2$

$k_x = k_y = k_z = \sqrt{\dfrac{I_x}{m}}$

(*e*) Sphere

Appendix D

SPRING DATA

The following catalog pages of helical compression and extension spring data were provided courtesy of the *Hardware Products Co., Chelsea, Massachusetts* *http://www.hardwareproducts.com/*

Other spring information can be found on the Web at:

http://www.leespring.com/

http://www.cookspring.com/

http://www.allrite.com/

http://www.springsfast.com/

http://www.asbg.com/

http://www.centuryspring.com/

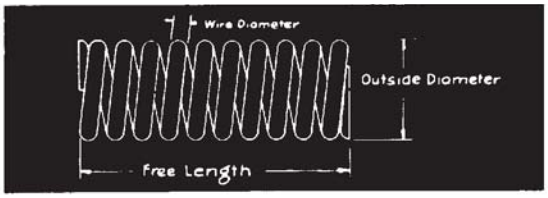
COMPRESSION SPRINGS

Will go in hole In.		7/16			1/2				5/8				3/4				7/8			
Wire Dia. In.		.031	.047	.062	.047	.062	.078	.094	.047	.062	.078	.094	.062	.078	094	.125	.062	.078	.094	.125
FREE LENGTHS 7/16	Catalog No.	247	248	249																
	Price Code	HB	HB	HC																
	lbs./in.	12	55	180																
	Max. Defl.	.32	.23	.16																
1/2	Catalog No.	250	251	252	283	284	285	286												
	Price Code	HB	HB	HC	HB	HB	HE	HE												
	lbs./in.	10	47	150	37	110	320	840												
	Max. Defl.	.37	.27	.19	.29	.22	.15	.10												
5/8	Catalog No.	253	254	255	287	288	289	290	331	332	333	334								
	Price Code	HB	HB	HC	HB	HB	HE	HE	HB	HB	HD	HE								
	lbs./in.	7.9	36	175	29	85	240	610	20	54	140	320								
	Max. Defl.	.47	.35	.25	.38	.29	.20	.14	.43	.35	.27	.20								
3/4	Catalog No.	256	257	258	291	292	293	294	335	336	337	338	375	376	377	378				
	Price Code	HB	HB	HC	HB	HB	HE	HE	HB	HB	HD	HE	HD	HD	HF	HG				
	lbs./in.	6.4	29	90	23	68	185	470	16	43	105	250	32	78	170	650				
	Max. Defl.	.58	.44	.32	.48	.37	.26	.18	.53	.44	.34	26	.59	.40	.32	.19				
7/8	Catalog No.	259	260	261	295	296	297	298	339	340	341	342	379	380	381	382	419	420	421	422
	Price Code	HB	HB	HC	HB	HB	HE	HE	HB	HB	HD	HE	HD	HD	HF	HG	HF	HF	HJ	HK
	lbs./in.	5.4	24	75	19	56	155	384	13	36	90	204	27	65	140	520	21	49	100	350
	Max. Defl.	.68	.52	.39	.57	.44	.32	.23	.64	.53	.42	.32	.58	.48	.39	.24	.62	.53	.44	.30
1	Catalog No.	262	263	264	299	300	301	302	343	344	345	346	383	384	385	386	423	424	425	426
	Price Code	HB	HB	HC	HB	HC	HE	HE	HB	HC	HD	HE	HD	HD	HF	HG	HF	HF	HJ	HK
	lbs./in.	4.7	21	65	17	48	130	320	11	31	77	170	23	55	115	430	18	42	86	290
	Max. Defl.	.79	.60	.45	.66	.51	.37	.27	.74	.62	.49	.38	.68	.57	.46	.29	.73	.63	.53	.36
1¼	Catalog No.	265	266	267	303	304	305	306	347	348	349	350	387	388	389	390	427	428	429	430
	Price Code	HB	HC	HC	HC	HC	HF	HF	HC	HC	HD	HE	HE	HE	HF	HG	HG	HG	HJ	HK
	lbs./in.	3.7	16	50	13	38	100	245	9.0	24	59	130	18	42	89	320	14	32	66	220
	Max. Defl.	1.0	.77	.58	.84	.66	.49	.35	.94	.80	.64	.49	.88	.74	.60	39	94	.81	.69	.47
1½	Catalog No.	268	269	270	307	308	309	310	351	352	353	354	391	392	393	394	431	432	433	434
	Price Code	HB	HC	HC	HC	HC	HF	HF	HD	HD	HE	HF	HE	HE	HF	HG	HG	HG	HJ	HK
	lbs./in.	3.1	14	41	11	31	83	200	7.4	20	48	105	15	34	72	260	12	26	53	175
	Max. Defl.	1.2	.94	.70	1.0	.81	.60	.43	1.1	.98	.78	.61	1.1	.91	.74	48	1.1	1.0	85	59
1¾	Catalog No.	271	272	273	311	312	313	314	355	356	357	358	395	396	397	398	435	436	437	438
	Price Code	HC	HD	HE	HC	HD	HF	HF	HD	HD	HC	HF	HE	HE	HF	HG	HG	HG	HJ	HK
	lbs./in.	2.6	11	35	9.1	26	70	170	6.2	17	41	90	12.4	29	61	216	9.9	22	45	147
	Max. Defl.	1.4	1.1	.84	1.2	.96	.71	.52	1.3	1.1	.93	.73	1.3	1.1	.89	.58	1.35	1.2	1.0	71
2	Catalog No.	274	275	276	315	316	317	318	359	360	361	362	399	400	401	402	439	440	441	442
	Price Code	HD	HD	HE	HC	HD	HF	HF	HD	HD	HE	HF	HE	HE	HF	HG	HG	HG	HJ	HL
	lbs./in.	2.3	10	30	7.9	23	60	145	5.4	14	35	77	11	25	52	185	8.6	19	38	125
	Max. Defl.	1.6	1.3	.96	1.4	1.1	.82	.60	1.5	1.3	1.1	.85	1.4	1.2	1.0	.68	1.5	1.4	1.2	.83
3	Catalog No.	277	278	279	319	320	321	322	363	364	365	366	403	404	405	406	443	444	445	446
	Price Code	HD	HE	HE	HF	HF	HG	HG	HD	HD	HF	HG	HF	HF	HG	HK	HJ	HJ	HK	HL
	lbs./in.	1.5	6.6	20	5.2	15	39	94	3.6	9.4	23	50	7	16	34	115	5.6	12	25	80
	Max. Defl.	2.4	1.9	1.4	2.1	1.7	1.2	.93	2.4	2.0	1.6	1.3	2.2	1.9	1.6	1.0	2.4	2.1	1.8	1.3
4	Catalog No.	280	281	282	323	324	325	326	367	368	369	370	407	408	409	410	447	448	449	450
	Price Code	HE	HE	HE	HE	HF	HG	HG	HE	HE	HF	HG	HF	HF	HG	HL	HJ	HJ	HL	HM
	lbs./in.	1.1	4.9	15	3.9	11	29	69	2.6	6.9	17	37	5.2	12	25	86	4.2	9.2	18	59
	Max. Defl.	3.3	2.6	2.0	2.8	2.3	1.7	1.2	3.2	2.7	2.2	1.8	3.0	2.6	2.1	1.4	3.2	2.8	2.5	1.8
6	Catalog No.				327	328	329	330	371	372	373	374	411	412	413	414	451	452	453	454
	Price Code				HF	HF	HG	HG	HF	HF	HG	HG	HG	HG	HJ	HN	HK	HK	HL	HO
	lbs./in.				2.5	7.0	17	45	1.8	4.6	11	24	3.4	7.9	16	56	2.7	6.0	12	38
	Max. Defl.				4.4	3.5	2.5	2.	4.8	4.2	3.4	2.7	4.6	3.9	3.3	2.2	4.9	4.3	3.8	2.7
8	Catalog No.												415	416	417	418	455	456	457	458
	Price Code.												HJ	HJ	HK	HO	HL	HL	HM	HP
	lbs./in.												2.6	6	11	40	2.0	4.5	8.9	28
	Max. Defl.												6.1	5.2	4.5	3.0	6.5	5.8	5.1	3.7
Maximum Load		3.7	12.7	29	11	25	45	88	8.3	19	38	66	15.8	31.2	54	125	13.4	26.3	45	105
Will work free over		.347	.315	.285	.375	.345	.313	.281	.505	.475	.443	.411	.585	.554	.522	.460	.700	.670	.638	.576
Pitch		.195	.141	.128	.173	.151	.141	.141	.259	.214	.188	.177	.284	.240	.217	.204	.371	.306	.268	.239
Solid Stress (000 omitted)		125	118	113	118	113	109	105	118	113	109	105	113	109	105	99	113	109	105	99

Pounds per inch figure is a constant for each spring, and represents the number of pounds required to compress the spring 1". To compress the spring ½" or ¼" requires ½ or ¼ of this value.

Maximum Deflection is the amount spring deflects to give the maximum load. This value subtracted from the free length gives the solid or compressed length.

NOTE: Stock springs can be ordered in stainless steel or plated. Prices quoted upon request.



FREE LENGTHS

Will go in hole In.		1				1 1/4			1 1/2			2			3			4			6	
Wire Dia. In.		.078	.094	.125	.187	.094	.125	.187	.125	.187	.250	.187	.250	.375	.250	.375	.500	.375	.500	.750	.750	1.000
1	Catalog No.	459	460	461	462																	
	Price Code	HK	HL	HL	HR																	
	lbs./in.	34	67	210	1500																	
	Max. Defl.	.67	.58	.41	.19																	
1¼	Catalog No.	463	464	465	466	499	500	501														
	Price Code	HL	HM	HM	HS	HN	HN	HM														
	lbs./in.	26	52	160	1100	35	100	600														
	Max. Defl.	.87	.76	.55	.26	.85	.67	.37														
1½	Catalog No.	467	468	469	470	502	503	504	526	527	528											
	Price Code	HL	HM	HN	HS	HN	HO	HT	HR	HX	HAC											
	lbs./in.	21	42	130	870	29	82	460	60	300	1200											
	Max. Defl.	1.0	.93	.69	.34	1.1	.84	.48	.95	.60	.35											
1¾	Catalog No.	471	472	473	474	505	506	507	529	530	531											
	Price Code	HL	HM	HN	HS	HN	HO	HT	HR	HX	HAC											
	lbs./in.	18	35	108	712	24	68	379	50	244	960											
	Max. Defl.	1.3	1.1	.83	.41	1.3	1.0	.59	1.1	.74	.44											
2	Catalog No.	475	476	477	478	508	509	510	532	533	534	553	554	555								
	Price Code	HM	HN	HO	HT	HO	HP	HU	HS	HZ	HAE	HAA	HAG	HZZ								
	lbs./in.	16	30	93	600	21	59	320	43	200	800	115	390	3000								
	Max. Defl.	1.4	1.3	.97	.49	1.4	1.2	.70	1.3	.87	.53	1.1	.77	.34								
3	Catalog No.	479	480	481	482	511	512	513	535	536	537	556	557	558	577	578	579					
	Price Code	HN	HO	HP	HZ	HP	HR	HAA	HT	HAD	HAL	HAE	HAN	HZZ	HAR	HZZ	HZZ					
	lbs./in.	10	19	59	370	13	37	200	27	130	480	73	230	1650	105	560	2300					
	Max. Defl.	2.2	2.0	1.5	.79	2.2	1.8	1.1	2.1	1.4	.89	1.8	1.3	.61	1.8	1.1	.64					
4	Catalog No.	483	484	485	486	514	515	516	538	539	540	559	560	561	580	581	582	598	599	610		
	Price Code	HP	HR	HS	HAC	HS	HT	HAD	HW	HAG	HAO	HAJ	HAR	HZZ	HAT	HZZ	HZZ	HZZ	HZZ	HZZ		
	lbs./in.	7.4	14	43	270	9.9	27	144	20	93	340	53	170	1150	76	390	1500	210	720	4600		
	Max. Defl.	3.0	2.7	2.1	1.1	3.0	2.5	1.5	2.8	1.9	1.2	2.5	1.8	.88	2.5	1.6	.96	2.1	1.4	.8		
6	Catalog No.	487	488	489	490	517	518	519	541	542	543	562	563	564	583	584	585	600	601	611	616	621
	Price Code	HR	HT	HU	HAD	HU	HW	HAE	HX	HAJ	HAT	HAM	HAW	HZZ	HAZ	HZZ	HZZ	HZZ	HZZ	HZZ	HZZ	HZZ
	lbs./in.	4.9	9.4	28	175	6.5	18	93	13	60	220	34	105	710	49	240	920	130	430	2840	850	3500
	Max. Defl.	4.6	4.1	3.2	1.7	4.7	3.9	2.4	4.3	3.0	1.9	3.8	2.8	1.4	4.0	2.6	1.6	3.4	2.4	1.3	1.9	1.4
8	Catalog No.	491	492	493	494	520	521	522	544	545	546	565	566	567	586	587	588	602	603	612	617	622
	Price Code	HS	HU	HW	HAL	HW	HX	HAM	HAA	HAP	HAW	HAR	HAZ	HZZ	HBD	HZZ	HZZ	HZZ	HZZ	HZZ	HZZ	HZZ
	lbs./in.	3.6	7.0	21	125	4.8	13	68	9.6	44	160	25	79	510	36	175	660	95	310	2050	630	2500
	Max. Defl.	6.2	5.6	4.3	2.3	6.3	5.2	3.2	5.9	4.1	2.7	5.2	3.9	1.9	5.4	3.6	2.2	4.5	3.4	1.8	2.7	2.0
12	Catalog No.	495	496	497	498	523	524	525	547	548	549	568	569	570	589	590	591	604	605	613	618	623
	Price Code	HT	HW	HZ	HAP	HX	HAA	HAR	HAC	HAU	HBA	HAZ	HBE	HZZ	HBK	HZZ	HZZ	HZZ	HZZ	HZZ	HZZ	HZZ
	lbs./in.	2.4	4.6	14	84	3.2	8.7	45	6.3	29	105	16	52	330	23	110	420	61	195	1325	400	1580
	Max. Defl.	9.4	8.4	6.5	3.5	9.5	7.9	5.0	8.9	6.2	4.1	8.0	5.9	3.0	8.3	5.5	3.5	7.3	5.3	2.6	4.3	3.1
16	Catalog No.								550	551	552	571	572	573	592	593	594	606	607	614	619	624
	Price Code								HAE	HAW	HBD	HAZ	HBG	HZZ	HBL	HZZ	HZZ	HZZ	HZZ	HZZ	HZZ	HZZ
	lbs./in.								4.7	21	74	12	38	240	17	83	310	45	145	975	300	1170
	Max. Defl.								11.9	8.5	5.6	10.7	8.0	4.1	11.3	7.5	4.0	10	7.3	3.8	6.1	4.3
24	Catalog No.											574	575	576	595	596	597	608	609	615	620	625
	Price Code											HBA	HBL	HZZ	HBP	HZZ	HZZ	HZZ	HZZ	HZZ	HZZ	HZZ
	lbs./in.											7.8	23.4	150	11.4	54	200	29	94	640	175	760
	Max. Defl.											16.3	12.1	7.0	17.1	11.5	7.3	15.2	11.1	5.8	9.4	6.5
Maximum Load		23	39	90	295	30	69	224	57	180	428	131	307	1000	195	624	1470	449	1040	3700	2000	4800
Will work free over		.784	.752	.690	.565	1.00	.940	.815	1.19	1.06	.940	1.52	1.39	1.14	2.33	2.08	1.83	3.08	2.83	2.25	4.25	3.75
Pitch		.382	.328	.279	.268	.481	.384	.327	.516	.403	.388	.596	.518	.514	.917	.741	.736	1.08	.969	1.00	1.3	1.4
Solid Stress (000 omitted)		109	105	99	90	105	99	90	99	90	85	90	85	77	85	77	73	77	73	70	70	65

Pounds per inch figure is a constant for each spring, and represents the number of pounds required to compress the spring 1". To compress the spring ½" or ¼" requires ½ or ¼ of this value.

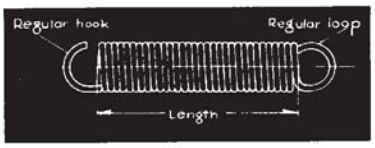
Maximum Deflection is the amount spring deflects to give the maximum load. This value subtracted from the free length gives the solid or compressed length.

NOTE: Stock springs can be ordered in stainless steel or plated. Prices quoted upon request.

Hardware Products Company, Inc.

D

EXTENSION SPRINGS



ORDER BY:
SE LENGTH x O.D. x WIRE DIA.

SPECIFY HOOKS OR LOOPS

The figures given for "Maximum Extension" and "lbs. per inch" are for a spring 1" long. For other lengths multiply the "Maximum Extension" and divide the "lbs. per inch" by the length in inches. The "Maximum Load" and "Initial Tension" remain constant for any length.

Example: A spring ½" diam. .062" wire and 4" long will have a safe maximum extension of 3.2" and it will require 4 lbs. to deflect it 1 in. The spring will hold approximately 3.3 lbs. before it starts to extend, and will hold a maximum of 16.1 lbs. without permanent stretch. If 8.5 lbs. is hung on the spring it will deflect 1.3". 8.5 lbs. minus 3.3 lbs. divided by 4 lbs. per inch equals 1.3".

NOTE: Stock springs can be ordered in stainless steel or plated. Prices quoted upon request.

Outside dia.	Wire dia.	Catalog No.	Price code	Safe maximum load in pounds	Safe maximum extension - in.	Approx. initial tension in pounds	Pound per inch extension	Stress at max. load (000 omitted)	Weight per foot (lbs.)
1/8	.012	01	EHE	.6	1.9	.07	.27	100	.012
	.016	02	EHD	1.3	.9	.2	1.2	93	.015
	.023	03	EHD	4.2	.35	.9	9.0	90	.02
5/32	.012	04	EHE	.47	3.5	.01	.12	100	.015
	.016	05	EHD	1.1	1.7	.15	.55	93	.019
	.023	06	EHD	3.2	.7	.5	3.9	90	.027
3/16	.016	07	EHD	.87	2.5	1	3	93	.024
	.023	08	EHD	2.6	1.0	.4	2.2	90	.032
	.031	09	EHD	6.5	.45	1.5	10.7	88	.04
7/32	.016	10	EHD	.75	4.0	.01	.18	93	.028
	.023	11	EHD	2.3	1.6	.32	1.2	90	.039
	.031	12	EHD	5.5	.7	1.0	6.5	88	.048
1/4	.023	13	EHD	1.8	1.9	.26	.8	90	.044
	.031	14	EHD	4.7	1.0	.75	3.8	88	.055
	.047	15	EHE	16.0	.3	3.5	40.0	83	.082
5/16	.023	16	EHE	1.5	3.5	.16	.38	90	.058
	.031	17	EHE	3.6	1.6	.55	1.9	88	.072
	.047	18	EHE	12.5	.9	2.2	10.8	83	.108
3/8	.031	19	EHE	2.9	2.5	.37	1.0	88	.084
	.047	20	EHE	10.5	.9	1.7	9.5	83	.13
	.062	21	EHF	23.0	.39	5.3	45.0	79	.16
7/16	.031	22	EHF	2.5	3.5	.26	.63	88	.105
	.047	23	EHF	8.5	1.2	1.4	5.7	83	.163
	.062	24	EHF	20.0	.6	4.3	26.0	79	.2
1/2	.047	25	EHF	7.3	1.6	1.1	3.7	83	.18
	.062	26	EHF	17.0	.8	3.3	16.0	79	.23
	.078	27	EHG	34.0	.45	8.0	57.0	77	.28
	.094	28	EHJ	57.0	.25	16.0	160.0	74	.32
5/8	.047	29	EHG	6.0	3.0	.7	1.7	83	.24
	.062	30	EHG	13.3	1.4	2.1	7.6	79	.3
	.078	31	EHG	27.0	.9	5.2	23.0	77	.37
	.094	32	EHJ	45.0	.4	11.0	73.0	74	.44
3/4	.062	33	EHG	10.5	2.2	1.5	4.1	79	.36
	.078	34	EHJ	22.0	1.3	3.5	14.0	77	.46
	.094	35	EHJ	36.0	.7	8.0	38.0	74	.51
	.125	36	EHK	85.0	.3	22.0	180.0	69	.64
7/8	.062	37	EHK	9.2	3.3	1.1	2.4	79	.4
	.078	38	EHK	18.0	1.7	2.6	8.7	77	.59
	.094	39	EHL	31.0	1.0	6.0	25.0	74	.64
	.125	40	EHM	72.0	.5	17.0	107.0	69	.8
1	.078	41	EHL	16.0	2.5	2.0	5.5	77	.67
	.094	42	EHL	26.0	1.5	4.5	13.7	74	.70
	.125	43	EHN	65.0	.75	14.0	68.0	69	.90
	.187	44	EHW	200.0	.23	60.0	600.0	63	1.4
1¼	.094	45	EHM	21.0	2.6	2.8	6.8	74	.94
	.125	46	EHO	47.0	1.2	9.0	31.0	69	1.3
	.187	47	EHZ	148.0	.3	40.0	290.0	63	1.8
1½	.125	48	EHS	39.0	1.9	6.0	17.0	69	1.4
	.187	49	EHAA	122.0	.6	33.0	150.0	63	2.2
	.250	50	EHAC	290.0	.27	90.0	720.0	60	2.6
2	.187	51	EHAD	90.0	1.3	20.0	54.0	63	3.1
	.250	52	EHAG	210.0	.6	55.0	260.0	60	3.7

Carried in-stock in 3-foot lengths - cut to length and looped to order.

Appendix E

COUPLER CURVE ATLASES

E.1 HRONES AND NELSON ATLAS OF FOURBAR LINKAGES

The entire Hrones and Nelson coupler curve atlas is downloadable as PDF files. Figure 3-17 in Section 3.6 shows one page from this atlas and describes how to use it. Read the first chapter within the Hrones and Nelson atlas for more information on how it is arranged and how to use it. The downloadable video ***Coupler Curves and Linkage Atlases*** gives detailed instructions on its use and shows an example. Once you extract a trial linkage geometry from the atlas, use program **LINKAGES** to investigate its behavior and to vary the linkage geometry.

E.2 ZHANG, NORTON, HAMMOND ATLAS OF GEARED FIVEBAR LINKAGES

The entire Zhang atlas is downloadable as PDF files. A sample page is shown in Figure 3-23. Read the first chapter within the Zhang atlas for information on how it is arranged and how to use it. See Sections 2.4, 3.6, 4.9, 6.8, and 7.4 for more information on the geared fivebar linkages. The video ***Coupler Curves and Linkage Atlases*** gives a brief overview of this atlas. Once you extract a trial linkage geometry from the atlas, use program **LINKAGES** to investigate its behavior and to vary the linkage geometry.

A summary of the parameters in the Zhang atlas is:

Alpha = Coupler Link 3 / Link 2

Beta = Ground Link 1 / Link 2

Lambda = Gear Ratio = Gear 5 / Gear 2.

Phase angle is noted on each plot of a coupler curve.

The dots along curves are at every 10 degrees of Link 2's rotation.

Linkage is symmetrical: Link 2 = Link 5 and Link 3 = Link 4

Note that the *Lambda* in the atlas is the inverse of the λ that is defined in Sections 4.9, 6.8, and 7.4. See also Figures P4-4, P6-4, and P7-4. For example, a gear ratio *Lambda* of 2 in the Zhang atlas corresponds to a λ of 0.5 in the text and in program **LINKAGES**. (The difference merely corresponds to a mirroring of the linkage from left to right.)

Appendix **F**

ANSWERS TO SELECTED PROBLEMS

CHAPTER 2 KINEMATICS FUNDAMENTALS

2-1

a. 1	b. 1	c. 2	d. 1	e. 7	f. 1	g. 4
h. 4	i. 4	j. 2	k. 1	l. 1	m. 2	n. 2
o. 4						

2-3 a. 1 b. 3 c. 3 d. 3 e. 2

2-4 a. 6 b. 6 c. 5 d. 4, but 2 are dynamically coupled* e. 4 f. 3

2-5 force-closed

2-6

a. pure rotation
b. complex planar motion
c. pure translation
d. pure translation
e. pure rotation
f. complex planar motion
g. complex planar motion

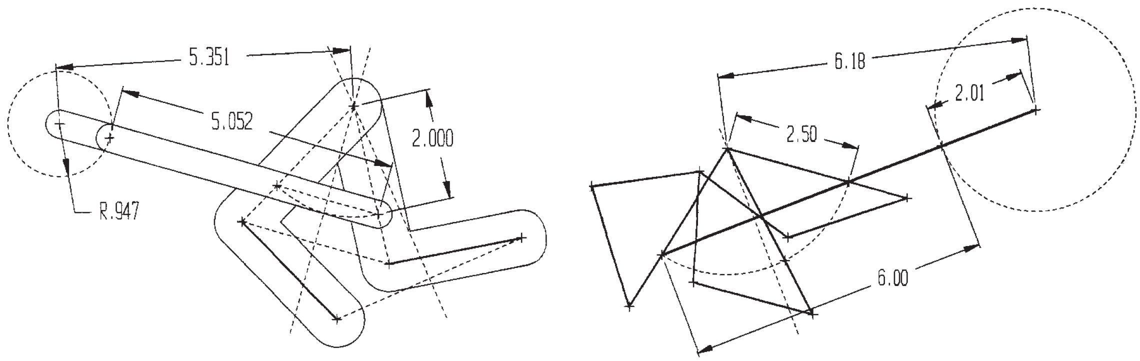
2-7 a. 0 b. 1 c. 1 d. 3

2-8

a. structure - $DOF = 0$
b. mechanism - $DOF = 1$
c. mechanism - $DOF = 1$
d. mechanism - $DOF = 3$

2-15 a. Grashof b. non-Grashof c. special-case Grashof

* Dynamically coupled means that, at speed, leaning the bike to the side results in its turning to the side to which it is leaning. So the angular freedom of this machine in the plane of the road is coupled with its ability to rotate about its long axis (lean). Except at very low speed, you steer a motorcycle by pushing down (toward the ground) on the handlebar on the inside of the turn, rather than by actually turning the handlebar in the direction of the turn. If you are moving the bike with your feet to park it, then you turn the handlebar. But at any significant speed, the gyroscopic effect takes over and leaning the bike makes it turn. This is true of a pedal bike as well if it has sufficient forward speed.



(*a*) One possible solution to Problem 3-3

(*b*) One possible solution to Problem 3-5

FIGURE S3-1

Solutions to Problems 3-3 and 3-5

2-21

a. $M = 1$	b. $M = 1$	c. $M = 1$
d. $M = 1$	e. $M = -1$ (a paradox)	f. $M = 1$
g. $M = 1$	h. $M = 0$ (a paradox)	

2-24 a. $M = 1$ b. $M = 1$

2-26 $M = 1$

2-27 $M = 0$

2-35 $M = 1$, fourbar slider-crank

2-61 a. $M = 3$ b. $M = 2$ c. $M = 1$

2-62 a. $M = 1$ b. $M = 2$ c. $M = 4$

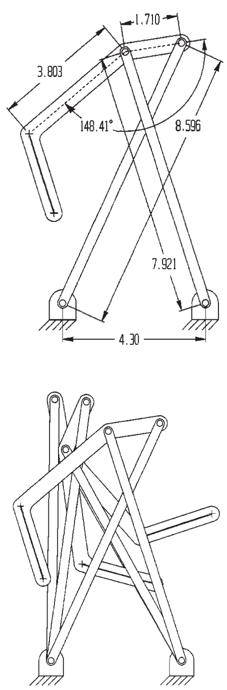


FIGURE S3-2

Unique solution to Problem 3-6

CHAPTER 3 GRAPHICAL LINKAGE SYNTHESIS

3-1

a. path generation
b. motion generation
c. function generation
d. path generation
e. path generation

Note that synthesis problems have many valid solutions. We cannot provide a "right answer" to all of these design problems. Check your solution with a cardboard model and/or by putting it into one of the programs supplied with the text.

3-3 See Figure S3-1.

3-5 See Figure S3-1.

3-6 See Figure S3-2.

3-8 See Figure S3-3.

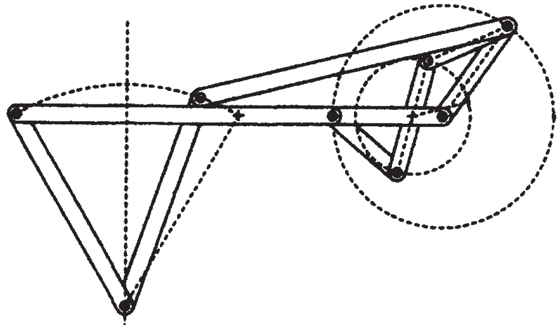


FIGURE S3-3

One possible solution to Problem 3-8

3-10 The solution using Figure 3-17 is shown in Figure S3-4. (Use program LINKAGES to check your solution.)

3-22 The transmission angle ranges from 31.5° to 89.9°.

3-23 Grashof crank-rocker. Transmission angle ranges from 58.1° to 89.8°.

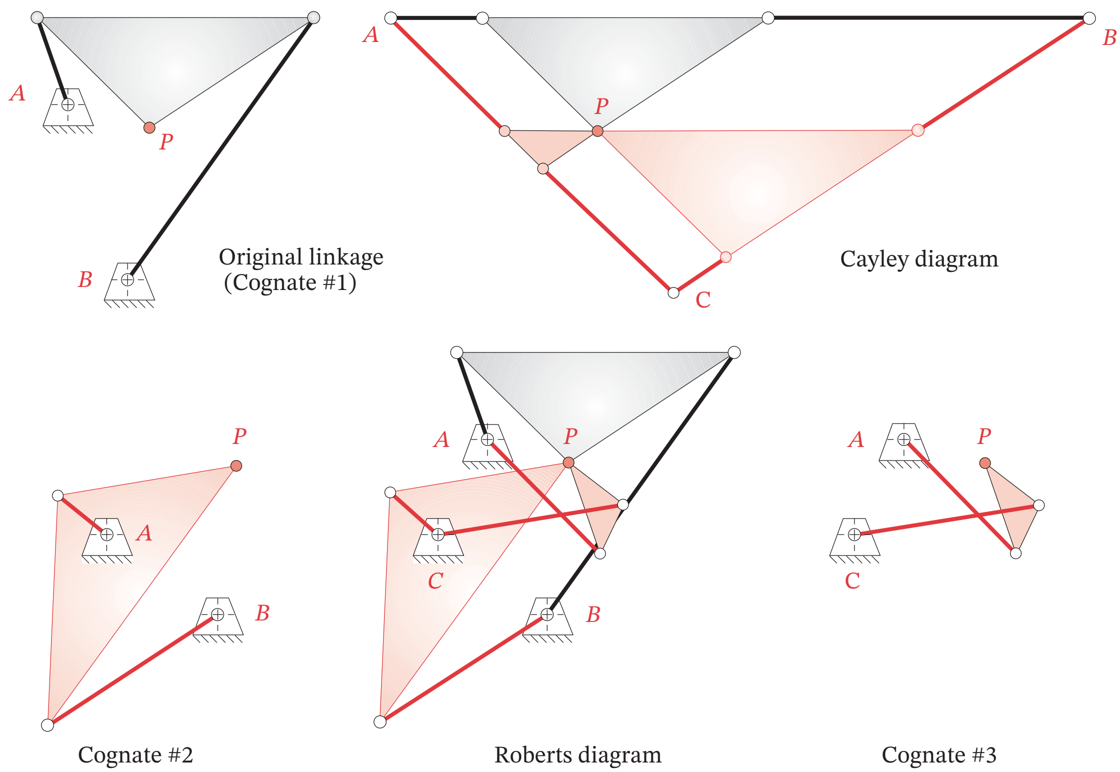


FIGURE S3-4

Solution to Problem 3-10. Finding the cognates of the fourbar linkage shown in Figure 3-17

3-31 $L_1 = 160.6$, $L_2 = 81.3$, $L_3 = 200.2$, $L_4 = 200.2$ mm.

3-36 Grashof double-rocker. Works from 56° to 158° and from 202° to 310°. Transmission angle ranges from 0° to 90°.

3-39 Non-Grashof triple-rocker. Toggles at ±116°. Transmission angle ranges from 0° to 88°.

3-42 Non-Grashof triple-rocker. Toggles at ±55.4°. Transmission angle ranges from 0° to 88.8°.

3-79 Link 2 = 1, link 3 = link 4 = link 1 = 1.5. Coupler point is at 1.414 @ 135° versus link 3. Put these data into program LINKAGES to see the coupler curve.

CHAPTER 4 POSITION ANALYSIS

4-6 and **4-7** See Table S4-1 and the file P07-04*row*.4br.

4-9 and **4-10** See Table S4-2.

4-11 and **4-12** See Table S4-3.

4-13 See Table S4-1.

4-14 Open the file P07-04*row*.4br† in program LINKAGES to see this solution.*

4-15 Open the file P07-04*row*.4br† in program LINKAGES to see this solution.*

4-16 See Table S4-4.

4-17 See Table S4-4.

4-21 Open the file P04-21.4br in program LINKAGES to see this solution.*

4-23 Open the file P04-23.4br in program LINKAGES to see this solution.*

4-25 Open the file P04-25.4br in program LINKAGES to see this solution.*

4-26 Open the file P04-26.4br in program LINKAGES to see this solution.*

4-29 Open the file P04-29.4br in program LINKAGES to see this solution.*

4-30 Open the file P04-30.4br in program LINKAGES to see this solution.*

4-31 $r_1 = -6.265$, $r_2 = -0.709$.

CHAPTER 5 ANALYTICAL LINKAGE SYNTHESIS

5-8 Given: $\alpha_2 = -62.5°$, $P_{21} = 2.47$, $\delta_2 = 120°$

For left dyad: Assume: $z = 1.075, \varphi = 204°$ $\beta_2 = -27°$

Calculate: $\mathbf{W} = 3.67$ @ $-113.5°$

For right dyad: Assume: $s = 1.24$, $\psi = 74°$ $\gamma_2 = -40°$

Calculate: $\mathbf{U} = 5.46$ @ $-125.6°$

* These files can be found in the PROBLEM SOLUTIONS folder downloadable with this text.

† The letter *x* in the filename represents the row number from the table of problem data.

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TABLE S4-1 Solutions for Problems 4-6, 4-7, and 4-13

Row	θ_3 Open	θ_4 Open	Trans Ang	θ_3 Crossed	θ_4 Crossed	Trans Ang
a	88.8	117.3	28.4	–115.2	–143.6	28.4
c	–53.1	16.5	69.6	173.3	103.6	69.6
e	7.5	78.2	70.7	– 79.0	–149.7	70.7
g	–16.3	7.2	23.5	155.7	132.2	23.5
i	–1.5	103.1	75.4	–113.5	141.8	75.4
k	–13.2	31.9	45.2	–102.1	–147.3	45.2
m	–3.5	35.9	39.4	–96.5	–135.9	39.4

TABLE S4-2 Solutions for Problems 4-9 to 4-10

Row	θ_3 Open	Slider Open	θ_3 Crossed	Slider Crossed
a	180.1	5.0	–0.14	–3.0
c	205.9	9.8	–25.90	–4.6
e	175.0	16.4	4.20	–23.5
g	212.7	27.1	–32.70	–14.9

TABLE S4-3 Solutions for Problems 4-11 to 4-12

Row	θ_3 Open	θ_4 Open	R_B Open	θ_3 Crossed	θ_4 Crossed	R_B Crossed
a	232.7	142.7	1.79	–79.0	–169.0	1.79
c	91.4	46.4	2.72	208.7	163.7	11.20
e	158.2	128.2	6.17	–36.2	–66.2	9.63

TABLE S4-4 Solutions for Problems 4-16 to 4-17

Row	θ_3 Open	θ_4 Open	θ_3 Crossed	θ_4 Crossed
a	173.6	–177.7	–115.2	– 124.0
c	17.6	64.0	–133.7	180.0
e	–164.0	–94.4	111.2	41.6
g	44.2	124.4	–69.1	–149.3
i	37.1	120.2	–67.4	–150.5

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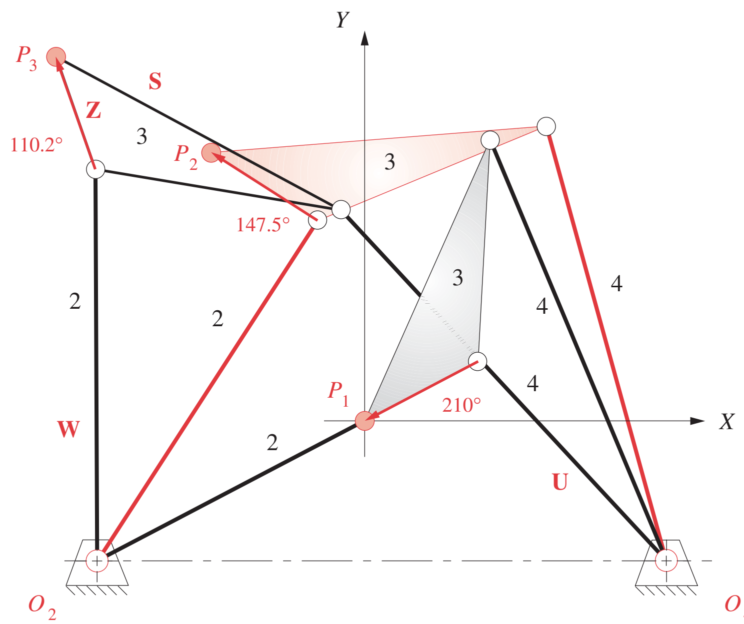

FIGURE S5-1

Solution to Problem 5-11. Open the file P05-11 in program LINKAGES for more information

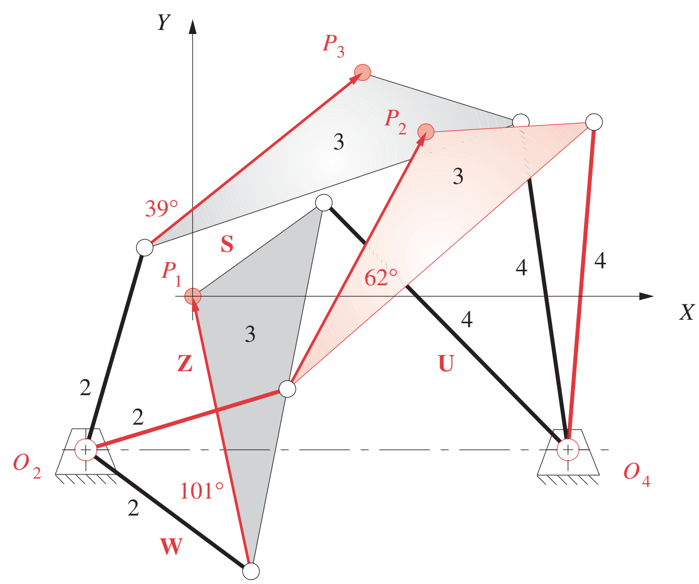

FIGURE S5-2

Solution to Problem 5-15. Open the file P05-15 in program LINKAGES for more information

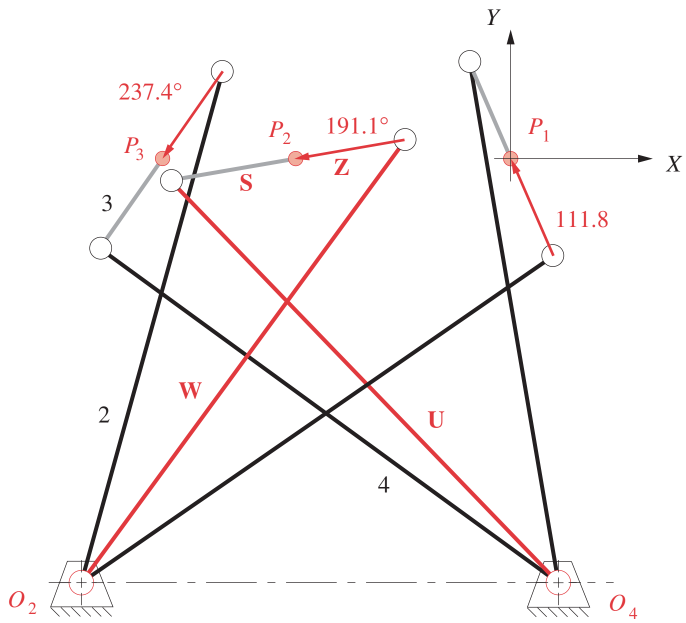

FIGURE S5-3

Solution to Problem 5-19. Open the file P05-19 in program LINKAGES for more information

5-11 See Figure S5-1 for the solution. The link lengths are:

Link 1 = 4.35, Link 2 = 3.39, Link 3 = 1.94, Link 4 = 3.87

5-15 See Figure S5-2 for the solution. The link lengths are:

Link 1 = 3.95, Link 2 = 1.68, Link 3 = 3.05, Link 4 = 0.89

5-19 See Figure S5-3 for the solution. The link lengths are:

Link 1 = 2, Link 2 = 2.5, Link 3 = 1, Link 4 = 2.5

5-26 Given: $\alpha_2 = -45°$, $P_{21} = 184.78$ mm, $\delta_2 = -5.28°$

$\alpha_3 = -90°$, $P_{31} = 277.35$ mm, $\delta_3 = -40.47°$

$O_{2x} = 86$ mm $O_{2y} = -132$ mm

$O_{4x} = 104$ mm $O_{4y} = -155$ mm

For left dyad: Calculate: $\beta_2 = -85.24°$ $\beta_3 = -164.47°$

Calculate: $W = 110.88$ mm $\theta = 124.24°$

Calculate: $Z = 46.74$ mm $\varphi = 120.34°$

For right dyad: Calculate: $\gamma_2 = -75.25°$ $\gamma_3 = -159.53°$

Calculate: $U = 120.70$ mm $\sigma = 104.35°$

Calculate: $S = 83.29$ mm $\psi = 152.80°$

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5-33	Given:	$\alpha_2 = -25°$,	$P_{21} = 133.20$ mm,	$\delta_2 = -12.58°$
		$\alpha_3 = -101°$,	$P_{31} = 238.48$ mm,	$\delta_3 = -51.64°$
		$O_{2x} = -6.2$ mm	$O_{2y} = -164.0$ mm	
		$O_{4x} = 28.0$ mm	$O_{4y} = -121.0$ mm	
	For left dyad:	Calculate: $\beta_2 = -53.07°$	$\beta_3 = -94.11°$	
		Calculate: $W = 128.34$ mm	$\theta = 118.85°$	
		Calculate: $Z = 85.45$ mm	$\varphi = 37.14°$	
	For right dyad:	Calculate: $\gamma_2 = -77.26°$	$\gamma_3 = -145.66°$	
		Calculate: $U = 92.80$ mm	$\sigma = 119.98°$	
		Calculate: $S = 83.29$ mm	$\psi = 65.66°$	
5-35	Given:	$\alpha_2 = -29.4°$,	$P_{21} = 99.85$ mm,	$\delta_2 = 7.48°$
		$\alpha_3 = -2.3°$,	$P_{31} = 188.23$ mm,	$\delta_3 = -53.75°$
		$O_{2x} = -111.5$ mm	$O_{2y} = 183.2$ mm	
		$O_{4x} = -111.5$ mm	$O_{4y} = -38.8$ mm	
	For left dyad:	Calculate: $\beta_2 = 69.98°$	$\beta_3 = 139.91°$	
		Calculate: $W = 100.06$ mm	$\theta = 150.03°$	
		Calculate: $Z = 306.82$ mm	$\varphi = -49.64°$	
	For right dyad:	Calculate: $\gamma_2 = -4.95°$	$\gamma_3 = -48.81°$	
		Calculate: $U = 232.66$ mm	$\sigma = 62.27°$	
		Calculate: $S = 167.17$ mm	$\psi = -88.89°$	

CHAPTER 6 VELOCITY ANALYSIS

6-4 and **6-5** See Table S6-1 and the file P07-04*row*.4br.

6-6 and **6-7** See Table S6-2.

6-8 and **6-9** See Table S6-3.

6-10 and **6-11** See Table S6-4.

6-16 $V_A = 12$ in/sec @ 124.3°, $V_B = 11.5$ in/sec @ 180°, $V_C = 5.65$ in/sec @ 153.3°, $\omega_3 = -5.69$ rad/sec.

6-47 Open the file P06-47.4br in program LINKAGES to see this solution.*

6-48 Open the file P06-48.4br in program LINKAGES to see this solution.*

6-49 Open the file P06-49.4br in program LINKAGES to see this solution.*

6-51 Open the file P06-51.4br in program LINKAGES to see this solution.*

6-62 Open the file P06-62.4br in program LINKAGES to see this solution.*

6-65 $V_A = 94.5$ in/sec, $V_B = 115.2$, $V_{slip} = 162.8$, V = 65.9, ω = –70 rad/sec.

* These files can be found in the PROBLEM SOLUTIONS folder downloadable with this text.

TABLE S6-1 Solutions for Problems 6-4 to 6-5

Row	ω_3 Open	ω_4 Open	V_P Mag	V_P Ang	ω_3 Crossed	ω_4 Crossed	V_P Mag	V_P Ang
a	–6.0	–4.0	40.8	58.2	–0.66	–2.66	22.0	129.4
c	–12.7	–19.8	273.8	–53.3	–22.70	–15.70	119.1	199.9
e	1.85	–40.8	260.5	–12.1	–23.30	19.30	139.9	42.0
g	76.4	146.8	798.4	92.9	239.00	168.60	1435.3	153.9
i	–25.3	25.6	103.1	–13.4	56.90	6.00	476.5	70.4
k	–56.2	–94.8	436.0	–77.4	–55.60	–16.90	362.7	79.3
m	18.3	83.0	680.8	149.2	7.73	–57.00	571.3	133.5

TABLE S6-2 Solutions for Problems 6-6 to 6-7

Row	V_A Mag	V_A Ang	ω_3 Open	V_B Mag Open	ω_3 Crossed	V_B Mag Crossed
a	14	135	–2.47	–9.9	2.47	–9.92
c	45	–120	5.42	–41.5	–5.42	–3.54
e	250	135	–8.86	–189.7	8.86	–163.80
g	700	60	–28.80	738.9	28.80	–38.90

TABLE S6-3 Solutions for Problems 6-8 to 6-9

Row	V_A Mag	V_A Ang	ω_3 Open	V_{slip} Open	V_B mag Open	ω_3 Crossed	V_{slip} Crossed	V_B Mag Crossed
a	20.0	120.0	–10.3	33.5	41.2	–3.6	–4.25	14.6
c	240.0	135.0	23.7	73.0	142.5	–14.9	130.50	89.4
e	180.0	–15.0	–2.7	–176.0	5.4	5.7	162.00	11.5

TABLE S6-4 Solutions for Problems 6-10 to 6-11

Row	ω_3 Open	ω_4 Open	ω_3 Crossed	ω_4 Crossed
a	32.6	16.9	–75.2	–59.6
c	10.7	–2.6	–8.2	5.1
e	–158.3	–81.3	–116.8	–193.9
g	–8.9	–40.9	–48.5	–16.5
i	–40.1	47.9	59.6	–28.4

TABLE S7-1 Solutions for Problems 7-3 to 7-4

Row	α_3 Open	α_4 Open	A_P Mag	A_P Ang	α_3 Crossed	α_4 Crossed	A_P Mag	A_P Ang
a	26.1	53.3	419	240.4	77.9	50.7	298	–11.3
c	–154.4	–71.6	4400	238.9	–65.2	–148.0	3554	100.6
e	331.9	275.6	10 260	264.8	1287.7	1344.1	19 340	–65.5
g	–23 510.0	–19 783.0	172 688	191.0	–43 709.0	–47 436.0	273 634	–63.0
i	–344.6	505.3	9492	–81.1	121.9	–728.0	27 871	150.0
k	–2693.0	–4054.0	56 271	220.2	311.0	1672.1	27 759	–39.1
m	680.8	149.2	35 149	261.5	9266.1	10 303.0	63 831	103.9

TABLE S7-2 Solutions for Problems 7-5 to 7-6

Row	A_A Mag	A_A Ang	α_3 Open	A_B Mag Open	A_B Ang Open	α_3 Crossed	A_B Mag Crossed	A_B Ang Crossed
a	140	–135	25	124	180	–25	74	180
c	676	153	–29	709	180	29	490	180
e	12 500	45	–447	6653	0	447	11 095	0
g	70 000	150	–1136	62 688	180	1136	58 429	180

TABLE S7-3 Solutions for Problems 7-7 to 7-8

Row	α_3 Open	α_4 Open	A_{slip} Open	α_3 Crossed	α_4 Crossed	A_{slip} Crossed
a	130.5	130.5	–128.5	–9.9	–9.9	19.0
c	–212.9	–212.9	1078.8	–217.8	–217.8	–728.2
e	896.3	896.3	–1818.6	595.6	595.6	1822.6

TABLE S7-4 Solutions for Problem 7-9

Row	α_3 Open	α_4 Open	α_3 Crossed	α_4 Crossed
a	3191	2492	–6648	–5949
c	314	228	87	147
e	2171	–6524	7 781	5414
g	–22 064	–23 717	–5529	–29 133
i	–5697	–3380	–2593	–7184

F

CHAPTER 7 ACCELERATION ANALYSIS

7-3 and **7-4** See Table S7-1 and the file P07-04*row*.4br.

7-5 and **7-6** See Table S7-2.

7-7 and **7-8** See Table S7-3.

7-9 See Table S7-4.

7-12 176.9 in/sec^2.

7-21 A_A = 26.26 m/sec^2 @ 211.1°, A_B = 8.328 m/sec^2 @ –13.9°.

7-24 A_A = 16 m/sec^2 @ 237.6°, A_B = 12.01 m/sec^2 @ 207.4°, α_4 = 92 rad/sec^2.

7-28 A_A = 39.38 m/sec^2 @ –129°, A_B = 39.7 m/sec^2 @ –90°.

7-39 Open the file P07-39.4br in program LINKAGES to see this solution.*

7-40 Open the file P07-40.4br in program LINKAGES to see this solution.*

7-41 Open the file P07-41.4br in program LINKAGES to see this solution.*

7-42 Open the file P07-42.4br in program LINKAGES to see this solution.*

7-44 Open the file P07-44.4br in program LINKAGES to see this solution.*

7-56 Tipover at 19.0 to 20.3 mph; load slides at 16.2 to 19.5 mph.

7-76 A_D = 7 554.1 in/sec^2 @ 150.8°, α_6 = 692.98 rad/sec^2.

7-78 A_A = 677.1 in/sec^2 @ –119.7°, A_B = 1 337.5 in/sec^2 @ –26.09°, A_P = 730.37 in/sec^2 @ –53.65°, α_4 = 431.175 rad/sec^2

7-87 A_C = 37.5 in/sec^2 @ 90°

CHAPTER 8 CAM DESIGN

Most of the problems in this cam chapter are design problems with more than one correct solution. Use program DYNACAM to check your solution obtained with *Mathcad*, *Matlab*, *Excel*, or *TKSolver* and also to explore various solutions and compare them to find the best one for the constraints given in each problem.

8-1 See Figure S8-1a.

8-2 See Figure S8-1b.

8-4 φ = 4.9°.

8-6 φ = 13.8°.

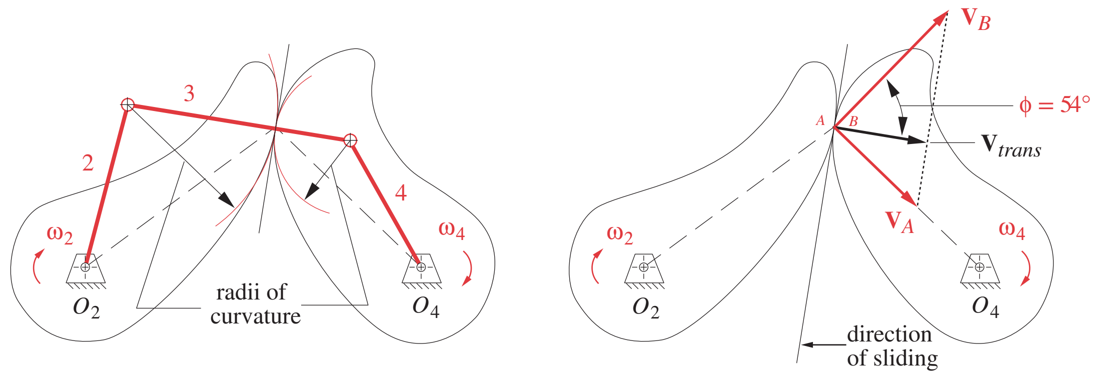
CHAPTER 9 GEAR TRAINS

9-1 Pitch diameter = 4.8, circular pitch = 0.628, addendum = 0.20, dedendum = 0.25, tooth thickness = 0.314, and clearance = 0.050.

9-5 a. p_d = 10, b. p_d = 6

9-6 Assume a minimum no. of teeth = 16, then: pinion = 16t and 1.600-in pitch dia. Gear = 112t and 11.240-in pitch dia. Contact ratio = 1.68.

* These files can be found in the PROBLEM SOLUTIONS folder downloadable with this text.



(*a*) Effective linkage for Problem 8-1

(*b*) Pressure angle ϕ for Problem 8-2

FIGURE S8-1

Solutions to Problems 8-1 and 8-2

9-7 Assume a minimum no. of teeth = 16, then: pinion = 16t and 3.20-in pitch dia. Gear = 96t and 19.20-in pitch dia. An idler gear of any dia. is needed to get the positive ratio. Contact ratio = 1.67.

9-10 Three stages of 4:1, 4:1, and 5:1 give –80:1. Stage 1 = 20t (d = 1.67 in) to 80t (d = 6.67in). Stage 2 = 20t (d = 1.67 in) to 80t (d = 6.67in). Stage 3 = 18t (d = 1.5 in) to 90t (d = 7.5 in).

9-12 The square root of 120 is > 10 so will need three stages. 5 x 4 x 6 = 150. Using a minimum no. of teeth = 18 gives 18:90, 18:72, and 18:108 teeth. Pitch dias. are 3.6, 18 and 21.6 in. An idler (18t) is needed to make the overall ratio positive.

9-14 The factors 4 x 7 = 28. The ratios 24:96 and 15:105 revert to same center distance of 7.5 in. Pitch dias. are 1.875, 3, 12, and 13.125 in.

9-16 The factors 6.5 x 10 = 65. The ratios 22:143 and 15:150 revert to same center distance of 10.3125 in. Pitch dias. are 2.75, 17.875, 1.875, and 18.75.

9-19 The factors 2 x 1.5 = 3. The ratios 15:30 and 18:27 revert to the same center distance of 3.75. Pitch dias. are 2.5, 5, 3, and 4.5. The reverse train uses the same 1:2 first stage as the forward train, so it needs a second stage of 1:2.25 which is obtained with a 12:27 gearset. The center distance of the 12:27 reverse stage is 3.25 which is less than that of the forward stage. This allows the reverse gears to engage through an idler of any suitable diameter to reverse output direction.

9-21 For the low speed of 6:1, the factors 2.333 x 2.571 = 6. The ratios 15:35 and 14:36 revert to the same center distance of 3.125. Pitch dias. are 1.875, 4.375, 1.75, and 4.5. The second speed train uses the same 1:2.333 first stage as the low-speed train, so it needs a second stage of 1:1.5 which is obtained with a 20:30 gearset which reverts to the same center distance of 3.125. The additional pitch dias. are 2.5 and 3.75. The reverse train also uses the same 1:2.333 first stage as both forward trains, so it needs a second stage of 1:1.714 which is obtained with a 14:24 gearset. The center distance of the 14:24 reverse stage is 2.375 which is less than that of the forward stages. This allows the reverse gears to engage through an idler of any suitable diameter to reverse output direction.

TABLE S9-1 Solution to Problem 9-29

Possible Ratios forTwo-Stage Compound Gear Train to Give the Ratio 2.718 28

Pinion 1	Gear 1	Ratio 1	Pinion 2	Gear 2	Ratio 2	Train Ratio	Abs Error
25	67	2.68	70	71	1.014	2.718 285 71	5.71E-06
29	57	1.966	47	65	1.383	2.718 268 53	1.15E-05
30	32	1.067	31	79	2.548	2.718 279 57	4.30E-07
30	64	2.133	62	79	1.274	2.718 279 57	4.30E-07
31	48	1.548	45	79	1.756	2.718 279 57	4.30E-07
31	64	2.065	60	79	1.317	2.718 279 57	4.30E-07
31	79	2.548	75	80	1.067	2.718 279 57	4.30E-07
35	67	1.914	50	71	1.420	2.718 285 71	5.71E-06

9-25 a. $\omega_2 = 790$, c. $\omega_{arm} = -4.544$, e. $\omega_6 = -61.98$

9-26 a. $\omega_2 = -59$, c. $\omega_{arm} = 61.54$, e. $\omega_6 = -63.33$

9-27 a. 577.7 rpm and 4.33 to 1, b. $x = 577.7 \times 2 - 800 = 355.4$ rpm

9-29 See Table S9-1 for solution. The third row has the smallest error and smallest gears.

9-35 $\eta = 0.963$.

9-37 $\eta = 0.996$.

9-39 $\omega_1 = 979.6$ rpm, $\omega_2 = 2742.9$ rpm.

9-41 $\omega_1 = -293.9$ rpm, $\omega_3 = -587.8$ rpm.

9-43 $\omega_G = -18.6$ rpm, $\omega_F = -187.7$ rpm.

9-67 $\varphi = 26.23°$.

9-69 Gear ratio = 2.4 and contact ratio = 1.698. Circular pitch = 0.785, base pitch = 0.738, pitch dia.= 6.25 and 15, outside dia. = 6.75 and 15.5, center dist. = 10.625, addendum = 0.250, dedendum = 0.313, whole depth = 0.562 5, clearance = 0.063 (all in inches).

9-71 Four stages with factors 6 x 5 x 5 x 5 x 5 = 750: Stage 1 = 14t to 84t. Stages 2, 3, 4 = 14t to 70t. Output in same direction as input due to even number of stages.

CHAPTER 10 DYNAMICS FUNDAMENTALS

10-1 *CG* @ 8.77 in from handle end, $I_{zz} = 0.394$ in-lb-sec^2, $k = 9.35$ in.

10-2 *CG* @ 8.08 in from handle end, $I_{zz} = 0.221$ in-lb-sec^2, $k = 8.95$ in.

10-4

a. $x = 3.547$, $y = 4.8835$, $z = 1.4308$, $w = -1.3341$

b. $x = -62.029$, $y = 0.2353$, $z = 17.897$, $w = 24.397$

F

10-6

a. In series: $k_{eff} = 3.09$, Softer spring dominates
b. In parallel: $k_{eff} = 37.4$, Stiffer spring dominates

10-9

a. In series: $c_{eff} = 1.09$, Softer damper dominates
b. In parallel: $c_{eff} = 13.7$, Stiffer damper dominates

10-12 $k_{eff} = 12$ N/mm, $m_{eff} = 0.688$ kg

10-14 $k_{eff} = 225$ N/mm, $m_{eff} = 58.5$ kg

10-20 Effective mass in 1st gear = 0.054 bl, 2nd gear = 0.096 bl, 3rd gear = 0.216 bl, 4th gear = 0.863 bl.

10-21 Effective spring constant at follower = 308.35 lb/in.

10-25 Effective spring constant = 111.1 N/mm, effective mass = 27 kg.

10-26 $x = 5.775$ in.

10-34 I_{crank} about pivot = 1 652 kg-mm^2, I_{rocker} about pivot = 18 420 kg-mm^2, $I_{coupler}$ about CG = 2106 kg-mm^2 (both couplers are the same).

10-35 $x = 774$ mm to strike point of ball.

CHAPTER 11 DYNAMIC FORCE ANALYSIS

11-3 Open file P11-03*row*.sld in program LINKAGES to check your solution.*

11-4 Open file P11-03*row*.sld in program LINKAGES to check your solution.*

11-5 Open file P11-05*row*.4br in program LINKAGES to check your solution.*

11-6 Open file P11-05*row*.4br in program LINKAGES to check your solution.*

11-7 Open file P11-07*row*.4br in program LINKAGES to check your solution.*

11-12 $F_{12x} = -1851$ N, $F_{12y} = 1315$ N; $F_{14x} = 1047$ N, $F_{14y} = -3156$ N; $F_{32x} = 479$ N, $F_{32y} = -275$ N; $F_{43x} = 53.7$ N, $F_{43y} = -1087$ N; $T_{12} = -45.3$ N-m

11-13 Open file P11-13.4br in program LINKAGES to check your solution.*

11-14 $F_{12} = 1\ 308$ lb, $F_{32} = 1\ 290$ lb, $F_{43} = 1\ 290$ lb, $F_{14} = 710$ lb, $F_{hand} = 63.2$ lb, $JFI = 0.645$.

11-25 $T_{12} = 463$ lb-in

11-40 Mass moment of inertia needed in flywheel = 11.8 bl-in^2. Many flywheel geometries are possible. Assuming a steel cylinder with a radius of 9.0 in, thickness = 1.474 in.

CHAPTER 12 BALANCING

12-1

a. $m_b r_b = 0.934$, $\theta_b = -75.5°$
c. $m_b r_b = 5.932$, $\theta_b = 152.3°$
e. $m_b r_b = 7.448$, $\theta_b = -80.76°$

* These files can be found in the PROBLEM SOLUTIONS folder downloadable with this text.

12-5

a. $m_a r_a = 0.814$, $\theta_a = -175.2°$, $m_b r_b = 5.50$, $\theta_b = 152.1°$

c. $m_a r_a = 7.482$, $\theta_a = -154.4°$, $m_b r_b = 7.993$, $\theta_b = 176.3°$

e. $m_a r_a = 6.254$, $\theta_a = -84.5°$, $m_b r_b = 3.671$, $\theta_b = -73.9°$

12-6 $W_a = 3.56$ lb, $\theta_a = 44.44°$, $W_b = 2.13$ lb, $\theta_b = -129.4°$

12-7 $W_a = 4.2$ lb, $\theta_a = -61.8°$, $W_b = 3.11$ lb, $\theta_b = 135°$

12-8 These are the same linkages as in Problem 11-5. Open the file P11-05*row*.4br in program LINKAGES to check your solution.* Then use the program to calculate the flywheel data.

12-9 Open the file P12-09.4br in program LINKAGES to check your solution.*

12-14 $R_3 = 5.85$ in, $\theta_3 = $ s–142.11°, $R_4 = 1.13$ in, $\theta_4 = 120°$

12-16 $W_4 = 14.48$ lb, $\theta_4 = 89.15°$, $W_5 = 5.04$ lb, $\theta_5 = 83.90°$

12-18 $d_3 = 18.95$ mm, $\theta_3 = -147.46°$, $d_4 = 20.8$ mm, $\theta_4 = 28.94°$

12-38 Plane 2: $e = 0.113$, $\theta = -152.15°$. Plane 3: $e = 0.184$, $\theta = 19.36°$.

CHAPTER 13 ENGINE DYNAMICS

13-1 Exact solution = – 42 679.272 in/sec @ 299.156° and 200 rad/sec

Fourier series approximation = – 42 703.631 in/sec @ 299.156° and 200 rad/sec

Error = –0.0571% (–0.000 571)

13-3 Gas torque = 2040 (approx.), Gas force = 3142

13-5 Gas torque = 2039.53 (approx.), Gas torque = 2039.91 (exact)

Error = 0.0186% (0.000 186)

13-7

a. $m_b = 0.007\,48$ at $l_b = 7.2$, $m_p = 0.012\,51$ at $l_p = 4.31$

b. $m_b = 0.008\,00$ at $l_b = 7.2$, $m_a = 0.012\,00$ at $l_a = 4.80$

c. $I_{model} = 0.691\,2$, Error = 11.48% (0.114 8)

13-9 $m_{2a} = 0.018$ at $r_a = 3.5$, $I_{model} = 0.220\,5$, Error = –26.5% (–0.265)

13-11 Open the file P13-11.eng in program ENGINE to check your solution.*

13-14 Open the file P13-14.eng in program ENGINE to check your solution.*

13-19 Open the file P13-19.eng in program ENGINE to check your solution.*

* These files can be found in the PROBLEM SOLUTIONS folder downloadable with this text.

TABLE S15-1
Solutions to Problem 15-6

	ω_n	ω_d	c_c
a	3.42	3.38	8.2
b	4.68	4.65	19.7
c	0.26	0.26	15.5
d	2.36	2.33	21.2
e	5.18	5.02	29.0
f	2.04	1.96	49.0

CHAPTER 14 MULTICYLINDER ENGINES

Note: Use program ENGINE to check your solutions.

14-23 *mr product* on the balance shafts = 5.017E–3 bl-in or 1.937 lb-in.

CHAPTER 15 CAM DYNAMICS

15-1 to **15-5** Use program DYNACAM to solve these problems. There is not any *one right answer* to these design problems.

15-6 See Table S15-1.

15-7 to **15-19** Use program DYNACAM to solve these problems. There is not any *one right answer* to these design problems.

Appendix G

EQUATIONS FOR UNDER- OR OVERBALANCED MULTICYLINDER ENGINES

G.1 INTRODUCTION

Chapter 14 developed the equations for shaking forces, moments, and torques in multicylinder engines of inline and vee configurations. In Chapter 14, it is assumed that the crank throws are all exactly balanced, an assumption that greatly simplifies the equations. However, some multicylinder engines overbalance the crank throws to reduce main bearing forces. This also can have an effect on shaking forces and moments.

This appendix provides replacement equations for the simplified versions in Chapter 14, and these equations do not assume exactly balanced crank throws.* The equation numbers used here correspond to those in Chapter 14 and can be substituted for the simplified ones if desired. In the equations that follow, m_A is the effective crank pin mass and m_B the effective wrist pin mass as defined in Chapter 13. The parameters m_c and r_c represent, respectively, the counterweight mass of any one crank throw and the radius to the counterweight's *CG*. All other parameters are the same as defined in Chapters 13 and 14.

* These complete equations are used in program LINKAGES.

For an inline engine (Section 14.3) the shaking forces for an engine with an under- or overbalanced crankshaft are:

$$\begin{aligned}F_{\mathbf{s}_x} \cong &(m_A + m_B) r\omega^2 \left[\cos\omega t \sum_{i=1}^{n} \cos\phi_i + \sin\omega t \sum_{i=1}^{n} \sin\phi_i \right] \\ &+ m_c r_c \omega^2 \left[\cos(\omega t + \pi) \sum_{i=1}^{n} \cos\phi_i + \sin(\omega t + \pi) \sum_{i=1}^{n} \sin\phi_i \right] \\ &+ \frac{m_B r^2 \omega^2}{l} \left[\cos 2\omega t \sum_{i=1}^{n} \cos 2\phi_i + \sin 2\omega t \sum_{i=1}^{n} \sin 2\phi_i \right] \hat{\mathbf{i}}\end{aligned} \tag{14.2d}$$

$$\begin{aligned}F_{\mathbf{s}_y} \cong &m_A r\omega^2 \left[\sin\omega t \sum_{i=1}^{n} \cos\phi_i - \cos\omega t \sum_{i=1}^{n} \sin\phi_i \right] \\ &+ m_c r_c \omega^2 \left[\sin(\omega t + \pi) \sum_{i=1}^{n} \cos\phi_i - \cos(\omega t + \pi) \sum_{i=1}^{n} \sin\phi_i \right] \hat{\mathbf{j}}\end{aligned}$$

For an inline engine (Section 14.3) the shaking moments for an engine with an under- or overbalanced crankshaft are:

$$\begin{aligned}M_{\mathbf{s}_x} \cong &(m_A + m_B) r\omega^2 \left[\cos\omega t \sum_{i=1}^{n} z_i \cos\phi_i + \sin\omega t \sum_{i=1}^{n} z_i \sin\phi_i \right] \\ &+ m_c r_c \omega^2 \left[\cos(\omega t + \pi) \sum_{i=1}^{n} z_i \cos\phi_i + \sin(\omega t + \pi) \sum_{i=1}^{n} z_i \sin\phi_i \right] \\ &+ \frac{m_B r^2 \omega^2}{l} \left[\cos 2\omega t \sum_{i=1}^{n} z_i \cos 2\phi_i + \sin 2\omega t \sum_{i=1}^{n} z_i \sin 2\phi_i \right] \hat{\mathbf{i}}\end{aligned} \tag{14.6b}$$

$$\begin{aligned}M_{\mathbf{s}_y} \cong &m_A r\omega^2 \left[\sin\omega t \sum_{i=1}^{n} z_i \cos\phi_i - \cos\omega t \sum_{i=1}^{n} z_i \sin\phi_i \right] \\ &+ m_c r_c \omega^2 \left[\sin(\omega t + \pi) \sum_{i=1}^{n} z_i \cos\phi_i - \cos(\omega t + \pi) \sum_{i=1}^{n} z_i \sin\phi_i \right] \hat{\mathbf{j}}\end{aligned}$$

For a vee or opposed engine (Sections 14.7 and 14.8) the shaking forces for an engine with an under- or overbalanced crankshaft are:

$$F_{\mathbf{s}_x} \cong \left(F_{s_L} + F_{s_R}\right)\cos\gamma + m_A r\omega^2 \left[\cos\omega t \sum_{i=1}^{n} \cos\phi_i + \sin\omega t \sum_{i=1}^{n} \sin\phi_i\right] + m_c r_c \omega^2 \left[\cos(\omega t + \pi) \sum_{i=1}^{n} \cos\phi_i + \sin(\omega t + \pi) \sum_{i=1}^{n} \sin\phi_i\right]\hat{\mathbf{i}} \tag{14.10j}$$

$$F_{\mathbf{s}_y} \cong \left(F_{s_L} - F_{s_R}\right)\sin\gamma + m_A r\omega^2 \left[\sin\omega t \sum_{i=1}^{n} \cos\phi_i - \cos\omega t \sum_{i=1}^{n} \sin\phi_i\right] + m_c r_c \omega^2 \left[\sin(\omega t + \pi) \sum_{i=1}^{n} \cos\phi_i - \cos(\omega t + \pi) \sum_{i=1}^{n} \sin\phi_i\right]\hat{\mathbf{j}}$$

$$\mathbf{F_s} = F_{s_x}\,\hat{\mathbf{i}} + F_{s_y}\,\hat{\mathbf{j}}$$

For a vee or opposed engine (Sections 14.7 and 14.8) the shaking moments for an engine with an under- or overbalanced crankshaft are:

$$M_{\mathbf{s}_x} \cong \left(M_{s_L} + M_{s_R}\right)\cos\gamma + m_A r\omega^2 \left[\cos\omega t \sum_{i=1}^{n} z_i \cos\phi_i + \sin\omega t \sum_{i=1}^{n} z_i \sin\phi_i\right] + m_c r_c \omega^2 \left[\cos(\omega t + \pi) \sum_{i=1}^{n} z_i \cos\phi_i + \sin(\omega t + \pi) \sum_{i=1}^{n} z_i \sin\phi_i\right]\hat{\mathbf{i}} \tag{14.11c}$$

$$M_{\mathbf{s}_y} \cong \left(M_{s_L} - M_{s_R}\right)\sin\gamma + m_A r\omega^2 \left[\sin\omega t \sum_{i=1}^{n} z_i \cos\phi_i - \cos\omega t \sum_{i=1}^{n} z_i \sin\phi_i\right] + m_c r_c \omega^2 \left[\sin(\omega t + \pi) \sum_{i=1}^{n} z_i \cos\phi_i - \cos(\omega t + \pi) \sum_{i=1}^{n} z_i \sin\phi_i\right]\hat{\mathbf{j}}$$

$$\mathbf{M_s} = M_{s_x}\,\hat{\mathbf{i}} + M_{s_y}\,\hat{\mathbf{j}}$$

Note that inertia torque is unaffected by crankshaft balance condition because, at constant angular velocity, the acceleration vector of the crank pin mass is centripetal and has no moment arm. The moment of inertia added to the crankshaft by any overbalance mass will increase the flywheel effect of the crankshaft and thus reduce its willingness to change rotational speed in transient angular acceleration. But, the size of the engine's physical flywheel can be reduced to compensate for the more massive crankshaft.

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DOWNLOADS INDEX

ANIMATIONS Folder

AVI, Working Model, and Matlab files by Sid Wang

These files are self-cataloging. Run the master catalog file Animation.html to access and run these animations. Most have AVI movie files in addition to their native file formats. The native Working Model files also can be accessed directly from the Working Model Files folder listed below.

CUSTOM PROGRAMS

Programs by R. L. Norton

PROGRAM DYNACAM

PROGRAM LINKAGES

PROGRAM MATRIX

These are available from the author's website at www.designofmachinery.com. Print-book users can register on my website as a student or professor, and I will send a password to access a protected site where they can download the latest versions of these programs. Student or professor registration will also allow print-book users to download all the files listed in this index. Digital book users will have access to the downloadable files in the Video Contents and in this Index, and the computer programs through the publisher's website.

Note that I personally review each of these requests for access to my protected site and will approve only those that are filled out completely and correctly according to the provided instructions. I require complete information and accept ONLY university email addresses for both you and your instructor. (No Gmail, Yahoo, Naver, etc.) So be sure to follow the instructions exactly, or your request will be denied.

Run the Install.exe file to install the program.

EXAMPLES AND FIGURES Folder

Data files for Norton's custom programs that match some examples and figures in text.

Chapter 2 Subfolder

F02-19b.5br

Chapter 3 Subfolder

Cognate1.4br
Cognate2.4br
Cognate3.4br
F03-01a.4br
F03-01b.4br
F03-04.4br
F03-06.4br
F03-07b.6br
F03-07c.6br
F03-08.4br
F03-09c.6br
F03-12.4br
F03-13a.6br
F03-17b.4br
F03-18.4br
F03-24.4br
F03-28a.4br
F03-28b.5br
F03-29a.4br
F03-29c.4br
F03-29d.4br
F03-29e.4br
F03-29f.4br
F03-31c.6br
F03-34.6br
F03-35.6br
FP03-07.4br
Straight.5br

Chapter 4 Subfolder

F04-11.5br
F04-15.4br

Chapter 5 Subfolder

E05-01.4br
E05-02a.mtr
E05-02b.mtr
E05-02.4br
E05-03.4br

Chapter 6 Subfolder

F06-14.4br
F06-15a.4br
F06-15b.4br
F06-17b.4br

Chapter 8 Subfolder

E08-03.cam
E08-04.cam
E08-05.cam
E08-06.cam
E08-07.cam
E08-08.cam
E08-09a.cam
E08-09b.cam
E08-10a.cam
E08-10b.cam
E08-10c.cam
E08-11.cam
E08-12.cam

Chapter 11 Subfolder

E11-01.mtr
E11-02.mtr
E11-03.mtr
E11-03.4br
F11-06.4br

Chapter 12 Subfolder

F12-05.4br

Chapter 14 Subfolder

BMWV12.eng
F14-12.eng
F14-14.eng
F14-18.eng
F14-24.eng

Chapter 15 Subfolder

E15-01.cam
E15-02.cam

Appendix A Subfolder

F_A-05.4br
F_A-11.5br

KEY TO FILENAME SUFFIXES

DYNACAM	.CAM
ENGINE*	.ENG
FIVEBAR*	.5BR
FOURBAR*	.4BR
LINKAGES	.BAR
MATLAB	.M
MATRIX	.MTX
SIXBAR*	.6BR
SLIDER*	.SLD
TKSOLVER	.TKW
WORKING MODEL	.WM2D, WM3

* Program LINKAGES will open these files.

LINKAGE ATLASES Folder

Contains PDF file of atlases of coupler curves for fourbar and geared fivebar linkages.

Hrones and Nelson Fourbar Atlas

Zhang et al. Geared Fivebar Atlas

PDF PROBLEM WORKBOOK Folder

Contains PDF files of all the figures needed to solve the text's end-of-chapter problems. Each PDF file contains one problem figure and all of the problem statements associated with it. They are grouped in subfolders by chapter and their filenames are the same as the figure number or problem number involved. These files provide the student with a printable workbook of illustrated problems in which graphical problem solutions can be directly worked out or analytical solution results recorded.

PROBLEM SOLUTIONS Folder

Data files that solve selected problems in the text.

Chapter 3 Subfolder

P03-14.4br
P03-22.4br
P03-23.4br
P03-36.4br
P03-42.4br

Chapter 4 Subfolder

P04-21.4br
P04-23.4br
P04-25.4br
P04-26.4br
P04-29.4br
P04-30.4br

Chapter 5 Subfolder

P05-08.4br
P05-11.4br
P05-15.4br
P05-19.4br
P05-26.4br

Chapter 6 Subfolder

P06-47.4br
P06-48.4br
P06-49.4br
P06-51.4br
P06-62.4br

Chapter 7 Subfolder

P07-04a.4br
P07-04c.4br
P07-04e.4br
P07-04g.4br
P07-04i.4br
P07-04k.4br
P07-04m.4br
P07-39.4br
P07-40.4br
P07-41.4br
P07-42.4br
P07-44.4br

Chapter 10 Subfolder

P10-04a.mtr
P10-04b.mtr

Chapter 11 Subfolder

P11-03a.sld
P11-03c.sld
P11-03e.sld
P11-03g.sld
P11-04a.tkw
P11-05a.tkw
P11-05a.4br
P11-05c.4br
P11-05e.4br
P11-05g.4br
P11-06a.tkw
P11-06c.tkw
P11-06e.tkw
P11-06g.tkw
P11-07a.4br
P11-07c.4br
P11-07e.4br
P11-12.4br
P11-13.4br

Chapter 12 Subfolder

P12-09.4br

Chapter 13 Subfolder

P13-11.eng
P13-14.eng
P13-19a.eng
P13-19b.eng

PROGRAM MANUAL Folder

Contains a PDF file of the user manual for programs LINKAGES, DYNACAM, *and* MATRIX.

TKSOLVER FILES Folder

TKSolver model files.

The TKsolver program is needed to run these files and is not included with this text. See www.uts.com.

Gears.tk Subfolder

Compound.tkw
Revert.tkw
Triple.tkw

Linkages.tk Subfolder

3 position FixPivots.tkw
3 position.tkw
Cognate.tkw
Coupler.tkw
DragSlider.tkw
Eq04-02.tkw
Ex11-04.tkw
Figure P05-05.tkw
Fivebar.tkw
Fourbar.tkw
Inverted slider-crank.tkw
SCCA.tkw
Slider_Cmpr.tkw
Slider.tkw
Soni Cognate.tkw
Symmetric.tkw
Transport.tkw
Virtual Work.tkw

Misc.tk Subfolder

CamCalc.tkw
Constrnt.tkw
Cubic.tkw
Cycloid.tkw
F04-18.tkw
Pressang.tkw
SCCA.tkw
Student.tkw

VIDEOS

See the **Video Contents**.

VIRTUAL LABS

See the **Video Contents**.

WORKING MODEL FILES Folder

Chapter 2 Subfolder

Working Model 2D Files

02-10b.wm2d - Scotch Yoke
02.12a.wm2d - Geneva
02-12b.wm2d - Ratchet and Pawl
02-12c.wm2d - Linear Geneva
02-13.wm2d - Slider-Crank
02-14abc.wm2d - Stephenson Inversion
02-14de.wm2d - Watt Inversions
02-15.wm2d - Grashof Inversions
02-16.wm2d - Non-Grashof Inversions
02-19b.wm2d - Geared Fivebar
02-20.wm2d - Desk Lamp
P2-01f.wm2d - Overhead Valve
P2-03.wm2d - Front End Loader
P2-04c.wm2d - Radial Engine
P2-04d.wm2d - Walking Beam
P2-04e.wm2d - Drafting Arm
P2-04g.wm2d - Drum Brake
P2-04h.wm2d - Compression Chamber
P2-05a.wm2d - Chebyschev Mechanism
P2-05b.wm2d - Kempe SL Mechanism
P2-07.wm2d - Throttle Mechanism

P2-08.wm2d - Scissors Jack
P2-10.wm2d - Watt's Engine
P2-13.wm2d - Crimping Tool
P2-14.wm2d - Pick and Place
P2-15.wm2d - Power Hacksaw
P2-16.wm2d - Powder Press
P2-18.wm2d - Oil Field Pump

Working Model 3D Files

P2-01h.wm3 - Cylindrical Cam

Chapter 3 Subfolder

Working Model 2D Files

03-04.wm2d - Example 3-1
03-05.wm2d - Example 3-2
03-07b.wm2d - Example 3-4
03-09c.wm2d - Example 3-6
03-11.wm2d - 3-Position Synthesis
03-12b.wm2d - 4br Quick Return
03-13a.wm2d - 6br Quick Return
03-14.wm2d - Quick-Return Shaper
03-14.-*wm2d - Quick-Return Shaper
03-15.wm2d - Coupler Curves
03-17.wm2d - Coupler Curve Atlas
03-17a.wm2d - Coupler Curve Atlas
03-18.wm2d - Camera Film Advance
03-18-*.wm2d - Camera Film Advance
03-19a.wm2d - Auto Suspensions
03-19a-*.wm2d - Auto Suspensions
03-24a.wm2d - Roberts Diagram
03-25a.wm2d - Roberts Diagram
03-25b.wm2d - Roberts Diagram
03-26.wm2d - Chebyschev Cognates
03-26a.wm2d - Roberts Diagram
03-26b.wm2d - Chebyschev Cognates
03-26b-*.wm2d - Chebyschev Cognates
03-27c.wm2d - Curvilinear Trans.
03-27d.wm2d - Curvilinear Trans.
03-28.wm2d - GFBM 4br Cognate
03-28-*.wm2d - GFBM Cognates (alt.)
03-29.wm2d - Straight-Line Linkages
03-29a.wm2d - Watt Straight-Line
03-29b.wm2d - Watt's Engine
03-29c.wm2d - Roberts Straight-Line
03-29d.wm2d - Chebyschev SL
03-29e.wm2d - Hoeken Straight-Line
03-29f.wm2d - Evans Straight-Line
03-29g.wm2d - Peaucellier Strt-Line
03-31c.wm2d - Single-Dwell—Rocker
03-31d.wm2d - Single-Dwell—Slider
03-32.wm2d - Double-Dwell Linkage
03-34.wm2d - 180° Rocker Output
03-35.wm2d - Washing Machine
03-36.wm2d - 360° Rocker Output
P3-03.wm2d - Treadle Wheel
P3-07.wm2d - Walking Beam
P3-08.wm2d - Loom Laybar Drive

Chapter 4 Subfolder

Working Model 2D Files

04-16.wm2d - Double Rocker Toggle
P4-01.wm2d - Fourbar Analysis
P4-02.wm2d - Slider-Crank Analysis
P4-03.wm2d - Inverted Slider-Crank
P4-05c.wm2d - Radial Engine
P4-05d.wm2d - Walking Beam
P4-05e.wm2d - Drafting Machine
P4-05g.wm2d - Drum Brake
P4-05h.wm2d - Compression Chamber
P4-06.wm2d - Pick and Place
P4-07.wm2d - Power Hacksaw
P4-09.wm2d - Walking Beam Conveyor
P4-11.wm2d - Loom Laybar Drive
P4-14.wm2d - Treadle Wheel
P4-18.wm2d - Elliptical Trammel

Chapter 6 Subfolder

Working Model 2D Files

06-05c.wm2d - Instant Centers
06-10b.wm2d - Instant Centers
06-11.wm2d - Rock Crusher
06-12.wm2d - Suspension
06-14a.wm2d - Centrodes 1
06-14b.wm2d - Centrodes 2
06-14c.wm2d - Centrodes 3
06-14d.wm2d - Centrodes 4
06-15a.wm2d - Centrodes 5
06-15b.wm2d - Centrodes 6
06-17a.wm2d - Cycloidal Motion
P6-01.wm2d - Fourbar Analysis
P6-02.wm2d - Slider-Crank Analysis
P6-03.wm2d - Inverted Slider-Crank
P6-08c.wm2d - Radial Engine
P6-08d.wm2d - Walking Beam
P6-08e.wm2d - Drafting Machine
P6-08g.wm2d - Drum Brake
P6-08h.wm2d - Compression Chamber
P6-15.wm2d - Power Hacksaw
P6-16.wm2d - Pick and Place
P6-18.wm2d - Powder Press
P6-19.wm2d - Walking Beam Conveyor
P6-21.wm2d - Toggle Pliers
P6-23.wm2d - Surface Grinder
P6-29.wm2d - Drum Pedal
P6-30.wm2d - Oil Field Pump
P6-32.wm2d - Elliptical Trammel

Working Model 3D Files

06-12.wm3 - Bump Steering

Chapter 7 Subfolder

Working Model 2D Files

P7-01.wm2d - Fourbar Analysis
P7-02.wm2d - Slider-Crank Analysis
P7-03.wm2d - Inverted Slider-Crank
P7-08c.wm2d - Radial Engine
P7-08d.wm2d - Walking Beam
P7-08e.wm2d - Drafting Machine
P7-08g.wm2d - Drum Brake
P7-08h.wm2d - Compress Chamber
P7-15.wm2d - Power Hacksaw
P7-16.wm2d - Pick and Place
P7-19.wm2d - Walking Beam
P7-20.wm2d - Surface Grinder
P7-24.wm2d - Drum Pedal

Chapter 8 Subfolder

Working Model 2D Files

08-02a.wm2d - Translating Follower
08-02b.wm2d - Oscillating Follower
08-03a.wm2d - Roller Follower
08-03c.wm2d - Flat-Faced Follower
08-39.wm2d - Cam and Follower
08-48.wm2d - Radii of Curvature
E8-02.wm2d - Example 8-2
E8-03.wm2d - Example 8-3
E8-04.wm2d - Example 8-4
E8-07.wm2d - Example 8-7

Working Model 3D Files

08-03a.wm3 - Roller Follower
08-04.wm3 - Cylindrical Cam

Chapter 9 Subfolder

Working Model 2D Files

09-01b.wm2d - Internal Gearset
09-04.wm2d - External Gearset
09-05.wm2d - Involute Curves
09-06.wm2d - Tooth Engagement
09-19.wm2d - Rack and Pinion
09-28.wm2d - Compound Gear Train
09-33.wm2d - Planetary Gearset

Working Model 3D Files

09-16.wm3 - Helical-Parallel Gears
09-17.wm3 - Helical-Crossed Gears
09-18.wm3 - Worm and Worm Gear
09-21.wm3 - Bevel Gears
09-30.wm3 - Gear Trains
09-34.wm3 - Planetary Gearset
09-44a.wm3 - Transmission - High
09-44b.wm3 - Transmission - Low
09-44c.wm3 - Transmission - Reverse
09-51.wm3 - Drive Train
P9-02.wm3 - Compound Epicyclic
P9-03_open.wm3 - Differential
P9-03_locked.wm3 - Differential

Chapter 10 Subfolder

Working Model 2D Files

10-11a.wm2d - Valve Train

Chapter 13 Subfolder

Working Model 2D Files

13-01.wm2d - Vee-Eight Engine


THE
END