

HEWLETT-PACKARD

HP-41

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Mechanical Engineering

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INTRODUCTION

This HP-41C Solutions book was written to help you get the most from your calculator. The programs were chosen to provide useful calculations for many of the common problems encountered.

They will provide you with immediate capabilities in your everyday calculations and you will find them useful as guides to programming techniques for writing your own customized software. The comments on each program listing describe the approach used to reach the solution and help you follow the programmer's logic as you become and expert on your HP calculator.

KEYING A PROGRAM INTO THE HP-41C

There are several things that you should keep in mind while you are keying in programs from the program listings provided in this book. The output from the HP 82143A printer provides a convenient way of listing and an easily understood method of keying in programs without showing every keystroke. This type of output is what appears in this handbook. Once you understand the procedure for keying programs in from the printed listings, you will find this method simple and fast. Here is the procedure:

- At the end of each program listing is a listing of status information required to properly execute that program. Included is the SIZE allocation required. Before you begin keying in the program, press **[XEQ]** **[ALPHA]** **SIZE** **[ALPHA]** and specify the allocation (three digits; e.g., 10 should be specified as 010).

Also included in the status information is the display format and status of flags important to the program. To ensure proper execution, check to see that the display status of the HP-41C is set as specified and check to see that all applicable flags are set or clear as specified.

- Set the HP-41C to PRGM mode (press the **[PRGM]** key) and press **[GTO]** **[.]** **[.]** to prepare the calculator for the new program.

- Begin keying in the program. Following is a list of hints that will help you when you key in your programs from the program listings in this handbook.

- When you see " (quote marks) around a character or group of characters in the program listing, those characters are ALPHA. To key them in, simply press **[ALPHA]**, key in the characters, then press **[ALPHA]** again. So "SAMPLE" would be keyed in as **[ALPHA]** "SAMPLE" **[ALPHA]**.
- The diamond in front of each LBL instruction is only a visual aid to help you locate labels in the program listings. When you key in a program, ignore the diamond.
- The printer indication of divide sign is /. When you see / in the program listing, press **[÷]**.
- The printer indication of the multiply sign is ×. When you see × in the program listing, press **[×]**.
- The L character in the program listing is an indication of the **[APPEND]** function. When you see L, press **[APPEND]** in ALPHA mode (press **[ALPHA]** and the K key).
- All operations requiring register addresses accept those addresses in these forms:

nn (a two-digit number)

IND nn (INDIRECT: **[IND]**, followed by a two-digit number)

X, Y, Z, T, or L (a STACK address: **[RST]** followed by X, Y, Z, T, or L)

IND X, Y, Z, T or L (INDIRECT stack: **[IND]** **[RST]** followed by X, Y, Z, T, or L)

Indirect addresses are specified by pressing **[IND]** and then the indirect address. Stack addresses are specified by pressing **[RST]** followed by X, Y, Z, T, or L. Indirect stack addresses are specified by pressing **[IND]** **[RST]** and X, Y, Z, T, or L.

Printer Listing

```

01 LBL "SAMPLE"
02 "THIS IS A"
03 "SAMPLE"
04 AVIEW
05 6
06 ENTER↑
07 -2
08 /
09 ABS
10 STO IND L
11 "R3="
12 ARCL 03
13 AVIEW
14 RTN

```

Keystrokes

```

[LBL] [ALPHA] SAMPLE [ALPHA]
[ALPHA] THIS IS A [ALPHA]
[ALPHA] [APPEND] SAMPLE
[ALPHA] AVIEW [ALPHA]
6
[ENTER↑]
2 [CHS]
[÷]
[XEQ] [ALPHA] ABS [ALPHA]
[STO] [RST] L
[ALPHA] R3= [ARCL] 03
[ALPHA] AVIEW
[ALPHA]
[RTN]

```

Display

```

01 LBLT SAMPLE
02T THIS IS A
03T L SAMPLE
04 AVIEW
05 6
06 ENTER↑
07 -2
08 /
09 ABS
10 STO IND L
11T R3=
12 ARCL 03
13 AVIEW
14 RTN

```

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	Solves any general linear equation of the form ($y - y_0$) = $m(x - x_0)$.	
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	Solves the differential equation $m\ddot{x} + c\dot{x} + kx = 0$.	
8.	INTERFERENCE FITS	68
	Calculates contact pressure or interference for concentric cylinders.	
9.	LINEAR OF ANGULAR DEFORMATION	78
	Solves for linear deflection under tensile load or angular deflection under torque.	
10.	CONSTANT ACCELERATION	84
	Calculates displacement, acceleration, initial velocity and time for an object undergoing constant acceleration.	

GEAR FORCES

This program computes three mutually perpendicular forces resulting from input torque on helical, bevel, or worm gears.

Helical gear equations:

$$F_t = \frac{T}{r}$$

$$F_{gs} = F_t \tan \phi$$

$$F_{gax} = F_t \tan \alpha$$

$$\tan \phi = \frac{\tan \phi_n}{\cos \alpha}$$

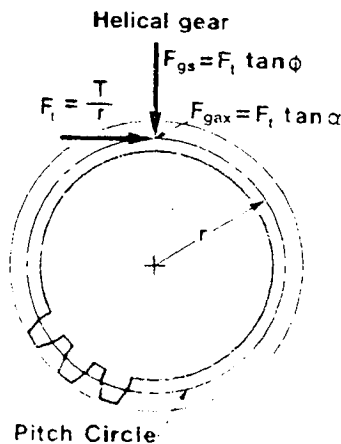


Figure 1-Helical Gear

where:

T is the input torque;

r is the pitch radius of the input gear;

F_t is the tangential force;

α is the helix angle measured from the axis of the gear (for spur gears $\alpha = 0$);

ϕ_n is the pressure angle measured perpendicular to the gear tooth;

ϕ is the pressure angle measured perpendicular to the gear axis;

F_{gs} is the radial force trying to separate the gears;

F_{gax} is the force parallel to the gear axis.

Bevel gear equations:

$$F_t = \frac{T}{r}$$

$$F_{bpax} = F_t \left(\frac{\tan \phi_n \sin (\text{cone} \angle)}{\cos \alpha} + \tan \alpha \cos (\text{cone} \angle) \right)$$

$$F_{bgax} = F_t \left(\frac{\tan \phi_n \cos (\text{cone} \angle)}{\cos \alpha} - \tan \alpha \sin (\text{cone} \angle) \right)$$

$$\tan \phi = \frac{\tan \phi_n}{\cos \alpha}$$

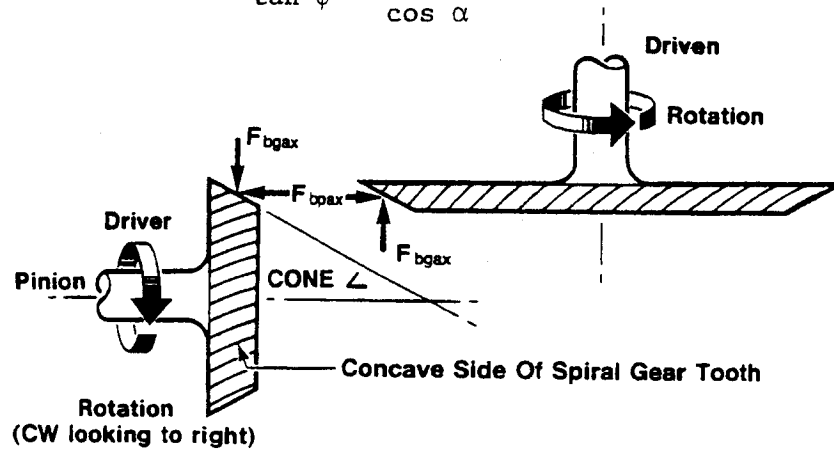


Figure 2—Spiral Bevel Gears

where:

T is the input (pinion) torque;

r is the pitch radius of the pinion gear;

F_t is the tangential force;

α is the pinion spiral angle (zero for straight tooth bevel gears);

ϕ_n is the pressure angle measured perpendicular to the gear tooth;

ϕ is the pressure angle measured perpendicular to the gear axis;

$\text{Cone} \angle$ is the pitch cone angle of the pinion;

F_{bpax} is the force along the axis of the bevel pinion;

F_{bgax} is the force along the axis of the bevel gear.

Worm gear equations:

$$F_t = \frac{T}{r}$$

$$F_{ws} = F_t \left(\frac{\sin \phi_n}{\cos \phi_n \sin \alpha + f \cos \alpha} \right)$$

$$F_{gax} = F_t \frac{1 - \frac{f \tan \alpha}{\cos \phi_n}}{\tan \alpha + \frac{f}{\cos \phi_n}}$$

$$\tan \phi = \frac{\tan \phi_n}{\cos \alpha}$$

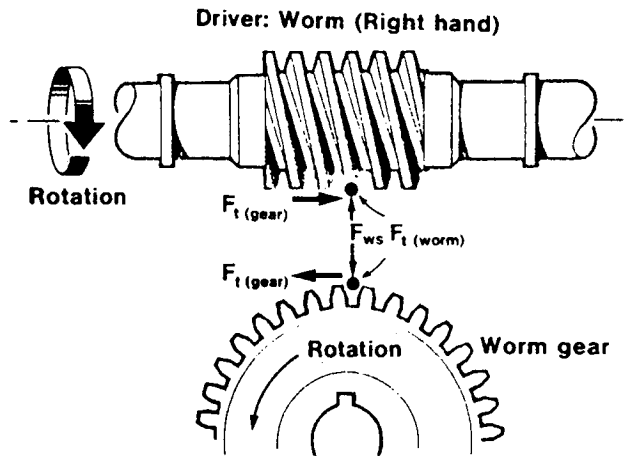


Figure 3
WORM GEAR

where:

T is the input (worm) torque;

n is the pitch radius of the worm;

F_t is the tangential force on the worm;

α is the lead angle of the worm ($\alpha = \tan^{-1}(L/2\pi r)$, where L is the lead of the worm);

ϕ_n is the pressure angle measured perpendicular to the worm teeth;

ϕ is the pressure angle measured parallel to the worm axis;

f is the coefficient of friction;

F_{ws} is the separating force between the worm and gear;

F_{gax} is the force parallel to the gear axis.

Example 1:

A helical gear with pitch radius 12 cm has a torque applied to it of 450,000 dyne-cm. The helix angle is 30° and the normal pressure angle, measured perpendicular to a tooth is 17.5° . Find the tangential, separating, and thrust forces.

Keystrokes:

[XEQ] [ALPHA] SIZE [ALPHA] 013

[XEQ] [ALPHA] GEAR [ALPHA]

450000 [R/S]

12 [R/S]

[R/S]

30 [R/S]

17.5 [R/S]

[XEQ] [ALPHA] HEL [ALPHA]

[R/S]

Display:

T?

R?

F=37,500.00

ALPHA?

AN?

FGS=13,652.84

FGAX=21,650.64

Example 2:

A spiral pinion with mean radius 1.73 inches is subjected to a torque of 745 in-lb. The pinion is cut with a normal pressure angle of 20° , a spiral angle of 35° , and a pitch cone of 18° . Find the forces acting on the pinion. Rotation is in the direction of the concave side of the pinion teeth, so α is positive 35° .

Keystrokes:

[XEQ] [ALPHA] GEAR [ALPHA]

745 [R/S]

1.73 [R/S]

[R/S]

35 [R/S]

20 [R/S]

[XEQ] [ALPHA] BEV [ALPHA]

18 [R/S]

[R/S]

Display:

T?

R?

F=430.64

ALPHA?

AN?

CONE $\angle$?

FBPAX=345.90

FBGAX=88.80

				SIZE: 013
STEP	INSTRUCTIONS	INPUT	FUNCTION	DISPLAY
1	Load program			
2	Begin execution		[XEQ] GEAR	T?
3	Input values:			
	Torque	T	[R/S]	R?
	Pitch radius	r	[R/S]	F=(F _t)
			[R/S]	ALPHA?
4	Input helix angle for helical gears, or			
	spiral angle for spiral bevel gears, or			
	lead angle for worm gears	α	[R/S]	AN?
5	Input normal pressure angle	ϕ_n	[R/S]	
	OR			
	Input pressure angle	ϕ	[XEQ] N	
6	Execute appropriate program			
	For helical gears		[XEQ] HEL	FGS=
			[R/S]	FGAX=
	For bevel gears		[XEQ] BEV	CONE $\angle$?
	input cone angle	CONE $\angle$	[R/S]	FBPAX=
			[R/S]	FBGAX=
	For worm gears		[XEQ] WORM	F?
	input coefficient of friction	f	[R/S]	FWS=
			[R/S]	FGAX=

Program Listings

<pre> 01♦LBL "GEA R" 02 FIX 2 03 "T?" 04 PROMPT 05 "R?" 06 PROMPT 07 / 08 STO 06 09 "F=" 10 XEQ 05 11 "ALPHA?" 12 PROMPT 13 STO 11 14 "AN?" 15 PROMPT 16♦LBL 10 17 STO 05 18 STOP 19♦LBL "HEL </pre>	Initialization	<pre> 50 RCL 11 51 TAN 52 * 53 RCL 12 54 X<>Y 55 P-R 56 R↑ 57 + 58 RDN 59 - 60 R↑ 61 "FBPAX=" 62 XEQ 05 63 X<>Y 64 "FBGAX=" 65 GTO 05 66♦LBL "WOR </pre>	
<pre> " 20 RCL 06 21 RCL 11 22 TAN 23 * 24 RCL 05 25 TAN 26 RCL 11 27 COS 28 / 29 RCL 06 30 * 31 "FGS=" 32 XEQ 05 33 X<>Y 34 "FGAX=" 35 GTO 05 36♦LBL "BEV </pre>	Helical gears	<pre> M" 67 "F?" 68 PROMPT 69 STO 04 70 RCL 05 71 SIN 72 LASTX 73 COS 74 RCL 11 75 SIN 76 * 77 RCL 11 78 COS 79 RCL 04 80 * 81 + 82 / 83 RCL 06 84 * 85 "FWS=" 86 XEQ 05 87 1 88 RCL 11 89 TAN 90 RCL 04 91 * 92 RCL 05 93 COS 94 / 95 - 96 RCL 11 97 TAN 98 RCL 04 99 RCL 05 </pre>	Worm gears
<pre> 37 "CONE2?" 38 PROMPT 39 STO 12 40 RCL 12 41 RCL 05 42 TAN 43 RCL 11 44 COS 45 / 46 RCL 06 47 * 48 P-R 49 RCL 06 </pre>	Bevel gears		

Program Listings

DATA REGISTERS				STATUS			
00		50		SIZE 013	TOT. REG. 43	USER MODE	
				ENG	FIX 2	SCI	ON OFF X
				DEG X	RAD	GRAD	
05	f φn Fr	55		FLAGS			
				#	INIT S/C	SET INDICATES	CLEAR INDICATES
10	α Cone	60					
15		65					
20		70					
25		75					
30		80					
35		85					
40		90		ASSIGNMENTS			
				FUNCTION	KEY	FUNCTION	KEY
45		95					

GEAR FORCES

PROGRAM REGISTERS NEEDED: 31

ROW 1 (1 - 3)



ROW 2 (4 - 10)



ROW 3 (11 - 14)



ROW 4 (15 - 21)



ROW 5 (22 - 31)



ROW 6 (31 - 35)



ROW 7 (36 - 37)



ROW 8 (37 - 49)



ROW 9 (50 - 61)



ROW 10 (61 - 64)



ROW 11 (64 - 66)



ROW 12 (67 - 77)



ROW 13 (78 - 86)



ROW 14 (86 - 97)



ROW 15 (98 - 106)



ROW 16 (106 - 113)



ROW 17 (114 - 119)

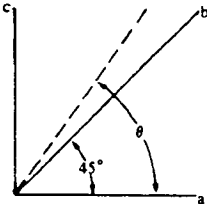
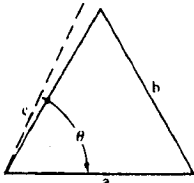


STRESS ON AN ELEMENT

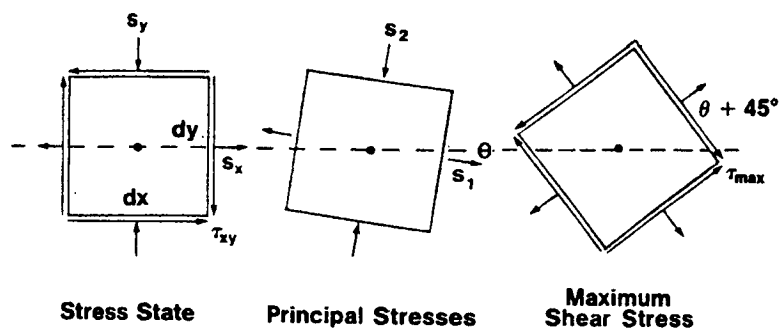
This program reduces data from rosette strain gage measurements and/or performs Mohr circle stress analysis calculations.

Correlations for rectangular and equiangular rosette configurations are included.

Strain Gage Equations:

CONFIGURATION CODE	1	2
TYPE OF ROSETTE	RECTANGULAR	DELTA (EQUIANGULAR)
		
PRINCIPAL STRAINS: ϵ_1, ϵ_2	$\frac{1}{2} [\epsilon_a + \epsilon_c \pm \sqrt{2(\epsilon_a - \epsilon_b)^2 + 2(\epsilon_b - \epsilon_c)^2}]$	$\frac{1}{3} [\epsilon_a + \epsilon_b + \epsilon_c \pm \sqrt{2(\epsilon_a - \epsilon_b)^2 + 2(\epsilon_b - \epsilon_c)^2 + 2(\epsilon_c - \epsilon_a)^2}]$
CENTER OF MOHR CIRCLE: $\frac{s_1 + s_2}{2}$	$\frac{E(\epsilon_a + \epsilon_c)}{2(1 - \nu)}$	$\frac{E(\epsilon_a + \epsilon_b + \epsilon_c)}{3(1 - \nu)}$
MAXIMUM SHEAR STRESS: τ_{max}	$\frac{E}{2(1 + \nu)} \sqrt{2(\epsilon_a - \epsilon_b)^2 + 2(\epsilon_b - \epsilon_c)^2}$	$\frac{E}{3(1 + \nu)} \sqrt{2(\epsilon_a - \epsilon_b)^2 + 2(\epsilon_b - \epsilon_c)^2 + 2(\epsilon_c - \epsilon_a)^2}$
ORIENTATION OF PRINCIPAL STRESSES	$\tan^{-1} \left[\frac{2\epsilon_b - \epsilon_a - \epsilon_c}{\epsilon_a - \epsilon_c} \right]$	$\tan^{-1} \left[\frac{\sqrt{3}(\epsilon_a - \epsilon_b)}{2\epsilon_a - \epsilon_b - \epsilon_c} \right]$

The Mohr circle portion of the program converts an arbitrary stress configuration to principal stresses, maximum shear stress and rotation angle. It is then possible to calculate the state of stress for an arbitrary orientation θ' .



Mohr Circle Equations:

$$\tau_{\max} = \sqrt{\left(\frac{S_x - S_y}{2}\right)^2 + \tau_{xy}^2}$$

$$S_1 = \frac{S_x + S_y}{2} + \tau_{\max}$$

$$S_2 = \frac{S_x + S_y}{2} - \tau_{\max}$$

$$\theta = \frac{1}{2} \tan^{-1} \left(\frac{2\tau_{xy}}{S_x - S_y} \right)$$

$$s = \frac{S_1 + S_2}{2} + \tau_{\max} \cos 2\theta'$$

$$\tau = \tau_{\max} \sin 2\theta'$$

where:

s is the normal stress, and τ is the shear stress.

ϵ_a , ϵ_b , and ϵ_c are the strains measured using rosette gages;

S_x is the stress in the x direction for Mohr circle input;

S_y is the stress in the y direction for Mohr circle input;

τ_{xy} is the shear stress on the element for Mohr circle input;

ϵ_1 and ϵ_2 are the principal strains;

S_1 and S_2 are the principal normal stresses;

$\tau_{\max}$ is the maximum shear stress;

θ is the counterclockwise angle of rotation from the specified axis to the principal axis. Note that this is opposite to the normal Mohr circle convention.

θ' is an arbitrary rotation angle from the original (x,y) axis;

E is modulus of elasticity.

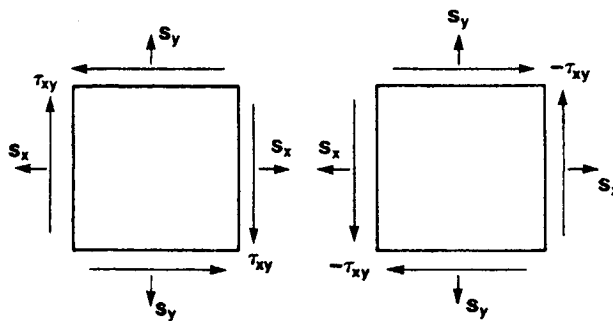
Reference:

Spotts, M.F., Design of Machine Elements; Prentice-Hall, 1971.

Beckwith, T. G., Buck, N. L., Mechanical Measurements; Addison-Wesley, 1969.

Remarks:

Negative stresses and strains indicate compression. Positive and negative shear are represented below:



Example:

A rectangular rosette measures the strains below. What are the principal strains and principal stresses?

$$\begin{aligned}\epsilon_a &= 90 \times 10^{-6} & \epsilon_b &= 137 \times 10^{-6} & \epsilon_c &= 305 \times 10^{-6} \\ \nu &= 0.3 & E &= 30 \times 10^6 \text{ psi}\end{aligned}$$

Keystrokes:

Display:

[USER]

[XEQ[[ALPHA] SIZE [ALPHA] 016

[XEQ] [ALPHA] ROSETTA [ALPHA]

RECT? Y/N

Y [R/S]

E?

30 [EEX] 6 [R/S]

RATIO?

.3 [R/S]

EA?

90 [EEX] 6 [CHS] [R/S]

EB?

137 [EEX] 6 [CHS] [R/S]

EC?

305 [EEX] 6 [CHS] [R/S]

E=320.9E-6

[R/S]

E=74.14E-6

[R/S]

$\angle$ =14.69E0

[R/S]

S=11.31E3

[R/S]

S=5.618E3

[R/S]

TMAX=2.847E3

[R/S]

$\angle$ =14.69E0

User Instructions

				SIZE: 016
STEP	INSTRUCTIONS	INPUT	FUNCTION	DISPLAY
1	Load program and set USER mode.		[USER]	
2	For Mohr's circle go to step 9.			
3	Initialize for rosetta strain gage data.		[XEQ] ROSETTA	RECT? Y/N
4	Choose configuration:			
	rectangular OR	Y	[R/S]	E?
	equiangular	N	[R/S]	E?
5	Input modulus of elasticity.	E	[R/S]	RATIO?
6	Input poisson's ratio.	ν	[R/S]	EA?
7	Input strains and calculate principal	ϵ_a	[R/S]	EB?
	strains and rotation angle.	ϵ_b	[R/S]	EC?
		ϵ_c	[R/S]	E=(ϵ_1)
			[R/S]	E=(ϵ_2)
			[R/S]	$\angle = (\theta)$
8	Calculate Mohr's circle data from strain			
	gage data.		[R/S]	S=(S_1)
			[R/S]	S=(S_2)
			[R/S]	TMAX=
			[R/S]	$\angle = (\theta)$
9	Initialize for Mohr's circle.		[XEQ] MOHR	SX?
10	Input stresses and calculate principal	s_x	[R/S]	SY?
	stresses and rotation angle.	s_y	[R/S]	TXY?
		τ_{xy}	[R/S]	S=(S_1)
			[R/S]	S=(S_2)
			[R/S]	TMAX=
			[R/S]	$\angle = (\theta)$
11	Optional: calculate stress at specific			
	angle.		[E]	$\angle$?

User Instructions

[illegible]

Program Listings

```
01*LBL "ROS
ETTA"
```

```
02 ENG 3
03 1
04 STO 10
05 "RECT? Y
/N"
```

```
06 AON
07 PROMPT
08 AOFF
09 ASTO X
10 "N"
11 ASTO Y
12 X=Y?
13 ISG 10
14*LBL 00
15 "E?"
16 PROMPT
17 STO 15
18 "RATIO?"
19 PROMPT
20 STO 09
21 "EA?"
22 PROMPT
23 STO 11
24 "EB?"
25 PROMPT
26 STO 12
27 "EC?"
28 PROMPT
29 STO 13
```

```
30 RCL 11
31 GTO IND
10
32*LBL 02
33 RCL 12
34 +
35*LBL 01
36 RCL 13
37 +
38 STO 06
39 0
40 GTO IND
10
41*LBL 02
42 RCL 13
43 RCL 11
44 -
45*LBL 01
46 RCL 12
47 RCL 13
48 -
```

Initialization

Calculate
 ϵ_1, ϵ_2

```
49 R-P
50 RCL 11
51 RCL 12
52 -
53 R-P
54 2
55 SQRT
56 *
57 STO 05
58 2
59 GTO IND
```

```
10
60*LBL 02
61 1
62 +
63*LBL 01
64 ST/ 05
65 ST/ 06
66 "E="
67 ASTO 00
68 XEQ 05
69 RCL 15
70 RCL 09
71 1
72 +
73 /
74 ST* 05
75 RCL 15
76 1
77 RCL 09
78 -
79 /
80 ST* 06
81 RCL 13
82 RCL 12
83 -
84 3
85 SQRT
86 GTO IND
```

```
10
87*LBL 01
88 2
89 RCL 12
90 *
91 RCL 11
92 -
93 RCL 13
94 -
95 RCL 11
96 RCL 13
97 GTO 04
98*LBL 02
```

Calculate $\tau_{\max}$

and $\frac{s_1 + s_2}{2}$

from strains

Program Listings

```

99 *
100 2
101 RCL 11
102 *
103 RCL 12
104 -
105 RCL 13
106 *LBL 04
107 -
108 XEQ 06
109 RDN
110 "Z="
111 ARCL X
112 AVIEW
113 STOP
114 GTO D
115 *LBL "MOH
R"
116 "SX?"
117 PROMPT
118 "SY?"
119 PROMPT
120 "TXY?"
121 PROMPT
122 R↑
123 R↑
124 STO 03
125 STO 06
126 R↑
127 ST+ 06
128 -
129 STO 04
130 2
131 ST/ 06
132 /
133 R↑
134 STO 02
135 ST+ 02
136 R-P
137 STO 05
138 RCL 02
139 CHS
140 RCL 04
141 XEQ 06
142 GTO D
143 *LBL 06
144 X=0?
145 /
146 ATAN
147 STO 02
148 2
149 /

```

Calculate $\tau_{\max}$
 and $\frac{s_1 + s_2}{2}$
 from $s_x, s_y,$
 τ_{xy}

```

150 0
151 RTN
152 *LBL D
153 "S="
154 ASTO 00 -
155 XEQ 05
156 RCL 05
157 "TMAX="
158 ARCL X
159 AVIEW
160 STOP
161 RCL 02
162 2
163 /
164 "Z="
165 ARCL X
166 AVIEW
167 STOP
168 *LBL E
169 "Z?"
170 PROMPT
171 ENTER↑
172 +
173 RCL 02
174 -
175 RCL 05
176 P-R
177 RCL 06
178 +
179 "S="
180 ARCL X
181 AVIEW
182 STOP
183 X<>Y
184 "T="
185 ARCL X
186 AVIEW
187 STOP
188 *LBL 05
189 RCL 06
190 RCL 05
191 +
192 ARCL X
193 AVIEW
194 STOP
195 RCL 06
196 RCL 05
197 -
198 CLA
199 ARCL 00
200 ARCL X
201 AVIEW

```

Output $S_1, S_2,$
 $\tau_{\max}$ and θ'

Calculate $\epsilon_1,$
 ϵ_2 , or S_1, S_2

Program Listings

202 STOP		51	
203 RTN			
204 .END.			
10		60	
20		70	
30		80	
40		90	
50		00	

DATA REGISTERS				STATUS			
00	Temp: ALPHA Storage	50		SIZE	016	TOT. REG.	61
	2θ			ENG	3	FIX	SCI
	Sx			DEG	X	RAD	GRAD
	Sx-Sy			USER MODE			
05	Tmax	55		ON ☒ OFF			
	(S ₁ + S ₂) / 2						
	v						
0	Control	60					
	ε _a						
	ε _b						
	ε _c						
5	E	65					
0		70					
5		75					
0		80					
5		85					
0		90					
5		95					

STRESS ON AN ELEMENT

PROGRAM REGISTERS NEEDED: 46

ROW 1 (1 - 2)



ROW 2 (3 - 6)



ROW 3 (7 - 15)



ROW 4 (15 - 20)



ROW 5 (21 - 27)



ROW 6 (27 - 36)



ROW 7 (37 - 48)



ROW 8 (49 - 60)



ROW 9 (61 - 68)



ROW 10 (68 - 78)



ROW 11 (79 - 89)



ROW 12 (90 - 101)



ROW 13 (102 - 110)



ROW 14 (111 - 115)



ROW 15 (115 - 120)



ROW 16 (120 - 128)



ROW 17 (129 - 139)



ROW 18 (140 - 148)



STRESS ON AN ELEMENT

ROW 19 (149 - 155)



ROW 20 (156 - 162)



ROW 21 (163 - 169)



ROW 22 (170 - 180)



ROW 23 (180 - 189)



ROW 24 (190 - 200)



ROW 25 (200 - 204)



EQUATIONS OF STATE

This program provides both ideal gas and Redlich-Kwong equations of state. Given four of the five state variables, the fifth is calculated. For the Redlich-Kwong solution, the critical pressure and temperature of the gas must be known. They are not needed for ideal gas solutions.

Values of the Universal Gas Constants

Value of R	Units of R	Units of P	Units of V	Units of T
8.314	N-m/g mole-K	N/m ²	m ³ /g mole	K
83.14	cm ³ -bar/g mole-K	bar	cm ³ /g mole	K
82.05	cm ³ -atm/g mole-K	atm	cm ³ /g mole	K
0.7302	atm-ft ³ /lb mole-°R	atm	ft ³ /lb mole	°R
10.73	psi-ft ³ /lb mole-°R	psi	ft ³ /lb mole	°R
1545	psf-ft ³ /lb mole-°R	psf	ft ³ /lb mole	°R

Critical Temperatures and Pressures

Substance	T _c , K	T _c , °R	P _c , ATM
Ammonia	405.6	730.1	112.5
Argon	151	272	48.0
Carbon dioxide	304.2	547.6	72.9
Carbon monoxide	133	239	34.5
Chlorine	417	751	76.1
Helium	5.3	9.5	2.26
Hydrogen	33.3	59.9	12.8
Nitrogen	126.2	227.2	33.5
Oxygen	154.8	278.6	50.1
Water	647.3	1165.1	218.2
Dichlorodifluoromethane	384.7	692.5	39.6
Dichlorofluoromethane	451.7	813.1	51.0
Ethane	305.5	549.9	48.2
Ethanol	516.3	929.3	63
Methanol	513.2	923.8	78.5
n-Butane	425.2	765.4	37.5
n-Hexane	507.9	914.2	29.9
n-Pentane	469.5	845.1	33.3
n-Octane	568.6	1023.5	24.6
Trichlorofluoromethane	471.2	848.1	43.2

Equations:

Ideal gas: $PV = nRT$

Redlich-Kwong:

$$P = \frac{nRT}{(V - b)} - \frac{a}{T^{1/2} V (V + b)}$$

$$a = 4.934 b nRT_c^{1.5}$$

$$b = 0.0867 \frac{nRT_c}{P_c}$$

where:

P is the absolute pressure;

V is the volume;

n is the number of moles present;

R is the universal gas constant;

T is the absolute temperature;

T_c is the critical temperature;

P_c is the critical pressure.

Remarks:

P, V, n and T must have units compatible with R.

At low temperatures or high pressures, the ideal gas law does not represent the behavior of real gases.

No equation of state is valid for all substances over an infinite range of conditions. The Redlich-Kwong equation gives moderate to good accuracy for a variety of substances over a wide range of conditions. Results should be used with caution and tempered by experience.

Solutions for V, n, R and T, using the Redlich-Kwong equation, require an iterative technique. Newton's method is employed using the ideal gas law to generate the initial guess. Iteration time is generally a function of the amount of deviation from ideal gas behavior. For extreme cases, the routine may fail to converge entirely, resulting in a "DATA ERROR".

Example 1:

0.63 g moles of air are enclosed in a 25,000 cm³ space at 1200 K. What is the pressure in bars? Assume an ideal gas.

Keystrokes:	Display:
[XEQ] [ALPHA] SIZE [ALPHA] 015	
[XEQ] [ALPHA] ID [ALPHA]	P?
0 [R/S]	V?
25,000 [R/S]	N?
0.63 [R/S]	R?
83.14 [R/S]	T?
1200 [R/S]	P=2.51

Example 2:

The specific volume of a gas in a container is 800 cm³/g mole. The temperature will reach 400K. What will the pressure be, according to the Redlich-Kwong relation?

$$P_c = 48.2 \text{ atm}$$

$$T_c = 305.5 \text{ K}$$

$$R = 82.05 \text{ cm}^3 - \text{atm/g mole-K}$$

Keystrokes:	Display:
[XEQ] [ALPHA] RK [ALPHA]	TC?
305.5 [R/S]	PC?
48.2 [R/S]	P?
0 [R/S]	V?
800 [R/S]	N?
1 [R/S]	R?
82.05 [R/S]	T?
400 [R/S]	P=36.27

Program Listings

<pre> 01*LBL "ID" 02 0 03 SF 00 04 GTO 00 05*LBL "RK" 06 1 07 CF 00 08 "TC?" 09 PROMPT 10 STO 13 11 "PC?" 12 PROMPT 13 STO 14 14*LBL 00 15 SF 02 16 CF 01 17 FIX 2 18 "P?" 19 PROMPT 20 5 21 XEQ 00 22 "V?" 23 PROMPT 24 6 25 XEQ 00 26 "N?" 27 PROMPT 28 7 29 XEQ 00 30 "R?" 31 PROMPT 32 8 33 XEQ 00 34 "T?" 35 PROMPT 36 CF 02 37 9 38*LBL 00 39 CF 01 40 STO 01 41 RDH 42 STO IND 01 43 X=0? 44 GTO 01 45 R↑ 46 STO 10 47 1 48 STO IND 01 49*LBL 01 </pre>	<pre> ----- Initialization </pre>	<pre> 50 FS? 02 51 RTN 52 GTO IND 10 53*LBL 05 54 "P=" 55 GTO 00 56*LBL 06 57 "V=" 58*LBL 00 59 RCL 07 60 RCL 08 61 * 62 RCL 09 63 * 64 RCL 05 65 RCL 06 66 * 67 / 68 STO IND 10 69 GTO 00 70*LBL 07 71 SF 01 72 "N=" 73 GTO 01 74*LBL 08 75 SF 01 76 "R=" 77 GTO 01 78*LBL 09 79 "T=" 80 SF 01 81*LBL 01 82 RCL 05 83 RCL 06 84 * 85 RCL 07 86 / 87 RCL 08 88 / 89 RCL 09 90 / 91 STO IND 10 92*LBL 00 93 FS? 00 94 GTO 10 95 XEQ 01 96 GTO 00 97*LBL 02 98 FS? 01 </pre>	<pre> ----- Calculate unknown ----- ----- If ideal, display ----- </pre>
--	-----------------------------------	--	---

Program Listings

99 XEQ 01		146 X↑2	
100♦LBL 00		147 /	
101 RCL 00		148 RCL 00	
102 RCL 09		149 RCL 09	
103 *	-----	150 *	
104 RCL 06	Calculate using	151 RCL 04	
105 RCL 12	Redlich-Kwong	152 X↑2	
106 -	equations	153 /	
107 STO 04		154 -	
108 /		155 RTN	-----
109 RCL 11		156♦LBL 09	$\frac{\partial P}{\partial T}$
110 RCL 09		157 RCL 00	
111 SORT		158 RCL 04	
112 /		159 /	
113 STO 02		160 RCL 02	
114 RCL 06		161 2	
115 /		162 /	
116 LASTX		163 RCL 09	
117 RCL 12		164 /	
118 +		165 RCL 06	
119 STO 03		166 /	
120 /		167 RCL 03	
121 -		168 /	
122 RCL 05		169 +	
123 -		170 RTN	-----
124 XEQ IND		171♦LBL 07	$\frac{\partial P}{\partial n}$ or $\frac{\partial P}{\partial R}$
10		172♦LBL 08	
125 /		173 RCL 09	
126 ST- IND		174 RCL 06	
10		175 *	
127 RCL IND		176 RCL 04	
10		177 X↑2	
128 /		178 /	
129 ABS		179 RCL 06	
130 1 E-4		180 ENTER↑	
131 X<=Y?		181 +	
132 GTO 02		182 RCL 12	
133 RCL IND		183 +	
10		184 RCL 00	
134 GTO 10	-----	185 /	
135♦LBL 06	$\frac{\partial P}{\partial V}$	186 RCL 06	
136 RCL 06		187 /	
137 ENTER↑		188 RCL 03	
138 +		189 X↑2	
139 RCL 12		190 /	
140 +		191 RCL 02	
141 RCL 02		192 *	
142 *		193 -	
143 RCL 03		194 RCL 00	
144 RCL 06		195 *	
145 *		196 RCL IND	
		10	

[illegible]

[illegible]

EQUATIONS OF STATE

PROGRAM REGISTERS NEEDED: 47

ROW 1 (1 - 5)



ROW 2 (5 - 10)



ROW 3 (11 - 17)



ROW 4 (18 - 24)



ROW 5 (25 - 30)



ROW 6 (30 - 37)



ROW 7 (38 - 47)



ROW 8 (48 - 55)



ROW 9 (55 - 65)



ROW 10 (66 - 73)



ROW 11 (73 - 79)



ROW 12 (80 - 91)



ROW 13 (91 - 98)



ROW 14 (98 - 108)



ROW 15 (109 - 121)



ROW 16 (122 - 130)



ROW 17 (130 - 138)



ROW 18 (139 - 151)



EQUATIONS OF STATE

ROW 19 (152 - 164)



ROW 20 (165 - 177)



ROW 21 (178 - 190)



ROW 22 (191 - 202)



ROW 23 (203 - 210)



ROW 24 (211 - 222)



ROW 25 (222 - 230)



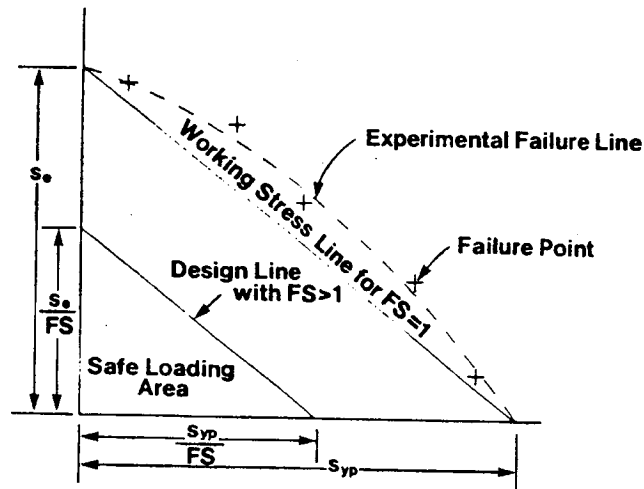
ROW 26 (230 - 230)



SODERBERG'S EQUATION FOR FATIGUE

This program will calculate the seventh variable from the other six values in Soderberg's equation. It is useful in sizing parts for cyclic loading, calculating factors of safety, choosing materials based on size constraints and estimating the fatigue resistance of available parts. Soderberg's equation is graphically represented in figure 1.

Equations:



Working Stress Diagram
Figure 1

$$\frac{S_{yp}}{FS} = \frac{S_{max} + S_{min}}{2} + K \left(\frac{S_{yp}}{S_e} \right) \left(\frac{S_{max} - S_{min}}{2} \right)$$

$$\frac{S_{max} + S_{min}}{2} = \frac{P_{max} + P_{min}}{2A}$$

$$\frac{S_{max} - S_{min}}{2} = \frac{P_{max} - P_{min}}{2A}$$

where:

S_{yp} is the yield point stress of the material;

S_e is the material endurance stress from reversed bending tests;

K is the stress concentration factor for the part;

FS is the factor of safety ($FS \geq 1.00$)

S_{max} is the maximum stress;

S_{min} is the minimum stress;

P_{max} is the maximum load;

P_{min} is the minimum load;

A is the cross sectional area of the part over which the force is evenly distributed.

Reference:

Spots, M. F., Design of Machine Elements; Prentice-Hall, Inc., 1971.

Baumeister, T., Marks Standard Handbook for Mechanical Engineers; McGraw-Hill Book Company, 1967.

Remarks:

If S_{max} and S_{min} are to be input or calculated instead of P_{max} or P_{min} , simply use 1.00 for the value of area.

This implementation of Soderberg's equation is for ductile materials only.

Values of stress concentration factors and material endurance limits may be found in the referenced sources.

In the presence of corrosive media, or for rough surfaces, fatigue effects may be much more significant than predicted by this program.

Example:

What is the maximum permissible cyclic load for a part if the minimum load is 2000 pounds and the area is 0.5 square inches?

$$S_{yp} = 70000 \text{ psi}$$

$$S_e = 25000 \text{ psi}$$

$$K = 1.25$$

$$FS = 2.0$$

Keystrokes:

Display:

[XEQ] [ALPHA] SIZE [ALPHA] 010

[XEQ] [ALPHA] SEF [ALPHA]

70000 [R/S]

25000 [R/S]

0.5 [R/S]

1.25 [R/S]

[R/S]

2000 [R/S]

2.0 [R/S]

[XEQ] [ALPHA] PMAX [ALPHA]

SYP?

SE?

A?

K?

PMAX?

PMIN?

FS?

PMAX=8.889E3

If P_{max} is changed to 10000 pounds, what will S_e have to be?

10000 [STO] 03

[XEQ] [ALPHA] SE [ALPHA]

SE=30.43E3

User Instructions

				SIZE: 010
STEP	INSTRUCTIONS	INPUT	FUNCTION	DISPLAY
1	Load program			
2	Begin execution		[XEQ] SEF	SYP?
3	Input values	Syp	[R/S]	SE?
	(skip unknown by pressing [R/S])	Se	[R/S]	A?
		Area*	[R/S]	K?
		K	[R/S]	PMAX? (Smax?)*
		$P_{max}(S_{max})^*$	[R/S]	PMIN? (Smin?)*
		$P_{min}(S_{min})^*$	[R/S]	FS?
		FS	[R/S]	
4	Calculate unknown			
	Syp		[XEQ] SYP	SYP=
	Se		[XEQ] SE	SE=
	Area		[XEQ] A	A=
	K		[XEQ] K	K=
	P_{max}		[XEQ] PMAX	PMAX=
	P_{min}		[XEQ] PMIN	PMIN=
	S_{max}		[XEQ] SMAX	SMAX=
	S_{min}		[XEQ] SMIN	SMIN=
	FS		[XEQ] FS	FS=
5	To change a value (then go to step 4)			
	Syp		[STO] 08	
	Se		[STO] 09	
	A		[STO] 01	
	K		[STO] 02	
	$P_{max}(S_{max})$		[STO] 03	
	$P_{min}(S_{min})$		[STO] 04	
	FS		[STO] 05	

*If S_{max} and S_{min} are to be input or calculated, use 1.00 for the value of area.

Program Listings

01*LBL "SEF"		51 RCL 08	
02 ENG 3		52 *	
03 "SYP?"		53 RCL 02	
04 PROMPT		54 *	
05 STO 08	Initialization	55 XEQ 01	
06 "SE?"		56 CHS	
07 PROMPT		57 RCL 08	
08 STO 09		58 RCL 05	
09 "A?"		59 /	
10 PROMPT		60 +	
11 STO 01		61 /	
12 1		62 STO 09	
13 -		63 "SE="	
14 CF 00		64 GT0 05	
15 X=0?		65*LBL "SMA	S _{max}
16 SF 00		X"	
17 "K?"		66*LBL "PMA	P _{max}
18 PROMPT		X"	
19 STO 02		67 RCL 01	
20 "PMA?"		68 ENTER↑	
21 FS? 00		69 +	
22 "SMA?"		70 RCL 08	
23 PROMPT		71 *	
24 STO 03		72 RCL 05	
25 "PMA?"		73 /	
26 FS? 00		74 RCL 02	
27 "SMA?"		75 RCL 08	
28 PROMPT		76 *	
29 STO 04		77 RCL 09	
30 "FS?"		78 /	
31 PROMPT		79 1	
32 STO 05		80 -	
33 STOP		81 RCL 04	
34*LBL "SYP"		82 *	
35 XEQ 01	S _{yp}	83 +	
36 XEQ 02		84 RCL 02	
37 RCL 02		85 RCL 08	
38 *		86 *	
39 RCL 09		87 RCL 09	
40 /		88 /	
41 CHS		89 1	
42 RCL 05		90 +	
43 1/X		91 /	
44 +		92 STO 03	
45 /		93 "PMA="	
46 STO 08		94 FS? 00	
47 "SYP="		95 "SMA="	
48 GT0 05		96 GT0 05	
49*LBL "SE"		97*LBL A	Area
50 XEQ 02	S _e	98 1	
		99 STO 01	
		100 XEQ 01	

Program Listings

```

101 XEQ 02
102 RCL 02
103 *
104 RCL 08
105 *
106 RCL 09
107 /
108 +
109 RCL 08
110 /
111 RCL 05
112 *
113 STO 01
114 "A="
115 GTO 05
116 *LBL "K"
117 RCL 08
118 RCL 05
119 /
120 XEQ 01
121 -
122 XEQ 02
123 RCL 08
124 *
125 RCL 09
126 /
127 /
128 STO 02
129 "K="
130 GTO 05
131 *LBL "SMI
N"
132 *LBL "PMI
N"
133 RCL 01
134 ENTER↑
135 +
136 RCL 08
137 *
138 RCL 05
139 /
140 RCL 02
141 RCL 08
142 *
143 RCL 09
144 /
145 1
146 +
147 RCL 03
148 *
149 -

```

K

Smin
Pmin

```

150 1
151 RCL 02
152 RCL 08
153 *
154 RCL 09
155 /
156 -
157 /
158 STO 04
159 "PMIN="
160 FS? 00
161 "SMIN="
162 GTO 05
163 *LBL "FS"
164 XEQ 01
165 XEQ 02
166 RCL 02
167 *
168 RCL 08
169 *
170 RCL 09
171 /
172 +
173 RCL 08
174 /
175 1/X
176 STO 05
177 "FS="
178 GTO 05
179 *LBL 02
180 RCL 03
181 RCL 04
182 CHS
183 GTO 00
184 *LBL 01
185 RCL 03
186 RCL 04
187 *LBL 00
188 +
189 RCL 01
190 /
191 2
192 /
193 RTN
194 *LBL 05
195 ARCL X
196 AVIEW
197 STOP
198 .END.

```

FS

 $Q = P_{\max} - P_{\min}$
 $Q = P_{\max} - P_{\min}$
 $\frac{Q}{2A}$

Display

DATA REGISTERS				STATUS				
00	A	50		SIZE	010	TOT. REG.	61	USER MODE
	K			ENG	3	FIX	SCI	ON OFF X
	P _{max} (S _{max})			DEG		RAD	GRAD	
	P _{min} (S _{min})							
	FS							
05		55		FLAGS				
				#	INIT S/C	SET INDICATES		CLEAR INDICATES
				00		S _{max} , S _{min}		P _{max} , P _{min}
	S _{yp}							
	S _e							
10		60						
15		65						
20		70						
25		75						
30		80						
35		85						
				ASSIGNMENTS				
				FUNCTION		KEY	FUNCTION	
40		90						
45		95						

SODERBERG'S EQUATION FOR
FATIGUE
PROGRAM REGISTERS NEEDED: 52

ROW 1 (1 - 3)



ROW 2 (3 - 10)



ROW 3 (11 - 19)



ROW 4 (20 - 22)



ROW 5 (22 - 27)



ROW 6 (27 - 33)



ROW 7 (34 - 36)



ROW 8 (37 - 47)



ROW 9 (47 - 50)



ROW 10 (51 - 61)



ROW 11 (62 - 65)



ROW 12 (65 - 69)



ROW 13 (70 - 82)



ROW 14 (83 - 93)



ROW 15 (93 - 96)



ROW 16 (97 - 104)



ROW 17 (105 - 115)



ROW 18 (115 - 121)



SODERBERG'S EQUATION FOR FATIGUE

ROW 19 (122 - 130)



ROW 20 (130 - 132)



ROW 21 (132 - 141)



ROW 22 (142 - 154)



ROW 23 (155 - 161)



ROW 24 (161 - 163)



ROW 25 (164 - 172)



ROW 26 (173 - 181)



ROW 27 (182 - 193)



ROW 28 (194 - 198)



SPRING CONSTANT

This program calculates the value of any variable (X_1 , F_1 , X_2 , F_2 , k) given the other four in the spring equation. It may be used to solve any general linear equation of the form $y - y_0 = m(x - x_0)$. It is also useful for linear interpolation in tables. Computed values are automatically stored to provide an interchangeable solution.

X_1 = Spring length

F_1 = Force required to retain spring at length X_1

X_2 = Spring length

F_2 = Force required to retain spring at length X_2

k = Spring constant

Equations:

$$k = \frac{F_1 - F_2}{X_2 - X_1}$$

$$F_1 = F_2 + k(X_2 - X_1)$$

$$F_2 = F_1 + k(X_1 - X_2)$$

$$X_1 = \frac{F_2 - F_1}{k} + X_2$$

$$X_2 = \frac{F_1 - F_2}{k} + X_1$$

Example 1:

A compression spring is 4.0 inches long under no compressive forces. A force of 270 lbf compresses the spring to a length of 2.8 inches. The solid height of the spring is 2.5 inches. Find the spring constant and the force required to fully compress the spring.

Keystrokes:

Display:

[XEQ] [ALPHA] SIZE [ALPHA] 005

[XEQ] [ALPHA] SP [ALPHA]

X1?

4 [R/S]

F1?

0 [R/S]

X2?

2.8 [R/S]

F2?

270 [R/S]

K?

[R/S]

[XEQ] [ALPHA] K [ALPHA]

K=225.00

2.5 [STO] 02

[XEQ] [ALPHA] F2 [ALPHA]

F2=377.50

Example 2:

10.00%	10.25%	?
215.93	222.60	219.97

From the table shown, find the linear approximation to a value of 219.9749.

Keystrokes:

Display:

[XEQ] [ALPHA] SP [ALPHA]

X1?

10 [R/S]

F1?

215.93 [R/S]

X2?

10.25 [R/S]

F2?

222.60 [R/S]

K?

[R/S]

[XEQ] [ALPHA] K [ALPHA]

K=-26.68

219.97 [STO] 03

[XEQ] [ALPHA] X2 [ALPHA]

X2=10.15

[illegible]

Program Listings

01*LBL "SP"		52 "F2="	
02 FIX 2	-----	53 GTO 05	k -----
03*LBL A	Initialization	54*LBL "K"	
04 "X1?"		55 RCL 01	
05 PROMPT		56 RCL 03	
06 STO 00		57 -	
07*LBL B		58 RCL 02	
08 "F1?"		59 RCL 00	
09 PROMPT		60 -	
10 STO 01		61 /	
11*LBL C		62 STO 04	-----
12 "X2?"		63 "K="	Display
13 PROMPT		64*LBL 05	
14 STO 02		65 ARCL X	
15*LBL D		66 AVIEW	-----
16 "F2?"		67 STOP	$\frac{F_2 - F_1}{k}$
17 PROMPT		68*LBL 01	
18 STO 03		69 RCL 03	
19*LBL E		70 RCL 01	
20 "K?"		71 -	
21 PROMPT		72 RCL 04	
22 STO 04		73 /	
23 STOP	-----	74 RTN	-----
24*LBL "X1"	X ₁	75*LBL 00	k(X ₂ - X ₁)
25 XEQ 01		76 RCL 02	
26 RCL 02		77 RCL 00	
27 +		78 -	
28 STO 00		79 RCL 04	
29 "X1="		80 *	
30 GTO 05	-----	81 RTN	
31*LBL "F1"	F ₁	82 .END.	
32 XEQ 00			
33 RCL 03			
34 +			
35 STO 01			
36 "F1="			
37 GTO 05	-----		
38*LBL "X2"	X ₂		
39 XEQ 01			
40 CHS			
41 RCL 00			
42 +		90	
43 STO 02			
44 "X2="			
45 GTO 05	-----		
46*LBL "F2"	F ₂		
47 XEQ 00			
48 CHS			
49 RCL 01			
50 +			
51 STO 03		00	

[illegible]

SPRING CONSTANT

PROGRAM REGISTERS NEEDED: 23

ROW 1 (1 - 4)



ROW 2 (4 - 11)



ROW 3 (12 - 17)



ROW 4 (18 - 24)



ROW 5 (24 - 30)



ROW 6 (30 - 35)



ROW 7 (36 - 39)



ROW 8 (39 - 46)



ROW 9 (46 - 52)



ROW 10 (52 - 57)



ROW 11 (58 - 67)



ROW 12 (68 - 80)

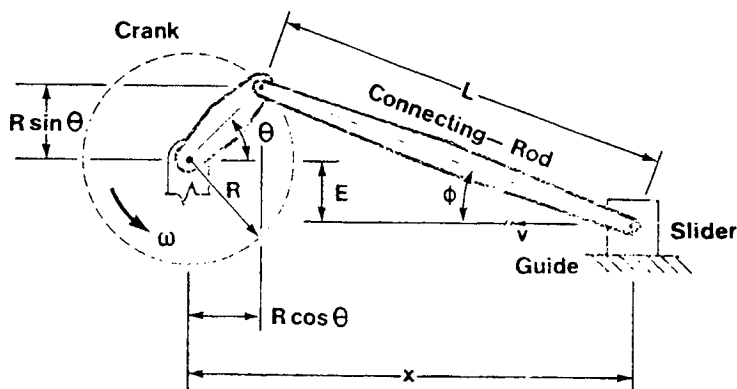


ROW 13 (81 - 82)



PROGRESSION OF A SLIDER CRANK

In a slider crank mechanism (e.g., the piston, wrist pin and connecting rod in an internal combustion engine), for given crank radius, connecting rod length, slider offset, crankshaft speed (RPM) and crank position, this program calculates the following: the displacement, velocity, and acceleration of the slider; the connecting rod angle, velocity and acceleration; the maximum and minimum displacements, and the maximum and minimum angular values for ϕ .



Equations:

$$\omega = \frac{\pi N}{30}$$

$$x = R \cos \theta + L \cos \phi$$

$$x_{\max} = (R + L) \cos \left[\sin^{-1} \left(\frac{E}{R + L} \right) \right]$$

$$x_{\min} = (L - R) \cos \left[\sin^{-1} \left(\frac{E}{L - R} \right) \right]$$

$$\Delta x = x_{\max} - x_{\min}$$

$$\phi = \sin^{-1} \left(\frac{E + R \sin \theta}{L} \right)$$

$$v = \frac{dx}{dt} = R\omega \left(\frac{-\sin (\theta + \phi)}{\cos \phi} \right)$$

$$a = \frac{d^2x}{dt^2} = R\omega^2 \left(\frac{-\cos(\theta + \phi)}{\cos \phi} - \frac{R \cos^2 \theta}{L \cos^3 \phi} \right)$$

$$\phi_{\max} = \sin^{-1} \left(\frac{E + R}{L} \right)$$

$$\phi_{\min} = \sin^{-1} \left(\frac{E - R}{L} \right)$$

$$\Delta\phi = \phi_{\max} - \phi_{\min}$$

$$\dot{\phi} = \frac{d\phi}{dt} = \omega \frac{R \cos \theta}{L \cos \phi}$$

$$\ddot{\phi} = \frac{d^2\phi}{dt^2} = \omega^2 \left[\left(\frac{d\phi}{d\theta} \right)^2 \tan \phi - \frac{R \sin \theta}{L \cos \phi} \right]$$

where:

N is crankshaft speed in RPM;

E is slider offset;

L is connecting rod length;

R is crank radius;

ω is crank angular velocity in radians/sec;

θ is crank angle;

x is slider displacement;

$x_{\max}$ is maximum slider displacement

$x_{\min}$ is minimum slider displacement;

Δx is stroke;

v is slider velocity;

a is slider acceleration;

ϕ is connecting rod angular displacement;

$\phi_{\max}$ is maximum connecting rod angular displacement;

$\phi_{\min}$ is minimum connecting rod angular displacement;

$\Delta\phi$ is total angular throw of connecting rod;

$\dot{\phi}$ is angular velocity of connecting rod;

$\ddot{\phi}$ is angular acceleration of connecting rod.

References:

H. A. Rothbart, Mechanical Design and Systems Handbook; McGraw-Hill, 1964.

V. M. Faires, Kinematics, McGraw-Hill; 1959.

Example 1:

For an in-line slider crank mechanism ($E = 0$), turning at 4800 RPM, having a crank radius of 2.0 inches and connecting rod length of 7.0 inches, find:

- (1) $x_{\max}$, $x_{\min}$ and $\phi_{\max}$, $\phi_{\min}$
- (2) x , v , and a of the wrist pin in the slider
- (3) $\dot{\phi}$, $\ddot{\phi}$, and ϕ of the connecting rod for $\theta = 0^\circ, 15^\circ, 45^\circ, 90^\circ, 135^\circ, 180^\circ, 225^\circ$

The table below was produced by the following keystrokes:

θ°	$x(\text{in})$	ϕ°	$v(\text{in/sec})$	$\dot{\phi}(\text{rad/sec})$	$a(\text{in/sec}^2)$	$\ddot{\phi}(\text{rad/sec}^2)$
0	9.00	0.00	0.00	143.62	-649701.96	0.00
15	8.91	4.24	-332.20	139.10	-614226.44	-17300.41
45	8.27	11.66	-857.50	103.69	-360454.40	-49902.29
90	6.71	16.60	-1005.31	0.00	150658.43	-75329.22
135	5.44	11.66	-564.22	-103.69	354181.29	-49902.29
180	5.00	0.00	0.00	-143.62	360945.53	0.00
225	5.44	-11.66	564.22	-103.69	354181.29	49902.29

Keystrokes:

[USER]
 [XEQ] [ALPHA] SIZE [ALPHA] 016
 [XEQ] [ALPHA] PSC [ALPHA]
 4800 [R/S]
 0 [R/S]
 7 [R/S]
 2 [R/S]
 [A]
 [R/S]
 [B]
 [R/S]
 [C]
 0 [R/S]

Display:

(set USER mode)
 N?
 E?
 L?
 R?
 W=502.65
 X=9.00 ($X_{\max}$)
 X=5.00 ($X_{\min}$)
 L=16.60 (max)
 L=-16.60 (min)
 L?
 X=9.00

Keystrokes:

[R/S]
 [D]
 [R/S]
 [E]
 [R/S]
 [C]
 15 [R/S]
 [R/S]
 [D]
 [R/S]
 ;
 [C]
 225 [R/S]
 [R/S]
 [D]
 [R/S]
 [E]
 [R/S]

Display:

$\Delta = 0.00$
 $V = 0.00$
 $d\Delta = 143.62$
 $A = -649,701.96$
 $d^2\Delta = 0.00$
 $\Delta?$
 $X = 8.91$
 $\Delta = 4.24$
 $V = -332.20$
 $d\Delta = 139.10$
 ;
 $\Delta?$
 $X = 5.44$
 $\Delta = -11.66$
 $V = 564.22$
 $d\Delta = -103.69$
 $A = 354,181.29$
 $d^2\Delta = 49,902.29$

User Instructions

				SIZE: 016
STEP	INSTRUCTIONS	INPUT	FUNCTION	DISPLAY
1	Load program (USER mode)		[USER]	
2	Begin execution and input:		[XEQ] PSC	N?
	Key in crankshaft speed in RPM	N	[R/S]	E?
	Key in slider offset	E	[R/S]	L?
	Key in connecting rod length	L	[R/S]	R?
	Key in crank radius	R	[R/S]	W=(ω)
3	For $X_{\max}$, $X_{\min}$		[A]	X=($X_{\max}$)
			[R/S]	X=($X_{\min}$)
4	For $\phi_{\max}$, $\phi_{\min}$		[B]	$\angle=(\theta_{\max})$
			[R/S]	$\angle=(\theta_{\min})$
5	For X, ϕ , V, $\dot{\phi}$, a, $\ddot{\phi}$:		[C]	$\angle?$
	Key in θ	θ	[R/S]	X=
			[R/S]	$\angle=(\phi)$
	then		[D]	V=
			[R/S]	d $\angle=(\dot{\phi})$
	then		[E]	A=
			[R/S]	d $\angle^2=(\ddot{\phi})$
6	For automatic display:		[F]	$\angle^2?$
	Key in ending θ	θ_2	[R/S]	$\angle^1?$
	Key in beginning θ	θ_1	[R/S]	N?
	Key in the number of sectors you wish	n	[R/S]	$\angle=(\theta)$
	to divide the interval into		[R/S]	X=
			[R/S]	$\angle=(\phi)$
			[R/S]	V=
			[R/S]	d $\angle=(\dot{\phi})$
			[R/S]	A=
	(continue pressing [R/S] until done.)		[R/S]	d $\angle^2=(\ddot{\phi})$

Program Listings

01♦LBL "PSC"		51 *	
02 FIX 2	-----	52 RCL 00	
03 "N?"	Initialization	53 COS	
04 PROMPT		54 STO 03	
05 STO 11		55 RCL 14	
06 "E?"		56 *	
07 PROMPT		57 +	
08 STO 12		58 STO 01	
09 "L?"		59 "X="	
10 PROMPT		60 XEQ 05	
11 STO 13		61 RCL 00	
12 "R?"		62 XEQ 02	
13 PROMPT	-----	63 "Z="	
14 STO 14	Calculate ω	64 GTO 05	-----
15 RCL 11		65♦LBL D	Calculate V + $\emptyset$
16 PI		66 RCL 00	
17 *		67 RCL 02	
18 30		68 +	
19 /		69 SIN	
20 STO 15		70 CHS	
21 "W="		71 RCL 04	
22 GTO 05	-----	72 /	
23♦LBL A	Xmax + Xmin	73 RCL 15	
24 CF 01		74 *	
25 XEQ 00		75 RCL 14	
26 SF 01		76 *	
27 STO 04		77 "V="	
28 XEQ 00		78 XEQ 05	
29 STOP	-----	79 RCL 04	
30♦LBL B	$\emptyset_{\max} + \emptyset_{\min}$	80 RCL 13	
31 1		81 *	
32 ASIN		82 RCL 14	
33 XEQ 02		83 /	
34 STO 04		84 1/X	
35 "Z="		85 STO 05	
36 XEQ 05		86 RCL 03	
37 -1		87 *	
38 ASIN		88 RCL 15	
39 XEQ 02		89 *	
40 "Z="		90 "dZ="	
41 GTO 05	-----	91 GTO 05	-----
42♦LBL C	Calculate X + $\emptyset$	92♦LBL E	Calculate A + $\emptyset$
43 "Z?"		93 RCL 03	
44 PROMPT		94 X↑2	
45 STO 00		95 RCL 14	
46♦LBL 07		96 *	
47 XEQ 02		97 RCL 13	
48 COS		98 /	
49 STO 04		99 RCL 04	
50 RCL 13		100 3	
		101 Y↑X	
		102 /	

Program Listings

```

103 RCL 00
104 RCL 02
105 +
106 COS
107 RCL 04
108 /
109 +
110 CHS
111 RCL 14
112 *
113 RCL 15
114 X↑2
115 *
116 "A="
117 XEQ 05
118 RCL 02
119 TAN
120 RCL 05
121 RCL 03
122 *
123 X↑2
124 *
125 RCL 00
126 SIN
127 RCL 05
128 *
129 -
130 RCL 15
131 X↑2
132 *
133 "d↑2Δ="
134 GTO 05
135♦LBL F
136 "Δ2?"
137 PROMPT
138 STO 08
139 "Δ1?"
140 PROMPT
141 STO 07
142 "N?"
143 PROMPT
144 STO 09
145 STO 10
146 ISG 10
147 RDN
148 RCL 07
149 RCL 08
150 -
151 CHS
152 RCL 09
153 /

```

Automatic
looping

```

154 STO 06
155♦LBL 04
156 RCL 07
157 "Δ="
158 ARCL X
159 AVIEW
160 STOP
161 STO 00
162 CF 01
163 XEQ 07
164 XEQ D
165 XEQ E
166 SF 01
167 DSE 10
168 GTO 03
169 RTN
170♦LBL 03
171 RCL 06
172 ST+ 07
173 GTO 04
174 RTN
175♦LBL 05
176 ARCL X
177 AVIEW
178 STOP
179 RTN
180♦LBL 00
181 RCL 12
182 RCL 13
183 RCL 14
184 FS? 01
185 CHS
186 +
187 /
188 ASIN
189 COS
190 RCL 13
191 RCL 14
192 FS? 01
193 CHS
194 +
195 *
196 "X="
197 XEQ 05
198 RTN
199♦LBL 02
200 SIN
201 RCL 14
202 *
203 RCL 12
204 +

```

display

Calculate Xmax +
Xmin

[illegible]

[illegible]

PROGRESSION OF A SLIDER CRANK

PROGRAM REGISTERS NEEDED: 46

ROW 1 (1 - 4)



ROW 2 (5 - 12)



ROW 3 (12 - 21)



ROW 4 (22 - 28)



ROW 5 (28 - 35)



ROW 6 (35 - 40)



ROW 7 (41 - 47)



ROW 8 (48 - 59)



ROW 9 (59 - 64)



ROW 10 (65 - 76)



ROW 11 (77 - 85)



ROW 12 (86 - 93)



ROW 13 (94 - 106)



ROW 14 (107 - 117)



ROW 15 (117 - 128)



ROW 16 (129 - 135)



ROW 17 (135 - 141)



ROW 18 (142 - 151)



PROGRESSION OF A SLIDER CRANK

ROW 19 (152 - 161)



ROW 20 (162 - 166)



ROW 21 (167 - 175)



ROW 22 (176 - 186)



ROW 23 (187 - 196)



ROW 24 (197 - 207)



ROW 25 (208 - 210)



FREE VIBRATIONS

This program provides an exact solution to the differential equation for a damped oscillator vibrating freely: $m\ddot{x} + c\dot{x} + kx = 0$.

The user inputs the mass m , spring constant k , and damping constant c .
The output will be:

1. ω for an underdamped system, i.e. $c < c_{\text{crit}}$ • c_{crit} is calculated by pressing [B].
2. 0 for a critically damped system, i.e. $c = c_{\text{crit}}$.
3. -1 for an overdamped system, i.e. $c > c_{\text{crit}}$.

The initial conditions are the displacement and velocity at time zero (x_0 and $\dot{x}_0$).

Equations:

$$c_{\text{crit}} = 2\sqrt{km}$$

$$\omega = \sqrt{\frac{k}{m} - \left(\frac{c}{2m}\right)^2}$$

$$\ddot{x} = -(c\dot{x} + kx)/m$$

Underdamping

$$(c^2 - 4km < 0)$$

$$x(t) = Re^{-\frac{c}{2m}t} \cos(\omega t - \delta)$$

$$\dot{x}(t) = -R\omega e^{-\frac{c}{2m}t} \sin(\omega t - \delta) - \frac{c}{2m} Re^{-\frac{c}{2m}t} \cos(\omega t - \delta)$$

where:

$$R \cos \delta = x_0$$

$$R \sin \delta = \frac{1}{\omega} \left[\dot{x}_0 + \frac{c}{2m} x_0 \right]$$

Critical damping

$$(c = c_{\text{crit}}, \text{ or } c^2 = 4km)$$

$$x(t) = (A_{\text{cr}} + B_{\text{cr}}t) e^{-\frac{c}{2m}t}$$

$$\dot{x}(t) = \left[B_{\text{cr}} - \frac{c}{2m} (A_{\text{cr}} + B_{\text{cr}}t) \right] e^{-\frac{c}{2m}t}$$

where:

$$A_{\text{cr}} = x_0$$

$$B_{\text{cr}} = \dot{x}_0 + \frac{c}{2m} x_0$$

Overdamping

$$(c^2 - 4km > 0)$$

$$\dot{x}(t) = A_{\text{ov}} e^{r_1 t} + B_{\text{ov}} e^{r_2 t}$$

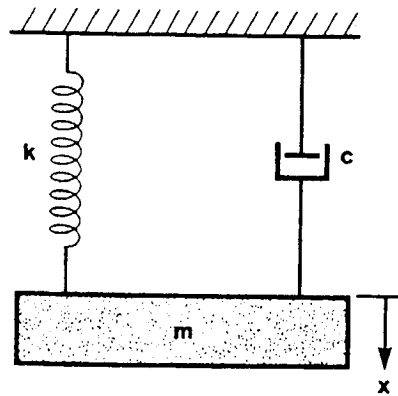
$$x(t) = A_{\text{ov}} r_1 e^{r_1 t} + B_{\text{ov}} r_2 e^{r_2 t}$$

where:

$$r_1, r_2 = -\frac{c}{2m} \pm \sqrt{\left(\frac{c}{2m}\right)^2 - \frac{k}{m}}$$

$$A_{\text{ov}} = x_0 - B_{\text{ov}}$$

$$B_{\text{ov}} = \frac{\dot{x}_0 - r_1 x_0}{r_2 - r_1}$$



Reference:

Boyce, W. E. and DiPrima, R. C., Elementary Differential Equations; John Wiley and Sons, 1969.

Remarks:

For overdamping, ω has no meaning and is, in fact, an imaginary number.

For $c = c_{\text{crit}}$, $\omega = 0$.

This program sets the angular mode of the calculator to radians. Erroneous answers will occur if the degrees mode is inadvertently set.

Example:

A mass of 20 g stretches a spiral spring 10 cm. The mass is pulled down an additional 4 cm, held, and then released. Find the mass displacement and velocity at 0.1 second intervals up to 1 second for $c = 50$ dyne-sec/cm.

$$k = \frac{F}{x} = \frac{mg}{x} = \frac{20g (980 \text{ cm/s}^2)}{10 \text{ cm}} = \frac{20 \times 980}{10} \text{ dyne/cm}$$

Keystrokes:

```

[USER]
[XEQ] [ALPHA] SIZE [ALPHA] 016
[XEQ] [ALPHA] VIB [ALPHA]
20 [R/S]
50 [R/S]
20 [ENTER↑] 980 [X] 10 [÷] [R/S]
[B]
[C]
4 [R/S]
0 [R/S]
0 [R/S]
[R/S]
[R/S]
[D]
0.1 [R/S]
[R/S]
[R/S]
[D]
:
(Repeat for t = .2, .3 ... 1.0)
:
1 [R/S]
[R/S]
[R/S]

```

Display:

```

M?
C?
K?
W=9.820
C=395.980
X?
dX?
T?
X=4.000
dX=-1.000E-9
d2X=-392.000
T?
X=2.334
dX=-29.296
d2X=-155.493
T?
:
:
X=-1.114
dX=4.406
d2X=98.132

```


Program Listings

01 *LBL "VIB"		51 PROMPT	
02 RAD	Initialization	52 STO 01	
03 FIX 3		53 *LBL D	
04 "M?"		54 "T?"	----- Calculate x(t), ẋ(t) and ẍ(t)
05 PROMPT		55 PROMPT	
06 STO 02		56 STO 07	
07 "C?"		57 RCL 14	
08 PROMPT		58 *	
09 STO 03		59 CHS	
10 "K?"		60 E↑X	
11 PROMPT		61 STO 13	
12 STO 04	----- Calculate	62 RCL 05	
13 RCL 02	$\left[\frac{k}{m} - \left(\frac{c}{2m} \right)^2 \right]^{\frac{1}{2}}$	63 X<0?	
14 /		64 GTO c	
15 STO 15		65 X=0?	----- C > C _{cr}
16 RCL 03		66 GTO b	
17 RCL 02		67 *LBL a	
18 2		68 RCL 14	
19 *		69 RCL 00	
20 /		70 *	
21 STO 14		71 RCL 01	
22 X↑2		72 +	
23 -		73 RCL 05	
24 RND		74 /	
25 X<0?		75 RCL 00	
26 GTO 01		76 R-P	
27 X=0?		77 STO 11	
28 STOP		78 RDN	
29 SQRT		79 STO 12	
30 STO 05		80 RCL 05	
31 "W="		81 RCL 07	
32 GTO 05		82 *	
33 *LBL 01		83 -	
34 STO 05		84 CHS	
35 -1		85 STO 09	
36 STOP	----- Calculate C _{cr}	86 COS	
37 *LBL B		87 RCL 13	
38 RCL 04		88 *	
39 RCL 02		89 RCL 11	
40 *		90 *	
41 SQRT		91 STO 02	
42 2		92 "X="	
43 *		93 XEQ 05	
44 "C="		94 RCL 14	
45 GTO 05	----- Initial conditions	95 *	
46 *LBL C		96 RCL 09	
47 "X?"		97 SIN	
48 PROMPT		98 RCL 13	
49 STO 00		99 *	
50 "dx?"		100 RCL 05	
		101 *	
		102 RCL 11	

Program Listings

```

103 *
104 +
105 CHS
106 "dX="
107 XEQ 05
108 GTD e
109*LBL b
110 RCL 14
111 RCL 00
112 *
113 RCL 01
114 +
115 STO 12
116 RCL 07
117 *
118 RCL 00
119 +
120 RCL 13
121 *
122 STO 02
123 "X="
124 XEQ 05
125 RCL 14
126 *
127 CHS
128 RCL 12
129 RCL 13
130 *
131 +
132 "dX="
133 XEQ 05
134 GTD e
135*LBL c
136 CHS
137 SQRT
138 ENTER↑
139 ENTER↑
140 RCL 14
141 -
142 STO 03
143 X<>Y
144 2
145 *
146 -
147 STO 04
148 RCL 01
149 RCL 03
150 RCL 00
151 *
152 -
153 RCL 04

```

 $C = C_{cr}$

 $C < C_{cr}$

```

154 RCL 03
155 -
156 /
157 STO 12
158 RCL 00
159 -
160 CHS
161 STO 11
162 RCL 03
163 RCL 07
164 *
165 E↑X
166 RCL 11
167 *
168 STO 02
169 RCL 03
170 *
171 STO 00
172 RCL 04
173 RCL 07
174 *
175 E↑X
176 RCL 12
177 *
178 ST+ 02
179 RCL 04
180 *
181 ST+ 00
182 RCL 02
183 "X="
184 XEQ 05
185 RCL 00
186 "dX="
187 XEQ 05
188*LBL e
189 RCL 14
190 2
191 *
192 *
193 RCL 02
194 RCL 15
195 *
196 +
197 CHS
198 "d2X="
199*LBL 05
200 ARCL X
201 RVIEW
202 STOP
203 RTN
204 .END.

```

Calculate
acceleration

Display

[illegible]

FREE VIBRATIONS

PROGRAM REGISTERS NEEDED: 41

ROW 1 (1 - 4)



ROW 2 (5 - 13)



ROW 3 (14 - 26)



ROW 4 (26 - 35)



ROW 5 (35 - 44)



ROW 6 (45 - 50)



ROW 7 (51 - 60)



ROW 8 (61 - 68)



ROW 9 (69 - 81)



ROW 10 (82 - 92)



ROW 11 (93 - 103)



ROW 12 (104 - 109)



ROW 13 (109 - 121)



ROW 14 (122 - 130)



ROW 15 (131 - 135)



ROW 16 (136 - 148)



ROW 17 (149 - 161)



ROW 18 (162 - 174)



FREE VIBRATIONS

ROW 19 (175 - 183)



ROW 20 (184 - 188)



ROW 21 (189 - 198)



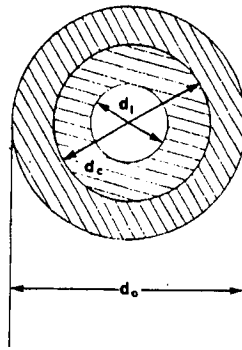
ROW 22 (198 - 204)



INTERFERENCE FITS

This program can be used to determine contact pressure or interference for concentric cylinders. Once the contact pressure has been determined, the actual tangential stresses at the surfaces of the cylinders can be determined. These stresses may be used in maximum shear theory of failure analysis. Modified tangential stresses for use in maximum strain theory of failure analysis can also be computed.

Concentric Cylinders



Equations:

for contact pressure:

$$\delta = d_c P_c \left[\frac{d_c^2 + d_i^2}{E_i (d_c^2 - d_i^2)} + \frac{d_o^2 + d_c^2}{E_o (d_o^2 - d_c^2)} - \frac{\mu_i}{E_i} + \frac{\mu_o}{E_o} \right]$$

for actual tangential stresses:

$$s_{to} = \frac{2P_c d_c^2}{d_o^2 - d_c^2}$$

$$s_{tco} = P_c \left(\frac{d_o^2 + d_c^2}{d_o^2 - d_c^2} \right)$$

$$s_{tci} = -P_c \left(\frac{d_c^2 + d_i^2}{d_c^2 - d_i^2} \right)$$

$$S_{ti} = \frac{-2P_c d_c^2}{d_c^2 - d_i^2}$$

for modified tangential stresses:

$$S'_{to} = \frac{2P_c d_c^2}{d_o^2 - d_c^2}$$

$$S'_{tco} = P_c \left(\frac{d_o^2 + d_c^2}{d_o^2 - d_c^2} + \mu_o \right)$$

$$S'_{tci} = -P_c \left(\frac{d_c^2 + d_i^2}{d_c^2 - d_i^2} - \mu_i \right)$$

$$S'_{ti} = \frac{-2P_c d_c^2}{d_c^2 - d_i^2}$$

where:

δ is the total interference;

P_c is the contact pressure;

d_i is the inside diameter;

d_c is the contact surface diameter;

d_o is the outside diameter;

μ_o is Poisson's ratio for the outside material;

μ_i is Poisson's ratio for the inside material;

E_o is the modulus of elasticity for the outside material;

E_i is the modulus of elasticity for the inside material;

S_{to} is the tangential stress of the outer surface;

S_{tco} is the tangential stress in the outer material at the contact surface;

S_{tci} is the tangential stress in the inner material at the contact surface;

S_{ti} is the stress at the inner surface of the inner cylinder;

S'_{to} , S'_{tco} , S'_{tci} , and S'_{ti} are the modified tangential stresses corresponding to the actual stresses just described.

Reference:

Hall, Holowenko, Laughlin,
Theory and Problems of Machine Design; Schaum's Outline Series,
McGraw Hill Co., 1961.

Example 1:

The choke at the end of a shotgun barrel is to be attached using an interference fit. If 5000 pounds per square inch must be developed to hold the choke in place, what is the minimum allowable interference? What are the values or actual stress?

$$d_i = 0.75 \text{ in}$$

$$d_c = 0.9375 \text{ in}$$

$$d_o = 1.125 \text{ in}$$

$$\mu_o = \mu_i = 0.3$$

$$E_o = E_i = 30 \times 10^6 \text{ psi}$$

Keystrokes:

[XEQ] [ALPHA] SIZE [ALPHA] 009

[XEQ] [ALPHA] INTER [ALPHA]

0.75 [R/S]

0.9375 [R/S]

1.125 [R/S]

0.3 [R/S]

Display:

DI?

DC?

DO?

RATIO 0?

EO?

Keystrokes:

30 [EEX] 6 [R/S]

0.3 [R/S]

30 [EEX] 6 [R/S]

5000 [R/S]

[R/S]

[R/S]

[R/S]

[R/S]

Display:

RATIO I?

EI?

Pc?

DELTA=1.578E-3

STO=22.73E3

STCO=27.73E3

STCI=-22.78E3

STI=-27.78E3

User Instructions

				SIZE: 009
STEP	INSTRUCTIONS	INPUT	FUNCTION	DISPLAY
1	Load program			
2	Begin execution			
	to find interference		[XEQ] INTER	DI?
	to find contact pressure		[XEQ] PRES	DI?
3	Input data			
		d_i	[R/S]	DC?
		d_c	[R/S]	DO?
		d_o	[R/S]	RATIO O?
		μ_o	[R/S]	EO?
		E_o	[R/S]	RATIO I?
		μ_i	[R/S]	EI?
		E_i	[R/S]	DELTA? or Pc?
		δ or P_c	[R/S]	
4	Output is automatic			Pc=
				(or)
				DELTA=
5	Continue to find:			
	S_{to}		[R/S]	STO=
	S_{tco}		[R/S]	STCO=
	S_{tci}		[R/S]	STCI=
	S_{ti}		[R/S]	STI=
	S'_{to}		[R/S]	S:T0=
	S'_{tco}		[R/S]	S:TCO=
	S'_{tci}		[R/S]	S:TCI=
	S'_{ti}		[R/S]	S:TI=

Program Listings

```

01*LBL "INT
ER"
02 SF 00
03 GTO 00
04*LBL "PRE
S"
05 CF 00
06*LBL 00
07 ENG 3
08 "DI?"
09 PROMPT
10 STO 01
11 "DC?"
12 PROMPT
13 STO 02
14 "DO?"
15 PROMPT
16 STO 03
17 "RATIO 0
?"
18 PROMPT
19 STO 04
20 "EQ?"
21 PROMPT
22 STO 05
23 "RATIO 1
?"
24 PROMPT
25 STO 06
26 "EI?"
27 PROMPT
28 STO 07
29 FS? 00
30 GTO A
31 "DELTA?"
32 PROMPT
33 STO 08
34 XEQ E
35 RCL 08
36 X<>Y
37 /
38 STO 08
39 "Pc="
40 XEQ d
41 GTO B
42*LBL A
43 "Pc?"
44 PROMPT
45 STO 08
46 XEQ E
47 RCL 08
48 *

```

Initialization

```

49 "DELTA="
50 XEQ d
51 GTO B
52*LBL E
53 RCL 01
54 X↑2
55 RCL 02
56 X↑2
57 +
58 LASTX
59 RCL 01
60 X↑2
61 -
62 /
63 RCL 07
64 /
65 RCL 02
66 X↑2
67 RCL 03
68 X↑2
69 +
70 LASTX
71 RCL 02
72 X↑2
73 -
74 /
75 RCL 05
76 /
77 +
78 RCL 06
79 RCL 07
80 /
81 -
82 RCL 04
83 RCL 05
84 /
85 +
86 RCL 02
87 *
88 RTN
89*LBL B
90 0
91 RCL 03
92 XEQ E
93 RCL 08
94 *
95 2
96 *
97 "ST0="
98 XEQ d
99 RCL 03
100 RCL 03

```

Subroutine "E"

Outputs

Program Listings

```

101 XEQ E
102 RCL 08
103 *
104 "STCO="
105 XEQ d
106 RCL 01
107 RCL 01
108 XEQ E
109 RCL 08
110 *
111 "STCI="
112 XEQ d
113 0
114 RCL 01
115 XEQ E
116 RCL 08
117 *
118 2
119 *
120 "STI="
121 XEQ d
122 0
123 RCL 03
124 XEQ E
125 RCL 08
126 *
127 2
128 *
129 "S:TO="
130 XEQ d
131 RCL 03
132 RCL 03
133 XEQ E
134 RCL 04
135 +
136 RCL 08
137 *
138 "S:TCO="
139 XEQ d
140 RCL 01
141 RCL 01
142 XEQ E
143 RCL 06
144 +
145 RCL 08
146 *
147 "S:TCI="
148 XEQ d
149 0
150 RCL 01
151 XEQ E
152 RCL 08

```

```

153 *
154 2
155 *
156 "S:TI="
157 GTO d
158 LBL E
159 X↑2
160 X<>Y
161 X↑2
162 RCL 02
163 X↑2
164 +
165 X<>Y
166 LASTX
167 -
168 /
169 RTN
170 LBL d
171 ARCL X
172 PROMPT
173 RTN
174 END

```

Subroutine "E"

Display

80

90

00

DATA REGISTERS				STATUS			
00		50		SIZE	009	TOT. REG.	57
	d _i			ENG	3	FIX	____
	d _c			DEG	____	SCI	____
	d ₀			RAD	____	GRAD	____
	μ ₀						
05	E ₀	55		FLAGS			
	μ _i			#	INIT S/C	SET INDICATES	CLEAR INDICATES
	E _i			00		Calculate δ	Calculate P _c
	P _c , δ						
10		60					
15		65					
20		70					
25		75					
30		80					
35		85					
				ASSIGNMENTS			
				FUNCTION	KEY	FUNCTION	KEY
40		90					
45		95					

INTERFERENCE FITS

PROGRAM REGISTERS NEEDED: 49

ROW 1 (1 - 3)



ROW 2 (4 - 7)



ROW 3 (8 - 14)



ROW 4 (14 - 17)



ROW 5 (17 - 23)



ROW 6 (23 - 28)



ROW 7 (29 - 32)



ROW 8 (33 - 40)



ROW 9 (40 - 45)



ROW 10 (46 - 50)



ROW 11 (50 - 58)



ROW 12 (59 - 71)



ROW 13 (72 - 84)



ROW 14 (85 - 94)



ROW 15 (95 - 101)



ROW 16 (101 - 105)



ROW 17 (106 - 111)



ROW 18 (112 - 120)



INTERFERENCE FITS

ROW 19 (120 - 125)



ROW 20 (126 - 131)



ROW 21 (132 - 138)



ROW 22 (138 - 145)



ROW 23 (146 - 150)



ROW 24 (151 - 156)



ROW 25 (157 - 166)



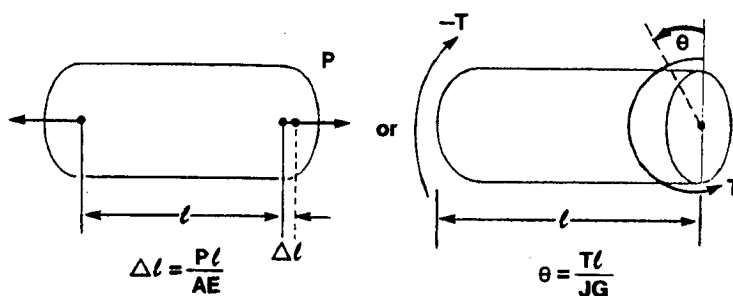
ROW 26 (167 - 174)



LINEAR OR ANGULAR DEFORMATION

This program solves for linear deflection under tensile load, or the analogous angular deflection under torque, using an interchangeable solution. Given four of the five variables, the unknown is calculated.

Equations:



where:

Δl is the change in length;

P is the applied load;

l is the length;

A is the cross sectional area;

E is the modulus of elasticity;

θ is the deflection angle in radians;

T is the applied torque;

J is the polar moment of the section;

G is the modulus of elasticity in shear.

Remarks:

This program is not applicable for non-elastic media or elastic media where stress exceeds the elastic limit. Materials must be isotropic. The equation for angular deflection is not valid in the neighborhood of the applied torque.

Example:

Steel bars affixed to the roof are to be used to support the end of a cantilever balcony. The load on each bar will be 50,000 newtons. If the maximum allowable deflection is 0.001 meters, what should the area of the bars be? $l = 10$ meters $E = 2.068 \times 10^{11}$ N/m²

Keystrokes:

Display:

[XEQ] [ALPHA] SIZE [ALPHA] 006

[XEQ] [ALPHA] LINEAR [ALPHA]

A

[R/S]

DELTA

.001 [R/S]

L

10 [R/S]

P

50,000 [R/S]

E

2.068 [EEX] 11 [R/S]

A=2.418E-3

User Instructions

[illegible]

Program Listings

01♦LBL "LINEAR"

02 CF 00
03 CLX
04 "A"
05 PROMPT
06 X=0?
07 XEQ b
08 STO 01
09 CLX
10 "DELTA"
11 PROMPT
12 X=0?
13 XEQ b
14 STO 02
15 CLX
16 "L"
17 PROMPT
18 X=0?
19 XEQ a
20 STO 03
21 CLX
22 "P"
23 PROMPT
24 X=0?
25 XEQ a
26 STO 04
27 CLX
28 "E"
29 PROMPT
30 X=0?
31 XEQ b
32 STO 05
33 GTO 00
34♦LBL "ANGULAR"

ULAR"
35 CF 00
36 CLX
37 "J"
38 PROMPT
39 X=0?
40 XEQ b
41 STO 01
42 CLX
43 "Z"
44 PROMPT
45 X=0?
46 XEQ b
47 STO 02
48 CLX
49 "L"
50 PROMPT

Initialization
"LINEAR"

Initialization
"ANGULAR"

51 X=0?
52 XEQ a
53 STO 03
54 CLX
55 "T"
56 PROMPT
57 X=0?
58 XEQ a
59 STO 04
60 CLX
61 "G"
62 PROMPT
63 X=0?
64 XEQ b
65 STO 05
66 GTO 00
67♦LBL a
68 SF 00
69♦LBL b
70 ASTO 00
71 1
72 RTN
73♦LBL 00
74 ENG 3
75 RCL 04
76 RCL 03
77 *
78 RCL 02
79 RCL 01
80 *
81 RCL 05
82 *
83 /
84 FS? 00
85 1/X
86 CLA
87 ARCL 00
88 "F="
89 ARCL X
90 RVIEW
91 STOP
92 .END.

Store output
label

Computation

Display

00

LINEAR OR ANGULAR DEFORMATION

PROGRAM REGISTERS NEEDED: 23

ROW 1 (1 - 3)



ROW 2 (4 - 10)



ROW 3 (10 - 18)



ROW 4 (19 - 26)



ROW 5 (27 - 34)



ROW 6 (34 - 37)



ROW 7 (37 - 46)



ROW 8 (46 - 54)



ROW 9 (55 - 63)



ROW 10 (64 - 70)



ROW 11 (70 - 81)



ROW 12 (82 - 89)



ROW 13 (90 - 92)



CONSTANT ACCELERATION

This program calculates an interchangeable solution among the variables displacement, acceleration, initial velocity, and time, for an object that undergoes constant acceleration. The motion may be either circular or linear. Final velocity as a function of initial velocity, acceleration, and displacement may also be computed.

Equations:

	Linear	Angular
Displacement	$x = v_o t + \frac{1}{2} a t^2$	$\theta = \omega_o t + \frac{1}{2} \alpha t^2$
Initial velocity	$v_o = \frac{x}{t} - \frac{1}{2} a t$	$\omega_o = \frac{\theta}{t} - \frac{1}{2} \alpha t$
Acceleration	$a = \frac{x - v_o t}{\frac{1}{2} t^2}$	$\alpha = \frac{\theta - \omega_o t}{\frac{1}{2} t^2}$
Time	$t = \frac{\sqrt{v_o^2 + 2ax} - v_o}{a}$	$t = \frac{\sqrt{\omega_o^2 + 2\alpha\theta} - \omega_o}{\alpha}$
Final velocity	$v = \sqrt{v_o^2 + 2ax}$	$\omega = \sqrt{\omega_o^2 + 2\alpha\theta}$

Remarks:

Any consistent set of units may be used.

Displacement, acceleration, and velocity should be considered as signed (vector) quantities. For example, if initial velocity and acceleration are in opposite directions, one should be positive and the other negative.

All equations assume that the initial displacement, x_o or θ_o , equals zero.

Example 1:

An automobile accelerates for 4 seconds from a speed of 35 mph and covers a distance of 264 feet. Assuming constant acceleration, what is the acceleration in ft/sec²? If the acceleration continues to be constant, what distance is covered in the next second?

Keytrokes:

[XEQ] [ALPHA] SIZE [ALPHA] 004
 [XEQ] [ALPHA] CA [ALPHA]
 264 [R/S]
 35 [ENTER] 5280 [*] 3600 [+] [R/S]
 4 [R/S]
 [R/S]
 [XEQ] A
 5 [STO] 02
 [XEQ] X
 264 [-]

Display:

X,Δ?
 VO,WO?
 T?
 A?

 A=7.33

 X,Δ=348.33
 (total distance)
 84.33

Program Listings

```

01♦LBL "CA"
02 FIX 2
03 "X,Δ?"
04 PROMPT
05 STO 00
06 "VO,W0?"
07 PROMPT
08 STO 01
09 "T?"
10 PROMPT
11 STO 02
12 "A?"
13 PROMPT
14 STO 03
15 STOP
16♦LBL "X"
17 RCL 02
18 X↑2
19 RCL 03
20 *
21 2
22 /
23 RCL 02
24 RCL 01
25 *
26 +
27 STO 00
28 "X,Δ="
29 GTO 05
30♦LBL "V0"
31 RCL 00
32 RCL 02
33 /
34 RCL 02
35 RCL 03
36 *
37 2
38 /
39 -
40 STO 01
41 "VO,W0="
42 GTO 05
43♦LBL A
44 RCL 00
45 RCL 01
46 RCL 02
47 *
48 -
49 RCL 02
50 X↑2
51 2
52 /

```

Initialization

Displacement

Initial
velocity

Acceleration

```

53 /
54 STO 03
55 "A="
56 GTO 05
57♦LBL "T"
58 CF 01
59 XEQ 01
60 RCL 01
61 -
62 RCL 03
63 /
64 STO 02
65 "T="
66 GTO 05
67♦LBL "V"
68 SF 01
69♦LBL 01
70 RCL 01
71 X↑2
72 RCL 03
73 RCL 00
74 *
75 2
76 *
77 +
78 SQRT
79 FC? 01
80 RTN
81 "V,W="
82♦LBL 05
83 ARCL X
84 AVIEW
85 STOP
86 .END.

```

Time

Final
velocity

Display

90

00

[illegible]

CONSTANT ACCELERATION

PROGRAM REGISTERS NEEDED: 22

ROW 1 (1 - 3)



ROW 2 (4 - 9)



ROW 3 (9 - 16)



ROW 4 (16 - 28)



ROW 5 (28 - 31)



ROW 6 (32 - 41)



ROW 7 (41 - 49)



ROW 8 (50 - 57)



ROW 9 (57 - 65)



ROW 10 (65 - 70)



ROW 11 (71 - 81)



ROW 12 (81 - 86)



NOTES

NOTES

NOTES

NOTES

NOTES

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