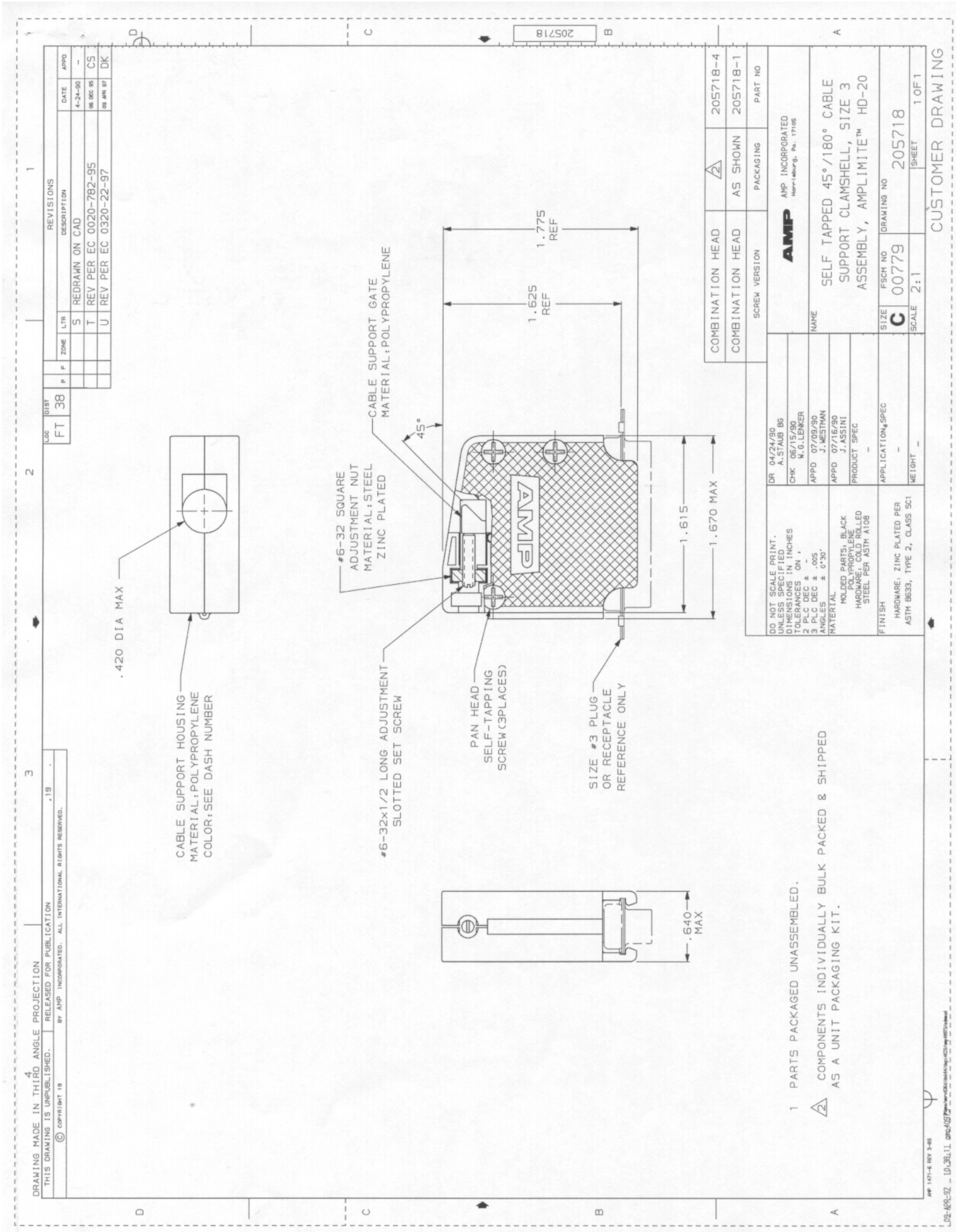
APPENDIX H - MANUFACTURER PART SPECIFICATIONS

The following pages are manufacturers' specifications for parts provided in the Official Kit of Parts.
Additional booklets are in the Kit.
Be sure to read these spec sheets in order to properly allocate and use components.
Specification sheets in this section are in the order listed below for the following suppliers:

Supplier	Kit Part
AMP Incorporated	Connector Housing
Associated Spring Raymond	Springs
BEI Systron Donner Inertial Division	Yaw Rate Sensor
Belimo	Actuator
Bourns, Inc.	Potentiometer
CP Clare	Reed Switch
Delphi Interior and Lightning Systems	Van Door Motor
Fisher-Price	Motor
Globe Motor	Motor and Drive Assembly
EBM Industries, Inc.	Muffin Fans
Honeywell - Microswitch Division	Limit Switch and Rocker Switch
Innovation FIRST	Speed Controller
ITT Automotive	Window Lift Motor
Keyang	Seat Motor
Pioneer Packard	Connectors
RadioShack	Potentiometer
S-B Power Tool Company	Drill Motors
Skyway Recreation Products	Wheel Chair Wheels
Snap-Action, Inc.	Circuit Breakers
Square D	Main Circuit Breaker
Thomas & Betts Corporation	Connectors and Mounting Bases
The Torrington Company	Ball Bearings
Tyton Hellerman Corporation	Wire Wrap, Grommet, and Grip Ties
Xenotronix	Battery Charger
VELCRO USA, Inc.	Velcoin®, One Wrap®, and Hoop and Loop
Yuasa Exide, Inc.	Battery


SELF TAPPED 45°/180° CABLE SUPPORT CLAMSHELL, SIZE 3 ASSEMBLY, AMPLIMITE™ HD-20
CUSTOMER DRAWING
205718
CABLE SUPPORT GATE MATERIAL:POLYPROPYLENE
#6-32 SQUARE ADJUSTMENT NUT MATERIAL:STEEL ZINC PLATED
CABLE SUPPORT HOUSING MATERIAL:POLYPROPYLENE COLOR:SEE DASH NUMBER
#6-32x1/2 LONG ADJUSTMENT SLOTTED SET SCREW
PAN HEAD SELF-TAPPING SCREW(3PLACES)
SIZE #3 PLUG OR RECEPTACLE REFERENCE ONLY
.420 DIA MAX
1.625 REF
1.775 REF
1.615
1.670 MAX
.640 MAX
45°
1 PARTS PACKAGED UNASSEMBLED.
2 COMPONENTS INDIVIDUALLY BULK PACKED & SHIPPED AS A UNIT PACKAGING KIT.
COMBINATION HEAD 205718-4
COMBINATION HEAD AS SHOWN 205718-1
REDRAWN ON CAD
REV PER EC 0020-782-95
REV PER EC 0320-22-97
AMP INCORPORATED

Subminiature D Connectors (AMPLIMITE)
Cable Clamps

205718-1 -- *1 of 1 products* Active

Y2K - OK

ASSEMBLY SUBCONTRACTORS | STEP SEARCH

DRAWINGS SPECIFICATIONS | SALES INFO | GENERAL INFO

Please use the customer drawing for all design activity.

- **Customer Drawing: 205718**, Rev. U
  Document Title: SELF TAPPED 45@27/180@27 CABLE SUPPORT CLAMSHELL, SIZE 3 ASSEMBLY, AMPLIMITE@PZTM HD-20
  167350.pdf (49K)

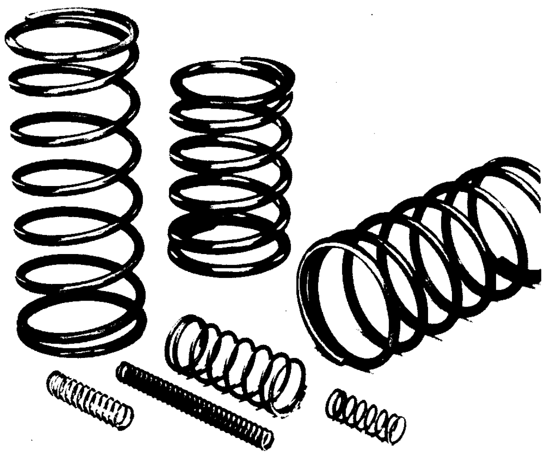
Line art and other pictures below are general representations of product dimensions, please use the customer drawing for all design activity.

Product Photo

Searchable Features:	
Product Type:	Cable Clamp
Cable Clamp Type:	Clam Shell
Cable Exit Angle:	Straight(180°)/45°
Cable Outer Diameter (mm [in]):	10.67 [.420] Max.
Shell Size:	3
Shielded:	No
Screws and Retainer Clips:	Without
Packaging Method:	Individual Kit

Other Properties:	
Product Series:	HD-20 (Solder Cup)
Clam Shell Length:	Standard
Body Material:	Thermoplastic
Body Finish:	Textured
Cable Support Gate Material:	Thermoplastic
Cable Clamp Material:	Thermoplastic
Square Nut Material:	Steel
Square Nut Plating:	Zinc
Screw Material:	Steel
Screw Plating:	Zinc
Screw Size:	6-32

Compression Springs



Stock sizes in music wire and stainless steel

Associated Spring offers a broad variety of helical compression springs in the SPEC selection. They are reliable, inexpensive and efficient — the right combination for general-purpose use throughout industry.

Material

Music wire
ASTM-A228 or AMS 5112

Stainless steel
Commercial Type 302, ASTM-A313 or
AMS 5688 spring temper. (chemical & physical only)

No charge for certificate of compliance when requested; certificate of chemical analysis available, see price book.

Music wire will be furnished unless stainless steel is specified. When inquiring or ordering, use letter "M" or letter "S" as suffix on catalog numbers to designate music wire or stainless steel wire, respectively.

Music wire springs are not recommended for applications where the temperature exceeds 250 deg F (121 deg C). Stainless steel springs are not recommended for applications where the temperature exceeds 500 deg F (260 deg C).

Direction of Helix

Right hand.

Ends

Squared and ground. Ends to be square within 3° with axis O.D. sizes 0.057-0.088 in (1.45-2.24 mm) squared ends not ground.

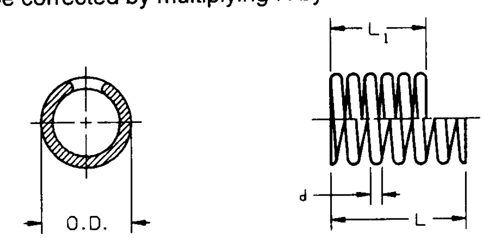
Free length L is for reference use only. Load P is attained at length L_1. For stainless steel multiply P by 0.833.

Load values shown are for music wire.

For normal service, springs should not be compressed below L_1.

To determine load P at any length other than L_1, multiply the proposed deflection by the rate R. *[P + (L-Lx) x R]

When stainless steel is used the value for rate R must be corrected by multiplying R by 0.833.



Finishes

Standard finish is that of the normal wire. Shot-peened and plated finishes furnished on request. Allow sufficient additional time for special finishes.

Tolerances

O.D. (English)	O.D. (Metric)
0.057 to 0.119 in ± 0.003 in	1.45 to 3.02 mm ± 0.08 mm
0.120 to 0.240 in ± 0.005 in	3.05 to 6.10 mm ± 0.13 mm
0.241 to 0.500 in ± 0.008 in	6.12 to 12.70 mm ± 0.20 mm
0.501 to 1.000 in ± 0.015 in	12.73 to 25.40 mm ± 0.38 mm
1.001 to 1.225 in ± 0.020 in	25.43 to 31.12 mm ± 0.51 mm
1.226 to 1.460 in ± 0.030 in	31.14 to 37.08 mm ± 0.76 mm
1.461 to 2.000 in ± 0.040 in	37.11 to 50.80 mm ± 1.02 mm

Load, P ± 10%
Spring Rate, R ± 10%
*Lx = Desired Load Length

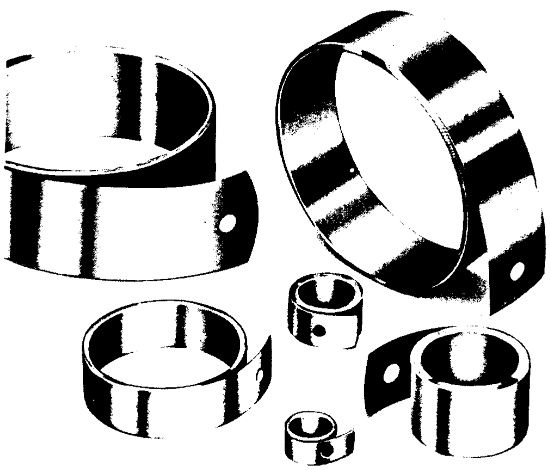
STOCK COMPRESSION SPRINGS
Music Wire and Stainless Steel

SPEC Associated Spring Raymond BARNES GROUP INC

CATALOG NUMBER*	Outside Diameter		Wire Diameter		Free Length L, Approx.		Load, P at L_1		Length, L_1		Solid Height, Approx.		Spring Rate, R	
	in	mm	in	mm	in	mm	lb†	N†	in	mm	in	mm	lb/in†	N/mm†
C0600-063-2000					2.00	50.80			1.059	26.90	0.700	17.78	18.0	3.15
C0600-063-2250					2.25	57.15			1.184	30.07	0.768	19.51	15.9	2.78
C0600-063-2500			0.063	1.60	2.50	63.50	18.00	80.07	1.308	33.22	0.836	21.23	14.2	2.49
C0600-063-2750					2.75	69.85			1.433	36.40	0.863	21.92	13.7	2.40
C0600-063-3000					3.00	76.20			1.558	39.57	0.927	23.55	12.5	2.19
C0600-063-3500					3.50	88.90			1.807	45.90	1.055	26.80	10.6	1.856
C0600-067-0625					0.62	15.75			0.360	9.14	0.300	7.62	80.0	14.01
C0600-067-0750					0.75	19.05			0.430	10.92	0.336	8.53	66.0	11.56
C0600-067-0880					0.88	22.35			0.455	11.56	0.401	10.19	50.0	8.76
C0600-067-1000					1.00	25.40			0.530	13.46	0.430	10.92	45.0	7.88
C0600-067-1250					1.25	31.75			0.665	16.89	0.505	12.83	36.0	6.30
C0600-067-1500			0.067	1.70	1.50	38.10	21.00	93.41	0.780	19.81	0.594	15.09	29.0	5.08
C0600-067-1750					1.75	44.45			0.830	21.08	0.715	18.16	23.0	4.03
C0600-067-2000					2.00	50.80			1.106	28.09	0.771	19.58	22.5	3.94
C0600-067-2250					2.25	57.15			1.236	31.39	0.847	21.51	19.8	3.47
C0600-067-2500					2.50	63.50			1.366	34.70	0.923	23.44	17.7	3.10
C0600-067-2750					2.75	69.85			1.496	38.00	0.966	24.54	16.7	2.92
C0600-067-3000					3.00	76.20			1.626	41.30	1.040	26.42	15.3	2.68
C0600-072-0620					0.62	15.75			0.405	10.29	0.381	9.68	114.5	20.05
C0600-072-0750					0.75	19.05			0.445	11.30	0.396	10.06	78.0	13.66
C0600-072-0880					0.88	22.35			0.520	13.21	0.433	11.00	68.0	11.91
C0600-072-1000					1.00	25.40			0.565	14.35	0.502	12.75	55.0	9.63
C0600-072-1250					1.25	31.75			0.710	18.03	0.581	14.76	45.0	7.88
C0600-072-1500			0.072	1.83	1.50	38.10	24.00	106.76	0.830	21.08	0.691	17.55	36.0	6.30
C0600-072-1750					1.75	44.45			0.950	24.13	0.801	20.35	30.0	5.25
C0600-072-2000					2.00	50.80			1.140	28.96	0.848	21.54	28.0	4.90
C0600-072-2250					2.25	57.15			1.301	33.05	0.946	24.03	25.9	4.54
C0600-072-2500					2.50	63.50			1.438	36.53	1.033	26.24	23.1	4.05
C0600-072-2750					2.75	69.85			1.601	40.67	1.119	28.42	20.9	3.66
C0600-072-3000	0.600	15.24			3.00	76.20			1.742	44.25	1.206	30.63	19.1	3.34
C0600-081-0620					0.62	15.75			0.466	11.84	0.412	10.46	212.6	37.23
C0600-081-0750					0.75	19.05			0.553	14.05	0.459	11.66	165.6	29.00
C0600-081-0880					0.88	22.35			0.639	16.23	0.507	12.88	135.6	23.74
C0600-081-1000					1.00	25.40			0.719	18.26	0.552	14.02	116.2	20.35
C0600-081-1250					1.25	31.75			0.885	22.48	0.644	16.36	89.5	15.67
C0600-081-1500					1.50	38.10			1.051	26.70	0.736	18.69	72.8	12.75
C0600-081-1750					1.75	44.45			1.217	30.91	0.828	21.03	61.3	10.73
C0600-081-2000					2.00	50.80			1.383	35.13	0.920	23.37	53.0	9.28
C0600-081-2250			0.081	2.06	2.25	57.15	32.69	145.41	1.549	39.34	1.012	25.70	46.6	8.16
C0600-081-2500					2.50	63.50			1.715	43.56	1.104	28.04	41.7	7.30
C0600-081-2750					2.75	69.85			1.881	47.78	1.196	30.38	37.6	6.58
C0600-081-3000					3.00	76.20			2.047	51.99	1.288	32.72	34.3	6.01
C0600-081-3250					3.25	82.55			2.213	56.21	1.380	35.05	31.5	5.52
C0600-081-3500					3.50	88.90			2.379	60.43	1.472	37.39	29.2	5.11
C0600-081-3750					3.75	95.25			2.545	64.64	1.564	39.73	27.1	4.75
C0600-081-4000					4.00	101.60			2.711	68.86	1.656	42.06	25.4	4.45
C0600-085-0620					0.62	15.75			0.477	12.12	0.433	11.00	262.5	45.96
C0600-085-0750					0.75	19.05			0.565	14.35	0.484	12.29	203.6	35.65
C0600-085-0880					0.88	22.35			0.654	16.61	0.536	13.61	166.4	29.14
C0600-085-1000					1.00	25.40			0.736	18.69	0.583	14.81	142.3	24.92
C0600-085-1250					1.25	31.75			0.906	23.01	0.682	17.32	109.4	19.16
C0600-085-1500					1.50	38.10			1.076	27.33	0.781	19.84	88.8	15.55
C0600-085-1750					1.75	44.45			1.247	31.67	0.880	22.35	74.8	13.10
C0600-085-2000					2.00	50.80			1.417	35.99	0.978	24.84	64.5	11.29
C0600-085-2250			0.085	2.16	2.25	57.15	37.62	167.33	1.588	40.34	1.077	27.36	56.8	9.95
C0600-085-2500					2.50	63.50			1.758	44.65	1.176	29.87	50.7	8.88
C0600-085-2750					2.75	69.85			1.928	48.97	1.275	32.39	45.8	8.02
C0600-085-3000					3.00	76.20			2.099	53.31	1.374	34.90	41.7	7.30
C0600-085-3250					3.25	82.55			2.269	57.63	1.473	37.41	38.3	6.71
C0600-085-3500					3.50	88.90			2.439	61.95	1.572	39.93	35.5	6.22
C0600-085-3750					3.75	95.25			2.610	66.29	1.670	42.42	33.0	5.78
C0600-085-4000					4.00	101.60			2.780	70.61	1.769	44.93	30.8	5.39
C0600-092-0750					0.75	19.05			0.591	15.01	0.524	13.31	291.5	51.04
C0600-092-0880			0.092	2.34	0.88	22.35	46.46	206.65	0.684	17.37	0.581	14.76	237.0	41.50
C0600-092-1000					1.00	25.40			0.770	19.56	0.633	16.08	202.2	35.41

†For stainless steel, multiply values by 0.833.
**When inquiring or ordering, use letter "M" or letter "S" as suffix on catalog numbers to designate music wire or stainless-steel wire, respectively.*

Constant-force Springs



Stock sizes in stainless steel

Constant-force springs are a special variety of extension spring. They consist of a spiral of strip material with built-in curvature so that each turn of the strip wraps tightly on its inner neighbor. When the strip is extended (deflected) the inherent stress resists the loading force, just as in a common extension spring, but at a nearly constant (zero) rate. The accompanying load/deflection curves illustrate this.

The constant-force spring is well suited to long extensions with no load build-up. In use, the spring is usually mounted with the ID tightly wrapped on a drum and the free end attached to the loading force, such as in a counterbalance application. This relationship can be reversed, however, with the free end mounted stationary and the spring itself providing the working force, as with carbon brushes in electrical apparatus.

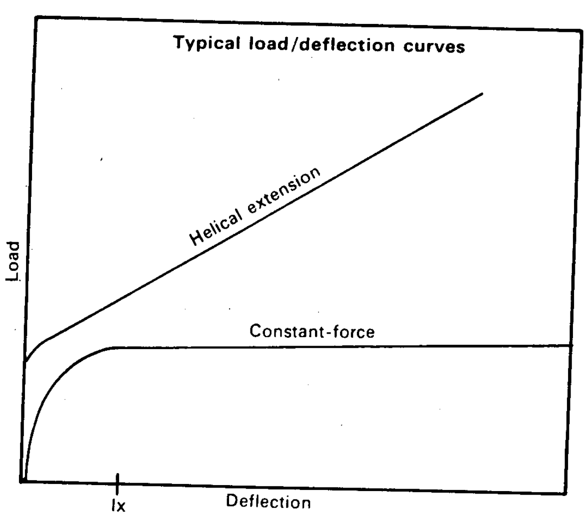
Considerable flexibility is possible with constant-force springs because the load capacity can be multiplied by using two or more strips in tandem, back-to-back, or laminated, as illustrated.

Material

Type 301 stainless steel.

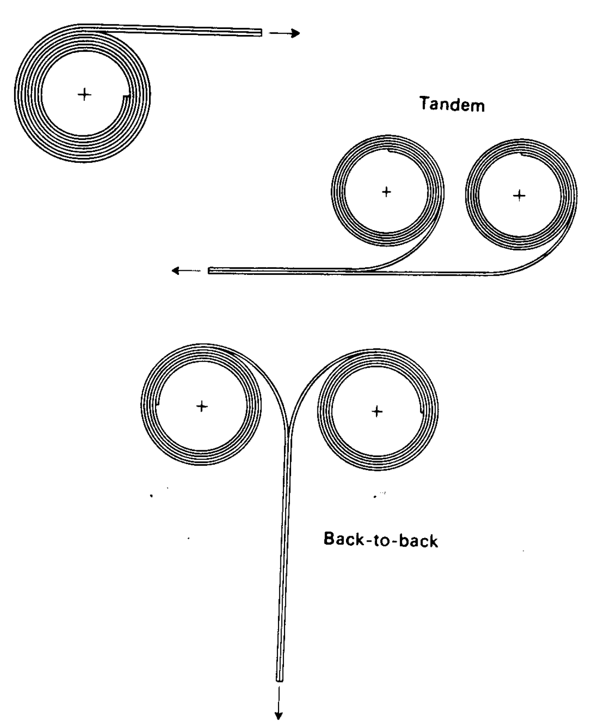
Note

Be sure to allow at least 1½ coils of material on the drum at full extension. The spring ID will wrap tightly on the drum so that in most applications no fastening method on the drum is required.



80

How to multiply constant-force spring load

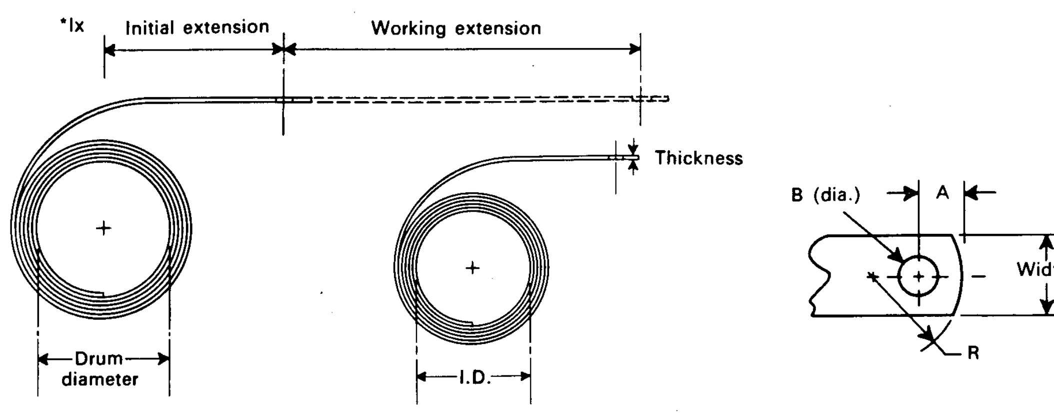


STOCK CONSTANT-FORCE SPRINGS
Stainless Steel

SPEC Associated Spring Raymond BARNES GROUP INC

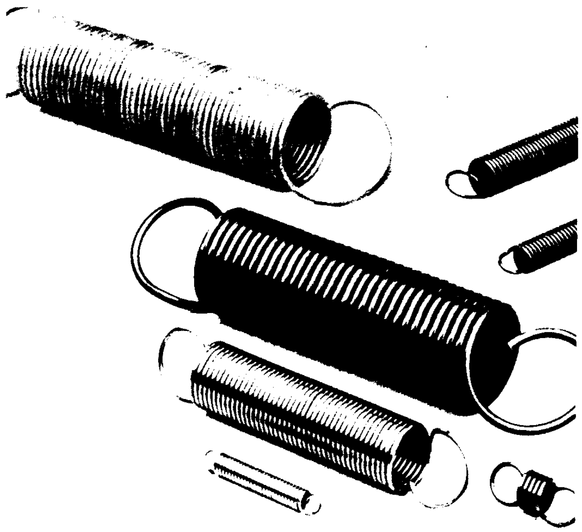
CATALOG NUMBER	Thickness		Width		Length		Initial Extension		Working Ext.		I.D. (Reference)		Drum Diameter		Load ±10%		End Configuration A		B		R	
	in	mm	in	mm	in	mm	in	mm	in	mm	in	mm	in	mm	lb	N	in	mm	in	mm	in	mm
Fatigue Life 4,000 Cycles																						
CF015-0050	0.004	*0.10*	0.25	*6.35*	15	*381*	0.61	*15.49*	12	*305*	0.34	*8.64*	0.40	*10.16*	0.50	*2.22*	3/8	*9.5*	0.131	*3.3*	1/2	*12.7*
CF018-0075	0.005	*0.13*	0.31	*7.87*	18	*457*	0.75	*19.05*	15	*381*	0.42	*10.67*	0.50	*12.70*	0.75	*3.34*	3/8	*9.5*	0.131	*3.3*	1/2	*12.7*
CF022-0112	0.006	*0.15*	0.37	*9.40*	22	*559*	0.92	*23.37*	18	*457*	0.51	*12.95*	0.62	*15.75*	1.12	*4.98*	3/8	*9.5*	0.131	*3.3*	1/2	*12.7*
CF026-0162	0.007	*0.18*	0.50	*12.70*	26	*660*	1.06	*26.92*	21	*533*	0.59	*14.99*	0.75	*19.05*	1.62	*7.21*	3/8	*9.5*	0.131	*3.3*	1/2	*12.7*
CF030-0237	0.008	*0.20*	0.59	*14.99*	30	*762*	1.22	*30.99*	24	*610*	0.68	*17.27*	0.87	*22.10*	2.37	*10.54*	3/8	*9.5*	0.187	*4.7*	7/8	*22.2*
CF034-0350	0.010	*0.25*	0.68	*17.27*	34	*864*	1.53	*38.86*	27	*686*	0.85	*21.59*	1.00	*25.40*	3.50	*15.57*	3/8	*9.5*	0.187	*4.7*	7/8	*22.2*
CF038-0500	0.012	*0.30*	0.81	*20.57*	38	*965*	1.84	*46.74*	30	*762*	1.02	*25.91*	1.25	*31.75*	5.00	*22.24*	3/8	*9.5*	0.187	*4.7*	7/8	*22.2*
CF043-0700	0.014	*0.36*	1.00	*25.40*	43	*1092*	2.14	*54.36*	33	*838*	1.19	*30.23*	1.50	*38.10*	7.00	*31.14*	3/8	*9.5*	0.187	*4.7*	7/8	*22.2*

Fatigue Life 40,000 Cycles																						
CF021-0025	0.006	*0.15*	0.37	*9.40*	21	*533*	2.03	*51.56*	12	*305*	1.13	*28.70*	1.36	*34.54*	0.25	*1.11*	3/8	*9.5*	0.131	*3.3*	1/2	*12.7*
CF025-0037	0.007	*0.18*	0.50	*12.70*	25	*635*	2.36	*59.94*	15	*381*	1.31	*33.27*	1.58	*40.13*	0.37	*1.65*	3/8	*9.5*	0.131	*3.3*	1/2	*12.7*
CF030-0050	0.008	*0.20*	0.59	*14.99*	30	*762*	2.72	*69.09*	18	*457*	1.51	*38.35*	1.81	*45.97*	0.50	*2.22*	3/8	*9.5*	0.187	*4.7*	7/8	*22.2*
CF036-0075	0.010	*0.25*	0.68	*17.27*	36	*914*	3.38	*85.85*	21	*533*	1.88	*47.75*	2.26	*57.40*	0.75	*3.34*	3/8	*9.5*	0.187	*4.7*	7/8	*22.2*
CF042-0112	0.012	*0.30*	0.81	*20.57*	42	*1067*	4.07	*103.40*	24	*610*	2.26	*57.40*	2.71	*68.83*	1.12	*4.98*	3/8	*9.5*	0.187	*4.7*	7/8	*22.2*
CF048-0162	0.014	*0.36*	1.00	*25.40*	48	*1219*	4.74	*120.40*	27	*686*	2.63	*66.80*	3.16	*80.26*	1.62	*7.21*	3/8	*9.5*	0.187	*4.7*	7/8	*22.2*



*Initial extension is the minimum amount of extension needed to operate the spring and achieve a linear rate. (see chart page 77)

Extension Springs



Stock sizes in music wire and stainless steel

All SPEC stock helical extension springs have uniform body diameter and are produced with full twist loops the same diameter as the body. They are wound with initial tension; some force is required before the coils are initially separated. As with other Associated Spring stock components, they are capable of wide application for experimental, development, prototype and maintenance work.

Material

Music wire
ASTM-A228 or AMS 5112
Stainless steel
Commercial Type 302, ASTM-A313 or
AMS 5688 spring temper. (chemical & physical only)
No charge for certificate of compliance when requested; certificate of chemical analysis available, see price book.

Music wire will be furnished unless stainless steel is specified. When inquiring or ordering, use letter "M" or letter "S" as suffix on catalog numbers to designate music wire or stainless steel wire, respectively.

Music wire springs are not recommended for applications where the temperature exceeds 250 deg F (121 deg C). Stainless steel springs are not recommended for applications where the temperature exceeds 500 deg F (260 deg C).

Direction of Helix

Right or left according to machine set-up at time of run.

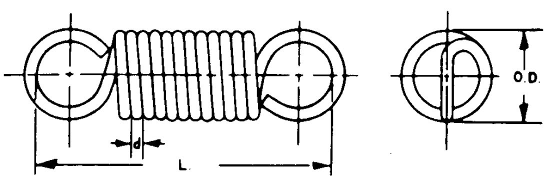
Ends

Full twist loop. Special ends on request.

Initial tension T is for reference only; free length dimension L is approximate.

Maximum load P is attained at extended length L_1.

To determine load P, rate R or initial tension T, for stainless steel, multiply the values given by 0.833. To determine load P*at any extension other than L_1, multiply the distance in inches that the spring will be extended from the free length L, by the spring rate R and add the initial tension T.



Finishes

Standard finish is that of the normal wire. Shot-peened and plated finishes furnished on request. Allow additional time for special finishes.

Tolerances

O.D. (English)	O.D. (Metric)
0.063 to 0.119 in ± 0.003 in	1.60 to 3.02 mm ± 0.08 mm
0.120 to 0.240 in ± 0.005 in	3.05 to 6.10 mm ± 0.13 mm
0.241 to 0.500 in ± 0.008 in	6.12 to 12.70 mm ± 0.20 mm
0.501 to 1.000 in ± 0.015 in	12.73 to 25.40 mm ± 0.38 mm
1.001 to 1.225 in ± 0.020 in	25.43 to 31.12 mm ± 0.51 mm
1.226 to 1.460 in ± 0.030 in	31.14 to 37.08 mm ± 0.76 mm
1.461 to 2.000 in ± 0.040 in	37.11 to 50.80 mm ± 1.02 mm

Load, P ± 10%
Spring Rate, R ± 10%
Position of Ends ± 22 deg

*P =(Lx-L) x R + T
Lx = Desired Load Length

55

STOCK EXTENSION SPRINGS
Music Wire and Stainless Steel

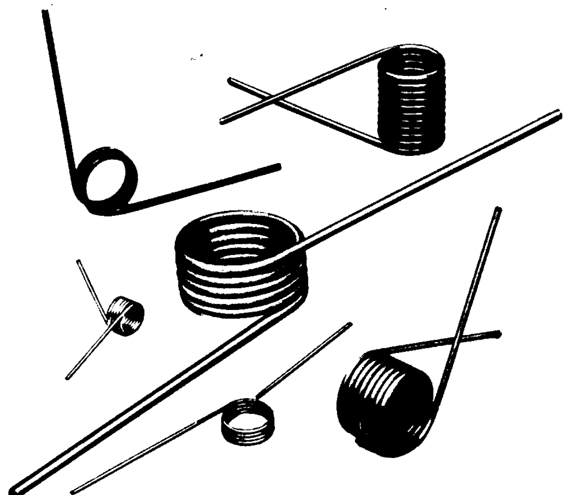
Associated Spring Raymond BARNES GROUP INC

CATALOG NUMBER*	Outside Diameter		Wire Diameter		Free Length L, Approx.		Load, P at L_1		Initial Tension, T**		Ext. L_1		Spring Rate, R	
	in	mm	in	mm	in	mm	lb†	N†	lb†	N†	in	mm	lb/in†	N/mm†
E0500-055-1250					1.25	31.75					1.75	44.45	24.4	4.27
E0500-055-1370					1.37	34.80					2.14	54.36	15.6	2.73
E0500-055-1500					1.50	38.10					2.41	61.21	13.0	2.28
E0500-055-1750					1.75	44.45					3.01	76.45	9.0	1.576
E0500-055-2000					2.00	50.80					3.60	91.44	7.4	1.296
E0500-055-2250					2.25	57.15					4.29	108.97	6.1	1.068
E0500-055-2500			0.055	1.40	2.50	63.50	13.10	58.27	1.20	5.34	4.82	122.43	5.1	0.893
E0500-055-2750					2.75	69.85					5.41	137.41	4.4	0.771
E0500-055-3000					3.00	76.20					6.01	152.65	3.9	0.683
E0500-055-3500					3.50	88.90					7.19	182.63	3.2	0.560
E0500-055-4000					4.00	101.60					8.38	212.85	2.7	0.473
E0500-055-4500					4.50	114.30					9.56	242.82	2.3	0.403
E0500-055-5000					5.00	127.00					11.10	281.94	2.0	0.350
E0500-063-1250					1.25	31.75					1.63	41.40	46.9	8.21
E0500-063-1370					1.37	34.80					1.92	48.77	31.2	5.46
E0500-063-1500					1.50	38.10					2.17	55.12	25.5	4.47
E0500-063-1750					1.75	44.45					2.66	67.56	18.7	3.27
E0500-063-2000					2.00	50.80					3.16	80.26	14.8	2.59
E0500-063-2250					2.25	57.15					3.65	92.71	12.2	2.14
E0500-063-2500			0.063	1.60	2.50	63.50	18.80	83.63	1.70	7.56	4.12	104.65	10.4	1.821
E0500-063-2750					2.75	69.85					4.60	116.84	9.2	1.611
E0500-063-3000					3.00	76.20					5.10	129.54	8.1	1.419
E0500-063-3500					3.50	88.90					6.08	154.43	6.6	1.156
E0500-063-4000					4.00	101.60					7.07	179.58	5.5	0.963
E0500-063-4500					4.50	114.30					8.06	204.72	4.8	0.841
E0500-063-5000	0.500	12.70			5.00	127.00					9.04	229.62	4.2	0.736
E0500-069-1250					1.25	31.75					1.55	39.37	74.0	12.96
E0500-069-1370					1.37	34.80					1.78	45.21	54.3	9.51
E0500-069-1500					1.50	38.10					1.99	50.55	45.2	7.92
E0500-069-1750					1.75	44.45					2.45	62.23	31.3	5.48
E0500-069-2000					2.00	50.80					2.89	73.41	24.7	4.33
E0500-069-2250					2.25	57.15					3.33	84.58	20.3	3.56
E0500-069-2500			0.069	1.75	2.50	63.50	24.21	107.69	2.18	9.70	3.77	95.76	17.3	3.03
E0500-069-2750					2.75	69.85					4.24	107.70	14.8	2.59
E0500-069-3000					3.00	76.20					4.68	118.87	13.1	2.29
E0500-069-3500					3.50	88.90					5.56	141.22	10.7	1.874
E0500-069-4000					4.00	101.60					6.46	164.08	8.9	1.559
E0500-069-4500					4.50	114.30					7.34	186.44	7.8	1.366
E0500-069-5000					5.00	127.00					8.25	209.55	6.8	1.191
E0500-075-1250					1.25	31.75					1.51	38.35	107.7	18.86
E0500-075-1370					1.37	34.80					1.70	43.18	84.6	14.81
E0500-075-1500					1.50	38.10					1.90	48.26	69.7	12.20
E0500-075-1750					1.75	44.45					2.31	58.67	49.4	8.65
E0500-075-2000					2.00	50.80					2.73	69.34	38.2	6.69
E0500-075-2250					2.25	57.15					3.12	79.25	32.0	5.60
E0500-075-2500			0.075	1.91	2.50	63.50	30.51	135.71	2.75	12.23	3.53	89.66	26.9	4.71
E0500-075-2750					2.75	69.85					3.95	100.33	23.2	4.06
E0500-075-3000					3.00	76.20					4.34	110.24	20.8	3.64
E0500-075-3500					3.50	88.90					5.16	131.06	16.7	2.92
E0500-075-4000					4.00	101.60					5.97	151.64	14.1	2.47
E0500-075-4500					4.50	114.30					6.77	171.96	12.2	2.14
E0500-075-5000					5.00	127.00					7.60	193.04	10.7	1.874
E0650-055-1500					1.50	38.10					2.21	56.13	13.4	2.35
E0650-055-1750					1.75	44.45					3.16	80.26	6.8	1.191
E0650-055-2000					2.00	50.80					4.20	106.68	4.1	0.718
E0650-055-2250					2.25	57.15					5.13	130.30	3.2	0.560
E0650-055-2500	0.650	16.51	0.055	1.40	2.50	63.50	10.10	44.93	0.90	4.00	5.98	151.89	2.6	0.455
E0650-055-2750					2.75	69.85					6.94	176.28	2.2	0.385
E0650-055-3000					3.00	76.20					7.83	198.88	1.9	0.333
E0650-055-3500					3.50	88.90					9.61	244.09	1.5	0.263
E0650-055-4000					4.00	101.60					11.38	289.05	1.2	0.210
E0650-063-1500					1.50	38.10					2.06	52.32	24.8	4.34
E0650-063-1750			0.063	1.60	1.75	44.45	14.80	65.83	1.40	6.23	2.81	71.37	13.2	2.31
E0650-063-2000					2.00	50.80					3.61	91.69	8.3	1.454

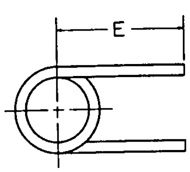
†For stainless steel, multiply values by 0.833.
**When inquiring or ordering, use letter "M" or letter "S" as suffix on catalog numbers to designate music wire or stainless-steel wire, respectively.*
***Initial tension is for reference only and may vary.*

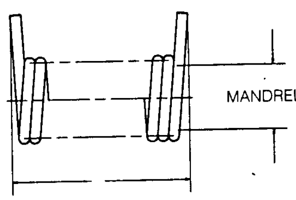
Torsion Springs

Stock sizes in stainless steel



LOADED POSITION
ALL PARTS





MIN. AXIAL SPACE

Associated Spring torsion springs are widely used to store and release energy of rotation or to maintain a pressure over a short distance. Our stock selection includes torsion springs with four end positions, as shown in the drawings on this page.

SPEC torsion springs are normally used over a supporting mandrel or arbor. Suggested mandrel sizes allow about 10% clearance at the deflections listed. If greater deflections are used, the arbor size should be reduced. Sufficient room (minimum axial space) must be provided in the assembly for the spring to function properly. The minimum axial space does not refer to the length of the coils.

SPEC torsion springs should be used in the direction that winds the coils. In the unwinding direction the maximum load is lower because of residual stresses.

Torque values listed are recommended maximum torques. These values can be increased about 20% for static conditions with only slight setting.

For inspection purposes the load should be applied at ½ leg length (E). Using other lengths appreciably alter the active length of wire and affect the test results.

The torque values listed can be translated to direct load by use of the formula $P = \frac{M}{E_n}$ where P is the load applied at the new leg length E_n. Example: For part T012-090-055, what is the load when $E_n = 0.187$? $P = \frac{M}{E_n} = \frac{0.047}{0.187} = 0.25$ lb.

The torque values listed will be attained at the deflections listed. Torque values at intermediate deflections can be computed by direct proration. Example: For part T030-180-250, the torque at 90 deg deflection is 0.312 in-lb.

Material

Stainless steel
Commercial Type 302 ASTM-A313 or
AMS 5688 (chemical & physical only)

No charge for certificate of compliance when requested; certificate of chemical analysis available, see price book.
See Page 77 for music wire torsion springs.

Direction of Helix

Must be specified by suffix to catalog number. Use L for left-hand wound, R for right-hand wound.

Ends

Straight torsion ends are standard.

Finish

Plain finish is standard. Allow additional time for special finishes.

Tolerances

Torque ±10%
O.D. ± 5%

Figures show springs wound left-hand

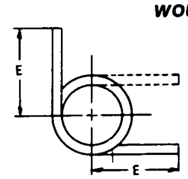


Fig. 1
90° Deflection

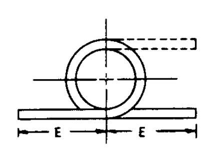


Fig. 2
180° Deflection

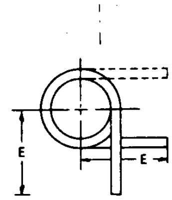


Fig. 3
270° Deflection

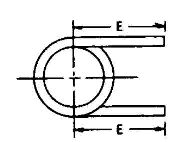


Fig. 4
360° Deflection

Dotted lines represent final loaded position.

73

STOCK TORSION SPRINGS
Stainless Steel

SPEC Associated Spring Raymond BARNES GROUP INC

CATALOG NUMBER*	Wire Diameter in	Wire Diameter mm	Outside Diameter in	Outside Diameter mm	Pos. of Ends, Fig.	Def., Deg.	Torque M in-lb	Torque M N-mm	Test Point ½ E in	Test Point ½ E mm	Suggested Mandrel Size in	Suggested Mandrel Size mm	E in	E mm	Min. Axial Space** in	Min. Axial Space** mm
T032-090-172			0.288	7.32	1	90			0.500	12.70	0.172	4.36	1.000	25.40	0.152	3.86
T032-180-156			0.270	6.86	2	180			0.500	12.70	0.156	3.96	1.000	25.40	0.272	6.91
T032-270-156	0.032	0.81	0.264	6.71	3	270	0.820	92.7	0.500	12.70	0.156	3.96	1.000	25.40	0.382	9.70
T032-180-218			0.366	9.30	2	180			0.500	12.70	0.218	5.54	1.000	25.40	0.208	5.28
T032-270-218			0.354	8.99	3	270			0.500	12.70	0.218	5.54	1.000	25.40	0.296	7.52
T032-360-234			0.382	9.70	4	360			0.500	12.70	0.234	5.95	1.000	25.40	0.352	8.94
T035-090-187			0.315	8.00	1	90			0.625	15.88	0.187	4.75	1.250	31.75	0.135	3.43
T035-180-187			0.303	7.70	2	180			0.625	15.88	0.187	4.75	1.250	31.75	0.290	7.37
T035-270-187	0.035	0.89	0.311	7.90	3	270	1.000	113.0	0.625	15.88	0.187	4.75	1.250	31.75	0.442	11.23
T035-180-281			0.450	11.43	2	180			0.625	15.88	0.281	7.14	1.250	31.75	0.212	5.38
T035-270-281			0.435	11.05	3	270			0.625	15.88	0.281	7.14	1.250	31.75	0.328	8.33
T035-360-312			0.471	11.96	4	360			0.625	15.88	0.312	7.92	1.250	31.75	0.405	10.29
T038-090-234			0.386	9.80	1	90			0.625	15.88	0.234	5.94	1.250	31.75	0.180	4.57
T038-180-218			0.368	9.35	2	180			0.625	15.88	0.218	5.54	1.250	31.75	0.323	8.20
T038-270-218	0.038	0.97	0.353	8.97	3	270	1.190	134.5	0.625	15.88	0.218	5.54	1.250	31.75	0.465	11.81
T038-180-312			0.487	12.37	2	180			0.625	15.88	0.318	8.08	1.250	31.75	0.247	6.27
T038-270-312			0.477	12.12	3	270			0.625	15.88	0.312	7.92	1.250	31.75	0.352	8.94
T038-360-328			0.514	13.06	4	360			0.625	15.88	0.328	8.33	1.250	31.75	0.418	10.62
T040-090-187			0.309	7.85	1	90			0.625	15.88	0.187	4.75	1.250	31.75	0.198	5.03
T040-180-218			0.348	8.84	2	180			0.625	15.88	0.218	5.54	1.250	31.75	0.374	9.50
T040-270-218	0.040	1.02	0.358	9.09	3	270	1.375	155.4	0.625	15.88	0.218	5.54	1.250	31.75	0.550	13.97
T040-180-343			0.518	13.16	2	180			1.000	25.40	0.343	8.71	2.000	50.80	0.242	6.15
T040-270-343			0.511	12.98	3	270			1.000	25.40	0.343	8.71	2.000	50.80	0.374	9.50
T040-360-343			0.507	12.88	4	360			1.000	25.40	0.343	8.71	2.000	50.80	0.508	12.90
T045-090-203			0.357	9.07	1	90			0.625	15.88	0.203	5.16	1.250	31.75	0.259	6.58
T045-180-218			0.377	9.58	2	180			0.625	15.88	0.218	5.54	1.250	31.75	0.427	10.85
T045-270-234	0.045	1.14	0.382	9.70	3	270	2.000	226.	0.625	15.88	0.234	5.94	1.250	31.75	0.595	15.11
T045-180-359			0.575	14.61	2	180			1.000	25.40	0.359	9.12	2.000	50.80	0.293	7.44
T045-270-359			0.556	14.12	3	270			1.000	25.40	0.359	9.12	2.000	50.80	0.415	10.54
T045-360-359			0.549	13.94	4	360			1.000	25.40	0.359	9.12	2.000	50.80	0.540	13.72
T048-090-218			0.375	9.53	1	90			0.625	15.88	0.218	5.54	1.250	31.75	0.238	6.05
T048-180-250			0.404	10.26	2	180			0.625	15.88	0.250	6.35	1.250	31.75	0.450	11.43
T048-270-250	0.048	1.22	0.416	10.57	3	270	2.500	282.	0.625	15.88	0.250	6.35	1.250	31.75	0.660	16.76
T048-180-406			0.618	15.70	2	180			1.000	25.40	0.406	10.31	2.000	50.80	0.292	7.42
T048-270-406			0.600	15.24	3	270			1.000	25.40	0.406	10.31	2.000	50.80	0.450	11.43
T048-360-406			0.594	15.09	4	360			1.000	25.40	0.406	10.31	2.000	50.80	0.610	15.49
T051-090-234			0.408	10.36	1	90			1.000	25.40	0.234	5.94	2.000	50.80	0.293	7.44
T051-180-250			0.430	10.92	2	180			1.000	25.40	0.250	6.35	2.000	50.80	0.485	12.32
T051-270-266	0.051	1.30	0.439	11.15	3	270	2.900	328.	1.000	25.40	0.266	6.76	2.000	50.80	0.675	17.15
T051-180-344			0.556	14.12	2	180			1.000	25.40	0.344	8.74	2.000	50.80	0.382	9.70
T051-270-359			0.571	14.50	3	270			1.000	25.40	0.359	9.12	2.000	50.80	0.522	13.26
T051-360-406			0.628	15.95	4	360			1.000	25.40	0.406	10.31	2.000	50.80	0.615	15.62
T054-090-296			0.484	12.29	1	90			1.000	25.40	0.296	7.52	2.000	50.80	0.310	7.87
T054-180-312			0.509	12.93	2	180			1.000	25.40	0.312	7.92	2.000	50.80	0.512	13.00
T054-270-312	0.054	1.37	0.514	13.06	3	270	3.275	370.	1.000	25.40	0.312	7.92	2.000	50.80	0.715	18.16
T054-180-421			0.654	16.61	2	180			1.000	25.40	0.421	10.69	2.000	50.80	0.405	10.26
T054-270-437			0.664	16.61	3	270			1.000	25.40	0.437	11.10	2.000	50.80	0.555	14.10
T054-360-453			0.694	16.61	4	360			1.000	25.40	0.453	11.51	2.000	50.80	0.705	17.91
T059-090-296			0.499	12.67	1	90			1.000	25.40	0.296	7.52	2.000	50.80	0.340	8.64
T059-180-328			0.526	13.36	2	180			1.000	25.40	0.328	8.33	2.000	50.80	0.560	14.22
T059-270-328	0.059	1.50	0.537	13.64	3	270	4.200	475.	1.000	25.40	0.328	8.33	2.000	50.80	0.785	19.94
T059-180-437			0.681	17.30	2	180			1.000	25.40	0.437	11.10	2.000	50.80	0.445	11.30
T059-270-453			0.699	17.75	3	270			1.000	25.40	0.453	11.51	2.000	50.80	0.605	15.37
T059-360-459			0.709	18.01	4	360			1.000	25.40	0.459	11.66	2.000	50.80	0.770	19.56
T063-090-343			0.560	14.22	1	90			1.000	25.40	0.343	8.71	2.000	50.80	0.362	9.19
T063-180-359			0.591	15.01	2	180			1.000	25.40	0.359	9.12	2.000	50.80	0.600	15.24
T063-270-375	0.063	1.60	0.600	15.24	3	270	5.150	582.	1.000	25.40	0.375	9.53	2.000	50.80	0.835	21.21
T063-180-500			0.767	19.48	2	180			1.000	25.40	0.500	12.70	2.000	50.80	0.475	12.07
T063-270-516			0.784	19.91	3	270			1.000	25.40	0.516	13.11	2.000	50.80	0.645	16.38
T063-360-516			0.798	20.27	4	360			1.000	25.40	0.516	13.11	2.000	50.80	0.820	20.83
T070-090-359			0.593	15.06	1	90			1.000	25.40	0.359	9.12	2.000	50.80	0.400	10.16
T070-180-390			0.625	15.88	2	180			1.000	25.40	0.390	9.91	2.000	50.80	0.665	16.89
T070-270-390	0.070	1.78	0.639	16.23	3	270	7.000	791.	1.000	25.40	0.390	9.91	2.000	50.80	0.930	23.62
T070-180-515			0.810	20.57	2	180			1.000	25.40	0.515	13.08	2.000	50.80	0.525	13.34
T070-270-531			0.826	20.98	3	270			1.000	25.40	0.531	13.49	2.000	50.80	0.717	18.21
T070-360-546			0.843	21.41	4	360			1.000	25.40	0.546	13.87	2.000	50.80	0.910	23.11

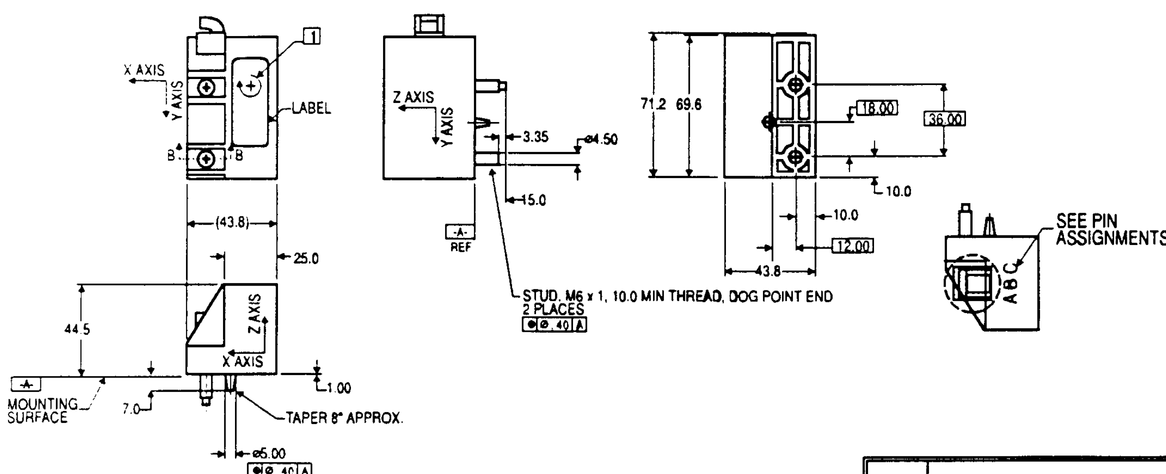
***Indicate direction of helix desired by suffix to catalog number — L for left hand wound, R for right hand wound.**
****Space needed on application to allow for operation of the spring. This dimension does not refer to the length of the coils.**

BEI SYSTRON DONNER INERTIAL DIVISION
SENSORS & SYSTEMS COMPANY

GyroChip®
Solid State Gyroscope

FIRST Project
AQRS-00064-109

PARAMETER	SUMMARY SPECIFICATION
POWER REQUIREMENTS	
Operating Voltage	+5 VDC ±0.25 VDC
Operating Current	20 mA (max.)
PERFORMANCE (typical for 5 Volt input)	
Range*	±64°/sec
Scale Factor*	
Full Range Output	+0.25 to +4.75 VDC
Nominal	35.16 mV/°/sec
Bias*	
Bias at Ambient	+2.50 VDC ±0.5
Bandwidth (90°)	>50 Hz
* Note: Output is ratiometric to supply voltage.	
ENVIRONMENTS	
Operating Temperature	70°F to 90°F
Storage Temperature	-40°F to +185°F
Vibration Operating	1.5 g RMS, 20 to 2,000 Hz
WEIGHT	125 grams max.

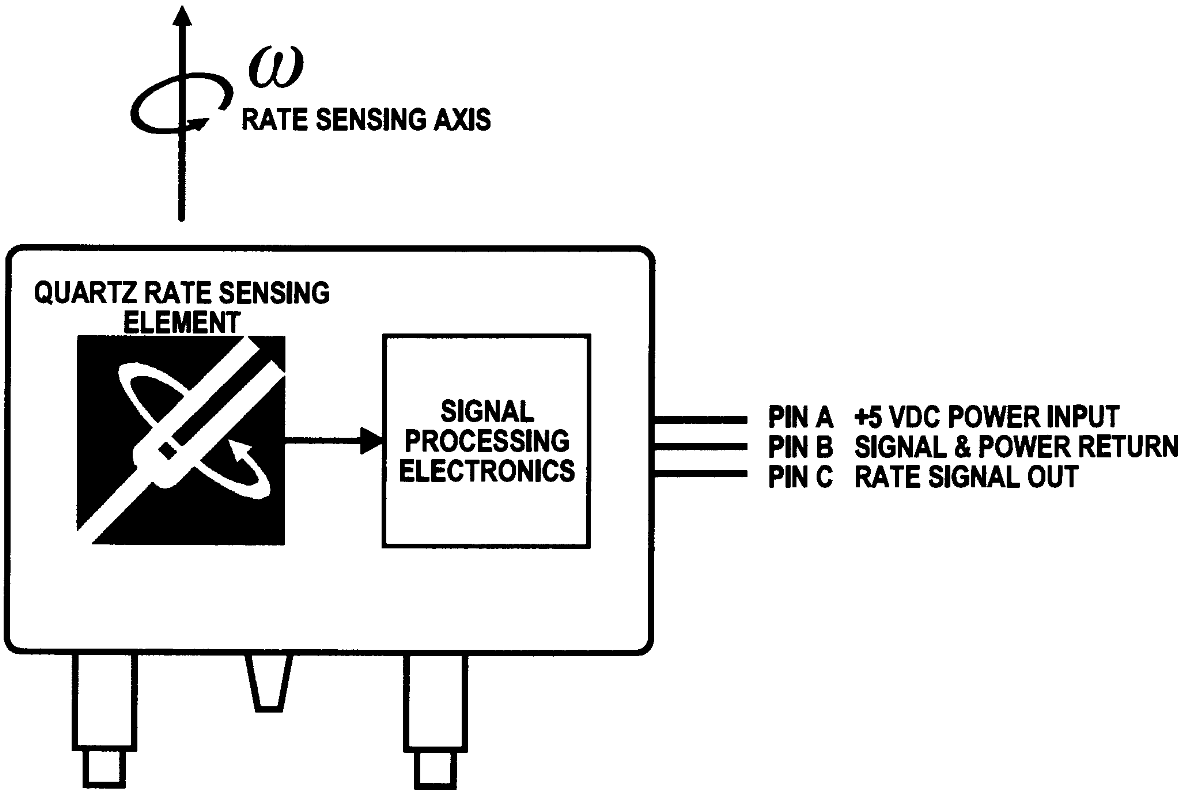


Not Supplied:
Mating Connector Kit (Pioneer Standard)
3 WAY Female – P/N 12064758 (1 ea.)
Terminal Female – P/N 12047767 (3 ea.)

NOTES:
1. ANGULAR RATE APPLIED AS SHOWN SHALL PRODUCE A MORE POSITIVE OUTPUT.
2. DIMENSIONS SHOWN ARE IN MILLIMETERS

Pin	Assignment
A	+5 VDC Input
B	Common
C	Rate Out (1Kohm output impedance)

Systron Donner Inertial Division • 2700 Systron Drive • Concord, California 94518 • Toll Free: (800) 227-1625
Sales: (925) 671-6601 • Customer Service: (925) 671-6499 • FAX: (925) 671-6647
European Business Office (Ashford, England): 44 1303 812778 • FAX: 44 1303 812708



Quartz Rate Sensor "GyroChip®"

NOTES:

- Rate Sensor Output is ratiometric to input power line voltage over the range of +4.75 to +5.25 VDC.
- Full scale factor rate range is ±64°/sec.
- Output signal is symmetrical about a +2.5 VDC (nominal) bias.
- Output Impedance is 1KΩ or less.

NOT SUPPLIED:
Mating Connector Kit (Pioneer Standard)
3 Way Female - P/N 12064758 (1 ea.)
Terminal Female - P/N 12047767 (3 ea.)

12/98:FIRSTOD.CDR:JSAS

BEI SYSTRON DONNER INERTIAL DIVISION
SENSORS & SYSTEMS COMPANY

A Quartz Rotational Rate Sensor

Based on inertial-sensing principles, the quartz rate sensor provides a simple, reliable measurement of rotational velocity.

The use of a vibrating element to measure rotational velocity by employing the Coriolis principle is a concept that has been around for more than 50 years. In fact, the idea developed long ago out of the observation that a certain species of fly uses a pair of vibrating antennae to stabilize its flight. This sensing technique has been given a practical embodiment: the quartz rate sensor (QRS).

THEORY OF OPERATION

To understand how the QRS works requires familiarity with the Coriolis principle. Simply stated, this means that a linear motion within a rotating framework will have some component of velocity that is perpendicular to that linear motion.

The handiest example of the Coriolis effect is that exhibited by wind patterns on Earth. Convection cells in the atmosphere set up a wind flow from the poles toward the equator (with a north-south orientation). The Earth's rotation, however, causes these linear flows to develop a sideways (orthogonal) component of motion. This "bends" the wind from a north-south to an east-west direction. It is the Coriolis effect that creates the east-west "trade winds," and which is responsible for the spirals of clouds observed in satellite photos.

Now let's apply this principle to our rotation sensor. In Figure 1 you can see that the QRS is essentially divided into two sections: drive and pickup.

The drive portion looks and acts exactly like a simple tuning fork. Because the drive tines are constructed of crystalline quartz, it is possible to electrically "ring" this tuning fork. Each fork tine has a mass and an instantaneous radial velocity that changes sinusoidally as the tine moves back and forth. As long as the fork's base is stationary, the momenta of the two tines exactly cancel each other and there is no energy transfer from the tines to the base. In fact, it takes only ~ 6 µW of power to keep the fork ringing.

As soon as the tuning fork is rotated around its axis of symmetry, however, the Coriolis principle exerts a profound influence on the behavior of this mechanism.

By convention (the "right-hand rule"), the rotational vector ω_i is described by an arrow that is aligned with the axis of rotation. The instantaneous radial velocity of each of the tines will, through the Coriolis effect, generate a vector cross-product with this rotation vector.

The net effect is that each tine will generate a force perpendicular to the instantaneous radial velocity of each of the other tines:

$$F = 2\,m\omega_i \bullet V_r \qquad (1)$$

where:

m = tine mass
ω_i = rotation rate
V_r = radial velocity

Note that this force is directly proportional to the rotation rate, and since the radial velocity of the tines is sinusoidal, the resultant force on each tine is also sinusoidal. Because the radial velocities of the two tines are equal and opposite,

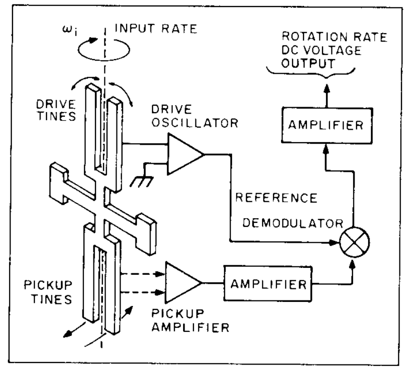


Figure 1. *An oscillating tuning fork senses rotational velocity by using the Coriolis force to translate the linear motion of the tines into an oscillating torque. This torque value is demodulated at the oscillation frequency to generate a DC voltage proportional to the rotation rate input.*

the Coriolis forces are equal and opposite, producing an oscillating torque at the base of the drive tine fork that is proportional to the input angular rate.

The pickup portion of the QRS now comes into play. The sinusoidal torque variation causes the pickup tines to begin moving tangentially to the rotation and at the same frequency as the drive vibration. Since the forces causing the pickup tines to move are directly proportional to the rotation rate, if there is no rotation the pickup tines will not move. The QRS can therefore truly detect a zero rotation input.

Once the pickup tines are in motion, it is a simple matter to amplify the pickup signal and then demodulate it using the drive frequency as a reference. One additional stage of amplification allows for some signal shaping and produces a DC signal output that is directly propor-

Scott D. Orlosky and Harold D. Morris, Systron Donner, a BEI Electronics Company

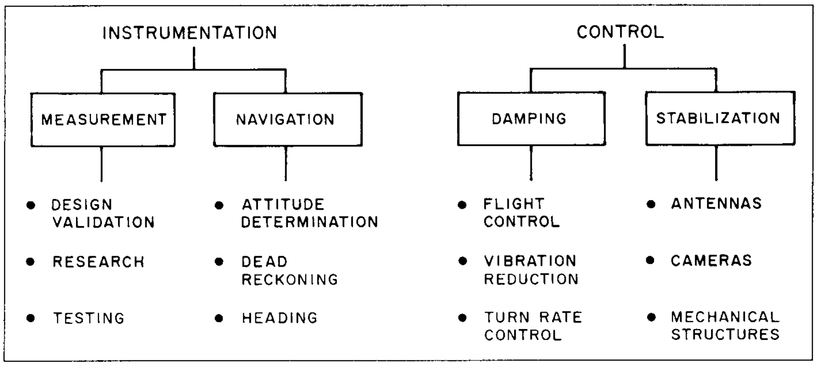


Figure 2. *A variety of instrumentation and control applications can benefit from rotational velocity as a means of improving designs, adding navigational capability to autonomous vehicles, and damping out unwanted motions of control surfaces or gimballed platforms.*

tional to the input angular rate. All of the electronics are fairly simple, and can be contained within the same package as the sensing element.

CONSTRUCTION

The QRS is fabricated from a wafer of single-crystal, synthetically grown quartz. The material's piezoelectric properties are particularly stable over temperature and time. Quartz exhibits a high modulus of elasticity and therefore can be made to ring very precisely with a high Q (quality factor). In addition, quartz can be worked by using conventional wet chemical etch production techniques similar to those favored by the semiconductor industry for producing chips.

APPLICATIONS

Until recently, the most common rotation sensors based on the principles of inertial mechanics were spring-restrained spinning-wheel gyroscopes. These tend to be large and heavy, and to consume large quantities of power. They also tend to wear out after only a few thousand hours of operation and so cannot be used continuously for long periods of time. Their use has been restricted to highly specialized applications such as in military aircraft and missiles, where the short mission times and availability of maintenance personnel made their use practical. By contrast, QRS technology, with its MTBF >100,000 hours and the low cost of ownership, is attractive to industrial and commercial customers as well. QRS applications fall into two broad categories: open-loop, or instrumentation applications; and closed-loop, or control applications (see Figure 2).

INSTRUMENTATION

These applications involve either instrumenting a structure for purposes of determining its rates of rotational motion (measurement), or processing that information in real time to generate information about orientation (navigation). Typical examples of rotational velocity measurement include instrumenting vehicles for crash studies, determining dynamics of specific platforms (e.g., boats, trains, robots, or even human beings), and environmental measurements such as earthquakes and wave motions.

Measurement. One key element in measurement system design is to determine the peak rotational velocities involved to ensure that an instrument with the proper range is used. If the selected range of the QRS is too low, the output will be clipped and valuable information will be lost.

A fairly straightforward way to determine the correct range requirement is to establish two parameters: the frequency of movement of the structure to be instrumented; and the peak angular displacement of that movement. Let's assume that we want to determine the dynamics of a vehicle's body roll while it takes a turn. The body roll motion can be described as:

$$\theta = A \bullet \sin(2\pi \bullet F_n \bullet t) \text{ in degrees} \quad (2)$$

where:

A = amplitude of movement
F_n = frequency of movement

The parameter of interest for measuring angular velocity is the change in angular position with time, or $(d\theta/dt)$. Taking the derivative of the above equation:

$$(d\theta/dt) = A \bullet 2\pi \bullet F_n \bullet \cos(2\pi \bullet F_n \bullet t) \quad (3)$$

Let's assume that the natural frequency of the vehicle suspension system is 6 Hz, and the peak body roll is 10°. By substituting these into Equation 3:

$$\begin{aligned}(d\theta/dt) &= 10 \bullet 2\pi \bullet 6 \bullet \cos(2\pi \bullet 6 \bullet t) \\ &= 377 \bullet \cos(37.7 \bullet t)°/s \quad (4)\end{aligned}$$

Since the cosine term has a maximum value of 1, the peak rotational velocity is 377°/s. So even a seemingly benign environment, a 10° roll at 6 Hz, generates fairly high peak rotational velocities.

Navigation. Navigation applications are becoming increasingly interesting for the QRS, expecially in light of the availablity of GPS receivers at a reasonable cost. In principle, by reading the output from the rotation sensor (rotational velocity) and integrating this output over time, it is possible to determine the sensor's angular displacement. A QRS can be used for sensing vehicle yaw as part of a navigation package (see Figure 3).

SYSTEM COMPONENTS

Anti-Aliasing Filter. Because a computer interface requires the use of an analog-to-digital (A/D) converter, the output from the QRS becomes part of a sampled data stream. In order to prevent aliasing of the output, a filter must be used with the corner frequency usually set at 1/4 to 1/2 of the sampling frequency.

A/D Converter. The A/D conversion should be carried out immediately after anti-aliasing since this puts the converter close to the QRS and reduces the overall noise of the system, yielding the most stable results. A 12-bit converter is generally adequate. The sample frequency should be appropriate for the system, but typical values range from 100 Hz to 1000 Hz.

Bandpass Filter. This filter is tailored to the specific application. When the sensor is used as part of a head-mounted display for a virtual reality application, for example, it is not necessary to track very small, high-frequency head movements because they may simply be part of the normal jostling associated with interactive game playing. Only larger, definite head swings need attention.

Similarly, low-frequency variations in the QRS output, which are usually associated with changes in environmental temperatures or warm-up, are not meaningful tracking information and should be rejected.

These two scenarios determine the lower and upper ranges of the bandpass filter. A reasonable starting point would be to choose upper and lower corner frequencies of 0.1 Hz and 10 Hz.

Integrator. This is where the angular velocity information is turned into angular position. Since the initial conditions are indeterminate at start-up, it is recommended that a reset capability be included. This allows you to initialize the integrator to zero or some known position at startup.

The portion of the platform that is to be measured must usually be held very steady during startup so that the initial conditions represent as closely as possible a true "zero input" state. Any residual error at startup will cause the apparent output from the integrator to drift.

One method to reduce the startup error is to average the input to the integrator for a few seconds during the initialization sequence, and then subtract this average value to establish the zero point.

As a practical matter, it is virtually impossible to measure the "pure" rotational velocity without introducing or reading some error at the same time. This accumulation of errors means that over time, the true angular position and the calculated angular position will diverge. The sensor output may not be drifting, but the apparent calculated angle is.

The rate of this divergence is determined by a variety of factors including: how well the initial conditions are established; the accuracy of the alignment of the sensor to the true axis of rotation; the quantization errors of the signal (if it has been digitized); and the stability of the environment in which the measurement is being done.

For most practical applications, therefore, the QRS is used only for short-term navigation. In order to prevent these incremental errors from growing too large, the common practice is to periodically update, or correct, the calculated angle

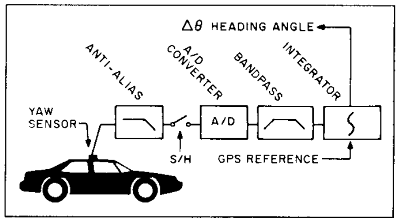


Figure 3. *By combining the quartz rotation sensor (QRS) with a fixed reference such as a GPS receiver, a complete navigation system can be created for an automobile. Attention to signal processing design as well as to blending the GPS reference signal produces a system that can cope with extended GPS blackouts.*

through the use of a fixed, external reference as shown in Figure 3.

The reference selected will depend on the situation; examples include a GPS signal, a corner-cube with optical line-of-sight, or an encoded magnetic signal. In fact, the combination of dead reckoning between fixed reference updates is a nearly ideal means of navigation through a variety of dynamic environments.

This method has been used for autonomous delivery robots in hospitals, automated forklifts in warehouses, and emergency vehicles deployed in urban environments.

CONTROL

To employ the QRS in control applications requires an understanding of how it works as part of a system. The typical system model takes into account the magnitude and phase relationships of the sensor response.

Damping. The ability to accurately measure rotational velocity opens up new possibilities for control of structures. One of the most useful types of

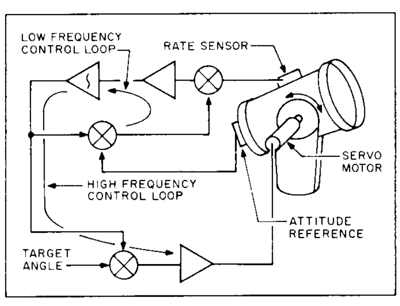


Figure 4. *As part of an attitude control system for a mobile telescope, the QRS can be combined with a simple tilt sensor to provide both absolute pointing accuracy as well as stability. Rapid motions are compensated for in the high-frequency control loop, while the low-frequency control loop provides a vertical reference to gravity.*

control applications is to damp out the resonant behavior of mechanical systems. Very few mechanical systems produce pure linear motion—most machines have parts that rotate or pivot. Aircraft, land vehicles, and ships are governed by means of roll, pitch, and/or yaw controls. By monitoring and controlling these motions it is possible to provide active roll damping on ships, remove "Dutch roll" from aircraft flight, reduce body roll on a car as it takes a turn, or damp out end-effector shake in an industrial robot.

Stabilization. This is a special instance of closed-loop control—stabilization—in which the item being controlled is intended to remain stationary even during movement of the platform to which it is attached. It is important that the QRS be tightly coupled mechanically to the object to be controlled, usually a camera or an antenna on a multi-axis gimbal. This gimbal mechanism must have no mechanical resonances in the bandwidth of the servo-control loop.

The system designer must take into account the transfer function of the system servo-loop and ensure enough phase margin to prevent oscillation. Because it is often necessary to independently move the camera or antenna, a commandable DC offset must be included in the control loop to allow an operator to rotate and point the camera in the gimbal. This method has been used successfully to stabilize antennas aboard ships and land vehicles, as well as cameras aboard helicopters and survey airplanes.

An example of such an application is shown in Figure 4. Here, the QRS is used as part of a servo-control loop to provide an absolute pointing angle in attitude as well as image stability for a mobile telescope.

For simplicity it is assumed that the telescope is mounted on a platform that can rotate only in attitude, and that the control mechanism is therefore an attitude control system only. The principle described can be applied to the other axes of rotation.

Refer first to the high-frequency control loop portion of Figure 4. Assume that this circuit is designed to operate at 10 Hz, which is a typical value for a servo control. Let's further assume that the telescope has a rotational inertia J =

12 slug-ft^2.

$$\text{Since: } \omega_n^2 = K_s/J$$
$$\text{then: } K_s = (10 \cdot 2 \cdot \pi)^2 \cdot 12 = 47{,}300 \text{ ft-lb./rad} \quad (5)$$

where:

ω_n = corner frequency of servo-loop
K_s represents the servo stiffness

The preceding implies that an external torque of 10 ft-lb. will allow a movement of only 10/47,300 = 0.0002 rad, or 0.7 arc-min.

Now let's look at the low-frequency control loop portion of Figure 4. This will act as a vertical reference unit and ensure that the absolute pointing angle of the telescope matches the commanded (or target) angle. To accomplish this, a stable, long-term attitude reference must be provided.

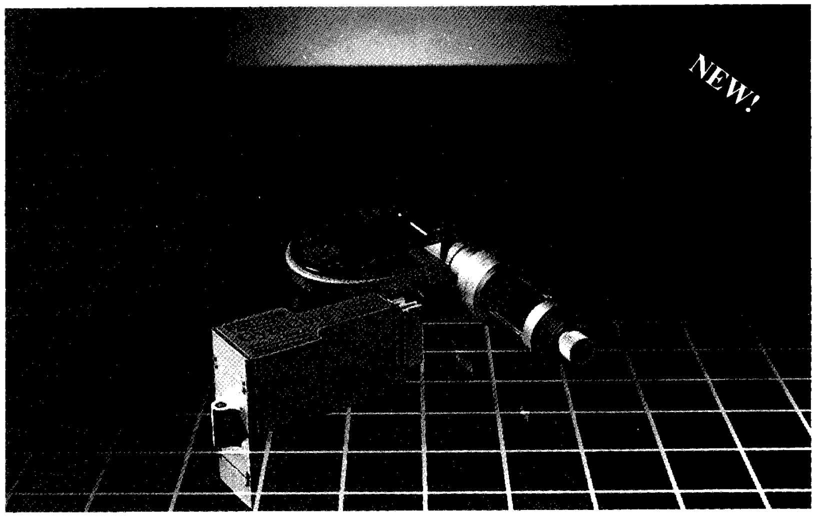
For most systems, gravity does the job quite nicely. A simple tilt sensor is always referenced to local gravity, and over a fairly narrow range it will behave linearly. To avoid coupling-in any high-frequency movements that are, by definition, not gravity related, this reference is part of a control loop with a time constant of typically 100 s. This allows the attitude reference to closely follow the typical platform motions you might find on most common mobile platforms, i.e., ships, trains, or planes.

In general, the loop will incorporate a proportional and differential control element that does not appear in the figure.

SUMMARY

A new type of sensor has been developed that can add significantly to the capabilities of engineers and designers alike. Based on inertial-sensing principles, the quartz rate sensor provides a simple, reliable measurement of rotational velocity that can be used to instrument structures in new ways and gain a more in-depth insight into designs; to aid in short-term navigation of autonomous mobile platforms; and to allow for improved methods of stabilizing structures.

Scott D. Orlosky is Director for Commercial Business and Harold D. Morris is Chief Scientist, Systron Donner Inertial Division, a BEI Electronics Company, 2700 Systron Dr., Concord, CA 94518; 510-671-6601, fax 510-671-6647.



Introducing a Solid-state Rate Sensor That Rivals the GyroChip.™

GyroChip II.

The makers of the GyroChip precision solid-state rotation sensor now offer the GyroChip II: a smaller, lighter, lower-cost rate sensor with all the precision manufacture and rugged reliability of the original.

The GyroChip II comes in two models: Standard, for use with battery systems (+12 V) and single-sided power supplies, and Low-noise, for use with double-sided (±15 V) supplies. Both models feature built-in power regulation and DC-in, DC-out operation.

The GyroChip II is ideal for:

- Servo Control
- Robotics
- Short Term Navigation
- GPS Augmentation
- Camera Stabilization
- Instrumentation

No matter how you use it, the GyroChip II gives you the assurance of quality that comes from our decades of experience in instrument design and manufacture.

BEI SYSTRON DONNER INERTIAL DIVISION
BEI Sensors & Systems Company

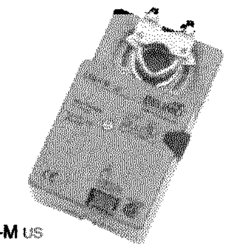
If It Moves, GyroChip It!

2700 Systron Drive, Concord, CA 94518-1399 • USA: (800) 227-1625 or (510) 671-6601 • Customer Service: (510) 671-6464 • FAX: (510) 671-6647
European Business Office • Tel: 44 1304216-281 • FAX: 44 1304214-638

World Wide Web: http://www.systron.com

BELIMO **LM24-M (-10P-M) US Special Application Actuator**

DC, reverse polarity control



LM24-M US

Torque 35 in-lb nominal

LM24-M US
LM24-10P-M US

Application

The LM24-M and LM24-10P-M actuators are designed for special, OEM control manufacturer use only. Actuator sizing should be done in accordance with the damper manufacturer's specifications. The actuator mounts directly to the damper operating shaft with a universal V-bolt clamp assembly.

Technical Data	LM24-M (-10P-M) US
Power supply	0 to 14 VDC (6 VDC nominal)
Maximum current source	35 mA (above this level will damage DC motor)
Power consumption	< 1 watt, based on controller circuit design
Electrical connection	5-pin, right-angle, Molex part #22-05 3051
Overload protection	None, must be provided by control manufacturer
Feedback	10 KΩ, 1 watt (LM24-10P-M only)
Angle of rotation	95°, adjust. with mechanical stops
Torque	35 in-lb [4Nm] nominal, function of motor control circuit
Direction of rotation	controlled by DC motor control circuit
Running time	80 to 110 sec. dependent on torque and motor control circuit
Manual override	external push button
Humidity	5 to 95% RH,
Ambient temperature	-22°F to +122°F [-20°C to +50°C]
Storage temperature	-40°F to +176°F [-40°C to +80°C]
Housing type	NEMA type 1
Housing material	UL94-5V
Noise level	less than 35 dB (A)
Servicing	maintenance free
Agency listings	UL873, CSA 4813 02 certified, CE
Quality standard	ISO 9001
Weight	1.2 lbs. [0.55 kg.]

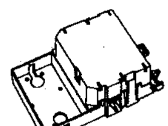
Operation

This series actuator does not incorporate any overload protection. The actuator is provided with a right-angle, 5-pin Molex connector which is wired directly to the internal DC motor (and 10K potentiometer in the LM24-10P-M). The direction of rotation is changed by reversing the polarity of the DC power to the DC motor. The OEM control manufacturer must design the control circuit, incorporating the overload protection, to control the actuator DC motor. A recommended, proven, sample circuit is provided by Belimo to the control manufacturer. Available only in 48-unit bulk packaging.

Note: Since Belimo does not provide the actuator control circuit, only the gear box is covered under warranty.

Accessories

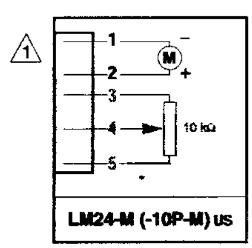
ZS-LM01 series	actuator/controller housing
Tool-02	8 mm wrench
LM-PL	L-type anti-rotation bracket
LM-P	T-type anti-rotation bracket



ZS-LM01

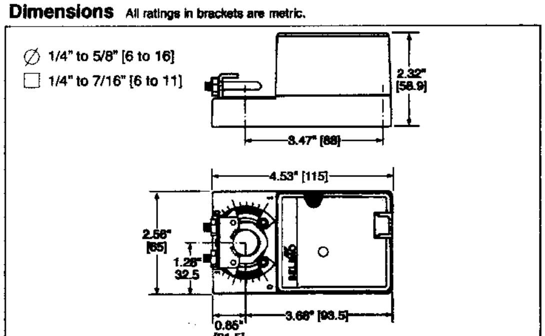
Typical Specification:
Control damper actuators shall be electronic direct coupled type which require no crank arm and linkage. Actuators shall be UL, CSA and CE listed, have a 2 year gear box warranty, and be manufactured under ISO 9001 International Quality Control Standards. Actuators shall have a manual override on the cover. Actuator will be provided with a right angle 5 pin Molex connector for electrical connections. If required, actuators shall be provided with a built-in 10 kΩ potentiometer (LM24-10P-M US). Actuators shall be as manufactured by Belimo.

Internal wiring of LM24-M (-10P-M) US



⚠1 Overload circuit for DC motor must be provided by control manufacturer.

Dimensions All ratings in brackets are metric.

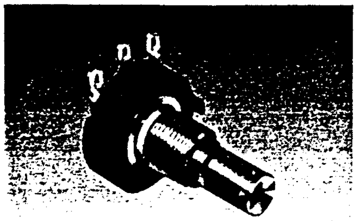


Belimo Torque Motor application note.

This device provides a reversible moment with a relatively large amount of torque, but at a low rotational speed over a limited angle of rotation determined by adjustable mechanical stops. It contains a low power motor connected to a large ratio gear train, and has a manual push button override that mechanically disengages the motor from the gear train. Output is provided by an integral V-bolt clamp assembly designed to be clamped to a round shaft.

There is no internal current limiting protection incorporated in the Torque Motor. At 12V operation its no load current draw is approximately 10mA and stall current is around 110mA. The power dissipation of the motor at stall condition is 1.3W. Although this is a low value, it is recommended that teams using the Torque Motor incorporate limit switches or some form of control system feedback in their robot's design to shut off current to the motor before the mechanical stops come into play.

Bourns



BOURNS®

3/4" (19MM) DIAMETER / CERMET OR CONDUCTIVE PLASTIC

- Single-turn (3851 and 3852)
- 3 -3/4-turn (3856)
- Minimal depth package
- Good resolution
- Linear and audio tapers
- Wide resistance range

FOR ORDERING INFORMATION SEE PAGE 258.

Models 3851/3852/3856

Bourns® Panel Controls

Initial Electrical Characteristics[1]	3851 Conductive Plastic Element	3852/3856 Cermet Element
Standard Resistance Range		
Linear Tapers (A, B, E, and H)	1K to 2.5 megohms	50 ohms to 5 megohms
audio Tapers (C, D, F, and G)	750 ohms to 2.5 megohms	1K ohms to 2.5 megohms
Resistance Tolerance	±20%	±10%
Zero Base Linearity	(B, D, & G tapers) ±20% (E taper) ±10%	(A, C, & F tapers) ±10% (H taper) ±5%
Independent Linearity	±10%	(A & H tapers) ±5%
Absolute Minimum Resistance	2 ohms maximum	2 ohms maximum
Continuity	Maintained for full mechanical angle	Maintained for full mechanical angle
Effective Electrical Angle	250° ±5°	250° ±5°
Contact Resistance Variation	±1%	±3% of total resistance or 3 ohms (whichever is greater)
Dielectric Withstanding Voltage	MIL-STD-202, Method 301	MIL-STD-202, Method 301
Sea Level	900 VAC minimum	900 VAC minimum
70,000 Feet	350 VAC minimum	350 VAC minimum
Insulation Resistance (500 VDC)	1,000 megohms minimum	1,000 megohms minimum
Power Rating (Voltage Limited By Power Dissipation or 316 VAC, Whichever Is Less)		
+70°C	(B & E tapers) 1 watt	(A & H tapers) 2 watts
	(D & G tapers) 0.5 watt	(C & F tapers) 1 watt
+125°C	0 watt	
+150°C		0 watt
Theoretical Resolution	Essentially infinite	Essentially infinite

Environmental Characteristics[1]		
Storage Temperature Range	-65°C to +125°C	-65°C to +150°C
Temperature Coefficient Over Storage Temperature Range	±1,000PPM/°C	±150PPM/°C
Vibration	20G	20G
Total Resistance Shift	±2% maximum	±2% maximum
Voltage Ratio Shift	±5% maximum	±6% maximum
Shock	100G	100G
Total Resistance Shift	±2% maximum	±2% maximum
Voltage Ratio Shift	±5% maximum	±6% maximum
Load Life	1,000 hours	1,000 hours
Total Resistance Shift	±10% maximum	±3% maximum
Rotational Life (No Load)	100,000 cycles	50,000 cycles
Total Resistance Shift	±15% maximum	±5% or 5 ohms (whichever is greater)
Moisture Resistance	MIL-STD-202, Method 103, Condition B	MIL-STD-202, Method 103, Condition B
Total Resistance Shift	±10% maximum	±2% maximum
Insulation Resistance (500 VDC)	100 megohms minimum	100 megohms minimum

Mechanical Characteristics[1]		
Shaft Torque	(A & B bushings) .05 to 6.0 oz.-in. (0.35 to 4.23 Ncm) (C & E bushings) 0.3 to 6.0 oz.-in. (0.21 to 4.23 Ncm)	3852 (A & B bushings) 0.5 to 6.0 oz.-in. (0.35 to 4.23 Ncm) (C & E bushings) 0.3 to 6.0 oz.-in. (0.21 to 4.23 Ncm) 3856 — 0.15 to 3.0 oz.-in. (0.11 to 2.12 Ncm)
Stop Strength	5 in.-lb. (56.5 Ncm)	5 in.-lb. (56.5 Ncm)
Mechanical Angle	280° ±5°	3852 — 280° ±5 3856 — 1350° ±50°
Weight	30 grams maximum	30 grams maximum
Terminals	Printed circuit terminals or solder lugs	Printed circuit terminals or solder lugs
Marking	Manufacturer's trademark, wiring diagram, date code, resistance, manufacturer's part number manufacturer's part number	Manufacturer's trademark, wiring diagram, date code, resistance, manufacturer's part number resistance, manufacturer's part number

[1]At room ambient: +25°C nominal and 50% relative humidity nominal, except as noted

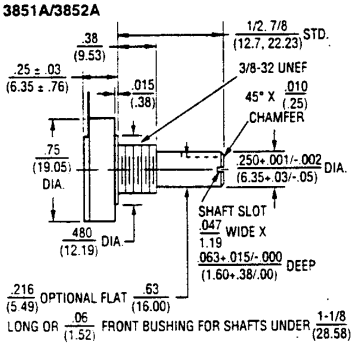
Specifications are subject to change without notice.

255

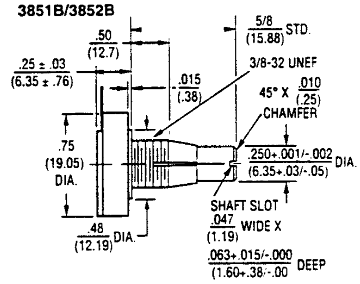
BOURNS®

DIMENSIONAL DRAWINGS AND TOLERANCES
Model 3851/3852/3856

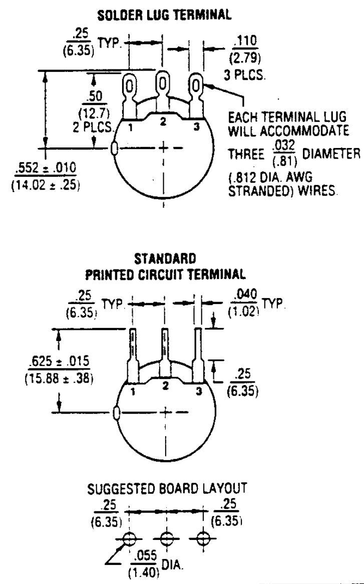
3851A/3852A



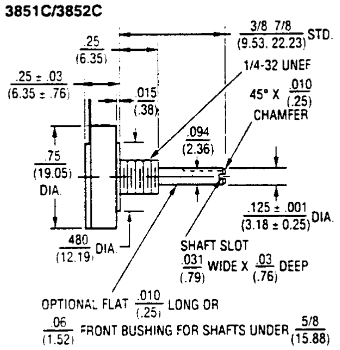
3851B/3852B



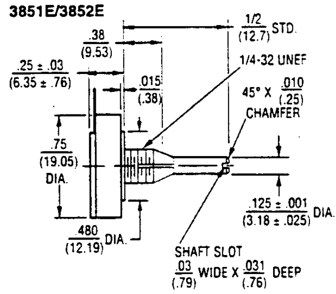
Terminal Configuration



3851C/3852C

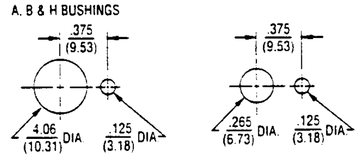


3851E/3852E

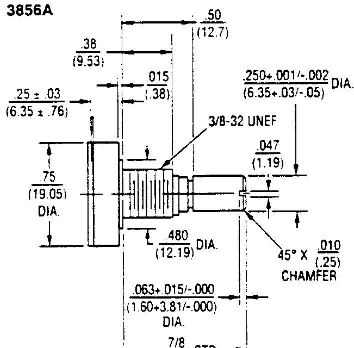


3851/3852/3856

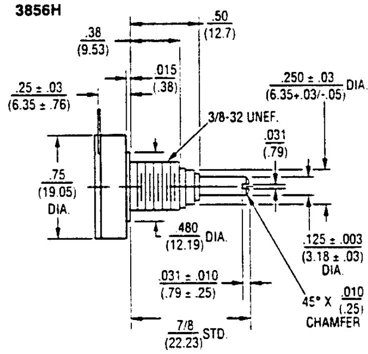
A, B & H BUSHINGS



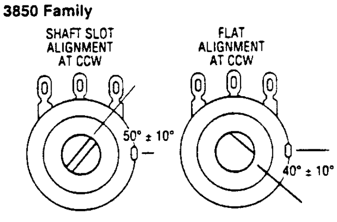
3856A



3856H



Shaft End Detail
3850 Family

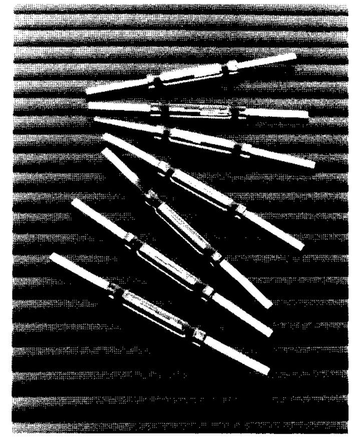


TOLERANCES EXCEPT AS NOTED:
DECIMALS: .XXX ± .005 (.127), .XX ± .015 (.38)
FRACTIONS: ± 1/64
ANGLE: ± 3°

Specifications are subject to change without notice

256

Reed Switch Specification



SERIES FR2

Clare

Over the past three decades, billions of reed switches have been used in hundreds of applications. Operating in microseconds, they are quiet in operation and need little or no energy for actuation. When driven with an electromagnetic coil, reed switches can accumulate millions of fault-free operations at speeds up to 500 Hz continuously. Reed switches actuated by permanent magnets may lay poised for years, even in hostile environments, and operate perfectly when called upon.

Enhancements made by Clare to reed switch design and manufacturing processes have opened exciting new application possibilities. With more than 30 years experience in reed switch manufacturing, Clare is the world leader in glass-sealed contact technology. Clare DYAD reed switches deliver immediate improvements in end user yields and productivity.

The CLARE FR2 series reed switch is trademarked the DYAD. Unique features of the DYAD include:

- Patented glass to metal seal provides a stronger hermetic seal. Glass breakage is virtually eliminated.
- Sputtered ruthenium contacts provide stable contact resistance throughout life.
- Bifurcated contacts reduce bounce on closure offering faster momentary action and longer life.
- Flat glass dampens the kinetic energy of the blades on opening, virtually eliminating reclosure.
- Flat leads offer more reliable solder, weld, or crimp joints.
- Flat glass and flat leads also lend themselves to surface mount processing capability.

Specifications

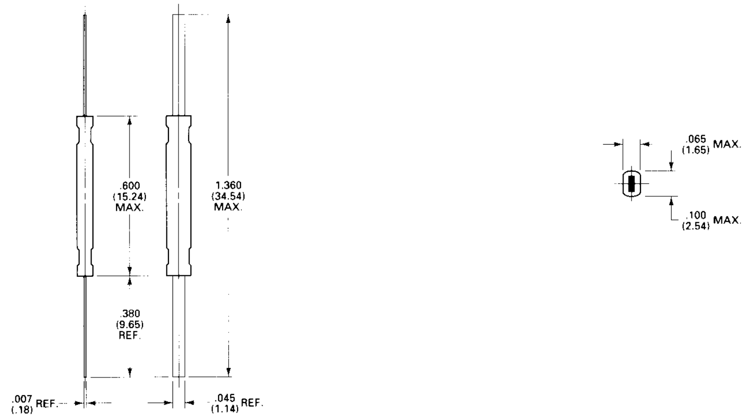
Clare

PHYSICAL AND MECHANICAL REQUIREMENTS	
■ Contact Form	SPST, Form A (center gap)
■ Contact Material	Ruthenium
■ Standard Overall Length	1.360 inches (34.54mm)
■ Maximum Glass Length	0.600 inches (15.24mm)
■ Terminals*	Nickel iron alloy 52
■ Test Coil	NARM I test coil: See page 3 for details
CONTACT RATING	
■ Maximum Switching Power	10 VA
■ Maximum Switching Voltage	200 VDC, VAC
■ Maximum Switching Current	0.50 A
■ Maximum Continuous Carry Current	1.50 A
ELECTRICAL RATING	
■ Operate Sensitivity Available in Minimum 5 NI Ranges	5-45 NI
■ Maximum Initial Contact Resistance	150 milliohms
■ Minimum Dielectric Voltage	250 VDC
■ Maximum Capacitance	1.0 pF
■ Minimum Insulation Resistance	10^{11} Ohms
OPERATING CHARACTERISTICS	
■ Maximum Operate Time, Including Bounce	0.50 ms
■ Maximum Release Time	0.20 ms
■ Maximum Operating Frequency	500 Hz
■ Operating Temperature Range	-40°C to +125°C
■ Shock	100g, 11 ms, 1/2 sinewave
■ Vibration	20g, or .125" D.A., 10 - 5000 Hz
■ Solderability	As defined by MIL-STD-202 F, Method 208D
■ Resistance to Solvents	The reed switch operating characteristics shall not be affected by water wash, rinse procedures, the use of mild to semi-active fluxes or conformal coating processes.

* If the switch is to be soldered in place, a solder plated terminal finish should be specified.

Ordering Information

Dimensions



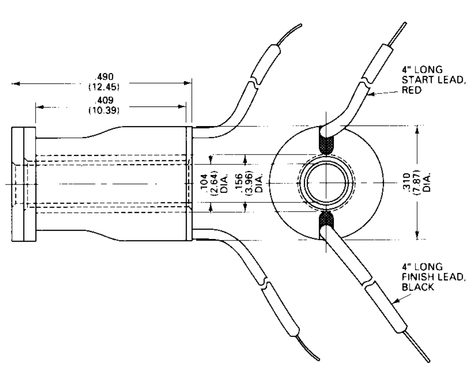
How to Order Clare Reed Switches

FR2 S 05 45—05 35 00

Switch Name
FR2 = Bifurcated Ruthenium Dry Reed
(Form A Contacts - SPST)

Terminal Finish
S= Solder Plated Terminals
W= Oxide Free for Welding
Minimum Operate Value
Maximum Operate Value
Minimum Release Value
Maximum Release Value
Standard Switch

Standard Test Coil



Introduction

The magnetic force (expressed in NI, AT, or Ampere Turns) required to cause the reed switch contacts to close is called the pull-in or operate value.

Coil Definition	*EIA/NARM I Standard*
Wire size	AWG 46
Number of turns	5000 ± 5 turns
Coil resistance	1200 Ohms ± 10%
Recommended Mounting Conditions	Vertical, with the coil magnetic field opposing the local earth's magnetic field.

The reed switch shall be placed in the test coil with the gap centered in the core of the coil winding.

Test leads and their clips must be non-magnetic.

The longitudinal axis of the test coil and test switch shall be vertical.

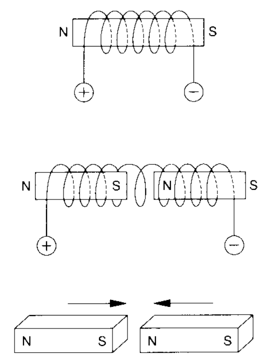
Switch Actuation

Clare

Operation of a Reed Switch Permanent Magnet and Electromagnetic Coil Actuation

The reed switch depends upon an induced magnetic field for its operation. Reed switches are activated by the presence of a magnetic field with sufficient flux to pull the reed blades together.

This can be accomplished by either using a permanent magnet—bringing the magnet close to the switch to turn it on—or by energizing a electromagnetic coil that is mounted around or near the switch. The balance of this page will review the actuating characteristics of a reed switch via these two methods.



Coil Actuation

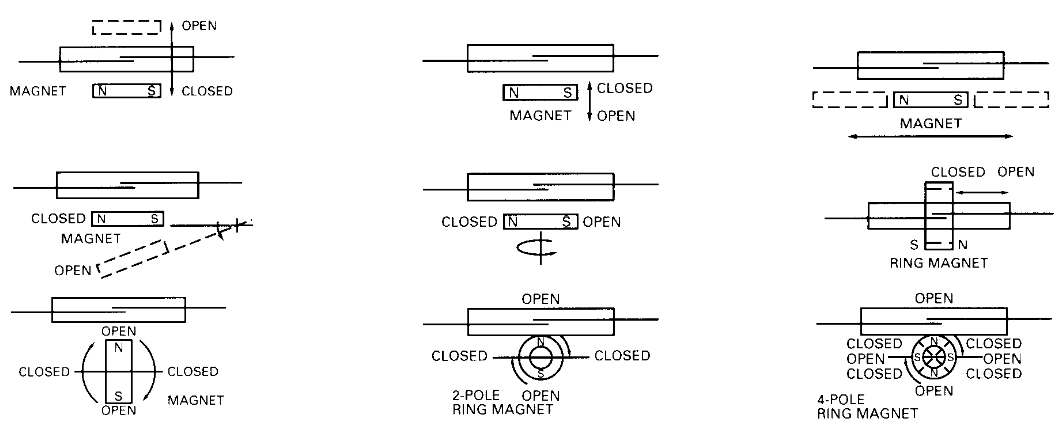
The operation of a reed switch via an electromagnetic coil provides the designer with a method of actuation from a remote source. This is a very simple method of actuation.

When the reed switch is placed inside or close to a coil of wire and a current is passed through the coil, each lead of the reed switch becomes strongly magnetized. One end of the reed switch will become a north pole and the other a south pole. Because the reed blades overlap in the center of the glass housing, with a few thousandths of an inch separating the overlapping ends, each lead will have a north and south pole. The overlapping reed blades come together (close) when the electrical current generates sufficient magnetic flux in the coil. When the current to the coil is turned off, the reed blades return to their open condition.

The efficiency of the reed switch actuation is largely dependent upon the coil. The size, shape, wire type, and the number of turns of wire on the coil determines its efficiency. In addition, the proximity of the switch to the coil determines the efficiency of the coil (ie, if the switch is placed inside or very close to the coil, the coil requires little current to actuate the switch. The farther the switch is from the coil, the more magnetic flux the coil must generate to cause switch closure). Two or more switches can be actuated by a single coil.

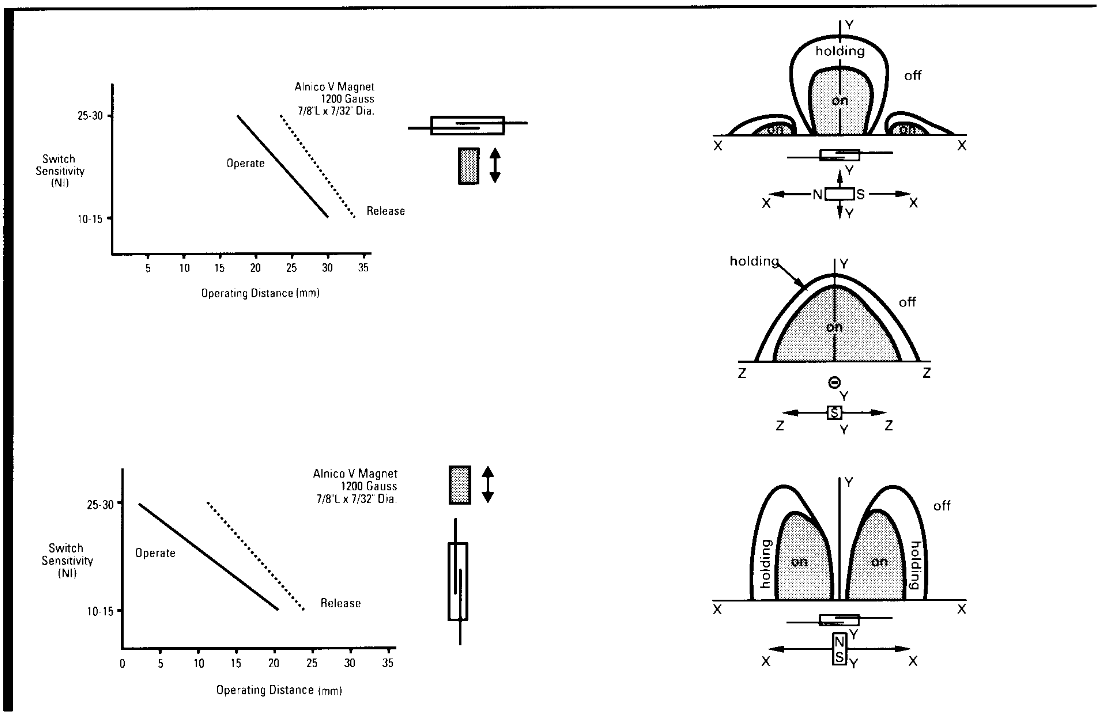
Permanent Magnet Actuation

A permanent magnet is the most common means of operating the reed switch. As with a coil, to actuate the reed switch, a magnet and switch must be positioned within a specific proximity of each other. This distance is related to the sensitivity of the switch and the strength of the magnet. For the normally open reed switch, when the magnetic field is close enough the contacts will close and when the magnetic field is taken away, the contacts will open. There are many ways to use a permanent magnet to actuate the reed switch. Below we have addressed the most popular techniques.



Switch Actuation

Permanent Magnet Actuation Distance (N. O. Contacts)



Form B Reed Switch Actuation

Bias Actuation

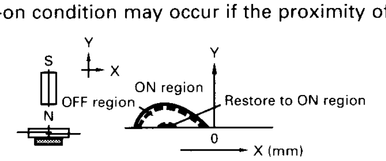
Form B, N. C. contact actuation is achieved by Clare through the use of the standard Form A dry reed switch that is biased closed by mounting a permanent magnet to the switch housing. This magnet is located such that it keeps the switch in the on (or closed) condition.

The switch is turned off (or opened) by bringing another magnet in the proximity of the switch/magnet assembly.

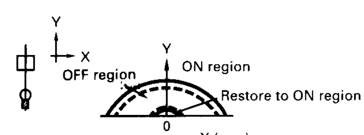
Note in the actuation charts shown below, that an on-off-on condition may occur if the proximity of the actuating magnet is brought very close to the switch/magnet assembly. This condition is, of course, dependent upon the size and strength of the actuating magnet.

Magnets

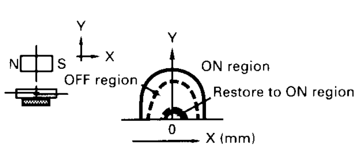
ALNICO V, ALNICO VIII, Ceramic and Barium ferrite are the most popular magnet materials used. The magnet type is usually chosen based on size, coercivity, cost, and temperature characteristics as defined by the application.



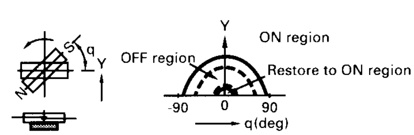
1. Perpendicular



3. Transverse



2. Horizontal

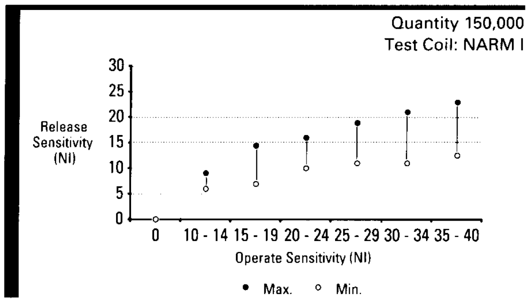


4. Rotational

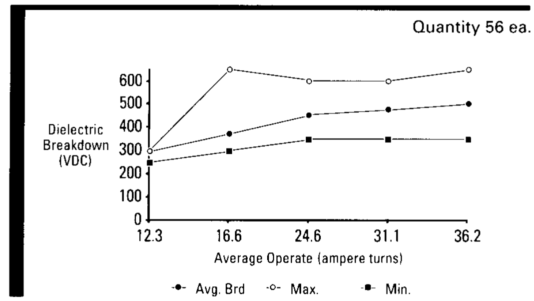
Performance Data

Clare

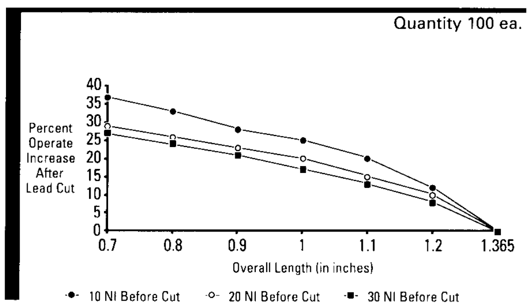
Operate NI vs. Release NI



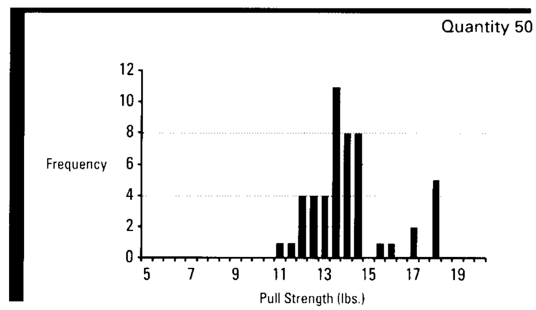
Dielectric Breakdown vs. Operate Sensitivity



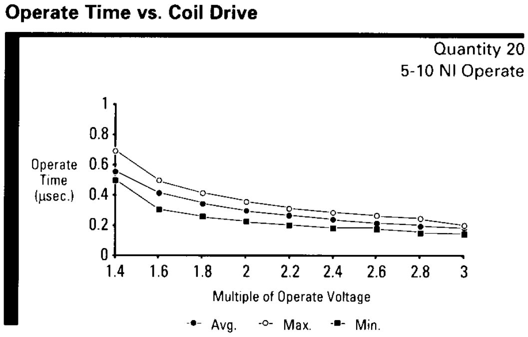
Operate Shift After Lead Trimming



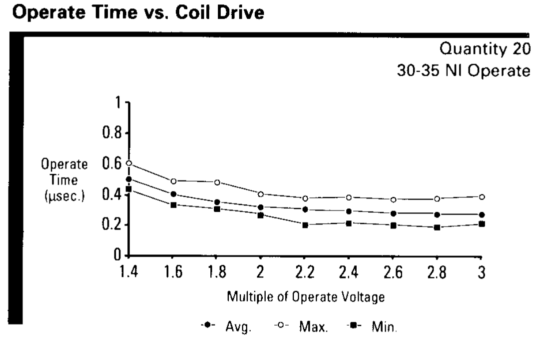
Pull To Fracture Test Distribution



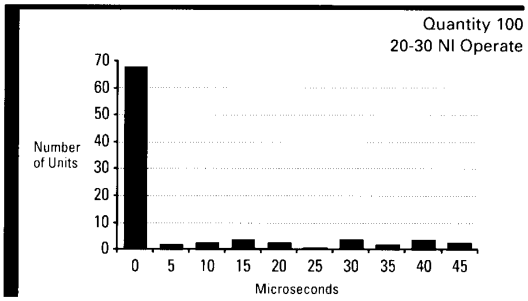
Operate Time vs. Coil Drive



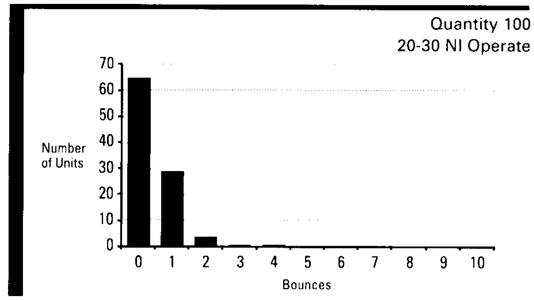
Operate Time vs. Coil Drive



Bounce Time

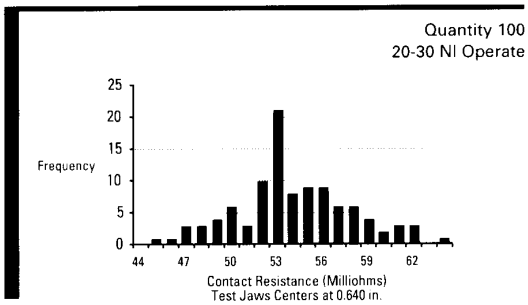


Number of Bounces

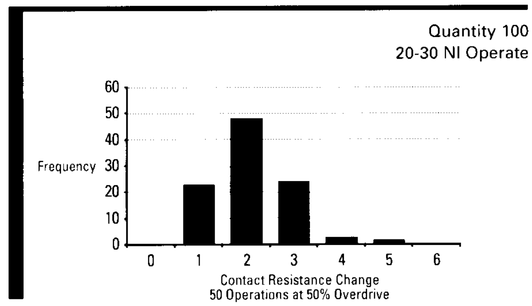


Performance Data

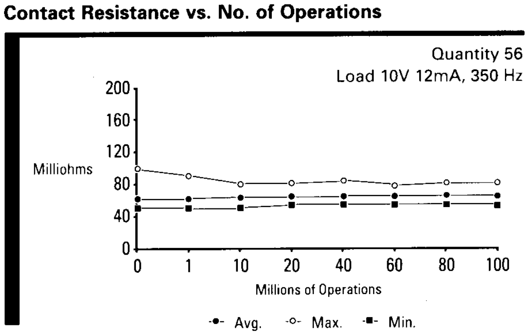
Contact Resistance



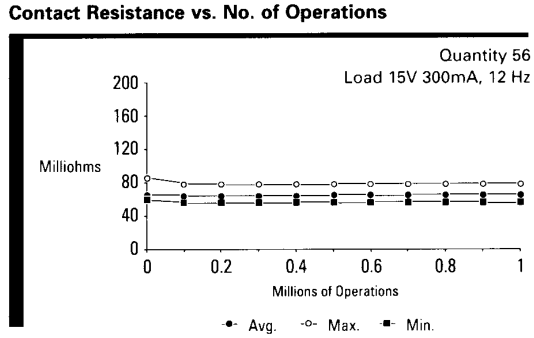
Contact Resistance Stability



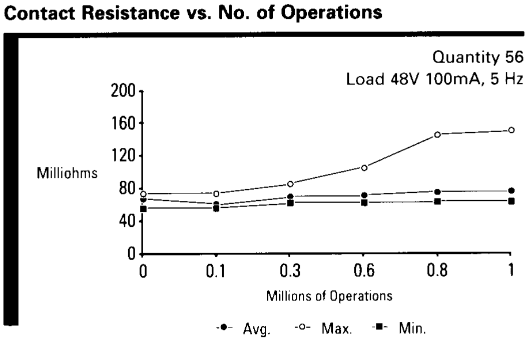
Contact Resistance vs. No. of Operations



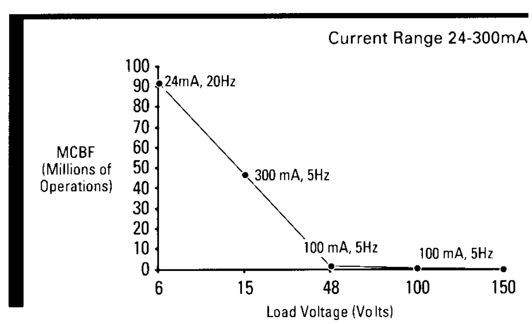
Contact Resistance vs. No. of Operations



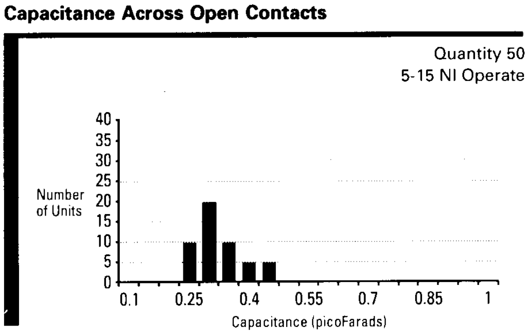
Contact Resistance vs. No. of Operations



Load Life



Capacitance Across Open Contacts



Capacitance Across Open Contacts