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Precision motion since 1982

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Miniature Metal Bellows & Electroforms

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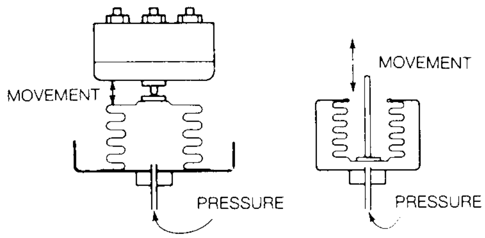
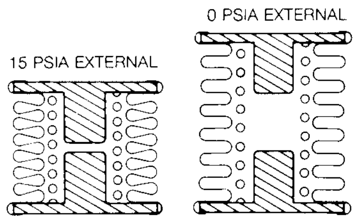
TYPICAL APPLICATIONS OF BELLOWS

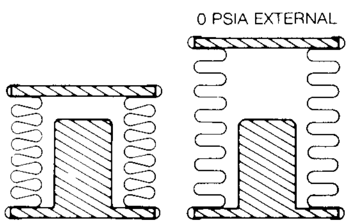
PRESSURE RESPONSIVE DEVICES



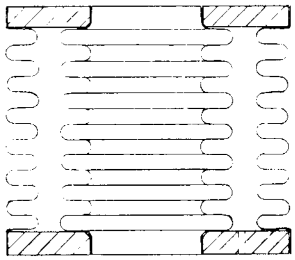
Pressure Switches Pressure Gauges
Pressure Actuators
Pressure-Electric Transducers



Full Range Aneroid:
0 to 15 PSIA

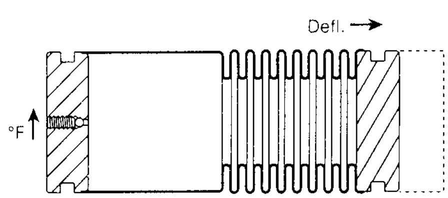


Short Range Aneroid Works
Only From 0 PSIA To A Small
Fraction Of One Atmosphere



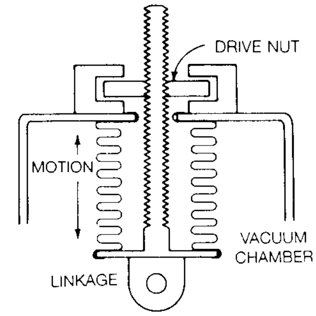
Double Bellows
Volume Compensator

ATHERMALIZATION BELLOWS ASSEMBLY

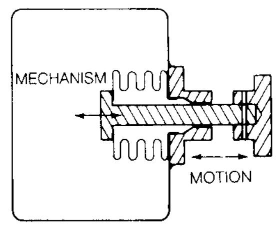


Translates Changes in Temperature
into Linear Displacement

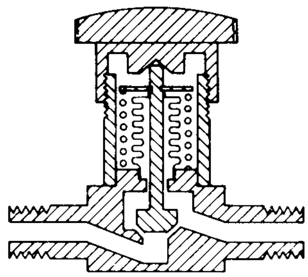
METALLIC SEALS FOR MOTION INTO A HERMETICALLY SEALED HOUSING



Laboratory Vacuum Systems
Manipulators, Crystal Growing Apparatus

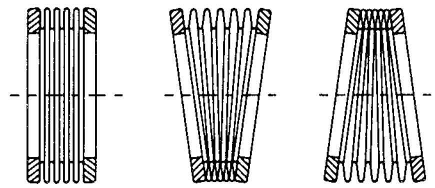


Electrical Circuit Breakers
Push Button Switches



The Bellows Sealed Valve Is
Absolutely Tight To Pressure Or Vacuum

FLEXIBLE BELLOWS SEALS

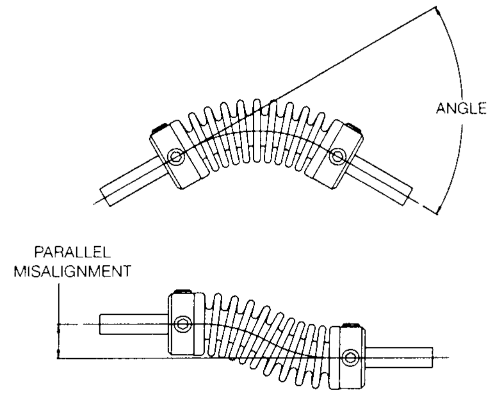


Dynamic Bellows Seals,
Helium Leaktight To 1 x 10^{-9} ccHe/sec.

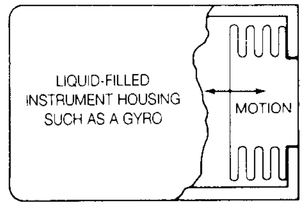
SOME OTHER APPLICATIONS

- A bellows will isolate vibration in piping between machinery and delicate apparatus.
- Thermostatic action is obtained by a bellows, capillary, and bulb liquid filled and sealed.
- Thermal expansion in metal piping can be absorbed by a short bellows inserted in it.
- A gold plated miniature bellows makes the most efficient spring contact in micro-wave electronic assemblies.
- Miniaturization of missile, satellite, or experimental equipment, can be done with Servometer bellows to .040" O.D.

FLEXIBLE SHAFT COUPLINGS

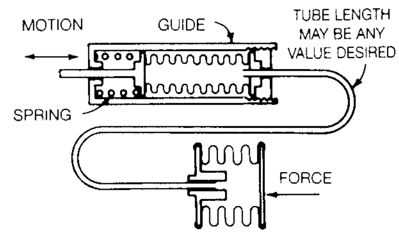


LIQUID EXPANSION ABSORBING BELLOWS



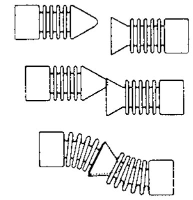
One Side Of Bellows
Exposed To The Atmosphere

HYDRAULIC MULTIPLIER AND/OR REMOTE TRANSMISSION



Two Bellows Connected By A
Long Capillary, And Liquid Filled,
Can Transmit Motion Or Force
Either Way – And At The Same Time
Multiply Or Divide

FLEXIBLE INTERCONNECT CONTACTS



Paired Contacts Will Self Align As They
Connect To Compensate For Angular And
Parallel Misalignment

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INTRODUCTIONS

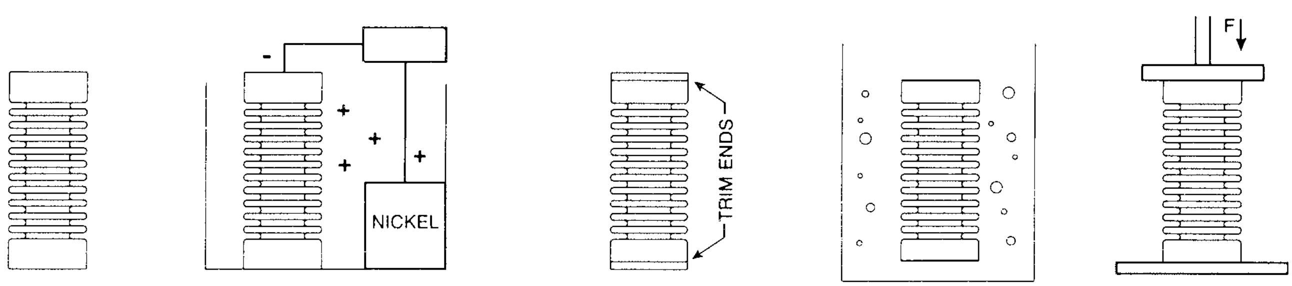
SERVOMETER ELECTRODEPOSITED METAL BELLOWS

There are five major types of metal bellows: rolled, hydroformed, welded, chemically deposited and electro-deposited. Electro-deposited bellows are manufactured by forming a mandrel to the shape of the inside of the bellows, depositing the proper thickness of spring quality metal onto this, trimming tie ends and dissolving out the mandrel.

Servometer Corp. is the foremost manufacturer of electro-deposited bellows. These bellows have the following advantages over other types.

1. Because the bellows wall can be thinner than other types (to .0003"), they are extremely sensitive, which makes them excellent for very accurate instrument applications requiring a high degree of sensitivity. They can provide large deflections with only very minute forces. They are up to 25 times as sensitive as hydroformed bellows in the same size range. Servometer manufactures bellows which can be fully compressed by a force as small as 4 grams.
2. They are the most flexible bellows. They offer superb performance in applications such as hermetic sealing of switches and circuit breakers, and other filled instruments.
3. Their stroke can be 60% of their extended length, and combined with a greater I.D./O.D. ratio, this gives them a volume displacement capacity equal to or larger than most other types.
4. They can be designed for infinite life expectancy and have a normal minimum life of 100,000 cycles.
5. They are seamless and non-porous. No dust, dirt or moisture can lodge in seams and cause contamination in critical applications. In addition, every Servometer bellows is leak tested to 10^{-9} ccHe/sec. by helium mass spectrometer.
6. They can be made in sizes smaller than any other bellows. Many of today's sophisticated applications require a miniaturized bellows. Servometer bellows can be made as small as .035" O.D. and still retain full sensitivity and flexibility. When other types are smaller than 1/4" O.D., they are usually stiff and useless for most applications.
7. Tooling is not required for most bellows, so that a large quantity need not be ordered to attain a reasonable price.

SERVOMETER'S PROCESS OF ELECTRODEPOSITION



Machine Mandrel — Electrodeposit Nickel onto Mandrel — Trim Plated Mandrel — Dissolve Mandrel — Spring Rate Bellows To Check Wall

SECTION I - BELLOWS DESIGN

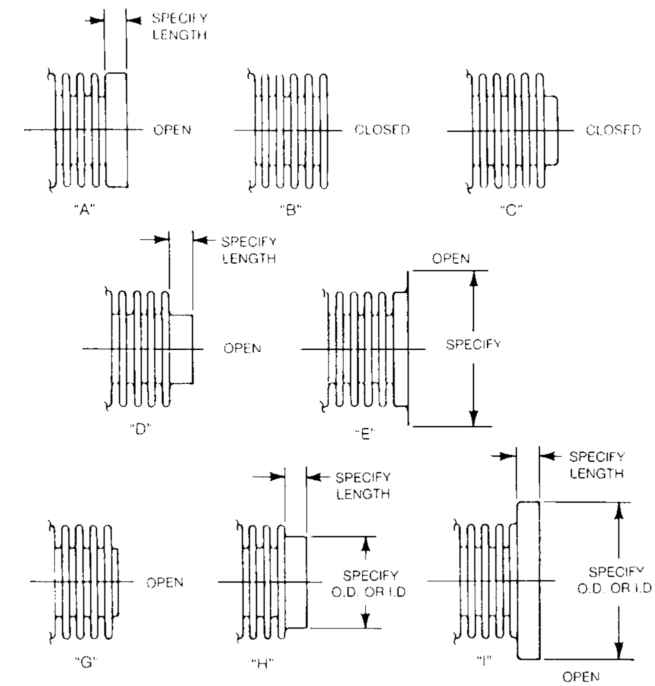
HOW TO ESTABLISH A BELLOWS DESIGN

Determine all of your requirements for the bellows design by answering the following eleven points, or using the bellows design request form provided on the next page.

1. Kind of flexing required of the bellows: Specify extension, or compression, or bending, or swiveling, or parallel-ends off-set, or torque, or speed of rotation. Provide a drawing or sketch showing related fittings and extremes of flexing where possible. This is very important to the manufacturer to enable him to work out a reliable design.
2. Specify the amount of compression or extension or flexing in fractions of an inch or in degrees, or by dimensions on the flexing diagram. (Maximums).
3. Specify pressure difference between inside and outside of the bellows, maximum instantaneous, and whether higher pressure is applied inside or outside the bellows.
4. Specify whether rigid stops will limit the extension or compression of the bellows to its rated stroke, or if the bellows will be required to withstand pressure un-restrained. This is very important since a restrained bellows will give a much better performance.
5. The spring rate in pounds per inch, or conversely the amount of force available to flex the bellows the desired amount, should be specified.
6. Specify the required useful life of the bellows expressed as the number of flexing cycles, and define the flexing cycle.
7. Extremes of temperature, both low and high, should be stated.
8. Corrosive conditions which apply should be described.
9. The method to be used to join the bellows to end fittings, such as soldering, brazing, welding, cementing, should be specified.
10. Specify vibration or shock to be experienced by the bellows.
11. Specify types and lengths of ends. Refer to the figure, Types of Bellows Ends.

After completing the bellows design request form, or setting down the information according to the eleven points listed above, send the information to Servometer. Our engineers will design a bellows to your requirements.

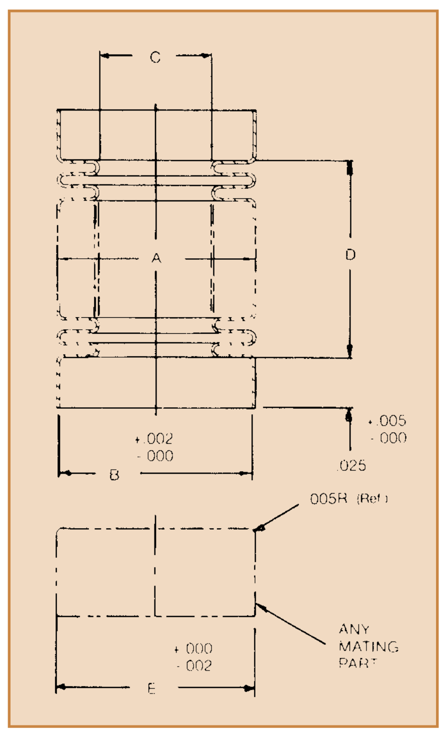
TYPES OF BELLOWS ENDS



If you prefer, for quick selection of a bellows design, you may select a bellows from the Table of Bellows Convolution Properties on page 6. These bellows are not available from stock. All bellows are custom made. If you need to make several trial designs, complete design mathematics are given in Section III of this catalog.

SERVOMETER STOCK BELLOWS- (IN STOCK AND ON THE SHELF)

BELLOWS											
Part	Fin O.D. "A"	Skirt I.D. "B"	I.D. "C"	Conv. Lgth. "D"	Wall Nom.	S.R. Lb/in. Nom.	Comp. Stroke (in.)	No. Of Conv.	Mating Part O.D. "E"	EFF. Area	Maximum Pres. for 1/2 Stroke
FC-1	.250	.248	.150	.740	.0015	5.9	.149	24	.246	.0292	290
FC-2	.250	.248	.150	.370	.0015	11.82	.070	12	.246		
FC-3	.250	.248	.150	.245	.0015	17.73	.045	8	.246		
FC-4	.250	.248	.150	.185	.0015	23.63	.032	6	.246		
FC-5	.375	.372	.250	.740	.0018	8.15	.194	24	.370	.0723	265
FC-6	.375	.372	.250	.550	.0018	10.87	.142	18	.370		
FC-7	.375	.372	.250	.370	.0018	16.31	.092	12	.370		
FC-8	.375	.372	.250	.305	.0018	19.57	.075	10	.370		
FC-9	.500	.495	.360	.740	.0025	21.62	.172	24	.493	.1382	410
FC-10	.500	.495	.360	.490	.0025	32.44	.112	16	.493		
FC-11	.500	.495	.360	.370	.0025	43.25	.082	12	.493		
FC-12	.750	.744	.570	.980	.0030	30.73	.208	21	.741	.328	355
FC-13	.750	.744	.570	.730	.0030	40.33	.156	16	.741		
FC-14	.750	.744	.570	.540	.0030	53.78	.114	12	.741		
FC-15	1.000	.994	.740	1.230	.0035	24.66	.320	18	.990	.5678	230
FC-16	1.000	.994	.740	.730	.0035	44.70	.169	10	.990		



ABSSAC BELLOWS REQUEST FORM

Tel : 01386 833301 Fax : 01386 831500 Email :sales@abssac.com

BELLOWS DESIGN REQUEST

PLEASE FILL IN THE DATA PERTINENT TO YOUR DESIGN ON THIS FORM
AND RETURN TO SERVOMETER CORPORATION

Describe function which bellows must perform to permit interpretation of possible conflicting requirements ______________________________

____

____

____

____

O.D. Max __________ Min __________ Type of Ends See Page 4

I.D. Max __________ Min __________ #1 __________ Length __________

Effective Area __________ #2 __________ Length __________

Pressure Sensitive: ☐ Yes ☐ No

Operating Pressure: Max __________ Int __________ Ext __________

Overall Length With Ends: __________

Bellows Spring Rate (#/in) __________ Tol __________%

Required Stroke: Comp __________ *OR* Ext __________

Rigid stops to limit stroke in Comp: ☐ Yes ☐ No

Ext: ☐ Yes ☐ No

Leak test requirements: __________

Required life expectancy in cycles: __________

Temperature range (operating and storage) __________°F to __________°F

Temperature Sensitive: ☐ Yes ☐ No

Media in which bellows will be in contact: Inside __________

Outside __________

Type of motion if other than compression or extension: __________

Arc bend: __________ degrees

Off-set bending: __________ inches

Torque: __________ inch/ounces

Surface Finish Requirements:

Gold Plate __________

Silver Plate __________

Other __________

Method of Assembly:

Solder __________

Weld __________

Other __________

SERVOMETER CAN SUPPLY YOUR COMPLETE ASSEMBLY
PLEASE INCLUDE DETAIL DRAWINGS OF YOUR ASSEMBLY AND
END CONNECTIONS FOR QUOTATION

NAME __________

COMPANY __________

ADDRESS __________

QTY NEEDS: *PRESENT* __________

FUTURE __________

____

City State Zip

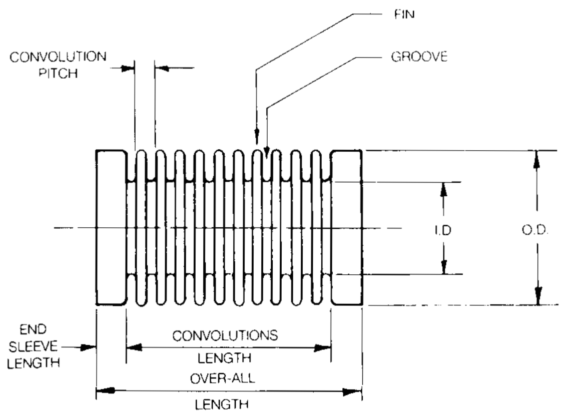
PURCHASING DEPT CONTACT __________

PHONE __________

HOW TO USE THE TABLE OF BELLOWS CONVOLUTION PROPERTIES

This table is for quick selection of a bellows design. It does not represent stocked bellows. Each line represents the properties of a single convolution with the O.D., I.D., and wall thickness indicated. A bellows will consist of the desired number of convolutions, plus ends, which can be selected from the illustration of Types of Bellows Ends (page 4).

Explanation of column headings of the table



O.D., I.D., and **Convolution Pitch** are shown in the figure above.
Wall thickness is the **average** metal thickness of the entire bellows.

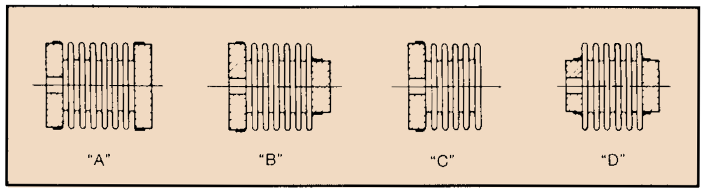
Effective area is the mean diameter between O.D. and I.D., squared and multiplied by .785. It is the equivalent piston area that will produce the same fluid displacement as the bellows for the same axial compression or extension.

Spring rate is the force in pounds applied axially to a bellows, divided by the compression (or extension) in inches resulting from this force, and is a measure of stiffness. The value in the table is for small compression or extension, not exceeding 10% of bellows convolutions length.

Maximum stroke per convolution is the allowable length of its movement from free length to a compressed condition for life of 100,000 cycles.

Maximum pressure for 1/2 stroke is the nominal pressure rating of the bellows. When pressure is applied to the bellows at the same time as deflection, the maximum permissible stroke must be reduced. See derating information in Section III for details.

Note: Number of active convolutions: When the end of a bellows is attached to a fitting, the convolution face touching the fitting is usually immobilized by solder. This means half a convolution of spring action is lost on that end. The number of



active convolutions always equals the number of active fins. (One less than the number of grooves in A, equal to the number of grooves in B & C, and one more than the number of grooves in D.

TABLE OF BELLOWS CONVOLUTION PROPERTIES - TO BE USED AS GUIDE ONLY - This Table Does Not Represent

stock bellows, See page 4 for stock bellows.

These are typical values. Any O.D. or I.D. can be made in steps of .001", and any wall thickness in steps of .0001" can be made, except the "DESIGN LIMITS" on page 7 apply. *These are not available from stock.*

O.D.	I.D.	Conv. Pitch	Wall Thickness	Eff. Area	Spring Rate Per Conv.	Maximum Stroke Per Conv.	Maximum Pres. for 1/2 Stroke
.063	.040	.010	.0003	.0020	24	.0016	218
.063	.040	.010	.0004	.0020	58	.0013	392
.063	.040	.010	.0005	.0020	115	.0010	617
.094	.060	.010	.0005	.0046	52	.0023	279
.094	.060	.010	.0006	.0046	90	.0020	398
.094	.060	.010	.0008	.0046	215	.0015	717
.125	.075	.014	.0008	.0078	87	.0030	332
.125	.075	.014	.0010	.0078	170	.0024	520
.125	.075	.014	.0012	.0078	294	.0020	749
.156	.090	.016	.0008	.0118	46	.0055	189
.156	.090	.016	.0010	.0118	90	.0043	296
.156	.090	.016	.0012	.0118	155	.0036	425
.187	.115	.020	.0010	.0179	86	.0050	248
.187	.115	.020	.0012	.0179	149	.0045	355
.187	.115	.020	.0015	.0179	292	.0035	558
.250	.150	.032	.0012	.0314	73	.0083	185
.250	.150	.032	.0015	.0314	141	.0067	290
.250	.150	.032	.0020	.0314	335	.0050	515
.312	.190	.036	.0010	.0495	29	.0145	86
.312	.190	.036	.0015	.0495	97	.0094	194
.312	.190	.036	.0020	.0495	230	.0072	344
.375	.250	.032	.0012	.077	58	.0125	118
.375	.250	.032	.0015	.077	114	.0100	184
.375	.250	.032	.0020	.077	270	.0075	328
.437	.315	.032	.0012	.110	72	.0120	122
.437	.315	.032	.0015	.110	141	.0095	192
437	.315	.032	.0018	.110	253	.0079	279
.437	.315	.032	.0022	.110	466	.0064	418

O.D.	I.D.	Conv. Pitch	Wall Thickness	Eff. Area	Spring Rate Per Conv.	Maximum Stroke Per Conv.	Maximum Pres. for 1/2 Stroke
.500	.360	.032	.0012	.145	56	.0120	94
.500	.360	.032	.0015	.145	110	.0103	147
.500	.360	.032	.0020	.145	263	.0094	261
.500	.360	.032	.0025	.145	515	.0075	411
.562	.420	.032	.0015	.189	121	.0120	143
.562	.420	.032	.0018	.189	212	.0105	206
.562	.420	.032	.0022	.189	388	.0087	308
.562	.420	.032	.0025	.189	570	.0075	399
.625	.450	.056	.0015	.226	71	.0200	94
.625	.450	.056	.0020	.226	169	.0150	161
.625	.450	.056	.0025	.226	331	.0115	260
.625	.450	.056	.0030	.226	575	.0097	375
.750	.570	.056	.0015	.342	80	.0205	88
.750	.570	.056	.0018	.342	139	.0170	127
.750	.570	.056	.0022	.342	254	.0140	190
.750	.570	.056	.0025	.342	373	.0120	247
.875	.615	.072	.0020	.435	70	.0300	74
.875	.615	.072	.0025	.435	137	.0260	113
.875	.615	.072	.0030	.435	236	.0210	166
.875	.615	.072	.0040	.435	565	.0160	305
1.000	.740	.080	.0020	.593	81	.0300	76
1.000	.740	.080	.0025	.593	160	.0260	118
1.000	.740	.080	.0030	.593	277	.0210	170
1.000	.740	.080	.0040	.593	660	.0160	306
1.250	.850	.135	.0025	.865	52	.0440	49
1.250	.850	.135	.0035	.865	144	.0440	96
1.250	.850	.135	.0045	.865	307	.0340	157
1.250	.850	.135	.0060	.865	740	.0250	284

Example Of The Use Of The Table:

Suppose a bellows is desired having .049 sq. in. effective area, 20 lbs./inch spring rate, .095" stroke and 40 psi max. applied pressure.

Choose the .312" O.D. bellows in the table because it has .0495 sq. in. area. For 40 psi rating one could choose the .0010" wall or the thicker walls, .0015" or .0020". The thicker walls result in longer bellows. Each will have to be worked out as follows:

Choose the .0020" wall first. Then, for 20 lbs./in. 230/20 equals 11.5 convolutions that are required. Usually a whole number applies so we must use 11 or 12. The stroke for one convolution is .0072" or for 12 (the whole bellows) it is .0865". Since 40 psi is less than 40% of the 344 psi rating, this full stroke applies. Since we need .095" stroke, one convolution is added, making 13 for a stroke of .094". However, our spring rate is 230/13, or 17.7, which is too low. We increase the wall, using the spring rate formula on page 9 to find the required wall thickness of the bellows. The bellows is now specified, except for ends which are chosen from the chart above.

SECTION II - PROPERTIES OF SERVOMETER® BELLOWS

TOLERANCES

Dimensions:

I.D.: ± .005" for bellows I.D. .250" or larger.
± .003" for bellows I.D. less than .250".
± .0015" for I.D. of open ends.

O.D.: Tolerance varies with wall thickness and size of bellows.

Length of convolutions: ± .010"
Length of end trims: ± .005"

Spring rate : ±30% normal. Servometer can supply ±10% at higher cost.

DESIGN LIMITS

1. Limits on the O.D. are 2.50" normally, but diameters up to 9" can be made at higher cost.
2. The ratio, I.D./O.D. should be 0.6 or greater. The optimum value for an efficient bellows is .65. Higher values can be supplied where maximum effective area or small space are required, but at the expense of the bellows stroke.
3. Wall thickness, outer groove widths, and inner groove widths, should conform to the values in the chart below.

Bellows O.D.	Minimum Wall Thickness	Outer Groove Width	Outer Groove Depth	Minimum Inner Groove Width
.063"	.0003"	.003"	.011"	.002"
.125"	.0005"	.004"	.024"	.003"
.250"	.0007"	.014"	.049"	.007"
.375"	.0009"	.024"	.074"	.010"
.500"	.0010"	.028"	.085"	.012"
.750"	.0014"	.047"	.122"	.017"
1.000"	.0020"	.075"	.180"	.025"
1.250"	.0022"	.090"	.200"	.030"
1.500"	.0025"	.100"	.250"	.035"
2.000"	.0030"	.100"	.250"	.040"
2.500"	.0035"	.125"	.250"	.043"
3.000"	.0040"	.125"	.250"	.045"

NOTE: For long bellows with internal pressure, a loose-fitting guide rod inside or a sleeve outside must be used to prevent buckling. The rod or sleeve should be about 65% as long as the bellows in the extended condition. Buckling pressure can be calculated from information in Section III.

METAL COMPOSITION

Nickel metal is our standard material. Contact our factory for other metals.

Normally our bellows have a .0001" lamination of copper between equal thicknesses of nickel.

Servometer bellows have about the same chemical analysis as commercial "A" nickel with the exclusion of the copper lamina.

Nickel plus cobalt: 99.80%
Interstitially deposited impurities: .05%
(Oxygen and carbon)
Two grades of nickel are supplied as required:

Regular Nickel: This metal is bright and high in yield strength. However, it cannot be welded or brazed because it contains .04% maximum sulfur which causes it to embrittle when heated about 350°F.

Sulfur Free Nickel: This metal is "satin" finish, equivalent to regular nickel except it contains only .02% maximum sulfur and is much more corrosion resistant. It can be welded or brazed without embrittlement, but care must be taken to avoid annealing of the convolutions.

MECHANICAL PROPERTIES OF BOTH TYPES OF NICKEL:

Yield strength	110,000 psi min
Tensile strength	125,000 psi min.
Elongation	1.0% min.
Hardness	270 Vickers, min.
Young's Modulus	23,350,000.
Metal hysteresis	within stress limits is very low.
Specific wgt.	0.321 lb/in^3.

SURFACE FINISHES

Servometer bellows normally have a bright corrosion resistant surface, but the following finishes are available:

1. Gold plate, 24 carats, to MIL-G-45204 is supplied either to enable soft soldering without flux, or to provide a surface for microwave fields.
2. Silver plate is sometimes applied where a bellows is used for a microwave guide.
3. Parylene coating can be supplied for certain corrosive conditions.

LEAK TIGHTNESS

All Servometer bellows except those used as shaft couplings and mechanical springs and those requiring pressure under liquid leak test, are leak tested 100% on a Helium Mass Spectrometer leak detector. No bellows is shipped if its leak rate exceeds 1 x 10^{-9} cc/sec. of helium. This rate amounts to one cubic centimeter of helium in 32 years.

ENVIRONMENTAL TOLERANCES

Temperature Tolerances:

Servometer nickel bellows are ideal at low temperatures such as liquid oxygen or liquid hydrogen points, where they retain toughness and gain some 30% in strength.

At high temperatures, the limit is about 350°F, above which the regular nickel embrittles and the sulfur free nickel anneals. In certain instances our sulfur free bellows have been "baked out" at 1400°F and used successfully at reduced stroke (because of the resultant anneal and reduced yield strength).

Magnetic Properties:

Servometer's electrodeposited nickel is ferromagnetic. Electrodeposited copper is non-magnetic and can be utilized for special applications.

Corrosion Resistance:

Nickel is more resistant to corrosion than brass or bronze but not as much so as stainless steel. Nickel bellows will not oxidize in air nor be affected by liquids that are alkaline, but will not withstand acids. In sea water, nickel bellows are attacked after a few weeks because of electrolysis where dissimilar metal fittings are used. Sulfur free bellows are much more corrosion resistant than regular nickel bellows.

As in all corrosion problems, each situation must be evaluated alone. Many corrosive conditions are successfully handled by nickel bellows, and the customer should request data and operate prototypes under their environmental conditions before adopting a design.

JOINING OF BELLOWS TO END FITTINGS

Success or failure of a bellows application depends on proper procedures for joining bellows ends to fittings. We urge our customers to consult with us on methods and specifications for making soft soldered, brazed, or welded joints.

Mechanical Strength:

Case 1: Where service conditions exert little tendency to pull the joint apart, or in the case of aneroids where pressure exerts a force to hold the parts together, no turning-over of the rim of the bellows onto a lip on the end fitting is necessary. Soft solder will serve to hold the parts and keep the joint leak-tight. If there is any question, consult our engineering department.

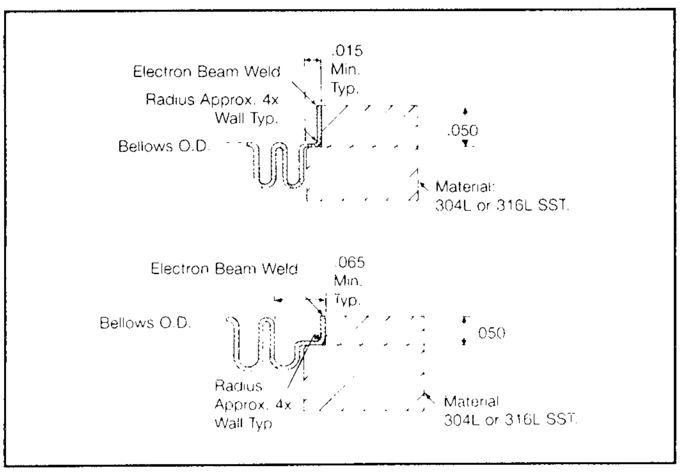
Case 2: Where a joint is under tension or torsion greater than soft solder will hold, braze or weld the bellows to the fittings.

Soft Soldered Joints: These are likely to leak if not properly done. To get consistently good results, pre-tin the bellows end and the engaging fitting rim first, then sweat the two pieces together, rotating the bellows 1/4 turn on the fitting while the solder is molten, to work out pockets of air or flux residue. Wash off all flux by soaking the assembly in boiling or hot tap water.

Flames or high temperatures will anneal or embrittle most bellows. Therefore, do not apply flames or induction heat to the bellows. Apply it to the fittings instead, and let the heat flow into the joint from the fitting. The bellows will then retain its spring qualities.

Silver Brazed Joints Sulfur free bellows must be used and great care is necessary to keep from overheating the bellows convolution next to the brazed joint. An asbestos wrap wetted with water can be applied to the bellows up to the rim being brazed. Heat is applied entirely to the fitting and allowed to flow into the joint. While difficult, good brazed joints can be made without heat damage to the bellows. Once set up, the procedure is relatively easy and economical.

Welded Joints Electron beam welding has the advantage of localized heat right at the weld. Hence, the bellows spring properties are not affected. As a rule the joints must be designed for welding, as shown in the drawings below.



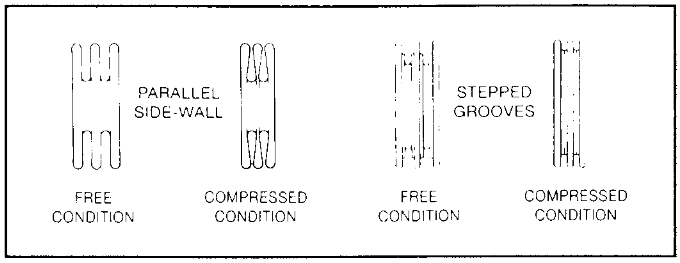
Before making final design drawings of these joints, consult our Engineering Department.

SPECIAL TYPES OF BELLOWS

HIGH COMPRESSION BELLOWS

Bellows with parallel side-walled grooves cannot be compressed more than about 40% of their active convolutions length.

Stepped grooves are provided for bellows which will compress up to 60% of active length. Stepped grooves are suitable only in compression; they stiffen up immediately when extension is attempted.



MULTI-PLY BELLOWS

The mechanical work that a bellows can do can be doubled or tripled by using 2 plies or 3 plies of metal wall. For example, one wall thickness will give a certain compression and withstand a given pressure. Two laminations of the same wall thickness will give the same compression and twice the pressure rating. Three laminations triple the pressure at the same stroke. The spring rate increases only as the first power of the laminations.

Thickening a bellows wall reduces stroke and increases spring rate as the cube of the thickness. Therefore this is no substitute for lamination.

PRE-COMPRESSED BELLOWS

A bellows application requiring extension only can benefit from the Servometer bellows with closed convolutions. This bellows is suitable for considerably more extension stroke and is much more linear than regular bellows. Please consult with our engineers when this type bellows appears desirable.

SYMBOLS

O = bellows outside diameter, inches.

I = bellows inside diameter, inches.

t = bellows wall thickness (average) inches.

N = number of active convolutions in the bellows.

E = Young's modulus of elasticity for ..the bellows metal. Use 23,350,000 for our electro-deposited nickel.

S = maximum permissible stroke for the bellows, inches.

s = maximum permissible stroke per convolution, inches.

n = length of one convolution of the bellows, inches.

L = length of the active convolutions portion of the bellows. This is the over-all length less ends, less 0, 1/2, or 1 convolution depending on what convolution faces are immobilized by end fittings joints, inches.

P = pressure applied to the bellows, or pressure rating of the bellows, lbs. per sq. in. differential.

π = 3.1416

A = angle subtended by a bellows bent in a natural circular arc, degrees.

r = spring rate of one convolution, lbs. per inch.

R = spring rate of the whole bellows, pounds per inch.

PRESSURE RATING

$$P = \frac{1.25\times10^6\ t^2}{(O-I-t)^2}\ \text{psi}$$

The above formula gives "nominal pressure rating".

Proof pressure is 1.75 times the above.

Burst pressure is 2.50 times the above.

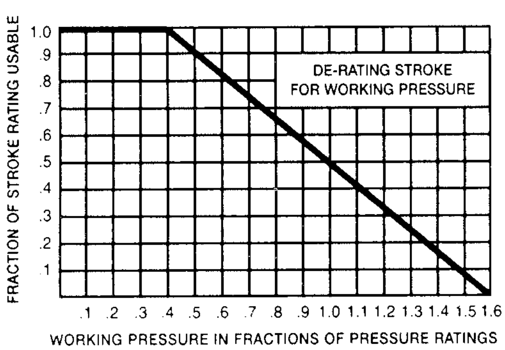
STROKE RATING

$$S = \frac{.0010\ (O-I-t)^2 N}{t}$$ inches compression, for 100,000 cycles life expectancy

The rating in extension is 75% of the above. The equation applies to all types of convolutions and is based on bending stress limits, except V and stepped type which can be used only in compression.

RATING BELLOWS FOR COMBINED STROKE & PRESSURE

Where the working pressure exceeds 40% of the nominal pressure rating of the bellows, select the permissible stroke (axial) from the chart below.



For example, assume a bellows rated at 100 psi (from pressure formula) is to work at 80 psi in service. Enter the chart above with 0.8 (for 80%) on the pressure scale and read out 0.67 on the usable stroke scale. Multiply this by the rated stroke (from the stroke formula) and get the usable stroke for the bellows at 80% working pressure.

LIFE EXPECTANCY

The life expectancy of a metal bellows is expressed in stroke cycles and not in time or speed of repetition of the cycles.

The following data, based on careful and extensive life test data on Servometer bellows, is conservative.

LIFE EXPECTANCY TABLE

Minimum Life Expectancy in Cycles	LIFE FACTOR, as a fraction of the bellows stroke at 100.000 cycles life expectancy	
	In Compression	In Off-set Rotation
1,000	1.50	1.70
10,000	1.25	1.40
100,000	1.00	1.00
1,000,000	.84	.82
10,000,000	.78	.74
100,000,000	.75	.73
Infinity	.72	.72

EXAMPLE: Suppose a given bellows design requires a minimum life expectancy of 1,000,000 cycles at a compression stroke of 0.313". The table shows a LIFE FACTOR of 0.84 for this case. This means that the permissible stroke is 0.84 times the formula value. Therefore the formula value 0.313 divided by 0.84 = 0.372". Enter this in the stroke formula and the result shows a bellows 19% longer would be required.

EXAMPLE: Suppose a shaft coupling bellows must operate at .020" shaft parallel off-set for 5,000,000 revolutions. Multiply 5,000,000 by 2, since 1 revolution is 2 bend cycles. Enter the 10,000,000 in the Off-set Rotation column and come out with the LIFE FACTOR (.74). Since the Off-set formula on Page 10 gives the allowable off-set for 100,000 cycles, the formula value for this case is 0.20 divided by .74 or .0272". Enter this in the formula and come out with the relationship between bellows length and bend angle. The bellows will be about 15% longer than would have been required for 100,000 cycles life.

DE-RATING BELLOWS STROKE FOR PRESSURE & LIFE

Obtain the FRACTION OF STROKE USABLE from the chart, DE-RATING STROKE FOR WORKING PRESSURE on this page. Assume this fraction is 0.65. Next, extract the LIFE FACTOR from the Life Expectancy Table for the required life. Assume this is 1.25. The bellows stroke rating would be (0.65 x 1.25) times the formula value of the stroke.

SPRING RATE

$$R = \frac{4.3\ E\ (O+I)t^3}{(O-I-t)^3 N}$$ pounds per inch.

This formula gives values for bellows with convolutions having parallel side walls. For bellows with stepped and V grooves the rate is 1/3 greater.

This formula gives a straight line compression vs. force characteristic and represents the spring resistance due to the bending of the convolution walls.

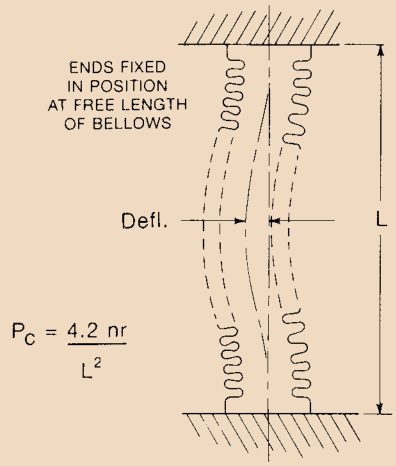
EFFECTIVE AREA

$$\text{Effective area} = 0.785\ \frac{(O+I)^2}{4}\ \text{sq. inches.}$$

This formula is not theoretically accurate but gives results close to actual bellows values.

CRITICAL BUCKLING PRESSURE

With increasing pressure applied inside a bellows whose ends are fixed, a critical pressure, P_C, will be reached at which the bellows will suddenly bow sideways. Below this P_C the bellows will not buckle; above it the bellows will buckle outward without control and damage itself at a few percent more pressure than P_C. The critical pressure is given by the following formula.



ALLOWABLE CIRCULAR ARC BENDING

This assumes a natural circular arc bend.

A = 71.6 Ns/O degrees

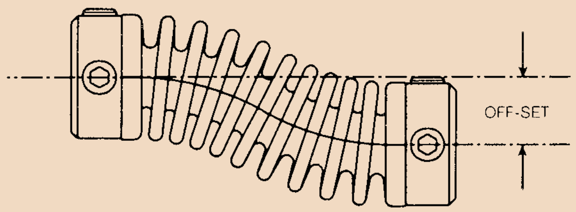
The value given by the formula may exceed the angle attainable by the bellows, unless the stroke per convolution, s, is limited to the value at which bellows convolutions touch.

The formula gives the value for 100,000 cycles life expectancy. For any other value use the LIFE FACTOR from the Life Expectancy Table and multiply this by the formula value of the angle.

OFF-SET BENDING WITH ENDS PARALLEL

Off-set = 0.25 N^2n s/O inches

The above formula is for bellows with bend angles smaller than 30°.



Note that in this arrangement the middle third of the bellows convolutions are nearly straight and unstressed while the end thirds get sharp bends.

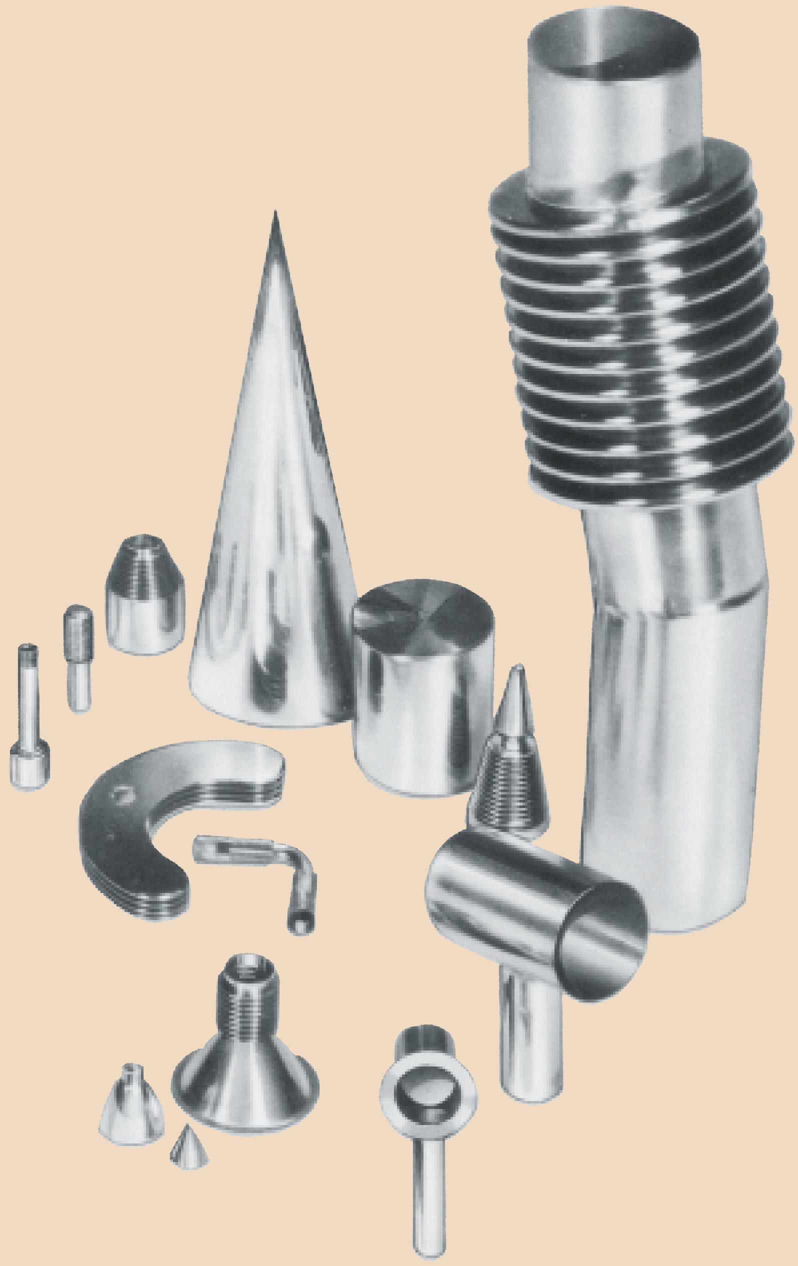
Since the number of convolutions, N, varies as the length of the bellows, the allowable off-set varies as the square of the active length.

This type usage is encountered in flexible shaft couplings.

The formula value is for 100,000 cycles. For any other value multiply the formula value by the LIFE FACTOR from the off-set rotation column of the Life Expectancy Table (page 9).

Servometer Electroforms...

- Provide exact internal dimensions
- Extremely close internal tolerances
- Light weight
- High strength
- Rugged and durable
- Thin walled
- Unusual shapes
- Custom engineered
- Sizes as small as 0.035" diameter
- Can be rigid or flexible, or both



Servometer. The ideal electroform when unusual shapes, close tolerances and high strength are required.

INTRODUCTION

The technique of making parts by electrodeposition is over 150 years old, yet it is only in the last 40 years that this method has been used successfully to make extremely intricate parts with deep crevices or odd shapes.

Over forty years ago, Servometer Corporation pioneered the manufacture of miniature metal bellows by electrodeposition, and we are today the leading supplier of bellows made by this method. The specialized knowledge that our engineers and production people have gained from this experience can now be applied to the manufacture of electroforms, particularly thin walled parts and shapes combined with a flexible element.

DESIGN CONSIDERATIONS

Since a mandrel (usually aluminum) is required to produce electroforms, they lend themselves best to parts with critical inside dimensions. All of the machining, grinding, or milling required to produce the inside of the finished part can thus be performed by external operations on the mandrel. Outside dimensions should have generous tolerances to eliminate secondary (after plating) operations. The wall thickness should be kept as thin as possible even if the electroform must be "backed up" with a cast epoxy or mounted into a machined part to permit installation into the finished product.

Electroforms are not normally an effective cost reducer if acceptable parts can be produced by high speed processes such as hydraulic forming or injection molding. If, however, tolerances are too close or the configuration too complex for these methods of manufacture, electroforming may provide a solution. Servometer's electroforms may also reduce product costs indirectly by easing assembly problems or via weight reductions.

ADVANTAGES

Servometer electroforms offer:

- extreme light weight, yet are tremendously rugged.
- unusual shapes which can even be made with varying cross sections.
- very small sizes.
- surface finishes as fine as 16 R.M.S.
- extremely close tolerances.
- varying wall thicknesses on a single part (if required).
- can be made as an integral unit with a bellows, eliminating welding or soldering.
- can withstand extreme temperatures, even down to -423° F.

MATERIALS AND PROPERTIES

Electrodeposited nickel is the basic material used for Servometer's electroforms. Copper, silver, and gold are also available either as a surface finish or as the base metal.

Servometer Nickel

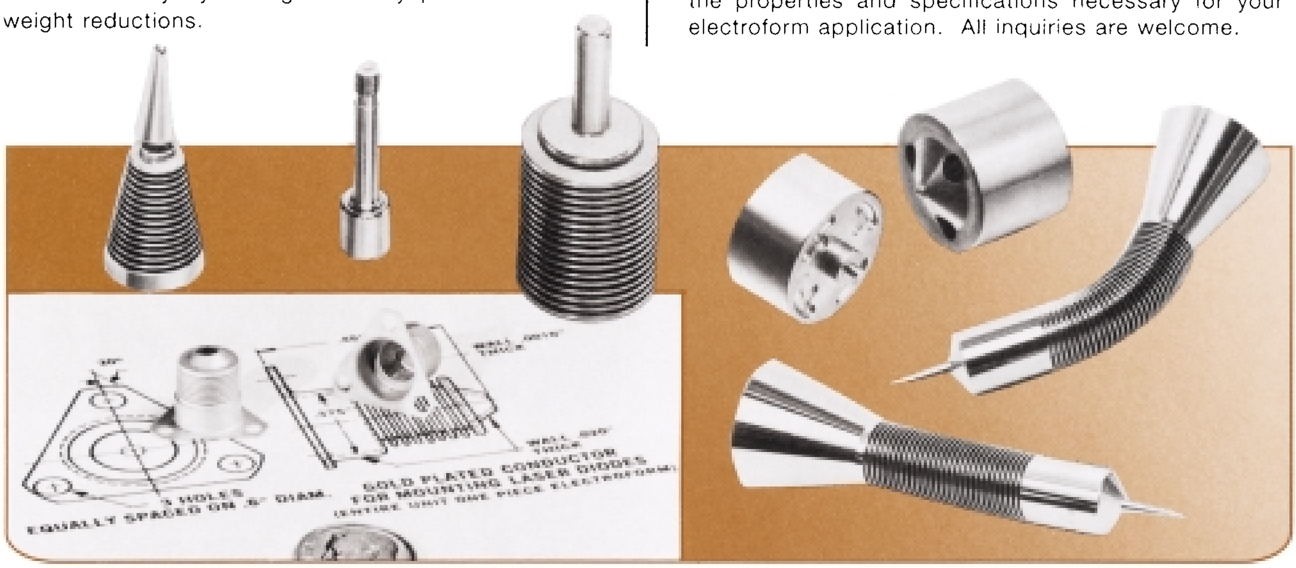
Tensile strength	125,000 psi min.
Yield strength	110,000 psi min.
Elongation	1% min.
Hardness-Vickers (100 gm.)	270 min.
Nickel plus cobalt	99.80%
Sulfur	.04% max.

SIZE LIMITATIONS

Servometer can supply electroforms which range from .030 inches to 3 inches in diameter and up to 12 inches in overall length. Larger parts are also practical in certain instances.

DESIGN ASSISTANCE

Our engineers will gladly assist you in determining the properties and specifications necessary for your electroform application. All inquiries are welcome.



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