Servometer®

MW Industries, Inc.

Bellows Design Guide

Custom Bellows to Fit Your Needs

SYSTEM CERTIFICATION AS 9100 SGS

servometer.com

INTRODUCTION

Thank you for choosing Servometer®, an MW Industries company, to design and manufacture your unique, new electrodeposited bellows for your particular application.

The definitions, formulas and design parameters inside this guide are here to help you answer important questions like Maximum OD, Length and Effective Area. We will use this information and apply the necessary specifications for the successful design of your prototype, experimental bellows, production bellows or electroform.

We realize some variables are either not important to your application or are yet to be determined. Answer as many questions as you can to the best of your ability and we will work together to complete other variables that may be missing for your application.

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 Data Form provided on the inside back cover. The complete catalog will assist you with the details.

1. Type of flexing required of the bellows: Specify extension, compression, bending, parallel off-set, and any combination of these. Provide a drawing or sketch showing related fittings and extremes of flexing where possible. This is very important to enable our engineers to work out a reliable design.
2. Specify the required compression, extension, or bending offset in length units, in degrees, or by dimensioning a drawing or diagram.
3. Specify pressure inside and outside of the bellows, maximum instantaneous pressure, and whether higher pressure will be 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. Note that a restrained bellows can typically withstand higher pressures.
5. Specify the spring rate, in pounds per inch, or conversely the amount of force available to flex the bellows the desired amount.
6. Specify the required useful life of the bellows expressed as the number of flexing cycles and define the flexing cycle.
7. State temperature extremes; both high and low.
8. Describe the working environment of the bellows and any potential for corrosive environment.
9. Specify vibration or shock to be experienced by the bellows
10. Specify the method to be used to join the bellows to end fittings, such as soldering, welding, or adhesive bonding
11. Specify types and lengths of ends.

After completing the bellows design data 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.

SERVOMETER® STANDARD BELLOWS

Part No.	Fin OD "A" (in.)	Skirt ID "B" (in.)	Inside Diameter "C" (in.)	Convolution Length "D" (in.)	Nominal Wall (in.)	Spring Rate (lb./in.)	Comp. Stroke* (in.)	Number of Conv.	Mating Part O.D. "E" (in.)	Effective Area (in²)	Working Pressure * (PSI)
FC-1	0.250	0.248	0.15	0.740	0.0015	5.90	0.149	24	.246	0.0292	
FC-2	0.250	0.248	0.15	0.370	0.0015	11.82	0.070	12	.246	0.0292	290
FC-3	0.250	0.248	0.15	0.245	0.0015	17.73	0.045	8	.246	0.0292	
FC-4	0.250	0.248	0.15	0.185	0.0015	23.63	0.032	6	.246	0.0292	
FC-5	0.375	0.372	0.25	0.740	0.0018	8.15	0.194	24	.370	0.0723	
FC-6	0.375	0.372	0.25	0.550	0.0018	10.87	0.142	18	.370	0.0723	265
FC-7	0.375	0.372	0.25	0.370	0.0018	16.31	0.092	12	.370	0.0723	
FC-8	0.375	0.372	0.25	0.305	0.0018	19.57	0.075	10	.370	0.0723	
FC-9	0.500	0.495	0.36	0.740	0.0025	21.62	0.172	24	.493	0.1382	
FC-10	0.500	0.495	0.36	0.490	0.0025	32.44	0.112	16	.493	0.1382	410
FC-11	0.500	0.495	0.36	0.370	0.0025	43.25	0.082	12	.493	0.1382	
FC-12	0.750	0.744	0.57	0.980	0.003	30.73	0.208	21	.493	0.3280	
FC-13	0.750	0.744	0.57	0.730	0.003	40.33	0.156	16	.741	0.3280	355
FC-14	0.750	0.744	0.57	0.540	0.003	53.78	0.114	12	.741	0.3280	
FC-15	1.000	0.994	0.74	1.230	0.0035	24.66	0.320	18	.741	0.5678	230
FC-16	1.000	0.994	0.74	0.730	0.0035	44.70	0.169	10	.741	0.5678	

TYPICAL TOLERANCES

Inside Diameter

- ± .005 inch for bellows ID .250 inch or larger
- Tolerance varies with wall thickness and diameter for bellows ID less than .250 inch

Outside Diameter

- Tolerance varies with wall thickness and size of bellows
- Maximum OD is 12 inches

Other important parameters

- Length of end trims: ± .005 inch
- Spring rate tolerance: ± 30% standard (± 10% possible)
- Minimum ID/OD ratio: 0.6 or greater (.65 optimal)*
- Maximum bellows length: 9 inches

*higher values are possible but these may compromise stroke, especially when requirements specify maximum effective area or a small space

DESIGN LIMITS

Wall thickness, outer groove widths, and inner groove widths should conform to the values in the chart below.

Bellows O.D.	Minimum Wall Thickness	Minimum Groove		Minimum FIN
		Width	Depth	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”

METAL COMPOSITION

We employ Servometer’s signature FlexNickel™, nickel alloy in our manufacturing process. We also offer copper, silver and gold as either a base metal or a surface finish. Our premium FlexNickel™ is available in three combinations of nickel alloy including Standard, Low Sulfur and Weldable grades.

Features:

- Bright and high in yield strength
- Contain 0.04% maximum sulfur (Standard)
- Contain 0.02% maximum sulfur (Low Sulfur and Weldable)
- Corrosion resistant
- Amendable to either welding, soldering or brazing depending upon application type

Normally our leak tight bellows have a .0001 inch lamination of copper between equal thicknesses of nickel to enhance leak tight properties, especially in thin walled bellows.

MECHANICAL PROPERTIES OF FLEX NICKEL

Yield strength	110,000 psi (min.)
Tensile strength	125,000 psi (min.)
Elongation	1.0%
Hardness	270 Vickers (min.)
Young’s Modulus	23,350,000
Metal hysteresis	within stress limits is very low.
Specific wgt.	.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, per ASTM B 488 is supplied either for enhanced corrosion resistance 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

Servometer bellows and belllows assemblies are leak tested to a standard of 1x10^{-6} cc He/sec. Servometer bellows and bellows assemblies can be leak tested to 1x10^{-9} cc He/sec on a Helium Mass Spectrometer. This rate amounts to one cubic centimeter of helium in 32 years.

ENVIRONMENTAL TOLERANCES

Temperature tolerances:	- 423° F to + 350° F
Magnetic properties:	Ferromagnetic (nickel alloy) Non-magnetic (copper)
Corrosion resistance:	High tolerance except for acids and seawater. Gold plate may be used in some instances to enhance resistance. Please ask for assistance in choosing the appropriate material for your application.

FORMULAS AND DESIGN EQUATIONS

Symbol	Definition	Units
O	Bellows outside diameter	inches (in)
I	Inside diameter	inches (in)
t	Nominal wall thickness	inches (in)
N	Number of convolutions active in the bellows	integer P-half convolution
E	Young's modulus of elasticity for the bellows material Use 23,350,000 for Servometer nickel	pounds per square inch (psi)
S	Maximum permissible stroke for the bellows	inches (in)
s	Maximum permissible stroke per convolution	inches (in)
n	Length of one convolution	inches (in)
L	Bellows active convolution length	inches (in)
P	Bellows pressure rating or pressure applied to the bellows	pounds per square inch (psi)
A	Angle subtended by a bellows bent in a circular arc. Angle is measured from bellows' free (straight) condition w/o extending or compressing the bellows during movement	degrees (°)
r	Spring rate of one convolution	pounds per inch (lbs/in)
R	Bellows spring rate (axial stiffness)	pounds per inch (lbs/in)

PRESSURE RATING

$$P = \frac{1.25 \times 10^6\, t^2}{(O - I - t)^2} \text{ psi}$$

The above formula gives "nominal pressure rating."

Proof pressure is 1.75 times the above.

Burst pressure is 2.50 times the above.

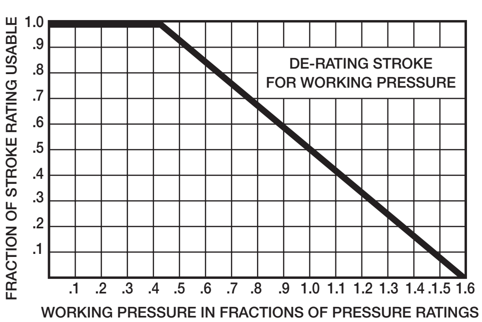
STROKE RATING

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

Normal parallel side walled convolutions may utilize up to 75% of the above calculation in extension. V and stepped convolutions are not suitable for extension.

RATING 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.



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 Life Expectancy Table is conservative, based on empirical life testing of Servometer bellows.

Maximum 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 4 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 cycle life.

DE-RATING STROKE FOR PRESSURE & LIFE

Obtain the FRACTION OF STROKE RATING USABLE from the chart, DE-RATING STROKE FOR WORKING PRESSURE on this page. For example, 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

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

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.

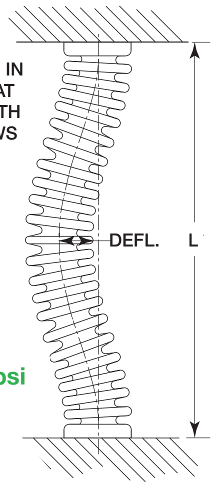
EFFECTIVE AREA

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

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 this P_C the bellows will buckle unpredictably and damage itself at a few percent more pressure than P_C. The critical pressure is given by the following formula.



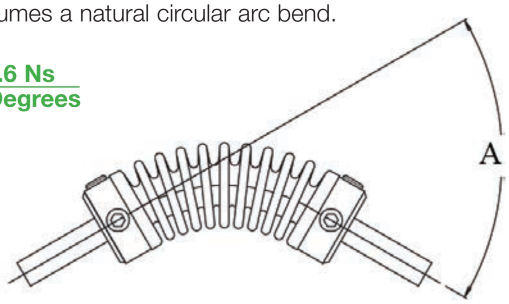
$$P_C = \frac{4.2\ nr}{L^2}\ \text{psi}$$

NOTE: For long bellows with internal pressure, a loose-fitting guide rod inside or a sleeve outside may be used to control buckling. The rod or sleeve should be about 65% as long as the bellows in the extended condition.

ALLOWABLE CIRCULAR ARC BENDING

This assumes a natural circular arc bend.

$$A = \frac{71.6\ Ns}{O\ \text{Degrees}}$$

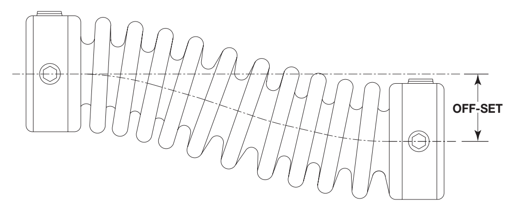


The value given by the formula may exceed the angle attainable by the bellows, unless the stroke per convolution, S, is limited to the value at which bellows convolutions touch.

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

OFF-SET BENDING WITH ENDS PARALLEL

$$\text{Offset} = \frac{0.25N^2\ n}{O\ \text{Degrees}}\ \text{inches}$$



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

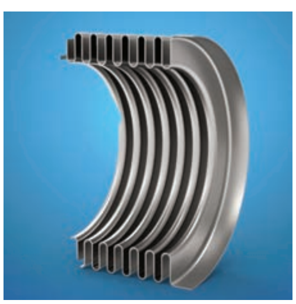
Since the number of convolutions, N, varies as the length of the bellows, the allowable off-set varies as the square of the active length.

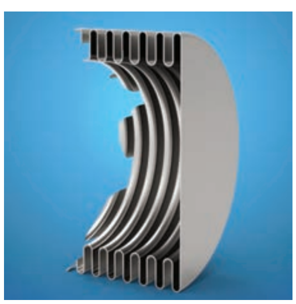
This type usage is encountered in flexible shaft couplings.

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 4).

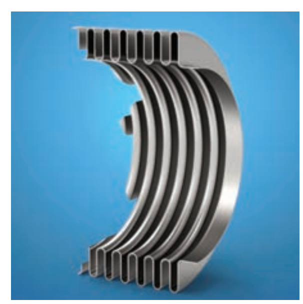
END STYLES

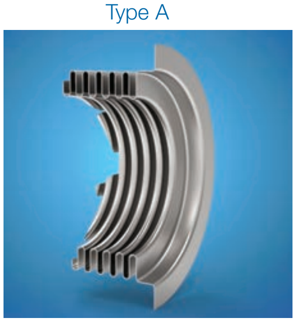
Choose from eight different end styles. Ends can be joined or attached using various methods including soft solder, silver braze, electron beam weld or adhesive. Servometer can recommend the best method for your particular application to ensure success.


Type A


Type B


Type C


Type D


Type E


Type G


Type H


Type I

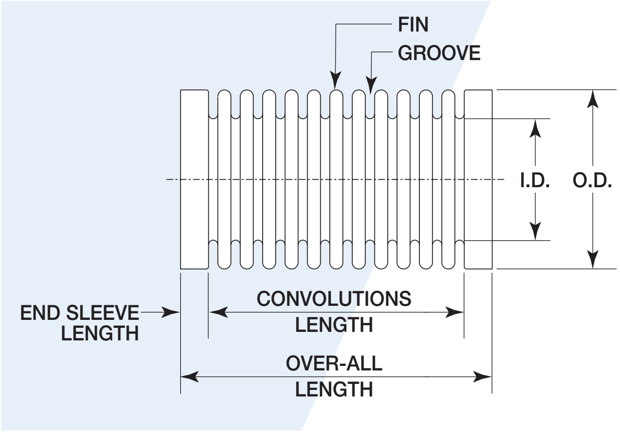
EXPLANATION OF DESIGN DATA FORM TERMS

Application Description: This gives a description on how the bellows will be used.

Application: This relates to whether the application is for a commercial, defense, or other application, and assists in determining what, if any Export Controls would apply to the bellows or bellows assembly.

DIMENSIONAL REQUIREMENTS

- **Bellows OD, max. /min:** The bellows acceptable outside diameter range for the application. This helps to define the acceptable size envelope for the bellows. It is critical for tool selection and to optimize performance.
- **Bellows ID, max. /min:** The bellows acceptable inside diameter range for the application. This helps to define the acceptable size envelope for the bellows.
- **Effective Area:** The mean diameter between OD and ID 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.
- **Bellows Free Length:** The manufactured length of the bellows convolutions, with the bellows at a neutral at rest position with no applied forces acting on it.
- **Assembly Required:** This lets the design engineer know if assembly of the bellows to end pieces is required.



ENVIRONMENTAL BACKGROUNDS

- **Bellows Material:** The bellows material required for the application, if known.
- **Temperature, Max/Min:** The potential range of temperatures that the bellows or bellows assembly might be exposed to in the application.
- **Operating Temperature:** The temperature that the bellows or bellows assembly will experience during normal operation.
- **Media / Environment:** The type of environment or substances (gas, liquids, and materials) the bellows would be exposed to in the application.

PERFORMANCE REQUIREMENTS

- **Pressure responsive:** What is the desired response with pressure changes?
- **Leak Test Required:** Determines whether the application requires the bellows or bellows assembly be leak tight.
- **Leak Rate:** If the bellows or bellows assembly is required to be leak tested, if known, give the required leak rate. The achievable leak rate will vary due to the design requirements (ID, OD, wall thickness, etc.)
- **Operating Pressure:** If the bellows needs to be leak tight, this is the differential pressure the bellows will be subjected to in the application. It is important to specify if the pressure will be applied internally or externally to the bellows.
- **Maximum Internal Pressure:** If the bellows needs to be leak tight, this is the maximum differential applied internally to the bellows, in the application.
- **Maximum External Pressure:** If the bellows needs to be leak tight, this is the maximum differential applied externally to the bellows, in the application.
- **Compression:** In the application this is the axial deflection from its nominal free length that the bellows will see in compression.
- **Extension:** The axial deflection from its nominal free length that the bellows will see in extension.
- **Lateral Offset:** The distance between the centerlines of the ends of the bellows that are parallel but not on the same line.
- **Angular Offset:** The angle between the centerlines of the ends of the bellows.
- **Spring Rate:** 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.
- **Cycle Life:** Number of cycles required for compression bending or offset movements. Loading is not a consideration.

Servometer

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Contact Name: ______________________
Company Name: ______________________
Address: ______________________
City, State, Zip: ______________________
Country: ______________________
Telephone: ______________________
Email: ______________________

Bellows Design Data Form

Please use this Guide to detail your bellows requirement. If you have any questions, please contact us.

Application Description: ______________________

____

Application (Check One): ☐ Aerospace ☐ Defense ☐ Medical ☐ Semiconductor ☐ Vacuum ☐ Instrumentation ☐ Energy ☐ Research/University/Laboratory ☐ Other (Explain) ______________

Quantities Required: ______________________ Date Required: ______________________

Target Price at Quantity: ______________________

Dimensional Requirements

Please enter bellows characteristics below. If a characteristic is unknown (UK), not applicable (N/A), or to be determined (TBD), please enter to clarify design requirements.

Bellows OD Max: __________ Min: __________ Effective Area: ______________________

Bellows ID Max: __________ Min: __________

Bellows Free Length: ______________________

Assembly Required: ☐ No ☐ Yes (Please provide drawing or sketch to detail concept and/or end pieces if applicable)

Environmental Background

Bellows Material: ______________________

Temperature: Max: __________ Min: __________ Operating: ______________________

Media/Environment:

Bellows/Contacts: Outer Dia. (OD): __________ Inner Dia. (ID): __________

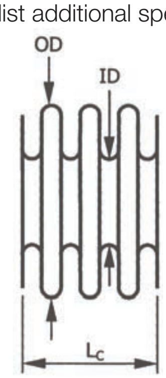
Convolution Length (L_0): __________ End Types: __________

(Refer to page 5 for bellows end type designations.)

Use space below to sketch bellows end or assembly geometry, or to list additional specification.

Performance Requirements

Pressure Responsive (Please explain desired response):



Leak Test Required: ☐ No ☐ Yes Leak Rate: ______________________

Operating Pressure: ______________________

Max. Internal Pressure: ______________________ Max External Pressure: ______________________

Total Stroke: ______________ Compression: ______________ Extension: ______________

Parallel Offset: ______________________ Angular Offset: ______________________

Spring Rate: ______________________ Cycle Life: ______________________

Servometer®'s Full Product Line:

Flexible Shaft Couplings | Electrical Contacts | Edge Welded Bellows | Electroformed Bellows

Making the Impossible... Possible!

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