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Manufacturer of Metal Bellows since 1961

Metal Bellows Design Guide

The following definitions are provided to assist in part selection and customization to meet engineering design requirements and objectives. The definitions in this design guide are related to columns 1 through 13 of the Stock Bellows Data List. Please contact Mini-Flex engineering staff for information on customizing products or if further clarification is required.

Formulas are listed at the end of this document.

Stock Number (Column 1): The stock number is used to identify each unique bellows made to standard dimensions. Available stock parts are presented in the Stock Bellows Data List. Stock number nomenclature is composed of four elements separated by dashes (-). The first element refers to the material; the second represents the outside diameter of the tubing used to form the bellows; the third identifies the wall thickness of the tube; and the fourth indicates the spring rate. An example of the nomenclature is shown below.

Example Stock Number	Material	Tube OD (inches)	Wall Thickness (inches)	Spring Rate (lbs./in.)
SS-125-46-80	SS (Stainless Steel)	0.125	0.0046	80

Material designation: B = brass, BC = beryllium copper, H = hastelloy, IX = inconel X-750, I600 = inconel 600, I625 = inconel 625, I718 = inconel 718, M = monel, N200 = nickel, NSC = Ni-span C, PB = phosphor bronze, R = rodar, SS = 300 series stainless steel.

Stock parts may be modified per customer’s specifications. A modified stock bellows is signified by an “M” at the end of the stock number (e.g., SS-125-46-80M).

Convolution Inside Diameter (Column 2): The nominal inside diameter (inches) of convolutions is based on the wall thickness and tooling used to form the convolutions. This is a fixed dimension that cannot be modified. The dimension will vary slightly when compressed or extended. The inside diameter in the “as formed” condition is approximately equal to the neck inside diameter. See definition for “Convolution Free Length” (Column 7) for additional information.

- Stock tolerances are typically ±0.005. Production runs average ±0.002.

Convolution Outside Diameter (Column 3): The nominal outside diameter (inches) of convolutions is inversely related to spring rate (an increase in outside diameter will reduce the spring rate) and the design tolerance is used to vary the spring rate.

- Stock tolerance is typically ±0.010. Custom tolerances of ±0.005 or less can be achieved when the spring rate is not critical.
-

Wall Thickness (**Column 4**)**:** Thickness (inches) of the tubing from which a bellows is formed. The wall thickness can be modified under certain conditions.

- This tolerance is specified at ±10% and normally purchased at ±5%. Actual thickness is typically better than ±3%.

Neck Outside Diameter (**Column 5**)**:** The neck of a bellows is located on both ends of the convolutions and is used to attach mating parts. The neck diameter (inches) is based on tooling but can be modified by expansion or contraction.

- Stock tolerance is typically ±0.002. Production runs average ±0.001. Custom tolerances of ±0.001 or less are possible. Tight tolerance control is achieved by applying uniform pressure on the outside diameter using a round collet while supporting the inside diameter with a standard plug gage. Care must be taken to not over stress thin-walled necks.

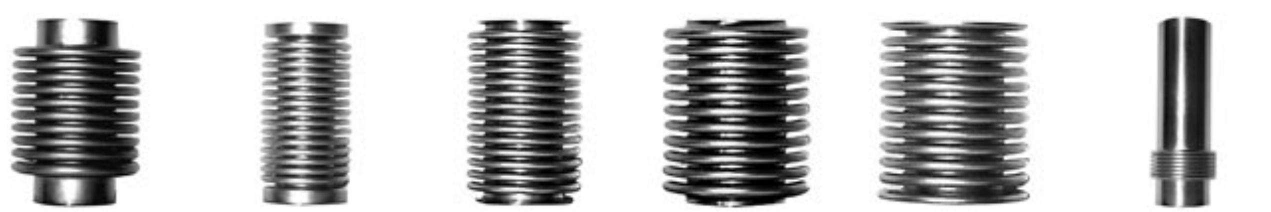
Neck Inside Diameter: The inside diameter (inches) of the neck is equal to the neck outside diameter minus twice the wall thickness.

- Tolerance on production runs average ±0.001. Custom tolerances of ±0.0005 or less are possible. Tight tolerance control is achieved by applying uniform pressure on the outside diameter using a round collet while supporting the inside diameter with a standard plug gage. Care must be taken to not over stress thin-walled necks.

Neck Length (**Column 6**)**:** The length of a tube neck (inches) is measured from the outer face of the end convolution to the end of the neck. The length of a cup neck is typically measured from the inner surface of the cup to the end of the neck. Other neck configurations are available for customized products (see “Neck Types” below) and neck lengths are based on customer specifications.

- Stock tolerance is typically ±0.015. Custom tolerances of ±0.005 or less are possible.

Neck Types



Tube Neck **Cup Neck** **Flange Neck** **Root Neck** **Split Convolute** **Custom Necks**

The Stock Bellows Data List presents available neck configurations for stock bellows. Stock bellows necks are typically tube or cup neck configurations. Other neck configurations are available as optional modifications for customized products.

Tube Neck: “A” type necks are the standard type and most consistent in size, and therefore preferable when tight tolerances are required.
Cup Neck: “C” type necks provide an alternate attachment configuration and are typically selected to meet limited access requirements.

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Flange Neck*: "F" type necks can be made on one or both ends of any bellows. The flange neck diameter is typically 75% of the convolution outside diameter (Column 3). The flange neck length can be customized upon request.
Root Neck*: "R" necks can be made on one or both ends of any bellows. Root necks are typically incorporated to customize the length of a stock bellows neck.
Split Convolution Neck*: "S" necks can be made on one or both ends of any bellows. Split convolution necks are also typically incorporated to customize the length or diameter of a stock bellows neck.
Custom Necks: Mini-Flex specializes in custom products. Please consult Mini-Flex engineering staff for details.

*Important Note: Cutting a stock bellows neck and modifying it with a flange, root, or split convolution neck will increase the spring rate and squirm pressure and decrease the convolution free length (Column 7) and maximum deflection in compression (Column 8).

Convolution Free Length (**Column 7**)**:** The convolution free length is the free relaxed length (inches) of the convoluted section of a bellows and is measured from the outer faces of the end convolutions. For bellows with cup type necks, the convolution free length is measured from the inner surface of the cup at the base of the neck(s). Overall length equals the convolution free length plus both neck lengths.

- Stock tolerance is typically held to +0.050 -0.010. Tolerance on production runs average ±0.005. Modified tolerances of ±0.005 or less are possible on custom products.

Supplemental information:

- The convolution pitch is approximately equal to the convolution free length divided by the number of convolutions (Column 13).
- The minimum free length or maximum compressed length of convolutions is equal to the convolution free length (Column 7) minus the maximum deflection in compression (Column 8).
- The convolution free length can be modified for certain applications. See "Number of Convolutions" (Column 13), "Maximum Deflection in Compression" (Column 8) and "Neck Types" for more information.
- For flexible hose applications: Stock bellows can be customized to a maximum of 200% of the stock convolution free length.

Maximum Deflection in Compression (**Column 8**)**:** The maximum deflection in compression is defined as the maximum compressed movement (inches) from the convolution free length position (Column 7) that will not result in permanent deformation of the convolutions. The maximum deflection in compression is determined by compressing the bellows until convolution contact creates a significant increase in force. Additional compression is available when the end convolution face(s) are free to move. The additional compression stroke is equal to approximately 40% of the stroke per convolution per end.

Supplemental Information:

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- Maximum compression per convolution (D_c) is equal to the maximum deflection in compression (D_m) (Column 8) divided by the number of convolutions (N): $D_c = D_m / N$
- Movement beyond the maximum deflection in compression or extension beyond the relaxed free length of convolutions will decrease cycle life, change the spring rate and cause permanent deformation which will not allow the bellows to return to its original length without the utilization of mechanical force.
- Increasing the maximum deflection in compression is achievable by extending the bellows free length (Column 7) by 175% maximum of the convolution free length.
- It is inadvisable to use the total maximum deflection in compression when long life is required.
- Hydro-formed bellows function best in the compressed state.

Spring Rate (**Column 9**)**:** Spring rate [pounds per inch (lbs./in.)] is the dead weight or force in pounds required to compress a bellows one inch. Stock bellows are usually rated at 30% to 50% of the maximum deflection in compression. Spring rate linearity varies from part to part and within the specified maximum compressed range (convolution free length minus maximum deflection in compression). Consult Mini-Flex engineering staff when linearity is a concern or when a specific spring rate is required at a designated stroke.

- Stock tolerance is typically ±20%. Custom tolerances of ±5 % or less can be achieved.

Supplemental Information:

- Force required to compress the bellows (within its specified range) equals the spring rate multiplied by the travel.
- Spring rate per convolution equals the spring rate multiplied by the number of convolutions.

Effective area (**Column 10**)**:** The effective area is the calculated area in square inches of the effective diameter, which lies approximately halfway between the inside and outside diameter of convolutions.

- The effective area tolerance is representative of the variation in the convolution outside diameter (the convolution inside diameter is fixed and cannot be modified).

Formulas:

(A) Mean Effective Area (square inches)
(A_e) External Effective Area (square inches)
(A_i) Internal Effective Area (square inches)
(O) Convolution Outside Diameter (inches)
(I) Convolution Inside Diameter (inches)

$A = \pi ((O+I)/4)^2$ or simplified; $A = 0.1963(O+I)^2$

$A_e = .1963(O+(I+2t))^2$

$A_i = .1963((O-(2t*.8))+I)^2$

Volume (V) in cubic inches equals effective area multiplied by length. Bellows volume capacity (less the neck inside diameter) is effective area multiplied by the convolution free length (L): **V=AL**. Volume displacement is equal to the stroke (D) times the effective area $\mathbf{V_d=AD}$.

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Pressure (P) in pounds per square inch required to compress the bellows any distance within its maximum deflection equals spring rate (R) multiplied by the deflection (D) and divided by the effective area (A): P= RD/A.

Critical Squirming Pressure (**Column 11**)**:** Critical squirm pressure is measured in pounds per square inch (PSI). Squirm occurs when the convolutions are unrestrained from sideways movement, the necks are fixed, and the bellows is subjected to internal pressure. When critical squirming pressure is reached, a slight bow, or sideways movement occurs. When pressure is increased, the bellows will lose stability and eventually enter into the form of a “U” bend. Squirm will not occur if the bellows is guided internally or externally by a rod stem or in a close fitting bore. Squirm is more likely to occur when the convolution free length exceeds the convolution outside diameter.

Supplemental Information:

- The squirm rating is provided for reference purposes and will vary with convolution wall thickness (within the tolerance range). Depending on application, the actual squirm pressure may be considered the maximum internal proof pressure (see “Maximum Operating Pressure” below).
- Higher critical squirm pressure ratings are more desirable when bellows function is critical (greater critical squirm pressure ratings result in increased safety factor and longer bellows life).
- Exceeding the actual squirm pressure will cause sidewall yield that may cause an increase in spring rate and a decrease in maximum deflection. In some cases this deformation is minor and will not affect the bellows function.
- External pressure does not cause squirm regardless of length.

Maximum Operating Pressure: The maximum operating pressure of a bellows is considered the proof pressure, and is unique for each application.

Burst Pressure (**Column 12**)**:** The minimum internal or external burst pressure [pounds per square inch (PSI)] represents the minimum internal or external pressure that will not result in fracture when a bellows is restrained from squirm or sideways movement. At this pressure, severe permanent deformation of convolutions takes place, possibly rendering the bellows useless. This designation is used for design information only and is dependent on the tensile strength of the forming material. Actual internal or external burst pressures are higher.

Number of Convolutions (**Column 13**)**:** Modifying a bellows convolution quantity is possible by splitting at the major or minor diameter or cutting a flange from or between any convolutions. This change would then become the bellows neck. See “Neck Types.”

Supplemental Information:

- Decreasing the number of convolutions will increase the spring rate and squirm rating and decrease the maximum travel and length.
- Increasing the number of convolutions will decrease the spring rate and squirm rating and increase the maximum travel and length.

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Formulas

Symbol	Definition
A	Effective area of a bellows (nominal)
A_e	Effective area of a bellows (external)
A_i	Effective area of a bellows (internal)
A_d	Effective diameter of a bellows
D	Axial movement per bellows (compression)
D_c	Axial movement per convolution (compression)
D_m	Maximum axial movement per bellows (compression)
F	Force (lbs.)
h	Convolution height (external)
I	I.D. of convolutions
L	Convolution free length
L_m	Free length minimum compressed length
N	Number of active convolutions
O	O.D. of convolutions
P	Pressure (PSI)
p	Pitch of convolution
R	Spring rate of bellows (lbs./in.)
R_c	Spring rate per convolution
t	Tubing wall thickness
V	Volume (cu.in.)
V_d	Volume displacement (cu.in.)

Formulas

$A=\pi((O+I)/4)^2$ or simplified; $A = 0.1963(O+I)^2$

$A=(R*D)/P$

$A=F/P$

$A_d=((O-I)/2)+I$

$A_e=0.1963(O+(I+2t))^2$

$A_i=0.1963((O-(2t*0.8)+I)^2$ Note: t corrected for wall thinning

$D=F/R$

$D=(P*A)/R$

$D_c=D_m/N$

$F=R*D$

$F=P*A$

$h= (O-(I+2t))/2$

$L_m=L-D_m$

$p=(((L/N)/2)+L)/N$

$P=(R*D)/A$

$P=F/A$

$R_c=R/N$

$V=A*L$

$V_d=A*D$

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