Putting Bellows Technology to Work to Solve Design Challenges

Introduction
What do medical pumps, diving watches, oxygen valves, flexible mechanical couplings, and semiconductor wafer handlers all have in common? They all rely on bellows: flexible, spring-like, precision-engineered components that come in a variety of designs, materials, and geometries.

Bellows technology is utilized in hundreds of mechanical components and OEM products for pressure compensation, volume compensation, switches, valves, expansion joints, feedthroughs, and more. Engineers rely on their unique performance capabilities for applications in aerospace, semiconductor, energy, medical, and industrial.

Each metal bellows technology has unique performance characteristics, materials, and manufacturing techniques. This article describes the various bellows technologies available from MW Industries companies BellowsTech, Servometer, and Ameriflex that will enable you to make an informed decision when choosing the bellows technology that best suits your application and budget.

Basics of Metal Bellows
A metal bellows is a precision-engineered, flexible, metal component that acts as a leak-tight seal separating two environments from each other. These versatile parts can convert changes in pressure, temperature, and position into linear motion or rotary transmission to maintain flexible mechanical and electrical connections.

The biggest difference among all the bellows offered by MW Industries is in the production method for each. Each of three production methods — electrodeposited, edge-welded, and hydroformed — has inherent advantages in their capabilities based upon the manufacturing technology employed.

Servometer’s electrodeposited bellows are made by plating nickel material onto aluminum mandrels. The aluminum is then removed, leaving a thin-walled metal bellows. Thin wall capability is the strongest characteristic of an electrodeposited bellows. Also, the mandrel can be made by conventional CNC turning machinery, providing the potential for large geometry variation that can meet demanding specifications without special tooling requirements.

Edge-welded bellows from BellowsTech are made by stamping diaphragms out of metal that are then alternatively welded together to form accordion-shaped bellows. The ability to choose from a large selection of materials for production, as well as the fact that they can compress up to 80 percent of their natural length, is their primary characteristic.

Hydroformed bellows from Ameriflex are made from tubing that is formed into the convolutions that make up the bellows. These bellows can be made from a variety of materials to meet environmental requirements. The primary characteristics of the hydroformed bellows are that they’re relatively easy to manufacture in large quantities and offer some of the lowest possible cost for a bellows. Another feature is their ability to be manufactured in thin walls with high tolerances.

Figure 1. Servometer’s thin-walled electrodeposited bellows are available with diameters from 0.020” to 9” in diameter.
Electrodeposited Bellow s
Electrodeposited bellows are made by plating metal onto a substrate similar to a chrome bumper on an old car; however, Servometer removes the bumper, leaving just the chrome shell — actually, a nickel or copper shell. This technology allows for the production of very-thin-walled bellows with diameters from 0.020” up to 9” (Figure 1). The unique aspect of Servometer bellows is that they can be made very flexible due to the thin walls and have very high cycle lives. Another important aspect is that the seamless construction is very resistant to high-vibration environments, making them ideal for temperature, pressure, and volumetric indication or actuation.

Electrodeposited bellows are made from a proprietary flex nickel and/or copper and also are available in gold or silver plating for added corrosion protection or electrical conductivity. Available stock products include nickel and/or copper bellows, shaft couplings, and gold-plated electrical contacts; custom bellows assemblies and electroforms are offered.

Manufacturing
The manufacturing process for bellows and electroforms is completed in five stages. Stage one starts with a 6061 T6 aluminum billet. Next, the aluminum is machined to the inside dimensions of the final part to make a mandrel. In stage three, the mandrel is plated with nickel and/or copper with additional gold or silver as specified for environmental resistance. Then, the mandrel is trimmed to the appropriate length to define the overall length of the bellows or electroformed parts. Finally, in stage five, the aluminum is completely removed through a chemical process known as leaching. Now the bellows can be tested and shipped or assembled with hubs or flanges to be incorporated into the next-level component.

Outside diameter (OD) can be as small as 0.020” (0.5 millimeter) or as large as 9”; overall length can be up to 10”. Typical compression stroke of a Servometer bellows is around 35% of the convolution length — upwards of 50% in compression for some applications. Standard leak rate is $1 \times 10^{-6}$ cubic centimeters (cc) of helium per second at 1 atmosphere. Rates as low as $1 \times 10^{-9}$ cc of helium per second at 1 atmosphere are achievable for most bellows. Standard couplings and electrical contacts are not leak-rated, as these applications typically do not require hermetic sealing.

Maximum differential pressure can be up to 10,000 psi but varies with diameter and application requirements such as stroke and cycle life. Maximum temperature is 350 °F. This limitation is because the nickel material may anneal or brittle at higher temperatures, which could change the spring rate of the bellows and performance ratings. Material temperature limitation for the nickel is much higher as a static electroform, where temperatures of up to 1,000 °F may be possible.

Low temperature rating is -423 °F but there are instances of Servometer bellows being used in millikelvin research as an angled coupling, so the actual lowest limit possible is unknown. Also, Servometer bellows have been successfully used to meter liquid helium, which is much lower than -423 °F. Servometer bellows can be designed to achieve a theoretical infinite lifecycle, which is called out at one billion cycles.

Applications
For aerospace applications, accumulators and reservoirs that flex with varying volume content due to heating and cooling of fluids are possible with a bellows design (Figure 3). These systems can be found in

Figure 2. Servometer bellows can be used as an actuator within a pick-and-place system to allow movement of a semiconductor wafer from chamber to chamber and as a shaft seal on a shutter assembly.
aneroids, a special type of assembly that has been fully evacuated and sealed with a sealed internal vacuum. The bellows would be shorter at sea level than at varied elevations; this change in length can be used for fuel control, modulation at varying altitude, as well as oxygen masks and indicators that may be needed during flight. A bellows is a natural actuator that will move with changes in pressure due to fluid or gas.

Bellows are flexible seals that allow for maintaining pressure requirements in inner and outer environments to allow transferring of motion into the opposing side while maintaining the pressure differential. In the semiconductor industry, the bellows can be used as accumulators that assure even fluid or gas flow with modulating pressures. Also, the bellows can be used as a flexible accumulator that can pump gas or fluid to change the pressure in different systems.

A common application for bellows is within a pick-and-place system in which it is used to draw vacuum through the bellows inside and hold onto parts during transfer as well as final positioning of the part after switching from vacuum to positive pressure (Figure 2). Pick-and-place machines move thousands of pieces per hour using a bellows as the actuation device. Also, aneroids can be used in vacuum systems to indicate appropriate vacuum levels needed for certain process activation or continuation.

In the medical industry, a bellows is a natural reservoir or accumulator for pumps and fluid or gas flow. Servometer also can make a pure gold part that may be implanted in the body to store fluid or gas. Bellows couplings are used to drive dosing pumps and machinery requiring very high rotary transmission compliance since the bellows coupling does not store rotational information and input-to-output ratio is 1:1 with very low wind-up. Also, the bellows as a flexible seal can be used in small-diameter tubing for endoscopy and other instrumentation.

**Edge-Welded Metal Bellows**

BellowsTech’s edge-welded bellows feature the most stroke length of the metal bellows manufacturing methods. This makes them ideal when maximum amount of axial movement is required or in applications where space is limited. Standard tests performed on all bellows assemblies include dimensional and helium mass spectrometry leak rate tests in multiple stages of production as well as spring rate and force testing. Other capabilities include cycle rate testing, metallurgical analysis, hydrostatic and pneumatic pressure testing, and performing SPC and DOE studies.

BellowsTech’s products include edge-welded metal bellows and bellows assemblies as well as machine components. These range from simple bellows with cuff or tube adaptor in-fittings, to much more complicated assemblies with multi-piece custom flanges and enclosures.

**Manufacturing**

Manufacturing of edge-welded bellows assemblies is a five-step process, with each step inspected for product integrity and quality. In step 1, the metal diaphragms are formed. In step 2, the metal diaphragms are stamped, and in step 3, the inside diameters are welded to form convolutions. At step 4, the outside diameters of the convolutions are welded to form the bellows. Finally, in step 5, any in-fittings are then welded onto the
bellows core. The bellows are then tested and shipped or assembled with higher-level components or processes.

The smallest OD is .358” (9.1 mm) and the largest is 26” (≈650 mm). The maximum stroke length for one section that BellowsTech has built is 96” (2,438 mm). The stroke capability is one of the most important parts of an edge-welded bellows. Certain bellows designs can stroke as long as the free length; typically, with a maximum of 25% of stroke in extension and 75% stroke in compression. These percentages can be modified with heat treatment for demanding designs.

Edge-welded bellows can be very pressure-sensitive and force-sensitive when desired. Sensitivity varies with bellows size, material thickness, and length. Spring rates of 1 pound per inch or less are easily achievable. Standard bellows material thicknesses range from 0.002” to 0.010” (.051 to .254 mm), depending on the bellows’ diameter and tooling.

The leak rate as tested on a helium mass spectrometer ranges from $1 \times 10^{-5}$ to $1 \times 10^{-9}$ cc of helium per second. This is driven by material and is equivalent to 1 cc every 32 years. Many applications require a high level of corrosion resistance, so a variety of materials are available for applications including salt water, acidic, alkaline, and down hole oil and gas environments.

Edge-welded bellows operate in a range of pressures. Certain smaller-diameter designs can withstand up to 2,500 psi external to the bellows; BellowsTech has achieved over 15,000 psi external with an internally oil-filled design. The bellows can be manufactured with materials to withstand a temperature range from 1,500 °F (815 °C) to -425 °F (-251 °C). Some common materials used to construct bellows include AM350, 316 stainless steel, 321 stainless steel, 347 stainless steel, Haynes 242, Hastelloy C276, Inconel 600, Inconel 625, Inconel 718, and aluminum. BellowsTech edge-welded bellows can achieve very high cycle rates — up to 3 million cycles with even greater cycles achieved.

Applications

Edge-welded bellows may perform unique or similar functions across a broad range of industries. Aerospace applications include accumulators, reservoirs, aneroids, mechanical seals, and actuators. As an example, actuators are used to provide positive pressure in the cooling systems for avionics to prevent cavitation and pressure spikes.

Oil and gas industry applications include accumulators, mechanical seals, reservoirs, actuators, and volume compensators. Pressure-balanced bellows in series allow for proper pressurization of welds by incorporating the bellows into a gas lift device.

Flexible seals, accumulators, and actuators are some of the semiconductor and high-vacuum applications; for example, shaft seal bellows allow for actuation of doors and gates in semiconductor equipment under vacuum such as CVD units.

In the medical field, applications include pumps, couplings, flexible seals, and pulse suppression. As an example, medical bellows can be used as surgery tools to aid in operations such as knee replacement to position the knee joint in the correct location before performing a surgical operation. Another example might be a pressure-isolation, pulse-suppression device in a small dialysis machine.
Thin-Walled Bellows

Ameriflex specializes in high and ultra-high vacuum hydroformed manufacturing of thin-walled bellows and bellows assemblies, maintaining an extremely tight tolerance. Capabilities focus on the production of hydroformed bellows, braided flex, lines, and machined parts (Figure 4). Helium leak check detection and die penetration testing ensures the structural integrity of completed products and welds along with other testing capabilities.

Core capabilities include formed bellows and tube manufacturing. All component fittings are machined in-house and each part is leak-checked to a standard of $1 \times 10^{-9}$ using barium helium mass spectrometers. Ameriflex offers cycle testing, pressure testing, spring rate testing, and in-house engineering support.

Manufacturing

There are three manufacturing options in an array of materials based on the application. Hydroforming is ideal for thin-walled, high-cycle-life requirements such as for valves, actuators, or other items. Material thicknesses range from .002" to .10”; tolerance is ±.015". Mechanical forming is ideal for roughing line, thick-walled, multiply applications such as aerospace and industrial. Material thicknesses range from .002" to .056" multiply and tolerance range is ±.030". Finally, diaphragm forming is ideal for extremely small thin-walled bellows applications below .5" ID. Material thicknesses range from .002" to .006", with ±.015" tolerance.

There is a six-step manufacturing process. Step 1 forms a metal tube from sheet. Step 2 forms convolutions by hydroform, mechanical, or diaphragm processes. In step 3, the final convolution pitch is set by rolling or segmenting; step 4 is the final end configuration of necks or weld preps. In step 5, welding of the end connections and a leak check are performed. Finally, at step 6, inspection and packaging are performed.

Some unique performance properties of Ameriflex bellows include OD that can be as small as .25" and as large as 43" currently tooled and 50" maximum not tooled. The maximum convolution length for one section varies by ID design, and material wall thicknesses can range from 3" to 200'. Typical compression and extension is based on the convoluted portion, which is also called the live length, and is approximately 15 percent compression and 10 percent of extension. Wall thicknesses as low as 0.002" to 0.056" are possible.

Maximum differential pressure can be up to 3,500 psi, but varies with diameter, wall thickness of the material, and application requirements such as stroke and cycle life. Maximum temperature for Ameriflex bellows in a stainless version is 900 °F. This limitation is due to the fact that the stainless material may anneal or embrittle at higher temperatures, which could change the spring rate of the bellows and performance ratings. A recommended material temperature limitation for Inconel is much higher, at a maximum of 2,000 °F. Low temperature rating is at -420 °F.

Figure 5. The Mars Rover Curiosity uses an Ameriflex fluid loop as part of its thermal control system.
Bellows materials available are nickel alloys, 321 stainless, 316L stainless steel, Inconel 600, Inconel 625, Inconel 718, Hastelloy C22 and C276, copper, brass, phosphorus bronze, titanium, and Monel. Corrosion-resistant material is utilized based on the application. Stainless 300 is appropriate for basic corrosion protection; Hastelloy C276 and C22 are highly corrosive-resistant. Monel is used for seawater applications, and Inconel is extremely heat- and corrosion-resistant. Ameriflex bellows can be designed to achieve a lifecycle of 1 million to 30 million cycles.

**Applications**

Ameriflex provides high-quality, high-precision manufacturing for semiconductor OEMs and distributors. Metal bellows are used in value applications with chip manufacturing equipment to aid in the control of pressure, vacuum, or motion. Steel braided hose can be found in roughing line applications, vacuum electronics manufacturing, and more.

Aerospace applications include reservoirs, mechanical seals, and thermal control systems. The Mars Rover Curiosity uses a fluid loop as part of its thermal control system. The fluid loop uses Ameriflex’s braided flex lines for circulating the single-phase fluid regulating the operating fluid at certain temperatures and pressures.

Ameriflex manufactures Inconel slip joint bellows for Indy car and NASCAR racing. These exhaust manifold components are designed to absorb heat and vibration generated by racecars’ high-performance engines. The slip joint bellows are made to withstand extreme temperatures without compromising performance.

**About MW Industries, Inc.**

MW Industries, Inc. is the world’s leading manufacturer of highly-engineered industrial springs, fasteners, bellows, and related metal components. With several manufacturing locations throughout the United States, MW Industries designs and creates products for a variety of industries, including medical, aerospace, energy, and automotive. Our products can be encountered in many everyday applications, such as driving a car, flying in an airplane, using electronics, or shopping at a grocery store. Through decades of growth, innovation, and dedication, MW Industries has proven to be a world-class supplier of custom springs, fasteners, and precision metal components.

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