Replacing Failed Bellows?
Consider These Reverse Engineering Guidelines

Seasoned expertise is required when the OEM is out of the picture and off-the-shelf replacements won't do

Produced by:

Servometer

METAL BELLOWS: 101 USES

"Used in sensitive military and aerospace applications, medical, semiconductor and oil and gas applications."

Metal bellows are used in a diverse array of industrial, aerospace, medical, oil-and-gas service, cryogenic, semiconductor/ultra-high vacuum (UHV), solar power, agricultural, test-stand, and other applications, to provide a response within a greater machine component or assembly. Specifically, a bellows converts pressure or vacuum changes into a linear motion response or provides mechanically driven feedthrough movement.

Today, bellows are used in components as varied as pressure and temperature sensors, hydraulic and pneumatic actuators, vacuum-handling systems, volume compensators, bourdon tube replacement, aerospace aneroids and altimeters, thermal compensators, mechanical seals, load cells, vacuum interrupters, exhaust bellows in engines, pipe-expansion joints, flexible shaft couplings, hermetic sealing of switches, and valve stem seals. Bellows are also widely used as mechanical backups for mission-critical electronic systems in sensitive military and aerospace applications.

Metal bellows can be manufactured in a wide range of sizes depending upon the technology. Edge welded bellows are most commonly manufactured with wall thickness ranging from .002 inches to .010 inches and outer diameters ranging from 0.358 inches to 25 inches (although manufacturers can often accommodate other dimensions, as well). Electroformed bellows dimensions also vary widely according to length and wall thickness but OD's range from 0.020 inches to 8.0 inches. Convolution lengths may be as long as 10.0 inches.

A metal bellows has the physical form of a flexible, spring-like accordion, but once it is filled with a liquid or gas under atmospheric or vacuum conditions and its ends are sealed, the bellows will be extremely sensitive to a variety of forces, providing a predictable, dynamic mechanical response. In vacuum or pressure applications bellows are fabricated as part of sealed, leak-tight assemblies, with appropriate ends to allow connection within the equipment itself.

THE IMPACT OF BELLOWS FAILURE

While the bellows itself is typically a small part of the overall machine assembly, it often plays a critical role in the overall functionality of the system especially operating in mission critical components. In some cases, the malfunction or failure of the bellows alone can result in forced shutdown for repair or replacement of an entire system, which can lead to harmful and extremely costly production and revenue losses, even loss of life.

Bellows are designed for thousands or even millions of cycles; however, some will ultimately experience failure due to stress, fatigue, corrosion, abrasion or misuse. Most bellows failures result in leakage of the internal fluid or gas, which will impact the system in which it is intended to function.

A broken or malfunctioning bellows can rarely be retrofit with an off the shelf solution that will achieve the desired fit, form and function of the original bellows. Therefore, users often prefer to seek a custom solution to replace the bellows, to ensure that the geometry and functionality of the new part meets the specific engineering requirements of the system (in terms of both required performance attributes and strict geometric or material requirements or constraints).

With the exception of shaft couplings, stock bellows offerings are typically limited. Custom-designed originals usually require custom designed replacements.

WHEN TO USE THE REVERSE ENGINEERNG APPROACH

When an existing bellows fails and a suitable replacement is not readily available, users often seek a reverse-engineered solution to incorporate all of the relevant specifications and design details needed for function in the application. Conditions that contribute to their decision include:

- *Legacy Replacement:*

When the bellows is part of an older, legacy machine assembly the original vendor may no longer be in business; technical personnel who were involved in the original design process may no longer be available for consultation, and/or spare parts may no longer exist.

"Rather, users often prefer to seek a custom solution to replace the bellows."

- *Lack of Documentation:*

  Design information can be forgotten, lost, stolen or misplaced. Without any drawings, CAD/CAM files or other documentation concerning the origin of the bellows, the user is unable to describe or specify the bellows in any meaningful way.

- *Customer Experience:*

  The customer would like to consider a different vendor due to pricing, unsatisfactory customer service or delivery times, or unreliable supply chain issues.

- *Optimized bellows design:*

  The user is seeking enhanced performance or reliability from the replacement bellows. In some cases, the user would like to take advantage of an improved material or ongoing design advances. One common example is the desire to switch from a bellows made from electroless nickel to one made from a more robust material that can be produced by electroforming or edge welding bellows processes.

- *Enhanced equipment:*

  The user may be making equipment upgrades that require changes to the bellows. When this happens, a reverse engineered bellows is often the only option.

CONDUCTING A FORENSIC INVESTIGATION

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The process of reverse engineering precision parts requires a blend of art and science, combining measurement, analysis, experimentation and research. There are generally two scenarios. In some cases, the user is able to supply key information and perhaps even the bellows itself to support the investigation and redesign and manufacturing process. In other cases, it is up to the user to collaborate with a reputable vendor to conduct a thorough investigation and gather or recreate as much of the relevant engineering information as possible to support the production of a suitable replacement.

An important caveat here is that too often, the customer seeking a reverse-engineered solution believes that the replacement bellows must "look and feel" exactly like the one it will be replacing. In truth, the primary consideration is that the replacement bellows will perform as required — not that it will look identical to its predecessor. In the final analysis, the new, custom bellows must mimic the function of its predecessor (and fit in the available size envelope), not necessarily mimic its earlier form.

In general, the user may be asked to supply as much of the following information as possible:

- Material of construction
- Critical dimensions
- Bellows internal and external pressure
- Temperature range
- Spring rate and the available tolerance. For instance, how many pounds of force are required to deflect the bellows through a given compression, or conversely, the amount of force available to flex the bellows and the desired amount of movement.
- Torque requirements or limitations for a coupling
- Total travel in compression and extension
- Types of deflection or flexing anticipated (for instance, axial, lateral or angular)
- The allowable leak rate for the application

- The lifecycle of the bellows, typically in terms of the number of defined flexing cycles
- Types or lengths of the ends required to connect the bellows into the machine assembly
- Anticipated vibration or shock
- Environmental or chemical exposures

EXAMINING THE EXISTING FAILED BELLOWS

The ability of the user to supply some or all of this design information will speed the process and improve the design. If the user is able to remove and provide a specimen of the failed bellows from the machine assembly or system for hands-on inspection, even better. With access to the existing bellows, a wide array of data can be gathered about the geometry, design and functional capabilities of the piece. Typical forensic testing involves the use of force testing, pressure testing and material analysis. The spring rate can be determined and effective area calculated. The bellows may be sectioned so that the design engineers can further examine its geometry and measure the thickness of individual convolutions.

In the case of a sealed assembly, the design engineer may assess the nature of the environment inside the assembly. Is it liquid, gas, both, or vacuum? Is it pressure sensitive? Temperature sensitive? Laboratory analysis may be performed on the fill fluids, solders and brazes. Effort can be made to measure the thermal expansion gradients with thermocouples and indicators. The information gathered can be used to define the specifications for the device. Engineers will turn these specifications into parametric models, drawings and documents to support the manufacture of replacements.

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DISCOVERY

"....nickel may be more resistant to some kinds of corrosion than brass or bronze..."

While the ability of the user to supply solid information and even a sample of the piece represents the ideal scenario, in most cases, users do not have complete information about the bellows. In some cases, they have no information at all and are not able to supply the faulty bellows assembly for hands-on investigation.

In these cases, the forensic process depends largely on answers to extensive questions about the application. The design engineer creates preliminary design solutions, based on the information available, and solicits feedback from the user. This approach is typically iterative and more deliberate, but often leads to significant improvements over the original design.

Consider, for example, the challenge of determining which material of construction is required (a choice that may include stainless steel, titanium, exotic nickel alloys and others). When no sample bellows is available to be tested, a series of questions may help to identify the target metal (or rule out options that would not be suitable for the installation). For instance:

- **Was the existing bellows used in a corrosive environment?** An understanding of the bellows' environment may narrow the field of choices. For instance, nickel, may be more resistant to some kinds of corrosion than brass or bronze, but not as much as stainless steel. Electroformed bellows will not oxidize in air or be affected by alkaline liquids, and they can be manufactured with coatings to protect them from harsh conditions. Edge welded bellows can be made from a variety of corrosion resistant metals and alloys.

- **Is the operating temperature experienced by the bellows above some key threshold value?** For instance, if the temperature is >800°F, the designer can rule out certain materials.

- **Are there requirements or limitations on the bellows magnetism?** Electrodeposited nickel is ferromagnetic, while other electrodeposited materials are non-magnetic. Edge welded bellows are predominately non-magnetic with the exception of AM350 Stainless Steel bellows which have slightly magnetic properties.

MODELING AND MANUFACTURING

Once the critical information about the bellows is amassed, the design engineer may use parametric CAD modeling to represent the bellows and associated components of the application. The CAD tool encourages interaction and collaboration between the designer and the user. Furthermore, it helps the designer manage the complex and often iterative design process.

Often the discovery process is continued in the design phase as the user realizes previously unknown aspects of the application or recognizes opportunities to make design improvements. These discoveries can help guide the design process and substantially influence the final product.

The CAD modeling process also allows the designer to leverage existing tooling and dies, which can accelerate production and minimize costs.

It may appear obvious, however, once the precise replacement bellows has been reversed engineered, users should consider ordering more than just one in order to have adequate spare parts to help avoid future downtime, production losses and of course, the need to go through the entire process again.

As far as timing is concerned, once the reverse engineering process is complete a bellows can be manufactured in a matter of four to six weeks (depending on the complexity and quantity of the job), although faster turnaround times are possible when extended downtime of mission-critical operations cannot be tolerated.

CONCLUSION

Reverse engineering is sometimes the only option when replacing legacy bellows due to obsolete parts, insufficient documentation, customer service issues and optimized designs. Using a reputable vendor with design engineering expertise in your field is critical to developing a suitable replacement. Be prepared to supply as much relevant engineering information as possible such as dimensions, material, spring rate, etc. to the engineering design team in order for them to conduct a thorough forensic investigation.

ABOUT THE AUTHORS

Brent Caldwell (brentC@servometer.com) is the Engineering Manager of Servometer, New Jersey, where he has served for 14 years. Caldwell holds a BS degree in Mechanical Engineering from the New Jersey Institute of Technology.

Brad Merkel (bmerkel@bellowstech.com) is Vice President of BellowsTech, Ormond Beach, FL. BellowsTech is a sister company to Servometer. Merkel holds a BS degree in Mechanical Engineering from Pennsylvania State University.

ABOUT SERVOMETER AND BELLOWSTECH

Making the Impossible Possible

Servometer, the pioneer of electrodeposited miniature metal bellows, bellows assemblies, contact springs, flexible shaft couplings and rigid electroforms offers over 50 years of engineering and manufacturing experience servicing the aerospace, defense, medical, test, semiconductor, UHV, solar and oil and gas industries. Servometer is ISO 9001:2008 certified. In 2007, Servometer acquired BellowsTech of Ormond Beach, Florida, a premiere manufacturer of edge welded bellows and bellows assemblies encompassing a wide array of alloys and dimensional configurations for oil and gas, semiconductor and vacuum technology industries. BellowsTech is AS9100-C compliant.