PENBERTHY®
A Tyco Flow Control Company

320 Locust Street
Prophetstown, IL 61277-1147
Voice: (815) 537-2311 Ext. 160
Fax: (815) 537-5764
E-Mail: gsanders@penberthy-online.com
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PenTech FAQ # 8 by Gary G. Sanders, Director of Engineering

A Case for Belleville Washers

No, this is not a sequel to the "The Hound of the Baskervilles", nor am I in any way approaching Sir Arthur Conan Doyle's style as an author. However, the concepts presented here may solve more of your mysteries / problems about compression seal leaks and gasket failures than the entire Holmes / Watson / Baker Street bunch series. So don your deerstalker (magnifying glass optional) and read on …..

Background
To achieve a compression seal – whether on a flange joint, a glass liquid level gage or a sight flow indicator (SFI) – adequate clamping (closing) force on the joint must be applied and maintained - usually by torqued bolting. Penberthy has adapted ASME Boiler and Pressure Vessel Code Section VIII, Division 1, Appendix 2 equations and 'm' and 'y' gasket factors to the geometry of liquid level gages and SFI's.

Example: When a Penberthy xTM5 liquid level gage with B7 bolting is torqued to its calculated value, the bolting is elastically stretched by 7.47 mils [0.19 mm]. The minimum bolt stretch required to maintain the seal at rated pressure is 4.93 mils [0.125 mm]. This means that the maximum allowable compression set for the gaskets and cushions is 2.54 mils [0.065 mm] or 0.64 mils [0.016 mm] per gasket/cushion in the compression stack. Refer to FAQ #1 for a discussion about initial compression set in gasketing.

Residual gasketing compression set distance may be many times the allowable bolting elastic stretch limit. In use, particularly in applications with frequent pressure and/or temperature excursions, retorquing is required on a continuing basis. Where vibration is present, the sprung mass of the covers and glass acts like a micro-hammer pounding the gasketing. Side connected liquid level gages apply a variable bending moment to the chamber beam that has the vessel connections – again beating on the gasketing. These hammering effects are particularly significant when using graphite gasketing due to its friability (Grafoil™ is the current standard gasketing material). Additionally time and temperature deteriorate the recovery elasticity of most gasketing (notable exceptions are graphite and certain polymers). The aforementioned effects conspire to reduce the compression stack height thereby reducing the bolt loading until there is insufficient closure force on the seal. Then the process media leaks or worse a gasket blow-out ensues.

Rhetorically, why do compression seals fail? Based on our experience with glass-metal seals, the primary reason is improper maintenance of closure force by bolt loading (read: torque) >95% of failures. FYI, other causes: ≈ 2% corrosion; ≈ 1% external mechanical or piping loads impressed upon the glass-metal product and ≈ 2% miscellaneous.

Discussion

Unless frequently retorqued, bolting alone cannot do the task – even by dangerous overtorquing. If torqued beyond its elastic limit, bolting will permanently stretch and become useless for generating closure force. This condition is usually referred to as necking (increasing torque has been a common field solution but ends up causing more long term problems than are solved).

An inexpensive solution – which adds the additional benefit of reduced maintenance / longer product service life is to extend the range of compression stack height reduction that can be compensated by adequate compression force. By placing a spring (with spring force > bolt load) into the compression stack, the effective force ≅ distance of the bolting may be multiplied. Due to the small area of bolt reaction (contact area of nut or bolt head) and the small bolting seat area on the gage / SFI covers – common springs do not work well in this application.

A Belleville washer is essentially a flat washer that has been formed into a truncated conic section (called dished) and spring tempered. Belleville washers provide very high restoring force for their volume when compared to standard springs. Unlike typical compression or tension springs, most Belleville washers exhibit a non-linear spring rate (their load line is a regressive curve from flat load to free height). Spring tempering (high hardness) precludes their qualification to NACE MR0175.

Materials

Penberthy's standard materials for Belleville washers with comments are:

1. Carbon steel H11/H13 (-20 to 1000°F [-30 to 540°C])
   Good for high temperature applications but avoid using in corrosive atmospheres.
2. Stainless steel 17-7PH (-100 to 500°F [-70 to 260°C])
   Good corrosion resistance, has high immunity to sulfide pitting corrosion.
3. Inconel™ IX750 (-150 to 1150°F [-100 to 620°C])
   Ni-Cr alloy; tough, good corrosion resistance with a broad temperature range.
4. Carpenter™ C455 (-258 to 500°F [-160 to 260°C])
   A stainless steel primarily used in cryogenic applications.

For extra corrosion resistance, Belleville washers may be special ordered with zinc or nickel plating or Teflon™ coating (more about coatings in FAQ #7).

Application

On Penberthy products, Belleville washers are nearly always used in parallel stacks to maintain closure force (a single Belleville washer typically does not have adequate load force). For product with through bolting, Belleville washers are placed symmetrically on both sides of the bolting. For u-bolt or stopped stud bolting the entire parallel set is placed under each nut.

Due to the high stress loading on Belleville washers and the limited bearing surface areas on liquid level gages and SFI's; at Penberthy, Belleville washers are engineered to be product specific. General replacement parts should not be used.

We are now recommending that Penberthy products with Belleville washers be torqued using the Installation, Operation and Maintenance manual (IOM) values (assumes cleaned, lightly lubricated bolting and Belleville seating surfaces). Be absolutely certain that no foreign material is between the Belleville washers in a parallel stack.
Note: in the past, we suggested using a height measurement to set the pre-load compression, it is the most accurate method. However, variability between Belleville stack and nut thicknesses and reference surface irregularities causes this method to be impractical. Older IOM's may still include this reference, please disregard.

Replacement schedule: due to a gradual loss of temper, we suggest that Belleville washers be replaced every other maintenance teardown of Penberthy products in process service at > 450°F [230°C] and every third maintenance teardown at lower temperature usage.

Conclusion

Penberthy glass-metal products have a much more difficult compression seal than metal-to-metal (flange) seals because glass has a much lower coefficient of friction than metal (in this case, largely a function of relative surface finish). Due to the frequency of pressure and temperature excursions, all Penberthy steam-water gage designs include Belleville washers. Their maintenance interval without Bellevilles would often be measured in days or hours (refer to Application Report #2781 for additional information). Specifying Belleville washers as an addition to process gages or SFI's can dramatically reduce the retorquing and maintenance requirements for these types of products.
An aside: Belleville washers could also provide an elegant, inexpensive solution for your difficult to seal flange or cover joints.

For those readers who claim they have never seen, heard of or used Belleville washers consider the rotary lawn mower. Belleville washers are used to pre-load the bolting that attaches the blade to its drive shaft. Under normal conditions, this live loading allows the blade to rotate at shaft speed and maintains bolting tension (imagine the destructive potential of an untethered spinning blade). Upon hitting a solid obstacle (e.g., a rock) instead of sudden engine stoppage and/or blade shatter, limited slippage will occur. You may damage the blade but catastrophe most likely will be avoided.

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