CROSS

White Paper

Metallic Sealing Rings for Valve Applications

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White Paper

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Now serving as a Director, Pete continues to drive new technology initiatives, seek opportunities for innovation, publish technical papers, file patents, and mentor the next generation of engineers.

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Jack Francis - Thanked for his detail design work on all the rings and following them through all the manufacturing stages. Jack also carried out all the test work under the authors guidance.
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Abstract

A test rig and associated control box was designed and made by Cross Manufacturing to evaluate the performance of sealing rings when used in applications such as Cage Guided Globe Valves. The 2.5 inch (63.5mm) diameter test rig is of modular design to allow a range of different ring and adjacent features to be evaluated. All tests were carried out using air at ambient temperature.

Testing butt gap, step gap, side cut step gap and scarf cut step gap rings showed that a pair of side cut step gap rings performed the best under the test conditions with the scarf cut step gap rings a very close second.

Other variables evaluated such as the number of butt gap rings in a groove and the groove and bore surface finish both had a measurable but much lower effect on the sealing performance of the rings.

Only the pair of side cut step gap rings, and the scarf cut step gap rings achieve the ANSI FCI 70-2 Class IV sealing performance requirement, the other ring configurations would achieve Class III requirements.

Introduction

Valves used to control the flow of fluids have been used since antiquity, many types are available now to cover a seemingly endless list of applications. A limited number of valves use metallic sealing rings within their body, an example of this is the Cage Guided Globe Valve shown in Figure 1. Metallic sealing rings (Shown as Plug Sealing Ring) are generally used where temperatures exceed the limit of polymer-based sealing arrangements.

Cross has been making metallic sealing rings for nearly one century, their rings are used in a wide range of industries including Aerospace, Automotive, Power Generation and Process industries. Sealing rings for valve applications have been made for many years for these industries, offering a robust solution, capable of operation in extreme environments. Generally metallic sealing rings offer a lower level of sealing than polymer-based solutions, due to the inherent compliance characteristics of polymers, but can operate at much higher temperatures.

This paper describes a leakage test rig developed by Cross and a series of tests performed on it to evaluate the performance of different designs of metallic sealing rings. The tests were all carried out on 2.5" (63.5mm) diameter sealing rings using air at ambient temperature as the test fluid with pressure drops of up to 80psi. Results were compared to international valve standards.

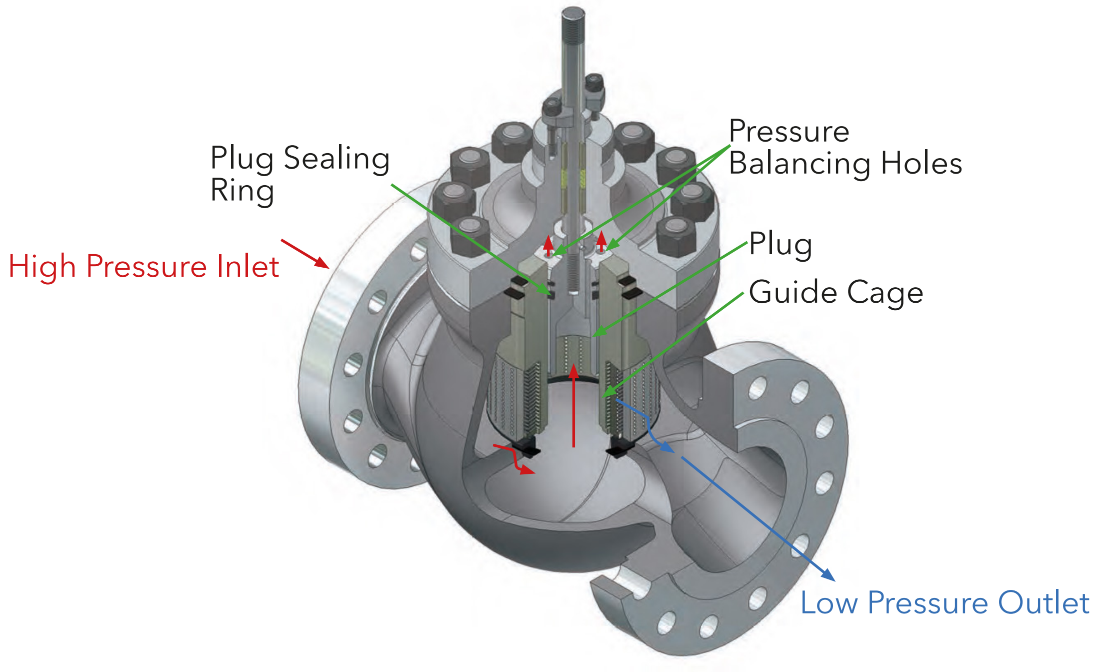

Figure 1 – Cage Guided Globe Control Valve
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Test Rig

A modular static test rig was designed to suit the 2.5" (63.5mm) diameter rings selected for the tests. The rig will allow for easy testing of rings of different axial widths, different gaps, different numbers of rings, different surface finishes on the bore and groove face as well as several other features. To accommodate these changes, we have had a range of different, groove width elements, groove face elements and test bores made.

It should be noted that all potential leak paths in the rig have been sealed with O rings, to verify there was no leakage elsewhere in the rig the first test carried out was with O rings in place of sealing rings and there was no measurable leakage.

A cross section through the test rig is shown below in Figure 2.

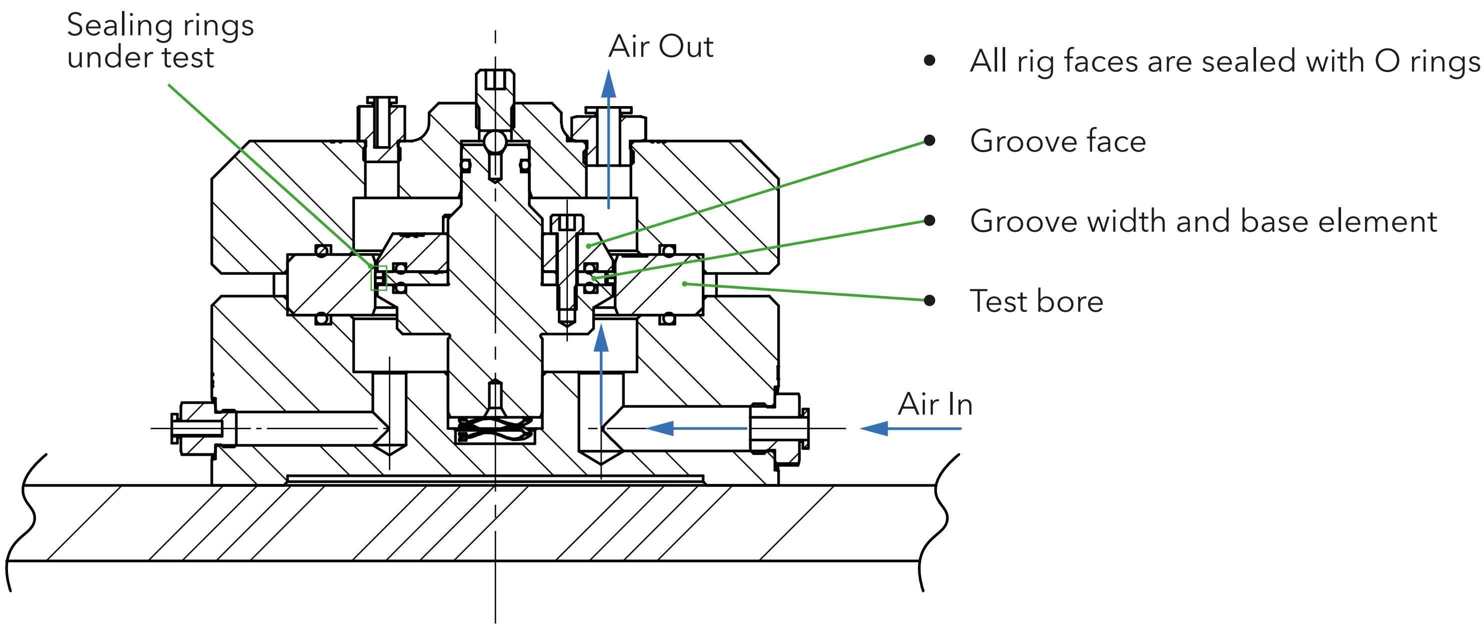


Figure 2 Cross Section Through Rig

Instrumentation and Control Box

To support the test rig, a new control box with dedicated precision pressure regulators, pressure sensors and flow meters was also designed and made to ensure accurate data was gathered. The pressure regulator is located before the 3 switchable flow meters, and the pressure reading is taken directly from the test housing. Prior to use, the control box was fully tested for any leaks.

The 3 mass flowmeters that are switchable in use, depending on the leakage level, were supplied by Omega and have a range of 0 – 1, 0 – 10 and 0 – 100 standard litres per minute of air with an accuracy of 1% of full-scale reading. The 3 flow meters ensure we have good accuracy over a very wide flow range, enabling different seal types to be evaluated.

The Pressure Sensor used was also supplied by Omega, it has a range of 0 to 145 psi with an accuracy of 0.25% of full scale.

A photograph of the Control box and Rig are shown in Figure 3.

Figure 3 Test Rig and Control Box

Sealing Rings Tested

The sealing rings designed and tested were all made in the Cross high volume manufacturing facility in Devizes. Made from 420S45 (AISI 420C or 1.4034) martensitic stainless steel, with a maximum temperature capability of 450°C, they would be suitable for many valve applications.

To ensure we were testing rings suitable for high temperature valve applications, all rings were gapped to a generous 0.039" (1mm). This allows for an extreme situation of the sealing bore being up to 450°C cooler than the sealing ring. A more typical gap value would be half of this (0.019" (0.5mm)) for this size of sealing ring.

Key of the critical sizes for the rings and fixture are below:-

Sealing diameter	2.500" +/-0.001" (63.5mm +/- 0.025)
Piston O/D	2.460" +/- 0.004" (62.484mm +/- 0.102)
Ring Radial	0.080 / 0.084" (2.032 / 2.134mm)
Piston Groove Base Dia	2.300" +/-.004" (58.42mm+/-0.102)

Ring Gap Type Variations and associated axial sizes were as per the table below:

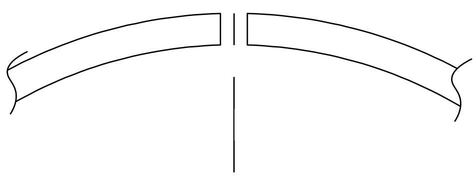
Ring Axial	Butt Gap	Step Gap	Side Cut Step	Scarf Cut Step
Half Axial 0.0313" (0.795mm)	X		X	
Full Axial 0.0625" (1.588mm)	X		X	
Double Axial 0.125" (3.175mm)	X	X		X

The Cylinder Bore and downstream face of the groove were manufactured with the following surface finishes 4, 16, 32, 64 and 128cla. The Surface finish on the ring faces was 16cla.

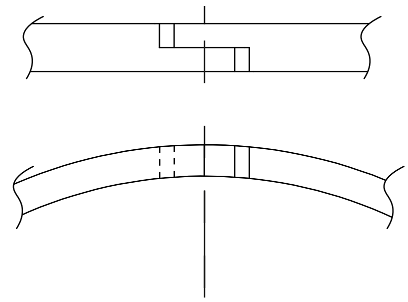
The groove width was adjusted to suit the axial width of the rings being tested with a nominal axial clearance of 0.0016" (0.04mm) at mid limit ring axial.

Sealing Rings Tested

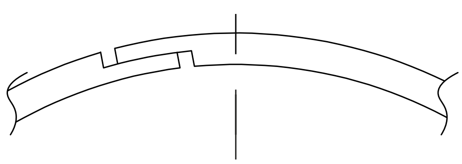
Details of the different gap designs are all shown in Figure 4.



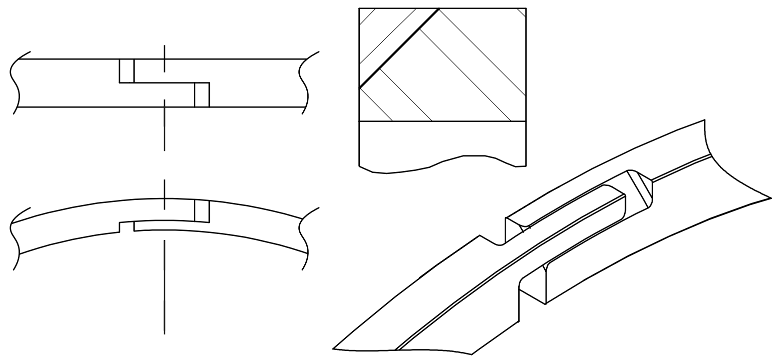
Plain Butt Gap



Step Gap



Side Cut Step Gap - Used in Pairs



Scarf Cut Step Gap

Figure 4 Ring Gap Details

Sealing Ring Leakage Paths

The different Leakage Paths for all the rings are shown in the sketches below.

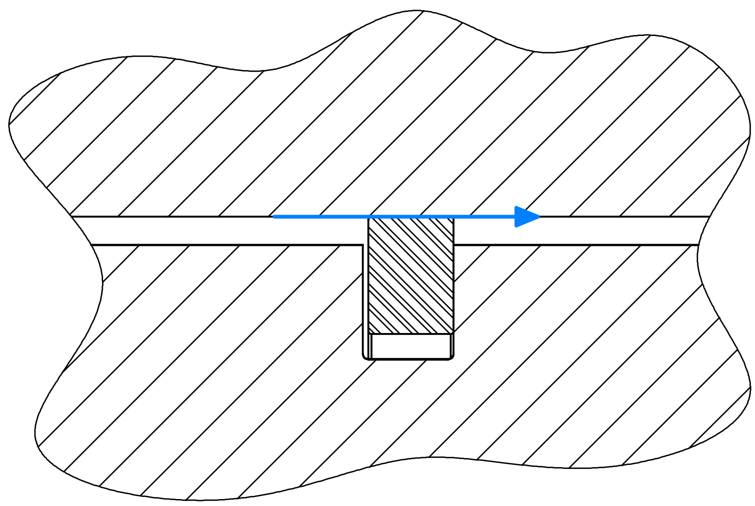


Figure 5 Leakage around periphery of ring

Figure 5 shows the leakage path around the periphery of the ring(s). The magnitude of this leakage is usually small and is controlled by the quality of the roundness of the fitted ring or Light Quality (measured in a ring gauge of 2.5" (63.5mm) diameter) and the surface finish of both the O/D of the ring and the cylinder bore. This leakage path is present in all types of ring and multiple ring packs tested.

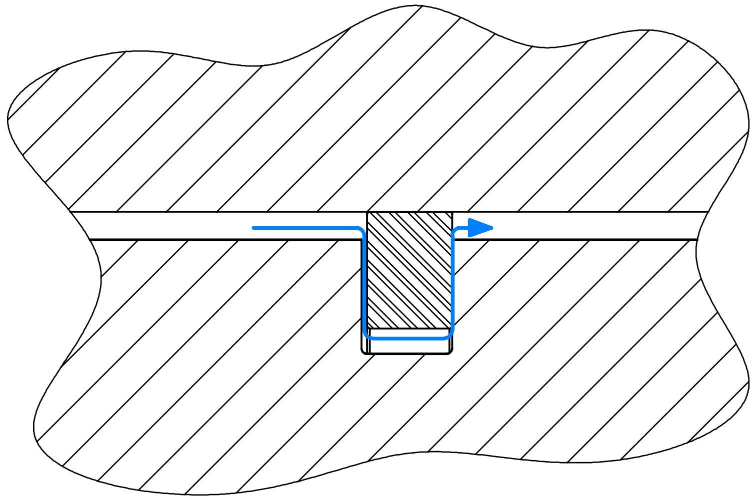


Figure 6 Leakage up the down stream side face of ring

Figure 6 shows the leakage path from under the ring and up the downstream side face of the ring, the magnitude of this leakage is usually small and controlled by the flatness of the ring and the surface finish of the side face of the ring and the downstream groove face. This leakage path is present in all types of ring and multiple ring packs tested.

Sealing Ring Leakage Paths

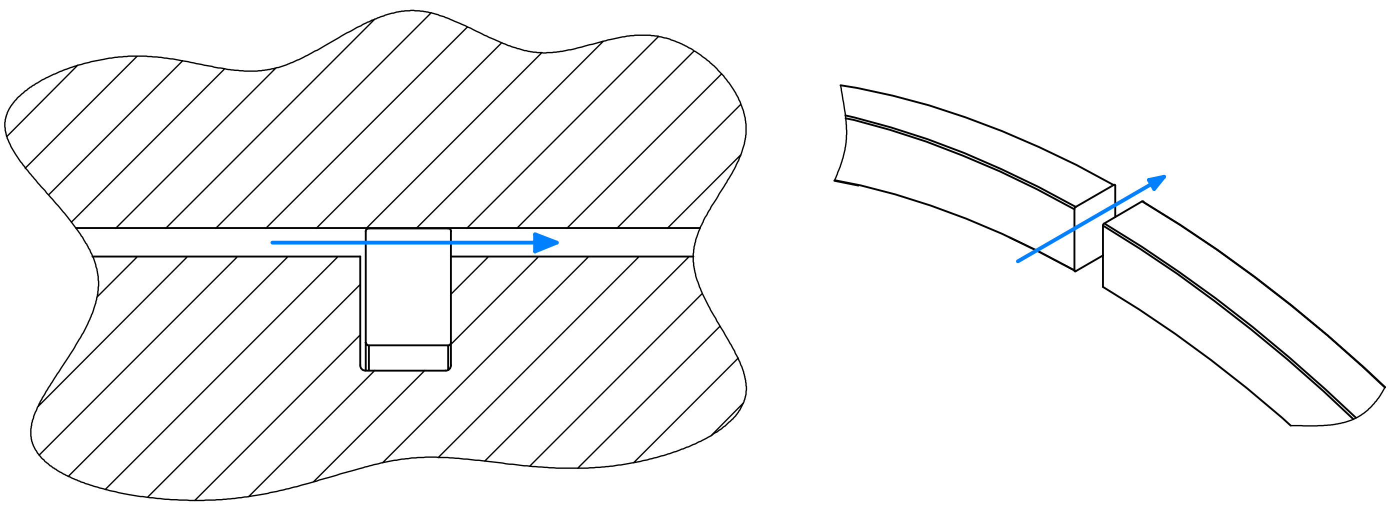


Figure 7 Leakage through gap on a single butt gap ring

Figure 7 shows the leakage path through the gap of a single butt gap ring; this usually has the largest magnitude of the 3 leakage paths. The leakage rate is controlled by the magnitude of the gap, the piston O/D and edge breaks on the rings. The gap leakage is the most variable aspect on all the different types of ring and multiple ring packs tested and these are shown below in figures 8 through 12.

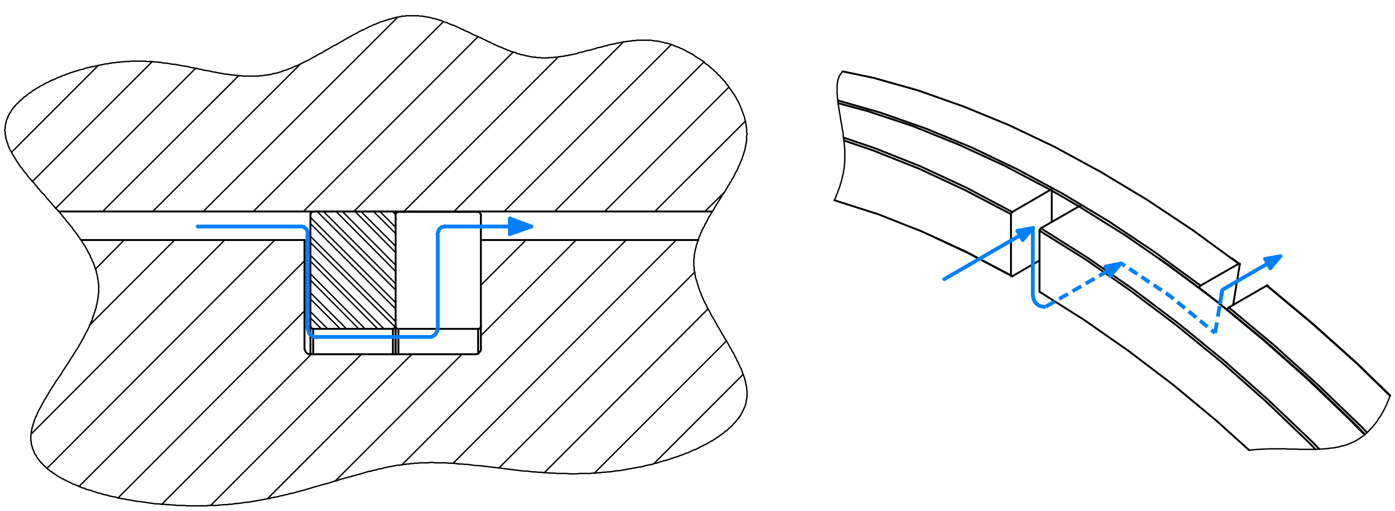


Figure 8 Leakage through the gaps on a pack of 2 butt gap rings

Sealing Ring Leakage Paths

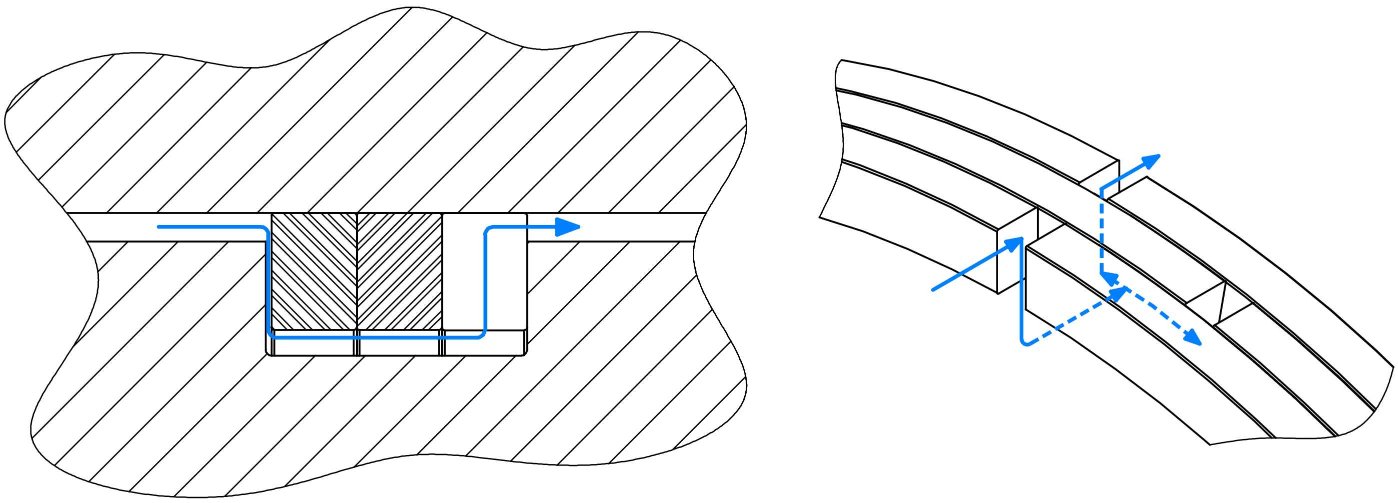


Figure 9 Leakage through the gaps on a pack of 3 butt gap rings

With multi ring packs with butt gap rings the fluid can leak through the gap and down the side face of the first ring, underneath the rings and then out of the gap on the downstream ring. Tests were carried out with all ring gaps approx. 90° apart. Having gaps equispaced may reduce the leakage further but not by a significant amount.

There would expect to be little improvement in sealing performance over 1 ring. On all muti ring packs there is also a secondary and much smaller leakage path not shown in the figures, air can leak through the gap in the first ring and into the small cavity created by the edge break on the O/D of the ring and the cylinder. The air can pass circumferentially around in this cavity until it finds the gap on the next ring. This creates a very small additional leakage path.

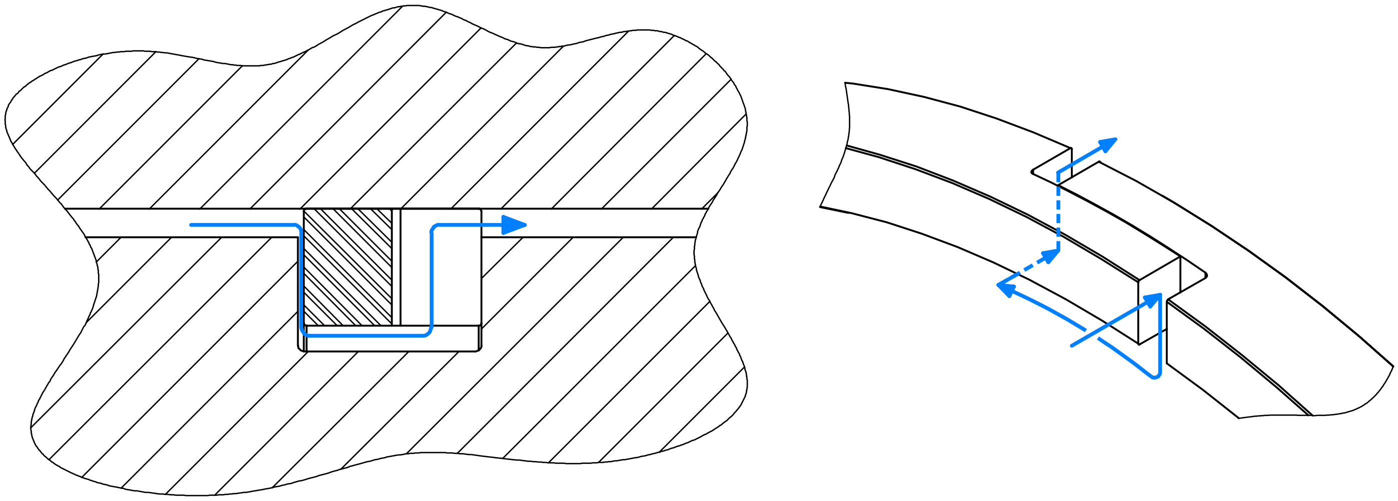


Figure 10 Leakage through gap on a step gap ring

A step gap ring will offer a similar performance to a pair of butt gap rings in a single groove as the fluid can leak down the upstream face and through the upstream gap, under the ring and out of the downstream gap.

Sealing Ring Leakage Paths

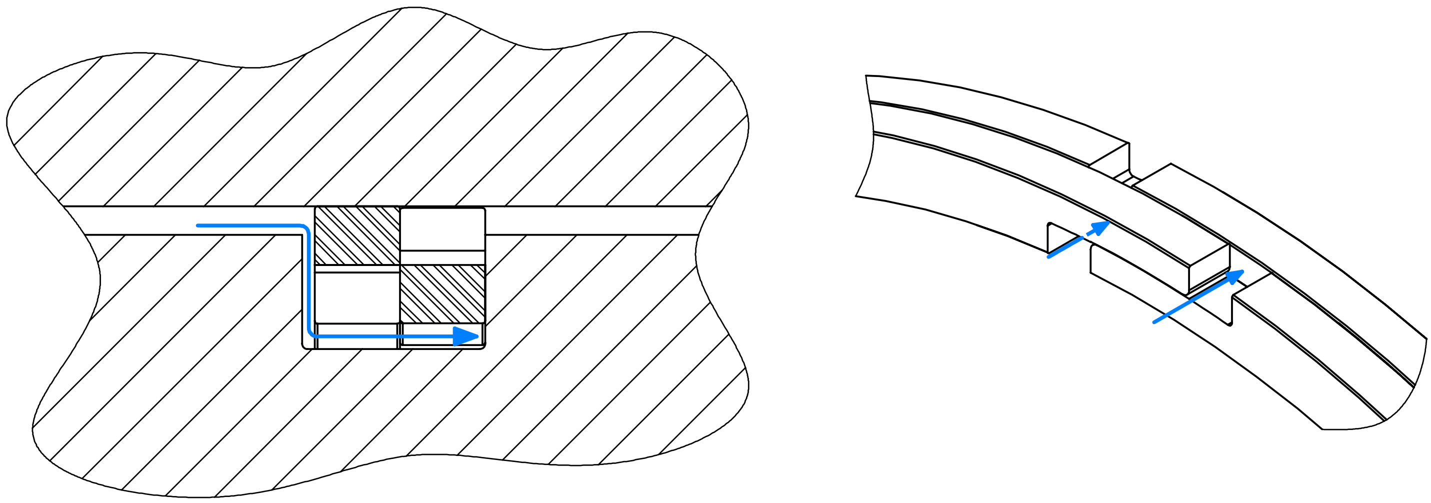


Figure 11 Leakage through gap on a two-ring pack with side cut step gaps

With a pair of side cut step gap rings there is no direct leakage path if the two gaps are not directly aligned with each other. Typically, there is a very small gap of 0.002″ (0.05mm) between the legs of the gap and this provides a very small leakage path for the air, there is also the leakage via the edge breaks on the O/D of the rings as described in the multi ring packs. This gap design should produce the lowest gap leakage of any of the multi-ring packs tested.

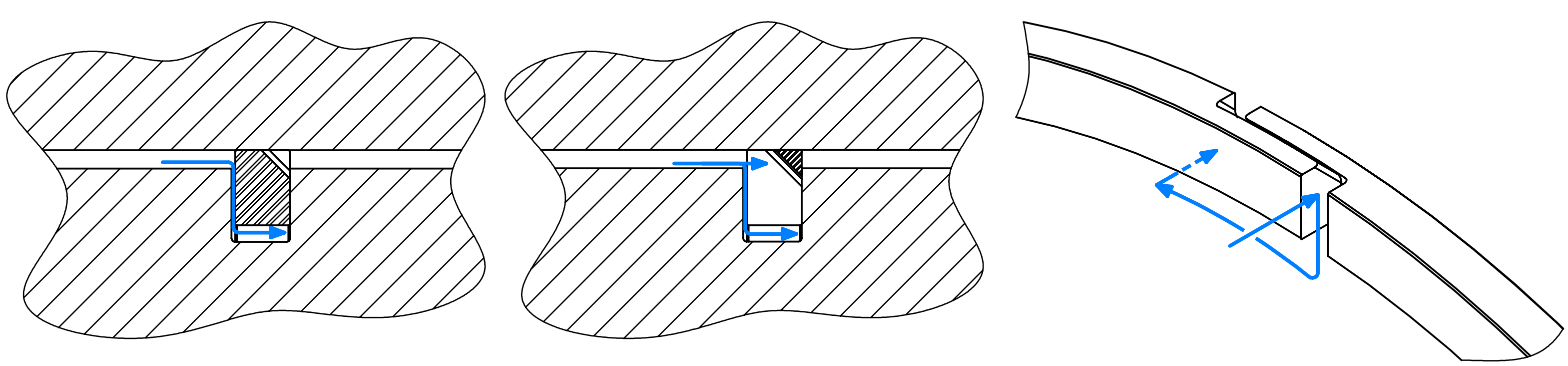


Figure 12 Leakage through the gap on a scarf cut step gap ring

With a scarf cut step gap again there is no direct leakage path if the ring is fitted correctly, there is just the small gap between the adjacent legs of the gap and this is generally in the order of 0.002″ (0.05mm) so very small compared to the magnitude of the ring gap at 0.040″ (1mm). This gap design should provide the lowest gap leakage of the single rings tested.

Test Procedure

To ensure good repeatability of results, a standard test procedure was developed and documented, this procedure was then followed for all testing.

To ensure that all rings tested were fully seated against the downstream groove face during testing, once the pressure had been set to 5psi, the piston was moved axially downwards a small amount until the leakage was seen to reduce to a minimum (Indicating the sealing ring(s) are seated).

The repeatability of testing was evaluated by repeating the test 10 times on the same test ring, with the rig being fully stripped down and ring removed between each test. This testing showed variation in the leakage of under 5% at all pressures from 5 to 80psi.

Unless otherwise stated all tests were carried out with a 32cla bore and groove face, with a single ring, full axial width with a butt gap.

Results

Results from the tests are summarised in the graphs shown in Figures 13, 14, 15 and 16.

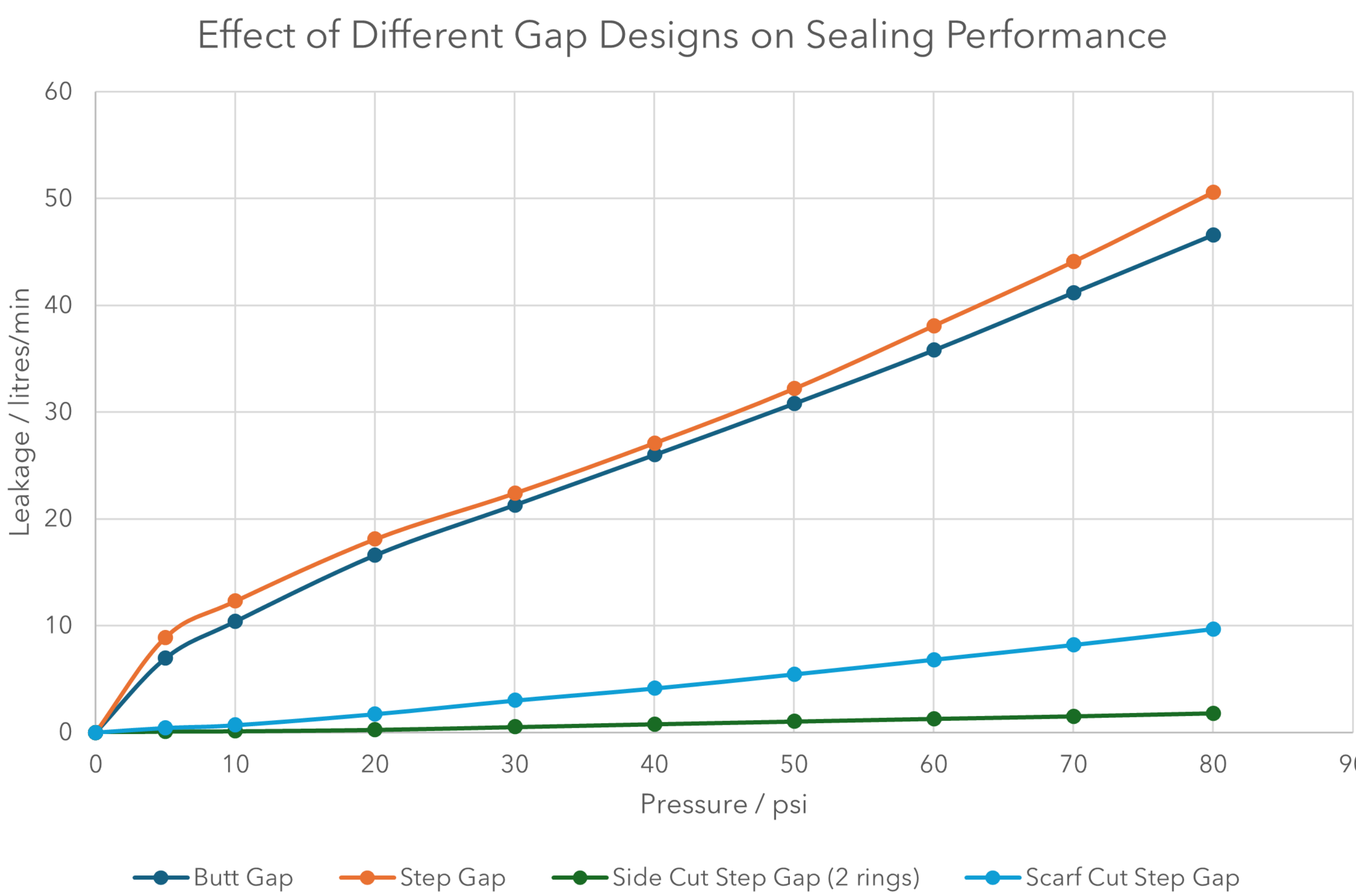


Figure 13 Effect of Different Gaps on Sealing Performance

From Figure 13 it is very evident that 2 types of ring gaps performed far better than the other 2 types in these tests. If we set the Butt gaps as our standard, the step gap design on average leaks 8% more than this baseline. The Scarf Cust Step gap leaks only 21% of the base line with the pair of rings with the side cut step gaps having the lowest leakage at only 4% of the baseline. This result was expected as both the scarf cut step gap and the pair of rings with the side cut step gaps do effectively provide a barrier for the gas with no direct flow path through the gap. The butt gap and the step gap however do not do this, with the butt gap you can see straight through the gap so there is an easy leakage path. With the step gap design, it is easy for the air to leak from the upstream side through the gap to go under the ring and then to leak out through the gap on the downstream side, as shown in figures 5 through 12.

Results

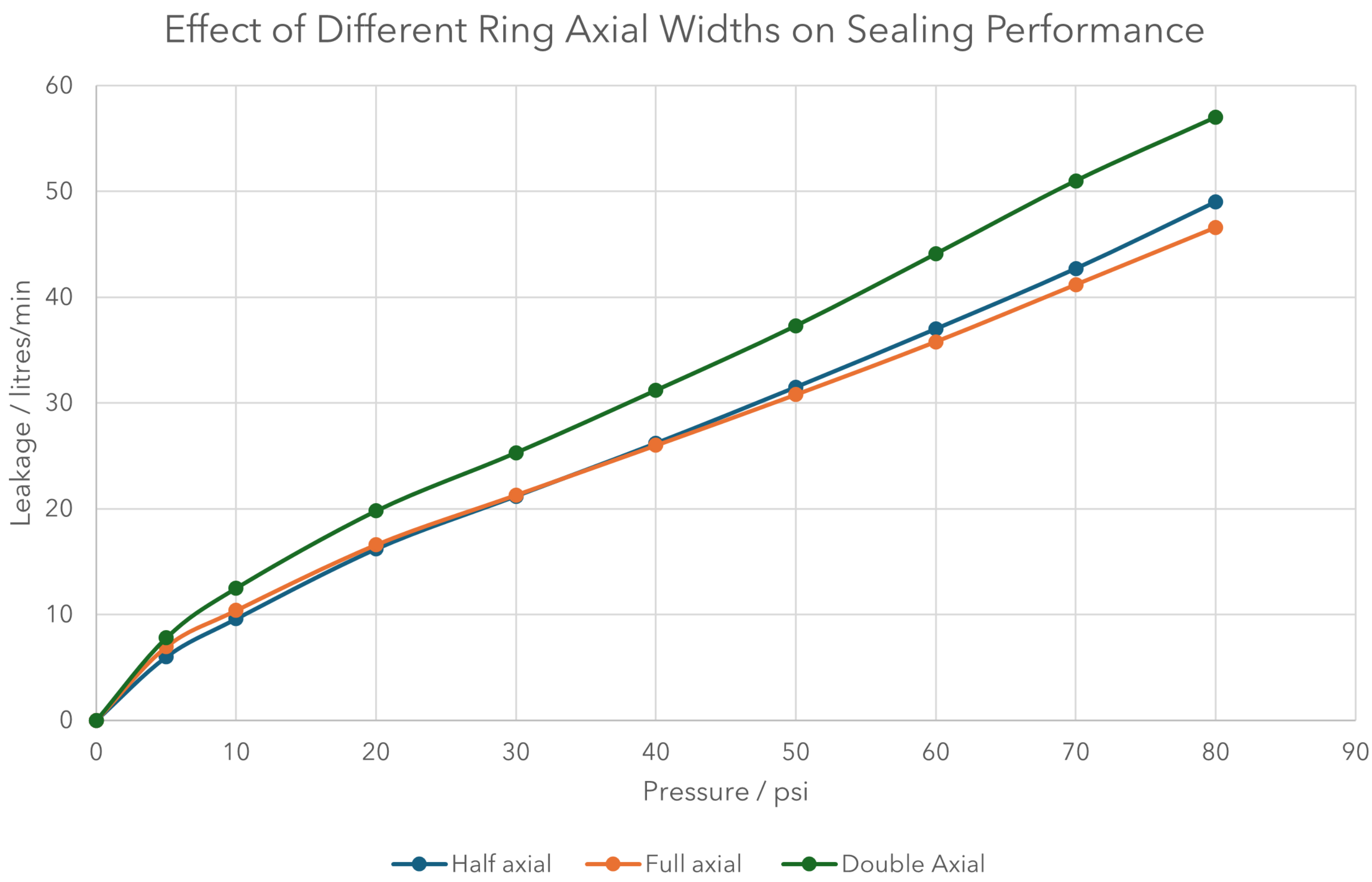


Figure 14 Effect of Different Axial Widths on Sealing Performance

Figure 14 is interesting; in this test, butt gapped rings of different axial widths were tested. If we set the full axial ring to be the baseline again then the half axial ring leaks up to 5% more at some pressures whilst the double axial leaks typically 22% more. On the double axial ring there is some twist in the section from the manufacturing processes, this varies in magnitude around the ring but will contribute to additional leakage. This is shown below, exaggerated in Figure 15, the axial faces are still parallel to the groove walls, but the O/D and I/D are tapered leading to the increased leakage. The half axial value of up to 5% more is on the edge of the repeatability of the rig so we would say that it has the same leakage as the full axial parts.

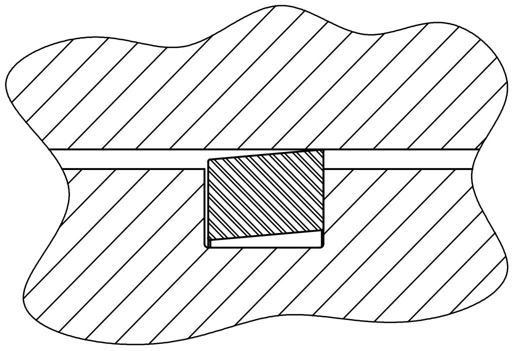


Figure 15 Greatly Exaggerated Twist in Section of Double Axial Ring

Results

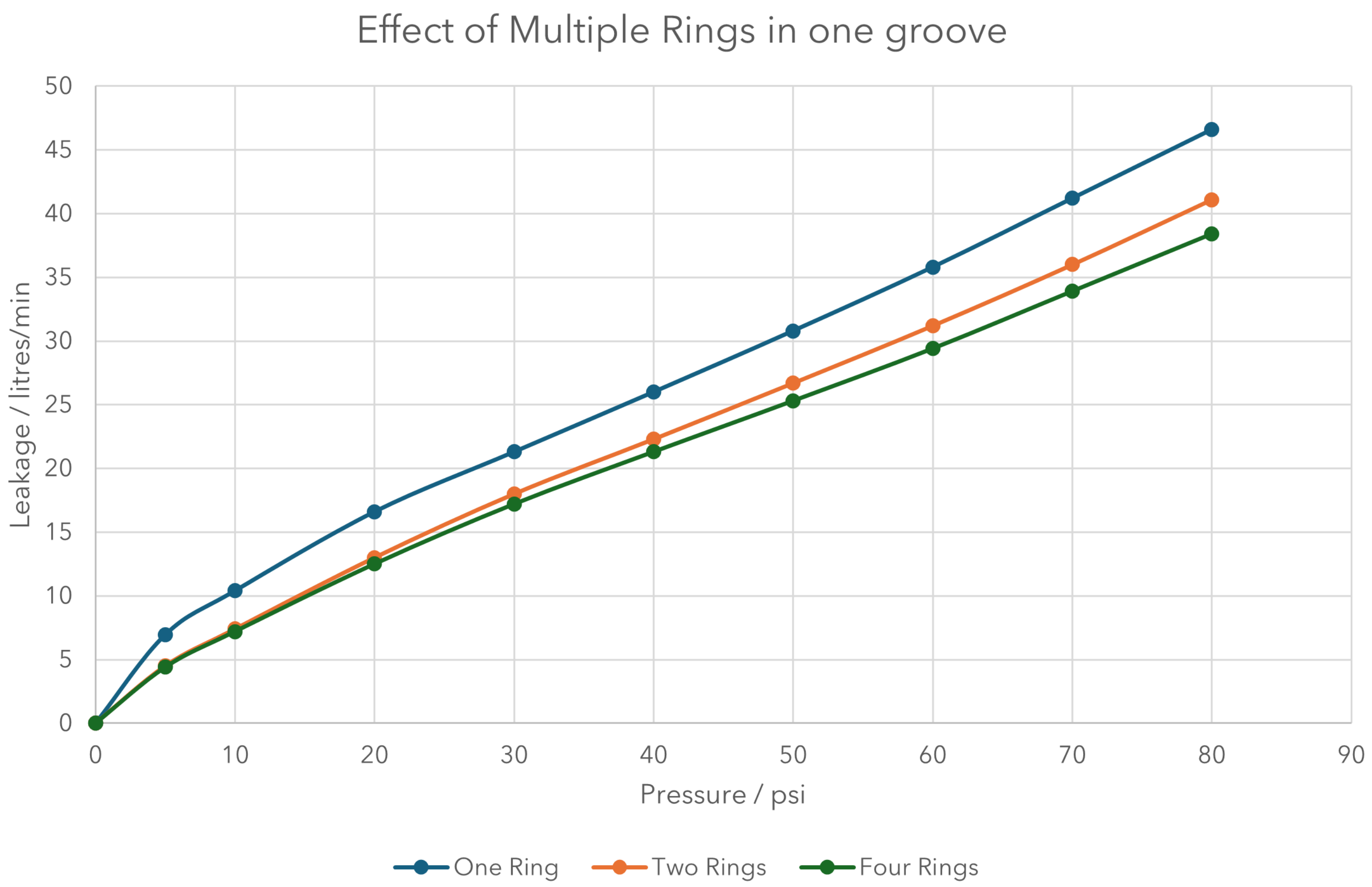


Figure 16 Effect of Multiple Butt Gap Rings in one groove on Sealing Performance

Figure 16 shows the effects of putting multiple rings in a single groove. The base line was again one single full axial butt gap ring, for the 2 rings test we used 2 full axial rings in the double width groove and for the 4 ring test we used 4 half axial rings in the double width groove. When we had multiple rings in a groove, gaps were always set 90deg apart on adjacent rings. Setting the single ring as our baseline the 2 rings had a 12% reduction on the leakage and the 4 rings a 18% reduction.

The reduction on leakage for the multiple rings can be attributed to the slightly more tortuous path the air has to follow. From the upstream side it leaks through the upstream gap, goes under the ring, goes around the ring to the downstream gap and then leaks up through that gap. The thinner axial of the 4 rings in the groove also helps to reduce the leakage areas and reduces the leakage a small amount more.

Results

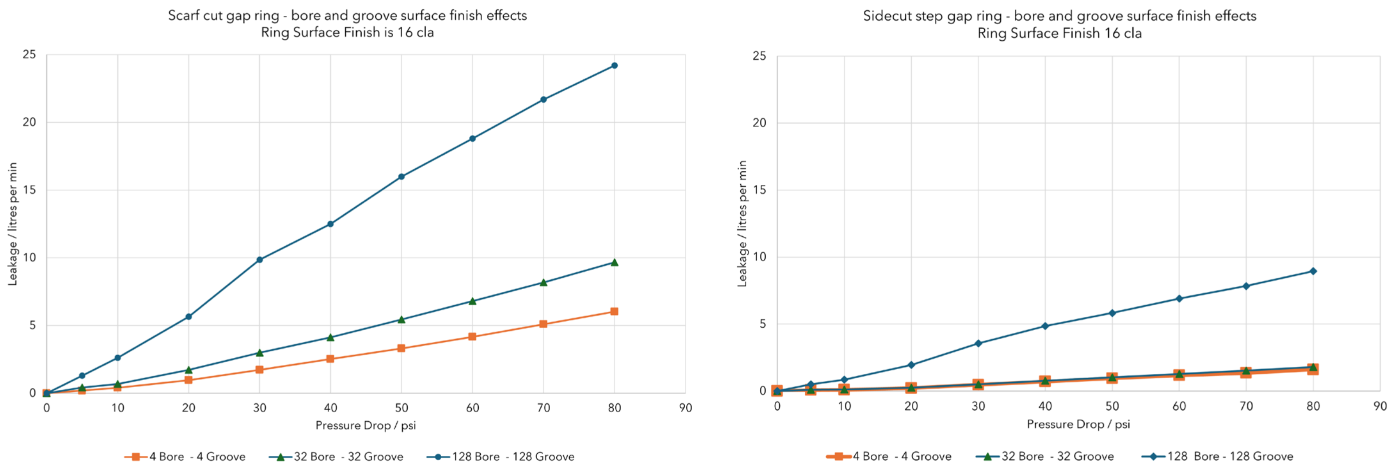


Figure 17 Effect of Bore and Groove face Surface Finish on Sealing Performance

Figure 17 shows the effect that varying both the surface finish on the bore and the downstream groove face has on the sealing performance of a single full axial ring with a scarf cut step gap with ring surface finish of 16cla on both its O/D and side faces. On the right hand chart the same data is shown for two side cut step gap rings. The same rings were used in all this testing.

As expected, the 128 Cla surface finish on both the bore and the groove side face shows a significant increase in leakage, the rougher surface finish allowing more leakage on these faces. The 4 cla surface finish shows a reduction in leakage values.

More work is needed on the effects of surface finish on the sealing performance as a compromise is needed between cost of improving the surface finish and performance gains achieved.

Discussion

From the results shown in figures 13 through to 17 the type of gap has the largest effect on the sealing performance of sealing rings tested in this program. The Side Cut Scarf gap rings show a 5 fold reduction in leakage when compared to the baseline butt gap, the real winner is however the pair of side cut step gap rings, showing a reduction of nearly 25x.

This can be explained from the details shown in Figures 5 through 12 with sketches showing flow path or lack of it through sealing rings.

The variation of other parameters such as number of rings, axial width and surface finish showed much smaller changes in leakage when compared to the single full axial ring with a but gap tested with 32cla bore and groove faces.

It is not that straight forward to relate these leakages to the requirements of valves. EN12266-1 provides some seat leakage values when tested on air at 3.5bar pressure drop related to the DN of the valve. If we assume that the DN is the same as the ring diameter, then the leakage values required are as follows:-

Rate A - No Leakage
Rate B - 0.3DN – This equates to 0.00114 litres /min
Rate C - 3DN – This equates to 0.0114 litres/min
Rate D - 30DN – this equates to 0.114 litres/min
Rate E - 300DN – This equates to 1.14 litres/min
Rate F - 3000DN – This equates to 11.4 litres/min
Rate G - 6000DN – this equates to 22.8 litres/min

The 3.5 bar tests pressure specified is 50.8psi so from Figure 5 we can see that the Side Cut Step gap rings and the scarf cut step gap rings would easily achieve Rates F and G, with side cut step gap rings also achieving rate E with both the 32 cla and 4 cla surface finishes. With additional surface finish work, and the associated additional costs, on the scarf cut step gap rings it may be possible to achieve level E but neither design will be able to achieve level D.

IEC 60534-4 or EN60534-4 for industrial process valves is more complex to relate to as for some classes the valve flow rate as is used as the reference. The commonly referenced international standard ANSI FCI 70–2 uses the same classes of flow rates. There are 7 classes of leakage from Class I – as agreed by the manufacturer and purchaser to Class VI where the value is 0.3xDeltap(bar)x leakage rate factor – this gives a value similar to Rate A in EN12266-1 (0.00063 litres/min for our 2.5” diameter ring) Class V equates to 0.0117litres/min when testing with air (Similar to Rate C above).

Discussion

A typical 2" diameter Cage Guided Globe valve has a CV of 54, equating this to air at 50.8psig and venting to ambient we get a capacity of 46,300litres/min

Class II is 0.005x rated capacity so 231.5litres/min

Class III is 0.001x rated capacity so 46.3litres/min

Class IV is 0.0001x rated capacity so 4.6litres/min

For the rings we have tested, all would meet Class II and Class III at 50.8psi.

The side cut step gap rings will meet the requirement of Class IV with the scarf cut step gap rings just outside of this level with the 32 cla bore and groove face but achieving the required level against the 4 cla bore and groove face.

It is unlikely that piston ring type seals could achieve class V leakage levels.

It is our understanding that most cage guided globe valves would require a ring to seal at Class IV levels, on this basis our recommendation would be to install a pair of side cut step gap rings, these comfortably met the performance requirements.

Conclusions

The testing programme has clearly demonstrated that the geometry of the ring gap is the dominant factor influencing the sealing performance of metallic piston-type rings used in valve applications. Among all designs evaluated, the pair of side cut step gap rings consistently delivered the lowest leakage levels across the full pressure range, outperforming all alternatives by a substantial margin. Their configuration effectively eliminates any direct flow path through the ring pack, leaving only minimal secondary leakage paths associated with surface finishes and edge breaks. This arrangement achieved leakage values approximately 25 times lower than the baseline butt gap configuration and comfortably satisfied the ANSI FCI 70–2 Class IV valve sealing requirements typically specified for cage guided globe valves.

The scarf cut step gap design also proved highly effective, achieving leakage reductions of around 80% relative to the baseline. While not matching the exceptionally low values obtained with the side cut step gap pair, the scarf cut step gap ring achieved Class IV performance with finer surface finishes and offers a strong single-ring alternative where groove width or assembly constraints limit the use of ring pairs.

Other variables such as axial width, multi-ring butt gap packs, and surface finish were found to influence leakage but to a far lesser extent than gap geometry. Wider sections introduced manufacturing-related twist that increased leakage, while multi-ring butt gap stacks produced only modest improvements owing to the still-present direct leakage paths. Surface finish changes produced measurable but relatively small variations and did not alter the fundamental ranking of the gap types.

The modular test rig developed for this work has proven highly effective, providing repeatable and reliable leakage measurements and enabling systematic evaluation of multiple design variables. Its flexibility will support future investigations into additional geometric configurations, material options, and tighter manufacturing tolerances. These studies will continue to inform the development of metallic sealing solutions capable of delivering reliable performance in demanding valve applications.