HIGH-PRESSURE FLUID APPLICATIONS

An Overview of Design and Material Selection for use with Bal Seal Spring-energized Seals

Technical Report
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TABLE OF CONTENTS

1.0 Summary

2.0 Design considerations

- 2.1 Pressure on the shaft or rod
- 2.2 Pressure on the cylinders or housing
- 2.3 Cylinder/Housing requirements
  - 2.3.1 Compound cylinders
  - 2.3.2 Autofrettaged cylinders

3.0 Material considerations

4.0 Factors affecting BAL Seal performance

- 4.1 Type of materials
- 4.2 Hardness
  - 4.2.1 Surface plating or coating hardness
  - 4.2.2 Gas nitriding

5.0 Surface finish of counterface

6.0 Type of surface finish

7.0 BAL Seals in high pressure applications

1.0 SUMMARY

This report provides design and material selection considerations for components used with BAL™ Seals at pressures from 10,000 to 100,000 psi (703 to 7,030 kg/cm^2).

2.0 DESIGN CONSIDERATIONS

Selection of the component parts in high pressure is determined to a great extent by the fluid pressure and the distribution of stress caused by that pressure. Pressure is applied on all the component parts, including the shaft or rod and the cylinder or bore.

2.1 Pressure on the shaft or rod

The stress acting on the shaft or rod is compressive stress. Therefore, for high-pressure applications, the shaft or rod materials should have high compressive strengths. Material selection should be based on material hardness, yield strength, and elongation.

2.2 Pressure on the cylinder or housing

Pressure applied on a cylinder or housing is not distributed equally throughout the wall thickness. Greater stress occurs on the inner wall and decreases towards the outer wall.

When a cylinder is stressed beyond the yield point, plastic deformation occurs on the inner portion of the cylinder. The outer area, because of lower stress, will tend to return to its original size, creating a plastic-elastic boundary where the two stresses meet. Exceeding the yield strength of the material at the boundary layer will cause failure of the material.

Cylinders must be designed to operate within the yield strength, unless a compounded or an autofrettaged cylinder is used.

2.3 Cylinder/Housing requirements

Cylinders must be designed to minimize expansion. If the cylinder expands excessively, the radial clearance (‘E’) between the cylinder and the piston may become too large and the BAL Seal could possibly extrude and fail.

Figure 1 shows a double acting intensifier indicating the radial clearance (‘E”) between the cylinder and the piston. Different types of BAL Seal products used in such applications are also shown.

To reduce expansion of the cylinder, compounded or autofrettaged cylinders should be used.

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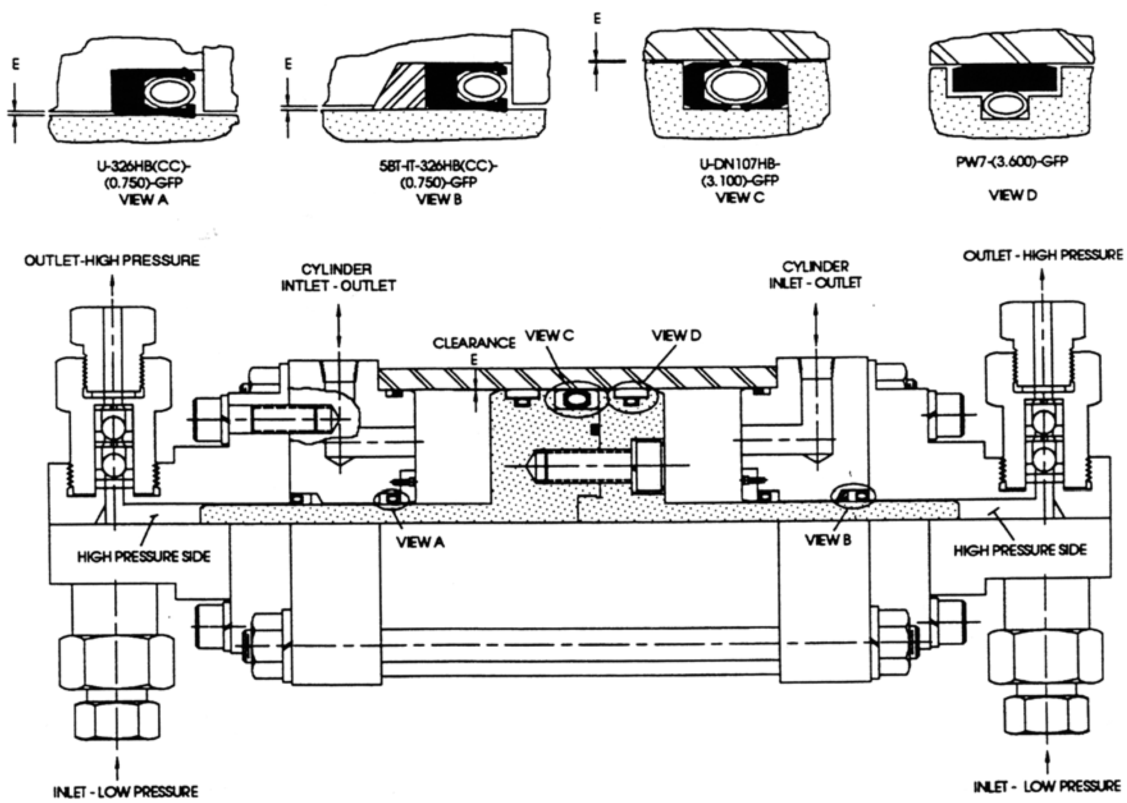
2.3.1 Compounded Cylinders

A compound cylinder consists of two cylinders, one inside the other with interference between them. The outside cylinder is heated and allowed to expand, permitting the internal cylinder to fit inside. The outer cylinder is then cooled and shrink-fitted onto the inner cylinder. This produces favorable stress distribution throughout the double wall thickness, as opposed to the usual stress distribution concentrated at the internal layer.

It is not necessary that both cylinders be made of the same material. If different materials are used, the inner cylinder should have the higher tensile and yield strengths, while the outer cylinder should have higher elongation to produce the desired internal stress at boundary of the two cylinders.

2.3.2 Autofrettaged Cylinders

An autofrettaged cylinder is a cylinder that has been stress hardened. The cylinder is pressurized until overstraining plasticizes the inner wall. The cylinder wall can then withstand higher pressure. Stresses at the plastic-elastic boundary help to contain the higher pressure.



Double Acting Intensifier

CYLINDER LOW PRESSURE = 2500 psi (176 kg/cm^2); PISTON HIGH PRESSURE = 60000 psi (4218 kg/cm^2)

FIGURE 1

3.0 MATERIAL CONSIDERATIONS

When selecting a shaft, rod, housing or bore material for high pressure applications, the most important material properties are tensile strength, yield strength, elongation, hardness and wear resistance. Yield strength results in plastic deformation and strain hardening of the material. Materials with an elongation under 10% should be used with great caution. High hardness and good wear resistance of the shaft are very important to reduce adhesion and abrasion of the BAL Seal and to promote increased seal life. Chart 1 lists the mechanical properties of materials used in high-pressure components.

4.0 FACTORS AFFECTING BAL™ SEAL PERFORMANCE

BAL Seal performance is strongly affected by material, surface hardness, and surface finish of the counterface. Fluid pressure, BAL Seal material, spring force, speed, temperature, and fluid media are other factors.

4.1 Type of material

In demanding applications, such as high pressure reciprocating intensifiers, tungsten carbide is an excellent shaft and plunger material because of its high hardness (approximately Rockwell 73C). Tungsten carbide can withstand many cycles of loading and unloading at high pressures. Refer to Chart 1.

4.2 Hardness

Cylinders and rods should be designed to provide maximum hardness consistent with other design parameters. Harder materials lower the adhesion between the seal and the sealing surface and lower the friction and wear. Various materials and their hardness are listed in Chart 1.

4.2.1 Surface Plating or Coating Hardness

Chrome plating, electroless nickel plating and plasma sprayed coatings increase surface hardness. Such platings or coatings are limited to fluid pressures to 30,000 psi (2110 kg/cm^2).

Chrome plating produces a surface hardness from RC-62 to RC-68. Electroless nickel plating produces a surface hardness between RC-50 and RC-62. Plasma sprayed coatings produce a hardness from RC-66 to RC-74 or its equivalent. See reports TR-14 on chrome plating, TR-16 on electroless nickel plating and TR-3 on plasma sprayed coatings for additional information.

4.2.2 Gas Nitriding

This process achieves a very high hardness (up to RC-74) by changing chromium oxides into chromium nitrides, which then diffuses onto the surface layer.

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5.0 SURFACE FINISH OF COUNTER SURFACES

Under conditions of high pressure, a very smooth surface finish lowers abrasion and wear to extend the seal life. Surface finishes between 2 and 6 RMS (1.8 to 5.5 Ra) generate the lowest wear to BAL Seal GFP (PTFE-based) material.

6.0 TYPE OF SURFACE FINISH

Surface finish has a great effect on BAL Seal performance. Counter surfaces that are finished by turning or grinding will wear a seal much faster than a counter surface that is finished by honing or super finishing. Honing and super finishing produce a desirable surface finish configuration, no radial or axial marks are left on the counter surface after finishing by either of the two methods. See technical report TR-29, "Obtaining Surface Finishes."

7.0 BAL™ SEALS IN HIGH PRESSURE APPLICATIONS

BAL Seals offer unique advantages in high-pressure devices. As the pressure increases, the coefficient of friction decreases and therefore reduces wear. BAL Seals are generally made from polytetrafluoroethylene fibers to reduce extrusion and provide lubrication for long-term service.

BAL Seals use a unique canted-coil spring as the loading medium. The spring helps maintain contact between the sealing surfaces at lower pressures, assuring better sealing reliability. Additional pressure increases sealing ability.

8.0 TYPICAL MATERIALS USED IN HIGH PRESURE APPLICATIONS AND THEIR MECHANICAL PROPERTIES

MATERIAL	TYPE OF MATERIAL	CONDITION	TENSILE STRENGTH (psi)	YIELD STRENGTH (psi)	ELONGATION (%)	ROCKWELL HARDNESS	BASIC COMPOSITION (% by wt.)							FOR USE IN	TYPICAL APPLICATION
STAINLESS STEEL	17-4 PH						C	Mn	Si	Cr	Ni	Cb	Cu	ROD AND HOUSING	General purpose Moderate Corrosion Resistance
		ANNEALED	150,000	110,000	10	35 C	0.07	1.0	1.0	16.0	4.0	0.25	4.0		
		HEAT TREATED	200,000	185,000	14	44 C									
	15-5PH						C	Mn	Si	Cr	Ni	Cb	-		General Purpose Higher mechanical properties than 17-4 PH
		ANNEALED	150,000	110,000	10	34 C	0.07	1.0	1.0	15.0	4.5	0.35	-		
		HEAT TREATED	200,000	185,000	14	44 C									
	13-8 PH						C	Mn	Si	Cr	Ni	Mo	Ti		General purpose Higher mechanical properties than 17-4 PH and 15-5PH
		ANNEALED	160,000	145,000	15	35 C	0.05	0.1	0.1	12.5	9.0	2.5	1.1		
		HEAT TREATED	214,000	185,000	16	46 C									
	A-286						C	Mn	Si	Cr	Ni	Mo	Ti		Excellent corrosion resistance salt water, petrochemical and downhole service
		SOLUTION ANNEALED AND AGED	169,000	115,000	22	30 C	0.05	1.4	0.5	14.75	25.25	1.3	2.15		
							Al	V							
							0.15	0.3							
HIGH ALLOY STEEL	4140						C	Mn	Si	Cr	Ni	Mo	P	HOUSING	General service application in non-corrosive media
		ANNEALED	95,000	60,000	26	187 Brinnel	0.4	0.85	0.3	0.95	-	0.25	0.4		
		HEAT TREATED	250,000	230,000	12	50 C									
	43-40						C	Mn	Si	Cr	Ni	Mo	-		General service with better mechanical properties than 4140
		ANNEALED	110,000	66,000	23	197 Brinnel	0.4	0.7	0.3	0.8	1.75	0.3	-		
		HEAT TREATED	250,000	230,000	10	50 C									
TOOL STEEL	H-13						C	Cr	V	Mo	-	-	-	ROD	High hardness, wear resistance, ductile core, limited corrosion resistance, no shock loads
		NITRIDING HARDENING TO 62 RC AT SURFACE; 48 RC AT CORE	Approx. 240,000	210,000	12	48 C	0.35	5.0	1.0	1.5	-	-	-		
VASCOMAX COBALT-FREE MARAGING STEEL	T-250						Ni	Mo	Ti	Al	Z	B	-		High strength ductility, impact strength, fatigue strength with high resistance to crack
		HEAT TREATED	260,000	255,000	10	48-52 C	18.5	3.0	1.4	0.1	0.01	0.003	-		
TUNGSTEN STEEL	KENNA-METAL K801	NONE	150,000	115,000	8	73 C	TUNGSTEN CARBIDE WITH 1.5% OR LESS NICKEL BINDER								Very high hardness. Good corrosion resistance and moderate wear resistance

Compressive strength varies from approximately 140,000 psi for 17-4 stainless steel to 765,000 psi for K801 tungsten carbide.

CHART 1

9. METHODS OF DETERMINING HIGH PRESSURE CYLINDER WALL THICKNESS FOR EXTERNAL OR INTERNAL PRESSURES

9.1 Cylinders Subject to Uniform Internal Pressure, i.e., housings or bores)

Using Barlow's formula for stress:*

$$S = \frac{P * OD}{2t}$$

Variable Description
P = internal pressure (psi)
OD = outside dia. Of cylinder (inch)
S =stress on cylinder (lb/in^2)
t =cylinder wall thickness (inch)

The same formula using the inside diameter is:

$$S = \frac{P(ID * 2t)}{2t}$$

ID = inside dia. of cylinder

To determine the required wall thickness of the cylinder use:

$$t = \frac{P * ID}{2(Sy - P)}$$

Sy = yield strength (tensile) of material (psi)

This formula includes a safety factor in the yield strength. To increase the safety factor, use the following formula:

$$t = \frac{P * ID}{2((Sy / Sf) - P)}$$

Sf = safety factor

9.2 Cylinders subject to uniform external pressure, i.e., shafts

External Pressure Stress Formula:**

$$S = \frac{2P*OD^2}{OD^2 - ID^2}$$

This formula can be rewritten as:

$$S = \frac{2P*OD^2}{OD^2 - (OD - 2t)^2} = \frac{P*OD^2}{2\text{t}*OD - 2t^2}$$

To determine the required wall thickness, use:

$$t = (OD/2) * (1 - \sqrt{1 - (2P/Sc)})$$

Sc = circumferential stress

To include a safety factor, use:

$$t = (OD/2) * (1 - \sqrt{1 - (2P * Sf / Sc)})$$

1. *Source: Mechanical Engineer's Handbook, Lionel S. Marks, Pg. 423
2. **Source: Formulas for Stress and Strain, Raymond I. Roark, Pg. 276

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