Basic O-Ring Seal Design Criteria

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There are so many different types of seals and sealing principles that to try to cover them all would require writing a book. So, to cover the basics we will talk about design criteria for O-ring seals. This should give you a basic start into sealing principles and what to consider when designing a seal for your application.

Types of O-Ring Seals

1st thing to consider is how is this seal going to seal? Is it static, nothing moves once installed, or dynamic, the seal or sealing surface rotates or reciprocates in the application. Does the O-ring seal axially or radially. Axially is when the O-ring is squeezed from the sides perpendicular to the parting line or, if you think of the O-ring as a wheel, in line with the axle. Radially would be squeezed perpendicular to the axle or in line with the O-ring parting line. So, we have static axial, static radial, dynamic axial and dynamic radial O-ring seals. Each type of seal is going to have it own design criteria to consider. There are other O-ring seal types like thread seals, tapered seats, or boss fittings which we will not consider in this article. SAE.org is a great place to start you search for design criteria. They have many military and aerospace design documents available for sale. A great start is ARP1231, "Gland Design, Elastomeric O-Ring Seals, General Considerations." This specification covers many aspects to consider in O-ring seal design. Aerospace recommended Practice ARP1232, ARP1233 and ARP1234 cover O-ring gland seal design for the AS568 series O-rings. These ARP documents contain groove dimensions and stretch and squeeze specifications. These specifications are a great starting point for a custom O-ring seal.

A couple of O-ring design flaws we encounter the most is excessive stretch and not enough groove width. The O-ring should not be stretch more than 5% max. Also, rubber O-rings are subject to the Poisson's Effect (Poisson's ratio). When solid rubber is compressed in one direction it expand in the other direction. For practical purposes, rubber is non compressible and you must account for the Poisson's Effect this in the design of your groove width.

Tolerances

Many of the design specification take into consideration the tolerances of the O-rings in their given sealing gland dimensions. However, when you are straying from a standard design specification you must take into consideration the applicable tolerances for the type of seal you are designing. Will the seal work on the low end of the tolerances and also on the high end of the tolerances? Simple calculations can be done to check the seals stretch and squeeze at each end of the applicable tolerance range. Don't forget to consider the tolerances of all parts associated with the sealing gland.

Compound Selection

There are 36 types of elastomer compound and the proper selection is an important part of your design. Selecting the wrong compound can cause premature failure in your application. Operating temperature, fluid resistance and whether the seal is dynamic or static are the 3 main questions I ask when selecting a compound. Weathering or ozone exposure , friction characteristics, abrasion resistance, compression set, elongation, tensile strength are other physical properties to consider in your selection.

Below are the more popular material that are readily available. There are also many chemical compatibility charts available on the internet to assist you in selecting a compound suitable for the fluid in your application.

Common Name	ASTM D1418	Chemical Name	Uses
Nitrile, Buna	NBR	Acrylonitrile-Butadiene ** sometimes referred to as Buna-N*	-40°F to 212°F/250°F, Good with oils, solvents, water, hydraulic fluids. Good compression set, tensile strength and abrasion resistance.
Ethylene Propylene, EP	EPDM, EPM	Ethylene Propylene Diene Monomer, Ethylene Propylene Monomer	-55°F to 250°F, Exceptionally good weather aging and ozone resistance. Excellent water and chemical resistance, gas permeability and aging due to exposure to steam. Good in ketones and alcohols.
Viton®	FKM	Fluorocarbon	-15°F to 400°F, Excellent weathering, ozone and heat resistance. Resistance to wide range of oils and solvents, specially all aliphatic, aromatic and halogenated hydrocarbons, acids, animal and vegetable oils.
Silicone	PVMQ	Polysiloxane	-65°F to 450°F, Excellent heat

		** Not to be confused with Silicon*	resistance and extreme low temperature properties. Low compression set and good resilience. Moderate solvent resistance. Good release characteristics.
Fluorosilicone	FVMQ	poly (trifluoropropyl) methylsiloxane	-100°F to 350°F, Excellent weathering, ozone and heat resistance. Good for special applications where general resistance to oxidizing chemicals, aromatic and chlorinated solvent bases are required.
Neoprene®	CR	Chloroprene	-40°F to 250°F, Good weather and ozone resistance. High resilience with low compression set. Flame resistance. Animal and Vegetable oil resistance.
Hydrogenated Nitrile, HSN	HNBR	Hydrogenated Acrylonitrile-Butadiene	-65°F to 300°F, Excellent weather resistance. Good resistance to ozone. Better wear resistance than standard Nitrile. Excellent abrasion, compression set, tensile strength and tear properties. Good resistance to heat aging up to 300°F and for short periods up to 350°F. Generally used for Laundry and dish washing detergents and air conditioning refrigerant.
Styrene Butadiene	SBR	Styrene Butadiene ** initially marketed as Buna-S*	0°F to 225°F, Low cost non-oil resistant material. Good water resistance and resilience up to 70 durometer. Satisfactory for most moderate chemical and wet or dry organic acids.
Natural Rubber	NR	cis-polyisoprene	-76°F to 212°F, Can be compounded to maintain good flexibility to -76°F. Low cost. Outstanding strength, low fatigue. Good creep and stress relaxation resistance.
Isoprene	IR	cis-polyisoprene, synthetic	Essentially the same as natural rubber except it may be weaker.
Butyl	IIR	Isobutene-Isoprene	-50°F to 250°F, Excellent weather, ozone, heat and chemical resistance. Excellent impermeability to gases.

Aflas®	FEPM	Tetrafluoroethylene-Propylene (TFE/P)	-5°F to 445°F, Excellent heat resistance up to 446°F. Good chemical resistance including strong acids and bases. Excellent oil resistance and electrical resistivity.
Polyurethane	AU, EU	Polyester-urethane, polyether-Urethane	-60°F to 180°F, Extreme abrasion and extrusion resistance. Used in high pressure applications up to 5000psi. Good weathering and ozone resistance. High tear and wear resistance. Good for hydrocarbon fuels, mineral oils, CO2.

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Hardness

Elastomer compounds range from very soft, 20 Shore A, to very hard, 90 Shore A. Rubber comes in various hardness' for several reasons. The sealing surface should range from 8 to 32 micron finish. That is pretty smooth. There are cases were the sealing surface may be porous or wavy such as is case metals and plastic moldings. Softer rubbers will fill in the small voids, pits and scratches that are pathways for fluid to escape. Softer rubbers are also easier to squeeze which can be useful during installation on some applications.

Harder rubber is most commonly used in high pressure applications, up to 1500 psi, to prevent the seal from extruding into the space between the two sealing surfaces. This will cause bits of rubber to be nibbled away eventually leading to the seal failing. See “How Does an O-Ring Seal Anyway” in Satori Seal's Technical Article “What is and O-Ring?”.

Coefficient of friction is effected by the hardness of the rubber. Softer rubbers will cause higher breakout and kinetic friction on dynamic seals compared to harder rubbers.

Prototyping

Before going to production on your new seal, getting prototypes made is a great way to check your design work. There are several ways to prototype your O-ring design, cut and splice, prototype tooling, and cast mold via stereo lithography.

An O-ring can be made from cord stock or other o-rings that are cut to length and the ends glues together. This can be done fast and cheap but slight leaking can occur around the splices. A more accurate samples can be made from a 1 cavity prototype tool. This is more expensive, but less than a production tool, and does take time to have the tool made and samples run in production.

Another option is to have the seal made from stereo lithography (SLA). A sample part is generated with SLA. This sample is used to make a cast mold. Cast parts can be made from this. Turn around on this can be quicker than a prototype tool but this is more costly and the prototype part may be silicone and not the compound you need for production.