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# Why O-Rings Fail

## Several O-Ring failure modes for O-Rings and their causes

O-Rings are sealing elements that can be used in demanding seal applications over a broad pressure and temperature range.

They are easy to assemble, economical, and readily available. Seal gland design, material selection, and specification of relevant characteristics require as least some attention to prevent later application problems for the user. From experience often is the case that little experience exists for application design and sourcing/procurement of o-rings. In other words, „getting smart“ often occurs after the damage has been done.

The purpose of this presentation is address this problem and describe some typical O-Ring failure modes and the root causes behind them. The presentation will compare specific failures and provide detailed failure analysis along with steps toward prevention.

## Manufacturing Defects

An O-Ring manufacturing operation faces such strong cost pressures that during vulcanization, as in molding of O-Rings, processes are often at the limit of what is doable. It follows that one expects a certain quantity of O-Rings will not meet the form and surface quality requirements of the end user. For this reason a final inspection, in which defective parts are sorted good from bad, is an important part of the manufacturing process. Various methods are used, from sampling plans, to belt and table inspection, to automated vision inspection machines. A differentiating characteristic between a good and poor O-Ring supplier is thus the type and quantity of defective parts that finally reach the end user. Photo’s 1 and 2 show two extreme manufacturing defects.

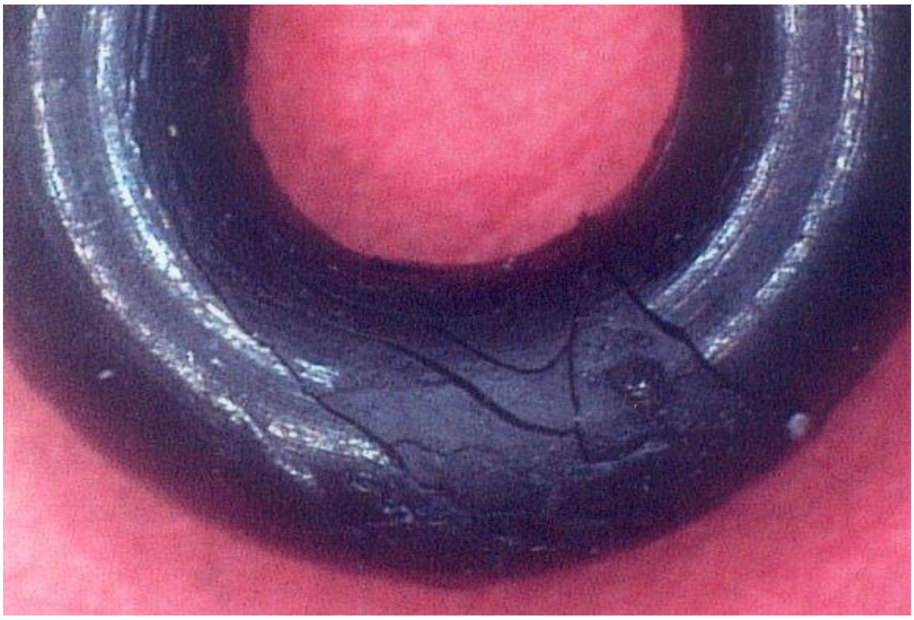

*Photo 1: Extreme flow lines;during injection if mold flow runners are too long or mold temperature too high, the material scorches.*

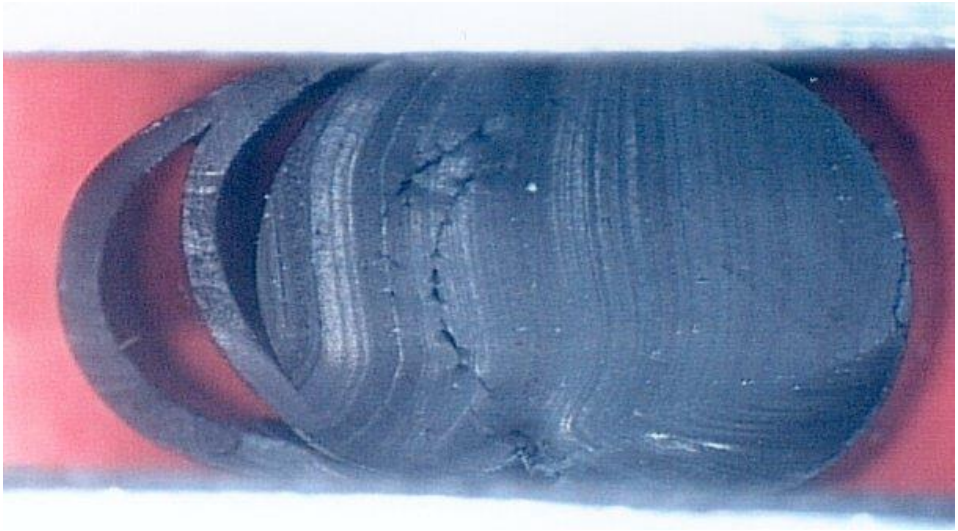

*Photo 2:  Internal splits, that propogate through the O-Ring during service.  The probable cause most likely the use of scorched material (expired shelf life).*

As effective control measure it is recommended that a consistent sample inspection for surface defects be implemented at incoming inspection.

**Assembly Defects**

O-Rings that come in contact with sharp edges can be damaged and can lead to subsequent failure.  This damage can occur  not only in the gland area when crossing over counter bores or channels, Photo 3, (another frequent problem are sharp groove edges and burrs), but also on the lead-in chamfer (Photo 4), or picking/grabbing of automatic O-Ring assembly equipment. During automated assembly operations, extremely fast stretching of parts can cause tears; just as immediate subsequent insertion does not always allow adequate time for the o-ring to recover from stretching and can be sheared.

*Photo 3: Sheared o-ring from passing over flow channel during assembly.*

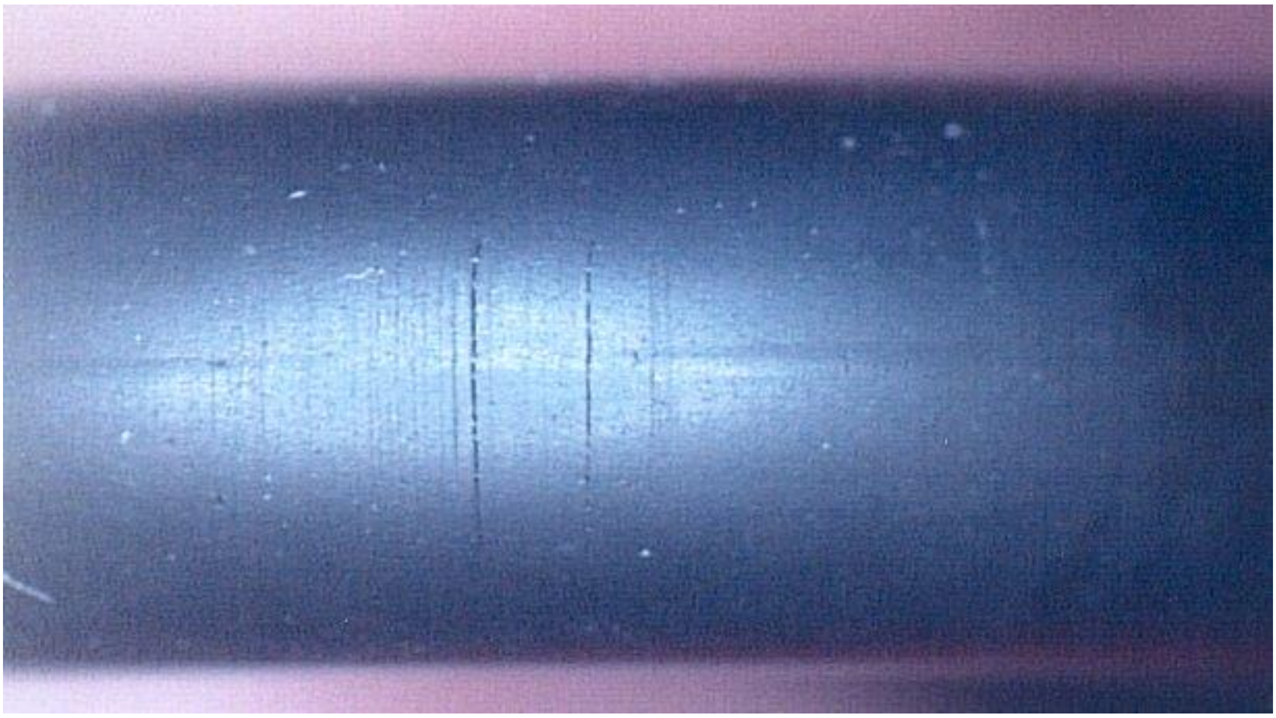

*Photo 4: O-Ring damage from passing over guide chamfer.*

Avoid assembly defects through careful design of gland and O-Ring lead-in guide chamfers. Reducing assembly friction of O-Rings greatly reduces assembly risk as well. Related is the flatness and roundness of o-rings (minimal „ potato chip“ and ovality); allowable tolerances should be agreed upon with the O-Ring supplier. With regards to O-Ring physical properties, especially elongation, minimum requirements should be defined.

## Ozone Effects

One should be careful when using NBR o-rings in environments where o-rings assembled on sub-components that are temporary stored prior to final assembly; exposure to air and weather can cause ozone cracks even after a short period of time, see Photo 5. This requires that pre-assembled NBR o-rings in temporary storage for more than several hours  be protected from air and direct  light. If this is not possible it is recommended that as minimum, an NBR recipe with improved ozone resistance be used, otherwise an ozone resistant elastomer such as EPDM or FKM be used.

*Photo 5: Ozone splits on an assembled o-ring on sub component following several weeks in storage without light and air protection.*

## Excessive Thermal Exposure

Excessive O-Ring temperature exposure can occur in two different forms. A short yet excessively high exposure temperature can cause surface cracks on the o-ring without the O-Ring actually getting brittle.  The other form follows from long term excessive thermal exposure which result in splits and ruptures, brittleness and permanent deformation, see Photo 6. These splits that develop due temperature generally occur on the contact surface (flattened side), while chemical attack occurs on surface exposed to the fluid (round side).

The thermal resistance of an elastomer can be compared to the fluid holding capacity of a vessel. Good temperature resistance is comparable to a high capacity vessel in that the incoming fluid flow when filling the vessel represents thermal exposure. Overfilling the vessel results in leakage. Even slowly filling the vessel, which would represent a relatively low temperature, will eventually cause the vessel to overflow after a longer period of time. For example, an NBR O-Ring exposed to 80° C long term temperature shows severe cracking and permanent set after 1-2 years, even though the material is recommended up to 100 C temperature resistance.

Photo 6: NBR O-Ring after excessive thermal exposure, with severe cracking and flattening.

**Poor Material Quality and/or Vulcanization Conditions**

Often underestimated are the influences of formulation and process quality of O-Rings. If O-Rings are of a poor quality formulation (ie high plasticizer content) or poorly vulcanized, severe compression set can result in just a few weeks or months, Photo 7. As a preventive measure, a compression set specification for production O-Rings should be established, as merely providing a data sheet for the material is not adequate assurance that O-Rings are properly vulcanized. Additional procurement requirements are naturally prudent as they relate to ensuring good vulcanization practices and material quality.

*Photo 7: Permanently deformed O-Ring.*

**High Pressures / Sharp Edges**

O-Rings are often used in high pressure hydraulic applications up to 400 bar, and in extreme cases beyond.

This is possible when recommended sealing gap limits are not exceeded for a given O-Ring durometer hardness. If these precautions are not followed the O-Ring will extrude into the seal gap, see Photo 8. The result is known to most designers. What is often missed is the impact of the groove edges. If these edges are not adequately rounded the O-Ring can become damaged even with relatively small seal gaps, see Photos 9 and 10. The O-ring in Photo 9 was used in a stack valve at 250 bar in which the outside diameter groove corners were sharp. Photo 10 shows an O-Ring taken from a water valve; the O-Ring was destroyed by a the sharp edge of a backup ring. It is especially recommended that for sealing of high pulsating pressures particular attention be given to the rounding of groove edges. When using backup rings, avoid those with sharp edges.

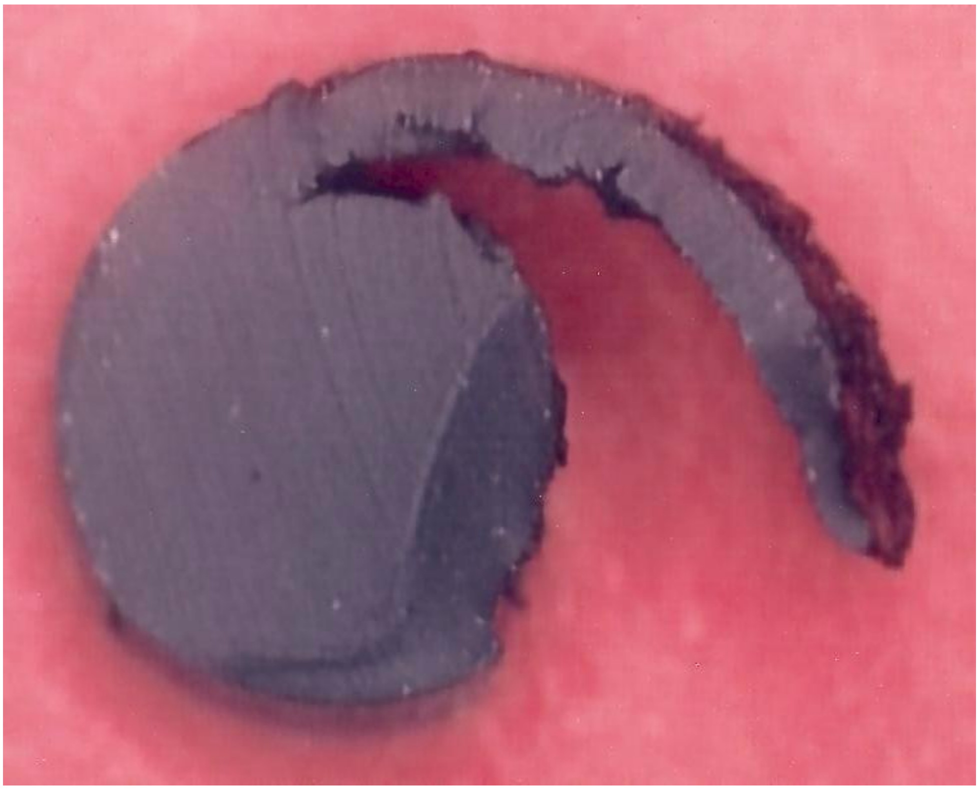

*Photo 8: Extruded O-Ring (excessive seal gap)*

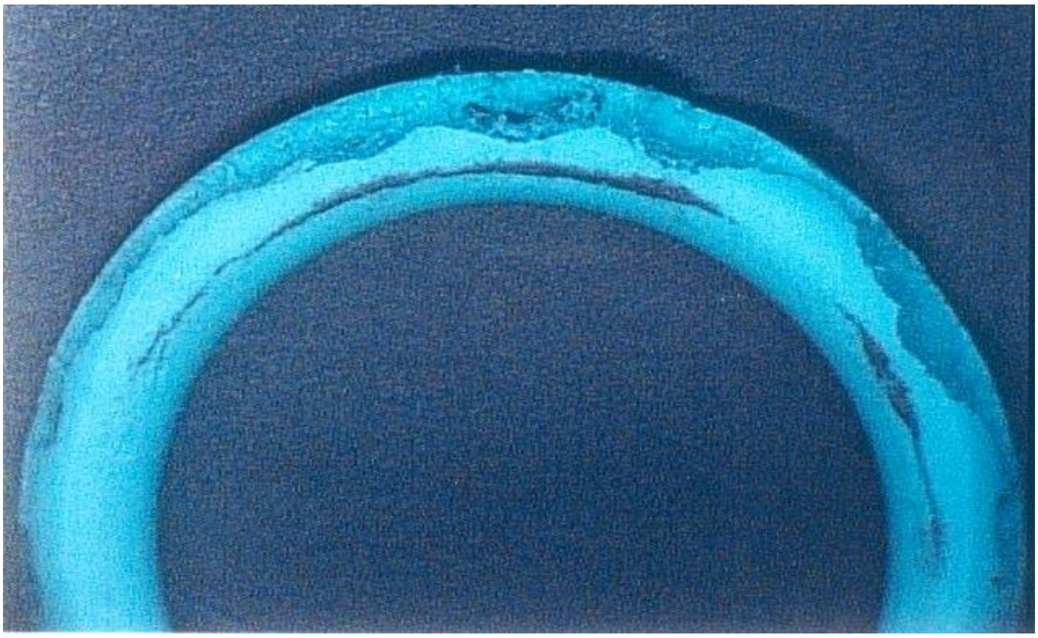

*Photo 9: Damaged O-Ring resulting from sharp corners and high pressures (ca. 250 bar).*

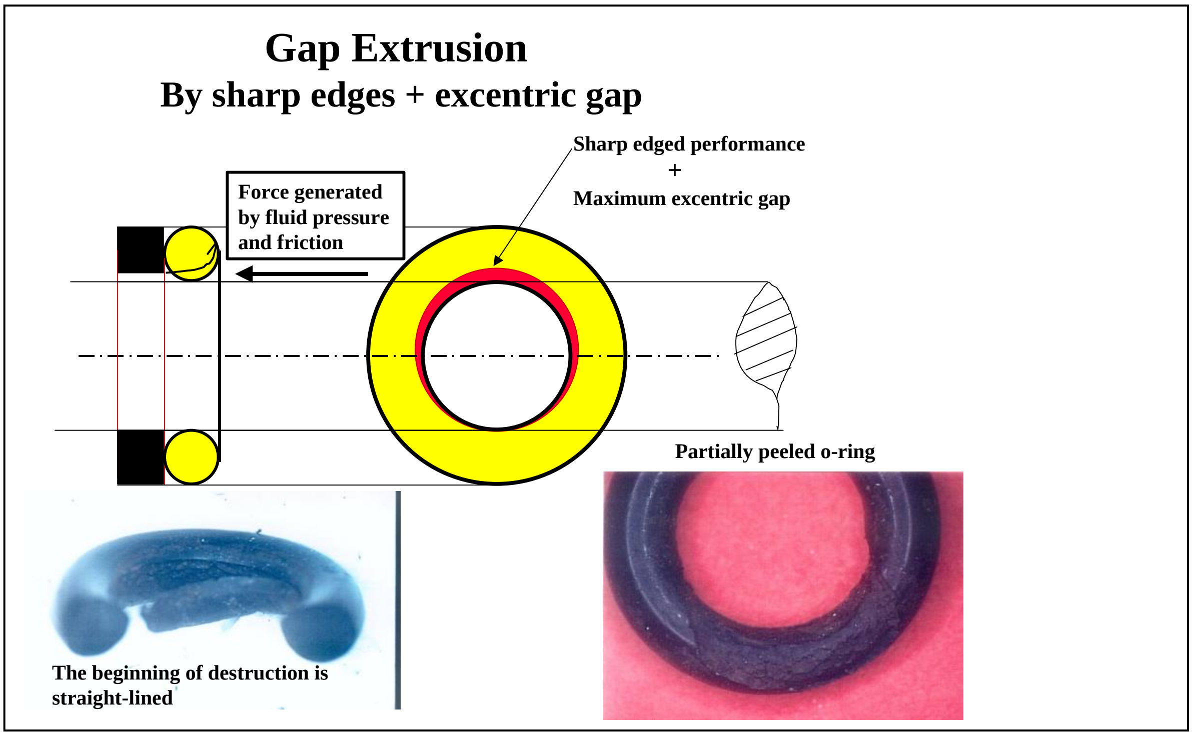


*Photo 10: Damage from a sharp edged backup ring at relatively low pressures (<50 bar).*

**Abrasion**

Next it must be noted that O-Rings are seldom the best technical solution for dynamic seals, while for static applications they are very capable. Greater wear compared to lip seals and less admissible gaps as examples. But even in static applications, a poorly machined gland can yield failures characteristic of dynamic seals, namely extreme flattening through abrasion, see Photo 11. At high pulsating pressures (>200 bar) even the small relative movement of a few tenths of millimeter against a poorly finished mating surface is enough to cause extreme abrasive flattening.  This relative movement can result from poor stiffness of mating components, poorly constructed joints, or excessively wide finish tolerances.

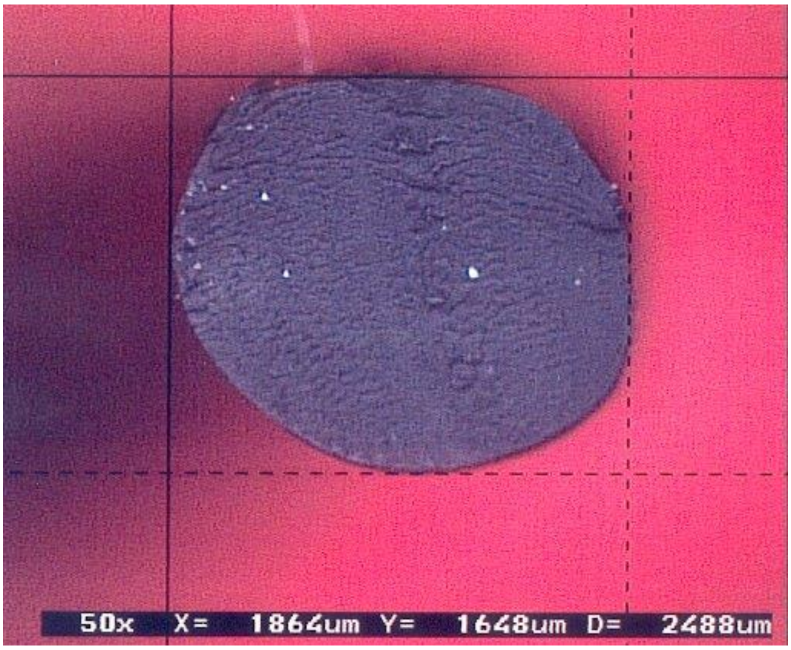


*Photo 11: Single abraided flat surface on O-Ring (static seal)*

**Chemical Attack**

Chemical incompatibility with the product or a cleaning/ sterilization media results in the loss of elasticity and often to the formation of cracks, Photo 12. Not seldom the cause for this is the selection of a material without considering all possible fluids that can come in contact with the O-Ring. Also inadequate immersion testing prior to material selection can be the reason for chemical compatibility problems, particularly when the effects of specific additives are not properly evaluated; as an example Standard FKM elastomers in highly additivated transmission oils.

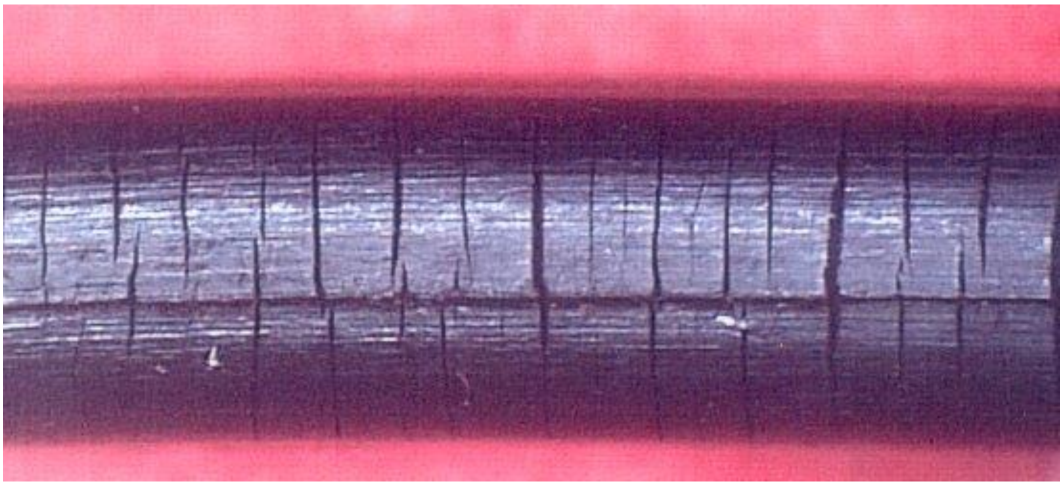

*Photo 12: Splits on the fluid side are typical characteristics of chemical attack.*

## Air in Oil

Mineral oils under increasing pressure dissolve increasing amounts of air that can expand in an explosive manner very quickly upon sudden pressure drops, resulting every so often in damage to the O-Ring, Photo 13. Unlike extrusion, the damage occurs on the pressure side of the O-Ring.

***Photo 13: Damage from explosive decompression of air.***

## Summary

The previously described failure modes should emphasize to users the importance of proper O-Ring seal design and at the same time assist in failure analysis/interpretation. These often overlooked aspects can result in great expense when compared to the cost of proper design. Finally, this presentation should benefit technical management in increasing the skill level of themselves and their respective associates.


## Thanks

A lot of thanks to John Lengenfelder, a friend and colleague during my time with Parker Hannifin (1984-1996), who did the translation from German in English, which requires own knowledge and experience with o-Rings .