NRL Memorandum Report 4809

O—Ring Installation for Underwater Components and Applications

C. J. Sandwith

Applied Physics Laboratory
University of Washington
Seattle, Washington 98105

April 15, 1982

NAVAL RESEARCH LABORATORY
Washington, D.C.

Approved for public release; distribution unlimited.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE *(When Data Entered)*

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER NRL MEMORANDUM REPORT 4809	2 GOVT ACCESSION NO.	3 RECIPIENT'S CATALOG NUMBER
4. TITLE *(and Subtitle)* (U) O-Ring Installation For Underwater Components and Applications		5 TYPE OF REPORT & PERIOD COVERED Final report on a completed contract 6 PERFORMING ORG. REPORT NUMBER
7 AUTHOR(s) Colin J. Sandwith		8 CONTRACT OR GRANT NUMBER(s) N00024-78-C-6018
9. PERFORMING ORGANIZATION NAME AND ADDRESS Applied Physics Laboratory University of Washington Seattle, WA 98105		10 PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS PE: 24281 NRL Work Unit: 59-0584
11 CONTROLLING OFFICE NAME AND ADDRESS Naval Research Laboratory Underwater Sound Reference Detachment PO Box 8337, Orlando, FL 32856		12. REPORT DATE 15 April 1982 13 NUMBER OF PAGES 93
14 MONITORING AGENCY NAME & ADDRESS *(if different from Controlling Office)* Naval Sea Systems Command (SEA63X5) Washington, DC 20362		15 SECURITY CLASS. *(of this report)* UNCLASSIFIED 15a DECLASSIFICATION/DOWNGRADING SCHEDULE

16 DISTRIBUTION STATEMENT *(of this Report)*

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT *(of the abstract entered in Block 20, if different from Report)*

18 SUPPLEMENTARY NOTES

This report was written under contract to the Applied Physics Laboratory, University of Washington, and sponsored by the Sonar Transducer Reliability Improvement Program (STRIP).

19 KEY WORDS *(Continue on reverse side if necessary and identify by block number)*

Gaskets	Reliability	Static seals
O-rings	Seals	Underwater seals

20 ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

This Handbook provides a standard procedure for installing O-ring seals in components designed for undersea applications. The undersea applications of primary concern here are components such as electrical connectors and fittings for sonar systems on submarines, surface ships, and other marine structures where seal reliability is critical. The principles and procedures recommended, however, can be applied to other static and some dynamic underwater seals. Although O-rings are the only type of gasket discussed, the principles and most of the procedures can be applied to quad-rings and other forms of (continued)

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE
S/N 0102-LF-014-6601

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE *(When Data Entered)* seal gaskets. The Handbook also provides general information to engineers, machinists, supply personnel, and procurement personnel concerning selection, design, storage, and handling of seal parts to ensure high reliability of the final seal assembly. It addresses lubricants and reliability as they apply to seal installation.

FOREWORD

The use of O-rings as seals has dramatically simplified the design, supply, and installation of reliable and durable seals. However, the proper installation of O-rings is far from obvious and in some assemblies is quite complex and demanding. Some installation procedures are still not agreed on among authorities. One example is lubricant quantity and distribution. A single mistake in the installation of one O-ring can mean the failure of the component or even the entire system. Therefore the reliability of the component or system depends on the reliability of the O-ring installation procedure. Even though this fact has been known for decades, no standard installation procedure has been adopted. At present, installation procedures are often determined by the installer and by the materials available at the time of installation.

Analyses of O-ring seals in certain underwater connectors that have been used for decades show that roughly 8 out of 13 leaks past the O-rings result from improper installation and assembly or from improper quality control and inspection procedures at the time of assembly. Stated another way, even though the O-ring seal design may be perfected by selecting the proper O-ring type (piston, face, or crush), by maximizing the cross-section thickness and squeeze, by selecting the proper O-ring size and material, and using two O-rings in each seal (double O-rings), a substantial number of O-ring failures will still occur because of improper installation and inspection procedures. Thus the reliability of underwater systems such as sonar transducer arrays would be significantly improved by the adoption of standard procedures for the installation and assembly of O-ring seals.

Reliable O-ring seals are the result of teamwork by knowledgeable designers, machinists, planners, inspectors, and installers who depend on one another to prevent mistakes (e.g., omissions, improper sizes or surface finishes, etc.). Because the installer has the last chance to see, accept, or reject the seal parts before installation, special responsibility falls on the installer to ensure that the correct seal parts are used and are properly installed. His guides are the engineering and production drawings and this Handbook. All installers should be trained in how O-rings work, how O-rings should be installed, and the importance of each step in the procedures. To produce a reliable seal (system), the installer must follow the proper installation procedure.

CONTENTS

FIGURES

TABLES

1. SCOPE

This Handbook provides a standard procedure for installing O-ring seals in components designed for undersea applications. The undersea applications of primary concern here are components such as electrical connectors and fittings for sonar systems on submarines, surface ships, and other marine structures where seal reliability is critical. The principles and procedures recommended, however, can be applied to other static and some dynamic underwater seals. Although O-rings are the only type of gasket discussed, the principles and most of the procedures can be applied to quad-rings and other forms of seal gaskets.

The Handbook also provides general information to engineers, machinists, supply personnel, and procurement personnel concerning selection, design, storage, and handling of seal parts to ensure high reliability of the final seal assembly. It addresses lubricants and reliability as they apply to seal installation.

2. APPLICATION

This Handbook describes the best procedures, based on past experiences, scientific analyses, and engineering data, to avoid leaks and gland damage due primarily to improperly installed O-ring seals.

2.1 Training. This Handbook can be used as a guide for training installers (mechanics), planners, inspectors, and engineers. Installers and inspectors (quality control personnel) should be required to study the entire Handbook, attend O-ring installation demonstrations, install O-rings in each type of O-ring seal, and, finally, take a written and performance test in order to qualify as installers or inspectors. Certain planners, quality assurance personnel, and engineers should read the entire Handbook and attend at least a one day class that reviews the Handbook. Sections 5-8, 10, and 12-15 are of special interest to engineers. Sections 6-12 are of special interest to planners. Sections 6-15 are of special interest to quality assurance personnel.

2.2 Shop. Part of this Handbook is intended to be used by the installer as a step by step guide in the shop. Each installer and inspector should have his own copy of Section 8.2.1, Abbreviated Step Method of O-Ring Installation. The entire Handbook should be available to installation, storage, and machine shop personnel for periodic reference and review.

2.3 Engineering. This Handbook provides a standard installation procedure for O-ring seals. Certain sections or the entire Handbook can be called out (required or recommended) in engineering and production drawings or production procedures to ensure seal reliability. The Handbook can also be used by engineering, materials and processes, procurement, and production groups as background information to improve seal reliability. The sections that should be referred to periodically by each group are given in Section 3.

3. ARRANGEMENT

The first five sections are needed by all personnel who are involved with O-rings, but the balance of the Handbook may be divided into three general parts. Part I, on O-ring installation, includes Sections 6, 8-12, and 14, and is intended primarily for shop applications. This part covers step-by-step procedures and do's and don'ts for mechanics and inspectors; these sections need to be available for use during installations. Part II, on engineering, includes Sections 5-8, 10, and 12-15, and covers some O-ring seal specifications and engineering design considerations--squeeze, material, type and storage. Part III, on background material, includes Sections 13-15, and describes O-ring seal problems, how the reliability of the final seal depends on each step of the installation, and how small changes in design or procedure can have a big effect (good or bad) on the reliability of the seal. These sections contain material that needs to be referred to from time to time to refresh the memory of mechanics, inspectors, and engineers.

4. DEFINITIONS

4.1 Glossary

The following terms are commonly used in literature on seals and O-rings. Most of the definitions given here are taken from Parker Hdbk ORD-5700.

ABRASION -- The wearing away of a surface in service by mechanical action such as rubbing, scraping, or erosion.

ABSORPTION -- The physical mechanism by which one substance attracts and takes up another substance (liquid, gas, or vapor) into its interior.

ACCELERATED LIFE TEST -- Any set of test conditions designed to reproduce in a short time the deteriorating effect obtained under normal service conditions.

ACCELERATOR -- A substance that hastens the vulcanization of an elastomer causing it to take place in a shorter time or at a lower temperature.

ADHERE -- To cling or stick together.

ADHESION -- Tendency of rubber to bond or cling to a contact surface.

ADSORPTION -- The physical mechanism by which one substance attracts another substance (either solid, liquid, gas, or vapor) to its surface and through molecular forces causes the incident substance to adhere thereon.

AFTER CURE -- Continuation of vulcanization after the desired cure is effected and the heat source removed.

AGING -- To undergo changes in physical properties with age or lapse of time.

AIR CHECKS -- Surface markings or depressions due to trapping air between the material being cured and the mold or press surface.

AIR CURING -- The vulcanization of a rubber product in air as distinguished from vulcanizing in a press or steam vulcanizer.

AMBIENT TEMPERATURE -- The surrounding temperature relative to the given point of application. NOTE: Ambient temperature is not necessarily the same as atmospheric temperature.

ANTIOXIDANT -- An organic substance that inhibits or retards oxidation.

ANTIOZONANT -- A substance that retards or prevents the occurrence of cracks when the elastomer is exposed under tension, either statically or dynamically, to air containing ozone.

ANTIRAD -- A material that inhibits radiation damage.

ATMOSPHERIC CRACKING -- Cracks produced in surface of rubber articles by exposure to atmospheric conditions.

BACKRIND -- Distortion at the parting line usually in the form of a ragged indentation.

BACKUP RING -- (anti-extrusion device) a ring of relatively hard and tough material placed in the gland between the O-ring and groove side walls, to prevent extrusion of the O-ring.

BAKE-OUT -- A process whereby a vacuum system is heated for a given time at some predetermined temperature to degas all the components, i.e., gauges, fittings, valves, seals, etc.

BENCH TEST -- A modified service test in which the service conditions are approximated, but the equipment is conventional laboratory equipment and not necessarily identical with that in which the product will be employed.

BLEEDING -- Migration to the surface of plasticizers, waxes, or similar materials to form a film or beads.

BLEMISH -- A mark, deformity, or injury that impairs the appearance.

BLISTERS -- A raised spot in the surface or a separation between layers usually forming a void or air-filled space in the vulcanized article.

BLOOM -- A dusty or milky looking deposit that sometimes appears on the surface of an O-ring after molding and storage, caused by migration of a liquid or solid to the surface. Not to be confused with dust from external sources.

BOND -- The term commonly used to denote the attachment of a given elastomer to some other member. Bonds may be classified by type as follows:

(a) Mechanical Bond -- purely physical attachment accomplished by such means as "through" holes, interlocking fingers, envelope design, riveting, etc.

(b) "Cold" Bond -- adhesion of previously vulcanized elastomer to another member through use of suitable contact cements.

(c) "Vulcanized" Bond -- adhesion of an elastomer to a previously primed surface using heat and pressure, thus vulcanizing the elastomer at the same time.

BREAK -- A separation or discontinuity in any part of an article.

BREAKOUT -- Force to inaugurate sliding. Expressed in same terms as friction. An excessive breakout value is taken as an indication of the development of adhesion.

BRITTLENESS -- Tendency to crack when deformed.

BUNA N -- Same as nitrile rubber.

BUNA S -- A general term for the copolymers of butadiene and styrene. Also known as SBR and GRS.

BUTT JOINT -- Joining two ends of a seal whereby the junction is perpendicular to the mold parting line.

BUTYL -- A copolymer of isobutylene and isoprene.

COEFFICIENT OF THERMAL EXPANSION -- Average expansion per degree over a stated temperature range, expressed as a fraction of initial dimension. May be linear or volumetric.

COLD FLEXIBILITY -- Flexibility following exposure to a predetermined low temperature for a predetermined time.

COLD FLOW -- Continued deformation under stress.

COMPOUND -- A term applied to a mixture of polymers and other ingredients, to produce a usable rubber material.

COMPRESSION MODULUS - The ratio of the compressive stress to the resulting compressive strain (the latter expressed as a fraction of the original height or thickness in the direction of the force). Compression modulus may be either static or dynamic.

COMPRESSION SET -- The amount by which a rubber specimen fails to return to original shape after release of compressive load.

CONDUCTIVE RUBBER -- A rubber capable of conducting electricity. Most generally applied to rubber products used to conduct static electricity.

CORROSION (PACKING) -- Corrosion of rigid member (usually metal) where it contacts packing. The actual corroding agent is fluid medium trapped in the interface.

CORROSIVE (PACKING) -- A property of packing whereby it is assumed, often incorrectly, to promote corrosion of the rigid member by the trapped fluid.

CRACKING -- A sharp break or fissure in the surface. Generally due to excessive strain.

CREEP -- The progressive relaxation of a given rubber material while it is under stress. This relaxation eventually results in permanent deformation or "set."

CROSS SECTION -- A seal as viewed if cut at right angles to the mold parting line showing internal structure.

CURE -- See Vulcanization.

CURE DATE -- Date when O-ring was molded, e.g., 2Q73 means the second quarter of 1973.

CURING TEMPERATURE -- The temperature at which the rubber product is vulcanized.

CYLINDER -- Chamber in which piston, plunger, ram, rod, or shaft is driven by or against the system fluid.

DIFFUSION -- The mixing of two or more substances (solids, liquids, gases, or combinations thereof) due to the random motion of their molecules. Gases diffuse more readily than liquids; similarly, liquids diffuse more readily than solids.

DUROMETER -- (a) An instrument for measuring the hardness of rubber. Measures the resistance to the penetration of an indenter point into the surface of rubber. (b) Numerical scale of rubber hardness.

DYNAMIC -- An application in which the seal is subject to movement or moving parts contact the seal.

DYNAMIC SEAL -- A seal required to prevent leakage past parts that are in relative motion.

ELASTICITY -- The property of an article that tends to return it to its original shape after deformation.

ELASTOMER -- Any synthetic or natural material with resilience or memory sufficient to return to its original shape after major or minor distortion.

ELEMENT -- The smallest part(s) that a seal or component can be divided into or the smallest procedure(s) that a process, such as installation, can be divided into.

ELONGATION -- Generally means "ultimate elongation" or percent increase in original length of a specimen before it breaks.

EVAPORATION -- The direct conversion from liquid state to vapor state of a given fluid.

EXTRUSION -- Distortion or flow, under pressure, of portion of seal into clearance between mating metal parts.

FILLER -- Chemically inert, finely divided material added to the elastomer to aid in processing, improve physical and mechanical properties (i.e., improve abrasion resistance and strength), and control hardness.

FLASH -- Excess rubber left around rubber part after molding due to space between mating mold surfaces; removed by trimming.

FLEX CRACKING -- A surface cracking induced by repeated bending or flexing.

FLEX RESISTANCE -- The relative ability of a rubber article to withstand dynamic bending stresses.

FLOCK -- Fibrous filler sometimes used in rubber compounding.

FLOW CRACKS -- Surface imperfections due to improper flow and failure of stock to knit or blend with itself during the molding operation.

FLUID -- A liquid or a gas.

FRICTION -- Resistance to motion due to the contact of surfaces.

FRICTION (BREAKOUT) -- Friction developed during initial or starting motion.

FRICTION (RUNNING) -- Constant friction developed during operation of a dynamic O-ring.

FUEL (AROMATIC) -- Fuel that contains benzene or aromatic hydrocarbons. Causes high swell of rubber.

FUEL (NONAROMATIC) -- Fuel that is composed of straight chain hydrocarbons. Causes little swell of rubber.

GASKET -- A device used to retain fluids under pressure or seal out foreign matter. Normally refers to a static seal.

GLAND -- Cavity into which O-ring is installed. Includes the groove and mating surface of second part that together confine the O-ring.

GROOVING -- Putting the O-ring into the groove.

HARDNESS -- Resistance to a distorting force. Measured by the relative resistance of the material to an indentor point of any one of a number of standard hardness testing instruments.

HARDNESS SHORE A -- The rubber durometer hardness as measured on a Shore "A" gauge. Higher numbers indicate harder material. A 35 Shore "A" durometer reading is considered soft; a 90 is considered hard.

HERMETIC SEAL -- An airtight seal evidencing no leakage.

HOMOGENEOUS (a) General -- a material of uniform composition throughout. (b) In seals -- a rubber seal without fabric or metal reinforcement.

HYPALON -- DuPont trade name for chlorosulphonated polyethylene, an elastomer.

IMMEDIATE SET -- The deformation found by measurement immediately after removal of the load causing the deformation.

IMMERSION -- Placing an article into a fluid, generally so it is completely covered.

IMPACT -- The single, instantaneous stroke or contact of a moving body with another, either moving or at rest, such as a large lump of material dropping on a conveyor belt.

LEAKAGE RATE -- The rate at which a fluid (either gas or liquid) passes a barrier. Total Leakage Rate includes the amounts that diffuse or permeate through the material of the barrier as well as the amount that escapes around it.

LOGY -- Sluggish, low snap or recovery of a material.

MEMORY -- Tendency of a material to return to original shape after deformation.

MIRROR FINISH -- A bright, polished surface.

MISMATCH -- Unsymmetrical seal caused by dissimilar cavities in mating mold sections.

MODULUS -- As a measure of stiffness for elastomers, the stress required for a given elongation, such as 100% or 300%.

MODULUS OF ELASTICITY -- Ratio of stress to elastic strain--a constant for metals but not for elastomers.

MOLD FINISH -- The uninterrupted surface produced by intimate contact of rubber with the surface of the mold at vulcanization.

MOLD MARKS -- Indentations or ridges embossed into the skin of the molded product by irregularities in the mold cavity surface. Parting line flash is an example.

MOONEY SCORCH - The measurement of the rate at which a rubber compound will cure or set up by means of the Mooney Viscometer test instrument.

MOONEY VISCOSITY -- The measurement of the plasticity or viscosity of an uncompounded or compounded, unvulcanized, elastomeric seal material by means of the Mooney Shearing Disk Viscometer.

NITRILE (BUNA-N) -- The most commonly used elastomer for O-rings because of its resistance to petroleum fluids, good physical properties, and useful temperature range.

NOMINAL DIMENSION -- Nearest fractional equivalent to actual decimal dimension.

OCCLUSION -- (a) The mechanical process by which vapors, gases, liquids, or solids are entrapped within the folds of a given substance during working or solidification. (b) The materials so trapped.

OFF-REGISTER -- Misalignment of mold halves causing out-of-round O-ring cross section.

OIL-RESISTANT -- Ability of a vulcanized rubber to resist the swelling and deteriorating effects of various type oils.

OIL SWELL - The change in volume of a rubber article due to absorption of oil or other fluid.

O-RING -- A torus; a circle of material with round cross section which effects a seal through squeeze and pressure.

O-RING SEAL -- The combination of a gland and an O-ring providing a fluid-tight closure. (Some designs may permit momentary or minimum leakage.)

Moving (dynamic) -- O-ring seal in which there is relative motion between some gland parts and the O-ring--oscillating, reciprocating or rotary motion.

Nonmoving (static) -- O-ring seal in which there is no relative motion between any part of the gland and the O-ring (distortion from fluid pressure or swell from fluid immersion is excluded).

OPTIMUM CURE -- State of vulcanization at which the most desirable combination of properties is attained.

OUTGASSING -- A vacuum phenomenon wherein a substance spontaneously releases volatile constituents in the form of vapors or gases. In rubber compounds, these constituents may include water vapor, plasticizers, air, inhibitors, etc.

OVERCURE -- A degree of cure greater than the optimum, causing some desirable properties to be degraded.

OXIDATION -- The reaction of oxygen on a compound usually detected by a change in the appearance or feel of the surface, or by a change in physical properties, or both.

OZONE RESISTANCE - Ability to withstand the deteriorating effect of ozone (which generally causes cracking).

PACKING -- A flexible device used to retain fluids under pressure or seal out foreign matter. Normally refers to a dynamic seal.

PARTING LINE FLASH -- Residual rubber that is squeezed out between the dies during molding.

PERMANENT SET - The deformation remaining after a specimen has been stressed in tension for a definite period and released for a definite period.

PERMEABILITY -- The rate at which a liquid or gas under pressure passes through a solid material by diffusion and solution. In rubber terminology, it is the rate of gas flow expressed in atmospheric cubic centimeters per second through an elastomeric material 1 centimeter square and 1 centimeter thick (atm cc/cm^2/cm/sec).

PIT OR POCK MARK -- A circular depression, usually small.

PLASTICIZER -- A substance, usually a heavy liquid, added to an elastomer to decrease stiffness, improve low temperature properties, and improve processing.

PLASTOMETER -- An instrument for measuring the plasticity of raw or unvulcanized compounded rubber.

POLYMER -- A material formed by the joining together of many (poly) individual units (mer) of one or more monomers; synonymous with elastomer.

POROSITY -- Quality or state of being porous.

POST CURE -- The second step in the vulcanization process for the more exotic elastomers. Provides stabilization of parts and drives off decomposition products resulting from the vulcanization process.

RADIATION - An emission of varying energy content from a disturbed atom undergoing internal change. There are two broad classifications or types:

(a) Corpuscular, comprising streams of particles either neutral or charged, e.g., protons, electrons, neutrons.

(b) Electromagnetic, comprising wave-like emissions such as ultraviolet radiation, x-rays, and gamma rays.

RADIATION DAMAGE -- A measure of the loss in certain physical and mechanical properties of organic substances such as elastomers, due principally to ionization of the long chain molecule. It is believed that this ionization process (i.e., electron loss) results in redundant cross-linking and possible scission of the molecule. This effect is cumulative.

REINFORCING AGENT -- Material dispersed in an elastomer to improve compression, shear, or other stress properties.

RELATIVE HUMIDITY -- The ratio of the quantity of water vapor actually present in the atmosphere to the greatest amount possible at the given temperature.

RESILIENT -- Requires much energy to deform elastically.

ROUGHNESS AVERAGE -- Arithmetic average of surface irregularities, abbreviated R_a; also called AA and CLA.

ROUGH TRIM -- Removal of superfluous material by pulling or picking. Usually the removal of a small portion of the flash or sprue which remains attached to the product.

RUBBER -- Same as elastomer.

RUBBER, NATURAL - Raw or crude rubber obtained from vegetable sources.

RUBBER, SYNTHETIC -- Manufactured or man-made elastomers.

RUNOUT (SHAFT) - Same as gyration; when expressed in inches alone or accompanied by abbreviation "TIR" (total indicator reading), it refers to twice the radial distance between shaft axis and axis of rotation.

SCORCHING -- Premature curing or setting up of raw compound during processing.

SEAL -- Any device used to prevent the passage of a fluid (gas or liquid).

SEATING -- Squeezing the O-ring between the sealing surfaces by closing the gland.

SERVICE -- Operating conditions to be met.

SHELF-AGING -- The change in a material's properties that occurs in storage with time.

SHORE A HARDNESS -- See Hardness and Durometer.

SHRINKAGE -- Decreased volume of seal, usually caused by extraction of soluble constituents by fluids followed by air drying.

SILICONE RUBBER -- Elastomer that retains good properties through extra wide temperature range.

SIZE, ACTUAL -- Actual dimensions of the O-ring or other seal, including tolerance limits.

SIZE, NOMINAL -- Approximate size of a part in fractional dimensions. May also indicate the actual size of the groove into which a nominal size seal fits.

SIZE NUMBER -- Number assigned to indicate inside and cross section diameters of an O-ring. Sizes established in SAE standard AS568 have been adopted by the military and industry.

SORPTION -- The term used to denote the combination of absorption and adsorption processes in the same substance.

SPECIFIC GRAVITY -- The ratio of the weight of a given substance to the weight of an equal volume of water at a specified temperature.

SPRUE MARKS -- Marks left on the surface of a rubber part, usually elevated, after removal of the sprue or cured compound in the gate through which the compound is injected or transfer molded.

SQUEEZE -- Cross section diametral compression of O-ring between surface of the groove bottom and surface of other mating metal part in the gland assembly.

STATIC SEAL -- Part designed to seal between parts having no relative motion. See Gasket.

STEP -- One or a group of elements in a procedure such as grooving.

STRAIN -- Deformation per unit original length.

STRESS -- Force per unit of original cross section area.

SUBLIMATION -- The direct conversion of a substance from solid state to vapor state without passing through a transitory liquid state. The vapor, upon recondensing, reforms into the solid state with no intervening liquid phase.

SUN CHECKING -- Surface cracks, checks or crazing caused by exposure to direct or indirect sunlight.

SWELL -- Increased volume of a specimen caused by immersion in a fluid (usually a liquid).

TEAR RESISTANCE -- Resistance to growth of a cut or nick when tension is applied to the cut specimen. Commonly expressed as pounds per inch thickness.

TEMPERATURE RANGE -- Maximum and minimum temperature limits within which a seal compound will function in a given application.

TENSILE STRENGTH -- Stress required to cause the rupture of a specimen of a rubber material.

THERMAL EXPANSION -- Expansion caused by increase in temperature. May be linear or volumetric.

TORQUE -- The turning force of a shaft.

TORSIONAL STRENGTH -- Ability of rubber to withstand twisting.

TRAPPED AIR -- Air that is trapped in a connector or seal.

TRIM -- The process involving removal of mold flash.

TRIM CUT -- Damage to mold skin or finish by too close trimming.

UNDERCURE -- Degree of cure less than optimum. May be evidenced by tackiness, loginess, or inferior physical properties.

ULTIMATE ELONGATION -- See Elongation.

VACUUM -- The term denoting a given space that is occupied by a gas at less than atmospheric pressure.

VAPOR -- A gas at a temperature below the critical temperature so that it can be liquefied by compression without lowering the temperature. Fog and gas streams from atomizers are common examples.

VAPOR PRESSURE -- The maximum pressure exerted by a liquid (or solid) heated to a given temperature in a closed container.

VISCOSITY -- The property of fluids and plastic solids by which they resist an instantaneous change of shape, i.e., resistance to flow.

VOID -- The absence of material or an area devoid of materials where not intended.

VOLATILIZATION -- The transition of either a liquid or a solid directly into the vapor state. In the case of a liquid, this transition is called evaporation, whereas in the case of a solid, it is termed sublimation.

VOLUME CHANGE -- A change in the volume of a seal as a result of immersion in a fluid, expressed as a percentage of the original volume.

VOLUME SWELL -- Increase in physical size caused by the swelling action of a liquid.

VULCANIZATION - A thermo-setting reaction involving the use of heat and pressure, resulting in greatly increased strength and elasticity of rubber-like materials.

VULCANIZING AGENT -- A material that produces vulcanization of an elastomer.

WIDTH -- Seal cross section or thickness.

WIPER RING -- A ring employed to remove excess fluid, mud, etc., from a reciprocating member before it reaches the packings.

4.2 Abbreviations

The following abbreviations are commonly used in literature on seals and O-rings. The source for most of these abbreviations is Parker Hdbk ORD-5700.

AA -- Arthmetic Average (roughness)
ACM -- Polyacrylate Rubber
AF -- Air Force
AIR -- Aerospace Information Report
AMS -- Aerospace Material Specification
AN -- (1) Army-Navy; (2) Air Force-Navy
AND -- Air Force-Navy Design
ARP -- Aerospace Recommended Practice; superseded by AS
AS -- Aerospace Standard
ASTM -- American Society for Testing and Materials
atm -- Atmosphere (atmospheric)
C or °C -- Degrees Centigrade
CLA -- Another term for AA and R_a
CO -- Epichlorohydrin Rubber
CR -- Chloroprene Rubber (neoprene)
CS -- Cross Section
Dia -- Diameter
EP, EPM, EPDM -- Ethylene-Propylene Rubber
F or °F -- Degrees Fahrenheit
FED -- Federal Specification
FPM -- Fluorocarbon Rubber (viton, fluorel)
FVMQ -- Fluorosilicone Rubber
ID -- Inside Diameter
IIR -- Butyl Rubber
In. -- Inch
IR -- Isoprene Rubber
JAN -- Joint Army-Navy
K or °K -- Degrees Kelvin (absolute), (°C+273)
Max - Maximum
MFR -- Manufacturer
MIL -- Military Specification
Min -- Minimum
MQ -- Silicone Rubber
MS -- Military Standard
NAS -- National Aerospace Standard; also National Aircraft Standards (older meaning)
NBR -- Nitrile or Buna N Rubber
No. -- Number
NR -- Natural Rubber
OD -- Outside Diameter
Pg -- Page
PMQ -- Silicone Rubber
PN -- Part Number
psi -- Pounds per square inch
PVMQ -- Silicone Rubber
QPL -- Military Qualified Products List

R_a -- Arithmetic Average Roughness
Rad -- Radius
rms -- Root-mean-square; the square root of the mean of the sum of the squares of the heights of surface irregularities
SAE -- Society of Automotive Engineers, Inc.
Spec -- Specification
Temp. -- Temperature
VMQ -- Silicone Rubber
W -- Width (seal cross section)

5. O-RING SEALS, GENERAL

5.1 O-ring Definition. An O-ring is a rubber torus, or doughnut-shaped ring, with a circular cross section as shown in Figure 5.1.

Figure 5.1
O-ring shape.

5.2 O-ring Dimensions. An O-ring is defined dimensionally by its cross-section diameter (thickness) W and inside diameter (ID) as shown in Figure 5.2. O-rings are commonly made in five standard cross sections with nominal inside diameters (like the diameter of the doughnut hole) ranging from 1/32 to 26 in. (0.79 to 660 mm). Refer to AN6227.

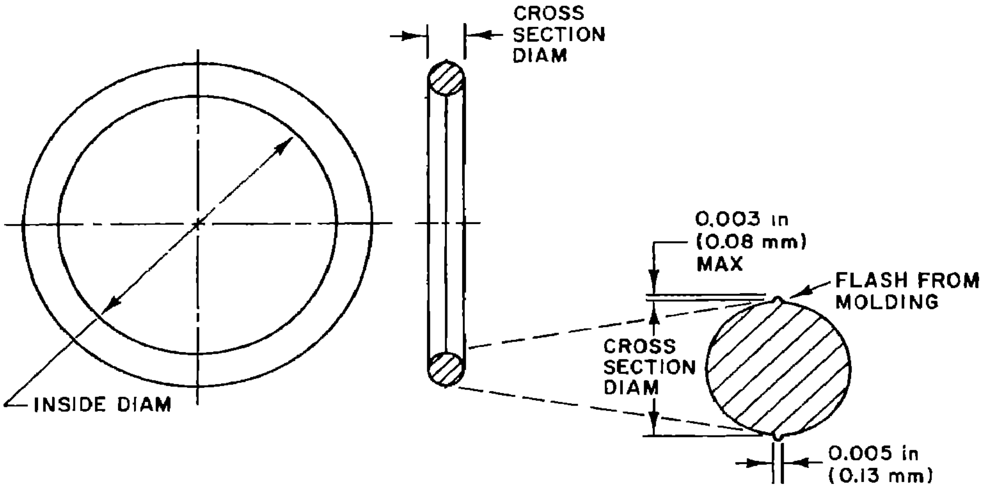


Figure 5.2
O-ring dimensions.

5.3 How O-rings Seal. When properly installed in its gland, the circular cross section of the O-ring is squeezed between the top of the gland and the bottom of the gland as shown in the top sketch in Figure 5.3. The gland is the cavity that contains the O-ring. As pressure is applied, the O-ring slides to the low pressure side of the gland and prevents the fluid (seawater or gas) from crossing the gland (bottom sketches in Figure 5.3). Sealing takes place because the pressure of the fluid and the initial installation squeeze force the O-ring against the gland walls and into the gap so hard that no liquid or gas molecules can pass. The critical sealing surfaces are shown in Figure 5.4. The critical surface is really an interface where three things (gland metal surface, rubber O-ring, and O-ring lubricant) are tightly compressed. The pressure produces the seal. The lubricant is applied to the O-ring and the gland surfaces for three main reasons--to reduce friction (i.e., to help the rubber O-ring slide during installation, form to the gland surface, and prevent adhesion); to keep water from the sealing surfaces; and to fill all voids under the rubber.

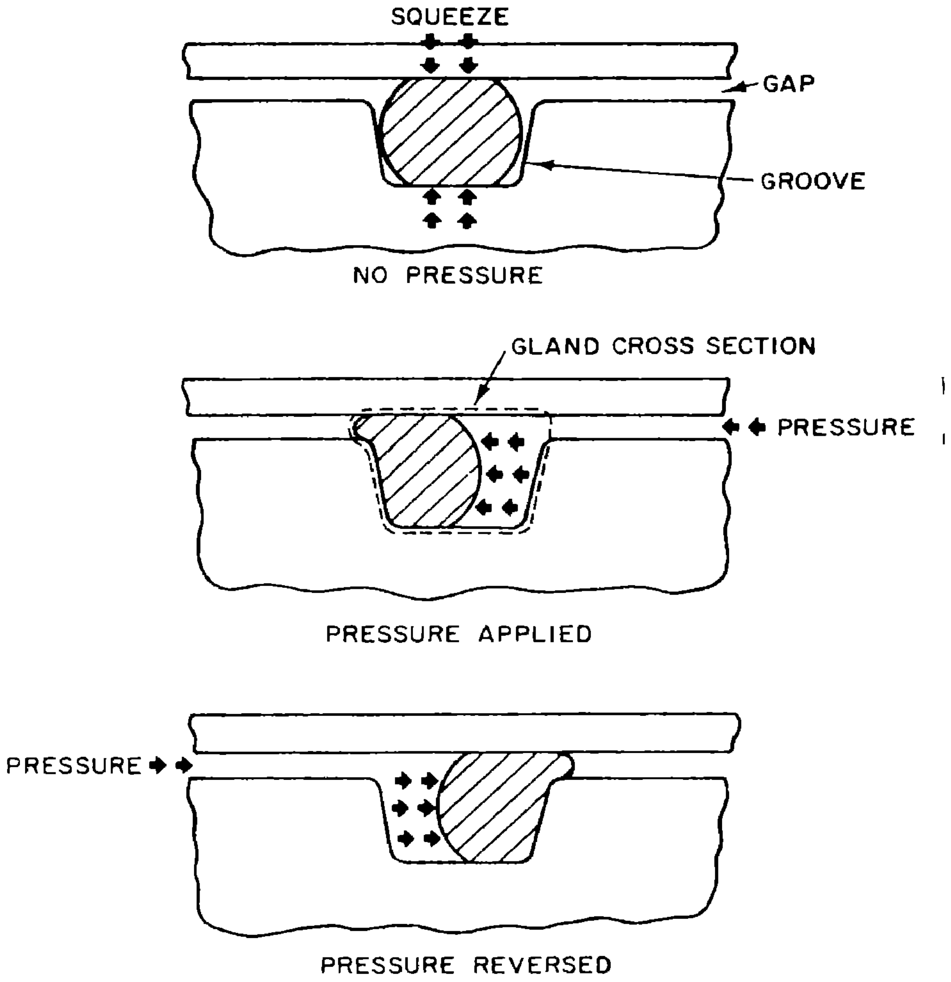


Figure 5.3
Sealing action.

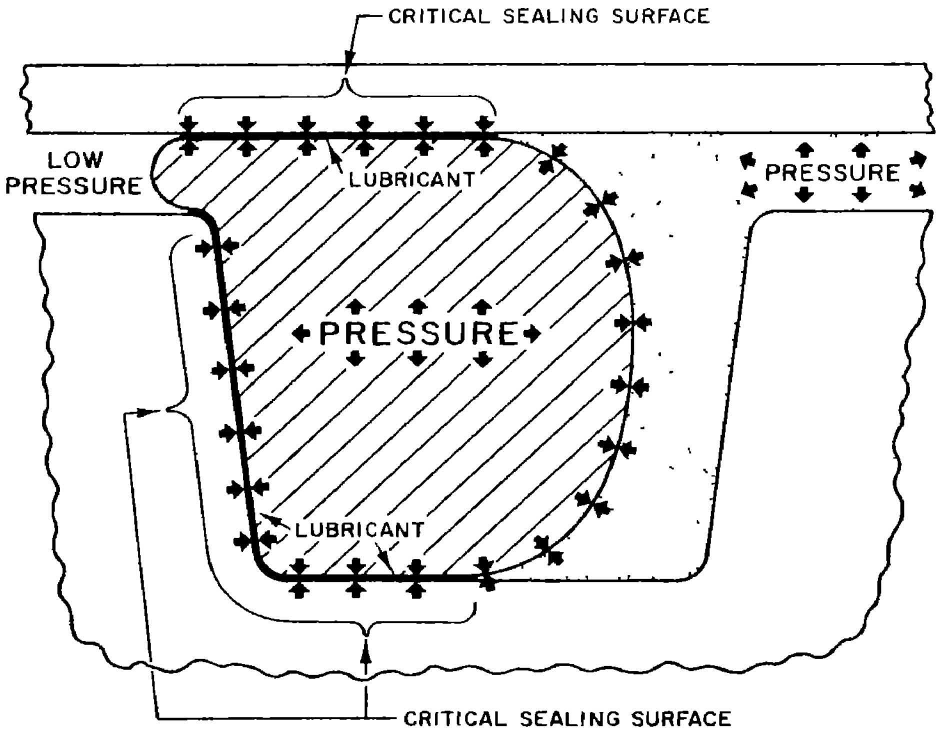


Figure 5.4

Critical sealing surfaces and sealing mechanism. Sealing is produced by the pressure between the O-ring and gland surfaces.

The O-ring rubber deforms to match nearly all of the fine machine-tool grooves (which are so small they are barely visible to the naked eye) and the lubricant fills all the rest of the grooves as shown in Figure 5.5. The reliability and success of the seal depend on this critical sealing surface, or interface, that runs all around the O-ring. If anything goes wrong anywhere on that interface, the seal will leak. Dirt, hair, fibers, scratches, or cuts cause LEAKS as shown in Figure 5.6. The water can wick through a fiber or dirt and break the seal. Thus surfaces must be clean and free of scratches or cuts.

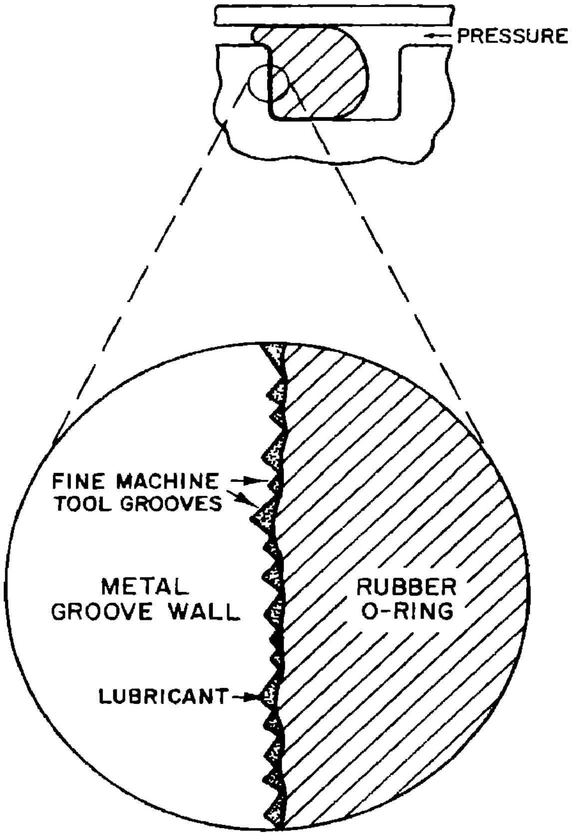


Figure 5.5 Enlarged view of critical gland sealing surface, or interface, where groove wall, rubber O-ring, and lubricant meet and are tightly compressed together to produce a reliable seal.

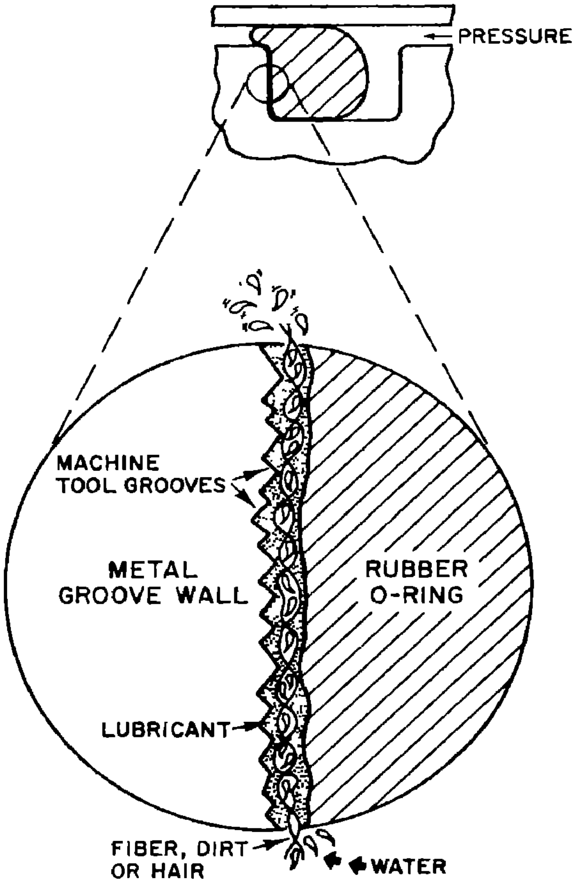


Figure 5.6 How water can leak pas the O-ring because of contaminatio. by fibers, dirt, or hair.

5.4 Types of O-ring Seals. O-ring seals are normally either dynamic (i.e., they often slide, rotate, or vibrate during use) or static (stationary). In this Handbook, only static O-ring seal designs are considered. Face seals (sometimes called flange seals) squeeze the O-ring into a groove with a flange or face plate as shown in Figure 5.7. Cap and plug seals are alike except for the gender of the glands as shown in Figure 5.8. The cap seal has the groove in the female part whereas the plug seal has the groove in the male part. The cap and plug are really forms of static piston seals because the plug is like a cylinder. The common static piston-type seals are shown in Figure 5.8. The dynamic piston-type (sometimes called rod-type) seals are shown in Figure 5.9. The crush-type seal is shown in Figure 5.10. Refer to MIL-G-5514F.

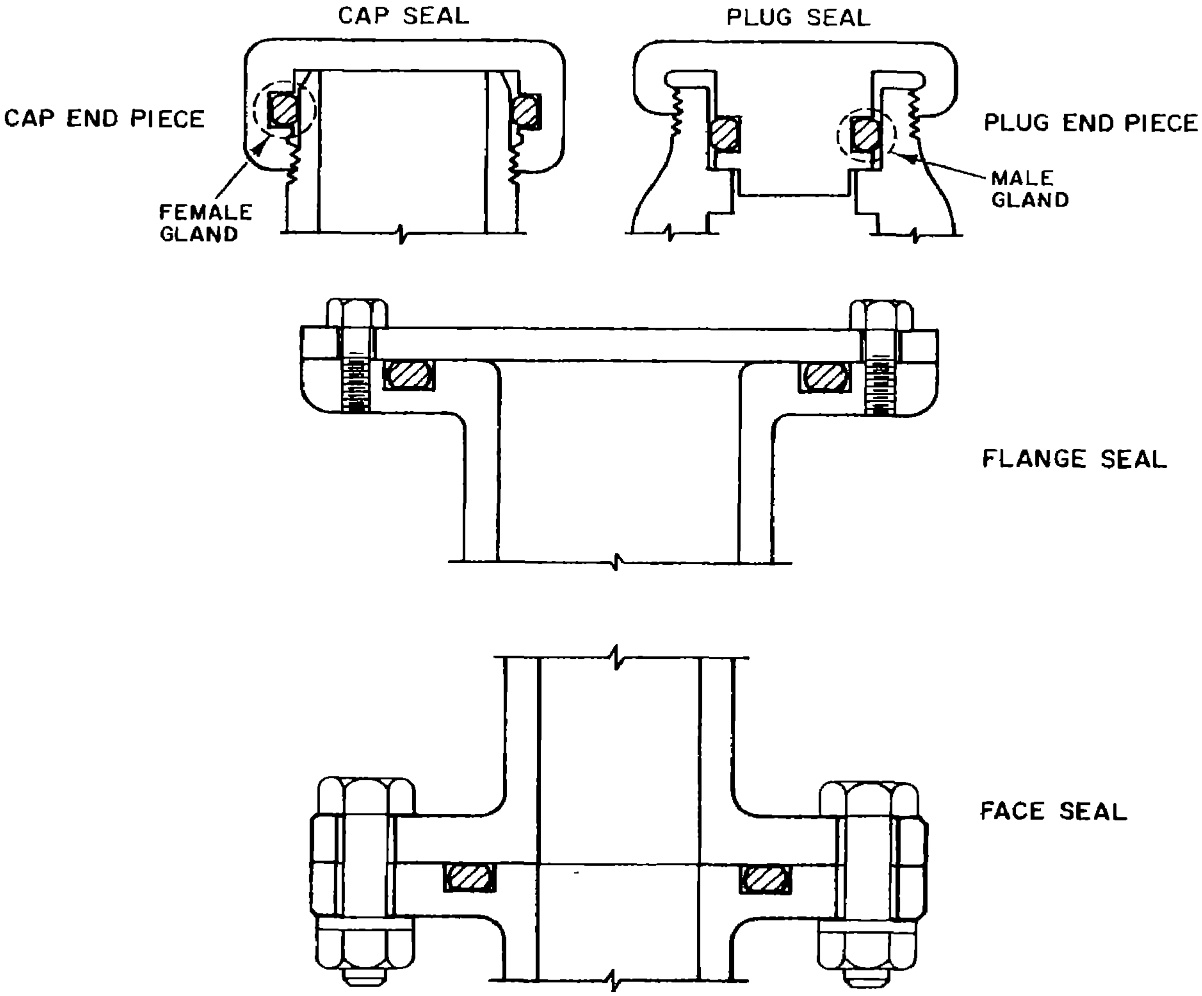


Figure 5.7. Static-type seals (cap, plug, flange, and face). Note that gap in flange and face seals can be essentially zero, permitting sealing of very high pressures.

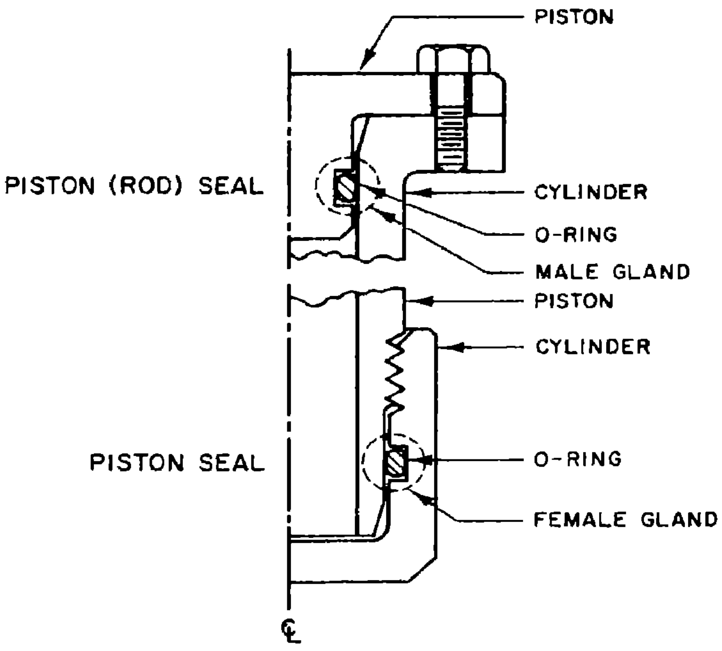


Figure 5.8
Common static piston-type seals.

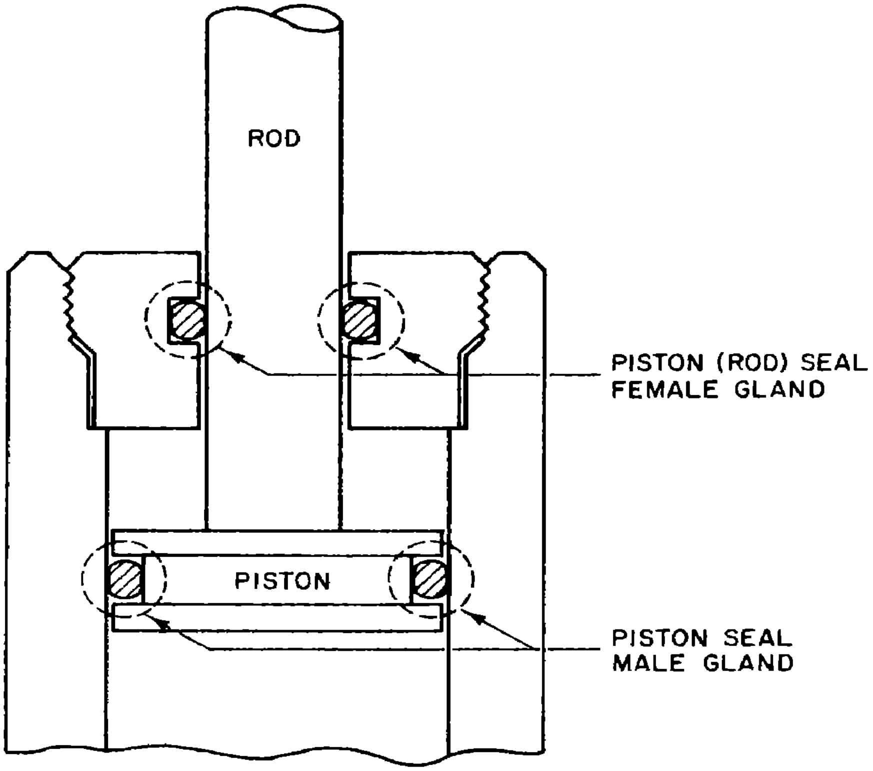


Figure 5.9
Dynamic piston-type (rod) seals (shown for comparison).

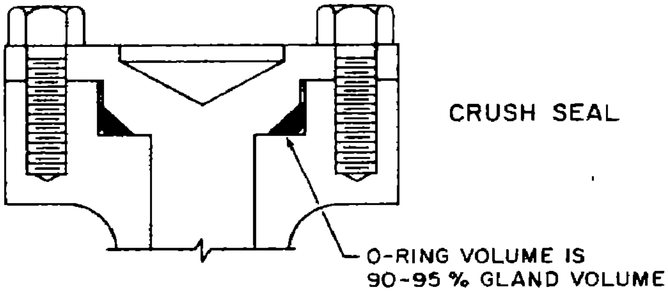


Figure 5.10
Crush-type seal.

5.5 Gland Definitions. The common parts of the static O-ring seal glands are identified in Figure 5.11.

5.6 Extrusion and Backup Rings. When the outside or inside pressure becomes very high or the clearance gap is necessarily large, the O-ring may be extruded (pushed too far into the gap). To prevent extrusion, a backup ring is installed between the low pressure side of the gland and the O-ring as shown in Figure 5.12. When high pressure may occur on either side of the O-ring, double backup rings are installed as shown in Figure 5.12. Backup rings are commonly made of hard rubber, plastic, or leather.

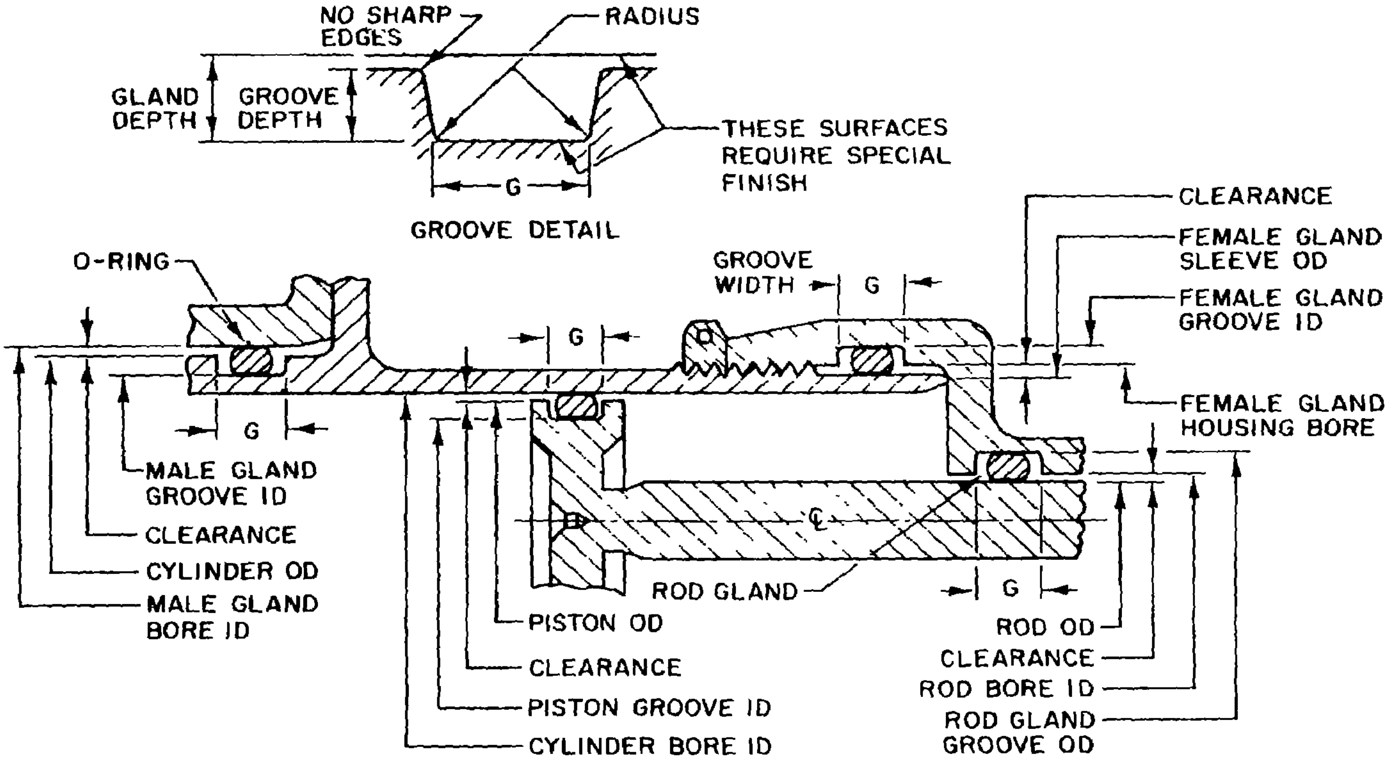


Figure 5.11. Gland definitions (common).

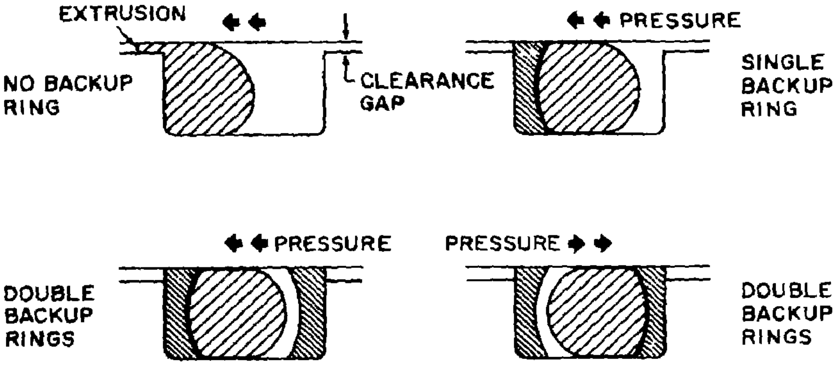


Figure 5.12 Typical backup rings.

6. O-RING SEAL PROBLEMS

6.1 General. O-ring seals leak or create other problems because at least one of the following has occurred before the end of expected service:

O-ring left out (see Figure 6.1)
Bad installation of good O-ring in good gland (see Figures 6.2-6.5)
Good installation, good O-ring, bad gland (see Figures 6.6-6.8 and 6.11)
Bad or wrong O-ring used in good gland (see Figures 6.9 and 6.10)
Good installation, good O-ring, good gland, wrong environment (too corrosive) or wrong gland material (see Figure 6.11)

6.2 O-ring Problems. O-ring problems and the responsible person or cause are as follows:

O-ring left out (see Figure 6.1) -- installer
O-ring cut or cracked (see Figures 6.4, 6.5, and 6.10) -- storage, installer, exposure
Dirty O-ring or gland (see Figures 6.2 and 6.3) -- installer, storage
Wrong O-ring (see Figure 6.9) -- installer, designer, or supplier.

The installer should not install an O-ring with any of the problems listed above. Even though the installer may not have caused the problem, he is responsible for seeing that damaged O-rings do not get installed.

6.3 Gland Problems. Gland problems and the responsible person or causes are as follows:

O-ring extrusion -- excessive clearance; designer or machinist (see Figure 6.8)
-- shallow groove; designer or machinist (see Figure 6.8)

O-ring leak -- insufficient squeeze; designer, machinist, or installer (see Figures 6.7 and 6.9)
-- cut O-ring; designer (chamfer, alignment) or installer (see Figures 6.4 and 6.5)
-- scratch in gland; machinist or installer (see Figure 6.6)
-- improper lubricant distribution*; installer (see Figures 6.4 and 6.11)
-- corrosion path; installer, designer, machinist, or heat treater (see Figure 6.11)
-- dirty or contaminated; installer (see Figures 6.2 and 6.3)

Gland interference -- machinist, designer

Gland burrs -- machinist

---

*Refer to Section 8.2.20 for description of proper lubrication.

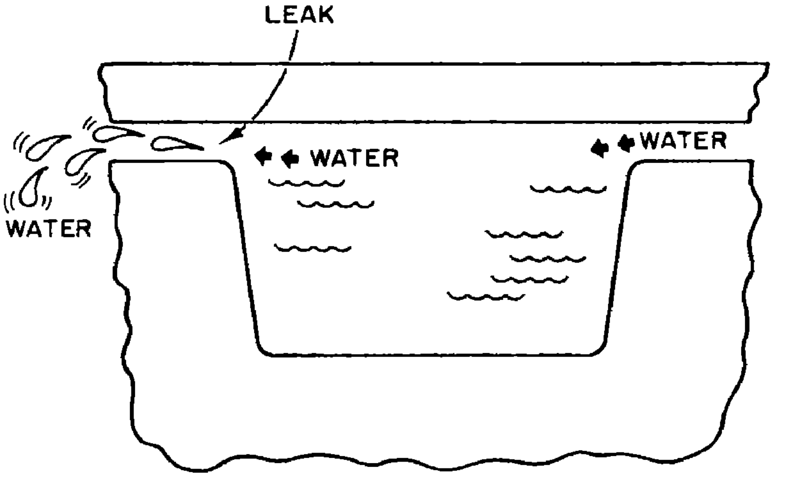


Figure 6.1
Leak path from O-ring omission.

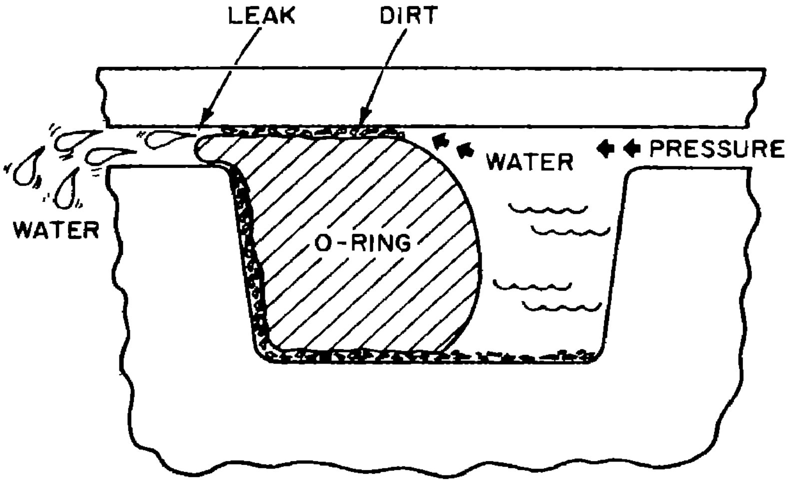


Figure 6.2
Leak path from dirt.

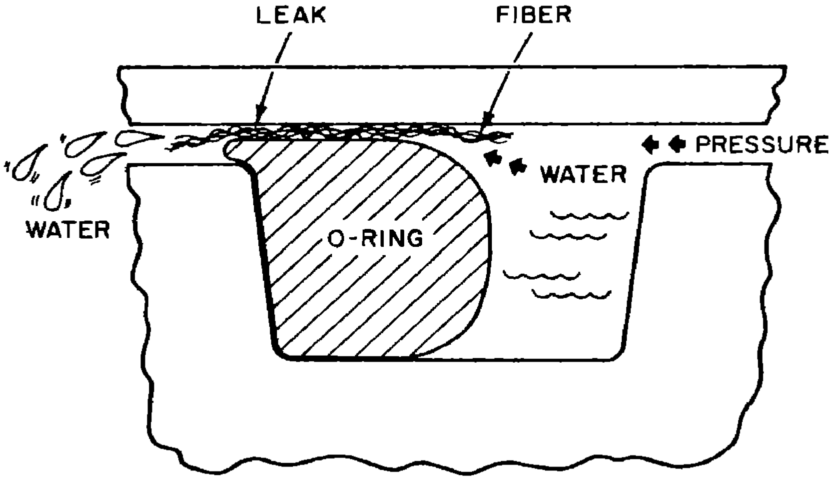


Figure 6.3
Leak path from fiber.

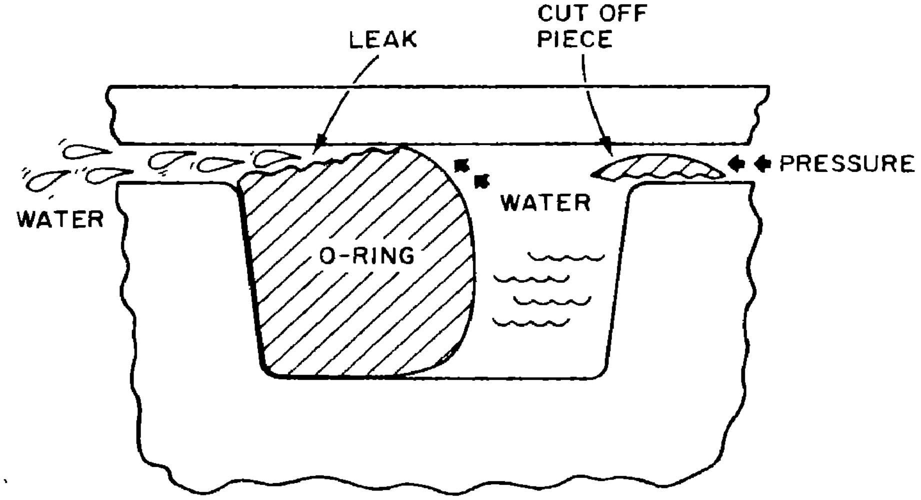


Figure 6.4

Leak path from cutting on installation (due to lack of lubricant or improper chamfer).

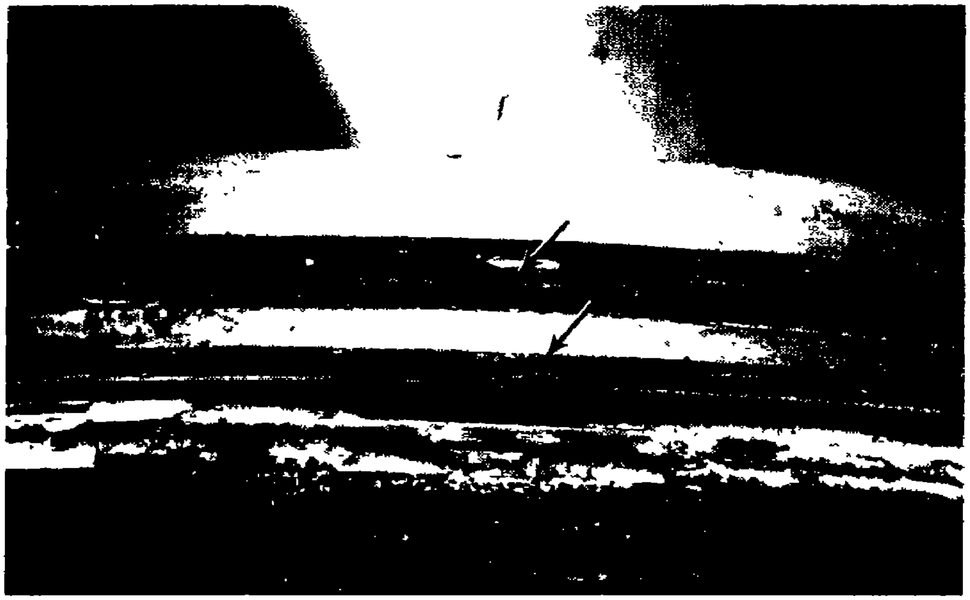


Figure 6.5

Double O-ring seal of main signal cable end of junction chamber, showing cut piece of O-ring backup gland deposited in the first O-ring groove. (Plug-type seal, male gland.) Cause: misalignment during installation.

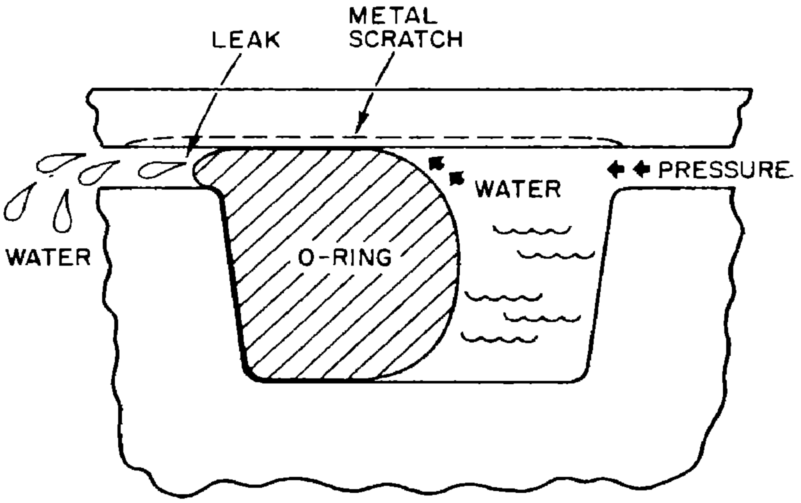


Figure 6.6

Leak path from metal scratch.

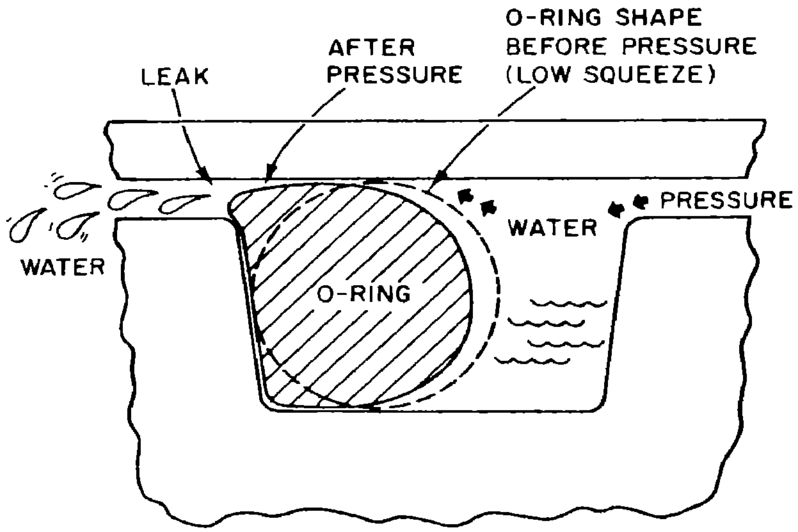


Figure 6.7

Leak path from low squeeze.

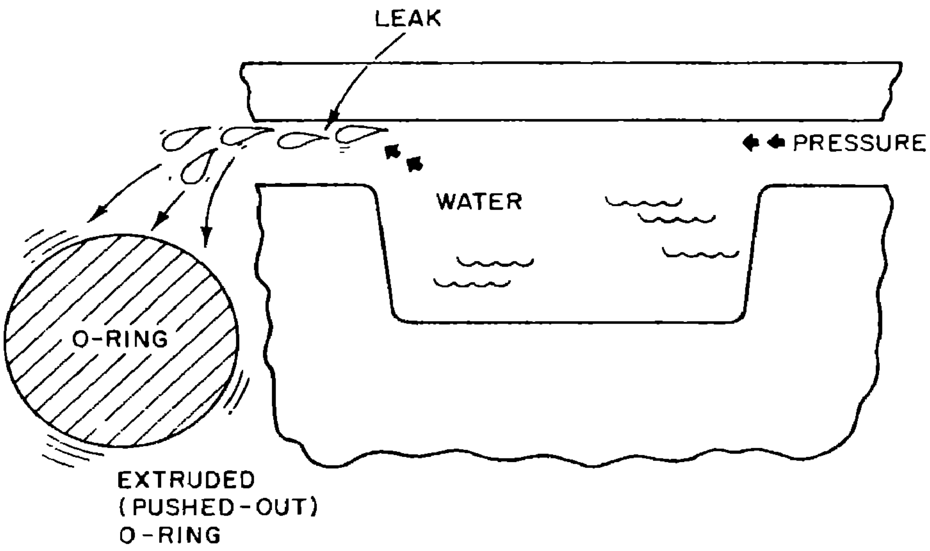


Figure 6.8

Leak path from extrusion (gap tolerance too high or groove too shallow).

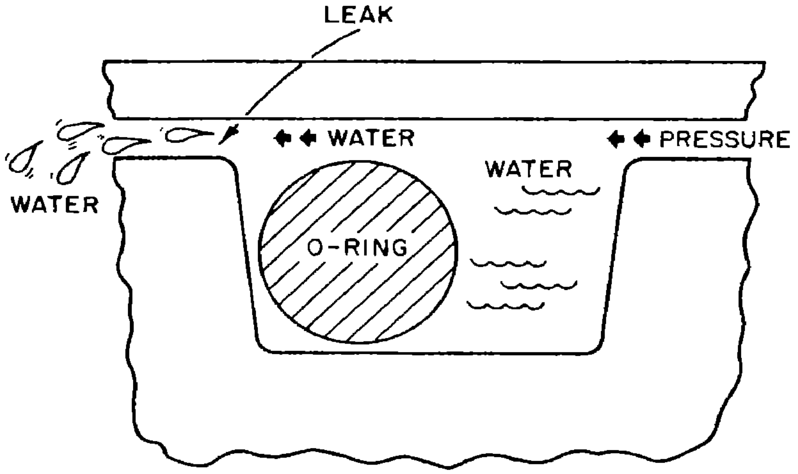


Figure 6.9

Leak path from wrong size O-ring.

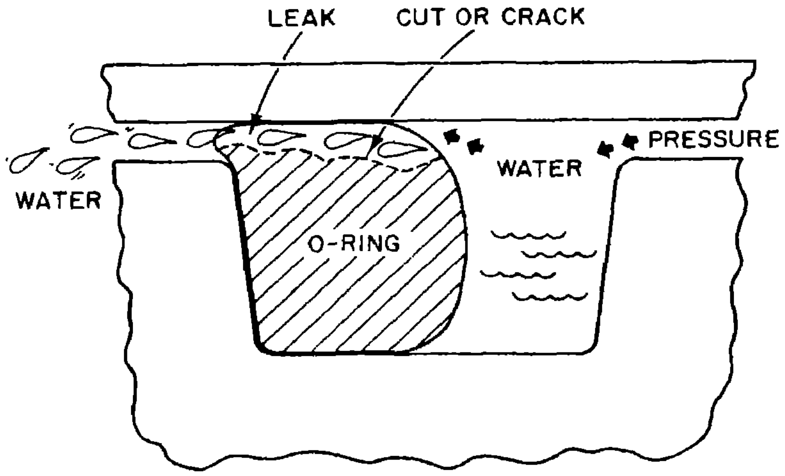


Figure 6.10

Leak path from cut (or cracked) O-ring.

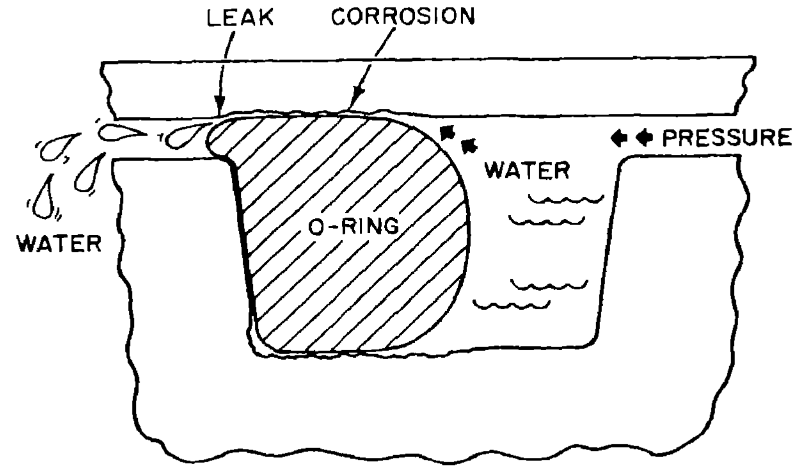


Figure 6.11

Leak path from corrosion (due to lack of lubricant and corrosive environment).

7. O-RING SEAL DESIGN AND MATERIAL, GENERAL

7.1 Design Steps. In general, the most reliable design uses the type of gland that best fits space requirements, ease of machining, ease of installation, and pressure requirements. The choice of gland material is often fixed by the material selected for the component and is usually a tradeoff between corrosion resistance, cost, and machinability. Although many connectors are machined from stainless steel alloys, stainless steels do stain and corrode in seawater. Of all the materials--copper-nickel (Monel), low-carbon steel, low-alloy steel, bronze, nonmetallics, and stainless steel alloys--that are used for components and glands, stainless steels exhibit the lowest resistance to pitting and crevice corrosion when in contact with O-rings. Careful design, fabrication, installation, and operation are required to reduce corrosion when stainless steel is used in O-ring seals. The choice of O-ring material and hardness depends on the capability of the rubber to resist the environment (seawater, metal, and lubricant) for the desired lifetime. Nitrile, butyl, and neoprene rubbers are compatible with seawater. Seven "simple" steps to O-ring seal design are as follows: (1) select O-ring cross section (thickness) to fit application; (2) select seal type and gland size to match O-ring and component to be sealed; (3) specify standard O-ring size and gland dimensions; (4) check for ease of machining and installation; (5) select specific compound and hardness; (6) specify O-ring part number; and (7) specify the lubricant. To complete these steps, the designer should make use of the following standards: (a) MIL-G-5514F, "Gland Design; Packings, Hydraulic, General Requirements For"; (b) MIL-HDBK-692(MR), "A Guide to the Selection of Rubber O-Rings"; (c) AN6227 and AN6230, "Air Force-Navy Aeronautical Standards"; (d) MS28775, "Military Standard"; (e) MIL-P-5516, "Packing, Preformed, Petroleum Hydraulic Fluid Resistant." In general, these standards can be used as follows:

MIL-G-5514F	To provide gland geometries (exact dimensions) and seal types that are suitable for the various O-ring cross sections.
AN6627, AN6230 and MS28775	To provide exact geometry and dimensions of O-rings and procurement specifications.
MIL-P-5516	To provide test specifications, performance requirements, and qualified suppliers and products (compounds) for the procurement of AN6227, AN6230, AN6238, and AN6225 O-rings.
MIL-HDBK-692(MR)	To provide information for selecting O-ring materials based on the environments in which the O-rings will be used. This Handbook contains a valuable table, "O-Ring Selection Table," which relates other O-ring specification requirements--such as Shore A hardness, tensile strength, age control,

packaging, and marking--with dimension specifications, material specifications, and elastomers commonly used in various environments.

Similar information is available in commercial O-ring handbooks such as Parker Handbook ORD-5700 and National O-Ring Design Guide OR-15R. The dimensions used in commercial gland designs can differ slightly from the gland dimensions specified in Military Standards.

7.1.1 Select the O-ring Cross Section. O-ring cross sections come in several standard sizes: 0.040 in. (1.02 mm), 0.050 in. (1.27 mm), 0.060 in. (1.52 mm), 0.070≈1/14 in. (1.78 mm); 0.103≈1/10 in. (2.62 mm); 0.139≈1/8 in. (3.53 mm); 0.210≈7/32 in. (5.33 mm); 0.275≈9/32 in. (6.99 mm). Metric O-rings in even millimeter widths are also available from manufacturers in the United States. The O-ring cross section (W) and inside diameter (ID) that fit the component will guide the selection.* The range of ID's is fixed by the component's diameter. Select the largest cross section (thickest or fattest) that will fit in the available space. Large (fat) O-rings are more resistant to damage by abrasion, rolling, or twisting during installation. They are also more resistant to damage due to stretch and squeeze. It is especially noted that fat O-rings produce a larger critical sealing surface and therefore are more resistant to leaks due to corrosion, dirt, scratches, etc. Refer to MIL-G-5514F, AN6227, AN6230, and MS28775.

7.1.2 Select the Seal Type and Gland Size. Select the seal type that makes the component easiest to use, machine, and assemble. Select the gland size that matches the seal type and the O-ring cross section.

7.1.3 Specify the Standard O-ring Size and the Gland Dimensions. Example: AN6227-32 = an O-ring with a width of 0.210 in. (5.33 mm) and and ID of 1.975 in. (50.17 mm).

7.1.4 Select the Elastomer and Specify the Compound. The common elastomers (about 15 total) include nitrile, ethylene-propylene, neoprene, fluorocarbon, and silicone. If an AN or MS O-ring is selected, the material and hardness as well as the dimensions are fixed because AN and MS drawings state that the O-ring must meet certain material specifications. AN6227, for example, requires that the material meet MIL-P-5516 Class B specifications. Although MIL-P-5516 does not require nitrile, it will probably be the material supplied because, at this time, it is the only compound that has been qualified by the manufacturers and approved by the military as meeting the tests specified in MIL-P-5516. How, then, can an engineer specify an O-ring with AN or MS dimensions but made out of some other material such as a silicone compound? One nonstandard but successful method is to contact the supplier (or use his catalogs) and specify the supplier's compound number for the desired material on the drawing and on the purchase order next to the O-ring AN number. The second, and more desirable, method is to translate the AN O-ring number into its corresponding AS O-ring size number. For example,

---

*OD = 2W + ID may also guide the selection.

AN6227B-25 dimensions correspond exactly to AS568-220 dimensions (refer to Section 15.1, AN6227), but whereas the AN drawing specifies a material, the AS drawing does not. The O-ring material must be specified by the engineer as meeting some material specification such as MIL-G-21569 Class II, which is met by certain silicone durometer 70 compounds [refer to MIL-HDBK-692(MR)]. If nonmilitary specifications are acceptable (for special cases only), suppliers' catalogs can be used to call out on the drawing and purchase order an O-ring made of a supplier's specific polymer, and even with a supplier's O-ring dimensions. The supplier's O-ring dimensions must be checked to be sure they match the desired dimensions.

7.1.5 Recommended Component and Seal Design Specifications. The following recommendations for component and seal design were developed from experience and were composed by members of the Undersea Cable and Connector Committee of the Marine Technology Society. (See Reference 21 in Section 15.2). The recommendations have been modified slightly for this Handbook.

1. The physical properties of the O-ring material should be such as to maintain pressure proof integrity in seawater and freshwater environments for a period of at least five years.

2. The O-ring should be capable of withstanding service temperatures from -65°F to +165°F (-54°C to +74°C).

3. The O-ring should be capable of passing thermal shock tests of -65°F to +28°F (-54°C to -2°C) and +165°F to +28°F (+74°C to -2°C). These are the conditions that are encountered in arctic and tropical climates.

4. The seal design must be such that the plug and receptacle can be mated and unmated many times without damaging or otherwise affecting the O-ring or seal surfaces. A recommended durability test is 100 cycles (one cycle is a mating and unmating).

5. The design of the plug and receptacle should be such that it does not require an O-ring that is not readily available. Standard O-ring shapes, sizes, and materials are preferable.

6. The O-rings chosen for the application should be inexpensive.

7. The seal design must be capable of withstanding at least 2000 hydrostatic pressure cycles to a pressure equivalent to the depth for which the seal is designed. If the characteristics of the O-ring material are not fully known, it may be desirable to superimpose a temperature cycle during the hydrostatic pressure tests.

8. The O-ring design should be capable of withstanding a static hydrostatic pressure test to 1.5 times the operating design depth for a period of 16 hours minimum.

9. The seal design should be such that the gasket is not dislodged during the mating and unmating cycles, as this could result in O-ring damage or loss.

10. Each O-ring should be individually packaged and properly identified as to material, size, shape, and shelf life.

11. The connector seal should be designed so that the O-ring is readily accessible for installation or removal. O-ring installation and removal tools should be designed to preclude damage to the O-ring or the O-ring seal surfaces.

12. The connector seal design should afford the maximum possible damage protection to the surfaces being sealed.

13. If the effectiveness of the seal design selected depends on the application of minimum torque values, the minimum and maximum allowable torque values should be specified.

14. The seal design and the O-ring should be such as to require a minimum of installation and removal instruction.

15. Where practical in the connector design, the use of double O-rings in separate glands (primary and secondary) is recommended. Each O-ring should be capable of maintaining a fully effective seal independently in the event of inadvertent omission of, or damage to, one of the O-rings.

16. The O-ring material should not deteriorate in the presence of hydraulic lubricating or compensating oils.

17. The connector seal design should be capable of withstanding the same shock and vibration as the unit to which it is attached.

18. The connector seal design should provide corrosion resistance in seawater and freshwater environments and should not promote corrosion in the adjacent seal areas.

19. The O-ring material should be fungus resistant.

7.1.6 Select and Specify Lubricant. Refer to Section 13 of this Handbook for specific data on, and descriptions of, the various O-ring lubricants. Petrolatum (petroleum base grease), MIL-G-4343 or DC 55 (silicone base grease), and Parker O-Lube (barium base grease) are among the 12 lubricants that are commonly used on O-rings. The deterioration of the lubricant with time in the seawater/gland environment and the lubricant's compatibility with the environment (i.e., whether it will produce undesirable swelling or shrinking of the O-ring) must be considered.

8. INSTALLATION

8.1 Arrangement. This section describes a step method of installing O-rings in new or used components for marine and other static pressure applications. First, an abbrevition of the step method is given, and then detailed descriptions and explanations.

8.2 Scope. Installation as used in this Handbook encompasses the steps or processes involved from obtaining the O-rings and component parts from stores or the shop to releasing the assembled component for service. Installation includes withdrawing, accounting for, inspecting, checking, testing, lubricating, grooving (putting the O-ring in the groove), seating, and testing. Installation is complete when tests of O-ring seating give no evidence of improper seating, and threaded or locking parts are secure but not necessarily tightened. The following steps for the installation should be followed unless other requirements are given in the engineering drawings.

8.2.1 Abbreviated Step Method of O-ring Installation

(a) Prepare for the installation by laying out the component parts on a clean, lint free surface.

(b) From the configuration and position of each part, determine the sequence of assembly to prevent damage to the O-ring or gland.

(c) Compare the part numbers with the drawings to ensure that the proper parts are being assembled.

(d) Check gland dimensions that set the squeeze and clearance gap against engineering drawings. (Tools: inside and outside calipers and a dial-indicating vernier caliper with 0.001 in. (0.025 mm) divisions.)

(e) Inspect gland sealing surfaces for cleanliness, proper finish, and absence of defects. Surfaces and edges must be free of all contaminants, dirt, nicks, scratches, gouges, marks, and burrs. Some minor burrs can be removed by "touching" them with 400 grit emery paper. Do not install O-rings on components that are not free of burrs or other imperfections.

(f) Clean sealing surfaces and all surfaces that the O-ring may contact. (Only proper solvents can be used; the proper solvent depends on the base polymer. Refer to 8.2.12.)

(g) Protect all sealing surfaces from contamination and damage.

(h) Determine which O-ring to install from the engineering drawings.

Example: AN6227B-25

(i) Withdraw the O-rings from stock just before (a few hours or days) assembly.

(j) Cross check the O-ring identification on the package with the drawings or specifications.

(k) Do not withdraw O-rings in damaged packages or with a cure date older than 20 calendar quarters (5 years). Refer to Section 12.3.

(l) Maintain accountability for each O-ring. Each installer should keep a record of the O-rings in his possession and record any change in disposition (withdrawn, rejected, lost, discarded, or installed) and the date.

(m) Do not remove the O-ring from the package until ready to lubricate it for installation.

(n) Handle carefully to protect the O-rings from damage by fingernails and tools, and from contamination by chemicals, dirt, and chips.

(o) Check the O-ring dimensions (W and OD) if on visual inspection or during installation the O-ring size appears to be improper.

(p) Carefully inspect the O-ring visually for cracks, nicks, dents, or flat spots. Refer to Section 8.2.14, MIL-STD-177, and MIL-STD-413. No defects are allowable.

(q) Prepare for grooving by masking sharp edges (not groove edges) such as threads and holes on the component. Ensure that chamfers are 10° to 20°.

(r) Determine the proper O-ring lubricant. If not specified on the engineering drawing, consult with the engineering department, which should select the lubricant from those listed in this Handbook or from manufacturer's information. See Section 13, Lubricants.

(s) Lubricate with a thin, continuous film the O-ring and all part surfaces and tools that will contact the O-ring during grooving. If service conditions are corrosive to sealing surfaces and assembly conditions permit, put sufficient lubrication in the O-ring groove that the groove will be full after the O-ring is in the groove. Refer to Section 8.2.20.

(t) Where possible, don't stretch or twist an O-ring. Preferably O-rings will not be stretched at any time more than 50% of the initial ID. For example, an O-ring with an ID of 1.00 in. (25.4 mm) should not be stretched over a cylinder greater than 1.50 in. (38.1 mm) in diameter.

(u) Groove the O-ring with the least amount of twisting, stretching, and rotation. Push the O-ring down to the bottom of the groove and toward the back of the groove all around its entire circumference. The back of the groove is the side that the O-ring will be pushed against during assembly of the gland. The back is not necessarily the side that the O-ring will push against during service. The O-ring may fill the groove in some designs. (See Figure 8.1.)

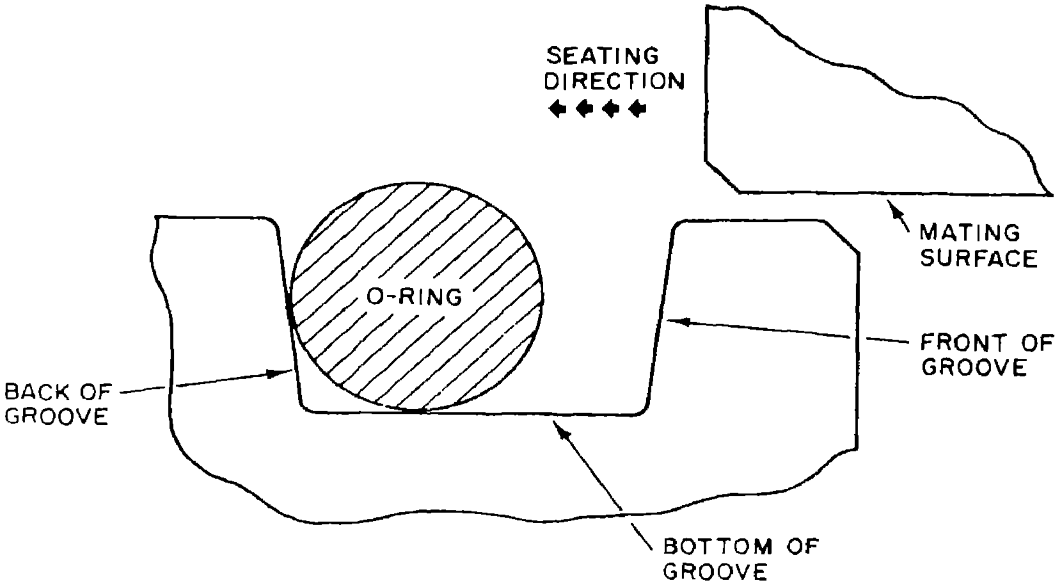


Figure 8.1. O-ring against back and bottom of groove.

(v) Remove all twists. The parting line, if visible, on the O-ring can be used to straighten the O-ring. (See Figure 8.2.)

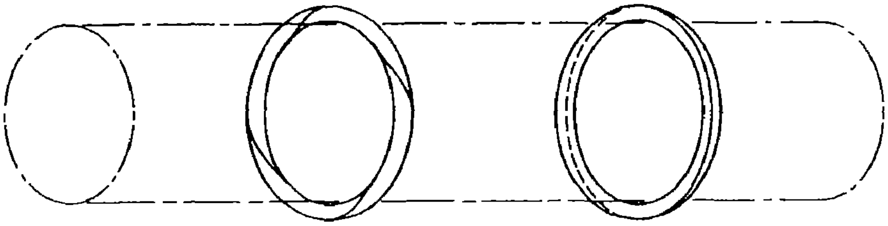


Figure 8.2. Twisted and untwisted O-rings, as shown by molding die marks (parting lines) on O-ring surface.

(w) Ensure that the O-ring is evenly distributed and the same height around the groove.

(x) Remove excess lubricant or add lubricant to produce a thick coating for corrosive service if assembly conditions permit, or a thin coat if assembly conditions do not permit a thick coat.

(y) For all installations that are deemed critical by design engineering, obtain assurance from quality control, and signature of approval on the O-ring accountability record, that the O-ring is properly grooved. This step may be required by quality control groups, quality assurance groups, or engineering groups to ensure that no O-ring is inadvertently omitted. This step increases reliability because it adds redundancy and fixes responsibility. However, it also increases manpower and procedural requirements. The tradeoff between increased reliability and increased cost must be considered in determining whether to include the step or not. Economic considerations may limit the use of this step to critical installations.

(z) Seat the O-ring by pushing or sliding the mating gland surfaces over or against the grooved O-ring. Seating shall be accomplished by a steady or a steadily increasing force. See Figure 8.3. CAUTION: impacts or hammering are not permitted. Do not rotate parts more than a few degrees during seating unless coupling or fastening methods require such rotation. Refer to Section 8.2.25(c).

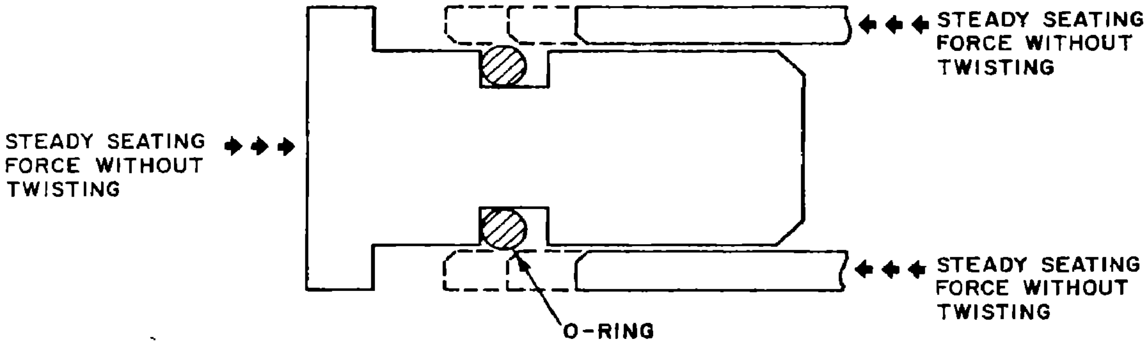


Figure 8.3. Seat O-ring with a steady or steadily increasing force --no twisting.

(aa) Test for proper seating by inspecting diametral clearance volumes, snugness, and torque resistance. CAUTION: DO NOT USE TORQUE RESISTANCE UNLESS REQUESTED BY ENGINEERING. Refer to 8.2.25(c).

(bb) If no evidence of improper seating or installation is present, fasteners can be tightened.

8.2.2 Which O-ring? Determine which O-ring and associated parts to install. Engineering assembly drawings and parts lists should identify the proper O-ring and associated parts for each assembly. The information in the current engineering assembly drawings, including notices of revision (NOR's) when available, shall supersede all other part information. What sort of information is used on engineering drawings and parts lists to identify a specific O-ring? Proper specifications include the military (or in some cases commercial) O-ring part number (which usually specifies the size, but sometimes also fixes the O-ring material), compound, hardness, manufacturer, batch, and cure date. Refer to Section 7.1. The dimensions of each O-ring are given by Army-Navy (AN) or Military Standard (MS) drawings and tables, or by manufacturers' catalogs or handbooks in the case of commercial size specifications. The basic document establishing these standard dimensions is Aerospace Standard (AS) 568A, published by the Society of Automotive Engineers (SAE). The Military Standard detailing the performance specifications for the O-ring compound is given on the AN, MS, or other military drawings. The compound number listed on the O-ring package is the supplier's number for a compound that meets the specification requirements. The supplier's number can be used with the supplier's catalog to determine the elastomer of the supplied O-ring (see Section 11.4). The following list summarizes the information found in some common O-ring part numbers.

AN6227B and AN6230B	Called series because each of these part numbers refers to many O-rings with similar uses. AN6227B O-rings differ from AN6230B O-rings only in that the AN6227B series are smaller than the AN6230B series for the same dash numbers.
AN6227B	Designates compound specification MIL-P-5516 which commonly means a nitrile (Buna N) elastomer similar to N304-75, a Parker compound.
AN6227B-25	The dash number (-25) designates the exact dimensions of the O-ring; ID = 1.359 ± 0.012 in.; W = 0.139 ± 0.004 in. (ID = 34.52 ± 0.30 mm; W = 3.53 ± 0.10 mm).
Parker P/N 2-220	Designates a Parker O-ring part number that has the same dimensions as AN6227B.
N304-75	Designates a Parker compound specification that meets the MIL-P-5516 requirements. The -75 specifies a Shore A-75 durometer hardness of the rubber.

8.2.3 Don't Hoard. Withdraw the O-rings from stock just before (i.e., a few hours or days) assembling the component.

8.2.4 O-Ring Package Identification. Each O-ring or O-ring seal assembly obtained from stores should be separately sealed in a package. Compare the O-ring size and compound markings on each package with the O-ring specifications on the engineering drawing to be sure that only correct O-rings are withdrawn. Refer to Section 11.4. The package should show the date of manufacture (cure date). Reject any O-ring that is more than 20 calendar quarters (5 years) old.

8.2.5 Package Inspection. Check each package to be sure that the package has not been opened or altered in such a way that the O-ring might be damaged by cuts, tears, pinches, or heating. Do not use O-rings in damaged packages. Do not open the packages until the O-ring can be installed.

8.2.6 Accountability. Each installer should maintain accountability on each O-ring withdrawn from stores. The quantity of each O-ring (identify by size, MFR/PN, batch number, and cure date) withdrawn should be recorded by the installer. The disposition of each O-ring should be recorded as the disposition changes: i.e., when it is withdrawn, installed, discarded, damaged, or lost. O-ring accountability records are intended to increase the reliability of O-ring seals. When installed, the O-ring's identity and the time, date, and name of installer should be recorded on the accountability record and other production records for each connector assembly.

8.2.7 Preparation. Prepare for installation by determining the sequence of assembly. To prevent contamination, rubbing, wear, cutting, disassembly, and scratches, where possible lay out all parts to be assembled on a clean, nonabrasive, lint-free surface (rubber, metal, plastic, or wood). Lay out all inspection and assembly tools and materials, including lubricants, tape, and wiping cloths.

8.2.8 Configuration. Determine the relative position and location of each seal component from the appropriate engineering drawing. If double backup rings are called for, the O-ring is normally positioned between the rings, with the flat side of the backup rings against the grove wall and the curved sides against the O-ring. If a single backup ring is called for, the ring usually is positioned on the low-pressure side of the O-ring and, if curved, the curved side of the backup ring is against the O-ring.

8.2.9 Inspect Component Gland Surfaces. Inspect all gland sealing surfaces on the component. Sealing surfaces must be free of nicks, scratches, gouges, burrs, abnormal tool marks, and contaminants such as chips, dust, and dirt. All surfaces must meet or exceed the requirements set forth in MIL-P-5514F, Sections 3.2.5 and 3.2.6.

8.2.10 Check Component Gland Dimensions. On each unfamiliar component or "first of a kind" component, check the size and shape of each gland against the dimensions given on the engineering drawing, and periodically measure the dimensions on routine components. Gauges with 0.001 in. (0.025 mm) divisions such as micrometers or calipers can be used, but go-no-go gauges are preferable for high production items. CAUTION: Care must be used to prevent scarring or roughening of sealed surfaces. Teflon-coated gauges should be used if necessary to prevent damage. Piston seal glands have four important dimensions (see Figure 8.4):

Female Gland	Male Gland
(a) rod diameter	(a) bore diameter
(b) throat diameter	(b) piston diameter
(c) groove diameter	(c) groove diameter
(d) groove width	(d) groove width.

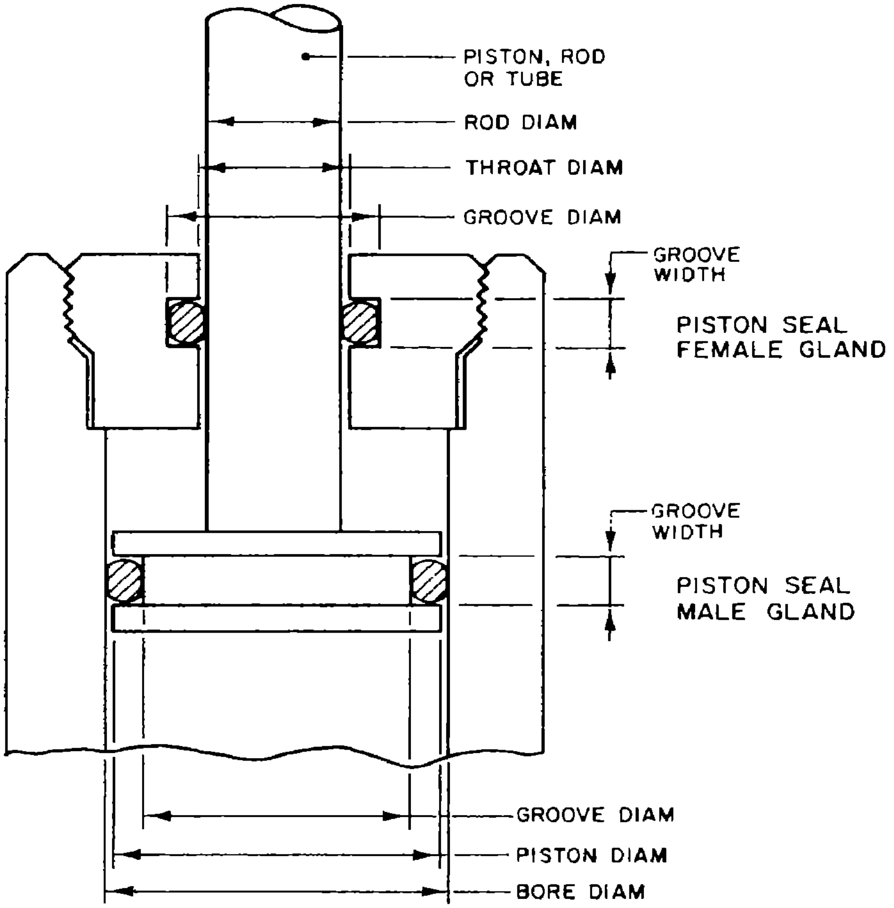


Figure 8.4. Piston seal dimensions.

Face seal glands have three important dimensions (see Figure 8.5):

(a) inside diameter of groove (external pressure) or outside diameter of groove (internal pressure)

(b) groove depth

(c) groove width.

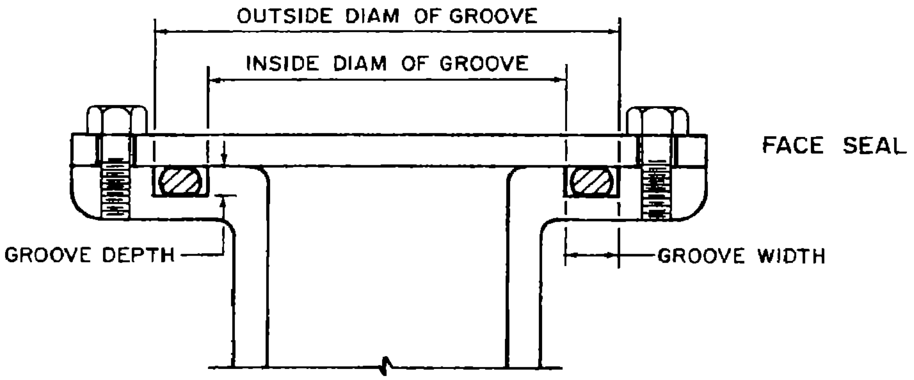


Figure 8.5
Face seal dimensions.

The allowable dimensions are given on the engineering drawings and can be checked with tables of gland dimensions for O-ring static seals for a given pressure range, seal type, and seal size. Refer to MIL-G-5514F or vendor handbooks for gland dimensions.

8.2.11 Check Gland Surface Texture. Check surface texture for required finish. The following average roughness or better will be required unless the engineering drawing, performance, or qualification tests indicate that other surface roughnesses are satisfactory. The finishes are indicated by surface roughness as defined in ANSI B46.1-1978.

Part of Component Static Pressure, Liquid Environment Only	Average Roughness, R_a (microinches)	(micrometers)
Cylinder bore or piston rod (diameter over which O-ring must slide or act)	32	0.80
O-ring groove diameter; all sides of crush-type seals and all other sealing surfaces	32	0.80
O-ring groove sidewall (sidewalls are not assumed to be sealing surfaces although in practice they may seal).	63	1.60

There is some dispute among authorities about the maximum roughness that is allowable. Research is needed to quantify the tradeoffs among squeeze, sealability, seal reliability, economic factors, and surface texture. Although O-rings are not designed to do so, they can produce a seal over very rough and gouged surfaces if the seal can be made to function exclusively as packing in a stuffing box (i.e., if they can be highly and uniformly squeezed and held fixed in a small volume as in a common water faucet or a crush-type O-ring seal). However, rough or gouged surfaces can damage O-rings in time and, if the O-rings move during use as they often do, they can be progressively damaged. This threat to the seal is eliminated by using smooth surfaces, i.e., good finishes. Good finishes are hard to define and accurately measure because surface roughness features are very complex in shape and character and are too minute to measure directly. Present terms used to refer to surface finish include roughness, waviness (widely spaced surface patterns), lay (direction of tool marks or other predominant metal deformation patterns), and flaws (localized ridges, scratches, cracks, pits, and burrs). However, quantitative measurement of these features currently is so difficult that only visual, tactile, and low magnification (5 to 25X) techniques are practical during installation. The lay (tool marks) on any part of the gland must not point from the high pressure to the low pressure side of the O-ring. Preferably the tool marks should be perpendicular to the cross section W of the part of the O-ring they contact. Do not install O-rings on sealing surfaces with waviness (especially ridges) that is visible to the naked eye or can be felt with finger tips. Do not install O-rings on sealing surfaces that have flaws that can be detected by careful inspection with the naked eye. Surface roughness is measured by the roughness average in units of microinches (10^{-6} in.) and symbolized by R_a. Descriptively speaking, R_a is the arithmetic average of heights of peaks and depths of valleys when the heights and depths are measured from the exact midpoint between the tops and bottoms of sampled peaks and valleys. Roughness average can be measured, for our purposes here, by visual and tactile comparison with standard samples or by stylus-type profilometers. Other terms sometimes used to refer to roughness average are arithmetic average roughness (AA) and surface roughness height. Refer to ANSI B46.1-1978, "Surface Texture," for a more complete coverage.

8.2.12 Clean Metal Surfaces with Solvents. Clean all metal sealing surfaces. Solvents such as Stoddard solvent (kerosene base with a rust-inhibiting film) can be used sparingly if they do not come in contact with or will not harm the O-ring material. Refer to fluid compatibility tables such as Table B-5 in Parker ORD-5700, or equivalent, for fluid compatibility ratings. Only solvents with a satisfactory or fair rating may be used. No other solvents should come in contact with the sealing surfaces after cleaning for O-ring installation. After cleaning and before applying lubricant, all traces of solvent must be removed by wiping and air drying. It is important to understand the difference between cleaning the metal sealing surfaces and cleaning the O-rings. Do not clean O-rings with chemical solvents. O-rings should be clean when taken from their package and remain clean, except for the film of lubricant which is added by the installer, until after they are installed. If minor cleaning is necessary to remove dust or dirt before the lubricant is added, a warm water and detergent solution can be used. Detergent-water solutions are not recommended for cleaning polyacrylate or polyurethane O-ring compounds. Wipe and air dry completely after cleaning any O-ring, especially before applying the lubricant. If an O-ring gets dirty after the lubricant has been applied and the dirt or contaminant cannot be easily removed by wiping with a clean, lint-free cloth, do not use the O-ring. Discard it. So many lubricants (especially silicone) require special solvents which may harm the O-ring and special procedures for cleaning that it is less expensive to discard the dirty one and use a new one. If chemical solvents must come in contact with O-rings, refer to compatibility tables such as B-5 in Parker ORD 5700 to ensure that the O-ring will not be damaged. At least one of the following solvents is compatible with the basic O-ring compounds:

Solvent	Use Restrictions
Stoddard solvent	Use only on nitrile, fluorocarbon, polyacrylate, polyurethane, and fluorosilicone compounds.
Isopropanol	Do not use on polyacrylate and polyurethane compounds.
Methanol	Do not use on fluorocarbon, polyacrylate, or polyurethane compounds.

Note that Stoddard solvent can not be used on neoprene or ethylene propylene O-rings. Only clean, lint-free swabs and cloths may be used to clean sealing surfaces or O-rings.

8.2.13 Protect Sealing Surfaces. Protect all sealing surfaces, especially after cleaning, to prevent contamination and damage.

8.2.14 Visually Inspect the O-ring. Remove the O-ring to be installed from its package and visually inspect it for cracks, nicks, dents, or flat spots that would impair sealing. Minute cracks can sometimes be detected by carefully bending or slightly stretching the O-ring. The sealing areas of the O-ring, and thus the areas to inspect more carefully, depend on the type of seal. The top and bottom surfaces are the most effective sealing surfaces in a face-type seal (see Figure 8.6).

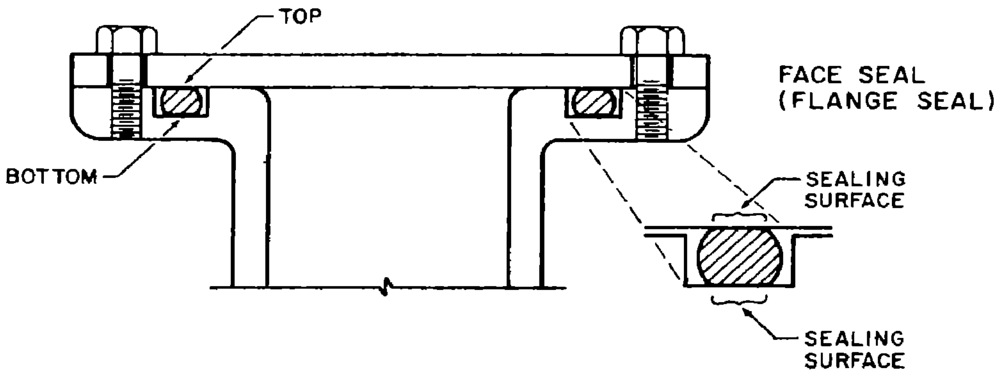


Figure 8.6. Sealing surfaces in face seal.

The inside and outside as well as the top or bottom are the sealing surfaces in a piston-type seal (see Figure 8.7). MIL-STD-413, "Visual Inspection Guide for Rubber O-rings," should be used to determine the adequacy of the O-ring. MIL-STD-177 defines the terms for visible defects of rubber products. No defects are allowed. Do not return defective O-rings to storage. Cut and discard them. Record in the accountability record the disposition and the reason for discarding. Because most O-rings are black, defects are difficult or impossible to see without proper lighting. Use a flashlight or lamp if the general lighting is not good enough for close inspection.

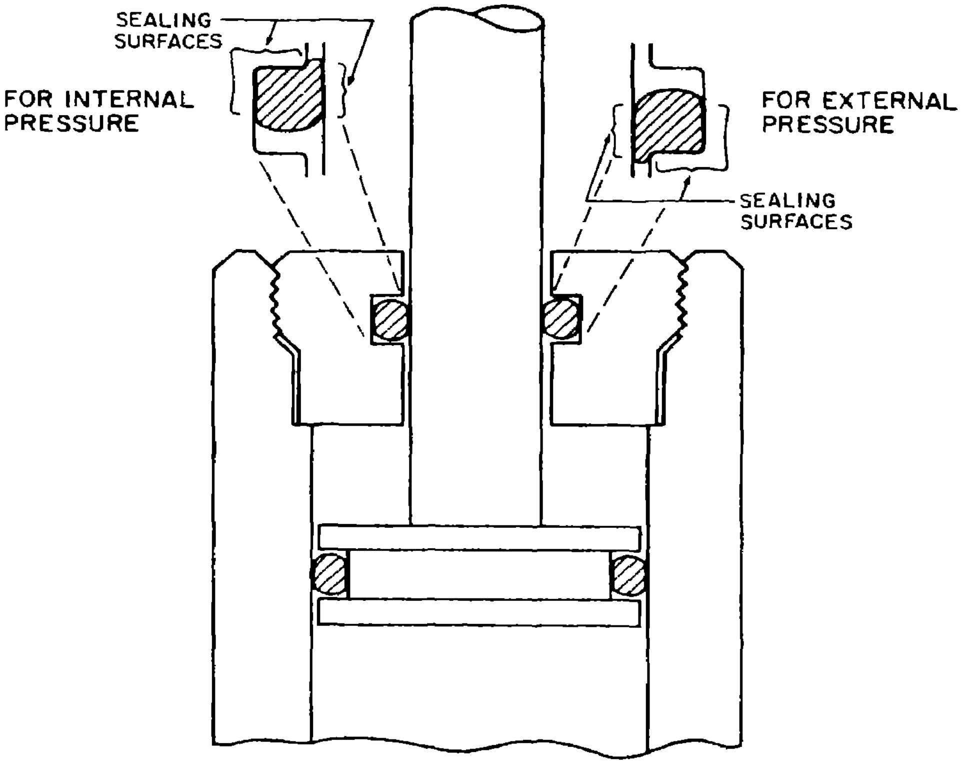


Figure 8.7. Sealing surfaces in piston seal.

8.2.15 Check O-ring Dimensions and Size. If on visual inspection the O-ring size appears to be incorrect for the housing or component, the O-ring's inside diameter (ID) and cross section width (W) should be measured with either a size gauge cone or a tape (Parker Seal Co. or equivalent). The width can also be measured with a micrometer or caliper. The measurements can be compared with the dimensions specified in the appropriate military or industrial standards to verify the size. O-rings that do not conform to engineering drawing dimensions or to the O-ring size specified in the engineering drawing shall not be installed.

8.2.16 Prevent Handling Damage. By careful handling, protect O-rings from damage by fingernails, tools, or sharp edges and contamination by threads, dirt, and chips. Clean, surgical-type gloves should be worn by installers with sharp fingernails or rings. Thread burrs can often be reduced by running a nut onto the thread. To prevent stretching, squeezing, and cutting, use only semi-rigid plastic tools or plastic-coated metal (see Section 9 for more details) to handle, install, or remove O-rings.

8.2.17 Mask Sharp Edges. If the O-ring must pass over sharp edges, corners, holes, or screw threads during installation, thin plastic tape or a sleeve of aluminum foil or equivalent should be used to protect the O-ring. Lubricant is applied to the mask or sleeve and the O-ring worked over the sleeve. Rolling the O-ring as opposed to sliding it is allowed but in most cases less desirable. For the special case where the O-ring rests on threads such as between a jam nut and the base of a tube or connector fitting, rolling may be used as a substitute for sleeves, which can only be used on initial installation. CAUTION: Remove all sleeves, shields, covers, and masks from the component after grooving and be careful that no part of the mask is left trapped under the O-ring. O-rings must not be left twisted after installation.

8.2.18 Lubricate Component Surfaces and Tools. Lubricate all sealing surfaces and all surfaces that the O-ring must contact during installation. For this purpose, apply a thin coating of the lubricant that will be used on the sealing surface. The installing lubricant helps protect the O-ring from damage and shall be wiped off after installation unless the installer is instructed otherwise. The lubricant can be applied with clean fingers or, preferably, when wearing clean surgical-type gloves. Care must be taken not to entrap any threads, lint, hair, or dirt in the lubricant. CAUTION: The installation lubricant (or any contaminant) shall not be removed with solvent when there is any probability that the solvent will contact the O-ring or the lubricant in the seal either during or after installation. Lubricated surfaces collect dirt and dust rapidly. Externally lubricated parts should not contact unclean surfaces and may need to be held in fixtures during installation. Surfaces should not be lubricated until just before installation and assembly. Lubricated parts must be covered if left out over night.

8.2.19 Lubricate the O-ring for Installation. Apply a thin, continuous film of approved lubricant to the entire area of each O-ring just prior to installation. The lubricant can be applied with clean fingers or, preferably, when wearing clean surgical-type gloves. Care shall be taken to prevent contamination of the lubricant by threads, lint, hair, or dirt. If possible, place the O-ring directly into the groove immediately after lubrication. Recognized lubricants are described in more detail in Section 13 of this Handbook. A brief listing of the lubricants is given here:

Petrolatum
Parker O-Lube
Parker Super-O-Lube
Dow Corning 55M, 111, 4, or 7
Celvacene
Versilube
Apiezon N
Fluorolube

Preferably, the O-ring lubricant will be specified on the engineering drawing. If not, the O-ring's intended service environment (temperature, chemicals, and pressure) and the O-ring material compatibility can be used with the lubricant tables in Section 13 of this Handbook, with MIL-L-4343, or with Parker Packing Engineering Handbook Table 6-1, "Compatibility of Typical Lubricants with Seal Compounds Used in Reciprocating Seals," p. 6-1, to select a lubricant. After placing the O-ring in the groove, excess lubricant may have to be removed or more lubricant may need to be added. The quantity of lubricant that should be left on the O-ring and in the groove is now discussed.

8.2.20 Quantity of Lubricant to Use in the O-Ring Seal. Experience shows that the particular environment and installation requirements must be considered in selecting the thickness, placement, distribution, and amount of lubricant to use in an O-ring seal. In general, there are two extremes in lubricant quantity: thick coats and thin coats.

(a) Thick coat: The O-ring is coated, and the groove and surrounding gaps within a few groove widths are filled with lubricant. The thick coat is used when service will be under corrosive conditions (seawater immersion), at stable low temperatures, and long term (several years).

(b) Thin coat: The O-ring and sealing surfaces are coated with a thin, continuous film of lubricant. The thin coat is used when corrosion is not an important problem, temperatures may fluctuate as much as a few hundred degrees, and when excess lubricant in the seal will probably cause the O-ring to be extruded.

One simple method that works well on most piston-type seals is to push the lubricated O-ring to the back of the groove where it will be after pressurization, fill the empty space in the groove with lubricant, and proceed with coupling. This method should not be applied indiscriminately since there are a few cases in which the coupling forces slide the O-ring to the opposite side of the groove from where the O-ring is pushed during pressurization. In general, once the O-ring is in the groove, lubricant shall be added or carefully removed with a clean and lint-free swab, soft plastic tool, or fingers to produce the selected thickness. Not all O-ring manufacturers or authorities agree on the need for, or manner of, lubricating an O-ring in a static seal application. However, the mechanics of O-ring function indicate that lubricant on the O-ring in a static seal helps the elastomer exude into the microscopic hills, valleys, and machined grooves of the seal faces and prevents sticking, especially during pressurization. Lubrication facilitates the installation and assembly of the components without undue forces and helps hold the O-ring in the groove during assembly. The basis for using lubricants may be stated as follows:

(a) It increases sealing capacity under low squeeze conditions.

(b) It lessens the risk of O-ring damage from rough, sharp, or defective glands during installation and during pressure cycles.

(c) It keeps corrosives away from the sealing surfaces and O-rings and thus reduces corrosion.

(d) It retards leaks and damage due to buildup of corrosion products around and under the O-ring.

(e) It reduces O-ring sticking, reduces twisting, and reduces nonuniform stress distribution.

(f) It reduces assembly forces and can reduce the tendency for shearing.

(g) It facilitates removal.

The basis for not using, or using less, lubricant may be stated as follows:

(a) It increases the hazard of contaminant entrapment.

(b) It causes swelling in some O-rings.

(c) It is not required for sealing in some static conditions even on rough surfaces, when squeeze is sufficiently high.

(d) It is difficult and time consuming to handle, apply, contain, and clean up (lubricants are messy).

(e) It can cause O-ring extrusion due to displacement by the lubricant.

(f) It can trap air.

In summing up the tradeoffs, experience and thought indicate that, although the use of lubricants complicates the installation procedure, the only way to increase the lifetime and the reliability of O-ring seals is to learn to cope with lubricants.

8.2.21 Limit Stretching. Install each O-ring with as little twisting and rotation as possible. A small amount of rotation during seating cannot be prevented when seating by hand, especially in the case of piston-type O-ring seals. However, the installer can keep the maximum rotation to <2°. The preferred maximum stretch during installation is 50% of the initial O-ring ID. For example, a 1.0 in. (25.4 mm) ID O-ring may be stretched over a 1.5 in. (38.1 mm) OD plug during installation. The maximum allowable stretch is 100% of initial O-ring ID; i.e., a 2.0 in. (50.17 mm) OD is the maximum over which a 1.0 in. (25.4 mm) ID O-ring can be stretched. Excessive stretch can damage the O-rings by causing possibly irreversible or long-term size changes or by opening microcracks.

8.2.22 Grooving. In this Handbook, putting the O-ring into the groove is referred to as grooving. Grooving is followed by seating, which involves joining, coupling, or assembling. Seating encloses the O-ring in its final chamber and completes the seal assembly except for tightening fasteners. Further accounting and testing complete the O-ring installation. Grooving puts the O-ring within three sides of the closed gland, in the case of piston and face-type seals, or locates the O-ring against two of the three sides of the gland in the case of the crush-type seal. Grooving includes pushing, sliding, or rolling the O-ring to ensure that it is properly positioned in the groove. After grooving, the O-ring should be inspected to ensure the following:

(a) The O-ring has no twists or rolls. If visible, the parting lines on the O-ring, i.e., the lines or shallow ridges around the OD and ID produced during molding (see Figure 8.2), can be used to ensure that no twists remain. The parting lines on all properly grooved O-rings should form a circle in one plane.

(b) The O-ring is evenly distributed around the circumference, and is not pressed to one side.

(c) The O-ring is pressed into the groove evenly so that only a thin, uniform film of lubricant is between the O-ring and the bottom of the groove. When positioned properly, the O-ring will extend a constant distance above the groove all around the groove (for a face seal, see Figure 8.8; for a piston seal, see Figure 8.9). The exception to this extension is the crush-type seal where the O-ring is grooved on the shoulder of the bore or piston (see Figure 8.10).

(d) In the case of a piston-type seal, the O-ring is pressed against the side of the groove that will restrain the O-ring during seating. The O-ring in a male gland groove, for example, should be pushed to the side of the groove opposite that which the bore circumference would pass over first during seating. The reason for pushing the O-ring to the back side of the groove is to reduce the possibility that lubricant in front of the O-ring will displace it during seating and cause it to be pushed out of the groove and extruded or sheared.

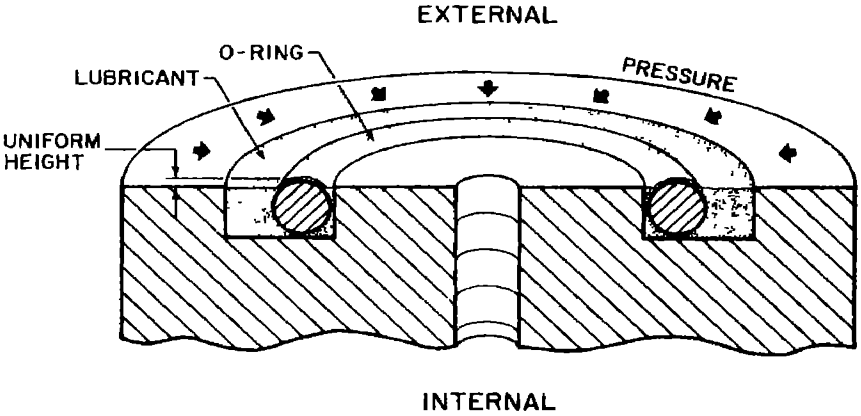


Figure 8.8. Properly grooved O-ring in face seal. In the diagram, the groove is filled to the top with a thick coat of lubricant (see Section 8.2.20.a); for a thin coat, only the groove walls would be coated (see Section 8.2.20.b). The O-ring is shown on the ID of the groove, as it would be if high pressure were on the external side during service; the O-ring will be in contact with the OD of the groove when high pressure is on the internal side during service.

> If the O-ring is not initially against the back side, it will be pushed there during coupling; if this pushing is nonuniform, it could cause the O-ring to bunch up and result in extrusion or shearing. Further, any misalignment of the mating member can be more effectively accommodated by an O-ring that is uniformly against the back side of the groove.

The inaccessibility and small size of the groove may make grooving difficult. Special plastic tools may have to be used to accomplish grooving. Common sense combined with the implied "do's and don'ts" in this section should indicate how to use the tools. See Section 9, Tools.

8.2.23 Inspection. An installer or quality control inspector should inspect each critical O-ring before seating to determine whether it has been properly grooved. If grooving is proper, the inspector shall indicate the number and size of the O-rings inspected, and sign and date the accountability record. The inspection of hard-to-reach O-rings may not include verification of the quantity of lubricant, but should always include visual proof that both the O-ring and the lubricant are in the groove.

8.2.24 Seating. Seating is closing the gland. In the case of a piston-type O-ring, seating is the operation of sliding (or forcing) the bore over the plug or the plug into the bore. In the case of a face-seal-type O-ring, seating is the operation of forcing a face plate against a grooved O-ring. Seating forms the sealing chamber and squeezes the O-ring into that chamber. Seating should be accomplished by a steady or steadily increasing force. CAUTION: Impacting or hammering are not permitted.

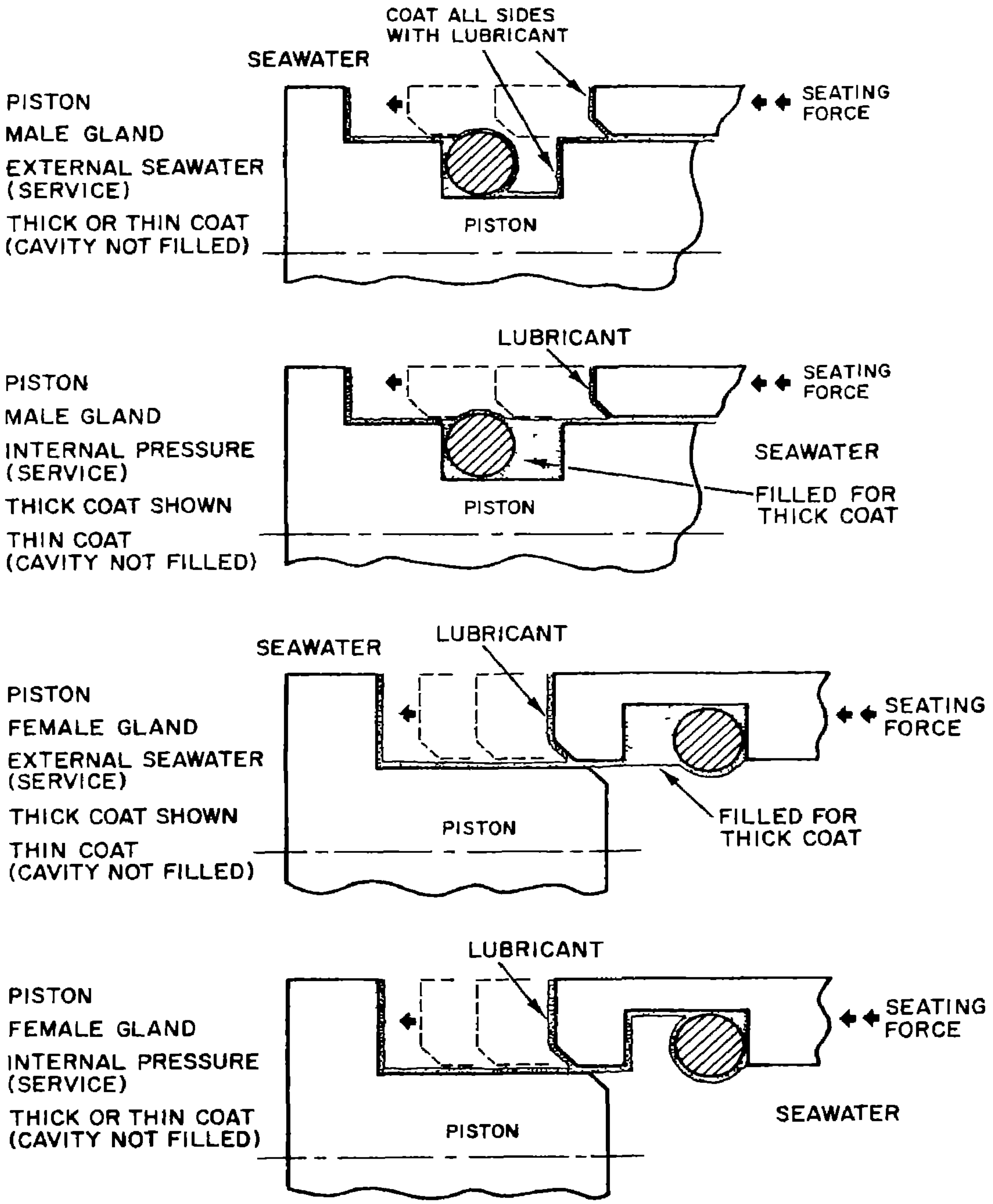


Figure 8.9. Properly grooved piston seals.

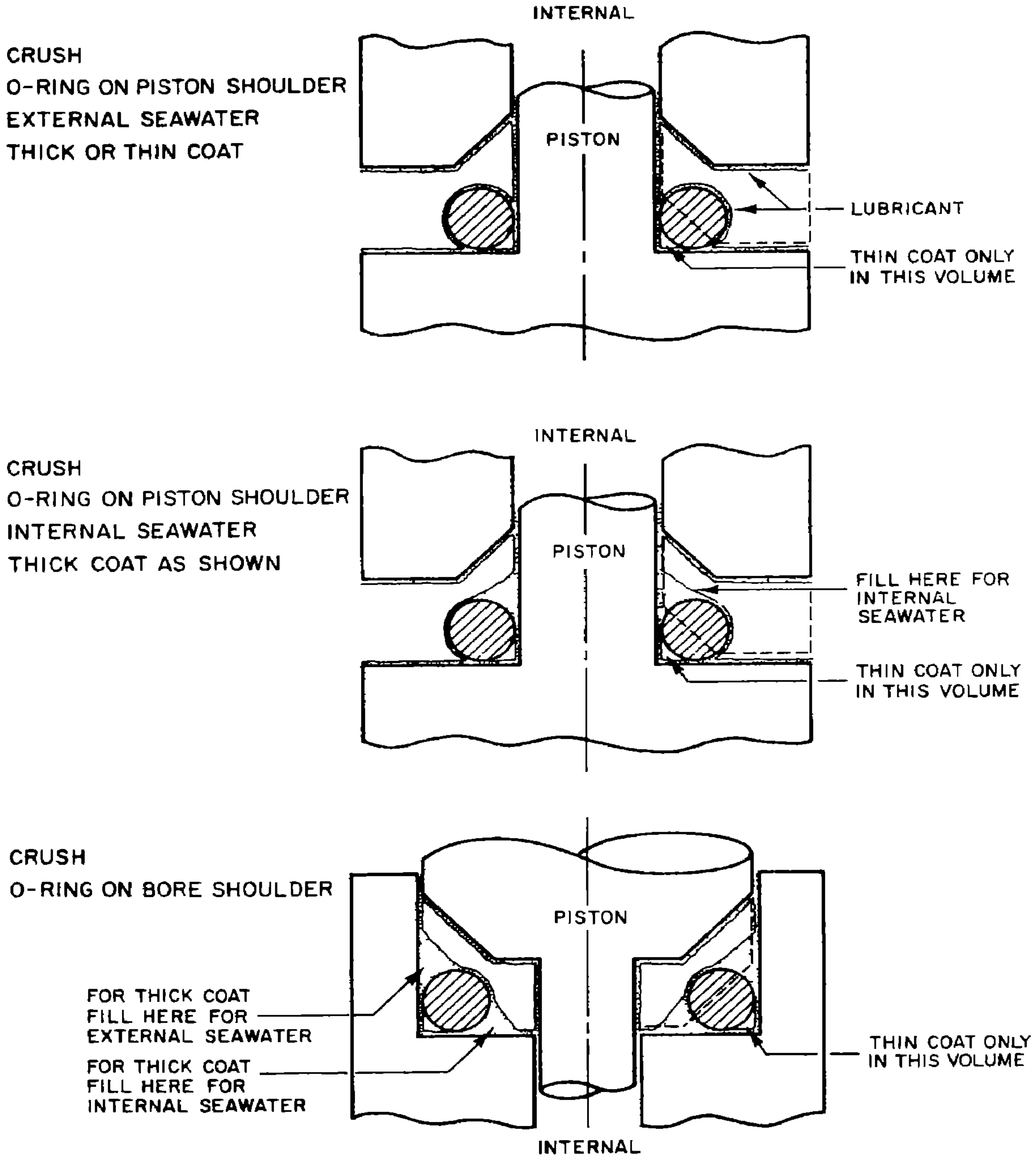


Figure 8.10. Properly grooved crush seals.

Parts should not be rotated while seating forces are being applied, as rotation can cause cuts, twists, and extrusion. (Note: Some parts are threaded and require rotation. See paragraph 8.2.1.aa.) The bore and plug should be carefully aligned and not cocked so that the forces pushing against the O-ring are uniform. Usually, in piston-type seals, the leading edges of the bore and the plug are chamfered (see Figure 8.3). The chamfer and lubricant help to squeeze the O-ring uniformly during seating but chamfering cannot alleviate the need for proper alignment and slow and steady seating forces. During seating when the O-ring in the plug (male) groove is squeezed under (into) the bore, the small clearances that resist O-ring extrusion under service pressures tend to shear the O-ring between the bore and the top of the groove. The shear strength, elastic deformation, and viscoelastic creep of the O-ring resist the tendency to shear. Aside from proper installation, the tendency to shear is reduced by proper design; i.e., by maximizing the diametral clearance, maximizing the groove depth, chamfering the leading-edge angle 10 to 20°, ensuring adequate chamfer depth so that the O-ring contacts only the chamfered surface of the leading edge, and maximizing O-ring cross section (W). It is important to remember that these shear forces are necessary in piston-type seals to squeeze the O-ring properly in the sealing chamber (the O-ring must be squeezed down as much as 30% of the initial W). Squeeze is necessary to prevent leaking under low pressures. The force required to squeeze the O-ring depends principally on the amount of squeeze, the hardness of the O-ring, and the chamfer of the bore or plug. Values for the compression load per linear inch of seal can be found in Figures A4-10 through A4-14 in Parker Handbook ORD-5700, December 1977. Based on static equilibrium, no friction, a chamfer angle of 20°, a diameter of 1.5 in. (38.1 mm), a hardness of Shore A-70 durometer, a cross section of 0.103 in. (2.62 mm), and a 30% compression squeeze (Figure A4-11), the seating force (Fs) can be estimated by the formula:

$$Fs = \pi D C_L \sin\theta ,$$

where

Fs = seating force (lb)

π = 3.1416

D = ID of bore or OD of plug (in.)

C_L = compression load per linear inch of seal (lb) - [from Fig. A4-11, p. A4-7, Parker Handbook ORD-5700]

θ = chamfer angle (angle between bore length and chamfer face), assumed to be 20°.

If the formula holds,

$$Fs = (1.5)\ (3.0)\ \sin 20\ \text{(lb)}$$

$$= 4.84\ \text{lb},$$

or approximately 5 lb. If the chamfer is improperly increased to 45°, the force increases by a factor of 2; i.e., Fs = 10 lb. Friction due to lack of lubricant, surface roughness, or burrs may increase the force several fold. The force can be further increased by impulse seating forces. The increased load can extrude the O-ring and result in shearing off part of the O-ring and thus threatening the reliability of the seal. Seating is complete when the parts, e.g., the bore and the plug, are snug in the proper position.

8.2.25 Tests of Proper Seating. The purpose of the following tests is to check for evidence of O-ring damage or improper seating. If evidence is detected that seating is not proper, the seal or component shall be carefully disassembled to determine the cause of the problem. The probable cause should be noted on the accountability record, and the problem area on the seal should be identified as well as the seal part number given on the drawing. The note on the cause should also show which of the following items, if any, are involved: lubricant absent, O-ring absent, groove out of tolerance, bore or plug (or both) out of tolerance, sealing surface damage, improper chamfer, O-ring damage, surface roughness, contamination, improper O-ring, or improper seating method.

(a) Snugness Test: The assembled parts should be gently shaken before tightening threaded joints or fasteners to check for rattles or looseness, which may indicate that the O-ring is the wrong size, has been extruded, or left out entirely.

(b) Inspection: The diametral clearances and possible locations of extruded O-ring parts should be carefully inspected to determine whether any O-ring or seal damage is visible.

(c) Torque resistance: Upon written approval from the engineering group, piston-type O-ring seals shall be rotated slightly (less than 2°) back and forth about the bore axis one time only to test for unexpected torque resistance. Excessive torque resistance may indicate extrusion of part or all of an O-ring into the diametral clearance area. Too little torque resistance may indicate a missing O-ring, improper O-ring size, or improper squeeze. (The test for torque resistance after seating should not be confused with the caution against rotating the O-ring during seating.)

NOTE: This test cannot be used on electrical connectors because the connector pins, keyways, leads, or conductors would prevent or hamper movement. Note also that the test is not allowed except on written approval from engineering or unless it is required on the engineering drawing.

CAUTION: If the test can be and is applied, the component must be returned to its initial position before the rotation; i.e., the O-ring stress must be nullified.

9. TOOLS

9.1 Intent. The intent of this section is to describe acceptable tools and their proper use for removing, installing, and checking O-rings without damaging the sealing surfaces, the O-rings, or the tools.

9.2 General. Traditionally, O-ring tools have been treated like "cave man weapons": use whatever object is within reach. Unfortunately, the most convenient tools--jackknives, screwdrivers, and scribers--are also the worst. DO NOT USE METAL OBJECTS OR METAL-TIPPED TOOLS TO REMOVE, EXTRACT, OR INSTALL O-RINGS. Metal tools, especially hardened steel, can ruin the metal sealing surface or damage the O-ring being installed. The finished or "smooth" metal sealing surfaces are very easy to damage with tools; in fact, they are more susceptible than some watch crystals. Only clean plastic (in some special cases, wood) tools should be used to install or remove O-rings. Although some tools composed of copper (brass, bronze, or yellow metal) alloys are available for O-ring handling, such tools are not recommended by this Handbook for general use and are disallowed on or around aluminum alloys intended for marine applications. (Copper accelerates pitting and general corrosion of aluminum.) Fortunately, fingers covered by clean surgical gloves are often the best "tools" available for handling and installing O-rings. However, extraction is a different matter--some "instrument" smaller than a finger is often needed to get under the grooved O-ring to pull or lift it out. A hook shaped like a tiny cane, just large enough to hold the O-ring cross section and also fit into the groove, is most often the best instrument for extracting and removing O-rings from grooves in a bore. A tiny spoon-shaped tool is most often the best instrument for extracting or removing an O-ring from a groove in a piston or from a face groove.

9.3 Instruments. Figure 9.1 shows the approximate shape and configuration of instruments that may be useful in O-ring manipulations. These instruments resemble the type that dentists use. A dentist's tools are often hardened steel or stainless steel, whereas O-ring tools are composed of either rigid plastic or metal coated with plastic. The instruments may be fashioned from plastic rods of rigid nylon, polyvinylchloride (PVC), polyethylene, or similar materials. All surfaces must be smooth, free of burrs, and clean. A surface finish equal to that of the sealing surfaces ($R_a = 32$) is necessary, since rough surfaces are easily contaminated and difficult or impossible to clean. Cleanliness is imperative!

9.4 Instrument Use. Instrument use during O-ring extraction and removal is shown in Figure 9.2. Extraction is the process of getting the first part of the O-ring out of the groove. Care must be taken during this step not to damage the sealing surfaces or break the tool and leave the broken parts or particles inside the seal or assembly. Extraction often requires prying and twisting with the tool, but only minimal forces (ounces) are allowable. Removal is the process of pulling the O-ring out of the groove and out of the bore or off the piston.

CAUTION: Check each instrument often and before each use to be sure it has not broken, been contaminated, or developed a sharp edge.

CAUTION: Every effort should be made to avoid contact of instruments with critical surfaces of parts. Discard instruments that are defective in any way.

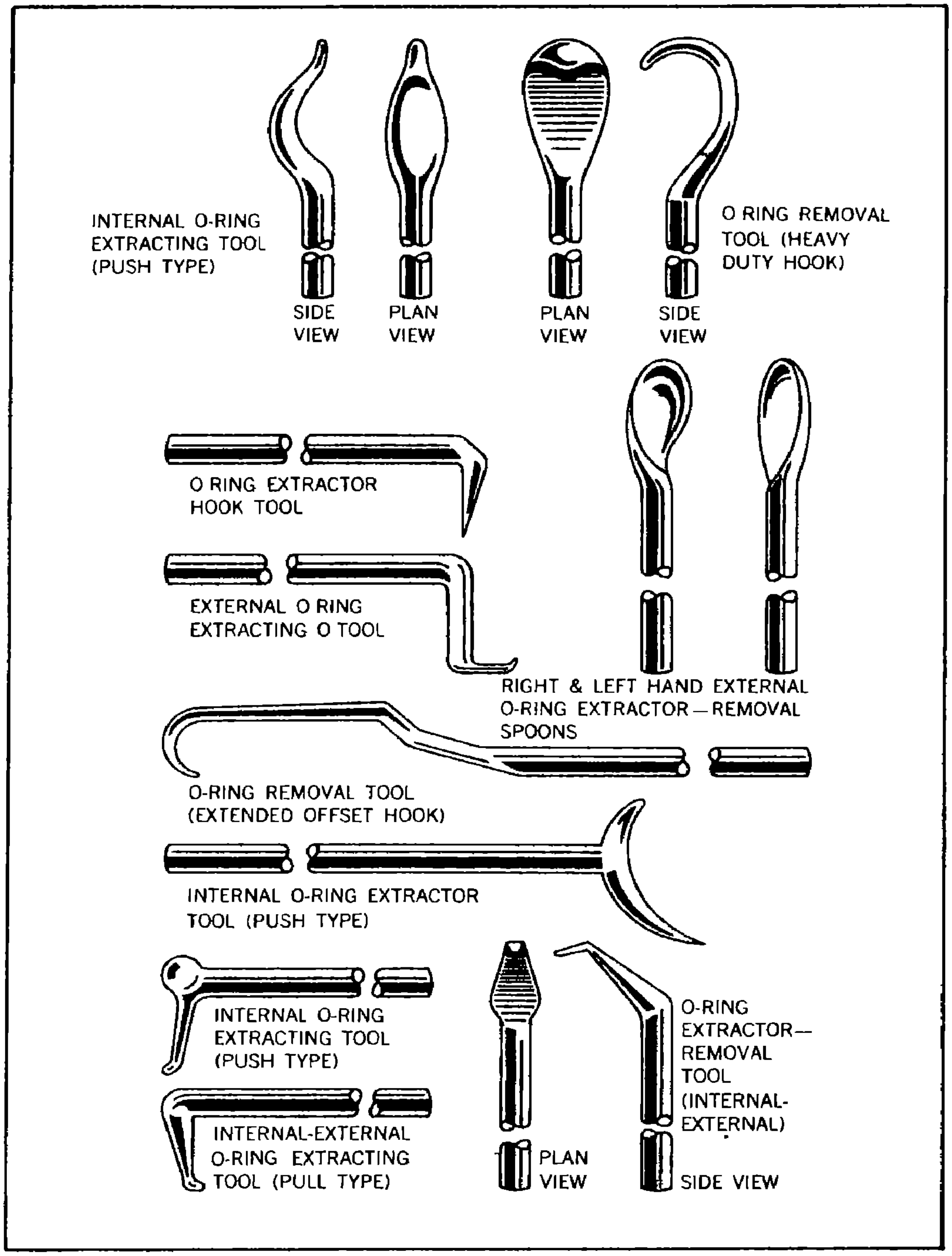
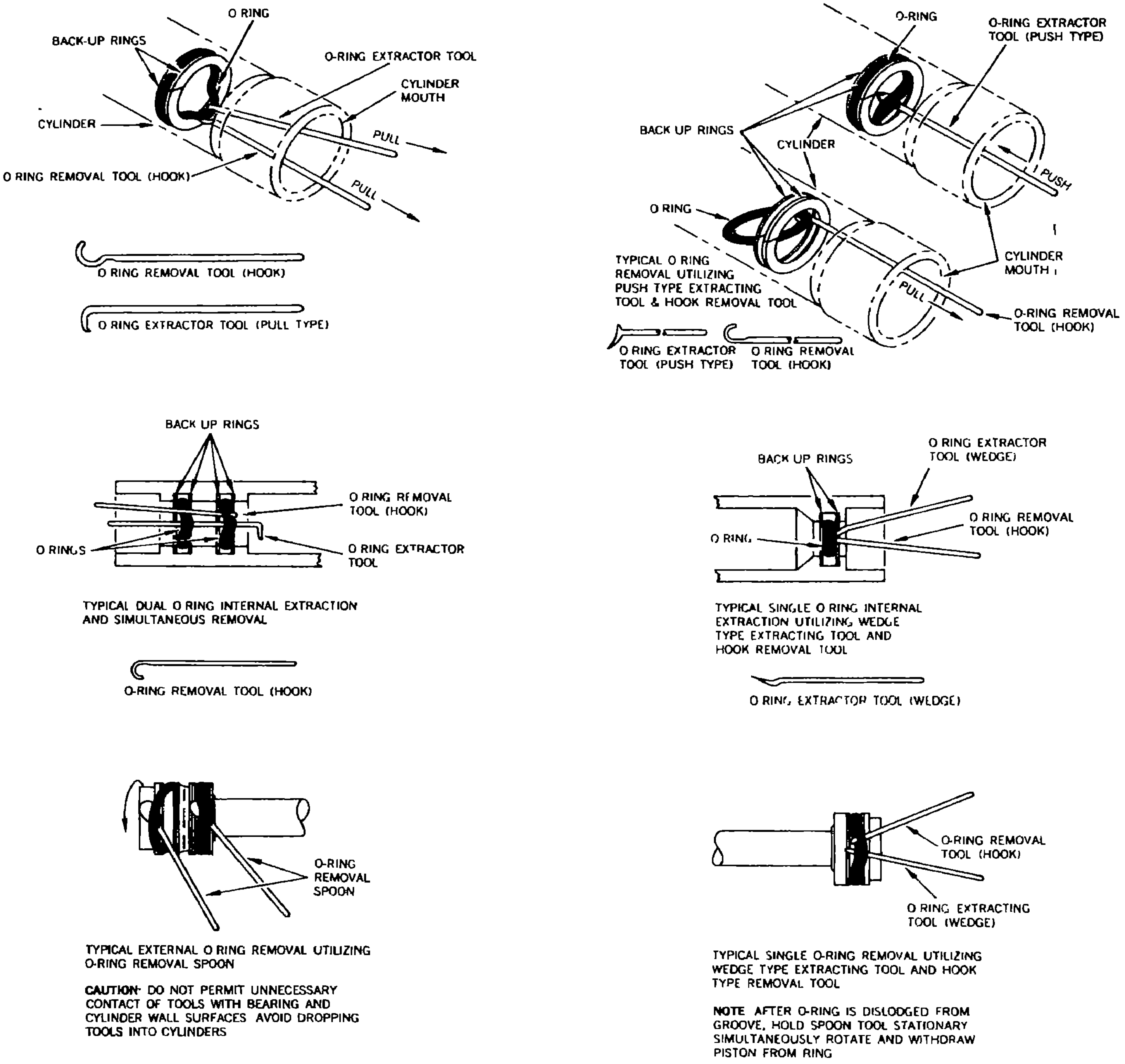


Figure 9.1. Plastic or plastic-coated instruments for extracting, removing, and installing O-rings. Source: "O-Ring Guide for Aircraft Maintenance Men," Parker Seal Co., Culver City, California, and Cleveland, Ohio.



TYPICAL O RING REMOVAL UTILIZING PUSH TYPE EXTRACTING TOOL & HOOK REMOVAL TOOL

TYPICAL DUAL O RING INTERNAL EXTRACTION AND SIMULTANEOUS REMOVAL

TYPICAL SINGLE O RING INTERNAL EXTRACTION UTILIZING WEDGE TYPE EXTRACTING TOOL AND HOOK REMOVAL TOOL

TYPICAL EXTERNAL O RING REMOVAL UTILIZING O-RING REMOVAL SPOON

CAUTION DO NOT PERMIT UNNECESSARY CONTACT OF TOOLS WITH BEARING AND CYLINDER WALL SURFACES AVOID DROPPING TOOLS INTO CYLINDERS

TYPICAL SINGLE O-RING REMOVAL UTILIZING WEDGE TYPE EXTRACTING TOOL AND HOOK TYPE REMOVAL TOOL

NOTE AFTER O-RING IS DISLODGED FROM GROOVE, HOLD SPOON TOOL STATIONARY SIMULTANEOUSLY ROTATE AND WITHDRAW PISTON FROM RING

Figure 9.2. Extraction and removal of O-rings with instruments. Source: "O-Ring Guide for Aircraft Maintenance Men," Parker Seal Co., Culver City, California, and Cleveland, Ohio.

10. INSPECTIONS AND TESTS

10.1 O-ring Inspections. O-rings shall be inspected to ensure that no defects, as described and pictured in MIL-STD-413, are present. Reject and discard all defective O-rings. The types of defects and their classification (major or minor) are listed in Table 10.1 to provide a feeling for the kinds of possible O-ring defects.

Table 10.1. Types and classification of O-ring defects. Source: MIL-STD-413.

Defect	Major	Minor
Backrind	X	---
Backrind, upper limit allowed[1]	([2])	([2])
Dent (peeling)	X	
Dent (peeling)	---	X
Dent (peeling), upper limit allowed[1]	([2])	([2])
Dent (reworked mold mark), upper limit allowed[1]	([2])	([2])
Depressions, multiple small, upper limit allowed[1]	([2])	([2])
Flash	X	---
Flow line, with delamination, indentation, or a marked change of contour	X	---
Flow line, no delamination or no marked change of contour, similar to the hair lines at the ends of the flow line of Figure 10, MIL-STD-413	([2])	([2])
Flow line (preform or knit mark)	X	---
Fill, bad	X	---
Fill, poor	---	X
Fill, poor, refer to Figures 5-7 in MIL-STD-413 for acceptable limits	---	---
Foreign material (inclusion)	X	---
Foreign material (inclusion)	---	X
Looseness of color code marking (when given in the specification)	X	---
Off-register (mismatch), outside cross-sectional tolerance	X	---
Off-register (mismatch), cross-sectional tolerance not exceeded	---	X
Off-register (mismatch), upper limit[1]	([2])	([2])
Split	X	---
Trim, material missing	X	---
Trim, small material missing	---	X

---

[1] Maximum allowable size.

[2] Not a defect.

10.2 O-ring Size Measurement. O-rings should also be checked for proper size and part number (i.e., those specified in the engineering drawing). Machinist gauges are normally required to make a precise measurement of O-ring size parameters. (Convenient devices available for determining O-ring size are shown in Figures 10.1-10.3. The tape shown in Figure 10.3 is for O-rings that are too large for the cone.)

10.3. O-ring Gland Inspection. Refer to Section 8, Installation, and the engineering drawings. All gland surfaces shall be visually inspected, or in certain cases measured, for:

- sharp edges or burrs (tactile and visual)
- nicks and scratches (visual plus 10X magnifier if suspect)
- 32 R_a or better finish
- dirt, hair, or fibers
- contamination
- cleanliness
- corrosion damage (visual plus 10X magnifier if suspect)
- dimensions affecting squeeze and clearance gap (refer to Section 8.2.1.d for measurement instruments required)
- gland size and shape.

10.4 Installed O-ring Seal. Refer to Section 8, Installation, and the engineering drawings. All installed seals shall be visually inspected or in certain cases measured to ensure:

- O-ring in gland
- proper O-ring
- snug fit
- expected number of threads engaged and exposed
- proper fit
- pressure-keeping capability (if possible).

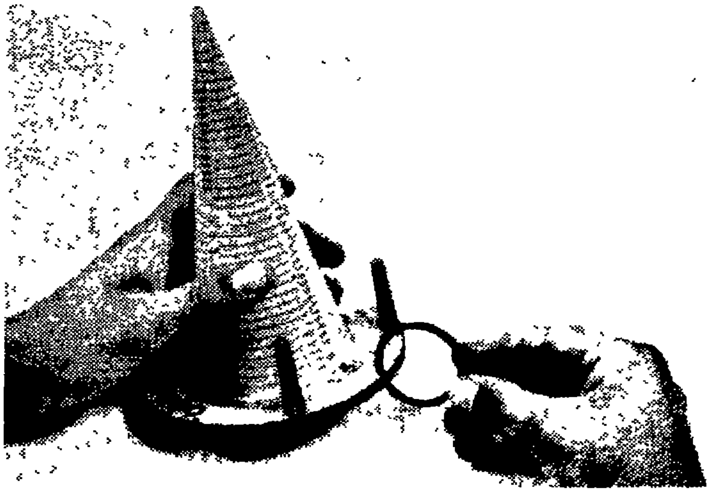


Figure 10.1

Checking O-ring cross section width (thickness). Source: "Parker Size Gauge for O-rings," Parker Seal Co., Culver City, California, and Lexington, Kentucky.

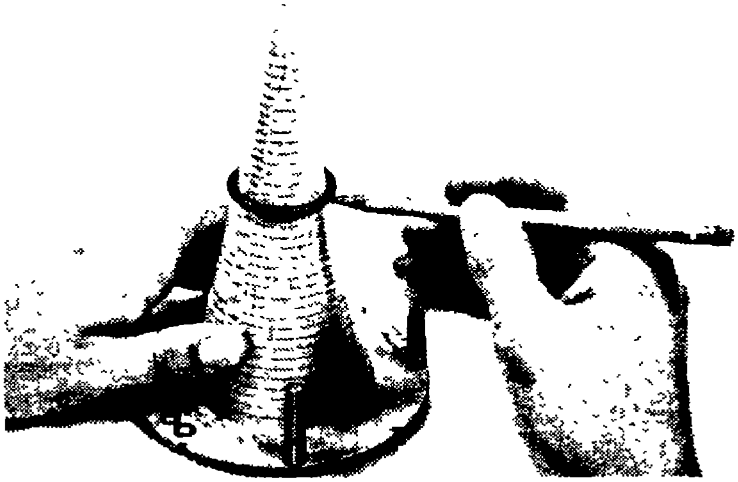


Figure 10.2

Determining size number with cone (read correct size directly above the O-ring). Source: "Parker Size Gauge for O-Rings," Parker Seal Co., Culver City, California, and Lexington, Kentucky.

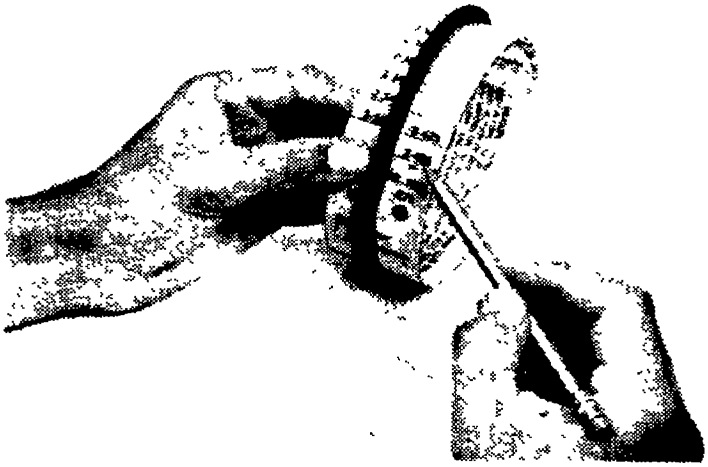


Figure 10.3

Determining size number with tape. Source: "Parker Size Gauge for O-Rings," Parker Seal Co., Culver City, California, and Lexington, Kentucky.

11. PACKAGING

11.1 Intent. The packaging methods prescribed in this section are intended to accomplish the following:

(a) Assure positive identification of each O-ring (and accompanying backup O-rings if required) by part number, batch, and cure date until it is installed in the connector or component.

(b) Assure positive identification by singly packaging O-rings and marking each package. Thus the need for marking or color coding individual O-rings is reduced.

(c) Provide protection of each O-ring from contamination, oxidation, and radiation damage until installation.

11.2 Unit Size. All O-rings procured for components used in marine applications shall be singly packaged in sealed packages. Included in the bag may be needed crush rings or backup rings.

11.3 General. Packages and packing procedures shall meet MIL-P-4861, "Individual (Unit) Packaging," MIL-P-116, "Methods of Preservation-Packaging," or other equivalent specifications (see Section 15.1, Numerical Listing of Applicable Standards, Handbooks, and Specifications). The packing and packages for all O-rings procured for critical applications shall meet or exceed MIL-P-116, method IC-1, or in special cases MIL-P-116, method IC-3. Method (submethod) IC-1 requires a sealed greaseproof and waterproof bag whereas method IC-3 requires only a sealed waterproof bag. The IC-1 bag is preferred because it protects against greases and often is supplied at no additional cost by suppliers; however, in the special case where it is known that no grease shall contact the packaged units, the packages need only meet or exceed the specifications in MIL-P-116, method IC-3. When any uncertainty in the shipping, handling, or storage environments exists, MIL-P-116 method IC-1 should be specified.

11.4 Marking. Both MIL-P-116 and MIL-P-4861 require marking or labeling of each package according to MIL-STD-129, "Marking for Shipment and Storage." MIL-STD-129 (under paragraph 5.1.1, Unit and intermediate packs and unpacked items, which apparently pertains to each singly packed O-ring) specifies the following identification markings:

(a) National stock number (NSN/NATO) (if it exists)
(b) Manufacturer's part number (MFR/PN)
(c) Item description
(d) Quantity and unit of issue
(e) Contract, purchase, or delivery order number
(f) Level of protection and date of packaging
(g) Gross weight and volume.

Figure 11.1 shows the typical markings on an AN6227B-25 O-ring bag and gives their meanings. The markings are not easily matched with the list from MIL-STD-129. No NSN/NATO exists so none appears, and gross weight

PACKAGE MARKINGS (FRONT)

AN6227B-25	Army-Navy standard drawing part number; -25 specifies dimensions (W ≈ 0.139 in. (3.53 mm), OD ≈ 1.637 in. (41.58 mm)
2-220	Manufacturer's part number corresponding to AN6227B-25
SPEC/MIL-P-5516 CL B AMEND 2	Military performance specifications for O-ring material
CONTRACT K805-601	Purchase contract number
CURED 1Q75	Date rubber O-rings were cured (first quarter of 1975)
BATCH 165164	Rubber compound batch number
COMP. PS1-30-5	Manufacturer's compound number for supplied O-ring material
DUROMETER 70	Shore A durometer hardness of specified material
ONE EACH PACKING	One singly packaged O-ring (quantity and item description)
SAN DIEGO, CALIF. PARKER SEAL CO. AEROSPACE SUPPLY INC.	Supplier and address

Figure 11.1. Markings on the front of an AN6227B-25 O-ring package and their meanings. The markings on the back pertain to packaging procedures and material (see Figure 11.3).

and volume are not given. Note the military performance specification for the material and the manufacturer's compound number for the supplied O-ring material. The manufacturer's compound number can be used with the manufacturer's O-ring catalogs or handbooks to learn what compound the supplied O-ring is made with. For instance, by checking the qualified products list in the material specification (MIL-P-5516 Class B Amendment 2) to find PSI-30-5 (now N304-75) and then checking the supplier's catalog, it can be learned that the O-ring compound is nitrile. Figure 11.2 shows the typical markings on an MS28775-117 O-ring bag and their meanings. Note that the markings are similar in almost every respect to those on the AN O-ring bag.

Figure 11.3 shows one variation of the markings that can appear on the bag of an O-ring procured by specifying the manufacturer's part number and compound number. The markings differ from the packages shown in Figures 11.1 and 11.2 because a supplier's number was used, but the O-ring dimensions are identical. The back of the package--which shows an arrow and the words MIL-B-117D, Type II, Class C, Style 1, Richmond Corp., Polykraft No. 18, 1/73--can be interpreted as follows: The package meets MIL-P-116G submethod IC-1, which specifies a greaseproof, waterproof, heat-sealed bag conforming to MIL-B-117, Type I or II, Class C, Style 1; the bag was made of Polykraft No. 18 by Richmond Corp.

PACKAGE MARKINGS (FRONT)

Marking	Meaning
MS28775-117	Military Standard drawing part number; -117 specifies dimensions of O-ring. W ≈ 0.103 in. (2 62 mm), OD ≈ 1.005 in. (25 53 mm)
2-117	Manufacturer's part number corresponding to MS28775-117
ONE EACH PACKING	One singly packaged O-ring (quantity and item description)
MIL-P-25732B	Military performance specification for the O-ring material
PARKER SEAL CO.	Manufacturer
COMP N304-75	Manufacturer's compound number for supplied O-ring material
DUROMETER 70	Shore A durometer hardness of specified material
BATCH 135923	Rubber compound batch number
CONTRACTH1215-605 006517	Purchase contract number
CURED 2Q73	Date rubber O-rings were cured (second quarter of 1973)
AEROSPACE SUPPLY INC. SAN DIEGO, CALIF.	Supplier and address

e 11.2. Markings on the front of an MS28775-117 O-ring package and their meanings. The markings on the back pertain to packaging procedures and material (see Figure 11.3).

BACK

MIL-B-117D, TYPE II,

CLASS C, STYLE 1

RICHMOND CORP.

POLYKRAFT NO. 18

1/73

FRONT

PREFORMED O-RING

PARKER P/N 2-220

MAT. SPEC: SAEJ200 6SE

705A 19B37 E 16 E36 F19

PARKER SEAL COMPANY

COMPOUND: S455-70

BATCH: 16562

P.O. #N00221-73-M-J065

CURE DATE: 4Q72

MCDOWELL & COMPANY

SILICONE, O-RING & NYLON
CRUSH RING ENCLOSED.

Figure 11.3. Front and back of singly packaged O-ring.

in the first month of 1973. The front of the package shown in Figure 11.3 shows all of the standard identification markings except the NSN/NATO, quantity, standard unit of issue, and gross weight and volume. What appears to be extra information in Figure 11.3 (i.e., manufacturer's name, SAE material specifications, manufacturer's material specifications, batch number, local supplier's name, and the common name of the package's contents) may be part of the information required by (c), Item description. Item description is the exact name and description of the item as it appears in the contract, purchase order, or requisition. Although rigorous adherence to item description would require using only the item names in Cataloging Handbook H6, "Federal Item Name Directory for Supply Cataloging," both purchasers and suppliers have allowed the use of various item descriptions which include more information than the minimum required by MIL-STD-129. Thus the information on some packages may not match exactly that called for and illustrated in the standard. Item (f), Level of protection and date of packaging, is not given in any of the figures except as the cure date for the O-ring material; a complete label might read, for example, A/B-1Q78, which would indicate level A preservation, level B packing, and the month and year of the earliest packaging date. Unfortunately, level A and level B are not carefully defined in the standards. Item (g), Gross weight and volume, is also not given in the figures. The experience of the author has been that Item (f), Level of protection, and Item (g), Gross weight and volume, are not always adhered to by the industry for small envelopes of singly packaged O-rings.

12. STORAGE AND AGING

12.1 Intent. The intent of the information given in this section is to increase the storage and service life of O-rings, and to increase reliability by knowing when the life has been decreased by adverse storage conditions and what the shelf life of O-rings should be under normal storage conditions. Knowledge of the conditions that are adverse and those that are beneficial is a basis for proper storage and timely discarding of O-rings. Storage life as used here includes the time that O-rings are in the possession of the supplier, shipper, stockroom, and installer, and are installed in the component before use.

12.2 General. Rubber and plastic deteriorate with time when exposed to common environments. This process is known as aging. Three common types of aging reactions occur in the long, chain-like hydrocarbon molecules composing rubber: (1) Scission--cutting of the chains into smaller lengths due to ozone, ultraviolet light, and nuclear type radiation; (2) Cross linking--production of bonds between chains along their length due principally to heat and oxygen; (3) Side group modification--small clumps of atoms on the molecules are changed, added, or lost along the length of the chains, primarily due to moisture and other contaminants. These aging reactions can be slowed down or stopped by removing the environmental causes. In other words, aging is controlled by the environment, and time itself is only indirectly a causative factor. Because time is easy to measure and describe and because most handling and storage facilities are assumed to have similar environments, time, both in storage and in actual service, is used to make a "conservative" estimate of the probable deterioration of O-rings. Nevertheless, time alone is not an accurate measure of deterioration. On the one hand, even a short exposure to adverse environments such as heat or ozone can produce deteriorated seals; on the other hand, discarding seals that have been stored under proper conditions after a short time only results in wasteful destruction of good seals. Some seal compounds are more resistant to aging than others. A final report to the Mare Island Naval Shipyard entitled "Effect of Shelf Aging on MIL-P-5516 O-rings" (Report 92-20, Project No. S-F013-13-01 Task No. 905, prepared 20 June 1967) states that no significant changes in physical properties from the standpoint of serviceability were observed after shelf aging O-rings 8 years beyond the recommended 4 years. Storage conditions varied from packaged to exposed to air and light. The allowable shelf life has not been and cannot be accurately determined until limits or standards on storage conditions, material, reliability, and property requirements (allowed degree of deterioration) are firmly set by the user. For the O-rings that are purchased, stored, and installed according to this Handbook, the acceptable storage life is 5 years, or 20 quarters. To reduce the possibility of using O-rings damaged by aging or improper storage, the installer must check for signs of such damage. The obvious signs of damage by aging due to exposure to air, ozone, or radiation include hard skin, minute cracks, discoloration, and irregular shape. Discoloration should not be confused with thin coatings of lubricants or mold release compound. (Refer to Section 8.2.14.)

12.3 Shelf Storage Life. No O-ring shall be installed in a component if the shelf life of the O-ring exceeds 5 years (20 calendar quarters beyond the cure date) unless instructions on the engineering drawings specifically allow longer storage periods. MIL-HDBK-695, "Rubber Products: Shelf Storage Life," provides information concerning the shelf life of O-rings. That handbook gives expected shelf storage lives ranging from 2 to 20 years depending on the O-ring material. MIL-HDBK-695 divides elastomers into three groups according to age resistance. For silicone or fluorosilicone (Silastic LS), for example, the suitable storage period is up to 20 years; for isobutylene/isoprene, butyl, neoprene or chloroprene, the period is 5 to 10 years, and for Nitrile (Buna N) and Buna S compounds, the period is 2 to 5 years. Table I of that handbook notes that nitrile rubber seals may have a shelf life as high as 10 years when aging resistance requirements are included in the specification. Department of Defense MIL-STD-1523 pertains specifically to the age control of nitrile compounds meeting specific military specifications. The standard attempts to give proper emphasis to the control of storage conditions as well as to time periods of storage.

12.4 Storage Conditions. Conditions for maximum storage life are as follows:

(a) Temperature not exceeding 120°F (49°C)

(b) Minimum practical exposure to air (avoid oxygen)

(c) Minimum practical exposure to ozone (avoid electrical motors and high voltage)

(d) Minimum practical exposure to light (avoid sunlight)

(e) Minimum practical exposure to contaminants (avoid vapors, solvents, and water)

(f) Minimum exposure to radiation

(g) Stress avoidance (i.e., avoid forces that cut, shear, squeeze, etc.).

The minimum practical exposures will be determined by the allowed storage period (from cure date to installation and presumed use date), by reliability requirements, and by economic considerations. For connector seals, the allowed storage period is 5 years (20 quarters), the reliability is critical, and economy is important. By storing each singly packed O-ring in a storeroom, or briefly in an orderly work area where continued attention is given to avoiding ozone, sunlight, contaminants, radiation, stresses and heat sources such as steam pipes, heaters, etc., the minimum practical exposure requirements can be met.

13. LUBRICANTS

13.1 Scope. This section lists satisfactory lubricants for use in static O-ring seals in marine environments, briefly discusses differences between and features of the lubricants, and presents a table listing lubricants for certain applications. Selected general features of lubricants are also discussed to promote understanding of their makeup, proper use, and cleanup, and applicable standards and specifications are mentioned.

13.2 Purpose. Lubricants are used to reduce friction, especially during installation, and to reduce corrosion. Refer to Sections 8.2.18 and 8.2.20 for further discussion of purpose.

13.3 Applicable Documents. Two military documents that are useful for selecting, storing, and using lubricants are: MIL-G-4343, "Grease, Pneumatic System," and MIL-L-17192, "Lubrication Design, Lubricants, and Lubrication Information for Electronic Equipment: General Specification." MIL-G-4343 identifies products that are qualified under that specification. MIL-C-4343 describes some important tests that are applied to shipments of grease from suppliers: Odor, corrosion on copper, oil separation, evaporation (2.5% of weight in 22 hours @ 210°F/99°C), oxidation, rubber swell limitations, rust prevention properties, storage stability, and homogeneity (no lumps or abrasive materials).

> CAUTION: Lubricants older than the shelf life recommended by the supplier should not be used.

13.4 General: Viscous lubricants, which are the only kind that are used with O-rings, can be either greases or synthetic grease-like compounds. The lubricating qualities of greases come from natural oils such as animal fat, vegetable oil, or petroleum bases. Grease can be described as a liquid lubricant that is thickened to a semifluid or solid by the addition of agents such as soaps or finely divided particles. Most common greases are thickened with soap. The thickening occurs when alkali metals such as calcium, sodium, lithium, barium, etc., are added to the liquid and react chemically with the fatty acids in the soap. Some greases are thickened by mixing into the liquid lubricant finely divided particles of graphite, talc, clay, molybdenum disulfide, etc. Additives are sometimes used in greases to provide corrosion protection, color changes, and oxidation resistance. The lubricating qualities of synthetic substances come from silicone, polyolefins, esters, and other chemicals of "low" molecular weight. In contrast to greases, which are usually thickened by a chemical reaction, synthetic lubricants are usually thickened by adding finely divided particles. As might be anticipated from this discussion, lubricants, both natural and synthetic, do change chemically, mechanically, and physically with time both in storage and during use. Further, the ingredients in these lubricants can sometimes react with rubber (the principal O-ring material), water, solvents, and metals in an adverse manner. The ingredients in some synthetics, for example, can cause rubber to shrink; others make it swell. Fats, of course, are digestible by many organisms and if conditions are right may decompose. In general, synthetic grease-like lubricants that contain no digestible components appear to be good candidates for long life in marine environments. Examples include Parker Super-O-Lube and Dow Corning 7, 4, and 111 silicone compounds. (The term compound is used here to differentiate lubricants made of high viscosity silicone from greases that are made of common oils and use soaps as thickeners.) Dow Corning 4, 7, and 111, however, can shrink O-rings by 1 to 2% in volume. Where O-ring squeeze is critical, such shrinkage may be unacceptable. Molykote 55M grease, a hybrid silicone-based lubricant that is soap-thickened by the reaction between lithium and animal fats, is used intentionally to produce slight swelling in some O-rings to promote sealing. Because stearates are digestible by some organisms, exposure to time, temperature, and certain organisms can result in decomposition. Parker O-Lube, which has a petroleum base with a barium soap thickener, swells any nonpetroleum-based O-ring material. In general, surface contamination by high-viscosity silicone compounds is very difficult to clean up, and care must be taken not to get them on surfaces that are to be painted, vulcanized, or otherwise coated. (Solvents for silicone lubricants include Chlorothene NU, perchloroethylene, mineral spirits, and methyl ethyl ketone.)

13.5 Long Life O-rings and Lubricants Paradox. The best lubricant for long shelf life and corrosion resistance is not recommended for use with the best O-ring compound for long shelf life and age resistance. Silicone O-ring compounds can have a shelf life of up to 20 years. However, the silicone-based lubricants that have a long shelf life, that are indigestible, that are stable, and that help protect glands from seawater are not recommended for use with silicone O-ring compounds. The silicone lubricants swell and soften silicone O-rings and some other synthetic O-ring compounds. Silicone O-rings and silicone lubricants should not be mixed because they are slightly soluble in each other. In contrast, the common O-ring compound used for marine applications (nitrile) that is compatible with silicone lubricants has a relatively short shelf life unless storage requirements specifically designed to control aging are specified. In practice, a compromise has resulted. Nitrile O-rings are commonly used in marine applications because they last for many years in this environment. The selected lubricant is usually a soap-thickened grease or a hybrid silicone-based lubricant, both of which compromise maximum service life but have minimum adverse reactions with the O-ring material. In short, the best lubricant to use in marine environments varies with the O-ring material and the service life required.

13.6 Comparison of O-ring Lubricants. Table 13.1 compares many of the available lubricants that could be used on O-rings for static marine applications. Because of the availability of new materials and information that were not studied or were not available, the table should not be considered complete. Comments have been added to the table to help distinguish some major differences between lubricants. More data gathering and evaluation on the basis of fixed criteria need to be accomplished before the best lubricant or lubricants can be identified with certainty. Table 13.1 is partly based on Table 6-1, Parker Packing Engineering Handbook, Parker-Hannifin Corp., Cleveland, Ohio.

Table 13.1. Comparison of O-ring lubricants.

NAME	MANUFACTURER	TYPE	TEMPERATURE RANGE, °F(°C)	SEAL USE	COMMENTS ON STATIC MARINE CONNECTOR APPLICATIONS	BEST SERVICE WITH (BASE RUBBER)
Petrolatum	Many	Petroleum base	-20 to +180 (-29 to +82) (may vary between sources)	Petroleum systems, i.e., fuel and hydraulic	OK but may vary	Nitrile, neoprene, and fluorocarbon
Parker O-Lube	Parker Seal Co., Culver City, CA, and Lexington, KY	Petroleum oil barium soap	-20 to +300 (-29 to +149)	Pneumatic (low pressure, 200 psi max)	Excellent but may deteriorate with time.	Nitrile, neoprene, fluorocarbon, and most other petroleum oil resistant rubbers
Parker Super-O-Lube	Parker Seal Co., Culver City, CA, and Lexington, KY	High viscosity silicone fluid	-65 to +400 (-54 to +204)	General purpose, high pressure pneumatic	Excellent (check shrinkage)	Fluorocarbon, fluorosilicone, neoprene, nitrile, butyl, and most other rubbers
Dow Corning DC 4	Dow Corning Corp., Midland, MI	Silicone fluid thickened with silica filler	-70 to +400 (-57 to +204)	General purpose, electrical insulating sealant	Excellent (check shrinkage)*	Most rubber and plastic O-rings (shrinkage and swelling must be checked)
DC 55 (MIL-G-4343)	Dow Corning Corp., Midland, MI	Silicone grease	-65 to +400 (-54 to +204)	General purpose, high pressure pneumatic	Excellent but may deteriorate after long time	Nitrile, butyl, ethylene-propylene, fluorocarbon, and neoprene (not for silicone base)
DC 111	Dow Corning Corp., Midland, MI	Silicone fluid (heavy consistency)	-40 to +400 (-40 to +204)	General thick sealant, lubricant, potting compound	Excellent but may be too thick (check shrinkage)*	Nitrile, butyl, ethylene-propylene, fluorocarbon, and neoprene (not for silicone base)
DC 7	Dow Corning Corp., Midland, MI	Silicone fluid (light consistency)	-40 to +400 (-40 to +204)	Mold release agent, general lubricant, and preservations	Excellent, but may be too thin (check shrinkage)*	Nitrile, butyl, ethylene-propylene, fluorocarbon, and neoprene (not for silicone base)
Celvacene	Consolidated Vacuum Co., Rochester, NY	Cellulose ester and castor oil	-40 to +266 (-40 to +130)	Vacuum, static, to 10^{-7} torr.	Good but may deteriorate by digestion	Silicone, nitrile, neoprene, fluorocarbon, butyl, and ethylene-propylene
Versilube	General Electric, Waterford, NY	Silicone grease	-100 to +400 (-73 to +204)	Pneumatic, 3000 psi and high speed	Good but shrinkage and compatibility must be checked	Nitrile, neoprene, and fluorocarbon (will shrink some compounds and will dissolve some silicone rubber)
Apiezon N	Made in England, dist. by Jason Biddle, Philadelphia	Low vapor pressure oil distillate	-60 to +85 (+15 to +30)	Vacuum 1×10^{-8} torr	Unknown by author	Nitrile, butyl, ethylene-propylene, fluorocarbon, and neoprene
Fluorolube	Hooker Chemical Corp., Niagara Falls, NY	Fluorocarbon fluid	-65 to +400 (-54 to +204)	Oxygen service -	Unknown by author	Silicone, nitrile, neoprene, ethylene-propylene, and butyl

---

*Although Dow Corning Form No. 71-448A-79 gives a shelf life of 18 months from data of purchase, experience indicates that the shelf life is unlimited if the containers are not damaged or opened and if storage conditions are normal.

14. RELIABILITY

14.1 Intent. The intent of this section is to explain how and why the design, materials, installation, and use of O-ring seals affect the reliability of component seals such as those used in connectors. The general concepts of reliability and its relation to probability are discussed.

14.2 General. Assuring high reliability of a seal requires ensuring that seal design, fabrication, material selection, material procurement, seal installation, the initial test of the seal, and seal service-use are properly accomplished. This Handbook directs needed attention to learning how to ensure proper seal installation and, to some degree, testing.

14.2.1 Definition of Reliability. Reliability is the probability that a system, in this case the seal, will function properly for a specified time under specified conditions.

14.2.2 Definition of Probability. Probability is a number that includes, but is normally between, 0 and 1 and that indicates the likelihood of a certain thing happening. The probability of a normal copper penny landing head up when flipped, for instance, is about 0.5, or about 50%. The probability for neither heads nor tails because the coin might stand on its edge is about 0.01, or 1 out of 100. The probability of getting either heads or tails, therefore, is 0.99 or 99%. Here, we have assumed that the probability of losing the coin is 0. A probability of 0 indicates that the event has no possibility of happening. If you flip a copper penny, the probability that it will turn into a $20 goldpiece is 0. The probability that at some time you will be given the wrong O-ring for a particular seal is somewhere between 0 and 1--probably not 1, and definitely not 0.

14.2.3 Reliability Explained. Because reliability is the probability of something happening (for example, a part functioning properly), it also is described by a number from 0 to 1. Then why use the term reliability instead of probability? Reliability applies to a system, an installation procedure, or a machine that is a collection of elements that all have individual probabilities of functioning. Further, since we more often know the probability of failure than of success, reliability is defined as 1 minus the probability of failure,

$$R = 1 - Pf.$$

This definition of reliability can be applied to an O-ring seal, which is a system, used in a component such as a connector. By carefully putting the seal system together one element at a time, we can understand how installation steps and how methods of accomplishing these steps can affect the seal's reliability. Note that the steps may be a collection of elements and the methods may be a collection of elements. The individual elements will have probabilities for success or failure as well as reliabilities, and the steps and methods will be discussed in terms of reliabilities.

14.2.4 Definition of Applied Reliability. In the application discussed here, reliability is 1 minus the probability that the O-ring seal will leak before 5 years of service either undersea or shipboard exposed to seawater spray.

14.2.5 Reliability of Installation Steps. The reliability of the seal installation can be calculated if the reliabilities of the installation steps and the parts are known. The method of calculation depends on how the steps and these elements are related. If an essential step cannot be properly taken unless the step or steps before it have been properly taken, we say that these steps are in series, and their reliabilities must be multiplied together to obtain the reliability that both (all) have been properly completed. If an essential step is composed of more than one element and one or more of these elements can be alternatives (i.e., if there is more than one method of accomplishing that step), we say that these methods are in parallel. The reliability of a step that has a parallel set of methods is calculated by subtracting from 1 the product of the methods' unreliabilities. This calculation will be explained in Section 14.2.10.

14.2.6 Definition of Series Relationship. A series relationship can exist between elements or steps. A system of series-related steps is one in which all steps are so interrelated that the entire system will fail if any one of its steps fails. For example, if an O-ring is left out during installation, the entire seal system will fail.

14.2.7 Definition of Parallel Relationship. A system of parallel related steps is one that will fail only if all of its steps fail. For example, if only one O-ring were left out of a double O-ring seal, the seal would probably not fail (i.e., not leak). However, if both of the O-rings were left out, the seal would definitely leak.

14.2.8 Reliability of Series-Related Steps. The reliability of a system of series-related steps is obtained by multiplying the reliabilities of the steps in the series; that is,

$$Rs = (Rs1)\ (Rs2)\ (Rs3)\ (Rs4)\ (Rs5),$$

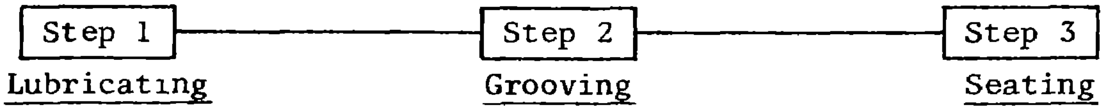
where Rs is the reliability of the system and Rs1, Rs2, etc., are the reliabilities of the steps. The reliability of a step of series related elements is obtained in the same manner. The value for the reliability of each step, hereafter called the step reliability, can be calculated from the definition of applied reliability:

$$Rs1 = 1 - Pf1$$

$$Rs2 = 1 - Pf2$$

etc.

The values for Pf1, Pf2, etc., could be obtained by experiments, based on manufacturers' estimates, judged from experience, or simply educated guesses. Consider the following example for estimating the reliability of part of an O-ring installation:



Pf1 = 0.05	Pf2 = 0.06	Pf3 = 0.07
Rs1 = 0.95	Rs2 = 0.94	Rs3 = 0.93

If steps 1, 2, and 3 are series-related steps, the reliability of this particular procedure is calculated as follows:

$$\begin{aligned} Rs &= (Rs1)\ (Rs2)\ (Rs3) \\ &= (0.95)\ (0.94)\ (0.93) \\ &= 0.83. \end{aligned}$$

The values given for each step reliability (and the probabilities of failure) have been selected for example purposes only. Note that if any of the step reliabilities were low, this system reliability would also be low. For example, if Rs3 were 0.09 instead of 0.95, the system reliability, Rs, would be 0.08 instead of 0.83--a 10 fold reduction in reliability! A system composed of series-related steps needs high reliability in each step procedure to have a high system reliability. Taking chances with any step in a series relationship dramatically reduces the reliability of the entire system.

14.2.9 Definition of Independent Relationship. An independent relationship is one in which the steps in a system are so unrelated that the performance of one step does not affect the reliability of the others. Although the concept of independent relationships may be clear, the application of the concept can be complex. The simple multiplication rule for calculating the reliability of series-type steps can only be accurately applied when the steps are independent; i.e., when the performance of one does not affect the reliability of the others. Unfortunately, many series-type steps are not independent. As the dependence between several steps increases, both the complexity of the calculation and the complexity of evaluating the individual step reliabilities increase. Flipping a balanced coin, for example, is an independent step and doesn't depend on skill; therefore, the probability of getting heads on each of two successive flips would be (0.5)(0.5) = 0.25. The probability of drawing two successive aces from a deck of cards, however, depends on how the drawing is accomplished. If on the first step the card is replaced, each draw is independent, and the probability of getting on ace on two successive draws is (4/52)(4/52) = 16/2704 = 0.0059. If, however, the drawn card is not replaced, the probability of drawing a second ace is not independent, but depends on both what was drawn and how many cards are left in the deck, and decreases to (4/52)(3/51) = 12/2652 = 0.0045; that is, the probability of drawing two successive aces when the first card is withheld is the probability of drawing an ace on the first draw (4/52) times the probability of drawing an ace on the second draw (3/51), assuming the first card is an ace. Card games and O-ring installations have some important similarities: Just as withholding a drawn ace reduces the probability of drawing an ace on the next draw, so improper grooving, for example, reduces the probability of proper seating. Further, the probability of correctly performing O-ring installation steps may not be the same each time, since the skill and care of the installer may change.

14.2.10 Reliability of Parallel-Related Steps. A system composed of independent steps that are parallel related will fail only if all of the steps fail. Thus, since reliability is 1 minus the probability for failure, we can write

$$Rp = 1 - (1-R1)\ (1-R2)\ (1-R3)\ .\ .\ .\ ,$$

where

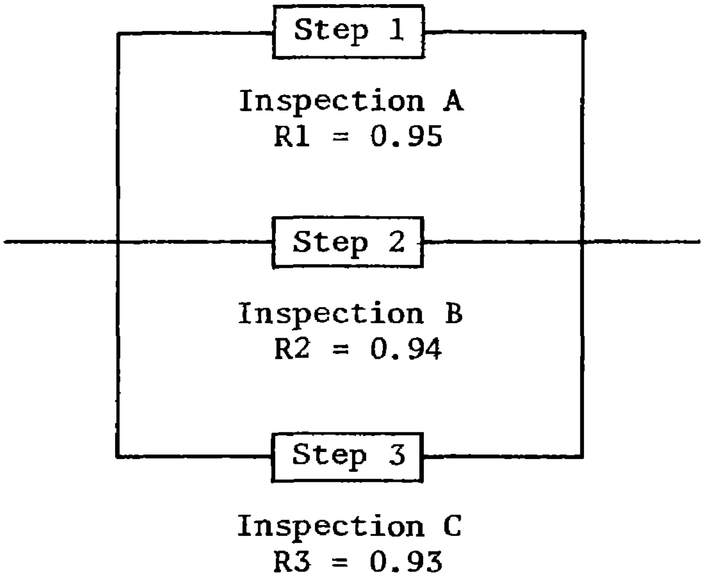
Rp is the reliability of the system

R1 is the reliability of step 1, and (1-R1) is the probability of failure of step 1

R2 is the reliability of step 2, and (1-R2) is the probability of failure of step 2

R3 is the reliability of step 3, etc.

The reliability of a step composed of parallel-related elements is obtained in the same manner. Consider the following example of parallel-related steps:



If steps 1, 2, and 3 are assumed to be independent, parallel-related steps, the reliability of this process is calculated as follows:

$$\begin{aligned} Rp &= 1 - (1-R1)\ (1-R2)\ (1-R3) \\ &= 1 - (0.05)\ (0.06)\ (0.07) \\ &= 1 - 0.00021 \\ &= 0.9998. \end{aligned}$$

Note that the reliability of the set of parallel steps is greater than the reliability of the set of steps that were in series, even though the step probabilities are the same. Further, even if step 3, for example, were reduced to 0.5, the overall reliability would still remain quite high:

$$\begin{aligned} Rp &= 1 - (0.05)\ (0.06)\ (0.5) \\ &= 1 - 0.0015 \\ &= 0.9985. \end{aligned}$$

14.2.11 Observations

(1) The addition of parallel steps can significantly increase the reliability of the installation procedures and systems in general.

(2) Addition of series steps can decrease the overall reliability.

(3) Increasing the reliability of individual steps, especially series-type steps, will increase the overall reliability.

(4) Errors must be avoided in deciding whether a step is a series type, a parallel type, independent, mutually exclusive, or redundant. One (exaggerated) error, for example, would be to assume that the three possible lubricating processes (thick, thin, or none), are parallel and independent steps. The possible lubricating procedures are not independent; they are mutually exclusive. Three independent and parallel steps would be an inspection to determine whether the O-ring is properly grooved by three separate people who do not influence each other before, during, or after their inspection. These three inspections are also examples of redundant steps. Redundant steps often improve reliability, and excess redundancies in production processes are not common.

(5) Replacement of a series step or a series part by several steps or parts connected in parallel is one way of increasing reliability. A good example is replacing a single O-ring with a double O-ring so that leaks will be prevented by either O-ring.

14.2.12 Definition of Mutually Exclusive Steps. Two or more steps are called mutually exclusive if the occurrence of any one of them excludes the occurrence of the others. For example, "You can't have your cake and eat it, too."

14.2.13 Definition of Redundant Steps. Two or more alternatives in a step are called redundant if they are independent and failure of all except any one alternative would not cause failure of the step. Unfortunately for reliability, Webster defines redundant as excessive or superfluous. In engineering, that is not necessarily so. Although the third wire in industrial and household wiring, for example, is a redundant grounding path, it cannot be called excessive or superfluous since it has saved and will save many lives from death by electrocution. In this case, it is obvious that the increased reliability due to a redundancy in return grounding wires is well worth the increased cost.

14.2.14 Definition of Failure. Failure has many meanings, and it must be defined for each use if there is any question about the intended meaning. Failure is used in this section to mean at least three things:

(1) The lack of occurrence of a step or the occurrence of a defect in an element; the probability of Type 1 failure is used to evaluate the reliability of the step or element and finally the system.

(2) The occurrence of a reliability for the overall installation procedure that is less than acceptable; the installation procedure is a failure if it does not produce a product with a high reliability.

(3) The failure of individual seals before 5 years (or some other acceptable period) of service. Such seals should be autopsied to determine which element, step, system, design, or use factor caused the failure. The result can then be used to correct the value used for the probability of Type 1 failures.

14.2.15 O-Ring Installation Using Series and Parallel Type Steps. Table 14.1 shows a "first-cut" at separating some of the steps involved in O-ring installation into series or parallel steps. This separation is intended only to develop a feeling for the influence of the steps on the reliability of an installation procedure.

14.2.16 Important Interpretations. The purpose of Table 14.1 is to provide a first cut at separating major series steps from the numerous more-parallel-than-series steps and to indicate the difficulty of categorizing the latter into either exclusively series-type steps or exclusively parallel-type steps. For example, the step "Withdraw O-ring" is certainly a series step in that absence of an O-ring means that the final seal will fail; i.e., no O-ring, no seal. The step "Withdraw the Correct O-Ring" cannot be accurately called a series step unless failure is defined as installation of any O-ring except the specified O-ring. There is a chance that an O-ring other than the specified one will produce a seal; however, the chance is extremely small, perhaps 1 in 10,000, that the seal will perform satisfactorily in service. Therefore, not only do we withdraw an O-ring but we try to ensure that it is the correct O-ring by proper checks and inspections, and thus increase the reliability of the withdrawal step. The same reasoning can be applied to all steps and thus the whole installation. If all of the steps were completely series or parallel, we could simply apply the definitions and relationships that have been developed in this section, and thus write the exact equation for the reliability of the O-ring installation. Then, if the reliability of each step were known or assumed and substituted into the equation, the numerical value of the reliability of the installation could be calculated. Then the improvement in the reliability of the installation by changing steps or the reliability of individual steps could be numerically evaluated. Accurate prediction of seal reliability and the effects of design changes on that reliability will require standardization of design and fabrication, and careful failure analysis, reliability analysis, and data collection.

Table 14.1. Example of a "first cut" at separating installation steps into series or parallel types.

SERIES	PARALLEL
Get installation assignment	Understand job Read work request Refer to engineering drawings Plan work
Handle O-ring	Handle gently Use rubber gloves Keep clean Store briefly only
Withdraw O-ring	Withdraw correct O-ring Inspect O-ring package Compare package markings Check cure date Account for O-ring Record O-ring disposition Discard out-of-date O-rings
Withdraw connector parts	Withdraw correct parts Check part numbers Compare size and shape
Lay out parts and O-ring	Count parts Plan steps and method Check sealing surface dimensions Inspect surface texture Inspect for burrs Inspect for contamination Lay out on clean area

Table 14.1, cont.

SERIES	PARALLEL
Clean parts	Use only proper solvents
	Use clean lint-free cloths
	Dry parts
	Clean sealing surfaces
	Clean adjacent areas
Remove O-ring from bag	Inspect O-ring for defects
	Check O-ring size
	Check O-ring cure date
	Discard if damaged or defective
	Record disposition
Obtain lubricant	Compare specifications
	Keep lubricant clean
	Don't use old or contaminated lubricant
Lubricate	Use proper lubricant
	Use proper amount on seal
	Use proper amount on O-ring
	Check lubricant quantity
	Check lubricant distribution
	Keep clean
	Use rubber gloves
	Use proper tools
	Use tools properly
Groove O-ring	Prepare for grooving
	Mask sharp edges
	Prevent rolling
	Prevent stretching
	Push evenly
	Remove twists
	Align parting line
	Evenly distribute O-ring
	Check for uneven height
	Check lubricant for quantity
	Check lubricant for distribution
	Push O-ring to back of the groove
	Add or remove lubricant
	Check for contamination
	Redundant inspection
	Record disposition
	Check for seal surface damage
	Check for O-ring surface damage
	Use proper tools
	Use tools properly

Table 14.1, cont.

SERIES	PARALLEL
Remove or degroove	Similar to grooving
Seat O-ring	Plan actions Position parts Support parts Careful aim at joining Prevent hard contact Check for contamination Check lubricant distribution Check lubricant quantity Check O-ring existence Check O-ring location Check part numbers Align pins Align keys Align piston and cylinder Apply steady forces Prevent rotation Avoid impacts On O-ring contact, steadily increase force to produce squeeze and seating Check seating Check clearances Check snugness Compare configuration with drawing Check torque resistance if allowed Tag assembly Record disposition
Assembly	Confirm task completion Confirm task was completed satisfactorily.

15. BIBLIOGRAPHY

15.1 Numerical Listing of Applicable Standards, Handbooks and Specifications (Refer to Section 15.3 for sources of standards)

SAE J14	Specifications for Elastomer Compounds for Automotive Applications. (Cancelled 1980. Superseded by SAE J200 and ASTM D2000.)
USASI B46.1-1962	Surface Texture: Surface Roughness, Waviness and Lay (Revised as ANSI B46.1-1978).
MIL-STD-105D	Sampling Procedures and Tables for Inspection by Attributes. Notice 2
MIL-P-116G	Methods of Preservation-Packaging
SAE J120A	Rubber Rings for Automotive Applications
MIL-STD-129H	Marking for Shipment and Storage. Notice 1, 1 Nov 78
MIL-STD-130E	Identification Marking of U.S. Military Property
MIL-STD-177A	Terms for Visible Defects of Rubber Products
MIL-STD-190C	Identification Marking of Rubber Products
SAE J200F	Classification System for Elastomeric Materials for Automotive Applications
MIL-HDBK-212	Gasket Materials (nonmetallic)
MIL-STD-413B	Visual Inspection Guide for Rubber O-rings
MIL-STD-417A	Classification System and Tests for Solid Elastomeric Materials (inactive for new design), Notice 1 (MR)
ANA-BULL 438	Age Controls of Age-Sensitive Elastomeric Items, Rev. C (cancelled; superseded by MIL-STD-1523).
SAE J515A	Hydraulic O-ring
ARP 568	Uniform Dash Numbering System for O-Rings. Superseded by AS568.
AS 568A	Aerospace Size Standard for O-ring.
FED-STD-601	Rubber, Sampling and Testing. Notice 7, 17 Aug 76
NAS 617-60	Packing Pre-formed, Straight Thread Tube-Fitting Boss, Synthetic Lubricant Resistant
MIL-HDBK-692A	A Guide to the Selection of Rubber O-rings

MIL-HDBK-695A	Rubber Products, Shelf Storage Life. Notice 3, 1 May 77
MIL-HDBK-699A	A Guide to the Specifications for Flexible Rubber Products
AS 708-65	Top Visual Quality O-ring Packaging and Gaskets.
MIL-STD-726F	Packaging Requirements Code. Notice 3, 28 Mar 78.
ASTM D735	Surface Inspection Guide and Acceptance Standards. (Cancelled. Superseded by SAE J200 and ASTM D2000.)
TT-S-735	Standard Test Fluids, Hydrocarbon
AS 757	Straight Thread Boss Dimensions
ZZ-R-765B(1)	Rubber, Silicone. (O-ring material specifications.)
AIR 786A-72	Elastometer Capability Considerations Relative to O-ring and Sealant Selection
AS 871A	Manufacturing and Inspection Standards for Pre-formed Packaging, O-Rings
MIL-G-1149B	Gasket Material, Synthetic Rubber, 50 and 65 Durometer Hardness
ARP 1231-73	Gland Design, Elastometer O-Ring Seals, General Considerations
ARP 1232A-77	Gland Design, Elastometer O-Ring Seals, Static Radial
ARP 1233-77	Gland Design, Elastometer O-Ring Seals, Dynamic Radial 1500 psi max.
ARP 1234A-79	Gland Design, Elastometer O-Ring Seals, Static Axle without Backup Rings
MIL-STD-1523	Age Control of Age-Sensitive Elastomeric Material
NAS 1593	Packing, Pre-formed, MIL-R-25897 Rubber, 75 Shore, O-Ring
NAS 1594	Packing, Pre-formed, MIL-R-25897 Rubber, 90 Shore, O-Ring
NAS 1595	Packing, Pre-formed, Straight Thread Tube-Fitting Boss, MIL-R-25897 Rubber, 75 Shore, O-Ring
NAS 1596	Packing, Pre-formed, Straight Thread Tube-Fitting Boss, MIL-R-25897 Rubber, 90 Shore, O-Ring

NAS 1613	Packing, O-Ring, Phosphate Ester Resistant
AIR 1707	Patterns of O-Ring Failures, Aerospace Information Report
ASTM D2000-80	Rubber Products in Automotive Applications, 28 Mar 80
AMS 2817B-75	Packaging and Identification, Pre-formed Packaging
MIL-R-3065D	Rubber, Fabricated Parts
AMS 3200E	Rubber, Nitrile, Petroleum-Base, Hydraulic Fluid Resistance 55-65
AMS 3201G-75	Rubber, Nitrile, Dry Heat Resistant 35-45
AMS 3202G-75	Rubber, Nitrile, Dry Heat Resistant 55-65
MIL-G-4343B	Grease, Pneumatic System
MIL-Q-9858A	Handwheel, Ordnance
MS 9970	Packing, Pre-formed, AMS 7279, O-Ring
MIL-P-25732	Packing, Pre-formed, Petroleum Hydraulic Fluid Resistant, Limited Service at 275°F (135°C)
MS 28775D	Packing, Pre-formed, Hydraulic, Plus 275°F (O-Ring)
MS 28778B	Packing, Pre-formed, Straight Thread Tube Fitting Boss
MS 28784D	Packing, O-Ring, Hydraulic, 275°F (Cancelled; superseded by MS 28775)
MS 28900	Packing, Pre-formed, for Electrical Use. (For sizes, see Reference 28)
MIL-P-4861B(4)	Packing, Pre-formed, Rubber, Packaging of
MIL-P-5315B(1)	Packing, Pre-formed, Hydrocarbon Fuel Resistant
MIL-P-5510C	Packing, Pre-formed, Straight Thread Tube Fitting Boss, Type 1 Hydraulic (-65° to 160°F)
MIL-G-5514F	Gland Design, Packings, Hydraulic, General Requirements For
MIL-P-5516C(2)	Packing, Pre-formed, Petroleum Hydraulic Fluid Resistant, 160°F. (Use MIL-P-25732 or MIL-P-83461)

AN6227 Packing, O-Ring Hydraulic (Rev. 8). (Compound per MIL-P-5516). O-ring dimensions correspond with AS568, but dash numbers are different. The table shows AN and AS corresponding dash numbers.

AN 6227	AS 568	AN 6227	AS 568	AN 6227	AS 568	AN 6227	AS 568
1	006	23	218	45	342	67	440
2	007	24	219	46	343	68	441
3	008	25	220	47	344	69	442
4	009	26	221	48	345	70	443
5	010	27	222	49	346	71	444
6	011	28	325	50	347	72	445
7	012	29	326	51	348	73	446
8	110	30	327	52	349	74	447
9	111	31	328	53	426	75	448
10	112	32	329	54	427	76	449
11	113	33	330	55	428	77	450
12	114	34	331	56	429	78	451
13	115	35	332	57	430	79	452
14	116	36	333	58	431	80	453
15	210	37	334	59	432	81	454
16	211	38	335	60	433	82	455
17	212	39	336	61	434	83	456
18	213	40	337	62	435	84	457
19	214	41	338	63	436	85	458
20	215	42	339	64	437	86	459
21	216	43	340	65	438	87	460
22	217	44	341	66	439	88	425

AN6230 Gasket, O-ring Hydraulic (Rev. 8). (Compound per MIL-P-5516). O-ring dimensions correspond with AS 568, but dash numbers are different. The table shows AN and AS corresponding dash numbers.

AN 6230	AS 568	AN 6230	AS 568	AN 6230	AS 568	AN 6230	AS 568
1	223	14	236	27	249	40	262
2	224	15	237	28	250	41	263
3	225	16	238	29	251	42	264
4	226	17	239	30	252	43	265
5	227	18	240	31	253	44	266
6	228	19	241	32	254	45	267
7	229	20	242	33	255	46	268
8	230	21	243	34	256	47	269
9	231	22	244	35	257	48	270
10	232	23	245	36	258	49	271
11	233	24	246	37	259	50	272
12	234	25	247	38	260	51	273
13	235	26	248	39	261	52	274

15.2 Selected References

1. Smoley, E.M., "Sealing with Gaskets," Machine Design, October 27, 1966.

2. Andrews, J.N., "Hollow Metal O-rings," Product Engineering, November 26, 1962.

3. Freeman, A.R., "Gaskets for High Pressure Vessels," ASME, Paper No. 52-11RD-5.

4. Elonka, S., "Gaskets," Power, March 1954.

5. "Design Manual on Nonmetallic Gaskets," Machine Design, 1954.

6. "Seals Reference Issue," Machine Design, June 19, 1969.

7. Warring, R.H., Seals and Packings, Trade and Technical Press, Ltd., Norden, Surrey, England, 1967.

8. Denny, D.F. and C.M. White, "The Sealing Mechanism of Flexible Packings," London: His Majesty's Stationery Office, 1948.

9. Bridgman, P.E., The Physics of High Pressure, Macmillan Co., New York, 1931.

10. Barbarin, R., "Keeping Seals Tight," Machine Design, August 26, 1976, pp. 92-93.

11. Ratelle, W., "Seal Selection Beyond 'Standard Practice,'" Machine Design, January 20, 1977, pp. 133-137.

12. Wilson, J.V., "Sonar Cable and Connector Problems," FY-78 STRIP TASK C-1 NRL; Tech. Memo. No. 43-79-01, Civil Engineering Laboratory, Port Hueneme, California 93043.

13. Sandwith, C.J. "Performance/Failure Analysis of Acoustic Array Connectors After 6-10 Years of Service," OCEANS 78-74-76790, September 1978, pp. 273-286.

14. Mark's Standard Handbook for Mechanical Engineers, Seventh Edition, Sections 6 and 8, 1958.

15. O-Ring Handbook ORD-5700, Parker Hannifin Corporation, Lexington, Kentucky.

16. O-Ring Guide for Industrial Maintenance Men, Parker Hannifin Corporation, Lexington, Kentucky.

17. O-Ring Guide for Aircraft Maintenance Men, Parker Hannifin Corporation, Lexington, Kentucky.

18. Abo, M.M., "Analysis of Array Components Recovered at St. Croix, VI," NAVTORPSTA Report 1332, Naval Torpedo Station, Keyport, Washington, May 1977.

19. Reference Manual on Interference Seals and Connectors for Undersea Electrical Applications, prepared by the Applied Physics Laboratory of the University of Washington for the Naval Facilities Engineering Command, Chesapeake Division (available from NTIS, 5285 Port Royal Road, Springfield, Virginia 22161; ref. Publ. ADA 036841), June 1976.

20. Jenkins, J.F., "Inspection of Objects Retrieved from the Deep Ocean - AUTEC Acoustic Array," Technical Note 1424, Civil Engineering Laboratory, Port Hueneme, California, February 1976.

21. "Design Recommendations for Pressure Proof Plug to Receptacle Seals," Static Seals Panel, Undersea Cable and Connector Committee, Marine Technology Society (assembled by Raymond Haworth, Carl Schweichert, and Edward Swartz), July 23, 1971.

22. Atkinson, W.B., "Gasket Materials for Electrical Equipment," Product Engineering, December 1949.

23. Frazier, E.C., "Designing for Economical Gasketing," Product Engineering, July 1951.

24. Bolz, R.W., "Gaskets in Design," Machine Design, March 1945.

25. Thron, F.C., "Compression and Stress Decay in Rubber Gaskets," ASTM Bulletin, October 1941.

26. Haworth, R.F., "Handbook for Connector and Cable Harness Design," (in preparation).

27. Sandwith, C.J., "Painting O-Ring Sealing Surfaces to Prevent Corrosion," in Corrosion Control by Organic Coatings, Henry Leidheiser, Jr., ed., National Association of Corrosion Engineers, 1981, pp. 285-294.

28. "National O-Ring Design Guide," OR-15R, Federal Mogul Corp., 1975 (rev. 1979).

15.3 Information Sources

15.3.1 Organizations

ORGANIZATION	LOCATION	CONTACT
Parker Hannifin Corp.	Culver City, CA	Robert Barbarin R.G. Ramsdell
Electric Boat	Groton, CT	Ray Haworth
Mare Island Naval Shipyard	Vallejo, CA	Barry Jan Cliff Porterfield (retired, Code 2703)
NAVSEC	Washington, D.C.	John Pratchios 6107BD
Naval Research Laboratory	Orlando, FL	Robert Timme Dick Hugus
Applied Physics Laboratory	University of Washington, Seattle, WA	Colin Sandwith
NUSC	New London, CT	Charlie Olds
NUWES	Keyport, WA	Joseph Abo Kay Miner Jack Green
University of Washington	Seattle, WA	James Morrison
D.G. O'Brien Co.	Seabrook, NH	D.G. O'Brien
Vector Cable Co.	Sugarland, TX	Tim Tyler
Parker Hannifin Corp.	Lexington, KY	Thomas Polk Dutch Haddock
Dow Corning	Midland, MI	David Romenesko George Kubezak

15.3.2 Standards and Specifications

1. All military listings in the Department of Defense Index of Standards and Specifications can be ordered, preferably with DD Form 1425, from:

   Commanding Officer
   Naval Publications and Forms Center
   ATTN: NPFC 3015
   5801 Tabor Avenue
   Philadelphia, PA 19120

   Refer to Department of Defense Index of Specifications and Standards (DODISS), Part I and Part II, for a complete alphabetical listing and other source information. DODISS is available to military activities from:

   Commanding Officer
   Naval Publications and Forms Center
   5801 Tabor Avenue
   Philadelphia, PA 19120

   and to private industry and individuals from:

   Superintendent of Documents
   U.S. Government Printing Office
   Washington, D.C. 20402

2. Federal Standardization Documents (TT-, ZZ-, and others) are available from:

   General Services Administration
   Specification and Consumer Information
   Distribution Section (WFSIS)
   Washington Navy Yard, Bldg. 197
   Washington, D.C. 20407

3. ANSI standards can be ordered from:

   American National Standards Institute (ANSI)
   Sales Department
   1430 Broadway
   New York, NY 10018

4. AS, ARP, AMS, and AIR sets of standards can be ordered from:

   Society of Automotive Engineers, Inc. (SAE)
   Dept. 331
   400 Commonwealth Drive
   Warrendale, PA 15096