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Installation and Use of Equilateral Triangle Cross-Section Hydraulic O-Ring Seal Backup Rings (Dyna-Baks)

1. INTRODUCTION:

The use of equilateral triangle cross-section hydraulic seal backup rings has been found to improve the life and reliability of high pressure O-ring seals especially for high temperature applications. This Aerospace Information Report (AIR) describes the design and operation of these backup rings, tabulates recommended seal groove and gland dimensions, offers recommendations and suggestions for their installation into hydraulic components, and outlines their advantages and limitations of their use.

2. DESCRIPTION:

2.1 Use:

The subject backup rings, sometimes called Delta backup rings and more commonly known as Dyna-Bak seal control rings, are used in both male and female configurations for piston type and rod gland type seals respectively. (See Fig. 1) They were developed specifically as anti-extrusion rings to protect elastomeric O-ring seals from extrusion into the clearance space between relatively moving or relatively stationary hydraulic component members where the elastomeric O-ring is used as either a static or dynamic fluid seal for any class of fluid service, but especially for use in high pressure hydraulic systems used in aircraft and aerospace vehicles. They also function to reduce O-ring wear and spiral failures in high pressure applications and leakage due to O-ring compression set in high temperature applications.

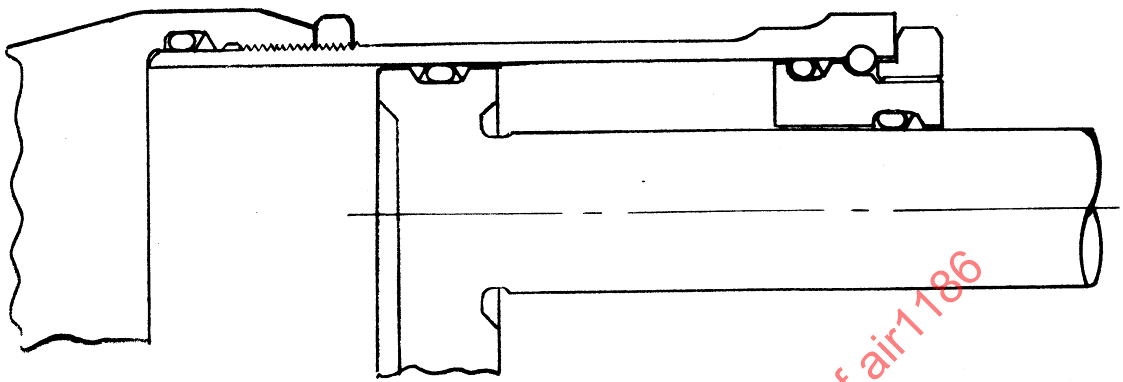


FIGURE 1 - TYPICAL DYNA-BAK INSTALLATIONS

2.2 Geometry:

The cross-sectional shape of the backup ring is in the form of a nearly perfect equilateral triangle with the base angles ø approximately matching the face angle θ of the seal groove. (See Fig. 2.) The sizes have been standardized for use with standard O-ring sizes per AS568, and part numbers correspond to the uniform dash number sizes. The standard groove diameters are per the dimensions of Table I of MIL-P-5514, and the rings are designed for use with the standard cylinder bore, piston rod, male gland bore, and female gland sleeve diameters contained therein.

The height of the backup ring is approximately 80 percent of the annular depth of the seal groove allowing generous radii at the bottom of the groove. Groove widths are sized to allow installation of O-ring and backup ring with relative ease without excessive side play and yet accommodate normal O-ring swell.

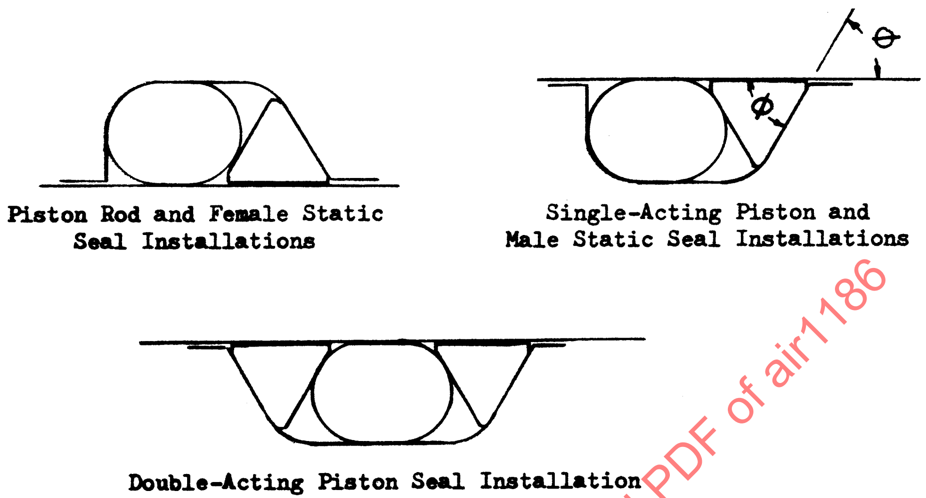


FIGURE 2 - BACKUP RING AND SEAL GROOVE GEOMETRY

2.3 Continuous or Scarf-Cut Rings:

The backup rings can be used either as continuous, uninterrupted rings or in a diagonally scarf-cut configuration. The scarf-cut rings are more easily installed in the seal grooves and will function satisfactorily in a great number of applications. For maximum seal protection, both during assembly of the hydraulic component and during operation, however, they should be used uncut. After a large number of cycles, the edges of the scarfed joint will eventually break down forming an extrusion gap where the O-ring will finally extrude and fail.

2.4 Materials:

The backup ring must be made of a material which is harder and substantially more resistant to extrusion than the O-ring it is designed to protect if it is to prevent O-ring extrusion without creating problems due to itself extruding into the clearance space between sealed members. On the other hand, the backup ring must be made of a relatively resilient stretchable material if it is to be installed in the non-cut configuration, in a normal one-piece seal groove. Pure Teflon TFE and various compounds of Teflon filled with materials such as graphite, bronze, and aluminum oxide fiber with molybdenum disulphide have all been tested with considerable success. Graphite-filled Teflon rings have demonstrated long life as rod seals at 400°F (204°C). The aluminum oxide fiber filled Teflon impregnated with molybdenum disulphide has proven satisfactory for piston rod seal backup rings at temperatures up to 550°F (288°C) but a very hard rod surface, such as flame plated tungsten carbide, must be used to prevent abrasive wear. For high temperature applications where extrusion resistance without abrasiveness is required, the polyimide resins, possibly modified with graphite, or other fortified polymers may have a more optimum combination of properties.

3. OPERATION:

3.1 Prevention of O-ring Extrusion and Nibbling Failures:

It is well known that, at pressures above 1500 psi, an O-ring seal is highly susceptible to extrusion and nibbling failure resulting from it. The nibbling occurs when a small portion of the O-ring which has extruded into the clearance space is cut off either by pressure relaxation and subsequent closing of the clearance space or by dynamic motion. Repeated applications can cause an O-ring to be completely chewed up. In rapidly pulsating systems, in the presence of high frequency vibrations, this has been known to occur in less than an hour. What is not so well known is that the rectangular cross-section Teflon backup rings, normally used to prevent extrusion, are unable to do so under the combined action of high pressure and temperature. Because of the standard backup's inability to seat firmly both on the sealing surface and in the bottom of the seal groove, an extrusion gap is always open (see Fig. 3) and, at high temperature, the O-ring being almost fluid will seek any gap. With the triangle design, however, pressure against the O-ring drives the backup ring upon the groove ramp camming it down on the sealing surface thereby positively closing all clearance gaps.

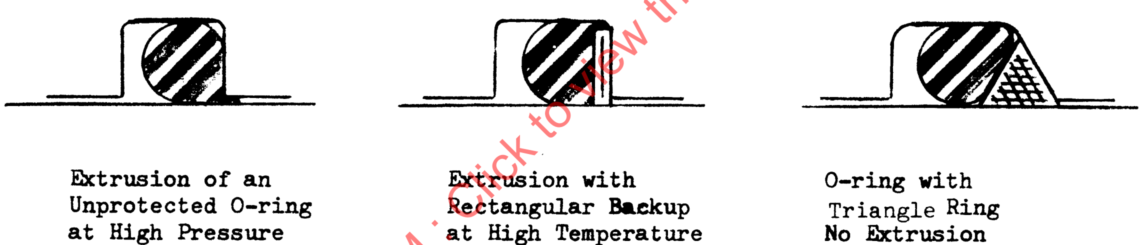


FIGURE 3 - EXAMPLES OF O-RING EXTRUSION

3.2 Prevention of O-ring Spiralling:

O-ring spiralling and resulting tearing is a phenomenon which occurs when the O-ring in dynamic axial reciprocating service does not slide uniformly against its mating sealing surface. In such a case, the O-ring might slide against the piston rod (or cylinder wall) for a portion of its circumference and roll on it for the remainder. In the process of so doing, the O-ring would be made to twist about its cross-sectional axis and eventually tear in a distinctive and classical shear pattern. This type of failure is readily distinguishable by long, spiral-like tears in the O-ring surface. Such a failure frequently occurs where the surface against which the O-ring is meant to seal in a sliding manner is poorly or irregularly lubricated. There are other conditions that can accelerate or induce spiral failure in large diameter O-ring seals, such as used in landing gear shock struts.

The triangular seal backup ring acts to minimize O-ring spiral failures because of its geometry. As can be seen in Fig. 4, the rubber-like material of the O-ring has been urged by pressure up the ramp of the backup ring thereby transferring the bulk of the sealing force against the relatively sliding surface from the O-ring to the backup ring.

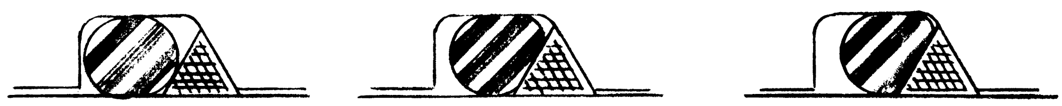


FIGURE 4 - MOVEMENT OF O-RING AGAINST TRIANGLE RING UNDER PRESSURE

3.2 (Continued):

White and Denny (see Reference 8.3) found by using a transparent hydraulic cylinder that O-rings used in undercut seal grooves would pull away from the sealing surface under pressure sufficiently to reduce the "footprint" or area in contact. (See Fig. 5.) By using a traveling microscope, they measured the movement and distortion of the seal under pressure. In their report, they presented data showing the variance of contact length under various pressures, groove undercut angles, and O-ring hardnesses from 60° to 90° Shore Durometer.

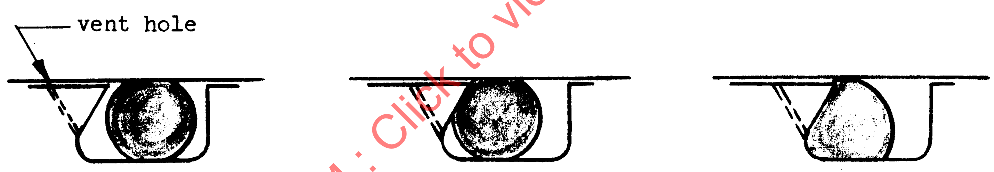


FIGURE 5 - DISTORTION OF O-RING UNDER PRESSURE IN UNDERCUT GROOVE

The triangle rings work in the same way as the undercut seal groove to reduce O-ring footprint area. Thus the tendency to spiral under high pressures is greatly minimized by two factors:

A. The backup ring carries a major portion of the sliding load against the sealing surface.

B. The O-ring is operating at reduced force against the sliding sealing surface and is wedgingly urged with great force and grip into the trapezoidal cavity formed by the seal gland and the backup ring.

Substantiating evidence of the validity of this design is found in the use of a similar backup ring which solved a severe nuisance leakage problem on the early B-52 landing gear shock struts due to O-ring spiralling. The use of the triangular backup ring completely solved the problem.

3.3 Reduction of O-ring Wear:

The same feature which eliminates the tendencies for spiral failure is a strong advantage in reducing the normal abrasive wear on the O-ring. The fact that pressure urges the O-ring into the trapezoidal cavity of the backup and the seal gland and forces the backup to carry the sliding load against the sealing surface minimizes the sliding load on the O-ring and greatly increases its normal operating life. White and Denny found that undercut grooves also greatly reduced the rate of O-ring wear.

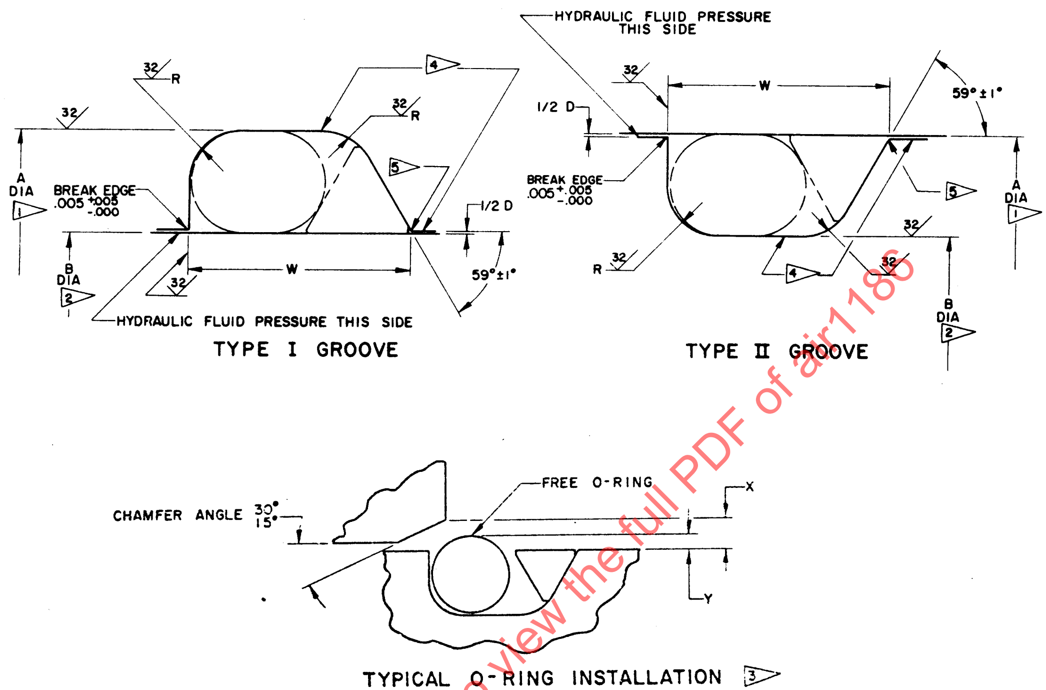
3.4 Reduction of Leakage Due to O-ring Compression Set:

Again, the geometry of the backup is a significant factor in allowing a high degree of compression set of the O-ring material to occur before it will affect the integrity of the seal. The very nature of the ramp-like surface of the backup facing the O-ring is such that, as pressure is applied, the backup will be forced sealingly against the sliding sealing surface (or stationary surface in the case of static seals). If no elastic recovery at all remains in the O-ring material, the backup would not necessarily be a reliable seal. However, very little residual elasticity in the O-ring is necessary to insure that the backup is forced into a sealing contact with its mating surface.

4. SEAL GROOVE AND GLAND DESIGN:

4.1 Groove Dimensions:

Recommended seal groove dimensions for the equilateral triangle cross-section backup rings used with standard size O-rings are shown in Fig. 6 and Table I.



1 DIMENSION "A" IS THE I.D. OF ANY SURFACE CONTACTED BY THE OUTSIDE CIRCUMFERENCE OF THE O-RING.

2 DIMENSION "B" IS THE O.D. OF ANY SURFACE CONTACTED BY THE INSIDE CIRCUMFERENCE OF THE O-RING.

3 CHAMFER TO SERVE AS "SHOE-HORN" TO FACILITATE INSTALLATION. MINIMUM X DIMENSIONS SHALL BE GREATER THAN MAXIMUM Y.

4 THESE SURFACES TO BE CONCENTRIC WITHIN THE FOLLOWING LIMITS (T.I.R.): .002 THRU -149, .003 FROM -210 THRU -274, .004 FROM -325 THRU -349, .005 FROM -425 THRU -443.

5 THIS EDGE TO BE CLEAN AND SHARP WITHIN .005 ± .003 EQUIVALENT RADIUS.

GROOVE CALL-OUTS SHALL SPECIFY GROOVE TYPE AND DASH NUMBER I.E. TYPE I GROOVE PER AIR 1186.

FINISH: 63 (PER USAS B46.1) UNLESS OTHERWISE NOTED.

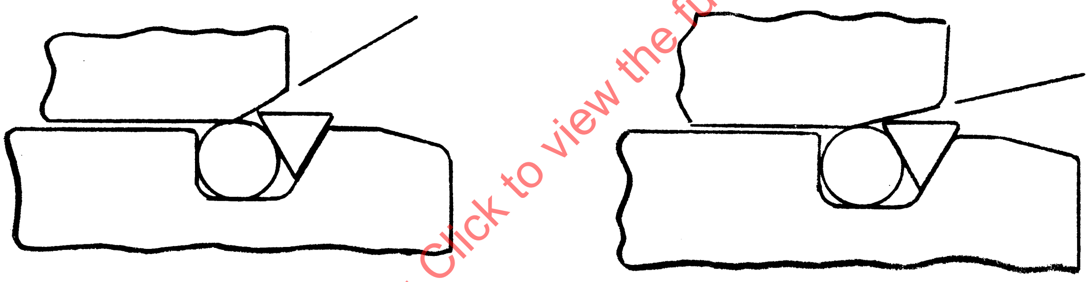
FIGURE 6 - RECOMMENDED SEAL GROOVE DIMENSIONS (ALSO SEE TABLE I)

4.2 OD Chamfers:

All edges of pistons, land, or other male diameters over which the seal must be installed should be adequately chamfered. These chamfers should be 30° maximum and all sharp edges rounded and polished. Wherever practicable, 15° chamfers should be used.

4.3 ID Chamfers:

Entrance chamfers to cylinders and other sealing bores should be held to 10° to 20° except as noted below. Note that this is a more shallow chamfer than the 15° to 30° angle suggested by MIL-P-5514. It is important in most cases, however, that the 10° to 20° chamfer be maintained in order to prevent pinching and shearing of the backup ring, especially scarf-cut backup rings, due to wedging action of the O-ring as illustrated in Fig. 7. For installations where the backup ring precedes the O-ring into the bore, a 15° to 30° entrance chamfer is adequate.



Chamfer angle too deep. O-ring wedges backup out of groove pinching and shearing it.

10° to 20° chamfer. Wedging insufficient to damage backup ring

FIGURE 7 - ILLUSTRATION OF THE IMPORTANCE OF SHALLOW ID CHAMFERS

4.4 ID Entrance Diameters:

To prevent pinching and shearing of the O-ring during assembly of parts, entrance diameters to inlet chamfers must always be greater than the free O-ring diameter. (See Fig. 8.) In determining that this requirement is met, the maximum groove diameter coupled with the maximum O-ring cross-section diameter within their respective tolerance ranges must be smaller than the minimum entrance chamfer within its tolerance range.

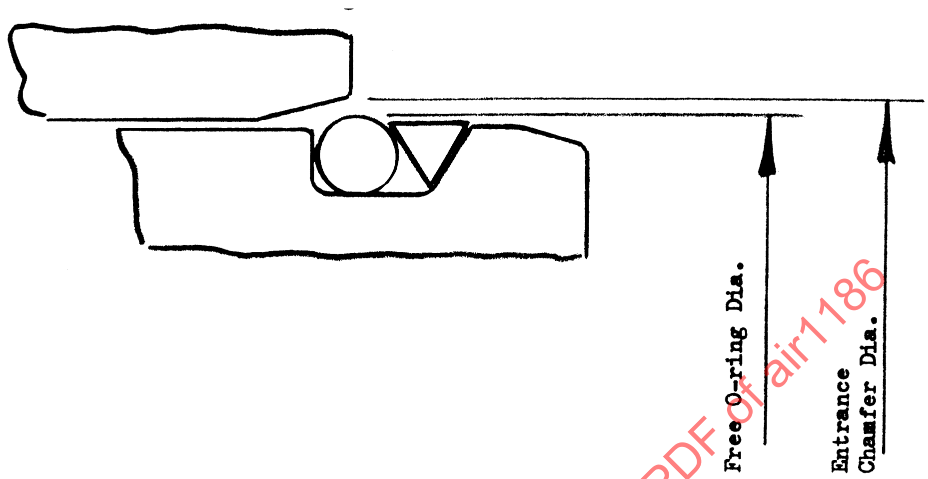


FIGURE 8 - ENTRANCE DIAMETERS MUST ALWAYS BE GREATER THAN FREE O-RING DIAMETER

4.5 Thread Clearance:

Components should be designed such that no damage to O-rings or backup rings will be incurred on installation by passing over threads or other sharp corners. The diameters of threads over which, or through which, packings confined in glands must be inserted at installation should be of such size that there will be a diametral clearance between the packings and the thread at the most unfavorable extreme tolerance. Chamfered edge annular undercuts should be used at all crossholes and intersecting oil ways. All threads and chamfered edges over which O-rings or backup rings will pass should have rounded edges with all machining burrs, dents, and nicks polished out.

4.6 Chamfers at Cross-Holes:

In addition, chamfers should be used at the ends of bores with sloped areas clear of intersecting holes. This is required because where a packing under squeeze crosses even a round-edge cross-hole, it may be partially severed as a result of localized protrusion. Illustrations of an unacceptable and an acceptable design are shown in Fig. 9.

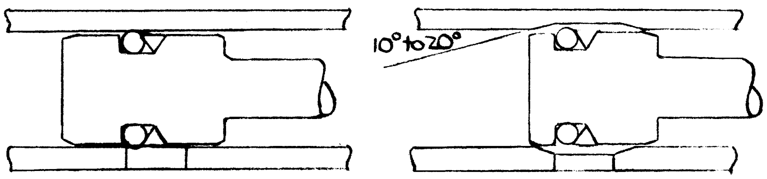


FIGURE 9 - RECOMMENDED CROSS-HOLE CHAMFER

5. INSTALLATION OF THE TRIANGULAR BACKUP RING IN ITS GROOVE:

5.1 Installation Over Short Piston Lands:

To install a continuous, non-cut, backup ring over a short piston land into a male groove, it is often possible to start with a short length in the groove and stretch the remainder over the land by gentle thumb pressure. With backup ring diameters at the small end of the range for each cross-section size, they may be difficult to stretch even over a short piston land. With virgin Teflon and graphite-filled Teflon, the rings become sufficiently pliable for installation by heating for a minute or so by use of a heat ray gun or by dipping in boiling water.

5.2 Installation Over Long Piston Lands or Threads:

For installation of continuous, non-cut, backup rings over long piston lands or threads preceding the seal groove, the following procedure is recommended:

A. Install a thin-wall bull-nosed thimble, similar to that shown in Fig. 10, over the piston land and/or threads.

B. Heat the backup ring and slide it onto the nose of the thimble then slide it uniformly up the ramp and along the skirt and into the seal groove. In many cases, thumbnail pressure will be adequate; however, a colleted pushing tool, as shown in Fig. 11, or a sleeve may prove useful in certain sizes or for production work.

C. The backup ring can then be allowed to slowly return to its initial diameter, due to the characteristic memory of Teflon, or be sized back to its initial diameter by inserting into a sizing bore similar to that shown in Fig. 12 or into the actual cylinder bore if an adequate inlet chamfer is provided. In cases where a sizing bore cannot be used, such as where a shoulder adjacent to the seal groove prevents full entry into a sizing bore, the reapplication of heat followed by placement of a properly-sized rubber band can be used to contract the ring back to size. The backup ring should always be allowed to return to its normal size prior to insertion into the cylinder bore.

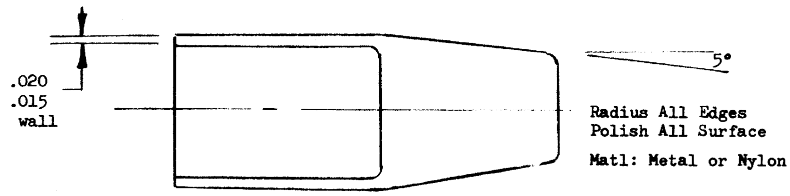


FIGURE 10 - BULL-NOSED THIMBLE

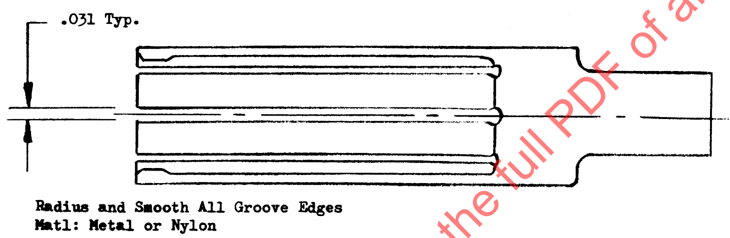


FIGURE 11 - COLLETING PUSHING TOOL

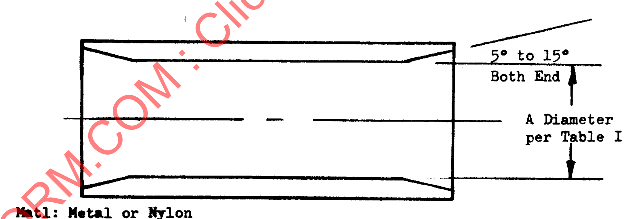


FIGURE 12 - SIZING BORE

5.3 Installation of Continuous Rings in Stiffer Materials:

For backup rings made of material less stretchable than Teflon, it may be necessary to use builtup grooves if the continuous non-cut rings are to be installed. The extra complexity may be warranted in order to obtain the added degree of protection offered by the continuous rings especially for high temperature or extremely long life applications.

5.4 Installation Into Female Grooves:

The installation of continuous, non-cut, backup rings into female grooves, is easily accomplished in most sizes by squeezing the ring into an ellipse and bending it so that it can be started into the groove. It can then be worked in the groove all around by gentle finger pressure. For ring diameters at the small ends of the size ranges, it may be necessary to heat as in the case of the male rings.

6. WEIGHT SAVING ADVANTAGE:

6.1 In addition to the reliability advantages, the use of the triangular backup rings allows a lower weight installation than the standard O-ring installation with two backup rings per MIL-P-5514 due to three factors, i.e.:

A. Due to a narrower groove

B. Due to elimination of a corner on the low pressure side of the groove

C. Due to reduction in metal behind the seal groove allowed because the larger corner radii in the bottom of groove reduces stress concentrations

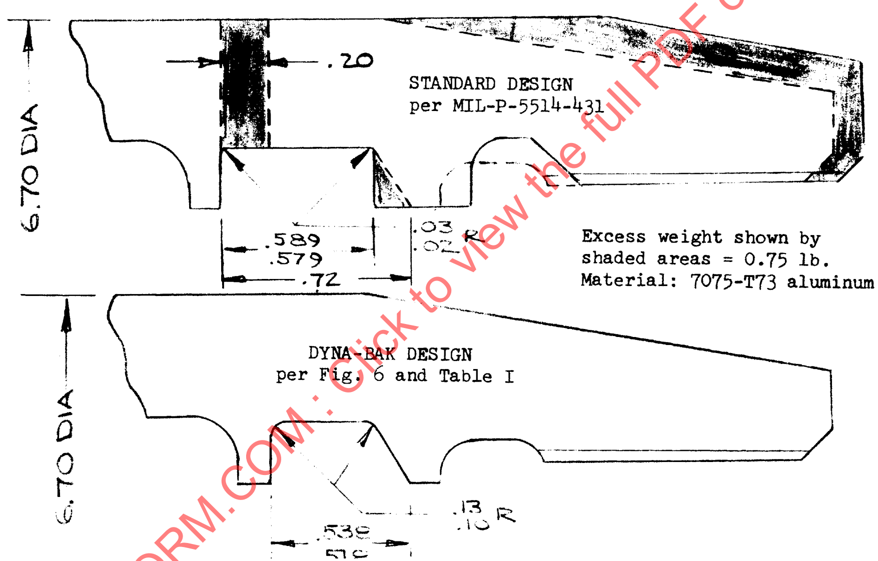


FIGURE 13 - ILLUSTRATION OF WEIGHT SAVING WITH TRIANGULAR BACKUP INSTALLATION

These may seem like minor increments; however, when totaled up they can produce a significant weight saving. In Fig. 13, the weightsaving for a single seal installation in an aluminum housing is shown. In an actual dual-tandem hydraulic flight control servoactuator, made of 200,000 psi steel alloy and weighing approximately 100 lb (45 kg), wherein Dyna-Baks were used as static seals and piston rod seals throughout, a weight saving of 3.5 lb (1.6 kg) was achieved, approximately 3.5%.