SURFACE VEHICLE RECOMMENDED PRACTICE

J2310™ DEC2024

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Superseding J2310 OCT2019

(R) Rectangular Cross Section Polymeric Sealing Rings

RATIONALE

This standard has been revised to provide updated seal material physical properties, add detailed calculations in 5.1 and 5.3, and improve clarity throughout the document.

SAE J2310 has been reaffirmed to comply with the SAE Five-Year Review policy.

1. SCOPE

The purpose of this SAE Recommended Practice is to establish guidelines for the automatic transmission and hydraulic systems engineer to design rectangular cross section seals for rotating and static grooved shaft applications. Also included are property comparisons of polymeric materials suitable for these applications. Historically, material covered in this document is not intended to include aluminum contact applications.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this specification to the extent specified herein. Unless otherwise indicated, the latest issue of SAE publications shall apply.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

SAE J1236 Cast Iron Sealing Rings (Metric)

Crawford, S., McMahan, T., and Van Ryper, R., "Improving Automatic Transmission Quality with High Performance Polyimide Rotary Seal Rings," SAE Technical Paper 980734, 1998, https://doi.org/10.4271/980734.

2.1.2 ASTM Publications

Available from ASTM International, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959, Tel: 610-832-9585, www.astm.org.

ASTM D648 Test Method for Deflection Temperature of Plastics Under Flexural Load

ASTM D695 Test Method for Compressive Properties of Rigid Plastics

ASTM D696 Test Method for Coefficient of Linear Thermal Expansion of Plastics

TO PLACE A DOCUMENT ORDER: **Tel: 877-606-7323 (inside USA and Canada)**
Tel: +1 724-776-4970 (outside USA)
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For more information on this standard, visit
https://www.sae.org/standards/content/J2310_202412/

ASTM D792 Test Method for Specific Gravity (Relative Density) and Density of Plastics by Displacement

ASTM D1708 Test Method for Tensile Properties of Plastics by Use of Microtensile Specimens

ASTM E228 Test Method for Linear Thermal Expansion of Solid Materials with a Vitreous Silica Delatometer

3. MATERIALS

Polymeric sealing rings are made from various materials as described in the following paragraphs. These base polymer materials may be compounded with a variety of filler types to achieve specific performance properties, such as increased resistance to wear and temperature and improved fluids compatability. Other desirable properties include reduced abrasion of mating components, reduced friction, increased strength, and resistance to damage. Examples of fillers include glass, graphite, and various polymers. Factors to be considered when choosing a material include application temperature, fluid type and pressure, contaminant exposure, configuration (solid or split), material interfaces, and assembly issues.

3.1 PTFE (Polytetrafluoroethylene)

These materials are normally sintered from powders which have been compacted/molded to specific sizes under extreme pressure. The materials are sintered to promote specific mechanical properties, crystallinity, and shape memory. The sintered materials are then cut into rings of specific dimensions, and can be split or left as a solid ring, depending on assembly and functional requirements. Solid rings must be stretched to install over the shaft diameter. If stretched, then a subsequent sizing operation may be required depending on the recovery rate of the material.

3.2 PI (Polyimide)

These materials are typically compression molded into the desired size and shape. Polyimide rings have a higher elasticity modulus than PTFE and also provide higher strength and tolerance to deformation under pressure. Due to the high modulus of polyimide, these rings must be split to install over the shaft diameter.

3.3 PEEK (Polyetheretherketone)

These materials are typically injection molded into the desired size and shape, or they are extruded and then finished by machining. PEEK rings will also require a split configuration due to its high modulus of elasticity and relative rigidity.

3.4 Comparison of Materials - Physical Properties (Table 1)

Physical properties listed are typical approximate values for reference only. Actual physical properties will vary significantly depending on types and amounts of filler materials. (Contact material supplier for details related to a specific material formulation.)

Table 1 - Comparison of materials - Physical properties

	ASTM Test #	Units	PTFE	PI	PEEK
Max Use Temp (No Load)	N/A	°C	93-316	200-330	230-315
Heat Deflect Temp (455 kPa)	D648	°C	121	238-271	NA
Heat Deflect Temp (1.82 MPa)	D648	°C	50-100	160-417	140-315
Coef. of Linear Expans (D696)	E228	10E-5/K	1.4-25.0	0.4-6.0	2.2-14.7
Ultimate Elongation	D1708	%	40-650	1.6-90.0	0.9-150
Specific Gravity	D792	g/cc	0.7-2.3	0.00545-2.05	1.23-1.53
Compressive Strength	D695	MPa	1.5-23.4	77-553	29-183
Coefficient of Friction	N/A	N/A	0.008-0.28	0.14-0.24	0.11-0.4

4. APPLICATION DESIGN DATA

The six configurations shown in Figures 1 to 6 are the most common. Other joint configurations are in use to solve specific applications issues.

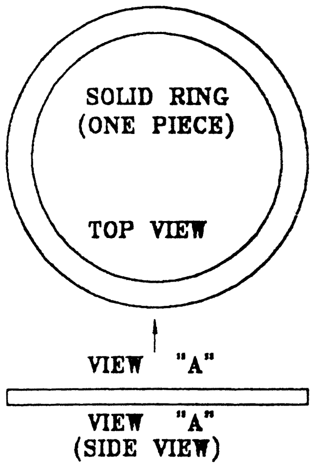

Figure 1 - Solid ring

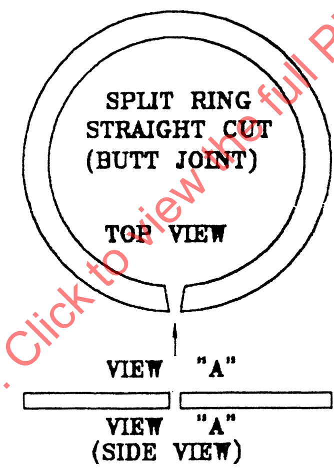

Figure 2 - Split ring - Straight cut

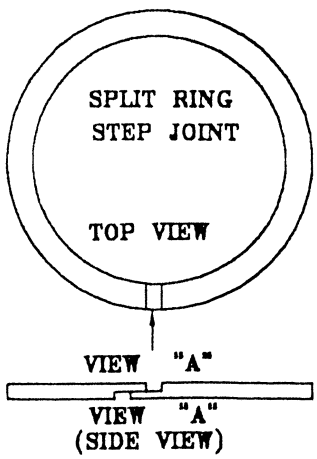

Figure 3 - Split ring - Step joint

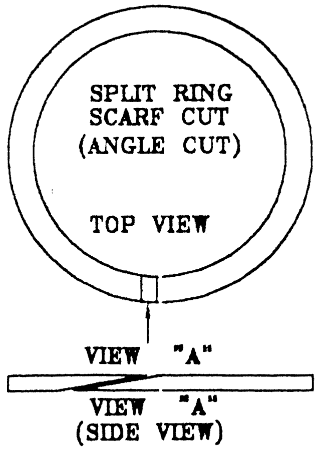

Figure 4 - Split ring - Scarf cut

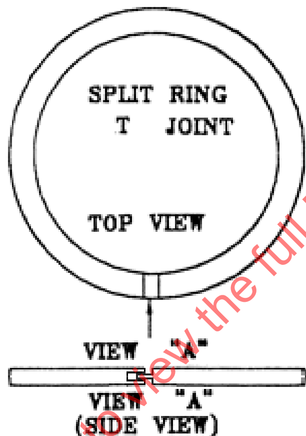

Figure 5 - Split ring - T-joint

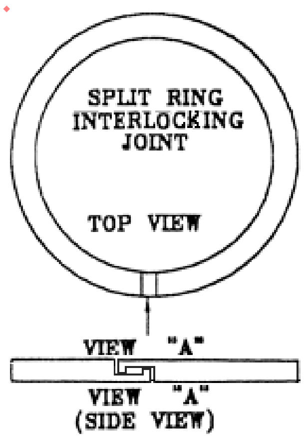

Figure 6 - Split ring - Interlocking

4.1 Axial Width (W)

(The widths shown in Table 2 are considered “common” sizes for regular rectangular seal rings.) The axial widths for polymeric sealing rings are dependent on the expected application pressure, and are calculated using the physical properties of the finished seal materials. Consult the seal ring manufacturer for specific applications. The values listed in Table 2 indicate a 0.08 mm minimum axial clearance between seal and groove width. This amount of clearance is intended for solid, straight cut, and step joint configurations. Scarf cut seals will require a greater amount of side clearance to prevent interference caused by “ramping” at joint location.

Table 2 - Sealing ring width

Minimum Axial Groove Width	Maximum Axial Sealing Ring Width	Maximum Suggested Seal Radial Wall (T)
2.00 mm	1.92 mm	1.73 mm
2.39 mm	2.31 mm	2.08 mm
3.00 mm	2.92 mm	2.63 mm
3.16 mm	3.08 mm	2.77 mm
3.97 mm	3.89 mm	3.50 mm
4.00 mm	3.92 mm	3.53 mm
4.75 mm	4.67 mm	4.20 mm
5.00 mm	4.92 mm	4.43 mm
6.00 mm	5.92 mm	5.33 mm
6.34 mm	6.26 mm	5.63 mm

4.2 Radial Wall Thickness (T)

For a regular rectangular seal ring, it is recommended that sealing ring radial wall thickness not exceed the axial width shown in Table 2. Radial wall thickness (T) typically should be 90% of the axial width for proper function, ease of assembly, and to minimize the required groove depth (see 4.8). However, many common seal ring shapes are no longer rectangular. Manufacturers are introducing chamfers/cutouts on the left and right edges of the seal. Those feaures are meant to reduce the frictional torque between the seal and the side of the groove. Reduction in friction toque will increase the overall efficiency of the system. The chamfers/cutouts also eliminate the possibility of the seal interaction with the bottom corners of the groove root.

4.3 End Clearance or Compressed Gap (G)

(See Figure 5.) This dimension is measured with seal ring installed inside a minimum diameter bore or ring gage at room temperature. Consult a ring manufacturer for the upper limit, since this dimension can affect cost and performance. The lower limit is calculated based on thermal expansion of the seal and bore.

4.3.1 PTFE Seals

Minimum gap should be zero at its lowest operating temperature for all joint types.

4.3.2 Polyimide and PEEK Seals

The minimum gap should approach zero at maximum operating temperature to minimize leakage at gap location on straight cut and step joints. Scarf cut seals should have zero minimum gap at its lowest operating temperature.

4.4 Continuous (Solid) Ring or Split

(See Figures 1 to 6.) This document applies to both solid and split rings. Polyimide and PEEK materials are not suitable for solid type rings due to rigidity. The size of split rings is controlled by gap dimension as described in 4.3, and the term “gap” only applies to split rings.

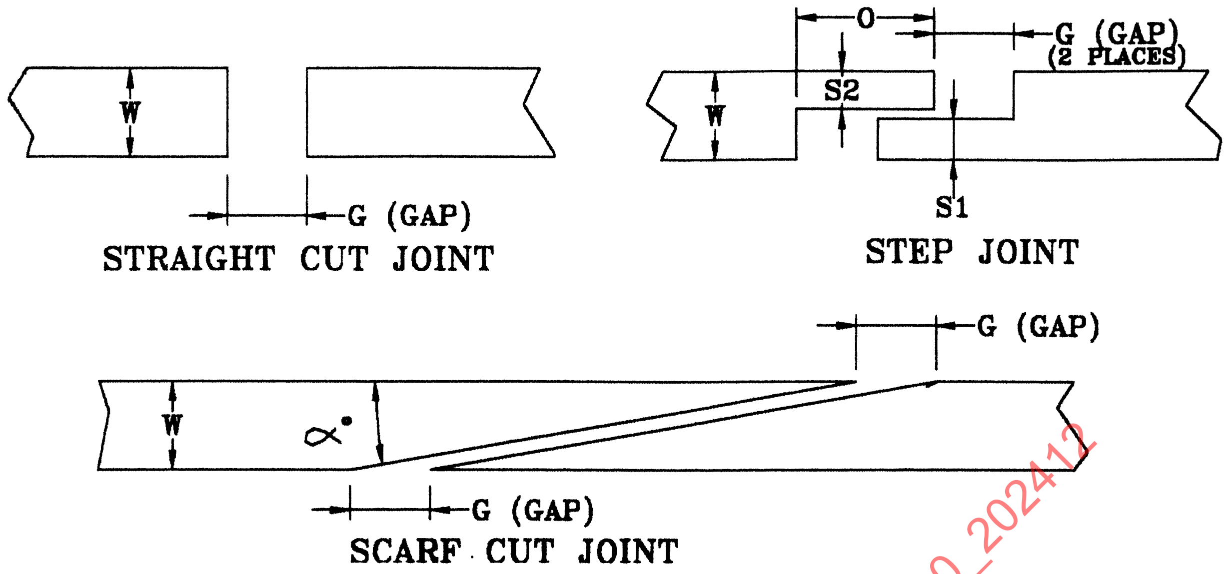

Figure 7 - Joint details

where:

G = compressed gap when installed in a minimum diameter bore at room temperature (allow sufficient gap to accommodate thermal expansion at maximum operating temperature) (see 4.3)

min "G" = zero at lowest operating temperature for all PTFE seals and all scarf cut seals

min "G" = [πBJ(max temp - lowest operating temp)] - [πBK(max temp - lowest operating temp)] for polyimide and PEEK straight cut and step joint seals

O = step length

W = axial width

S = step width (S1 + S2 must be $\leq$ W)

J = coefficient of linear thermal expansion for seal material

K = coefficient of linear thermal expansion for bore material

B = bore diameter (minimum)

α = Scarf cut angle. (10 to 12 degrees is recommended. A shallow angle is desired to minimize ramping effect. Small diameter seal rings may require a steeper angle. Axial clearance between groove and seal must be sufficient to prevent wedging in a groove.)

4.5 Joint Type Operating Principles

a. Straight Cut Joint (Figure 2): Some leakage at gap will result until gap closes from thermal expansion.

b. Step Cut Joint (Figure 3): Operating pressure seals gap and joint thickness remains constant regardless of thermal expansion. Step over-engagement can cause the ring to buckle, causing a loss of seal contact with the groove face.

c. Scarf Cut Joint (Figure 4): Operating pressure seals gap regardless of thermal expansion. However, thickness at joint will vary with thermal expansion variation. Excessive scarf cut overlap will result in ramping and possibly wedging of the seal with the groove at the gap area. PTFE will also possibly "weld" or stick together at the gap under pressure if the temperature is excessive.

d. T-Joint Cut (Figure 5): Similar to a step cut joint. However, it requires the seal to be a certain thickness in order to implement the T-joint.

e. Interlocking Joint (Figure 6): Similar to T-joint. The two interlocking fingers limit the opening of the gap of the seal at the joint.

4.6 Sealing Mechanism

The sealing of polymer rotary seal rings is accomplished by the hydraulic pressure compressing the seal face to the groove sidewall and the seal outer diameter to conform with the bore. This hydraulic pressure, coupled with thermal expansion of the seal when warmed up in operation, causes the surfaces of the gap to engage closer and minimize leakage. Minimum leakage will be achieved with solid, and step joint sealing rings. Leakage rates for straight and scarf cut joints will vary as the size of the gap changes with temperature. In some applications, it may be necessary to provide a controlled leakage rate to lubricate and cool bearings located downstream of the seal. If a controlled leakage is desirable, then it is recommended that grooves or slots be designed into the seal, to provide the required leak rate.

4.7 Mating Surface Finish

In an ideal rotating seal application, the outside diameter of the seal expands and remains stationary with the bore while the seal face rotates relative to the shaft groove sidewall (see Figure 6). Groove wall and bore surface finishes should have a circular lay pattern to achieve minimum leakage rates. Typical finish differential between bore and shaft = 2:1 to ensure low wear and proper relative motion (e.g., 3.0 µm Ra for the bore and 1.5 µm Ra for the groove sidewall). For reciprocating seals, which do not rotate, the finish ratio should approach 1:1. Finish values should be minimized to reduce wear. PTFE sealing rings generally do not require hardened interfaces. Polyimide sealing rings may require hardened interfaces with certain fillers. PEEK seals generally require hardened interfaces. The mating surface finishes for specific materials should be discussed with seal manufacturers.

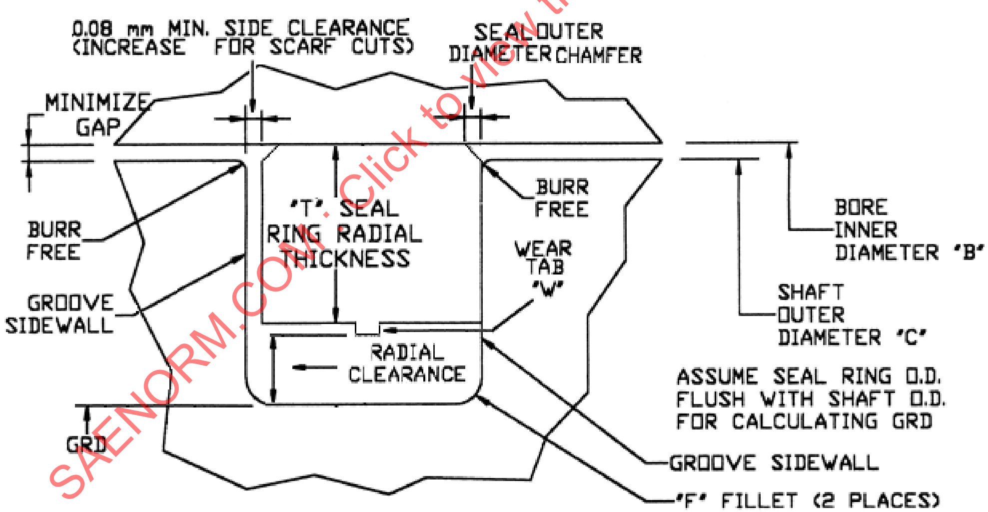

Figure 8 - Groove diameter and side clearance

Design the groove root diameter (GRD) to provide radial clearance to prevent seal corner interference with groove fillet radius "F" for polyimide and PEEK seals. Minor interference on PTFE seals will have no negative impact on seal performance. (Typical radial clearance for PTFE = 0.13 to 0.18 mm.)

E = eccentricity, GRD to C

$GRD_{MAX} = C_{MIN} - 2(T_{MAX} + E_{MAX} + F_{MAX})$

$GRD_{MIN} = GRD_{MAX} - 0.25$ mm

Recommended values for E and F:

E_{MAX} = 0.065 mm

F_{MAX} = 0.25 mm radius

Recommended C diameter: This dimension should be as large as possible for best ring function. The limiting factor is usually the runout or wobble of the shaft to the bore, with the shaft being sized so the lands do not contact the bore.

4.8 Handling and Installation

Solid type PTFE sealing rings will be stretched during assembly and may not recover fully depending on material properties. Seal sizing of these solid rings is recommended after installation to prevent seal damage from interference with bore during assembly. A cone type sizing sleeve should be used that sizes parts to the smallest size possible. It is recommended that this sizing sleeve remain over seal until shortly before installing shaft and seal assembly into bore.

Split rings must be assembled with care to assure that joint overlap is correct (see Figures 3 and 4).

Colored seal material is preferred in some applications. Colored seals will have the advantage of providing contrast when the seal is installed (e.g., overlap of the step joint). Black/gray seals usually do not offer the any contrast, which makes it difficult to inspect if the seal is installed correctly or not. Colored seals can also improve error proofing by color coding different seals that are similar in size in two different colors.

4.9 Alternative Geometry

Traditional rectangular shaped seals are ideal for sealing, but can produce a high amount of drag to the system due to the large contact area to the groove sidewall. Introduction of a step-like cutout such as a lubrication groove and other geometric features into the side face of the seal usually reduces the groove contact area, and therefore reduces drag. A lubrication groove also helps create a hydrodynamic surface where the seal would slip on the oil film instead of slipping on the interface with the groove sidewall. Reducing the groove contact area can introduce the seal to a higher pressure-velocity value when compared to a rectangular seal ring; this is mainly due to the seal reacting to the pressure using a smaller area that will magnify the pressure that the seal experiences. This phenomenon is illustrated in Equation 4. The comparison between groove contact area of a traditional rectangular seal and seal ring with lubrication grooves is shown in Figure 11.

5. SAMPLE CALCULATION

5.1 Loading Chamfer Diameter Calculation

In order to properly install the shaft and ring assembly in the bore, without a ring compressor, a chamfer of sufficient diameter is required to allow for the ring bottoming in the groove on one side and the ring hanging out on the other side as illustrated in Figure 7. The minimum radial dimension of the chamfer is equal to the maximum hang-down (necklacing) and can be calculated using Equation 1:

$$H_{MAX} = Z_{MAX} - \left(\frac{GRD_{MIN} + C_{MIN}}{2} + T_{MIN} - E_{MAX}\right) \quad \text{(Eq. 1)}$$

The minimum diameter of the chamfer can be calculated using Equation 2:

$$X_{MIN} = B_{MAX} + 2H_{MAX} \quad \text{(Eq. 2)}$$