连接器防水设计

连接器广泛应用于各种用电的场合，而连接器往往位于系统,子系统或部件/组件的界面位置，故防水有时成为连接器必不可少的要求。要实现可靠地防水，设计时需系统地考虑相关因素：

- 防护的等级要求
- 密封材料的选择
- 合适的尺寸结构-导向，密封件，槽位
- 密封件的外观质量
- 接触表面表面质量
- 安装要求/极限

防护的等级要求

设计连接器时应根据应用环境,应用特点和要求选择适当的防护等级。标准 IEC 60529 将防水分为 9 个等级(0-8)

Second characteristic numeral				
	0	Against ingress of water with harmful effects (non-protected)	–	Cl. 6
	1	vertically dripping		
	2	dripping (15° tilted)		
	3	spraying		
	4	splashing		
	5	jetting		
	6	powerful jetting		
	7	temporary immersion		
	8	continuous immersion		

而标准 ISO 20653 将防水分为 12 个等级

Second code element		Against water:
	0	— not protected
	1	— vertical water drips
	2	— water drips (15° inclination)
	3	— water spray
	4	— splash water
	4K	— splash water with increased pressure
	5	— high-velocity water
	6	— strong high-velocity water
	6K	— strong high-velocity water with increased pressure
	7	— temporary immersion
	8	— continuous submersion
	9K	— high-pressure/steam-jet cleaning

进行防水设计时，对于苛刻要求的情况需留意设计的合理性，如 9k 等级的测试水压要求是 8000-1000KPa(详见标准)，这时需保证密封件与被密封表面间的压强足够大---选择合适的材料（一定的杨氏模量或硬度）和足够的压缩量，需做必要的计算分析。

密封材料的选择

防水是通过密封件与被密封表面在密封路线处处保持紧密接触来实现的，故对密封材料有相当的要求，如密封材料不能被应用环境（包括安装过程接触的物质）腐蚀至少不能明显腐蚀，所谓材料对环境的兼容性。温度往往会对材料的性能产生影响，尤其是极端情况的温度，

密封材料也不例外。温度较高时密封材料的弹性范围会降低，设计连接器时要考虑密封材料在产品寿命内有足够的弹性范围，或者密封件件在产品寿命内在密封路线处处保持紧密接触，所以选择密封材料时永久压缩变形量（compression set）是非常重要的性能参数，尤其是高温老化后的参数。

密封材料种类繁多，ISO 标准针对各种工业应用对弹性材料进行分类

Table 2 — Suitability of elastomeric materials for industrial applications

Material [a]	Allowable low temperatures for the material [b]	Fluids based on mineral oil [c]					Fuels [c]			Fire resistant hydraulic fluids [c]						Enviromental fluids			Other service fluids [c]		
		Motor oils	Hypoid gear oils	Automatic transmission fluid	ISO 6743-4, HL, HM (Hydraulic oils)	Greases	Diesel fuel	Fuel for gasolene/petrol engines - normal	Fuel for gasolene/petrol engines - super	ISO 6743-4, HFA fluids (oil-in-water emulsion)	ISO 6743-4, HFB fluids (water-in-oil emulsion)	ISO 6743-4, HFC fluids (water polymer solutions)	ISO 6743-4, HFDR fluids (phosphate esters)	ISO 6743-4, HFDS fluids (chlorinated hydrocarbons)	ISO 6743-4, HFDT fluids (mixtures of HFDR/HFDS)	ISO 6743-4, HETG (vegetable oils)	ISO 6743-4, HEES (synthetic ester)	ISO 6743-4,HEPG (polyglycol)	Water/steam	Air	Brake fluids
	°C	Maximum continuous temperature in fluid °C [b]																			
NBR 70 IRHD NBR 90 IRHD	– 30	100	90	100	100	100	d	d	d	60	60	60	NS [e]	NS	NS	80	60	60	80	100	NS
FKM 70 IRHD	– 15	150	150	150	150	100	150	150	150	60	60	NS	150	150	150	80	100	80	100	200	NS
EPDM 70 IRHD	– 40	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	80	80	NS	NS	NS	NS	NS	140	130	130
VMQ 70 IRHD	– 50	d	d	d	d	100	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	100	200	80
HNBR 70 IRHD	– 30	130	110	130	130	100	d	d	d	60	60	60	NS	NS	NS	80	60	80	130	130	NS
ACM 70 IRHD	– 20	130	110	130	130	100	NS	NS	NS	NS	NS	NS	d	d	d	NS	NS	NS	NS	130	NS

NOTE 1 In respect of the material characteristics which vary from one manufacturer to another, only basic properties and fields of application have been specified.
NOTE 2 Data on material characteristics is available from the manufacturer.
NOTE 3 The specifier is to ensure that the selected elastomer will satisfy the required conditions of the application under which their equipment is designed to operate.

[a] The materials specified characterize a particular type of elastomer. From the basic elastomer, a number of mixtures may be prepared which exhibit similar basic characteristics but differ widely in their specific properties (e.g. tensile strength, elongation at break, rebound resilience, compression set and resistance to low and high temperatures).

[b] The information on service temperatures has been given for guidance only. It should be noted that, if the upper temperature limit is exceeded, a shorter service life may be expected. On the other hand, it may be necessary to lower this limit when using aggressive service fluids.
The fact that elastomeric material, when exposed to low temperatures, usually tends to exhibit excessive hardening without embrittlement, does not allow conclusions to be drawn on the service temperature since this is a function of other factors and should be agreed upon between the user and the manufacturer. There are special materials for use at lower temperatures.

[c] Although the behaviour of a mixture towards service fluids is mainly a function of the basic elastomer, the nature and the quantity of the other mixture components, such as plasticizers, fillers, curing agents and antioxidants are of relevance. Large quantities of extractable plasticizers, for example, may change the swelling properties of the elastomer so that it swells substantially less or even shrinks when used in mineral oils or solvents. Therefore, the data given is for general information only and intended to facilitate the selection of seal material for particular applications. In case of doubt, the manufacturer should be contacted.

[d] The elastomers of this group exhibit a different behaviour towards all or particular service fluids.

[e] NS denotes that the elastomer is not suitable for this group of service fluids.

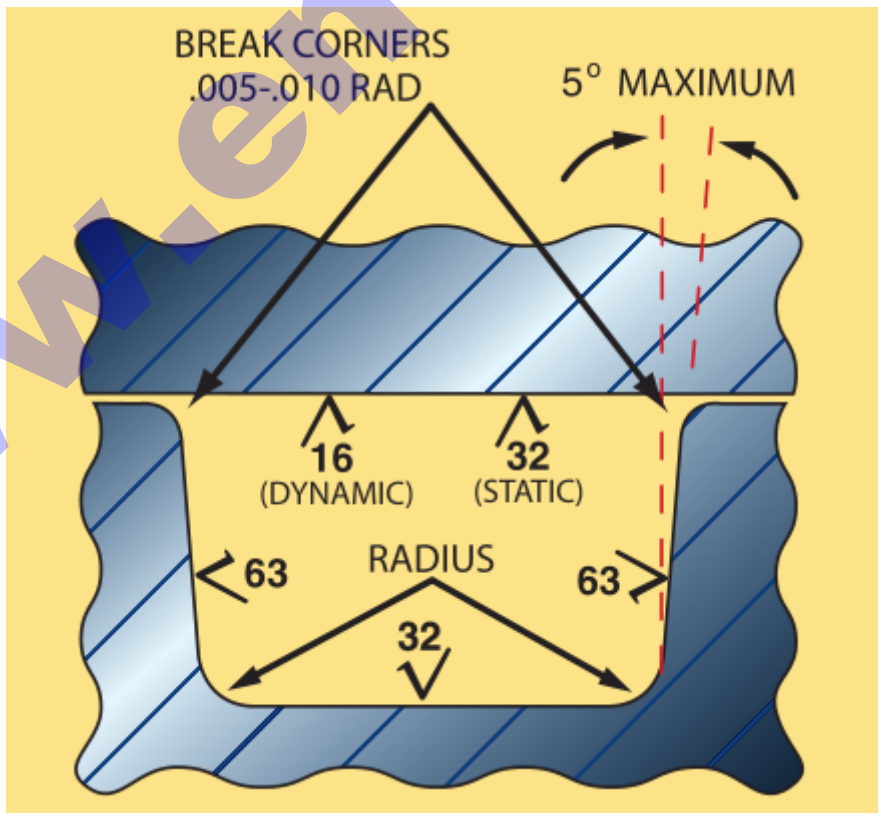
但美军标对连接器密封件只定义了两类材料，硅胶及氟硅胶，如40A 硅胶详细性能定义如下：

TABLE 1

3.2.1	As Received		
3.2.1.1	Hardness, Durometer "A" or equivalent	40 ± 5	ASTM D 2240
3.2.1.2	Tensile Strength, minimum	700 psi (4.83 MPa)	ASTM D 412, Die B or C
3.2.1.3	Elongation, minimum	250%	ASTM D 412, Die B or C
3.2.1.4	Tensile Stress at 100% Elongation, maximum	200 psi (1.38 MPa)	ASTM D 412, Die B or C Stretch specimen to 125% elongation twice within 5 minutes before testing.
3.2.1.5	Tear Resistance, minimum	55 pounds force per inch (9.63 kN/m)	ASTM D 624, Die B
3.2.1.6	Specific Gravity	Preproduction Value ± 0.03	ASTM D 297
3.2.2	Petroleum Lubricating Oil Resistance (Immediate Deteriorated Properties)		ASTM D 471 Medium: ASTM Oil No. 1 Temperature: 302 °F ± 5 (150 °C ± 3) Time: 70 hours ± 0.5
3.2.2.1	Hardness Change, Durometer "A" or equivalent	-15 to +5	
3.2.2.2	Tensile Strength, Change, maximum	-25%	
3.2.2.3	Elongation Change, maximum	-20%	
3.2.2.4	Volume Change, maximum	0 to 15%	
3.2.2.5	Decomposition	None	
3.2.2.6	Surface Tackiness	None	
3.2.3	Dry Heat Resistance		ASTM D 573 Temperature: 437 °F ± 5 (225 °C ± 3) Time: 70 hours ± 0.5
3.2.3.1	Hardness Change, Durometer "A" or equivalent	±10	
3.2.3.2	Tensile Strength Change, maximum	-20%	
3.2.3.3	Elongation Change, maximum	-40%	
3.2.3.4	Bend (flat)	No cracking or checking	
3.2.4	Compression Set		ASTM D 395, Method B Temperature: 302 °F ± 5 (150 °C ± 3) Time: 70 hours ± 0.5
3.2.4.1	Percent of Original Deflection, maximum	25	
3.2.5	Low Temperature Resistance		
3.2.5.1	Brittleness	Pass	ASTM D 2137, Method A Temperature: -85 °F ± 5 (-65 °C ± 3) Time: 3 minutes ± 0.3

结构设计

上面提到，防水是通过密封件与被密封表面在密封路线处处保持紧密接触来实现的，设计时这主要从两方面入手。要实现密封件与被密封表面在密封路线处处有一定量的过盈配合，首先要保证密封件有一定的压缩量。而压缩量主要通过产品结构来产生的，最小压缩量需考虑密封所需的压强和材料永久变形引起弹性压缩范围的减小，最大压缩量（至少包括安装及应用的情形）则需考虑材料是否能承受的这样的形变---材料性能是否显著改变），安装和应用是否方便---过大的弹力是否影响产品别的功能，性能。最大压缩量与最小压缩量之差则主要用于各相关零件尺寸和形位公差，各相关零件受力变形，各相关零件间的间隙及安装公差等。



A,环槽设计

环槽是最为常见的防水结构之一，槽两侧直角结构有利于防止密封件被挤压到零件间的间隙以致过度变形或咬伤。当应用环境压强较小槽位够高时往往把两侧做成一定倾角（如 5°）并且槽根本与口部做适当倒角降低安装或使用时尖锐棱角划伤密封件的可能。

密封件在使用过程中很可能发生变形或膨胀，故环槽型腔应保持一定体积空间，如比密封件最大体积大 10%，以防止密封材料被过度挤压以致发生质变令材料性能大为改变。

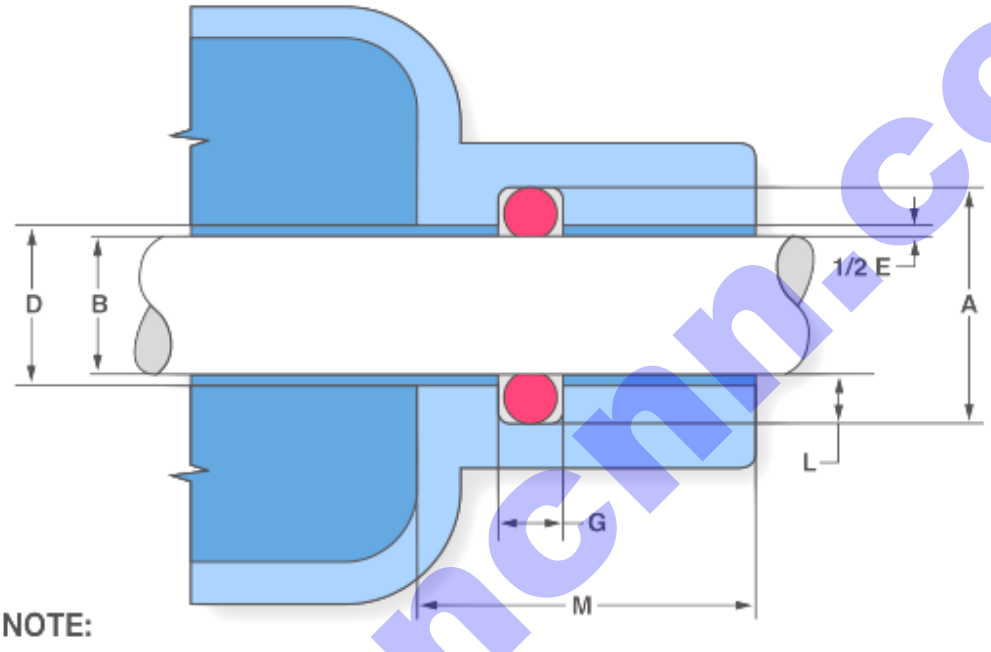
环槽外径或周长不宜比密封件内径或内周长大或长太多，如不超过 5%，过度拉伸不仅使密封件截面形状变形（远离设计所需的截面形状---影响压缩量）变小（减小压缩量），而且密封件密封表面应以受压状态为宜而不应受压---若被密封表面存在任何不平或凹陷状态，密封件只能被压进而不能被拉进不平处。

槽高也是关键的设计参数，在保证足够压缩量和尽可能小安装的拉伸量的情况下，尽量增加槽高尺寸，增加槽高尺寸能降低密封件被挤压到零件间的间隙以致过度变形或咬伤的可能性。

压缩量计算分析

压缩量计算分析是防水设计至关重要的一环，上面提到密封件的压缩量主要决定于结构设计，压缩量的分析主要是相关零件的尺寸计算，公差分析（包括尺寸公差和形位公差）及零件间的间隙分析。而

零件的间隙分析是最复杂的，最棘手的。它涉及相关零件的尺寸，公差，配合基准，变形。变形是最难分析的，牵涉零件的刚度和密封体的刚度。拿最简单的轴与孔的防水设计为列。



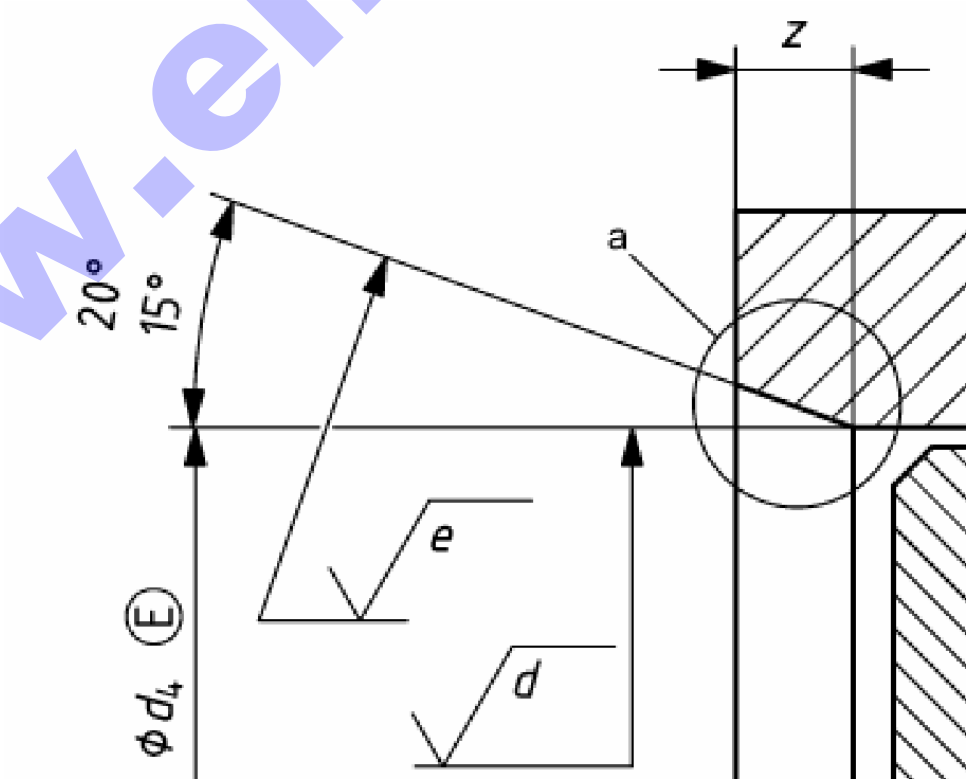
NOTE:

上图压缩量分析涉及环槽孔径 A 尺寸及其公差（包括形位公差），轴外径 B 尺寸及其公差（包括形位公差），O 形圈线径及公差和孔轴间的间隙确定。确定孔轴间的间隙不是易事，它涉及轴孔的受力位置（固定部位）和受力状况，密封体所受的压力，孔轴的刚度（尤其当零件较薄弱，如塑胶薄壁件）---这些因素决定孔轴的变形情况，而孔轴的变形情况又影响密封体所受的压力和压缩量。有时为了简化问题，保守将轴或孔极限偏心---将轴与孔一侧接触处理（但接触也存在接触变形问题）

导向压缩结构

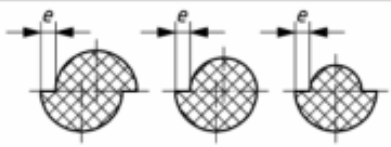
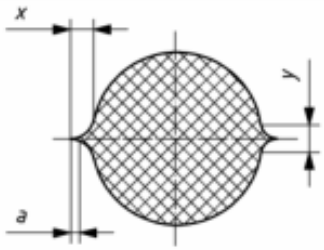
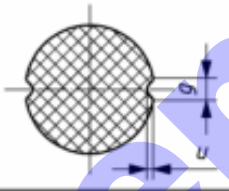
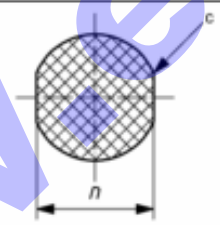
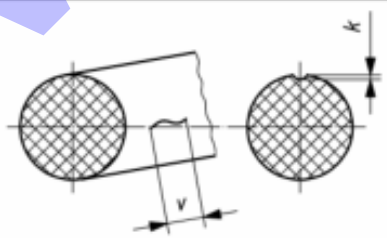
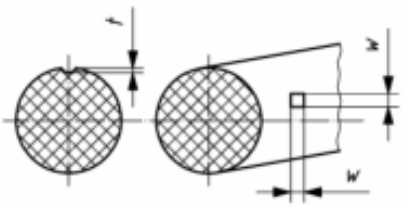
径向密封的密封件往往在安装时通过一定结构使密封件产生径向压缩，常见的结构是在相关零件加导向特征，斜面，倒角等结构，否则在安装时易将密封件压伤，刮伤，密封件内壁或外壁被剪切-内外径尺寸异常，以致密封失效。

若空间允许尽可能减小导入角度并光滑过度，也要控制接触表面的表面粗糙度。



密封件表面质量要求

ISO 标准对密封件表面质量做了相应要求，附件是其中一个等级的要求

Surface imperfection type	Diagrammatic representation	Limiting dimensions	Maximum limits of imperfections Grade N O-rings Cross-section, d_2				
			> 0,8[b] ⩽ 2,25	> 2,25 ⩽ 3,15	> 3,15 ⩽ 4,50	> 4,50 ⩽ 6,30	> 6,30 ⩽ 8,40[b]
Off-register, mismatch (offset)		e	0,08	0,10	0,13	0,15	0,15
Combined flash (combination of offset, flash and parting line projection)		x	0,10	0,12	0,14	0,16	0,18
		y	0,10	0,12	0,14	0,16	0,18
		a	When the flash can be differentiated, it shall not exceed 0,07 mm.				
Backrind		g	0,18	0,27	0,36	0,53	0,70
		u	0,08	0,08	0,10	0,10	0,13
Excessive trimming (radial tool marks not allowed)		n	Trimming is allowed provided the dimension n is not reduced below the minimum diameter d_2 for the O-ring.				
Flow marks (radial orientation of flow marks is not permissible)		v	1,50[a]	1,50[a]	6,50[a]	6,50[a]	6,50[a]
		k	0,08	0,08	0,08	0,08	0,08
Non-fills and indentations (including parting line indentations)		w	0,60	0,80	1,00	1,30	1,70
		t	0,08	0,08	0,10	0,10	0,13

[a] Or 0,05 times the O-ring's inside diameter (d_1), whichever is greater.
[b] Limits of imperfections for cross sections < 0,8 mm or > 8,40 mm shall be agreed upon between manufacturer and customer.
[c] Round edges.

安装注意事项

A,密封件安装时难免需要被拉伸，但需避免过度拉伸，对于常用的材料，如硅胶，若密封件是等截面 100%的拉伸量一般不会有什么问题

B,一般密封材料都是缺口敏感材料。安装时需将相关槽位，安装路径，接触表面清理干净。主要清理液体与密封材料是兼容材料。

C,安装时最好施加些与密封材料兼容的润滑剂，降低密封件的过度拉伸磨损。

D,必要时，可使用锥形套或模型夹具引导密封件安装。注意不宜使用硬度过高的辅助工具，硬度高材料易损伤密封件。密封件安装到位后要确认密封件平顺，不宜扭曲。

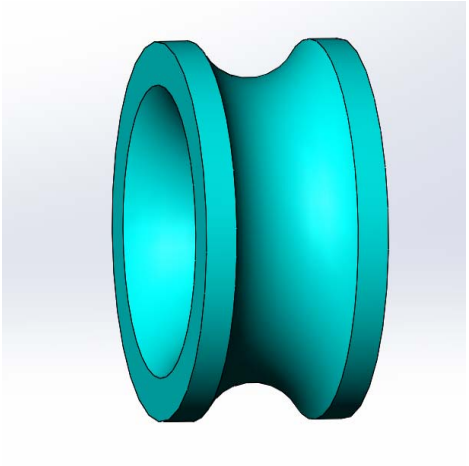
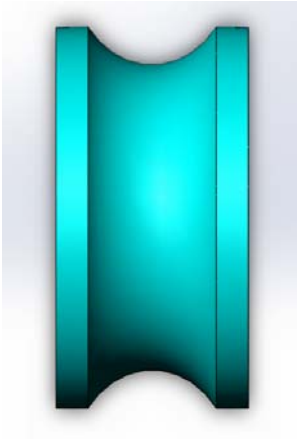
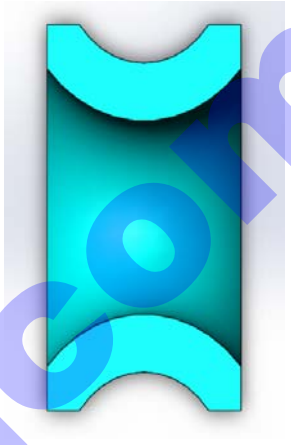
E,安装路径若存在螺纹或尖锐棱边，用胶带或薄膜包裹好，以免划伤密封件。

F,轴装入孔时，尽量平顺推入，避免转动，旋转，扭转，晃动。

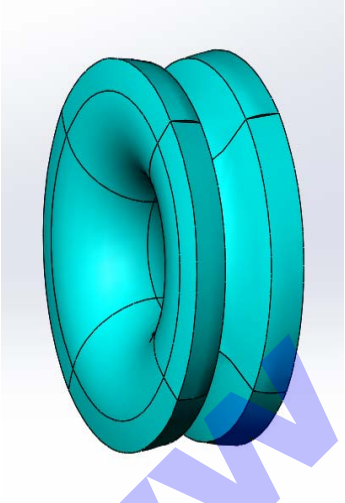
G,避免指甲触碰密封件。

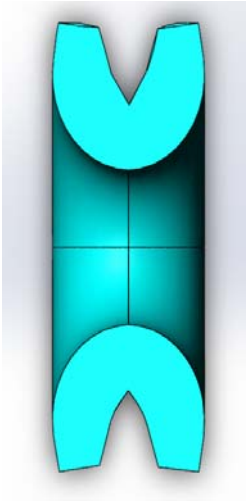
密封件压缩分析/仿真　案例一

压缩前

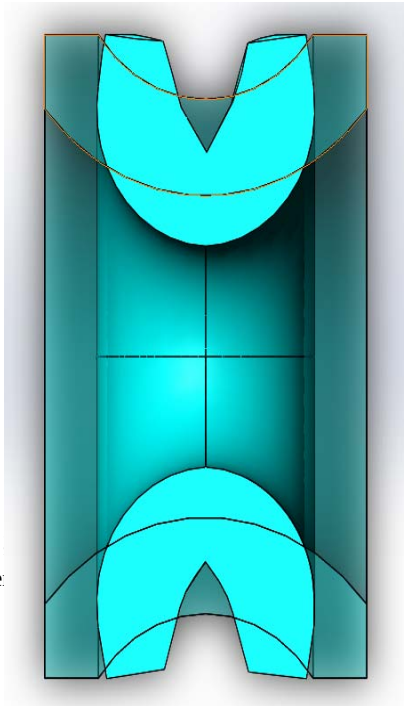




压缩后



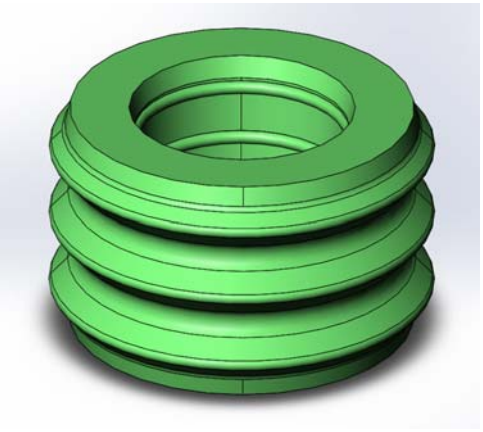


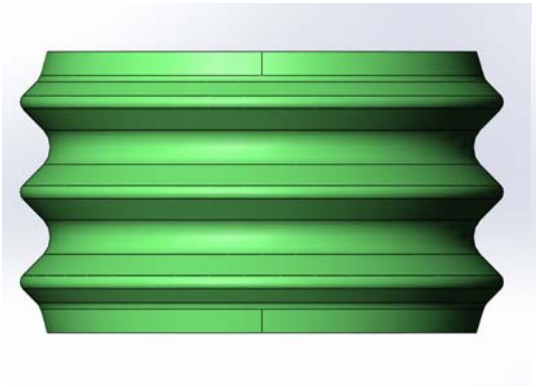
压缩前后比较

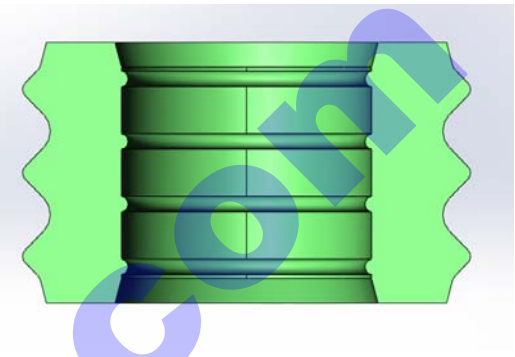


案例二

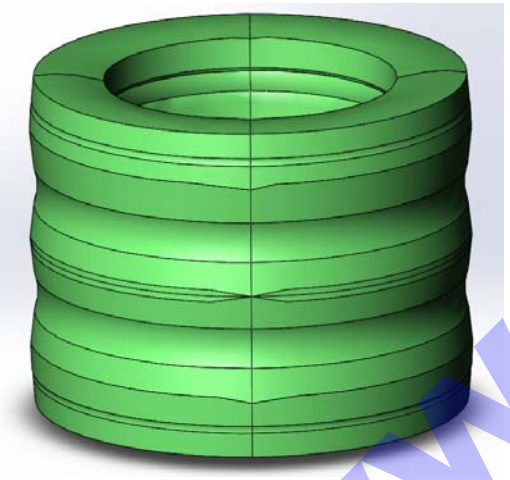
压缩前

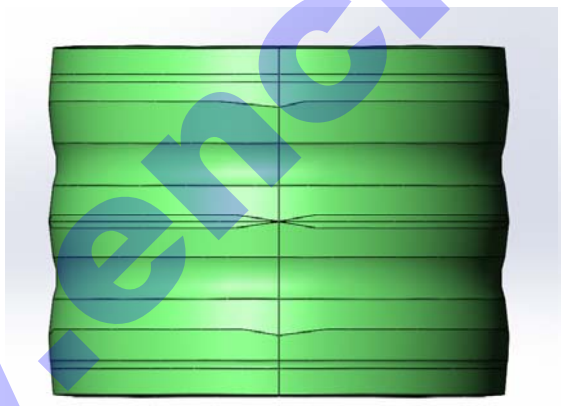


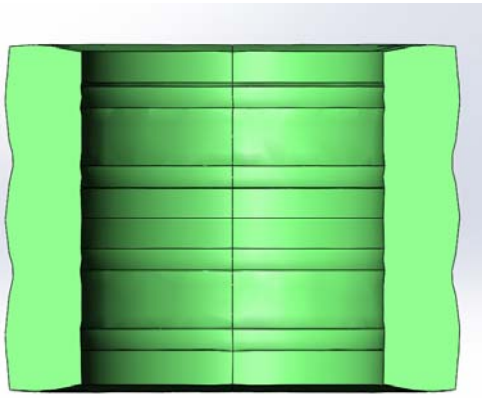




压缩后







压缩前后比较