ENGINEERING DESIGN

Smalley Spiral Retaining Ring and Snap Ring applications, although diverse, can be analyzed with a straight forward set of design calculations. There are four main areas that should be considered in most applications.

1. Material Selection
2. Load Capacity
3. Rotational Capacity
4. Installation Stress

Smalley Application Engineers are available to provide immediate technical assistance.

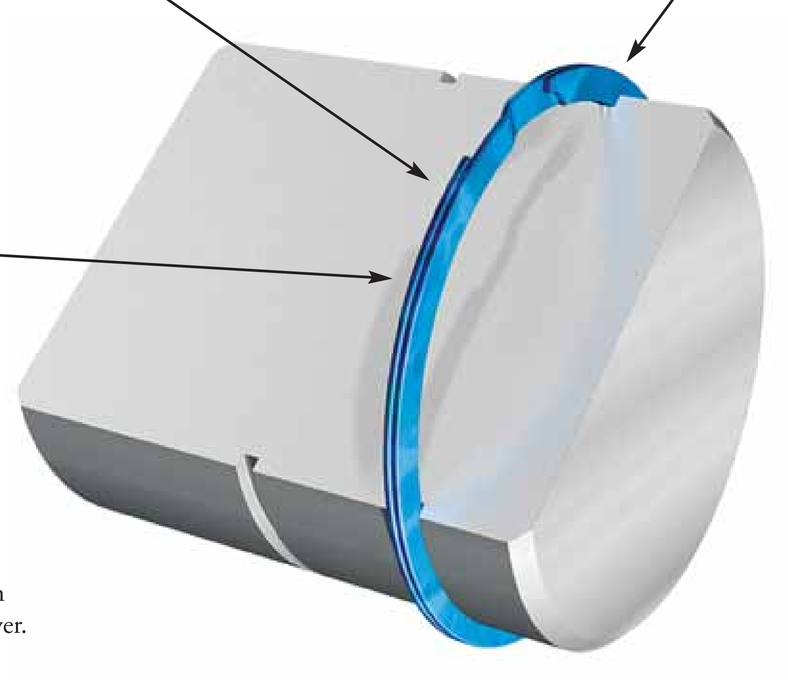
The following pages of Spiral Retaining Ring and Snap Ring engineering design have been developed from over 40 years of extensive testing and research into the various applications of retaining rings. The formulas are provided for the preliminary analysis of a ring application and the design of a Smalley® Retaining Ring.

Design engineers commonly associate the word "retaining ring" to a basic style or type of retaining device. In reality, retaining rings are nearly as diverse as their applications. Smalley Spiral Retaining Rings offer a distinct alternative and in many instances an advantage over the more common retaining rings available on the market today. Some of the major distinctions are:

360˚ RETAINING SURFACE
No gap – no protruding ears.

SPIRAL WOUND IN MULTIPLE TURNS
Increases load capacity yet allows easy assembly by hand or as an automated process.

Diameters from .200" to 90"



UNIFORM RADIAL SECTION
Provides a pleasant appearance on the assembled product. Beneficial when radial clearance is limited.

SIMPLIFIED ASSEMBLY
Wind into groove. No special pliers/tools needed to install or remove. Removal notch provided for easy removal using a screwdriver.

DESIGN FLEXIBILITY
Ring thickness can be changed to accommodate most any application by either varying material thickness and/or number of turns. Standard rings meet military and aerospace specifications. Special designs are produced quick and economical in many alloys.

LOAD CAPACITY

Understanding the load capacity of a Smalley Retaining Ring assembly requires calculations for both ring shear and groove deformation, with the design limitation being the lesser of the two.

The load capacity formulas do not take into account any dynamic or eccentric loading. If this type of loading exists, the proper safety factor should be applied and product testing conducted. In addition, the groove geometry and edge margin (i.e., the distance of the groove from the end of the shaft or housing) should be considered.

When abusive operating conditions exist, true ring performance is best determined thorough actual testing.

RING SHEAR

Although not commonly associated as a typical failure of Smalley Retaining Rings, ring shear can be a design limitation when hardened steel is used as a groove material. Ring thrust load capacities based on ring shear are provided within this catalog's tables of standard rings. These values are based on a shear strength of carbon steel with the recommended safety factor of 3.

FORMULA:

$$P_R = \frac{D\,T\,S_S\,\pi}{K}$$

Where:

P_R = Allowable thrust load based on ring shear (lb)

D = Shaft or housing diameter (in)

T = Ring thickness (in)

S_S = Shear strength of ring material (psi)

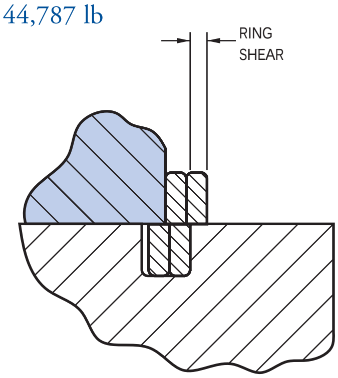
K = Safety factor (3 recommended)

EXAMPLE:

1. WH-550-S16
2. Safety factor = 3

$$P_R = \frac{5.500\ (.072)\ 108{,}000\ (\pi)}{3}$$

$$P_R = 44{,}787 \text{ lb}$$



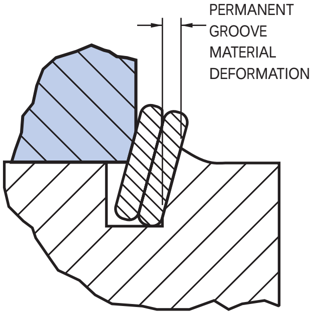
The thrust load based on ring shear above, must be compared to the thrust load based on groove deformation to determine which is the limiting factor in the design.

GROOVE DEFORMATION (YIELD)

Groove deformation is by far the most common design limitation of retaining rings. As permanent groove deformation occurs, the ring begins to twist. As the angle of twist increases, the ring begins to enlarge in diameter. Ultimately, the ring becomes dished and extrudes (rolls) out of the groove. As a conservative interpretation, the following equation calculates the point of initial groove deformation. This does not constitute failure which occurs at a much higher value. A safety factor of 2 is suggested. Ring thrust load capabilities based on groove deformation are provided within this catalog's tables of standard rings.

FORMULA:

$$P_G = \frac{D\,d\,S_y\,\pi}{K}$$



Where:

P_G = Allowable thrust load based on groove deformation (lb)

D = Shaft or housing diameter (in)

d = Groove depth (in)

S_y = Yield strength of groove material (psi), see Table 1

K = Safety factor (2 recommended)

EXAMPLE:

1. WH-550-S16
2. Groove material yield strength = 45,000 psi
3. Safety factor = 2

$$P_G = \frac{5.500\ (.074)\ 45{,}000\ (\pi)}{2}$$

$$P_G = 28{,}769 \text{ lb}$$

TYPICAL GROOVE MATERIAL YIELD STRENGTHS

Hardened Steel 8620	110,000 psi
Cold Drawn Steel 1018	70,000 psi
Hot Rolled Steel 1018	45,000 psi
Aluminum 2017	40,000 psi
Cast Iron	10-40,000 psi

Table 1

Since ring shear was calculated at 44,787 lb, the groove yields before the ring shears. Therefore 28,769 lb is the load capacity of the retaining ring.

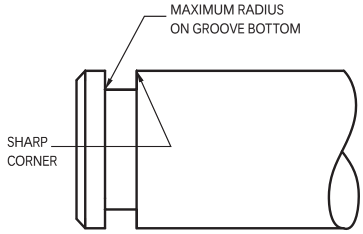
GROOVE GEOMETRY

GROOVE RADIUS

To assure maximum load capacity it is essential to have square corners on the groove and retained components. Additionally, retained components must always be square to the ring groove in order to maintain a uniform concentric load against the retained part. The radius at the bottom of the groove should be no larger than table 2 states.

SHAFT OR HOUSING DIAMETER	MAXIMUM RADIUS ON GROOVE BOTTOM
1 inch and under	.005 Max.
Over 1 inch	.010 Max.

Table 2



RETAINED COMPONENT

The retained part ideally has a square corner and contacts the ring as close as possible to the housing or shaft. The maximum recommended radius or chamfer allowable on the retained part can be calculated with the following formulas.

Where:
- b = Radial wall (in)
- d = Groove depth (in)

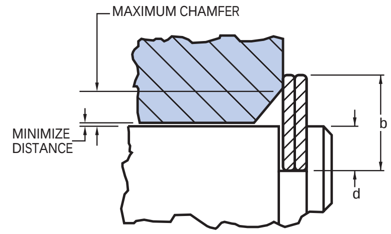
EXAMPLE:

1. WH-100

Maximum Chamfer = .375(.075-.021) = .020 in
Maximum Radius = .5(.075-.021) = .027 in

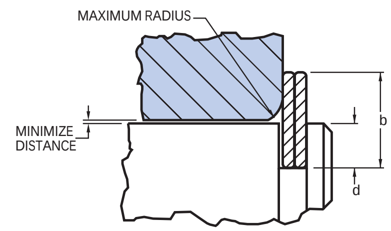
FORMULA:

Maximum Chamfer = .375(b - d)
(on retained component)



FORMULA:

Maximum Radius = .5(b - d)
(on retained component)



EDGE MARGIN

Ring grooves which are located near the end of a shaft or housing should have an adequate edge margin to maximize strength. Both shear and bending should be checked and the larger value selected for the edge margin. As a general rule, the minimum edge margin may be approximated by a value of 3 times the groove depth.

FORMULA:

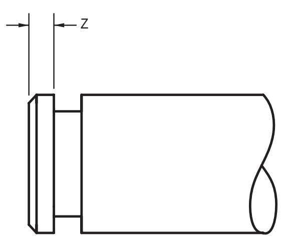
Shear

$$z = \frac{K\,3\,P}{S_Y\,D_G\,\pi}$$

Bending

$$z = \left[\frac{K\,6\,d\,P}{S_Y\,D_G\,\pi}\right]^{1/2}$$

Where:
- z = Edge margin (in)
- P = Load (lb)
- D_G = Groove diameter (in)
- S_Y = Yield strength of groove material (psi), Table 1
- d = Groove depth (in)
- K = Safety factor (3 recommended)



EXAMPLE:

1. VS-125
2. Groove material yield strength = 40,000 psi
3. Safety factor = 3
4. Load = 1000 lb

Shear

$$z = \frac{3\,(3)\,1000}{40{,}000\,(1.206)\,\pi}$$

z = .059 in

Bending

$$z = \left[\frac{3\,(6)\,.022\,(1000)}{40{,}000\,(1.206)\,\pi}\right]^{1/2}$$

z = .051 in

Therefore the minimum edge margin that should be used is .059 in

ROTATIONAL CAPACITY

The maximum recommended RPM for all standard external Smalley Retaining Rings are listed in the ring tables of this manual.

A Smalley Retaining Ring, operating on a rotating shaft, can be limited by centrifugal forces. Failure may occur when these centrifugal forces are great enough to lift the ring from the groove. The formula below calculates the RPM at which the force holding the ring tight on the groove (cling) becomes zero.

Rapid acceleration of the assembly may cause failure of the retaining ring. If this is a potential problem, contact Smalley engineering for design assistance.

MAXIMUM RPM

FORMULA:

$$N = \left[\frac{3600\ V\ E\ I\ g}{(4\pi^2)\ Y\ \gamma\ A\ R_M^5} \right]^{1/2}$$

Where:
- N = Maximum allowable rpm (rpm)
- E = Modulus of elasticity (psi)
- I = Moment of inertia = $(t \times b^3) \div 12$ (in^4)
- g = Gravitational acceleration (in/sec^2), 386.4 in/sec^2
- V = Cling÷2 = $(D_G - D_I) \div 2$ (in)
- D_G = Groove diameter (in)
- D_I = Free inside diameter (in)
- Y = Multiple turn factor, Table 3
- n = Number of turns
- γ = Material density (lb/in^3), (assume .283 lb/in^3)
- A = Cross sectional area = $(t \times b) - (.12)t^2$ (in^2)
- t = Material thickness (in)
- b = Radial wall (in)
- R_M = Mean free radius = $(D_I + b) \div 2$ (in)

n	1	2	3	4
Y	1.909	3.407	4.958	6.520

Table 3

EXAMPLE:

1. WSM-150

$V = (D_G - D_I) \div 2 = (1.406-1.390) \div 2 = .008$ in

$I = (t \times b^3) \div 12 = (.024 \times .118^3) \div 12 = 3.29 \times 10^{-6}\ in^4$

$A = (t \times b) - (.12)t^2 = (.024 \times .118) - .12(.024)^2 = .00276\ in^2$

$R_M = (D_I + b) \div 2 = (1.390 + .118) \div 2 = .754$ in

$$N = \left[\frac{3600\ (.008)\ 30{,}000{,}000\ (3.29 \times 10^{-6})\ 386.4}{(4\pi^2)\ 3.407\ (.283)\ .00276\ (.754)^5} \right]^{1/2}$$

N = 6,539 rpm

SELF-LOCKING

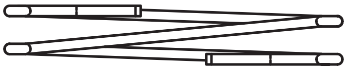
This feature allows the ring to function properly at speeds that exceed the recommended rotational capacity. The self-locking option can be incorporated for both external and internal rings. The self-locking feature utilizes a small tab on the inside turn "locking" into a slot on the outside turn. Self-locking allows the ring to operate at high speeds, withstand vibration, function under rapid acceleration and absorb a degree of impact loading.

BALANCED

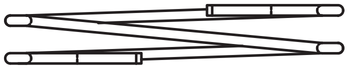
Smalley's balanced feature statically balances the retaining ring. A series of slots, opposite the gap end, account for the missing material in the gap. This characteristic is very useful when the balance of the assembly is critical and it is necessary to reduce eccentric loading.

LEFT HAND WOUND

Smalley retaining rings are wound standard in a clockwise direction. In special applications it is sometimes favorable to have the retaining ring reverse, left hand wound.



Right Hand (Standard Wound)



Left Hand (Reverse Wound)

MAXIMUM ALLOWABLE RPM FOR SMALLEY® RETAINING RINGS — SAE

PART NUMBER	VS	WS	WST	WSM	FSE
25	45 227	–	–	36 651	–
31	39 946	–	–	31 364	–
37	31 161	–	–	23 025	–
43	24 067	–	–	18 019	–
46	–	–	28 820	21 450	–
50	28 030	24 650	20 780	20 600	32 573
56	–	–	–	–	32 410
53	–	21 280	–	–	–
55	–	19 440	18 130	18 260	–
56	21 060	18 520	17 270	17 400	–
59	–	17 290	15 200	15 390	–
62	17 850	19 500	15 700	14 730	22 107
65	–	16 270	–	–	–
66	–	16 510	15 600	13 860	–
68	15 340	15 470	15 600	13 510	19 520
71	–	13 050	–	–	–
75	12 350	14 290	12 750	12 190	22 451
78	–	12 960	11 590	11 110	–
81	15 380	12 470	11 300	10 150	17 414
84	–	10 770	–	–	–
87	12 800	10 570	10 660	10 340	17 374
90	–	9 180	–	–	–
93	11 500	9 400	9 100	8 760	12 757
96	–	8 920	–	–	–
98	–	9 530	6 980	8 640	–
100	9 800	9 160	7 800	8 940	18 675
102	–	9 070	7 400	8 500	–
103	–	8 080	–	–	–
106	11 490	8 610	8 660	11 260	11 446
109	–	7 350	–	–	–
112	9 990	7 470	7 960	9 820	12 107
115	–	6 700	–	–	–
118	9 220	7 350	6 320	9 040	15 056
121	–	6 340	–	–	–
125	8 500	6 750	6 500	8 042	11 970
128	–	5 860	–	–	–
131	7 880	6 310	5 800	8 280	13 786
134	–	5 960	–	–	–
137	7 030	6 110	6 000	7 430	11 008
140	–	5 580	–	–	–
143	6 560	5 490	5 160	6 700	11 594

PART NUMBER	VS	WS	WST	WSM	FSE
146	–	5 020	–	–	–
150	5 900	4 940	4 670	6 540	12 178
156	7 720	5 343	5 160	6 110	9 004
157	–	5 240	–	–	–
162	7 220	4 880	4 690	5 750	9 118
168	6 590	4 930	4 110	5 260	8 595
175	6 200	4 510	3 930	4 970	8 101
177	–	4 410	3 960	4 990	–
181	5 700	4 290	4 170	4 720	8 470
187	5 380	4 240	3 850	4 540	6 440
193	5 100	4 020	–	–	8 047
196	–	3 860	3 320	4 730	–
200	4 720	3 740	3 410	4 560	7 650
206	5 970	3 550	3 340	3 810	7 103
212	5 550	3 400	3 120	3 560	6 603
215	–	3 490	3 120	3 450	–
216	–	3 370	–	–	–
218	5 290	3 290	–	–	6 316
225	5 050	3 220	2 820	3 240	6 040
231	4 720	3 020	2 730	3 040	5 786
236	–	2 870	–	–	–
237	4 520	2 890	2 560	3 380	6 343
243	4 240	2 920	2 480	3 180	5 089
250	4 063	2 750	3 040	3 090	4 994
255	–	2 600	3 430	2 920	–
256	3 900	2 600	–	–	5 118
262	3 680	2 500	2 780	2 750	4 073
268	3 540	2 470	2 630	2 680	4 797
275	3 400	2 340	2 560	2 790	3 981
281	3 220	2 380	–	–	4 074
287	3 100	2 260	2 260	2 590	3 927
293	2 940	2 140	2 200	2 460	3 727
295	–	2 160	–	–	–
300	2 840	2 080	2 150	2 410	3 537
306	3 670	2 020	2 090	2 290	3 245
312	3 030	1 980	1 990	2 240	3 853
314	–	1 980	–	–	–
315	–	–	1 990	2 190	–
318	2 930	1 930	–	–	3 731
325	2 790	1 870	1 900	2 100	3 557
331	2 700	1 840	–	–	3 595

PART NUMBER	VS	WS	WST	WSM	FSE
334	–	1 840	1 810	1 960	–
337	2 630	1 790	–	–	3 433
343	3 500	1 750	1 690	1 880	3 334
350	2 440	1 700	2 020	2 090	3 236
354	–	1 730	1 960	2 080	–
356	2 370	1 680	–	1 970	3 528
362	2 270	1 660	1 860	1 890	2 970
368	2 210	1 600	1 860	1 890	2 890
374	–	1 520	–	–	–
375	2 120	1 530	1 790	1 860	2 964
381	2 060	1 470	–	–	2 701
387	2 010	1 500	1 620	1 750	2 934
393	1 930	1 510	1 560	1 690	2 529
400	1 880	1 470	1 560	1 660	2 264
406	–	1 400	–	–	–
412	2 090	1 350	–	–	2 367
413	–	1 380	–	–	–
418	–	1 360	–	–	–
425	1 960	1 360	1 350	1 440	2 350
431	–	1 300	–	–	–
433	–	1 300	–	–	–
437	1 850	1 290	1 250	1 360	2 215
443	–	1 230	–	–	–
450	1 750	1 270	1 210	1 300	2 116
456	–	1 280	–	–	–
462	1 670	1 240	–	–	2 001
468	–	1 220	–	–	–
472	–	1 180	–	–	–
475	1 580	1 180	1 160	1 180	2 193
481	–	1 140	–	–	–
487	1 520	1 120	–	–	1 816
493	–	1 090	–	–	–
500	1 440	1 050	1 020	1 080	1 724
511	–	1 000	–	–	–
512	–	1 020	–	–	–
525	1 310	970	1 280	1 210	
537	–	900	–	–	–
550	1 190	890	1 170	1 120	
551	–	870	–	–	–
562	–	840	–	–	–
575	1 090	820	1 100	1 030	–

MAXIMUM ALLOWABLE RPM FOR SMALLEY® RETAINING RINGS — METRIC

PART NUMBER	VSM	ES	DNS	FS
6	51 561	-	-	-
7	39 742	-	-	-
8	40 518	-	-	-
9	35 627	-	-	-
10	31 833	-	-	-
11	25 202	-	-	-
12	30 875	22 153	-	-
13	26 805	20 094	22 915	31 185
14	22 359	18 471	19 967	21 602
15	19 625	14 543	17 836	24 273
16	17 364	14 149	18 132	29 110
17	14 958	15 923	15 677	19 841
18	13 439	12 233	16 195	22 605
19	12 140	11 685	14 221	20 417
20	11 066	10 810	12 948	18 532
21	15 326	9 641	12 475	16 896
22	13 341	10 397	11 421	13 523
23	-	9 652	10 495	14 213
24	11 035	8 479	10 825	19 083
25	10 214	8 524	10 020	11 982
26	12 483	8 642	9 301	12 494
27	-	11 357	8 721	14 320
28	10 648	10 259	8 609	15 229
29	9 973	9 765	8 060	18 016
30	9 534	9 149	7 562	12 189
31	-	8 495	-	-
32	8 437	7 778	8 686	14 215
33	-	-	8 205	9 511
34	7 398	7 982	7 763	10 847
35	7 004	7 485	7 628	11 685
36	6 641	6 903	8 474	11 640
37	-	7 227	-	-
38	5 994	7 174	7 556	10 520
40	7 573	6 172	7 181	10 841
42	6 888	5 715	6 546	8 972
45	6 021	5 158	5 740	7 861
46	-	4 909	5 505	7 006
47	-	5 570	5 283	7 232
48	5 309	5 744	5 075	7 881

PART NUMBER	VSM	ES	DNS	FS
50	4 901	4 084	5 651	7 885
52	6 057	3 616	5 251	7 318
53	-	3 450	-	-
54	-	3 295	4 842	6 811
55	5 380	3 360	4 680	6 576
56	5 238	3 215	4 525	6 354
58	4 890	3 111	4 359	5 942
59	-	2 982	-	-
60	4 575	2 862	4 050	4 793
61	-	2 683	-	-
62	4 323	2 884	3 738	5 490
63	4 220	2 773	3 691	5 071
64	-	2 780	-	-
65	3 967	2 577	3 430	4 806
66	-	2 526	-	-
67	-	2 275	3 239	4 463
68	3 602	2 486	3 201	3 945
69	-	2 438	-	-
70	3 402	2 315	2 982	4 411
71	-	2 309	-	-
72	3 218	2 321	2 805	3 947
75	2 949	2 152	2 537	3 648
77	-	-	2 379	3 467
78	3 158	2 007	2 304	3 731
80	3 025	1 981	2 576	3 747
82	2 900	1 895	2 425	3 574
85	2 703	1 825	2 333	3 476
88	2 526	1 737	2 143	3 252
90	2 443	1 721	2 029	2 731
92	-	-	-	-
95	2 174	1 509	1 777	2 598
98	-	-	1 659	2 377
100	1 955	1 508	1 579	2 542
102			1 530	2 746
105	2 082	1 399	1 435	2 640
108			1 368	2 418
110	1 902	1 323	1 391	2 279
115	1 745	1 248	1 280	2 090
120	1 606	1 176	1 175	1 694

PART NUMBER	VSM	ES	DNS	FS
125	1 483	1 092	1 088	1 778
130	1 374	993	1 017	1 647
135	1 270	934	952	1 530
140	1 186	870	888	1 519
145		821	835	1 331
150	1 022	755	788	1 470
155	961	891	733	1 379
160	1 060	831	690	1 296
165	1 000	795	753	1 201
170	945	749	715	1 151
175	894	697	671	1 088
180	848	657	636	1 030
185	898	631	601	1 115
190	854	591	577	860
195	813	569	551	880
200	775	534	518	837
205			495	1 068
210	802	579	466	1 077
220	734	530	425	932
230	674	482	527	854
240	622	444	486	735
250	575	413	451	726
260	582	381	424	743
270	541	354	390	718
280	505	328	363	714
290	472	-	382	624
300	443	-	357	584
310	-	-	342	-
320	-	-	316	-
330	-	-	299	-
340	-	-	343	-
350	-	-	322	-
360	-	-	305	-
370	-	-	291	-
380	-	-	276	-
390	-	-	262	-
400	-	-	251	-

INSTALLATION STRESS ANALYSIS

The equations provided are used to check that the elastic stress limit of the ring material is not exceeded by stress due to installation. Standard parts that are assembled manually in the recommended shaft/bore and groove diameters do not require stress analysis. Special rings, or rings being assembled with special tooling, require stress analysis.

To select a safe stress value, it is necessary to estimate the elastic limit of the raw material. The minimum tensile strength, as shown in the materials table of the catalog, can be used as a suitable estimate. As with any theoretical calculation, a closer analysis of the actual application may reveal that these stress values can be exceeded. However, particular consideration must be made to functional characteristics such as installation method, the number of times the ring will be installed and removed, thrust load and/or centrifugal capacity.

After forming, the ring's natural tendency is to return to its original state. This places the inner edge of the radial wall in residual tension and the outer edge in residual compression. To account for the residual stress in the ring when expansion is taking place, only 80% of the minimum tensile strength should be used to compare to the installation stress; see table 4.

In special designs, where the installation stress exceeds the material's elastic limit, rings can be produced to diameters which will yield a predetermined amount during assembly. Once installed, the ring will have the proper cling (grip) on the groove.

INSTALLATION STRESS

FORMULA:

For external rings

$$S_E = \frac{E\, b\, (D_S - D_I)}{(D_I + b)(D_S + b)}$$

For internal rings

$$S_C = \frac{E\, b\, (D_O - D_H)}{(D_O - b)(D_H - b)}$$

Application	Percent of Minimum Tensile Strength
Shaft	80%
Housing	100%

Table 4

Where:

- S_E = Stress due to expansion (psi)
- S_C = Stress due to compression (psi)
- E = Modulus of elasticity (psi)
- b = Radial wall (in)
- D_S = Shaft diameter (in)
- D_H = Housing diameter (in)
- D_I = Free inside diameter, minimum (in)
- D_O = Free outside diameter, maximum (in)

EXAMPLE: Compare theoretical installation stress to percent of minimum tensile strength.

1. WS-100-S02

$$S_E = \frac{28{,}000{,}000\ (.075)\ (1.000 - .933)}{(.933 + .075)(1.000 + .075)}$$

$$S_E = 129{,}845 \text{ psi}$$

Minimum tensile strength of the ring material: 210,000 psi.
Using 80%, (Table 4), of 210,000 psi = 168,000 psi.

$$129{,}845 \text{ psi} < 168{,}000 \text{ psi}$$

Since the installation stress is less than 80% of the minimum tensile strength, permanent set is not expected.