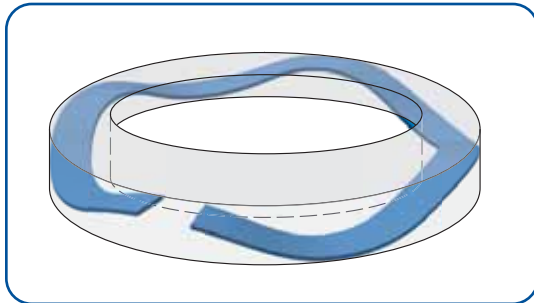


## SPRING DESIGN

### DEFINING THE SPRING REQUIREMENTS

Although wave spring applications are extremely diverse, there is a consistently basic set of rules for defining spring requirements. Those requirements are used to select a stock/standard spring or design a special spring to meet the specifications.

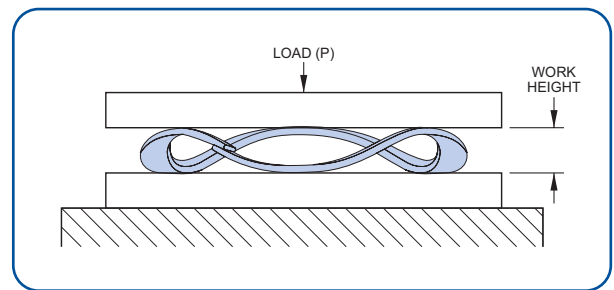


### WORKING CAVITY

The working cavity usually consists of a bore the spring operates in and/or a shaft the spring clears. The spring stays positioned by piloting in the bore or on the shaft. The distance between the loading surfaces defines the axial working cavity or work height of the spring.

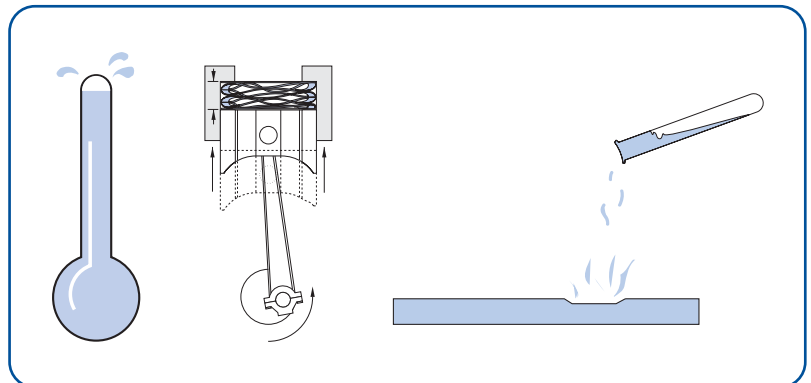
### LOAD REQUIREMENT

The load requirement is defined by the amount of axial force the spring must produce when installed at its work height. Some applications require multiple working heights, where loads at 2 or more operating heights are critical and must be considered in the design. Often minimum and/or maximum loads are satisfactory solutions, particularly where tolerance stack-ups are inherent in the application.



### OPERATING ENVIRONMENT

High temperature, dynamic loading (fatigue), a corrosive media or other unusual operating conditions must be considered in spring applications. Solutions to various environmental conditions typically require selection of the optimal raw material and operating stress.



### STANDARD SPRINGS vs. SPECIAL SPRINGS

Finding the right spring can be as easy as selecting a standard catalog item. A Smalley engineer can help you choose from over 2000 standard parts available from stock in carbon and stainless steel. Smalley's "no-tooling" method of manufacturing provides the utmost in flexibility and quality. Whether the requirement is for 1 spring or 1,000,000 consider Smalley for your special spring requirements.

### LET SMALLEY DESIGN YOUR SPRING

Over 50% of Smalley's business is in the design and manufacturing of special springs to suit individual applications. Whether it's a technical question, or the most complex spring design, Smalley engineers are always available and welcome the opportunity to assist you. Utilize the Application Checklist found in this catalog. Or at [www.smalley.com](http://www.smalley.com) we provide a simple procedure to e-mail us your known design parameters. An engineer will recommend a standard catalog item or provide you with design options for a special spring.

# SPRING DESIGN

## NOMENCLATURE

b	Radial Width of Material, in [(O.D. - I.D.)÷2]
D <sub>m</sub>	Mean Diameter, in [(O.D. + I.D.)÷2]
E	Modulus of Elasticity, psi
f	Deflection, in
H	Free height, in
I.D.	Inside Diameter, in
K	Multiple Wave Factor, see Table 1
L	Length, Overall Linear, in
N	Number of Waves (per turn)
O.D.	Outside Diameter, in

P	Load, lb
S	Operating Stress, psi
t	Thickness of Material, in
W.H.	Work Height, in (H-f)
Z	Number of Turns

Table 1

### MULTIPLE WAVE FACTOR (K)

N	2.0-4.0	4.5-6.5	7.0-9.5	10.0 & Over
K	3.88	2.90	2.30	2.13

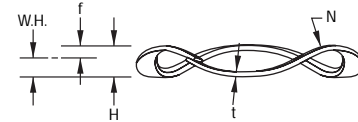
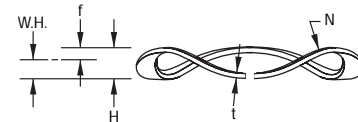
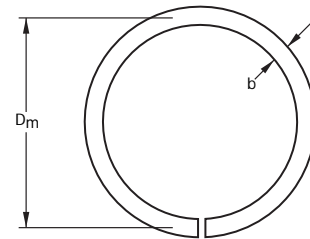
## SINGLE TURN GAP OR OVERLAP TYPE

### APPLICATIONS

1. Low-Medium Force
2. Low-Medium Spring Rate
3. Short Deflection
4. Precise Load/Deflection Characteristics

Single turn wave springs are the basic and most common wave spring product. They are used in the widest variety of spring applications due to their lower cost and simplified design configuration.

Single turn wave springs provide the most flexibility to designers. There are few restrictions in their design. They are specified in the majority of small axial and radial space constraint applications.



### FORMULAS:

$$\text{Deflection} = f = \frac{P K D_m^3}{E b t^3 N^4} * \frac{\text{I.D.}}{\text{O.D.}}$$

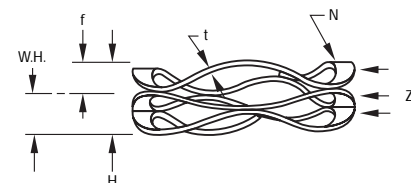
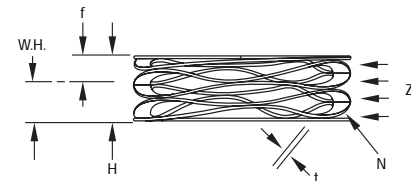
$$\text{Operating Stress} = S = \frac{3 \pi P D_m}{4 b t^2 N^2}$$

## CREST-TO-CREST® SPIRAWAVE (SERIES STACKED)

### APPLICATIONS

1. Low-Medium Force
2. Low-Medium Spring Rate
3. Long Deflection
4. Precise Load/Deflection Characteristics

Crest-to-Crest Spirawave flat wire compression springs are pre-stacked in series, decreasing the spring rate by a factor related to the number of turns.



### FORMULAS:

$$\text{Deflection} = f = \frac{P K D_m^3 Z}{E b t^3 N^4} * \frac{\text{I.D.}}{\text{O.D.}}$$

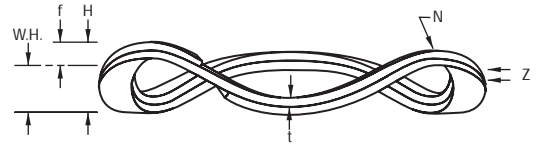
$$\text{Operating Stress} = S = \frac{3 \pi P D_m}{4 b t^2 N^2}$$

Note: N must be in 1/2 wave increments  
Z = Number of active turns

## NESTED SPIRAWAVE® (PARALLEL STACKED)

1. Higher Force
2. Higher Spring Rate
3. Short Deflection
4. Precise Load/Deflection Characteristics

Nested Spirawave Wave Springs are pre-stacked in parallel, increasing the spring rate by a factor related to the number of turns.



### FORMULAS:

$$\text{Deflection} = f = \frac{P K D_m^3}{E b t^3 N^4 Z} * \frac{\text{I.D.}}{\text{O.D.}} \quad \text{Operating Stress} = S = \frac{3 \pi P D_m}{4 b t^2 N^2 Z}$$

### EXAMPLE: Smalley Part Number SSR-0200

Calculate free height and operating stress for Smalley part number SSR-0200 (Gap Type, Single Turn, Carbon Spring Temper Steel).

Where:

$P = 34 \text{ lb}$	$D_m = 1.835 \text{ in}$
$t = .024 \text{ in}$	$N = 4$
$b = .150 \text{ in}$	$E = 30 \times 10^6 \text{ psi}$
$\text{O.D.} = 1.985 \text{ in}$	$K = 3.88$
$\text{I.D.} = 1.685 \text{ in}$	$\text{W.H.} = .093 \text{ in}$

$$\text{Deflection} = f = \frac{(34)(3.88)(1.835)^3}{(30 \times 10^6)(.150)(.024)^3(4)^4} * \frac{1.685}{1.985} = .043 \text{ in}$$

$$\text{*Free Height} = H = (\text{W.H.} + f) = .093 + .043 = .136 \text{ in}$$

$$\text{Operating Stress} = S = \frac{(3)(\pi)(34)(1.835)}{(4)(.150)(.024)^2(4)^2} = 106,339 \text{ psi}$$

\*Calculated free height may not be the same as the actual springs measure due to variations in raw material and manufacturing process.

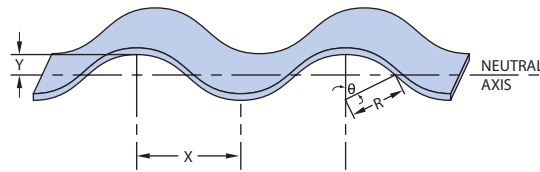
## DIAMETER EXPANSION

Nested & Crest-to-Crest Spirawaves Only: Multiple turn Spirawaves expand in diameter when compressed. The formula shown below is used to predict the maximum fully compressed diameter.

**FORMULA:** Maximum outside diameter at 100% deflection (solid height) =  $.02222 * R * N * \theta + b$

Where:

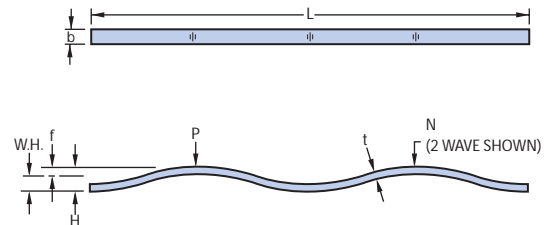
$R = \text{Wave Radius} = (4Y^2 + X^2) \div 8Y$
$N = \text{Number of Waves}$
$\theta = \text{Angle, degrees} = \text{ArcSin}(X \div 2R)$
$b = \text{Radial Wall}$
$X = \frac{1}{2} \text{ Wave Frequency} = \pi D_m \div 2N$
$Y = \frac{1}{2} \text{ Mean Free Height} = (H-t) \div 2$
Where $H = \text{Per Turn Free Height}$



## LINEAR EXPANDERS

Linear Expanders are a continuous wave formed (marcelled) wire length produced from spring temper materials. They act as a load bearing device having approximately the same load/deflection characteristics as a wave spring.

Forces act axially or radially depending on the installed position. Axial pressure is obtained by lying the expander flat in a straight line. Circular wrapping the expander (around a piston for example) produces a radial force or outward pressure.



### FORMULA: Single wave expander where N=1

$$\text{Deflection} = f = \frac{P L^3}{4 E b t^3} \quad \text{Operating Stress} = S = \frac{3 P L}{2 b t^2}$$

### FORMULA: 2 or more wave expander where N>1

$$\text{Deflection} = f = \frac{P L^3}{16 E b t^3 N^4} \quad \text{Operating Stress} = S = \frac{3 P L}{4 b t^2 N^2}$$

## STRESS

### OPERATING STRESS

Compressing a wave spring creates bending stresses similar to a simple beam in bending. These compressive and tensile stresses limit the amount a spring can be compressed before it yields or “takes a set”. Although spring set is sometimes not acceptable, load and deflection requirements will often drive the design to accept some set or “relaxation” over time.

### MAXIMUM DESIGN STRESS

**Static Applications** Smalley utilizes the Minimum Tensile Strength found in this catalog’s “Materials” section to approximate yield strength due to the minimal elongation of the hardened flat wire used in Smalley products. When designing springs for static applications we recommend the calculated operating stress be no greater than 100% of the minimum tensile strength. However, depending on certain applications, operating stress can exceed the minimum tensile strength with allowances for yield strength. Typical factors to consider are permanent set, relaxation, loss of load and/or loss of free height.

**Dynamic Applications** When designing wave springs for dynamic applications, Smalley recommends that the calculation of operating stress not exceed 80% of the minimum tensile strength. Refer to the “Fatigue Stress Ratio” and Table 2 for further fatigue guidelines.

### RESIDUAL STRESS/PRE-SETTING

Increasing the load capacity and/or fatigue life can be achieved by compressing a spring beyond its yield point or “presetting”. Preset springs are manufactured to a higher than needed free height and load and then compressed solid. Both the free height and load are reduced and the material surfaces now exhibit residual stresses, which enhance spring performance.

## FATIGUE

Fatigue cycling is an important consideration in wave spring design and determining precisely how much the spring will deflect can greatly impact the price of the spring. An analysis should include whether the spring deflects full stroke or only a few thousandths each cycle or possibly a combination of both as parts wear or temperature changes.

The fatigue guidelines in Table 2 provide a conservative approach and allow for calculation of cycle life between 2 work heights. Although these methods of fatigue analysis have proven to be a good approximation, testing is recommended whenever cycle life is critical.

#### FORMULA:

$$\text{Fatigue Stress Ratio} = X = \frac{(\sigma - S_1)}{(\sigma - S_2)}$$

(refer to Table 2)

Where:  $\sigma$  = Material tensile strength

$S_1$  = Calculated operating stress at lower work height (must be less than  $\sigma$ )

$S_2$  = Calculated operating stress at upper work height

#### FATIGUE GUIDELINES

X	Estimated Cycle Life
< .40	Under 30,000
.40 - .49	30,000 – 50,000
.50 - .55	50,000 – 75,000
.56 - .60	75,000 – 100,000
.61 - .67	100,000 – 200,000
.68 - .70	200,000 – 1,000,000
> .70	Over 1,000,000

Table 2

## LOAD/DEFLECTION

A comparison of the actual spring rate to the theoretical (calculated) spring rate provides practical limits for the working range of the spring. Spring rate (P/f) can be calculated by manipulating the deflection equations. See formulas in the spring design section.

Figure 1 shows a graph of theoretical and tested spring rate. Typically, theoretical rate is accurate until the spring starts to bottom out or reach its “solid height”.

As a general rule, the calculated spring rate is linear through the first 80% of available deflection and for work heights down to 2 times the solid height. Although the spring can operate beyond this “linear” range, measured loads will be much higher than calculated.

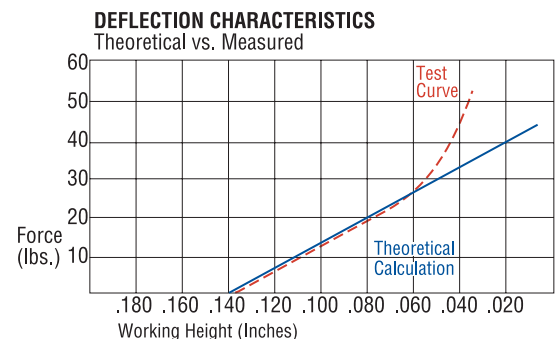


Figure 1

## HYSTERESIS

Wave springs exert a greater force upon loading and lower force upon unloading. This effect is known as hysteresis. The shaded area shows a graphic representation between the curves in Figure 2.

In a single turn spring, friction due to circumferential and radial movements are the prime causes. Crest-to-Crest and Nested Springs also contribute to the frictional loss as adjacent layers rub against each other. Sufficient lubrication will minimize this effect.

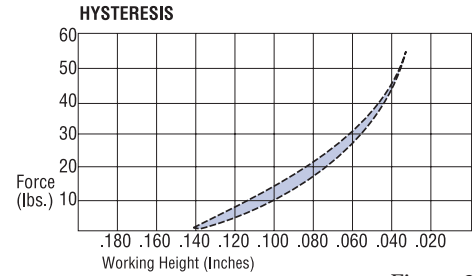


Figure 2

## DESIGN GUIDELINES

### MATERIAL CROSS-SECTION

Material cross-section plays an important role in wave spring design. The most economical materials are those used in manufacturing Smalley standard springs and retaining rings. In addition, many other material cross sections are commonly used in special spring manufacture designs. Smalley engineering can provide assistance in selecting an economical alloy and cross section.

As a basic guideline, use our standard 'SSR'-Wave Spring series for cross-section/diameter relationships. Lighter material sections are usually acceptable. Heavier sections for a given diameter may be incorporated using the following information:

#### SPECIAL WAVE SPRING DESIGN CRITERIA FOR SELECTING MATERIAL CROSS-SECTIONS:

- Maximum material thickness = standard ("SSR-") thickness \* 2
- Maximum radial wall = material thickness (any value) \* 10
- Minimum radial wall = material thickness (any value) \* 3

For Overlap Type Wave Springs and multiple turn Spirawaves, the radial wall must be sufficient to prevent misalignment between adjacent layers. For springs with a narrow radial wall, radial misalignment can occur during handling or during operation if the spring is not contained or closely piloted.

Solutions to this problem include dimensioning the spring to pilot closely on the I.D. and/or O.D. or designing the spring as a single turn Gap Type.

### DIAMETERS

Figure 3 illustrates two methods of specifying diameters. In either case, the spring diameter is developed to provide proper operation between the bore and the shaft.

Note: Smalley's manufacturing process of edgewinding controls either the O.D. or the I.D. The material radial wall is also tightly controlled. Therefore whenever possible, tolerance only one diameter and the radial wall instead of tolerancing both the O.D. and I.D.

### BORE PILOT

For springs that pilot in the bore as shown in figure 3a, the bore and shaft diameters should be included in the spring specifications. Commonly used requirements would read:

“Spring must pilot and operate in a (minimum bore) bore diameter.”

“Spring must clear a (maximum shaft) shaft diameter.”

The actual spring diameter is then developed at time of manufacture to provide the best fit and prevent binding due to expansion.

For Gap Type and Overlap Type Springs, the outside diameter can be specified because binding is not a concern. The outside diameter can be toleranced to provide a minimum clearance in the bore or provide cling in the bore, as do the Smalley Bearing Preload Springs.

### SHAFT PILOT

For springs that pilot on a shaft as shown in Figure 3b, the inside diameter can be toleranced to provide a minimum clearance from the shaft. Since wave springs expand during compression, interference with the shaft is generally not a concern.

To insure proper operation, include shaft and bore diameters in the spring specifications. Commonly used requirements would read:

“Spring pilots over and clears a (maximum shaft) shaft diameter.”

“Spring operates in a (minimum bore) bore diameter.”

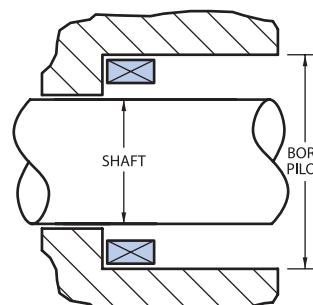


Figure 3a

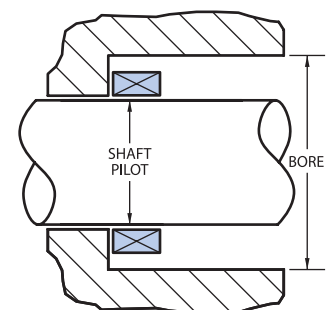


Figure 3b