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F. A. MOHAMED, H. S. AHMED, A. R. Y. DIAA, A. G. A. S. MOHAMED
Fayoum University, Al Fayoum, Egypt
S. A. SUKHETSKAYA
Belarusian State University of Transport, Gomel

WAVE SPRING FEATURES

The features of different types of wave springs are being examined, their advantages and disadvantages are being described. They are compared with the currently used coil springs. It is shown that having the same stiffness coefficient the wave springs are 3 or more times smaller than the coil ones.

Nowadays wave springs are used in machine design [1]. The "Smalley Steel Ring Company" is the main producer of them [2]. Wave springs are twisted in a smooth spiral from the sinusoidal molded belt. They are made of preliminary hardened rolling profile with rounded edges and have numerous advantages compared to the stamped products. Load and stiffness coefficients are more predictable for such springs. Also manufactured tolerances can be reduced by 50% compared with the stamped ones. The wave spring force evenly increases during working stroke.

These springs have a number of advantages over currently used coil springs. In particular, they allow to minimize the spring height and cavity, assembly size and cost (figure 1).

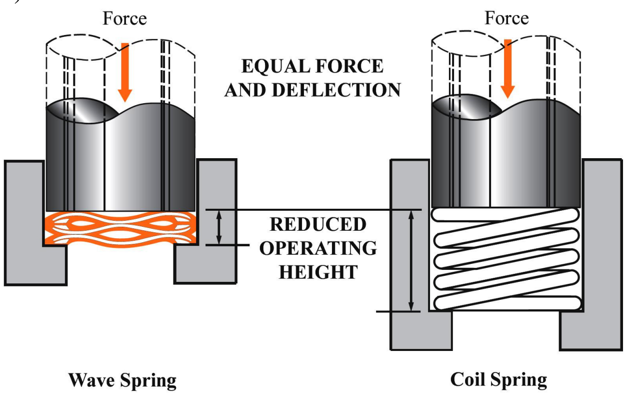

Figure 1 – Wave spring benefits

There are some types of wave springs (figure 2): Single Turn Wave Spring, Wavo Spring, Nested Wave Spring, Crest-To-Crest Wave Spring, Linear Expander.

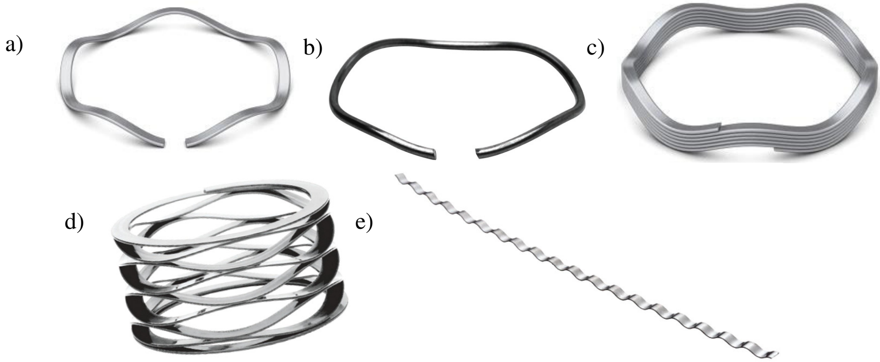

Figure 2 – Types of wave springs: *a* – Single Turn Wave Spring; *b* – Wavo Spring; *c* – Nested Wave Spring; *d* – Crest-to-Crest Wave Spring; *e* – Linear Expander.

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

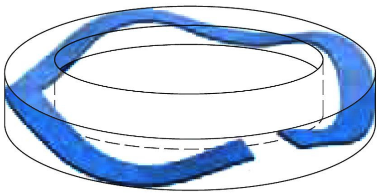

Figure 3 – Working cavity

The *working cavity* (figure 3) 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.

The load requirement is defined by the amount of axial force the spring must produce when installed at its work height (figure 4). Some applications require multiple working heights, where loads at 2 or more operating heights are critical and must be considered in the design process.

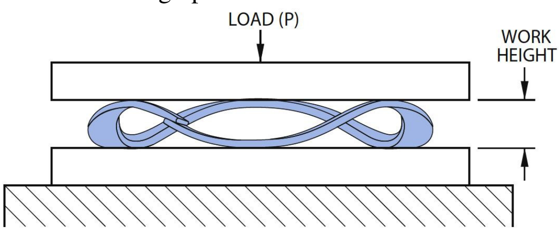

Figure 4 – Load Requirement

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.

Nomenclature. *O. D.* – Outside Diameter, m; *I. D.* – Inside Diameter, m; H – Free height, m; b – Radial Width of Material, m [$b = (O.\ D. - I.\ D.)/2$], D_m – Mean Diameter, m [$D_m = (O.\ D. + I.\ D.)/2$]; E – Modulus of Elasticity, Pa; f – Deflection, m; K – Multiple Wave Factor; L – Length, Overall Linear, m; N – Number of Waves (per turn); P – Load, N; S – Operating Stress, Pa; t – Thickness of Material, m; *W. H.* – Work Height, m (*W. H.* $= H - f$); Z – Number of Turns.

Table 1 – **Wave factors**

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. They are applied for:

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.

The calculating formulas are the following:

Deflection $f = \dfrac{PKD_m^3}{Ebt^3N^4} \times \dfrac{I.D.}{O.D.}$;

Operating Stress $S = \dfrac{3\pi P D_m}{4bt^2N^2}$.

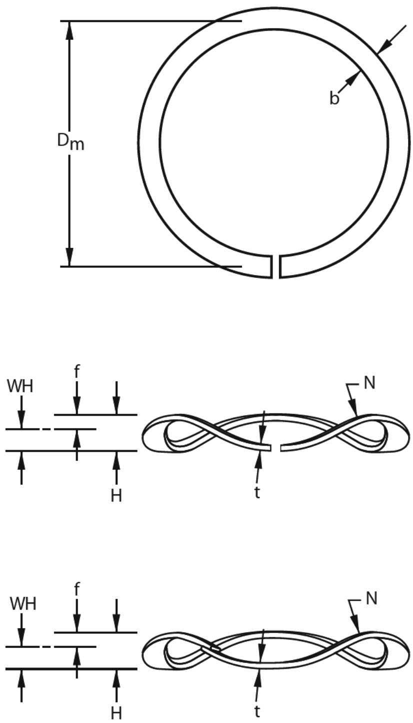

Figure 5 – Single Turn wave spring

*Crest – to Crest or Spirawave (Series Stacked)***.** They are applied for:

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.

The calculating formulas are the following:

$$\text{Deflection} \quad f = \frac{PKD_m{}^3 Z}{Ebt^3 N^4} \times \frac{I.D.}{O.D.};$$

$$\text{Operating Stress} \quad S = \frac{3\pi P D_m}{4bt^2 N^2},$$

when Z – Number of active turns.

Note: N must be in $1/2$ wave increments

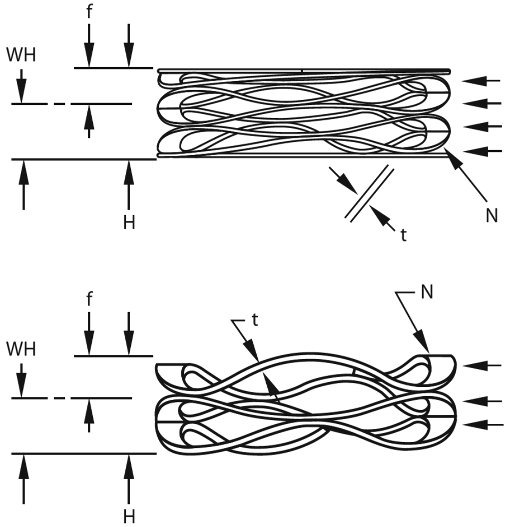

Figure 6 – Crest – to Crest or Spirawave

*Nested Spirawave (Parallel Stacked)***.**

They are applied for:

1 Low-Medium Force.

2 Low-Medium Spring Rate.

3 Long 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.

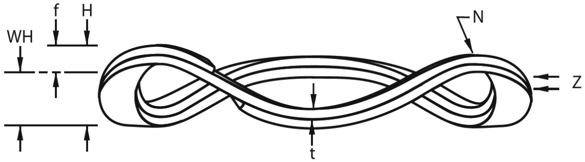

Figure 7 – Nested Spirawave

The calculating formulas are the following:

$$\text{Deflection} \quad f = \frac{PKD_m^{\;3}}{Ebt^3N^4Z} \times \frac{I.D.}{O.D.};$$

$$\text{Operating Stress} \quad S = \frac{3\pi PD_m}{4bt^2N^2}.$$

Multiple turn Spirawave expands in diameter when compressed. The formula shown below is used to predict the maximum fully compressed diameter.

The calculating formulas are the following:
Maximum outside diameter at 100 % deflection

$$\text{(solid height)} = 0{,}02222\, R\, N\, \theta + b,$$

where R – Wave Radius = (4Y 2 + X 2) / 8Y; N – Number of Waves; θ – Angle, degrees = Arcsine (X/2R); b – Radial Wall; H – Per Turn Free Height; X = 1 ⁄ 2 Wave Frequency = π D m /2N; Y = 1 ⁄ 2 Mean Free Height = (H – t) / 2.

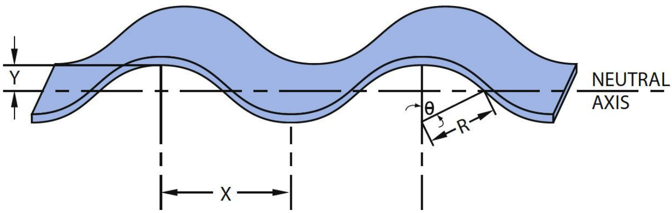

Figure 8 – Diameter expansion

Linear Expanders are the continuous waves formed from spring temper materials. They act as a load bearing device having approximately the same load/deflection characteristics as wave springs.

Forces act axially or radically depending on the installed position. Axial pressure is obtained by laying the expander flat along a straight line. The expander circular wrapping (around a piston for example) produces a radial force or outward pressure.

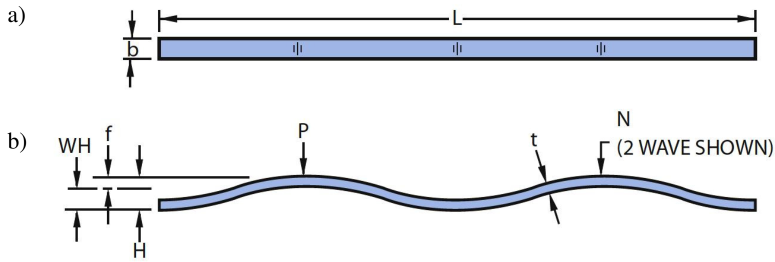

Figure 9 – Linear Expander: *a* – Plan; *b* – Side view

Formulas for single-wave expander where $N = 1$:

$$\text{Deflection } f = \frac{PL^3}{4Ebt^3};$$

$$\text{Operating Stress } S = \frac{3PL}{2bt^2}.$$

Formulas for 2- or more wave expander where $N > 1$:

$$\text{Deflection } f = \frac{PL^3}{16Ebt^3N^4};$$

$$\text{Operating Stress } S = \frac{3PL}{4bt^2N^2}.$$

Stresses.

Operating Stress. Compressing a wave spring creates bending stresses similar to a simple beam in bending. These compressive and tensile stresses are limited by a yield strength value. 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 for Static Applications.

Smalley utilizes the Minimum Tensile Strength to approximate yield strength due to the minimal elongation of the hardened flat wire used in Smalley products. When designing springs for static applications it is recommended 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.

Maximum Design Stress for Dynamic Applications. When designing wave springs for dynamic applications, Smalley recommends that the calculation of operating stress do not exceed 80 % of the minimum tensile strength.

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 by stretching the spring to the bigger size than free height up to yield point. Both the free height and load are reduced and the material surfaces now exhibit residual stresses, which enhance spring performance.

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

The fatigue guidelines in table 2 provide a conservative approach and allow to calculate the cycle life between 2 work heights. Although these methods of fatigue analyses have proved to be a good approximation, testing is recommended whenever cycle life is critical.

The calculating formula is the following:

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

where σ – material tensile strength; S_1 – calculated operating stress at lower work height (must be less than σ); S_2 – calculated operating stress at upper work height.

Table 2 – **Fatigue guide line**

X	Estimated Cycle Life
< 0,40	Under 30000
0,40–0,49	30000 – 50000
0,50–0,55	50000 – 75000
0,56–0,60	75000 – 100000
0,61–0,67	100000 – 200000
0,68–0,70	200000 – 1000000
> 0,70	Over 1000000

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.

Figure 10 shows a graph of theoretical and tested spring rate. As a general rule, the calculated spring rate is linear at the first 80 % of available deflection and for work heights it is twice smaller compared to solid height. Although the spring can operate beyond this “linear” range, measured loads will be much higher than calculated.

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 11.

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 layer rubbing against each other. Sufficient lubrication will minimize this effect.

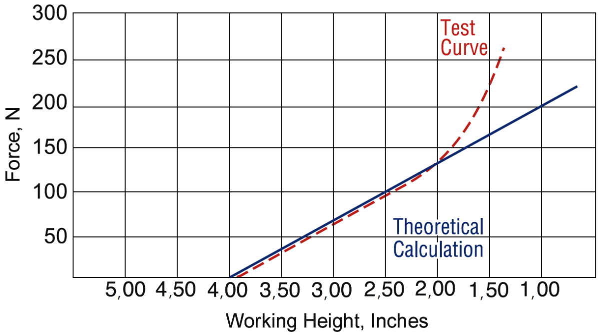

Figure 10 – Deflection characteristics, Theoretical and Measured

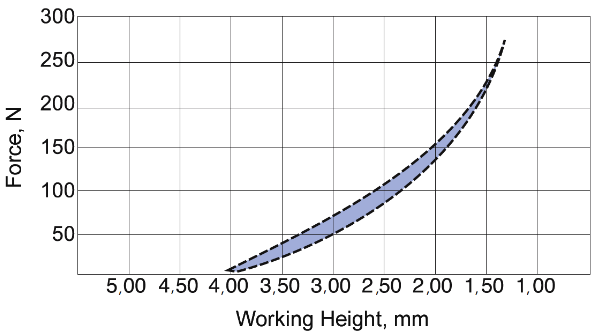

Figure 11 – Hysteresis

Design guide lines.

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.

As a basic guideline, use standard 'SSR'-Wave Spring series for cross-section/diameter relationships. Lighter material sections are usually acceptable.

For Overlap Type Wave Springs and Multiple Turn Spirawave, 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.

The comparative analysis of wave and coil springs working under the same pressure has been made. The calculating formulas for defining the size of a coil spring are:

$$d = \sqrt[3]{\frac{16FR}{\pi\tau}}, \quad \frac{Ebt^3N^4O.D.}{KZI.D.} = \frac{Gd^4}{8n}, \quad n = \frac{Gd^4KZI.D.}{8Ebt^3N^4O.D.}, \quad H = nd + f,$$

when d – diameter of a coil spring wire; R – radius of a coil spring; τ – acceptable shearing stress; n – number of coils; f – deflection.

The results are given in table 3 and show that the height of wave spring is 3 times smaller than the height of a coil spring.

Table 3 – **The comparison of wave and coil springs**

Wave Spring Type	Load, H	Stiffness Rate	Wave Spring Height, mm	Coil Spring Height, mm
CM15-H4	80	19,56	17,8	67,163
SSB-1221	849,9	264	7,11	836,868
CM30-H5	130	16,25	17,78	71,091

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МОХАМЕД Ф. А., АХМЕД Х. С., ДИАА А. Р. Й., МОХАМЕД А. Г. А. С., СУХЕЦКАЯ С. А.

ОСОБЕННОСТИ ВОЛНИСТЫХ ПРУЖИН

Рассмотрены особенности различных видов волновых пружин, описаны их достоинства и недостатки. Выполнено сравнение их характеристик с используемыми в настоящее время винтовыми пружинами. Показано, что волнистые пружины при тех же параметрах жесткости имеют высоту в три и более раза меньшую, чем винтовые.

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