# GUIDE TO SPRING DESIGN


MID-WEST SPRING AND STAMPING

ENGINEERING SOLUTIONS

ISO 9001:2000

For Stock Springs visit our website www.mwspring.com

## Contents



## How To Use This Guide

This Guide to Spring Design was developed to assist engineers an designers plan design and specify custom springs, wire forms and stampings. The data it summaries is intended to help you avoid costly errors and omissions.

You can submit your request for a quote by visiting our web site at www.mwspring.com and complete the necessary forms which are e-mailed to us, or send a fax to our quoting department at (888) 643-9781. When submitting a quote via fax, please include the following information along with a sketch of the part you are designing:

**Identification Information**

- Your Name, Title, Company
- Name and Full Address
- Phone and Fax Numbers

**Design Data**

- Material
- Wire diameter
- Outside/Inside diameter
- Free length
- Are relative position of ends important?
- Total number of coils
- Type of ends
- Finish
- Coil direction as left, right, or optional
- Maximum length

**Working Conditions**

- Actual function of the part
- Specify load
- Specify the hole diameter the spring works in or the rod diameter the spring works over
- Specify range of operating temperatures
- Cycle rate (deflections per minute)
- Life expectancy
- Total working range
- Corrosion protection
- Annual usage
- Buy or release quantities
- Whether cosmetic appearances are important

## FREE Value Engineering Study

Mid-West Spring can also supply you with a free value engineering study utilizing the knowledge and experience of our design engineers. We will conduct a computerized value analysis and send the results back to you within 48 hours. You can receive our Value Engineering Study by supplying the information listed above via fax at (888) 643-9781. Please clearly indicate on your fax that you would like our Value Engineering Study.

# Nobody offers more than Mid-West.

At Mid-West Spring & Stamping, the custom compression, torsion and extension springs discussed in this guide are only the beginning of our capabilities. We're also your high quality certifiable source for many other types of springs, wire forms and stampings like those shown below.

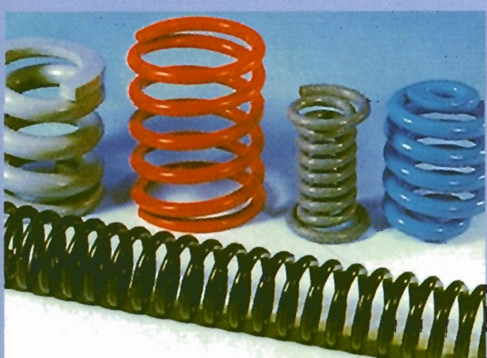
**Stock springs** Mid-West stocks a wide selection of compression, torsion, extension, and die springs for immediate shipment. Prepackaged assortments are also available for maintenance and R&D requirements. For a listing of stock springs visit our website at www.mwspring.com.

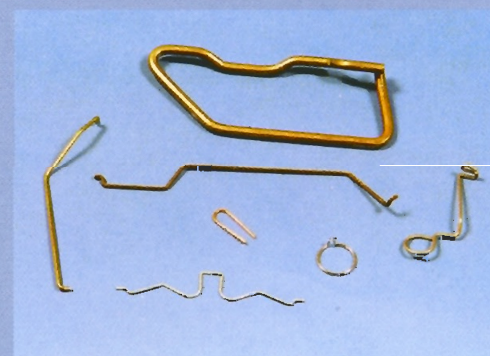
**Clock, die and special springs**

Custom die springs are available in most lengths and deflections; we can produce flat spiral clock or motor springs for most design specifications.

**Hot wound coil springs**

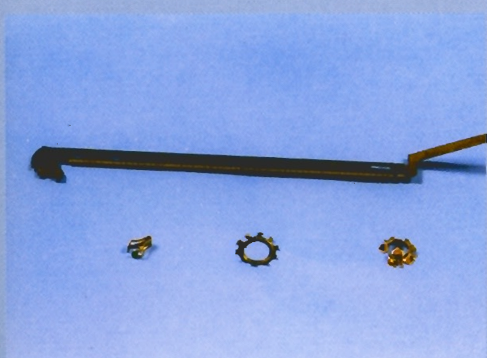
Available in wire diameters up to 2" for your heavy duty coil spring applications.





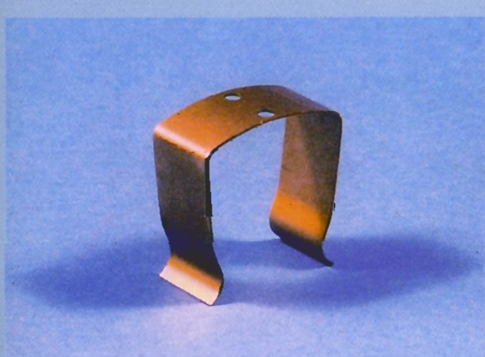
**Wire Forms**

Mid-West can supply virtually any form your require from .010" to .250" round, square, or rectangular wire. Our specialized background and equipment allow for an unlimited range of possibilities - from clips and clamps to the unusual in size, shape and application.



**Precision-engineered formed parts**

Mid-West specializes in complex, precision custom designs. Professional, skilled and responsive engineers at Mid-West Spring offer unlimited option in the design and manufacture of high-precision parts. Competitively priced, Mid-West Spring supplies millions of these parts to meet industry needs each year.



**Multi-Slide, Flat springs and stampings**

Mid-West supplies an array of multi-slide stampings and flat springs. Produced from annealed materials hardened and tempered to your critical shape and form design. Applications include connectors, fasteners, hinges and holding brackets.

**Spring washers and snap rings**

Available in slotted, curved, wave, Belleville disc and special. To solve problems of high loads in limited space. SNAP RINGS in round, square or rectangular wire for retention of components.

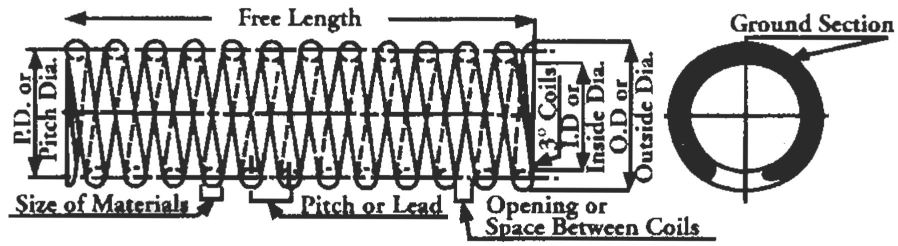
# Compression Springs

Materials: Most metals and alloys

Wire Sizes: .004" to 2" round, square or rectangular

Quantity: Any

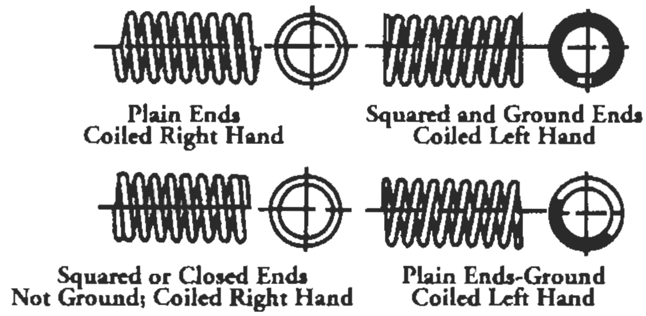
Typical Applications: Fluid/air controls, automotive, switches, off-road equipment, aerospace




$$d = \sqrt[3]{\frac{8PD}{\pi S}}$$

$$n = \frac{Gd^4}{8RD^3}$$

$$S = \frac{8PD}{\pi d^3} \text{ psi}$$




## Solid Height

The solid height of a compression spring is its length measured when the spring is under load sufficient to: 1) bring each coil into contact with the adjacent coils; and 2) ensure that the additional load causes no further deflection.

## Determining Rate

1. Deflect spring to approximately 20% of available deflection and measure load.

2. Deflect spring not more than 80% of available deflection and measure load ($P_2$) and spring length ($L_2$). Be certain that no coils (other than closed ends) are touching $L_2$.

3. Calculate rate (R) lb/in.

$$R = (P_2 - P_1) / (L_1 - L_2)$$

## Wahl Curvature Stress Correction Formula Key

$$K = \frac{4C-1}{4C-4} + \frac{0.615}{C}$$

Where $C = \frac{D}{d}$

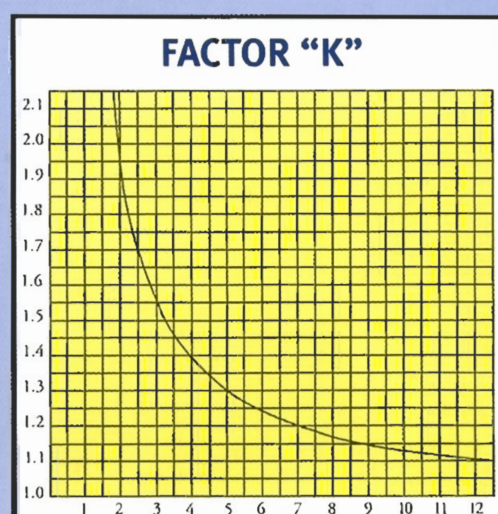
and in the graph at right

Ration = $\frac{\text{Mean Diameter}}{\text{Wire Diameter}}$

$$R = \frac{Gd^4}{8nD^3} \text{ lb per in.}$$

$$S = \frac{8PD}{\pi d^3} \text{ psi;}$$

$$S_k = KS \text{ psi}$$




## Formula Index

R = Rate per inch
P = Load in pounds
S = Stress (uncorrected)
H = Solid Height
G = Torsional modulus of elasticity
p = Pitch
M = Moment or torque, in lb
E = Modules of elasticity
n = Active coils
N = Total coils
D = Mean diameter of coil
d = Diameter of wire
$\pi$ = 3.14
L = Free Length
T = Revolutions of springs
$S_k$ = Corrected Stress

# Compression Spring Categories

Compression springs should be stress relieved to remove residual bending stresses produced in the coiling operation. Depending on design and space limitations, compression springs may be categorized according to stress levels as follows:

**A.** Springs that can be compressed solid without permanent set, so that set removal is unnecessary. These spring are designed with fully compressed torsional stress levels that do not exceed approximately 45% of the minimal tensile strength of the material.

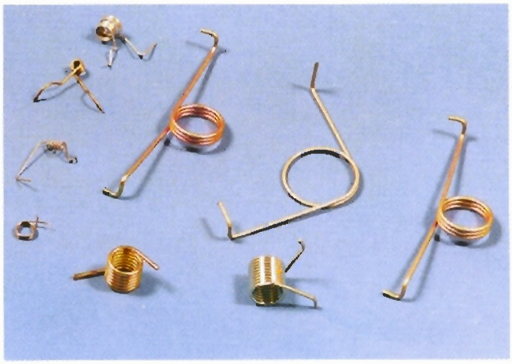
**B.** Springs that can be compressed solid without permanent set only after set has initially been removed. These springs may be preset either by the spring manufacturer as an additional operation or by the user prior or during the assembly operation. Fully compressed torsional stress levels in these springs do not exceed approximately 65% of the minimal tensile strength of the material.

**C.** Springs that, because set cannot be completely removed in advance, cannot be compressed solid without causing some further permanent set. These springs have torsional stress levels that exceed 65% of the minimal tensile strength of the material. When springs in this category are specified, the manufacturer will generally advise the user of the maximum spring deflection that is allowable without set.

| Dimensional Characteristics | Type of Ends | | | |
|---|---|---|---|---|
| | Open or Plain (Not Ground) | Open or Plain (Ground) | Squared Only | Squared and Ground |
| Solid Height ($L_s$) | $(N_t+1)d$ | $N_t d$ | $(N_t+1)d$ | $N_t d$* |
| Pitch (p) | $\frac{L_f-d}{N_a}$ | $\frac{L_f}{N_t}$ | $\frac{L_f-3d}{N_a}$ | $\frac{L_f-2d}{N_a}$ |
| Active Colors ($N_a$) | $\frac{L_f-d}{p}$ | $\frac{L_f}{p}-1$ | $\frac{L_f-3d}{p}$ | $\frac{L_f-2d}{p}$ |
| Total Coils ($N_t$) | $N_a$ | $N_a+1$ | $N_a+2$ | $N_a+2$ |
| Free Length ($L_f$) | $p N_t+d$ | $p N_t$ | $p N_a+3d$ | $p N_a+2d$ |

## Torsional Modulus of Elasticity

Steel .................... $11.5 \times 10^6$
Stainless Steel .................... $10 \times 10^6$
Chrome Vanadium .................... $11.5 \times 10^6$
Chrome Silicon .................... $11.5 \times 10^6$
Phosphor Bronze .................... $6.25 \times 10^6$
Brass .................... $5.5 \times 10^6$



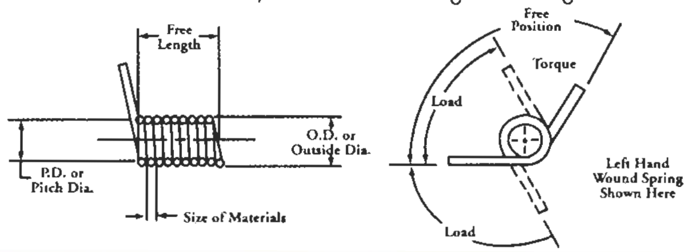
## Torsion Springs

**Materials:** Most metals and alloys

**Wire Sizes:** .003" to 2" round, square to .375", rectangular to specification

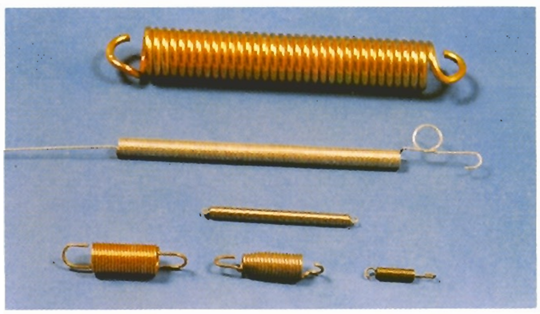
**Quantity:** Any

**Typical Applications:** Automotive, irrigation, heavy agriculture and construction equipment. Tortion springs generally require ample room axial room, with the best designs working over an arbor or shaft.




$$d = \sqrt[3]{\frac{32M}{\pi S_2}} \qquad n = \frac{Ed^4T}{10.8\,DM}$$

$$S = \frac{32M}{\pi d^3}\ \text{psi} \qquad M = \frac{Ed^4T}{10.8\,ND}$$



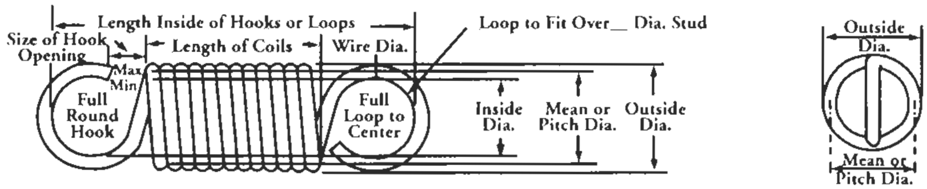
## Extension Springs

**Materials:** Most metals and alloys

**Wire Sizes:** .003" to 2" round, square to .375", rectangular to specification

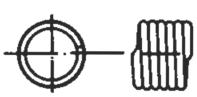
**Quantity:** Any

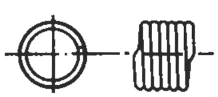
**Typical Applications:** Automotive, window components, lawn and garden equipment, and many other OEM applications. An unlimited selection of end styles is available

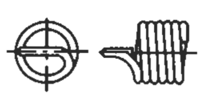


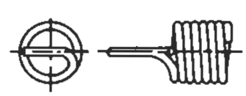

$$d = \sqrt[3]{\frac{8PD}{\pi S}} \qquad n = \frac{Gd^4}{8RD^3}$$

$$S = \frac{8P_2D}{\pi d^3}\ \text{psi}$$


No. 2 Plain Cut-Off


No. 3 Machine Cut-Off


No. 4 Short Twisted Cut-Off

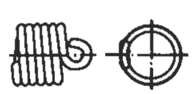

No. 5 Full Twisted Cut-Off

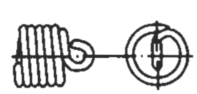

No. 6 Full Loop at Side


No. 7 Double Twisted Loop

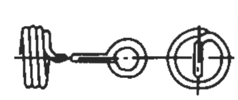

No. 8 Raised Hook

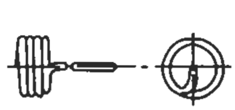

No. 9 Rectangular Hook


No. 10 Reduced Side Loop


No. 11 Reduced Center Loop

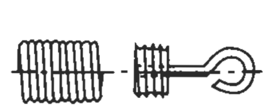

No. 12 Point or V Hook


No. 13 Extended Loop


No. 14 Straight End From Center


No. 15 Swivel Hook


No. 16 Offset Hook


No. 17 Threaded Plug for Plain End Spring

### Formula Index

- R = Rate per inch
- P = Load in pounds
- S = Stress (uncorrected)
- H = Solid Height
- G = Torsional modulus of elasticity
- p = Pitch
- M = Moment or torque, in lb
- E = Modules of elasticity
- n = Active coils
- N = Total coils
- D = Mean diameter of coil
- d = Diameter of wire
- $\pi$ = 3.14
- L = Free Length
- T = Revolutions of springs
- $S_k$ = Corrected Stress

### Torsional Modulus of Elasticity

| | | | |
|---|---|---|---|
| Steel | $11.5 \times 10^6$ | Chrome Silicon | $11.5 \times 10^6$ |
| Stainless Steel | $10 \times 10^6$ | Phosphor Bronze | $6.25 \times 10^6$ |
| Chrome Vanadium | $11.5 \times 10^6$ | Brass | $5.5 \times 10^6$ |

Use Compression Rate and Stress Formulas for calculating extension springs.
1.75 x ID = Height of regular hooks (divided by 2 for one end)

| | Materials | Nominal Analysis | Tensile Properties: Minimum Tensile Strength psi x$10^6$ | Tensile Properties: Modules of Elasticity E psi x$10^6$ | Torsional Properties: Design Stress % Minimum Tensile | Torsional Properties: Modules in Torsion G psi x$10^6$ | Maximum Temperature °F | Maximum Temperature °C | Rockwell Hardness | Method of Manufacture Chief Uses Special Properties |
|---|---|---|---|---|---|---|---|---|---|---|
| High Carbon Spring Wire | Music Wire<br>ASTM 228 | C .70 - 1.00%<br>Mn .20 - 60% | 230 -399 | 30 | 45 | 11.5 | 250 | 121 | C41-60 | Cold drawn. High and uniform Tensile. High quality springs and wire forms. |
| | Hard Drawn<br>ASTM A 227 | C .45 - 85%<br>Mn .60 - 1.30% | CLI 147-283<br>CLII 171-324 | 30 | 40 | 11.5 | 250 | 121 | C31-52 | Cold drawn. Average stress applications. Lower cost springs and wire forms. |
| | High Tensile Hard Drawn<br>ASTM A 679 | C .65 - 1.00%<br>Mn .20 - 1.30% | 238-350 | 30 | 45 | 11.5 | 250 | 121 | C41-60 | Cold drawn. Higher quality springs and wire forms. |
| | Oil Tempered<br>ASTM A 229 | C .55 - .85%<br>Mn .60 - 1.20% | CLI 165-295<br>CLII 191-324 | 30 | 45 | 11.5 | 250 | 121 | C42-55 | Cold drawn and heat treated before fabrication. General purpose spring wire. |
| | Carbon Valve<br>ASTM A 230 | C .60 - .75%<br>Mn .60 - .90% | 2115-240 | 30 | 45 | 11.5 | 250 | 121 | C45-49 | Cold drawn and heat treated before fabrication. Good surface condition and uniform tensile. |

**General.** High-carbon spring steels are the most commonly used of all springs materials. Try to use these materials in preference to others because they are least expensive readily available easily worked, and most popular. These materials are not satisfactory for high or low temperatures or for shock or impact loading.

| | Materials | Nominal Analysis | Tensile Properties: Minimum Tensile Strength psi x$10^6$ | Tensile Properties: Modules of Elasticity E psi x$10^6$ | Torsional Properties: Design Stress % Minimum Tensile | Torsional Properties: Modules in Torsion G psi x$10^6$ | Maximum Temperature °F | Maximum Temperature °C | Rockwell Hardness | Method of Manufacture Chief Uses Special Properties |
|---|---|---|---|---|---|---|---|---|---|---|
| Alloy Steel Wire | Chrome Vanadium<br>ASMA 231 | C .48-53%<br>Cr .80-1.10%<br>V .15 min% | 190-300 | 30 | 45 | 11.5 | 425 | 218.5 | C41-55 | Cold drawn and heat treated before fabrication. Used for shock loads and moderately elevated temperature. |
| | Chrome Silicon<br>ASTMA 401 | C .51-59%<br>Cr .60-80%<br>Si 1.20-1.60% | 235-300 | 30 | 45 | 11.5 | 475 | 246 | C48-55 | Cold drawn and heat treated before fabrication. Used for shock loads and moderately elevated temperature. |

**General.** The alloy spring steels shave a definite place in the field of spring materials. Try to use these materiols, particularly for conditions involving high stress and for applications where shock or impact loading occurs. Alloy spring steels also can withstond higher and lower temperatures than the high-carbon steels and are obtainable in either the onnealed or pretempered conditions. Note: These materials are not regularly stocked in a wide variety of sizes.

| | Materials | Nominal Analysis | Tensile Properties: Minimum Tensile Strength psi x$10^6$ | Tensile Properties: Modules of Elasticity E psi x$10^6$ | Torsional Properties: Design Stress % Minimum Tensile | Torsional Properties: Modules in Torsion G psi x$10^6$ | Maximum Temperature °F | Maximum Temperature °C | Rockwell Hardness | Method of Manufacture Chief Uses Special Properties |
|---|---|---|---|---|---|---|---|---|---|---|
| Stainless Steel Wire | AISI 302-304<br>ASTM 313 | Cr 17.0-19.0%<br>Ni 8.0-10.0% | 125-325 | 28 | 30-40 | 10 | 550 | 288 | C35-45 | Cold draw, general purpose corrosion and heat resistant. Magnetic in spring temper. |
| | AISI 316<br>ASTMA 313 | Cr 16.0-18.0%<br>Ni 10.0-14.0%<br>Mo 2.0-3.0% | 110-245 | 28 | 40 | 10 | 550 | 288 | C35-45 | Cold drawn. Heat resistant and better corrosion resistance than 302. magnetic in spring temper. |
| | 17-7 PH<br>ASTMA 313 (631) | Cr 16.0-18.0%<br>Ni 6.5-7.5%<br>Al .75-1.5% | Cond CH<br>235-335 | 29.5 | 45 | 11 | 650 | 343 | C38-57 | Cold drawn & precipitation hardened after fabrication. High strength and general purpose corrosion resistance. Slightly magnetic in spring temper. |

**General.** The use of stainless steels has increased considerable in recent years. Several new compositions are now available to withstand corrosion. All of these materials can be used for high temperatures up to 650 F.

| | Materials | Nominal Analysis | Tensile Properties: Minimum Tensile Strength psi x$10^6$ | Tensile Properties: Modules of Elasticity E psi x$10^6$ | Torsional Properties: Design Stress % Minimum Tensile | Torsional Properties: Modules in Torsion G psi x$10^6$ | Maximum Temperature °F | Maximum Temperature °C | Rockwell Hardness | Method of Manufacture Chief Uses Special Properties |
|---|---|---|---|---|---|---|---|---|---|---|
| Non-Ferrous Alloy Wire | Phosphor Bronze<br>Grade A ASTM B159 | Cu 94.0-96.0%<br>Sn 4.0-6.0% | 105-145 | 15 | 40 | 6.25 | 200 | 93.8 | 898-104 | Cold drawn. Good corrosion resistance and electrical conductivity. |
| | Beryllium Cooper<br>ASTM B197 | Cu 98.0%<br>Be 2.0% | 150-230 | 18.5 | 45 | 7.0 | 400 | 204 | C35-42 | Cold drawn and may be mill hardened before fabrication, Good corrosion resistance and electrical conductivity. High physicals. |
| | Monel 40<br>AMS 7233 | Ni 66.0%<br>Cu 31.5%<br>C/Fe | 145-180 | 26 | 40 | 9.5 | 450 | 232 | C23-32 | Cold drawn. Good corrosion resistance at moderately elevated temperature. |
| | Monel K 500<br>QQ-N-286 | Ni 65.0%<br>Cu 29.5%<br>C/Fe/A/Ti | 160-200 | 26 | 40 | 9.5 | 550 | 288 | C23-35 | Excellent corrosion resistance at moderately elevated temperature. |

**General.** Copper-based alloys are important spring materials because of their good electrical properties combined with their excellent resistance to corrosion. Although these materials are more expensive than the high-carbon and alloy steels, they nevertheless are frequently used in electrical components and in subzero temperatures. All copper-based alloys are drawn to the American wire gage (same as Brown & Sharpe gage) and are nonmagnetic.

| | Materials | Nominal Analysis | Tensile Properties: Minimum Tensile Strength psi x$10^6$ | Tensile Properties: Modules of Elasticity E psi x$10^6$ | Torsional Properties: Design Stress % Minimum Tensile | Torsional Properties: Modules in Torsion G psi x$10^6$ | Maximum Temperature °F | Maximum Temperature °C | Rockwell Hardness | Method of Manufacture Chief Uses Special Properties |
|---|---|---|---|---|---|---|---|---|---|---|
| High Temperature Alloy Wire | A 286 Alloy | Ni 26.0%<br>Cr 15.0%<br>Fe 53.0% | 160-200 | 29 | 35 | 10.4 | 950 | 510 | C35-42 | Cold drawn and precipitation hardened after fabrication. Good corrosion resistance at elevated temperature. |
| | Inconel 600<br>QQ-W-390 | Ni 76.0%<br>Cr 15.8%<br>Fe 7.2% | 170-230 | 31 | 40 | 11.0 | 700 | 371 | C35-45 | Cold drawn. Good corrosion resistance at elevated temperature. |
| | Inconel 718 | Ni 52.5%<br>Cr 18.6%<br>Fe 18.5% | 210-250 | 29 | 40 | 11.2 | 1100 | 593 | C45-50 | Cold drawn and precipitation hardened after fabrication. Good corrosion resistance at elevated temperature. |
| | Inconel X-750<br>AMS 5698,5699 | Ni 7.3%<br>Cr 15.5%<br>Fe 6.75% | No.IT 155min.<br>Spg. T 190-230 | 31 | 40 | 12 | 750-1100 | 399-593 | C34-39<br>C42-48 | Cold drawn and precipitation hardened after fabrication. Good corrosion resistance at elevated temperature. |

**General.** Nickel-based alloys are especially useful spring materials to combat corrosion and to withstand both elevated and below-zero temperature applications. Their nonmagnetic characteristic is important for such devices as gyroscopes, chronoscopes, and indicating instruments. These materials have high electrical resistance and should not be used for conductors of electrical current.

| | |
|---|---|
| **Flat High-Carbon Spring Steels** | Flat High-Carbon Spring Steels General. Although several types of thin flat strip are obtainable for specific applications in watches, clocks and certain instruments only two types are readily available. These two compositions are used for over 95% of all applications requiring flat high-carbon strip. Although these materials are frequently plated sections under 0.015 in. having carbon content over 0.85 with hardness over Rockwell C47 are highly susceptible to hydrogen-embrittlement even though special plating and beating operations are employed. (properties not displayed). |

**Active coils (n)** Those coils free to deflect under *load.*

**Closed ends** In compression springs, ends in which the pitch of the terminal coils is reduced so that they touch the adjacent coils.

**Closed and ground ends** Closed ends ground to provide a flat plane.

**Close-wound** Spring coiled with adjacent coils touching.

**Coils per inch** See *pitch.*

**Deflection (F)** Motion of spring ends or arms under the application or removal of an external *load* (P).

**Elastic limit** Maximum stress to which a material can be subjected without *permanent set.*

**Free angle** In torsion springs, the angle formed by the spring's arms under no *load.*

**Free length (L)** The overall length of a spring under no *load.*

**Heat setting** Fixturing a spring at elevated temperature to minimize loss of *load* at operating temperature.

**Helix** The spiral form (open or closed) of compression, extension and torsion springs.

**Hooks** The open loops or ends of an extension spring.

**Hydrogen embrittlement** Condition in which hydrogen is absorbed into carbon steel causing brittleness and susceptibility to cracking, particularly under sustained *loads.* Often occurs during electroplating or pickling.

**Initial tension (P)** The resistance that tends to keep the coils of an extension spring closed. This force must be overcome before those coils will begin to open.

**Load (P)** Any force applied to a spring which, in sufficient degree, will cause *deflection.*

**Loops** Coil-like wire shapes at the end of extension springs that provide for attachment and force application.

**Mean coil diameter (D)** Outside spring diameter (OD) minus one wire diameter (d).

**Modulus in shear or torsion (G)** Coefficient or stiffness for extension and compression springs.

**Moment (M)** see *torque.*

**Open ends** In compression springs, ends with a constant *pitch* for each coil. May be ground or unground.

**Passivating** Acid treatment to remove contaminants and improve corrosion resistance in stainless steel.

**Permanent set** Condition in which a material does not return to its original condition when a *load* is removed. Occurs when the material's *elastic limit* has been exceeded

**Pitch (p)** The center-to-center distance between adjacent *active coils.* (The recommended practice is to specify number of *active coils* rather than pitch).

**Rate (R)** The change in *load* pr unit of *deflection.* Most often given in lb/in.

**Remove set** The process of closing to *solid height* a compression spring that has been coiled longer than the desired finished length, so as to increase the apparent *elastic limit.*

**Residual stress** Stress induced by set removal, *shot peening,* cold working, forming or other operations. May be beneficial or detrimental, depending on the application.

**Set** See *permanent set.*

**Solid height (H)** The length of a compression spring under *load* sufficient to bring each coil into contact with adjacent coils.

**Spring index** Ration of *mean coil diameter* (D) to wire (d).

**Squared and ground ends** See closed and ground end.

**Squared ends** See *closed ends.*

**Stress range** The difference in *operating stress* under minimum and maximum *loads.*

**Stress relieve** To subject springs to low-temperature heat treatment to relieve *residual stress.*

**Shot peening** A cold-working process in which the material surface is peened to induce compressive stresses, thereby improving fatigue life.

**Torque (M)** In torsion springs, twisting action that tends to produce rotation. Equals load x distance (moment arm) from the *load* to the axis of the spring body. Most often expressed in-oz or ft-lb.

**Total number of coils (N)** Number of *active coils* (n) plus the coils forming the ends.

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