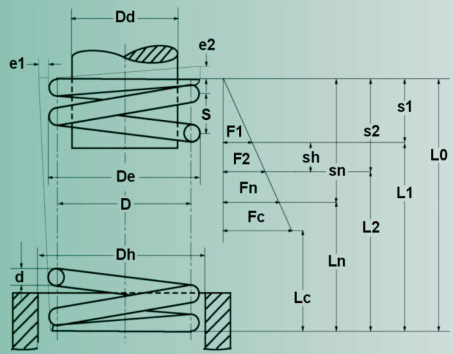
Metal Springs 1x1

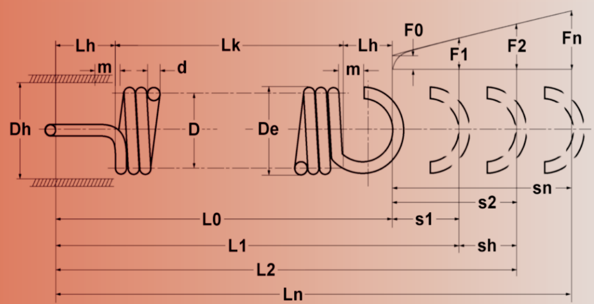
Metal springs - basics, materials, calculation

1st edition

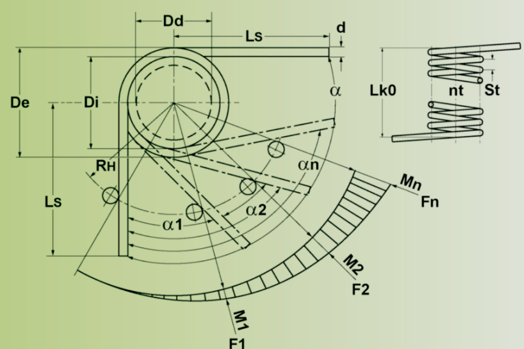
Compression springs



Extension springs



Torsion springs



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Gutekunst Federn "Metal Springs 1x1" has been compiled from selected sources of information and Gutekunst Federn's many years of experience. It is intended to give you a brief insight into the basics of spring design and calculation. Designed for the main spring types compression, extension, torsion and disc springs (disc springs are not offered by Gutekunst Federn), "Metal Springs 1x1" contains the basic formulas, possible applications and material properties in a short and clear summary.

We hope you enjoy reading the information brochure "Metal Springs 1x1". If you have any questions or would like more detailed information, please contact us directly at the following addresses.

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METAL SPRINGS

BASICS, MATERIALS, CALCULATION

Table of Contents

1. formula symbol

F	Force in N
s	Spring travel in mm (s1, s2, sn and sc correspond to the respective spring lengths)
L0	unloaded spring length in mm
L1, L2	Extensioned spring length in
mm Ln	smallest usable length in mm
Lc	Block length in mm
F1, F2, Fn, Fc	Spring force in N, related to the clamped lengths
R	Spring rate in N/mm
R_M	Moment spring rate in Nmm/°
R_H	Lever arm of the spring force in mm
M	Bending moment in Nmm
α, α_1, α_2	Angle of rotation in °
αn	Maximum angle of rotation in °
W	Spring work in Nmm
G, G20	Sliding or shearing modulus in N/mm² (at 20°C)
E, E20	Modulus of elasticity in N/mm² (at 20°C)
G_t	temperature-dependent shear modulus in N/mm²
E_t	Temperature-dependent modulus of elasticity in N/mm²
D, Dm	mean diameter in mm
De, Di	Outer diameter, inner diameter in mm
Dd, Dh	Mandrel diameter, sleeve diameter in mm
d	Wire thickness in mm
n	Number of resilient coils
nt	Number of total turns
τ, τk	Shear stress, corrected shear stress in N/mm²
σ, σ_q	Bending stress, corrected bending stress in N/mm²
k, q	Voltage correction factor
τ_{zul}, τ_c	Permissible stress in N/mm²
σ_{zul}	Permissible bending stress in N/mm²
Sa	Sum of the minimum distances between the windings in mm
S	Slope of the spring in mm (centre distance of the coils)
s_K	Knding spring travel in mm
Rm	Minimum tensile strength in N/mm²
Re	Yield strength in N/mm²
T	Temperature in °C
F0	Internal preload in N
LK	Body length of Extension springs in mm
LH	Eye height in mm
h0	Internal height ofthe unloaded spring plate
t	Thickness of the spring plate
t'	Thickness of the spring plate with bearing surfaces
μ	Poisson's ratio

1.1 Introduction

Springs are elements that deform selectively under load and return to their original shape when unloaded. The technical spring, once insignificant and neglected, has been elevated to the ranks of the most important machine elements by the rapid development of technology. Whether in vehicles, precision mechanical or electrotechnical apparatus, whether in power machines, machine tools or agricultural machinery, whether in medical equipment, computer technology or household appliances, the function of the entire device or machine part usually depends on the trouble-free operation of the springs.

1.2 Basics

In the field of technical springs, there is a wide variety of designs and types.

<table>
<tr><td colspan="3">Metallic springs</td><td rowspan="2">Non-metallic feathers</td><td rowspan="3">Fluid springs</td><td rowspan="3">Gas springs</td></tr>
<tr><td>Extension, compression loaded springs</td><td>Bending springs</td><td>Torsion springs</td></tr>
<tr><td>Extension rod spring
Ring spring</td><td>Leaf spring
Spiral spring
Torsion spring
Belleville washer</td><td>Torsion bar
Pressure spring
Extension spring</td><td>Rubber spring
Plastic spring</td></tr>
</table>

In the following, the types of springs which are predominantly used in almost all branches of production are dealt with: the cold-formed coil springs. In addition, the disc spring, which is also frequently used in practice, is presented.
Coil springs are divided into 3 main groups (shown in Figure 1.1):

1. Compression springs
2. Extension springs
3. Torsion springs

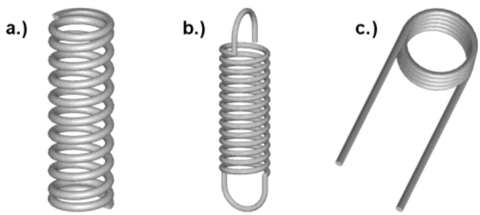

Figure 1.1: Compression spring (a), extension spring (b), torsion spring(c)

The type of stress is decisive for the calculation, therefore the spring types are differentiated according to their predominant stress (bending or torsion).

Compression and Extension springs: The type of force application causes **torsional stress** as the main stress in the material cross-section of the springs.

Torsion springs, disc springs: The introduction of an external force leads to a **bending stress** in the spring cross-section. Other occurring stresses are usually negligible.

1.2.1 Spring characteristic

The properties of the springs are assessed according to their characteristic curve. This represents the dependence of the spring force *F* on the spring travel *s*. Depending on the shape of the spring, a distinction is made between linear, progressive, degressive and combined characteristics (see Fig. 1.2).

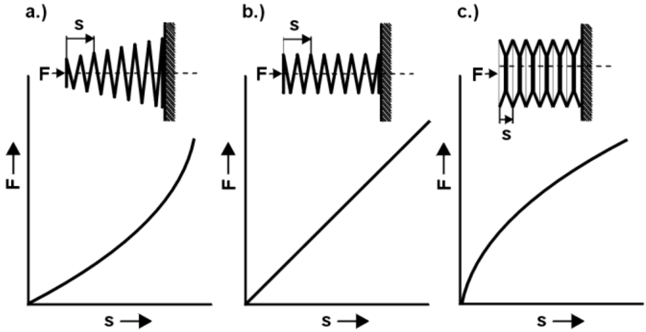

Figure 1.2: Spring characteristics a) progressive of a conical compression spring, b) linear of a cylindrical compression spring, c) degressive of a disc spring column

1.2.2 Spring rate

The spring rate R is the slope of the spring characteristic curve in the spring diagram. With a linear characteristic curve, the spring rate is constant. Springs with a curved characteristic have a variable spring rate. In case of straight characteristic curve applies:

$$R = \frac{F2 - F1}{s2 - s1}$$ Compression and extension springs

respectively

$$R = \frac{M2 - M1}{\alpha 2 - \alpha 1} \qquad \text{Torsion springs}$$

Many springs are deformable in several directions, therefore, depending on the direction of force or degree of freedom of the free end of the spring, a distinction must be made between longitudinal, transverse and torsional spring rates.

1.2.3 Spring work

When a spring is Extensioned, work is performed which the spring releases again when it is unExtensioned. The spring work always results as an area below the spring characteristic curve. With a linear characteristic curve, the following therefore applies:

$$W = \frac{1}{2} F \cdot s \qquad \text{compression and exExtension springs}$$

$$W = \frac{1}{2} M \cdot \alpha \qquad \text{Torsion springs}$$

1.2.4 Hysteresis

The suspension behaviour is influenced by friction. These frictional forces hinder the rebound deformation. In the case of alternating stress, this manifests itself in the form of a hysteresis loop (see Figure 1.3). Part of the spring work is converted into heat and is thus "lost". Since this is undesirable, especially when using springs for measuring tasks, any friction should be avoided constructively by the arrangement and design of the springs.

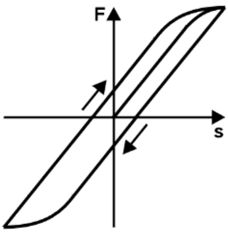

Figure 1.3: Friction-induced hysteresis loop

1.2.5 Relaxation

If a compression spring is compressed by a certain amount between parallel plates at a higher temperature, it can be seen that the spring force gradually decreases over time. This loss of force increases with increasing temperature and Extension.

Relaxation of the material is a plastic deformation, which manifests itself as a loss of force at constant installation length. This is indicated as a percentage in relation to the initial force F1:

$$\mathrm{Re}laxation = \frac{\Delta F \cdot 100}{F1}$$

The basic course of the relaxation and the relaxation speed is shown in Figure 1.4.
The relaxation values according to

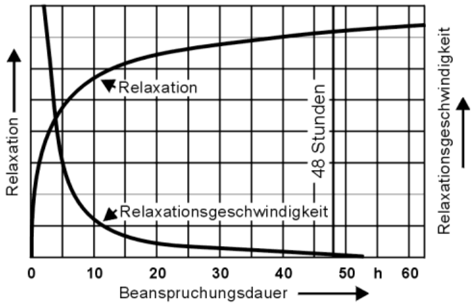

Figure 1.4: Time course of relaxation and relaxation speed for helical compression springs

48 hours are considered as characteristic values, although at this time the relaxation is not yet completely finished. EN 13906-1 contains material-dependent relaxation diagrams. These should only be included by the designer if high demands are made on the constancy of the spring force.

1.3 Materials

Springs must be made of a suitable material and must be designed and constructed in such a way that they return to their original shape after an applied load has been removed. This property is expressed in the modulus of elasticity or the sliding modulus. These material parameters express the relationship between stress and strain and should have the highest possible value (see Table 1.1).
In addition, spring materials:

- have high elastic limits, i.e. a large purely elastic range,
- withstand the corresponding stresses even at elevated temperatures without major loss of force (low relaxation),
- have a high fatigue strength (fine-grained structure, free of impurities),
- have sufficient deformation capacity,
- have a surface that is as slippery as possible,
- withstand certain corrosion protection requirements,
- possibly be electrically conductive or non-magnetic.

Table 1.1: Elasticity and sliding moduli of different materials

Material	E-modulus [N/mm²]	G-modulus [N/mm²]
Patented drawn spring steel wire according to EN10270-1	206000	81500
Oil tempered valve spring wire according to EN10270-2	206000	81500
Hot rolled steel according to EN10089	206000	78500
Cold rolled strip according to EN10132	206000	78500
X10 CrNi 18 8 (1.4310)	185000	70000
X7 CrNiAl 17 7 (1.4568)	195000	73000
X5 CrNiMo 17-12-2 (1.4401)	180000	68000
CuSn6 R950 according to EN12166	115000	42000
CuZn36 R700 according to EN12166	110000	39000
CuBe2 according to EN12166	120000	47000
CuNi18Zn20 according to EN12166	135000	45000
CuCo2Be according to EN12166	130000	48000
Inconel X750	213000	76000
Nimonic 90	213000	83000
Hastelloy C4	210000	76000
Titanium alloy TiAl6V4	104000	39000

1.3.1 Spring steel wire according to EN 10270-1

Most springs are made of spring steel wire according to EN 10270-1. It is produced by patenting (a heat treatment consisting of austenitizing and rapid cooling to a temperature above the martensite point) and cold drawing from unalloyed steels. Depending on the required stress, they are classified into five types of wire: SL, SM, SH, DM and DH. If springs are subjected to static or occasionally dynamic stresses, a wire grade for static stress (S) is used. In other cases with frequent or predominantly dynamic loading and with small winding ratios or narrow bending radius, a wire grade for dynamic loading (D) is used. Depending on the level of stress, spring wire is produced in 3 tensile strength classes: low (SL), medium (SM, DM) and high (SH, DH). Due to the high requirements in the industry, the grades SH and DH are mainly used in practice.

1.3.2 Valve spring wire according to EN 10270-2

Valve spring wire (VD) according to EN 10270-2 should be used for high continuous vibration stresses. SiCr-alloyed valve spring wires in particular have proven their worth, as they have high fatigue strength as well as high tensile strength and can be used up to operating temperatures of 160°C. The wire is manufactured by drawing and subsequent oil tempering to achieve high strength.

1.3.3 Stainless spring steel

The above materials must be provided with surface protection to prevent corrosion. Austenitic chromium-nickel steels, on the other hand, exhibit chemical resistance in moist air and water. They are also resistant in cold, dilute mineral acids such as phosphoric acid, nitric acid and chromic acid. The addition of molybdenum, as well as nickel, increases resistance in non-oxidizing acids, such as sulfuric acid. Stainless steels show good resistance in many neutral salt solutions at normal temperature and low chlorine content. Nitrites, nitrates, sulphites, sulphates, carbonates, etc. do not exert a corrosive effect on the steels. Chlorides and bromides do not cause general corrosion, but are dangerous in that they can attack the steel in places.

In neutral and acidic solutions containing chloride or bromide, stainless steels can be attacked by pitting and crevice corrosion. Resistance to this type of attack is improved mainly by molybdenum and chromium.

The high alloy stainless steels are also used for high or low temperature applications see section 1.3.5.

1.3.4 Non-ferrous metals

1.3.4.1 Copper alloys

Wrought copper alloys are increasingly being pushed out of spring production. They can only hold their own where good electrical properties (see Table 1.2) are required at the same time. Wrought copper alloys are non-magnetic and resistant to seawater. If there is a risk of stress corrosion cracking, CuSn6 is preferable.

Table 1.2: Electrical conductivity of some copper alloys

Material	**Electrical conductivity [m/Ωmm²]**
CuZn36 (brass)	15
CuSn6 (tin bronze)	10
CuNi18Zn20 (nickel silver)	3
CuBe2 (beryllium bronze)	8-13

1.3.4.2 Nickel alloys

Nickel alloys have high heat and corrosion resistance. They also have a high electrical resistance and are usually non-magnetic. The strength values are lower than those of steels, but at high temperatures they are superior to them. In particular, the very good corrosion resistance of Hastelloy C4 is associated with low tensile strength (Table1.3).

Table 1.3: Tensile strength of selected nickel alloys

Material	Tensile strength in N/mm²
Inconel X750 (NiCr15Fe7Ti2Al)	1400
Nimonic 90 (NiCr20Co18TiAl)	1200
Hastelloy C4 (NiMo16Cr16Ti)	800

1.3.4.3 Titanium alloys

Since titanium compounds have a favorable strength-to-mass ratio, they are interesting for aeronautical engineering. They are also characterized by insensitivity to cold, heat resistance and corrosion resistance.

1.3.5 Influence of the working temperature

1.3.5.1 Behaviour at increased operating temperatures

The level of the working temperature can have a considerable influence on the function of a spring, as the tendency to relaxation increases with rising temperature (see Chapter 1.2.5). By evaluating the relaxation diagrams, the limit temperatures shown in Table 1.4 can be determined for the individual materials.

Table 1.4: Limit temperatures of spring materials at minimum relaxation

Material	**Maximum working temperature in °C at**	
	High load	**Low load**
Patented drawn spring steel wire according to EN10270-1	60-80	80-150
Oil tempered valve spring wire according to EN10270-2	80-160	120-160
X10CrNi 18.8 (1.4310)	160	250
X7CrNiAl 17.7 (1.4568)	200	350
X5CrNiMo 17-12-2 (1.4401)	160	300
CuSn6	80	100
CuZn36	40	60
CuBe2	80	120
CuNi18Zn20	80	120
Inconel X750	475	550
Nimonic90	500	500

In addition, the material properties of modulus of elasticity and shear modulus, which are important for the spring function, decrease with increasing temperature. Both the shear modulus and the modulus of elasticity are determined at higher temperatures according to the following formula, using the material properties at room temperature (20°C) as a basis (Table 1.1).

$$G_t = G_{20}\frac{3620-T}{3600} \quad \text{respectively} \quad E_t = E_{20}\frac{3620-T}{3600}$$

This allows the designer to determine the actual spring forces at the anticipated operating temperature.

1.3.5.2 Behaviour at low operating temperatures

When used in refrigeration systems, in space or in severe winter cold, temperatures as low as - 200 ° must sometimes be endured. Despite increasing tensile strength, low temperatures have an unfavourable effect, as the toughness of the materials decreases and brittle fractures can occur. Stainless spring steels as well as copper and nickel alloys are preferable to patented spring wires and valve spring wires for low- temperature applications. Table 1.5 shows the limit temperatures.

Table 1.5: Recommendations for low-temperature use

Material	**Minimum working temperature in °C**
Patented drawn spring steel wire acc. to EN10270-1	- 60
Oil tempered valve spring wire acc. to EN10270-2	- 60
X10CrNi 18.8 (1.4310)	- 200
X7CrNiAl 17.7 (1.4568)	- 200
X5CrNiMo 17-12-2 (1.4401)	- 200
CuSn6	- 200
CuZn36	- 200
CuBe2	- 200
CuNi18Zn20	- 200
Inconel X750	- 100
Nimonic90	- 100

Surface defects caused by machining (e.g. scoring) or bends with small bending radii should be avoided as far as possible in low-temperature applications.

1.4 Calculation

The aim of spring design is to find the most economical spring for the given task, taking into account all circumstances, which also fits into the available space and achieves the required service life. In addition to these manufacturing and material requirements, the correct spring design is of particular importance.

The designer should compile the following requirements:

1. Load type (static or dynamic)
2. Lifetime
3. Operating temperature
4. Ambient medium
5. Required forces and spring deflections
6. Available installation space
7. Tolerances
8. Installation situation (buckling, transverse suspension)

Each spring design consists of two stages:
Functional verification: Checking the spring rate, forces and spring deflections, vibration behaviour, etc.
Strength verification: verification of compliance with the permissible stresses or fatigue strength verification

This requires an iterative approach.
The strength verification is based on the decision whether the spring is subjected to static, quasi-static or dynamic loading. The following criteria should be used for differentiation:

Static or quasi-static loading: Time constant (static) load or time varying load with less than 10000 strokes in total.

Dynamic loading: time-varying loads with more than 10,000 strokes. The spring is usually preloaded and subjected to periodic swell loading with a sinusoidal curve, which occurs randomly (stochastically), e.g. in motor vehicle suspensions. In some cases, abrupt changes in force occur.

When dimensioning springs, stress limits must be specified which are based on the strength values of the materials and take into account the type of stress. For this purpose, a safety factor is included and thus the permissible stress is determined. After a comparison with the actually existing stress, the spring dimensioning must be revised by iterative procedure.

***Rated voltage Permissible voltage*≤**

1.4.1 Spring systems

For design reasons, several springs must sometimes be used to absorb forces and execute movements. Simple spring systems result from the parallel or series connection of individual springs.

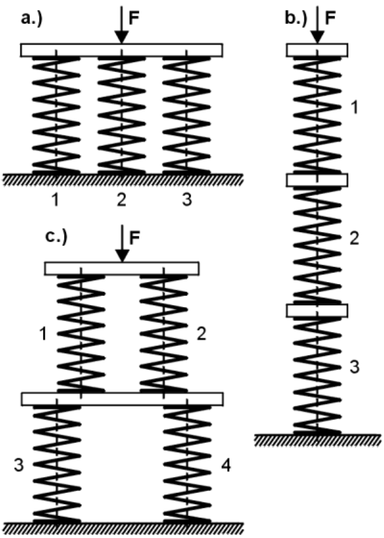

Figure 1.5: Spring systems; a) parallel connection; b) series connection; c) mixed connection

1.4.1.1 Parallel connection

The springs are arranged (Figure 1.5) in such a way that the external load F is distributed proportionally among the individual springs, but the travel of the individual springs is the same. This results in:

$s = s1 = s2 = s3 = ...$ Total spring travel

$F = F1 + F2 + F3 + ...$ Total spring force

$R = R1 + R2 + R3 + ...$ Total spring rate

> The spring rate of the overall system of a parallel circuit is always greater than the spring rate of the individual springs.

1.4.1.2 Series connection

The springs are arranged one behind the other (Figure 1.5), so that the same force acts on each spring, but the spring travel is divided between the individual springs. The result is:

$s = s1 + s2 + s3 + ...$ Total spring travel

$F = F1 = F2 = F3 = ...$ Total spring force

$$R = \frac{1}{\frac{1}{R1} + \frac{1}{R2} + \frac{1}{R3} + \ldots}$$ Total spring rate

The spring rate of the overall system of a series connection is always smaller than the spring rate of the individual springs.

1.4.1.3 Mixing circuit

Several springs are connected in parallel and in series. Figure 1.5 shows that the following applies to the case shown:

$$R = \frac{1}{\frac{1}{R1 + R2} + \frac{1}{R3 + R4} + \ldots}$$ Total spring rate

Because of the equilibrium R1=R2 and R3=R4 must be.

The spring rate of the total system of the shown mixed circuit is between the smallest and the largest spring rate of the individual springs.

1.4.2 Compression springs

Compression spring calculation
https://www.federnshop.com/en/products/compression_springs/calculation.html

1.4.2.1 General

Cold-formed cylindrical compression springs with constant pitch are most commonly used in practice. The wire is cold formed by coiling around a mandrel. Depending on the feed rate of the pitch pin, the coil spacing and the contact of the spring is regulated. After coiling, tempering is carried out in order to reduce residual stresses in the spring and to increase the shear elasticity limit. Thus, the setting amount is reduced. Tempering temperatures and times depend on the material; cooling takes place in air at normal room temperature.

Other important operations in spring production are grinding and setting. The spring ends are usually ground from a wire thickness of 0.50 mm into ensure a plane-parallel bearing of the spring as well as optimum force transmission.
If the shear stress exceeds the permissible value when the spring is loaded, a permanent deformation occurs, which is expressed in the reduction of the unExtensioned length. This process is called "settling" in spring technology, which is equivalent to the terms "creep" and "relaxation" from materials technology. To counteract this, the compression springs are coiled longer by the expected settling amount and later compressed to block length. This pre-setting enables a better material utilization and allows a higher load in later use.

1.4.2.2 Calculation of cylindrical compression springs

The calculation is based on the calculation equations contained in EN 13906-1 (see also Figure 1.6):

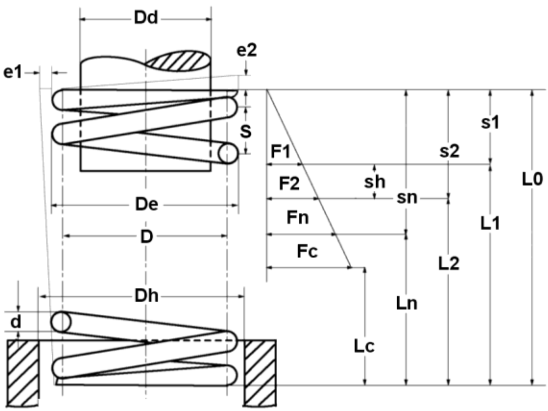

Figure 1.6: Theoretical compression spring diagram

Proof of function

The following applies to cylindrical compression springs made of wire with a circular cross-section:

Spring Rate: $$R = \frac{Gd^4}{8D^3 n}$$

follows from R=F/s (see section 1.2.2):

Spring Force: $$F = \frac{Gd^4 s}{8D^3 n}$$

as well as:

Spring deflection: $$s = \frac{8D^3 nF}{Gd^4}$$

Strength verification

After determining the spring dimensions, the strength verification must be carried out. For this purpose, the existing shear stress is determined:

Extension from force: $$\tau = \frac{8DF}{\pi d^3}$$

Voltage off deflection: $$\tau = \frac{Gds}{\pi n D^2}$$

While the shear stress τ is to be used for the design of statically or quasi-statically loaded springs, the corrected shear stress τk applies to dynamically loaded springs. The shear stress distribution in the wire cross-section of a spring is non-uniform, the highest stress occurs at the inner diameter of the spring. The highest stress can be approximately determined using the stress correction factor k, which depends on the coiling ratio (ratio of the mean diameter to the wire thickness) of the spring. Thus, for dynamically stressed springs, the following results:

Corrected shear stress: $$\tau_k = k \cdot \tau$$

where holds for k (according to Bergsträsser):

$$k = \frac{\frac{D}{d} + 0{,}5}{\frac{D}{d} - 0{,}75}$$

Now the comparison is made with the permissible voltage. This is defined as follows:

Permissible voltage: $$\tau_{zul} = 0{,}5 \cdot R_m$$

$$\tau_{czul} = 0{,}56 \cdot R_m$$

The values for the minimum tensile strength Rm depend on the wire thickness and can be found in the standards for the corresponding materials.
As a rule, it must be possible to compress compression springs up to the block length, therefore the permissible stress at block length τ_{czul} must be taken into account.
In the case of dynamic loading, the lower and upper stress (τ_{k1} and τ_{k2}) of the corresponding stroke must be determined. The difference is the stroke stress. Both the upper stress and the stroke stress must not exceed the corresponding permissible values. These can be found in the fatigue strength diagrams of EN 13906-1:2002. If the stresses withstand this comparison, the spring is fatigue resistant at a limiting load cycle number of 10^7.

Table 1.6: Geometry relationships for compression springs

Federkenngröße	Berechnungsgleichung
Total number of turns	$n_t = n + 2$
Block length of the ground spring	$L_c = n_t\, d_{max}$
Block length of the unground spring	$L_c = (n_t + 1{,}5)d_{max}$
Smallest usable length	$L_n = L_c + S_a$
Unstressed length	$L_0 = L_n + s_n$
Sum of the minimum distances between the coils	$S_a = \left(0{,}0015\frac{D^2}{d} + 0{,}1d\right)\cdot n$
Increase of the outer diameter under load	$\Delta D_e = 0{,}1\frac{S^2 - 0{,}8Sd - 0{,}2d^2}{D}$
Gradient	$S = \frac{L_0 - d}{n}$ (grounded) $S = \frac{L_0 - 2{,}5d}{n}$ (unpolished)
Buckling spring deflection (valid for different bearing coefficientsn, see EN 13906-1:2002)	$s_K = L_0 \frac{0{,}5}{1-\frac{G}{E}}\left[1-\sqrt{1-\frac{1-\frac{G}{E}}{0{,}5+\frac{G}{E}}\left(\frac{\pi D}{\nu L_0}\right)^2}\right]$

All dynamically stressed springs with a wire thickness > 1 mm should be shot peened. In this way, an increase in the fatigue strength can be achieved. After both the functional verification and the strength verification have been carried out, various geometry calculations must be carried out and taken into account in order to be able to fit the spring into the construction of the component (Table 1.6). The block length cannot be fallen short of, because the coils are tightly connected, the smallest usable length should not be fallen short of, because then a linear force course as well as dynamic loading capacity are no longer guaranteed. In addition, the permissible tolerances according to DIN 2095 must be taken into account.

1.4.3 Extension springs

Extension spring calculation
https://www.federnshop.com/en/products/extension_springs/calculation.html

1.4.3.1 General

Extension springs are wound around a mandrel in exactly the same way as compression springs, but with no coil spacing and with different spring ends for fastening the spring (see Figure 1.7). The coils are pressed tightly together in the manufacturing process. This internal preload F0 depends on the coiling ratio and cannot be finished to any desired level. Reference values for the amount of preload are provided by the calculation software WinFSB from Gutekunst Federn after entering the respective spring data.

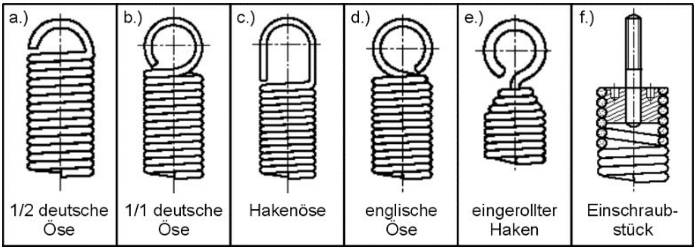

Figure 1.7: Common eye shapes: a.) half German eye; b.) whole German eye; c.) hook eye; d.) English eye; e.) rolled-in hook; f.) screw-in piece

The advantage of exExtension springs is that they do not buckle; the disadvantage is the larger installation space and the complete interruption of the force flow in the event of spring breakage.

1.4.3.2 Calculation of Extension springs

Corresponding to the calculation equations for compression springs but taking into account the prestressing force, the following relationships apply to cylindrical Extension springs made of round wire (see also Figure 1.8):

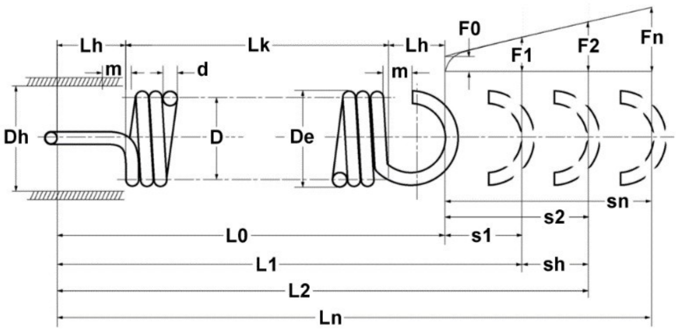

Figure 1.8: Theoretical Extension spring diagram

<u>Proof of function</u>

Spring Rate:

$$R = \frac{Gd^4}{8D^3n} = \frac{F - F_0}{s}$$

follows from R=F/s (see section 1.2.2):

Spring Force:

$$F = \frac{Gd^4 s}{8D^3n} + F_0$$

as well as:

Spring deflection: $$s = \frac{8D^3 n(F - F_0)}{Gd^4}$$

Strength verification

As with compression spring calculations, the existing shear stress must be determined.

Shear stress: $$\tau = \frac{8DF}{\pi d^3}$$

Likewise, the corrected stroke stress must be calculated for dynamic loading (see Chapter 1.4.2.2).

Corrected shear stress: $$\tau_k = k \cdot \tau$$

Permissible voltage: $$\tau_{zul} = 0{,}45 \cdot R_m$$

The existing maximum stress τ_n at the largest spring travel s_n is set equal to the permissible stress. However, in order to avoid relaxation, only 80 % of this spring travel should be used in practice.

$$s_2 = 0{,}8 \cdot s_n$$

No generally valid fatigue strength values can be given for dynamic stresses, as additional stresses may occur at the bending points of the eyelets, some of which may exceed the permissible stresses. Extension springs should therefore only be subjected to static loads if possible. If dynamic stress cannot be avoided, bent eyes should be avoided and rolled or screwed-in end pieces should be used. It makes sense to carry out a service life test under later conditions of use. Surface hardening by shot peening is not feasible due to the closely spaced coils. Table 1.7 shows the relationship of various Extension spring characteristics.

Table 1.7: Geometry relationships for Extension springs

Spring parameter	Calculation equation
Body length	LK = (nt + 1) d
Unstressed length	L0 = LK + 2 LH
Eyelet height half German eyelet	LH = 0.55Di to 0.80Di
Eyelet height whole German eyelet	LH = 0.80Di to 1.10Di
Eye height hook eye	LH > 1.10Di
Eyelet height English eyelet	LH = 1.10Di

The permissible manufacturing tolerances according to DIN 2097 must be taken into account.

1.4.4 Torsion springs

Torsion spring calculation
https://www.federnshop.com/en/products/torsion_springs/calculation.html

1.4.4.1 General

Coiled cylindrical torsion springs have essentially the same shape as cylindrical compression and exExtension springs, but with the exception of the spring ends. These are bent in a leg shape to allow the spring body to rotate around the spring axis. This means that they can be used in a wide variety of applications, e.g. as return springs or hinge springs. The torsion spring should be mounted on a guide mandrel and the load should only be applied in the winding direction. The inside diameter is reduced in this case (see Table 1.8). The springs are usually wound without a pitch. However, if friction is absolutely undesirable, torsion springs can also be manufactured with coil pitch. In case of dynamic stress, it is necessary to ensure that there are no sharp bends at the ends of the spring in order to avoid unpredictable stress peaks.

1.4.4.2 Calculation of torsion springs(leg springs)

The calculation is carried out according to the guidelines of EN 13906-3:2001.
(see also Figure 1.9):

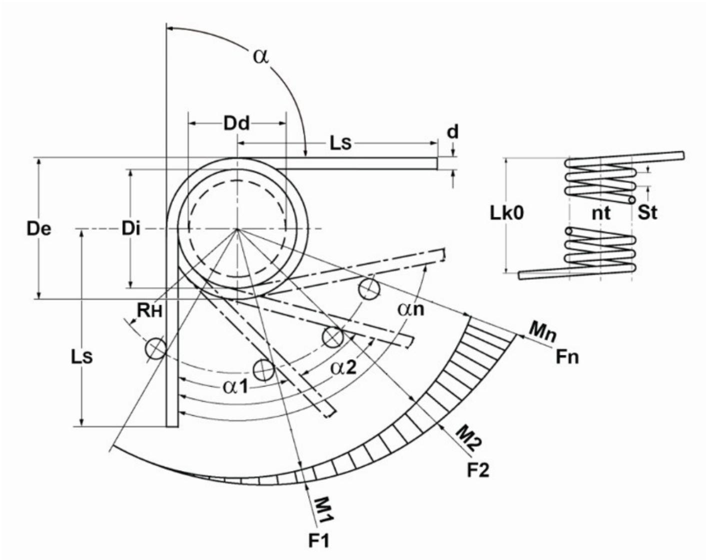

Figure 1.9: Theoretical torsion spring diagram

Proof of function

Fed Mom Rate: $$R_M = \frac{M}{\alpha} = \frac{d^4 E}{3667 Dn}$$

Spring Moment: $$M = FR_H = \frac{d^4 E\alpha}{3667 Dn}$$

Rotation angle: $$\alpha = \frac{3667 DMn}{Ed^4}$$

Strength verification

The existing bending stress is determined and compared with the allowable stress. In the case of dynamic loading, the corrected stress must again be used for comparison.

Bending stress: $$\sigma = \frac{32M}{\pi d^3}$$

Corrected bending stress: $$\sigma_q = q\sigma$$

where q is:

$$q = \frac{\frac{D}{d} + 0{,}07}{\frac{D}{d} - 0{,}75}$$

Permissible bending stress: $$\sigma_{zul} = 0{,}7 R_m$$

In the case of dynamic loading, the lower and upper stress (tk1 and tk2) of the corresponding stroke must be determined. The difference is the stroke stress. Both the upper stress and the stroke stress must not exceed the corresponding permissible values. For spring steel wire, these can be taken from the fatigue strength diagrams in EN 13906-3:2001. If the stresses withstand this comparison, the spring is fatigue resistant at a limiting load cycle number of 10^7.

Table 1.8 lists geometry relationships that are important for the design of the component:

Table 1.8: Geometrical relationships for torsion springs

Spring parameter	Calculation equation
Reduction of the inner diameter at maximum load	$D_{in} = \frac{Dn}{n + \frac{\alpha}{360}} - d$
Unloaded body length	$L_k = (n + 1{,}5)d$
Body length in maximum loaded condition	$L_{Kn} = (n + 1{,}5 + \frac{\alpha}{360})d$
Spring travel	$s_n = \frac{\alpha_n R_H}{57{,}3}$

In addition, the manufacturing tolerances according to DIN 2194 must be taken into account.

1.4.5 Disc springs

Not in the Gutekunst delivery program!

1.4.5.1 General

Disc springs are conically shaped annular discs made of spring steel strip. They are subjected to axial bending loads. They are used either as a single spring (Fig. 1.10) or layered as a disc spring column (Fig. 1.2c). Due to their high spring rate, disc springs are mainly used for large forces and small spring deflections, e.g. in couplings, as clamping elements for devices and tools or for vibration damping of vehicles.
The springs are made of hot rolled steel according to EN 10089 and cold rolled steel according to EN 10132-4.
Disc springs are divided into 3 groups:
Group 1: t < 1.25
Group 2: 1.25 < t < 6
Group 3: t > 6 (with bearing surfaces)

1.4.5.2 Calculation of single disc springs

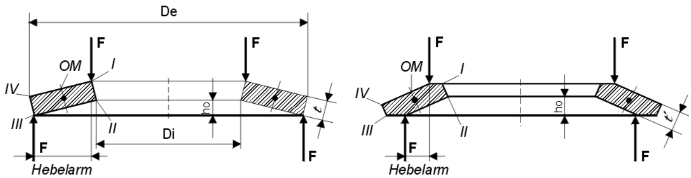

Figure 1.10: Single Belleville Spring

Proof of Function:
For disc springs without bearing surfaces, the following applies in accordance with DIN 2092 (see Figure 1.10):

Spring Forde: $$F = \frac{4E}{1-\mu^2} \cdot \frac{t^4}{K_1 D_e^2} \cdot \frac{s}{t}\left[\left(\frac{h_0}{t} - \frac{s}{t}\right)\left(\frac{h_0}{t} - \frac{s}{2t}\right) + 1\right]$$

Spring Rate: $$R = \frac{F}{s} = \frac{4E}{1-\mu^2} \cdot \frac{t^3}{K_1 D_e^2}\left[\left(\frac{h_0}{t}\right)^2 - \frac{3h_0 s}{t^2} + \frac{3s^2}{2t^2} + 1\right]$$

In the case of group 3 disc springs (with contact surfaces), the reduced thickness t' should be used for t. This reduced thickness counteracts an increase in force due to the shortened lever arm.

Strength verification:
The existing stresses are determined and compared with the permissible stresses:

Stresses at the edges 0M, I, II, III and IV:

$$\sigma_{0M} = -\frac{4E}{1-\mu^2} \cdot \frac{t^2}{K_1 D_e^2} \cdot \frac{s}{t} \cdot \frac{3}{\pi}$$

$$\sigma_I = -\frac{4E}{1-\mu^2} \cdot \frac{t^2}{K_1 D_e^2} \cdot \frac{s}{t}\left[K_2\left(\frac{h_0}{t} - \frac{s}{2t}\right) + K_3\right]$$

$$\sigma_{II} = -\frac{4E}{1-\mu^2} \cdot \frac{t^2}{K_1 D_e^2} \cdot \frac{s}{t}\left[K_2\left(\frac{h_0}{t} - \frac{s}{2t}\right) - K_3\right]$$

$$\sigma_{III} = -\frac{4E}{1-\mu^2} \cdot \frac{t^2}{K_1 D_e^2} \cdot \frac{s}{t} \cdot \frac{1}{\delta}\left[(K_2 - 2K_3)\left(\frac{h_0}{t} - \frac{s}{2t}\right) - K_3\right]$$

$$\sigma_{IV} = -\frac{4E}{1-\mu^2} \cdot \frac{t^2}{K_1 D_e^2} \cdot \frac{s}{t} \cdot \frac{1}{\delta}\left[(K_2 - 2K_3)\left(\frac{h_0}{t} - \frac{s}{2t}\right) + K_3\right]$$

Positive results are tensile stresses, negative results are compressive stresses.

Characteristics:

$$\delta = \frac{D_e}{D_i} \qquad K_1 = \frac{1}{\pi} \cdot \frac{\left(\frac{\delta-1}{\delta}\right)^2}{\frac{\delta+1}{\delta-1} - \frac{2}{\ln\delta}}$$

$$K_2 = \frac{6}{\pi} \cdot \frac{\frac{\delta-1}{\ln\delta} - 1}{\ln\delta} \qquad K_3 = \frac{3}{\pi} \cdot \frac{(\delta-1)}{\ln\delta}$$

Permissible stresses under static loading in the flat position:

$\sigma_{I\,zul} = 2600$ N/mm² and $\sigma_{0M\,zul} = Re$ (for steels according to EN 10089 as well as 10132 applies: $Re = 1400$ to 1600 N/mm²)

Permissible stress under dynamic loading:

In the case of dynamic stress, the lower and upper stress of the corresponding stroke must be determined at the particularly endangered points II or III. The difference is the hoisting stress. Both the upper stress and the hoisting stress must not exceed the corresponding permissible values. These can be taken from the fatigue strength diagrams in DIN 2093. If the stresses withstand this comparison, the spring is fatigue resistant at a limiting load cycle number of 2 x 10^6.

1.4.5.3 Combination of single disc springs

Spring assembly: Single plate springs layered in the same direction. If friction is neglected, the total force corresponds to the sum of the individual forces. The total spring travel corresponds to the spring travel of the single plate.
Spring column: alternately lined up individual disc springs or spring assemblies. If friction is neglected, the total force corresponds to the sum of the individual forces. Likewise, the total spring travel corresponds to the sum of the spring travels of the individual plates or packs.
By layering individual plates of different strengths in various combinations, almost any desired characteristic curve can be achieved. However, very long spring columns should be avoided due to the ever-increasing friction.

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Literature:
Decker K.H.: Maschinenelemente. Munich. Vienna: Hanser 1998
DIN paperback 29: Feathers 1. Berlin. Vienna. Zurich: Beuth 2003
DIN Pocketbook 349: Feathers 2. Berlin. Vienna. Zurich. Beuth 2002
Meissner, M.; Schorcht, H.J.: Metallfedern. Berlin. Heidelberg: Springer 1997
Niemann, G.; Winter, H.; Höhn, B.R.: Maschinenelemente. Berlin. Heidelberg: Springer 2001
Company publications and catalogues of the companies: Gutekunst Federn, Metzingen; Sandvik, Düsseldorf; Scherdel, Marktredwitz.

Metal Springs 1x1

by Gutekunst Federn

Selecting the right spring for the desired application is not always easy. There are many technical books on the fundamentals of design, but the subject of springs is often dealt with in connection with other machine elements. Yet springs are only supposedly simple machine elements and even centuries after Leonardo da Vinci's first experiments with tension and compression springs, development work still has to be put into the small force accumulators every day.

In order to give a small insight into spring construction Gutekunst Federn has prepared this brochure "Metal Springs 1x1". It is intended to support the design of the right spring in short, clearly arranged topics.

Gutekunst Federn specialises in the development and manufacture of compression, extension and torsion springs and wire bending parts. In addition to the catalogue programme with over 12,600 different spring sizes directly from stock, Gutekunst manufactures any desired individual spring up to 12.0 mm wire thickness in small quantities and large series.

Founded in 1964, the company is now one of the most successful spring manufacturers in Europe with 4 branches in Germany and France. Around 100,000 customers worldwide from a wide range of industries such as automotive, mechanical engineering, aerospace, medical, furniture and food industries rely on Gutekunst Federn products.

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