BS EN 13906-2:2013

BSI Standards Publication

Cylindrical helical springs made from round wire and bar — Calculation and design

Part 2: Extension springs

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National foreword

This British Standard is the UK implementation of EN 13906-2:2013. It supersedes BS EN 13906-2:2001 which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee FME/9/3, Springs.

A list of organizations represented on this committee can be obtained on request to its secretary.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

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Compliance with a British Standard cannot confer immunity from legal obligations.

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Cylindrical helical springs made from round wire and bar - Calculation and design - Part 2: Extension springs

Ressorts hélicoïdaux cylindriques fabriqués à partir de fils ronds et de barres - Calcul et conception - Partie 2: Ressorts de traction

Zylindrische Schraubenfedern aus runden Drähten und Stäben - Berechnung und Konstruktion - Teil 2: Zugfedern

This European Standard was approved by CEN on 16 May 2013.

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EUROPEAN COMMITTEE FOR STANDARDIZATION
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EUROPÄISCHES KOMITEE FÜR NORMUNG

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Contents

Foreword

This document (EN 13906-2:2013) has been prepared by Technical Committee CEN/TC 407 “Project Committee - Cylindrical helical springs made from round wire and bar - Calculation and design”, the secretariat of which is held by AFNOR.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by December 2013, and conflicting national standards shall be withdrawn at the latest by December 2013.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN [and/or CENELEC] shall not be held responsible for identifying any or all such patent rights.

This European Standard has been prepared by the initiative of the Association of the European Spring Federation ESF.

This document supersedes EN 13906-2:2001.

This European Standard constitutes a revision of EN 13906-2:2001 for which it has been technically revised. The main modifications are listed below:

— updating of the normative references,

— technical corrections.

EN 13906 consists of the following parts, under the general title *Cylindrical helical springs made from round wire and bar — Calculation and design*:

— *Part 1: Compression springs;*

— *Part 2: Extension springs;*

— *Part 3: Torsion springs.*

According to the CEN-CENELEC Internal Regulations, the national standards organisations of the following countries are bound to implement this European Standard: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, Former Yugoslav Republic of Macedonia, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and the United Kingdom.

1 Scope

This European Standard specifies the calculation and design of cold and hot coiled helical extension springs made from round wire and bar with values according to Table 1, loaded in the direction of the spring axis and operating at normal ambient temperatures.

Table 1

Characteristic	Cold coiled extension spring	Hot coiled extension spring
Wire or bar diameter	$d \leq$ 20 mm	$d \geq$10 mm
Number of active coils	$n \geq 3$	$n \geq 3$
Spring index	$4 \leq w \leq 20$	$4 \leq w \leq 12$

NOTE In cases of substantially higher or lower working temperature, it is advisable to seek the manufacturer's advice.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 10270-1, *Steel wire for mechanical springs — Part 1: Patented cold drawn unalloyed spring steel wire*

EN 10270-2, *Steel wire for mechanical springs — Part 2: Oil hardened and tempered spring steel wire*

EN 10270-3, *Steel wire for mechanical springs — Part 3: Stainless spring steel wire*

EN 10089, *Hot-rolled steels for quenched and tempered springs — Technical delivery conditions*

EN 12166, *Copper and copper alloys — Wire for general purposes*

EN ISO 26909:2010, *Springs — Vocabulary (ISO 26909:2009)*

ISO 26910-1, *Springs — Shot peening — Part 1: General procedures*

3 Terms and definitions, symbols, units and abbreviated terms

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in EN ISO 26909:2010 and the following apply.

3.1.1
spring
mechanical device designed to store energy when deflected and to return the equivalent amount of energy when released

[SOURCE: EN ISO 26909:2010, 1.1]

3.1.2
extension spring
spring (1.1) that offers resistance to an axial force tending to extend its length, with or without initial tension

[SOURCE: EN ISO 26909:2010, 1.3]

3.1.3
helical extension spring
extension spring (1.3) normally made of wire of circular cross-section wound around an axis, with or without spaces between its coils (open- or close-wound)

[SOURCE: EN ISO 26909:2010, 3.13]

3.2 Symbols, units and abbreviated terms

Table 2 contains the symbols, units and abbreviated terms used in this European Standard.

Table 2 *(1 of 2)*

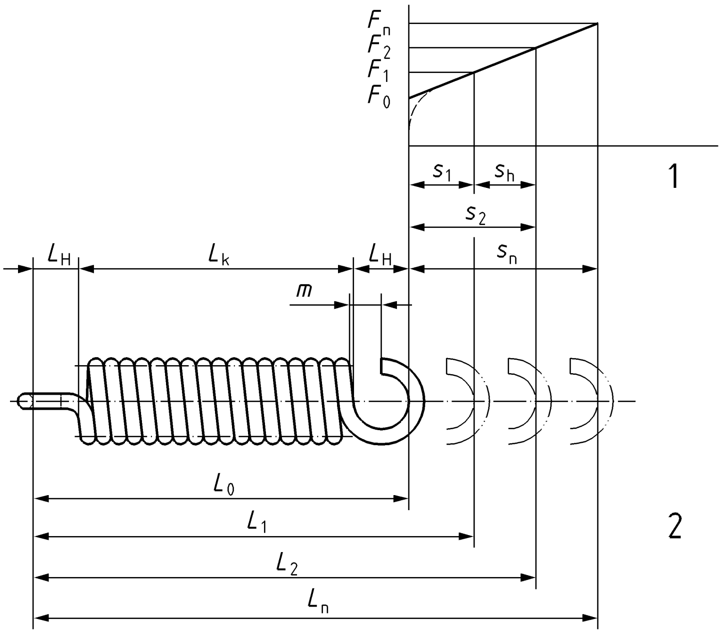
Symbols	Units	Terms
$D = \frac{D_e + D_i}{2}$	mm	mean diameter of coil
D_e	mm	outside diameter of the spring
D_i	mm	inside diameter of the spring
d	mm	nominal diameter of wire (or bar)
E	N/mm² (MPa)	modulus of elasticity (or Young's modulus)
F_0	N	initial tension force
F	N	spring force
F_1, F_2....	N	spring forces, for the spring lengths L_1, L_2 ... (at ambient temperature of 20 °C)
F_n	N	maximum permissible spring force for the maximum permissible spring length L_n
G	N/mm² (MPa)	modulus of rigidity
k	-	stress correction factor (depending on D/d)
L	mm	spring length
L_0	mm	Nominal free length of spring
L_1, L_2....	mm	spring lengths for the spring forces F_1, F_2 ...
L_H	mm	distance from inner radius of loop to spring body
L_K	mm	body length when unloaded but subject to initial tension force
L_n	mm	maximum permissible spring length for the spring force F_n
m	mm	hook opening
N	-	Number of cycles up to rupture
n	-	number of active coils
n_t	-	total number of coils
R	N/mm	spring rate

Table 2 *(2 of 2)*

Symbols	Units	Terms
R_m	N/mm² (MPa)	minimum value of tensile strength
s	mm	spring deflection
s_1, s_2 ...	mm	spring deflections, for the spring forces F_1, F_2 ...
s_h	mm	deflection of spring (stroke) between two positions
s_n	mm	spring deflection, for the spring force F_n
W	Nmm	spring work
$w = \frac{D}{d}$	-	spring index
ρ	kg/dm^3	density
τ	N/mm² (MPa)	uncorrected torsional stress (without the influence of the wire curvature being taken into account)
τ_0	N/mm² (MPa)	uncorrected torsional stress, for the initial tension force F_0
τ_1, τ_2 ...	N/mm² (MPa)	uncorrected torsional stress, for the spring forces F_1, F_2 ...
τ_k	N/mm² (MPa)	corrected torsional stress, (according to the correction factor k)
τ_{k1}, τ_{k2} ...	N/mm² (MPa)	corrected torsional stress, for the spring forces F_1, F_2 ...
τ_{kh}	N/mm² (MPa)	corrected torsional stress range, for the stroke s_h
τ_{kn}	N/mm² (MPa)	corrected torsional stress, for the spring force F_n
τ_n	N/mm² (MPa)	uncorrected torsional stress, for the spring force F_n
τ_{zul}	N/mm² (MPa)	permissible torsional stress

4 Theoretical extension spring diagram

The illustration of the extension spring corresponds to Figure 5.1 from EN ISO 2162-1:1996. The theoretical extension spring diagram is given in Figure 1.



Key

1 spring deflection
2 spring lengths

Figure 1 — Theoretical extension spring diagram

5 Types of loading

5.1 General

Before carrying out design calculations, it should be specified whether they will be subjected to static loading, quasi-static loading or dynamic loading.

5.2 Static and/or quasi-static loading

A static loading is:

— a loading constant in time.

A quasi-static loading is:

— a loading variable with time with a negligibly small torsional stress range (stroke stress) (e.g. torsional stress range up to 10 % of fatigue strength);

— a variable loading with greater torsional stress range but only a number of cycles of up to 10^4.

5.3 Dynamic loading

In the case of extension springs dynamic loading is loading variable with time with a number of loading cycles over 10^4 and torsional stress range greater than 10 % of fatigue strength at:

a) constant torsional stress range;

b) variable torsional stress range.

Depending on the required number of cycles N up to rupture it is necessary to differentiate between two cases as follows:

1) infinite life fatigue in which the number of cycles

   — $N \geq 10^7$ for cold coiled springs

   In this case, the torsional stress range is lower than the infinite life fatigue limit

2) limited life fatigue in which

   — $N < 10^7$ for cold coiled springs

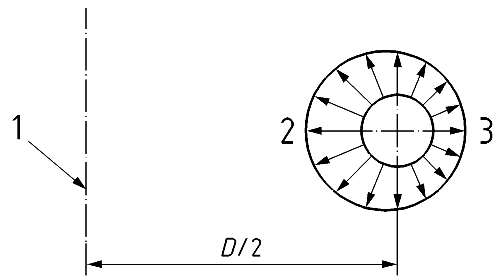
   In this case, the torsional stress range is greater than the infinite life fatigue limit but smaller than the low cycle fatigue limit.

In the case of springs with a time-variable torsional stress range and mean torsional stress, (set of torsional stress combinations) the maximum values of which are situated above the infinite fatigue life limit, the service life can be calculated as a rough approximation with the aid of cumulative damage hypotheses. In such circumstances, the service life shall be verified by means of a fatigue test.

6 Stress correction factor *k*

The distribution of torsional stresses over the cross section of the wire or bar of a spring is not uniform. The highest torsional stress occurs at the inside coil surface of the spring due to the curvature of the wire or bar (see Figure 2).

The maximum torsional stress can be determined by approximation with the aid of a stress correction factor k, which is dependent on the spring index. The factor shall be taken into account in the calculation of the maximum torsional stress, the minimum torsional stress and torsional stress range of dynamically loaded springs. Its dependency on the spring index can be calculated with the aid of the approximate Formula (1), or obtained from Figure 3.



Key

1 spring axis
2 maximum torsional stress
3 minimum torsional stress

Figure 2 — Distribution of torsional stresses at the surface of the wire or bar

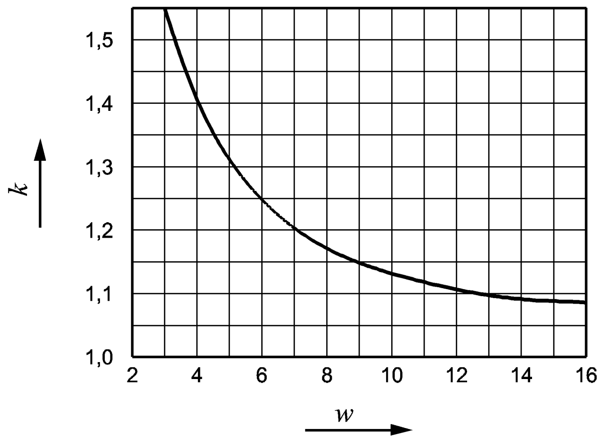


Figure 3 — Stress correction factor *k* as a function of the spring index *w*

Approximation formula for the relationship between the stress correction factor k and the spring index w is according to Bergsträsser:

$$k = \frac{w + 0{,}5}{w - 0{,}75} \tag{1}$$

NOTE According to Wahl, an alternative to Formula (1) can also be used, giving approximately the same results:

$$k = \frac{4w - 1}{4w - 4} + \frac{0{,}615}{w}$$

7 Initial tension force F_0

Initial tension force is the force which shall be applied to the spring in order to overcome the force which presses the coils one against the other. Initial tension force is introduced by coiling the coils so that they exert a certain pressure against each other. The initial tension force obtainable in this way is governed primarily by the quality of the wire (tensile strength), the nominal diameter of the wire d, the spring index w and the manufacturing method applied. In addition, the initial tension force depends on the uncorrected maximum permissible torsional stress τ_n (see 10.4).

The winding in of initial tension force F_0 is only practicable for cold coiled springs which are not given a final annealing heat treatment.

Extension springs with initial tension force have their coils pressed tightly together. It may be specified for an extension spring that its coils shall lie loosely in contact with each other without any initial tension force, in such cases however, a small amount of initial tension force shall be accepted, since it is not possible to achieve uniformly tension-free coiling.

Hot coiled extension springs cannot be made with initial tension force. The heat treatment applied causes gaps to occur between the coils, the size of the gap being dependent on the spring index w and the degree of torsional stress involved.

For hot coiled extension springs up to 25 mm bar diameter the following approximate figures apply:

— Gap between the active coils ≈ 0,5 mm to 5 mm corresponding to a permissible torsional stress $\tau_{zul} \approx$ 400 N/mm² (MPa) to 600 N/mm² (MPa) (at spring force F_n).

8 Material property values for the calculation of springs

8.1 The material property values are for ambient temperature only and are given in Table 3.

Table 3

Material	E N/mm^2 (MPa)	G N/mm^2 (MPa)	ρ kg/dm^3
Spring steel wire according to EN 10270-1	206 000	81 500	7,85
Spring steel wire according to EN 10270-2	206 000	79 500	7,85
Steels according to EN 10089	206 000	78 500	7,85
Stainless steel wire according to EN 10270-3[a]			
X10CrNi18-8	180 000	70 000	7,9
X5CrNiMo17-12-2	175 000	68 000	8,0
X7CrNiAl17-7	190 000	73 000	7,8
X5CrNi18-10	185 000	65 000	7,9
X2CrNiMoN22-5-3	200 000	77 000	7,8
X1NiCrMoCu25-20-5	180 000	69 000	8,0
Copper-tin alloy CuSn6 R950 according to EN 12166 drawn spring hard	115 000	42 000	8,73
Copper-zinc alloy CuZn36 R700 according to EN 12166 drawn spring hard	110 000	39 000	8,40
Copper-beryllium alloy CuBe2 according to EN 12166	120 000	47 000	8,80
Copper-cobalt-beryllium alloy CuCo2Be according to EN 12166	130 000	48 000	8,80

[a] The modulus E and G dependent on tempering conditions and working temperature.

8.2 The influence of the operating temperature on the modulus of elasticity and modulus of rigidity is given by the following formula, for averaged values, for the material listed in Table 3:

$$G = G_{20} \times \left[1 - r \times (t - 20)\right] \qquad (2)$$

with the following r values:

- $0{,}25 \times 10^{-3}$ for springs steel wire according to EN 10270-1, EN 10270-2 and EN 10089;
- $0{,}40 \times 10^{-3}$ for springs steel wire according to EN 10270-3;
- $0{,}40 \times 10^{-3}$ for springs alloy wire according to EN 12166.

9 Calculation formulae

9.1 General

NOTE Without initial tension force F_0 = 0 N

9.2 Spring work

$$W = \frac{(F + F_0)s}{2} \qquad (3)$$

9.3 Spring Force

$$F = \frac{G\,d^4\,s}{8\,D^3\,n} + F_0 \tag{4}$$

9.4 Spring deflection

$$s = \frac{8\,D^3\,n\left(F - F_0\right)}{G\,d^4} \tag{5}$$

9.5 Spring rate

$$R = \frac{\Delta F}{\Delta s} = \frac{\left(F - F_0\right)}{s} = \frac{G\,d^4}{8\,D^3\,n} \tag{6}$$

9.6 Torsional stresses

$$\tau = \frac{8\,D\,F}{\pi\,d^3} \tag{7}$$

$$\tau_k = k\,\tau \tag{8}$$

Whilst the torsional stress τ shall be adopted for the calculation of statically or quasi-statically loaded springs, the corrected torsional stress τ_k shall apply for dynamically loaded springs.

9.7 Nominal diameter of wire or bar

To calculate the optimum nominal diameter d of wire or bar then torsional stress τ is replaced with τ_{zul} as shown below.

$$d \geq \sqrt[3]{\frac{8\,F\,D}{\pi\,\tau_{zul}}} \tag{9}$$

The permissible torsional stress τ_{zul} shall be selected according to the design case concerned (see Clause 10 in this connection).

9.8 Number of active coils

$$n = \frac{G\,d^4\,s}{8\quad D^3\left(F - F_0\right)} \tag{10}$$

9.9 Total number of coils

The following expression gives an approximate value for the total number of coils in an extension spring with initial tension force.

$$n_t = \frac{L_k}{d} - 1 \tag{11}$$

For extension springs with open loops according to Annex A, Figures A.1 to A.8 and A.13, $n = n_t$.

For extension springs with tapered-in hooks or with threaded plugs, according to Annex A, Figures A.9 to A.12, $n < n_t$ depending on the shape of the spring ends.

9.10 Initial tension force

$$F_0 = F - s\,R = F - \frac{G\,d^4\,s}{8\,D^3\,n} \qquad (12)$$

10 Permissible torsional stress under static or quasi-static loading

10.1 General

Apart from the space available, the principal data for the design of an extension spring are the spring work and the maximum permissible force $F_{n.}$

If at the maximum permissible force F_n the limit of τ_{zul} is reached, it shall be assumed that after a certain time the spring forces will decrease, according to a decreasing initial tension force F_0 (relaxation).

10.2 Permissible torsional stress τ_{zul} for cold coiled springs

The permissible torsional stress τ_{zul} is usually equal to 0,45R_m at the maximum permissible force F_n. The value for R_m (minimum value of tensile strength) is determined from the relevant standards referred to in Table 3. The strength values for the wires according to EN 10270-3 shall be those specified for the stress relieved or for the artificially aged condition.

NOTE This value takes into consideration the stresses in the hooks in addition to the stresses into the body.

10.3 Permissible torsional stress τ_{zul} for hot coiled springs

For hot coiled springs the value

τ_{zul} = 600 N/mm²

for the maximum permissible force F_n shall not be exceeded.

Hot coiled springs shall only be used in diameters up to 35 mm bar diameter. For manufacturing reasons it is recommended that the type without loops and threaded end plugs according to Annex A, Figure A.11 shall be used.

10.4 Initial tension torsional stress τ_0

The torsional stress induced in cold coiled springs as a result of the initial tension force F_0 is called the initial tension torsional stress τ_0.

The attainable initial tension force F_0 depends on the level of the maximum available initial tension torsional stress τ_0.

τ_0 shall be determined from the Formulae (13) and (14) and applies to the wires grade SL, SM, SH, DM and DH according to EN 10270-1 and for the wires type FD according to EN 10270-2.

— coiling on hand coiling machines (only the loop types according to Annex A, Figures A.1 to A.5, Figure A.8 and Figures A.11 to A.13.)

$$\tau_0 = \left(0{,}135 - \frac{0{,}00625D}{d}\right)R_m \qquad (13)$$

— coiling on automatic coilers

$$\tau_0 = \left(0{,}075 - \frac{0{,}00375D}{d}\right)R_m \quad (14)$$

Under certain conditions, e.g. a high initial tension force F_0 and a small deflection (stroke), at the maximum permissible force F_n the value for the permissible torsional stress, τ_{zul} is not fully used (see also 10.2). In this case, the value for the initial tension torsional stress τ_0 shall be exceeded when coiling on a hand coiling machine. It is recommended that in these cases the advice of the spring manufacturer shall be sought.

11 Calculation of extension springs for dynamic loading

The durability estimation of cold coiled springs under dynamic loading is difficult because of the complex shape of these springs. When deflecting springs there is a non-uniform distribution of torsional stresses due to the curvature of the wire in the active coils as in the case of compression springs (see Figure 2). The maximum torsional stress shall be taken into account, using the stress correction factor k (see Clause 6).

When using the correction factor k, the calculation is related to the active coils only. In this case the value of the corrected torsional stress range τ_{kh} is important, i.e. the differences of the torsional stresses at F_1 and F_2.

The fatigue life of springs is also especially influenced by the shape of the loops or the end plugs. In the transition area from the spring body to the loops there are additional torsional stresses, which can exceed the permissible bending stresses. For this reason there cannot be given general values for the fatigue strength (as in EN 13906-1).

It is recommended that fatigue testing is carried out under actual service conditions. In this case, a sufficient number of test pieces shall be taken because of the large scatter in the fatigue performance.

For extension springs according to this standard with loops according to Annex A dynamic loading shall be avoided, because the springs are unsuitable for shot peening due to the close position of the adjacent coils.

If dynamic loading cannot be avoided, then cold coiled springs with loops or end plugs according to Annex A, Figures A.9 to A.12 shall preferably be used. If bent loops or hooks are necessary for design reasons, the radius in the transition area to the spring body shall be made as large as possible.

When the limit of τ_{zul} is reached at the maximum permissible force F_n, it shall be assumed that the spring force F will decrease after a certain time because of relaxation of the initial tension force.

Fatigue failures caused by failure of the material are not excluded.

In special cases, the spring manufacturer's advice shall be sought concerning the detailed design of loops or end plugs.

To improve the fatigue life, the shot-peening should be recommended, particularly on the hooks. The process of shot peening shall be defined in accordance with ISO 26910-1. The peening intensity and coverage should be as agreed between the purchaser and the supplier. Shot peening can generally be carried out on springs with a wire diameter d > 1 mm and a spring index w = 15.

Annex A
(informative)

Types of spring ends

Table A.1 gives some examples of spring ends

Table A.1 *(1 of 2)*

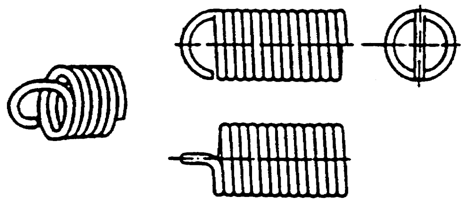
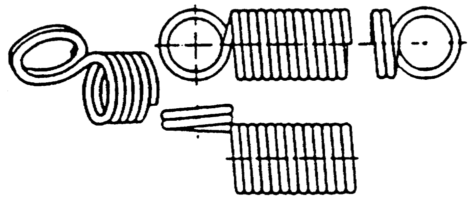
	

Figure A.1 — Half German hook **$L_H = 0{,}55\ D_i$ to $0{,}8\ D_i$ (Open loop)**	**Figure A.5 — Extended German side loop** **$L_H \approx D_i$ (double loop at side)**

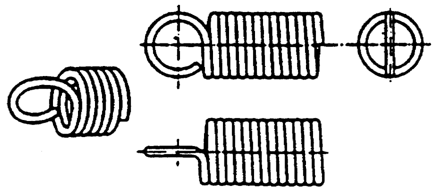
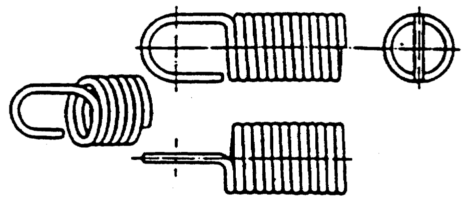

	

Figure A.2 — Closed German loop **$L_H = 0{,}8\ D_i$ to $1{,}1\ D_i$ (Full loop)**	**Figure A.6 — Hooks (Raised hook)**

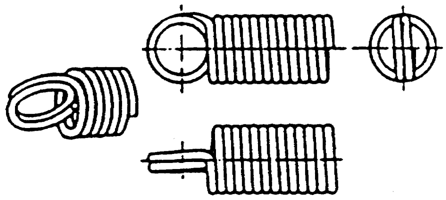
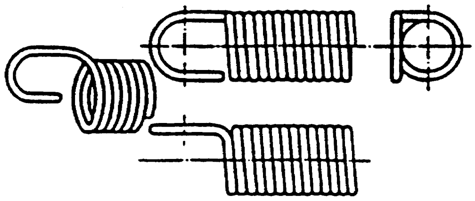

	

Figure A.3 — Double German loop **$L_H = 0{,}8\ D_i$ to $1{,}1\ D_i$ (Double loop)**	**Figure A.7 — Extended side hook** **(Raised side hook)**

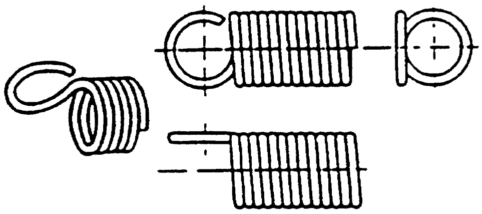
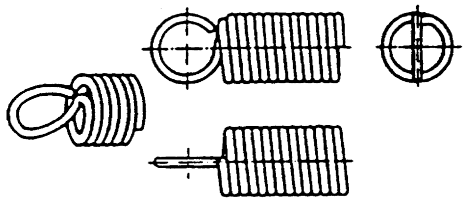

	

Figure A.4 — German side loop **$L_H \approx D_i$ (Full loop at side)**	**Figure A.8 — English loop** **$L_H \approx 1{,}1\ D_i$ (Full loop with offset)**

Table A.1 *(2 of 2)*

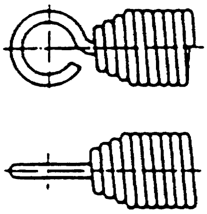
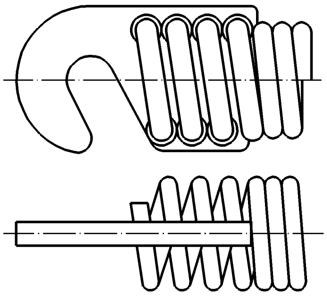
	

Figure A.9 — Coiled in hook (Swivel hook)	**Figure A.12 — Screwed in shackle (threaded-on plate) Number of screwed in coils 2 to 4**

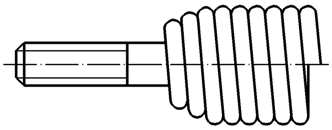
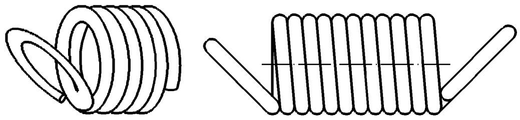

	

Figure A.10 — Coiled in screwed plug (Rolled in stud)	**Figure A.13 — Closed German loop (Angled full loop) Inclined and extended, closed German loop**

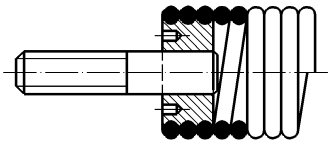
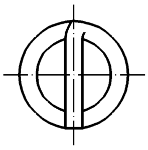
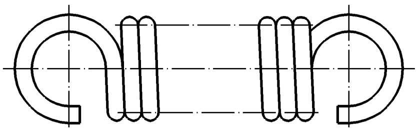
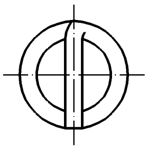
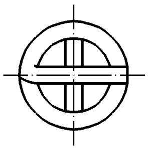
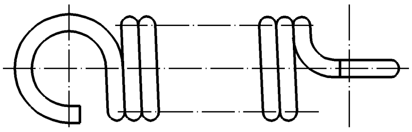
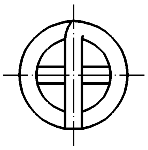
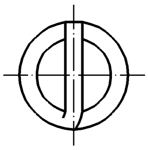
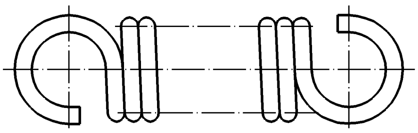
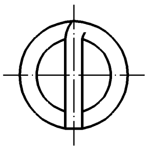
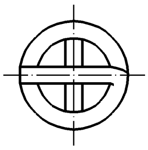
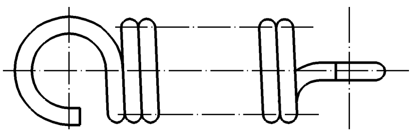
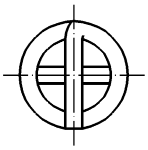
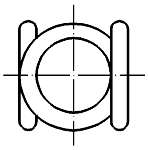
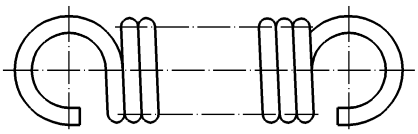
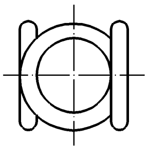
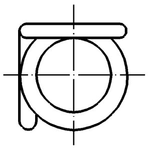
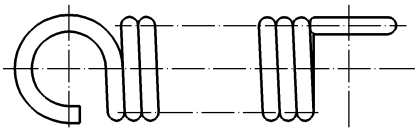
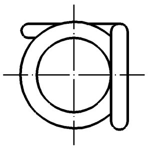
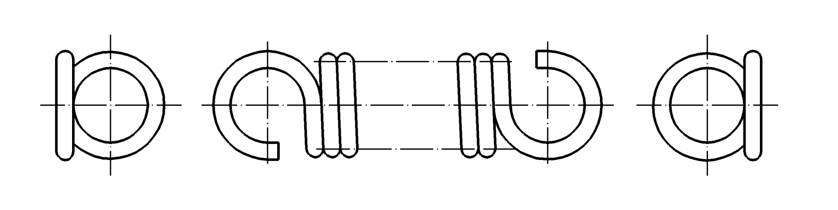
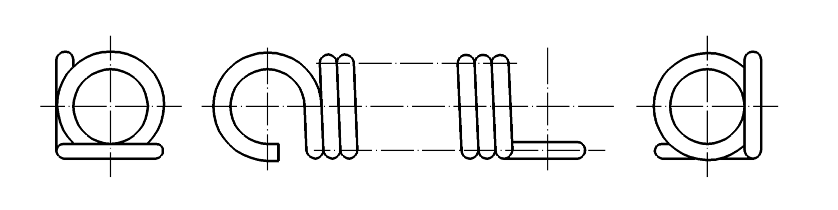



Figure A.11 — Screwed in plug (Threaded plug) Number of screwed in coils 2 to 4	

Representation of loop (hook) position		
Type of loop according to figure given in Table A.1 of this standard	Number of coils following the decimal comma	Loop (hook) openings mutually offset clockwise
		
A.2	… 00 (0)	0°
		
A.2	… 25 (1/4)	90°
		
A.2	… 50 (1/2)	180°
		
A.2	… 75 (3/4)	270°
		
A.4	… 50 (1/2)	0°
		
A.4	… 75 (3/4)	90°



A.4	… 00 (0)	180°



A.4	… 25 (1/4)	270°

Figure A.14 — Most commonly used positions of loop openings and related data regarding total number of coils

Bibliography

[1] EN 13906-1, *Cylindrical helical springs made from round wire and bar — Calculation and design — Part 1: Compression springs*

[2] EN ISO 2162-1:1996, *Technical product documentation — Springs — Part 1: Simplified representation (ISO 2162-1:1993)*

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