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BSI Standards Publication

Disc springs — Calculation

National foreword

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European foreword

This document (EN 16984:2016) has been prepared by Technical Committee CEN/TC 407 “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of an identical text or by endorsement, at the latest by May 2017, and conflicting national standards shall be withdrawn at the latest by May 2017.

This European Standard has been prepared by the initiative of the Association of the European Spring Federation ESF and is based on the German Standard DIN 2092 “Disc springs — Calculation”, which is known and used in many European countries.

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1 Scope

This standard specifies design criteria and features of disc springs, whether as single disc springs or as stacks of disc springs. It includes the definition of relevant concepts as well as design formulae, and covers the fatigue life of such springs.

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 16983:2016, *Disc springs - Quality specifications - Dimensions*

EN ISO 26909, *Springs - Vocabulary (ISO 26909)*

3 Terms, 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 apply.

NOTE Disc springs are annular coned elements that offer resistance to a compressive load applied axially. They may be designed as single disc springs or as disc springs stacked in parallel or in series, either singly or in multiples. They may be subjected to both static and fatigue loading, and may have flat bearings.

3.2 Symbols, units and abbreviated terms

For the purposes of this document, the following symbols, units and abbreviated terms apply

Table 1 — Symbols, units and abbreviated terms

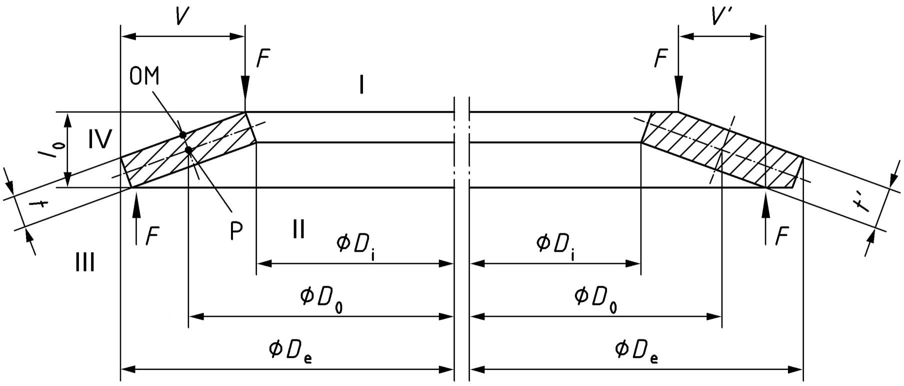
Symbol	Unit	Description
D_e	mm	Outer diameter of spring
D_i	mm	Inner diameter of spring
D_0	mm	Diameter of centre of rotation
E	MPa	Modulus of elasticity (see EN 16983:2016)
F	N	Spring load
F_1, F_2, F_3 ...	N	Spring loads related to spring deflections s_1, s_2, s_3...
F_c	N	Design spring load when spring is in the flattened position
F_{ges}	N	Spring load of springs stacked in parallel, related to spring deflection s_{ges}
$F_{ges\ R}$	N	Spring load of springs stacked in parallel, allowance being made for friction
F_t	N	Test load for length L_t or l_t
K_1, K_2, K_3, K_4		Constants (see 5.3)
L_0	mm	Length of springs stacked in series or in parallel, in

Symbol	Unit	Description
		the initial position
L_1, L_2, L_3 ...	mm	Lengths of loaded springs stacked in series or in parallel, related to spring loads F_1, F_2, F_3...
L_t	mm	Test length of springs stacked in series or in parallel
L_c	mm	Design length of springs stacked in series or in parallel, in the flattened position
N		Number of cycles to failure
R	N/mm	Spring rate
W	N mm	Energy capacity of spring
h_0	mm	Initial cone height of springs without flat bearings, $h_0 = l_0 - t$
h'_0	mm	Initial cone height of springs with flat bearings, $h'_0 = l_0 - t'$
i		Number of disc springs or packets stacked in series
l_0	mm	Free overall height of spring in its initial position
l_1, l_2, l_3 ...	mm	Length of loaded spring related to spring loads F_1, F_2, F_3...
L_t	mm	Test length of spring
n		Number of single disc springs stacked in parallel
P		Theoretical centre of rotation of disc cross section (see Figure 1)
s	mm	Deflection of single disc spring
s_1, s_2, s_3 ...	mm	Spring deflections related to spring loads F_1, F_2, F_3...
s_{ges}	mm	Deflection of springs stacked in series or in parallel, no allowance being made for friction. Recommended maximum value: $s_{ges} = 0{,}75\ (L_0 - L_c)$
t	mm	Thickness of single disc spring
t'	mm	Reduced thickness of single disc spring with flat bearings (group 3)
w_M, w_R		Coefficients of friction (see Table 3)
$\delta = \frac{D_e}{D_i}$		Ratio of outer to inner diameter
μ		Poisson's ratio
σ	MPa	Design stress
$\sigma_{OM}, \sigma_{I}, \sigma_{II}, \sigma_{III}, \sigma_{IV}$	MPa	Design stresses at the points designated OM, I, II, III, IV (see Figure 1)
σ_{O}	MPa	Maximum design stress in springs subject to fatigue

Symbol	Unit	Description
		loading
σ_u	MPa	Minimum design stress in springs subject to fatigue loading
σ_h	MPa	Fatigue stress related to the deflection of springs subject to fatigue loading
σ_O	MPa	Maximum fatigue stress
σ_U	MPa	Minimum fatigue stress
$\sigma_H = \sigma_O - \sigma_U$	MPa	Permanent range of fatigue stress
V, V'	mm	Lever arms

4 Representation

4.1 Single disc spring



a) without flat bearings: group 1 group 2

b) with flat bearings: group 3

Figure 1 — Single disc spring (sectional view), including the relevant points of loading

4.2 Disc springs stacked in parallel

The stack consists of *n* single disc springs stacked in parallel.

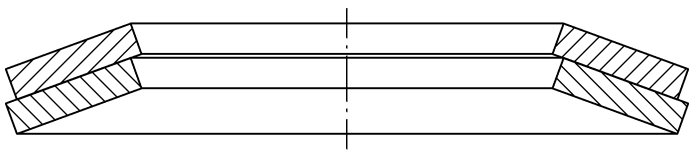


Figure 2 — Packet - Disc springs stacked in parallel

4.3 Disc springs stacked in series

The stack consists of *i* single disc springs stacked in series.

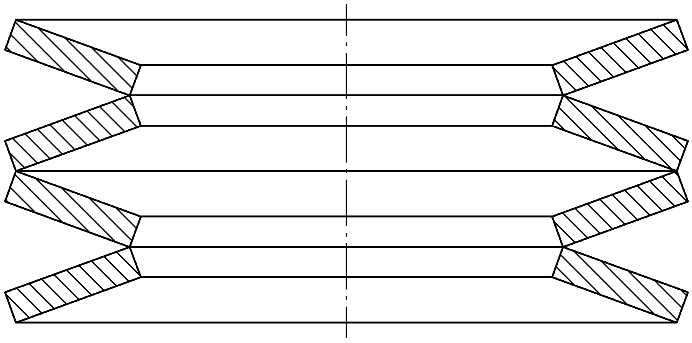


Figure 3 — Stack - Disc springs stacked in series

4.4 Disc spring diagram

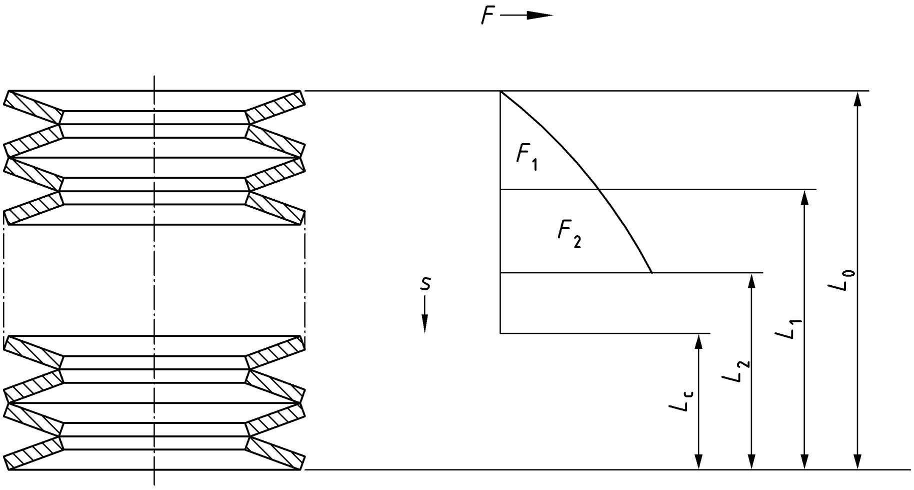


Figure 4 — Example of disc springs stacked in series

5 Design formulae for single disc springs

5.1 General

The following formulae apply to single disc springs with or without flat bearings, where $16 < D_e / t < 40$ or $1{,}8 < D_e / D_i < 2{,}5$, and which are made of materials as specified in EN 16983:2016.

In the case of other designs, it is recommended that the spring manufacturer should be consulted.

5.2 Test load

The test load of single disc springs or disc springs stacked in series, F_t, is designed for a deflection $s = 0{,}75\ h_0$. Single disc springs with flat bearings shall have the same test load for a test length L_t as ones without, where the principal dimensions D_e, D_i and l_0 are the same. Flat bearings have the effect of reducing the length of the lever arm. The increased load which results can be compensated by reducing the thickness of the disc spring. The load/deflection curve of such springs deviates from those without flat bearings, with the exception of the point at which the curves intersect, l_t.

Guideline values for the reduction in disc spring thickness as a function of dimensional series are given in Table 2.

Table 2 — Guideline values for the reduction in disc spring thickness as a function of dimensional series

Dimensional series	A	B	C
t'/t	0,94	0,94	0,96

5.3 Deflection factors

$$\delta = \frac{D_e}{D_i} \tag{1}$$

$$K_1 = \frac{1}{\pi} \times \frac{\left(\frac{\delta - 1}{\delta}\right)^2}{\frac{\delta+1}{\delta-1} - \frac{2}{\ln\delta}} \tag{2}$$

$$K_2 = \frac{6}{\pi} \times \frac{\frac{\delta-1}{\ln\delta} - 1}{\ln\delta} \tag{3}$$

$$K_3 = \frac{3}{\pi} \times \frac{\delta-1}{\ln\delta} \tag{4}$$

$$K_4 = \sqrt{-\frac{C_1}{2} + \sqrt{\left(\frac{C_1}{2}\right)^2 + C_2}} \tag{5}$$

where

$$C_1 = \frac{\left(\frac{t'}{t}\right)^2}{\left(\frac{1}{4} \times \frac{l_0}{t} - \frac{t'}{t} + \frac{3}{4}\right)\left(\frac{5}{8} \times \frac{l_0}{t} - \frac{t'}{t} + \frac{3}{8}\right)} \tag{6}$$

$$C_2 = \frac{C_1}{\left(\frac{t'}{t}\right)^3}\left[\frac{5}{32}\left(\frac{l_0}{t} - 1\right)^2 + 1\right] \tag{7}$$

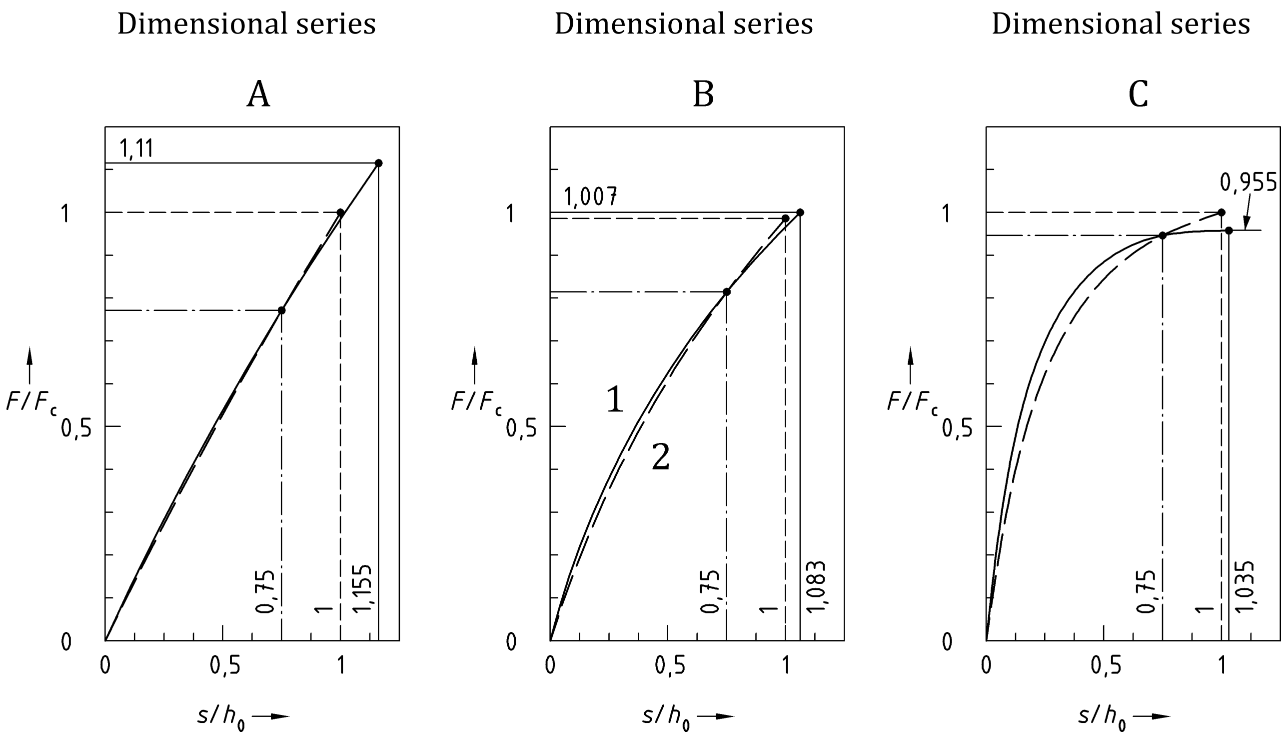
In the case of springs without flat bearings, $K_4 = 1$

In the case of springs with flat bearings, K_4 shall be calculated using Formula (5) and, in all subsequent formulae, t' shall be substituted for t, and h'_0 (i.e. $l_0 - t'$) for h_0.

5.4 Spring load

$$F = \frac{4E}{1-\mu^2} \times \frac{t^4}{K_1 \times D_e^2} \times K_4^2 \times \frac{s}{t}\left[K_4^2 \times \left(\frac{h_0}{t} - \frac{s}{t}\right)\left(\frac{h_0}{t} - \frac{s}{2t}\right) + 1\right] \tag{8}$$

$$F_C = F\left(s = h_0\right) = \frac{4E}{1-\mu^2} \times \frac{t^3 \times h_0}{K_1 \times D_e^2} \times K_4^2 \tag{9}$$



Key

1 with flat bearings

2 without flat bearings

Figure 5 — Load/deflection curves for disc springs with or without flat bearings (in the above figures, F_c applies to disc springs without flat bearings)

NOTE In the case of springs with flat bearings, $l_t = l_0 - 0{,}75 \times h_0$.

5.5 Design stresses

$$\sigma_{OM} = -\frac{4E}{1-\mu^2} \times \frac{t^2}{K_1 \times D_e^2} \times K_4 \times \frac{s}{t} \times \frac{3}{\pi} \tag{10}$$

$$\sigma_I = -\frac{4E}{1-\mu^2} \times \frac{t^2}{K_1 \times D_e^2} \times K_4 \times \frac{s}{t}\left[K_4 \times K_2\left(\frac{h_0}{t} - \frac{s}{2t}\right) + K_3\right] \tag{11}$$

$$\sigma_{II} = -\frac{4E}{1-\mu^2} \times \frac{t^2}{K_1 \times D_e^2} \times K_4 \times \frac{s}{t}\left[K_4 \times K_2\left(\frac{h_0}{t} - \frac{s}{2t}\right) - K_3\right] \tag{12}$$

$$\sigma_{III} = -\frac{4E}{1-\mu^2} \times \frac{t^2}{K_1 \times D_e^2} \times K_4 \times \frac{1}{\delta} \times \frac{s}{t}\left[K_4 \times (K_2 - 2K_3) \times \left(\frac{h_0}{t} - \frac{s}{2t}\right) - K_3\right] \tag{13}$$

$$\sigma_{IV} = -\frac{4E}{1-\mu^2} \times \frac{t^2}{K_1 \times D_e^2} \times K_4 \times \frac{1}{\delta} \times \frac{s}{t}\left[K_4 \times (K_2 - 2K_3) \times \left(\frac{h_0}{t} - \frac{s}{2t}\right) + K_3\right] \tag{14}$$

Positive stresses are tensile stresses.

Negative stresses are compressive stresses.

5.6 Spring rate

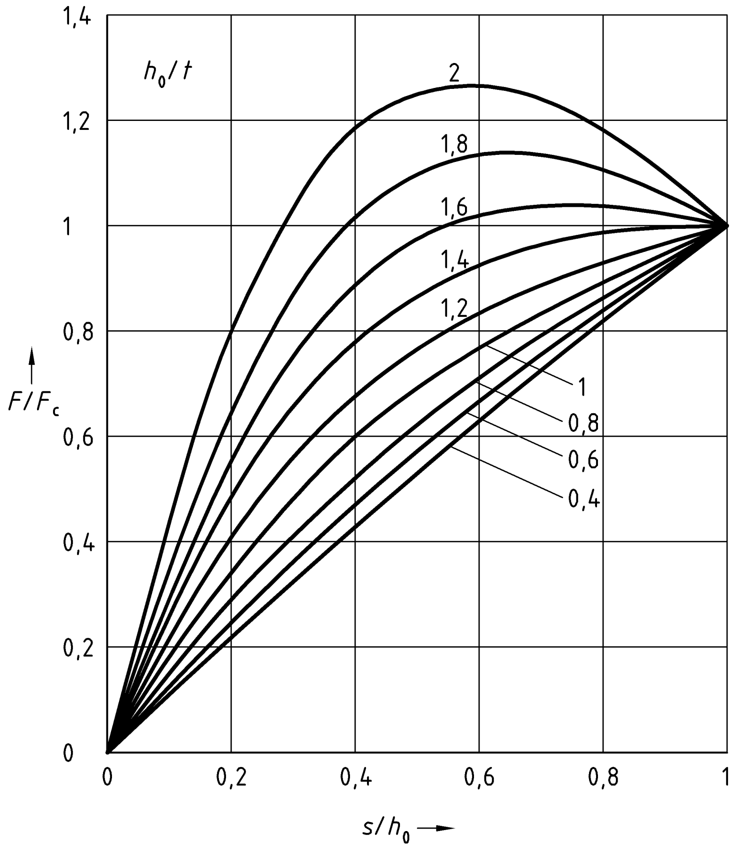
$$R=\frac{dF}{ds}=\frac{4E}{1-\mu^2}\times\frac{t^3}{K_1\times D_e^2}\times K_4^2\times\left[K_4^2\left\{\left(\frac{h_0}{t}\right)^2-3\times\frac{h_0}{t}\times\frac{s}{t}+\frac{3}{2}\left(\frac{s}{t}\right)^2\right\}+1\right] \tag{15}$$

5.7 Energy capacity of springs

$$W=\int_0^s F\times ds=\frac{2E}{1-\mu^2}\times\frac{t^5}{K_1\times D_e^2}\times K_4^2\times\left(\frac{s}{t}\right)^2\times\left[K_4^2\times\left(\frac{h_0}{t}-\frac{s}{2t}\right)^2+1\right] \tag{16}$$

6 Load/deflection curve for a single disc spring

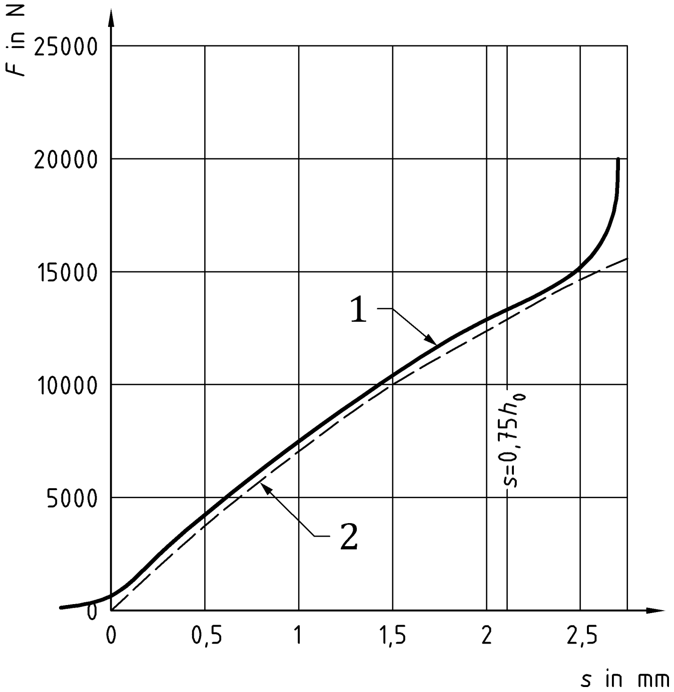
The load/deflection curve for a single disc spring is not linear, its shape being rather a function of the ratio h_0/t. Figure 6 illustrates load/deflection curves as a function of the ratio h_0/t or $K_4 \times h'_0/t'$.



NOTE In the case of springs with flat bearings, $K_4 \times h'_0/t'$ shall be substituted for h_0/t.

Figure 6 — Load/deflection curves for various h_0/t ratios

See Formula (9) for determining the design spring load of springs in the flattened position, F_c.



Key

1 actual curve

2 design curve

Figure 7 — Actual and design load/deflection curves for a EN 16983:2016 B 50 disc spring

When $s/h_0 > 0{,}75$, the actual curve will deviate more and more from the design curve, since the disc springs will be in contact with each other or with the support plate, which results in a steady reduction in the length of the lever arm (see Figure 7).

7 Stacking of disc springs

A number of possibilities exist for combining single disc springs or several disc springs stacked in series and/or in parallel.

In the case of single disc springs with constant deflection stacked in parallel, the spring load will be in direct proportion to the number of single disc springs making up the stack (see Figures 8a and 8b).

In the case of single disc springs with constant spring load stacked in series, the deflection will be in direct proportion to the number of single disc springs making up the stack (see Figures 8a and 8c).

$$F_{ges} = n \times F \quad (17)$$

$$s_{ges} = i \times s \quad (18)$$

$$L_0 = i\left[l_0 + (n-1)t\right] \quad (19)$$

In the case of springs with flat bearings, t' shall be substituted for t.

In the case of packets stacked in series, the spring load will increase with the number of single disc springs making up each packet, and the deflection, with the number of packets making up the stack (see Figure 8d).

In the case of springs stacked in series, where $h_0/t >$ approximately 1,25, it may be assumed that the deflection of the single disc springs will not be uniform, which may cause a failure.

Where single disc springs of different thicknesses are stacked in series (see Figure 9a), the load/deflection curve will be progressive. The same applies where an increasing number of single disc springs of identical thickness are combined in the packets making up the stack (see Figure 9b). The permissible stresses in the elements numbered 1 and 2, however, shall be taken into account.

Note that the information given in Figures 8 and 9 does not account for friction.

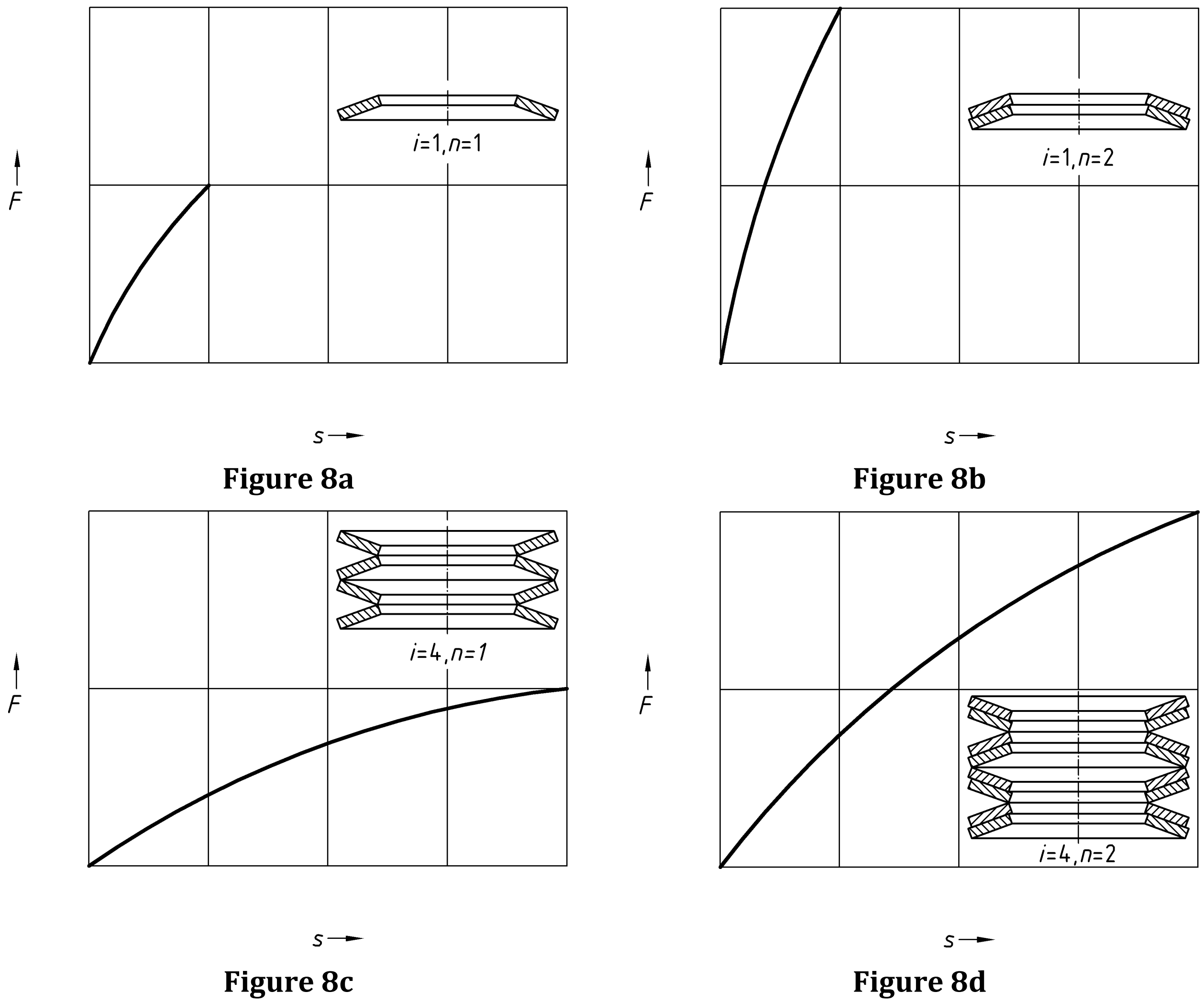


Figure 8 — Variations in load/deflection curves as a function of disc spring stacking

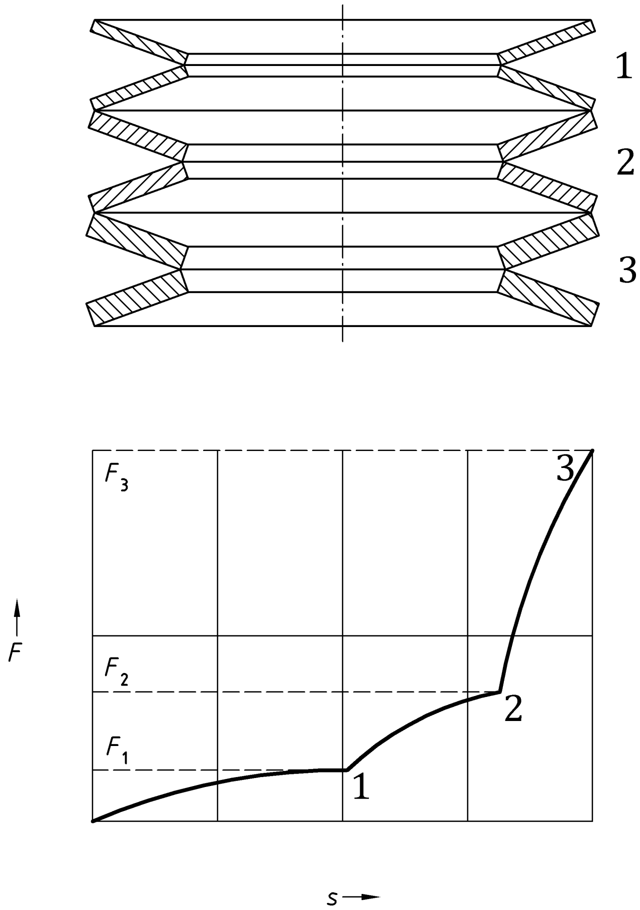


Figure 9a

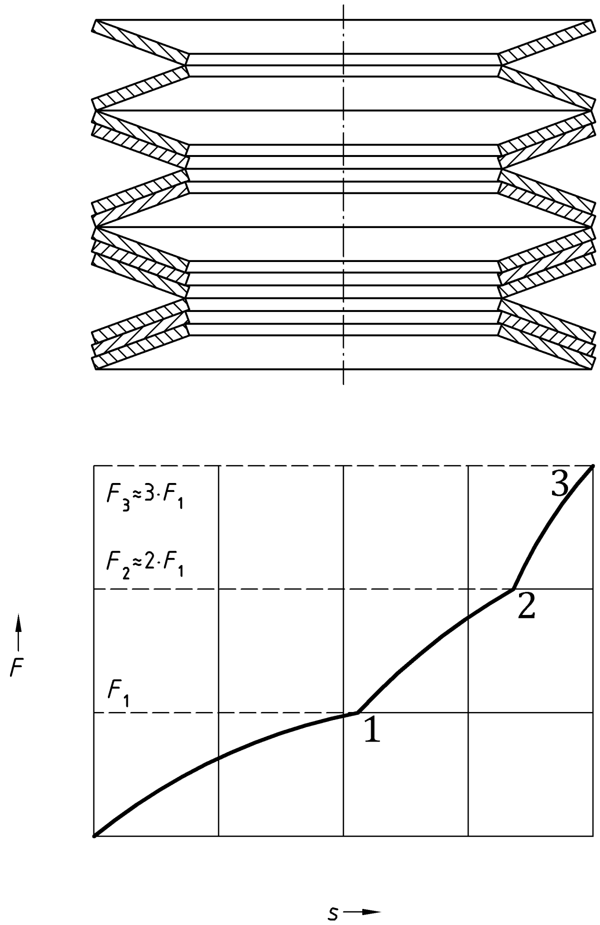


Figure 9b

Figure 9 — Progressive load/deflection curves for disc springs with different thicknesses or stackings

8 Effect of friction in load/deflection characteristic

When designing springs, friction shall be accounted for. The associated load component is a function of the number of single disc springs or elements making up a stack of springs. In this regard, surface finish and lubrication are also of relevance.

Frictional loads act between the conical contact surfaces of the individual springs (factor w_M) and the contact surfaces of the flat plates between the spring is compressed (factor w_R). Such loads have the effect of increasing the spring load when the spring is loaded, and decreasing it when the load is removed.

The load/deflection characteristic shall be calculated using the following formula:

$$F_{gesR} = F \times \frac{n}{1 \mp w_M \times (n-1) \mp w_R} \tag{20}$$

where

- \- indicates the loading
- \+ indicates the unloading

Table 3 — Values of inter-surface friction (factor w_M) and edge friction (factor w_R)
(does not apply to shot peened springs)

Dimensional series as in EN 16983:2016	w_M	w_R
A	0,005 to 0,03	0,03 to 0,05
B	0,003 to 0,02	0,02 to 0,04
C	0,002 to 0,015	0,01 to 0,03

Formula (20) also accounts for the frictional behaviour of a single disc spring.

Within permissible tolerances, the actual spring will deviate from the geometrically ideal form. In the case of springs stacked in parallel, such inevitable deviation results in an actual load/deflection curve that is different from the theoretical curve (and increasingly different as the number of packets making up the stack increases), particularly in the lower range of the curve.

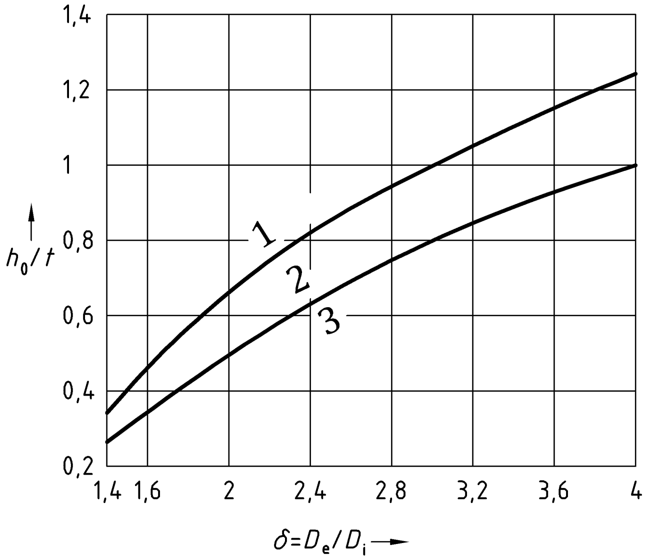
9 Design stresses

Since there are residual stresses in the spring as a result of the manufacturing process used, the results obtained from Formulae (10) to (14) do not reflect the actual values involved, but rather any nominal values. Thus, all information relating to stress in the present standard and in EN 16983:2016, Tables 5 to 7, represent these nominal values.

An estimate of the permissible free overall height of the spring, l_0, may be based on a determination of the design stress σ_{OM}, which should be about equal to the tensile strength, R_m, of the material used (for materials as in EN 16983:2016, max. 1 600 MPa).

The most important parameter for springs subject to fatigue loading is the calculated tensile stress on the bottom side of a single disc spring. The point most vulnerable to fatigue failure will be either the lower inner edge, point II, or the lower outer edge, point III (see Figure 10), depending on the ratios $D_e/D_i = \delta$, h_0/t and s/h_0.

This is illustrated in Figure 10, and applies to springs with or without flat bearings.



Key

1 Point III

2 Point II or III

3 Point II

NOTE In the case of springs with flat bearings, $K_4 \times h'_0/t'$ shall be substituted for h_0/t.

Figure 10 — Relevant points of loading for springs subject to fatigue loading

Since the ratio s/h_0 is a factor of influence with regard to the magnitude of tensile stress at points II and III, it is recommended, for the zone between these points, that σ_{II} and σ_{III} be determined in accordance with the formulae given in 5.5.

Graphical representations of the fatigue life of springs are given in EN 16983:2016.

10 Types of loading

10.1 Static loading and moderate fatigue conditions

Springs shall be deemed to be subject to static loading:

a) where such is the only type of loading and where it does not change;

b) if they shall be deemed to be subject to moderate fatigue conditions where the loading does change, but only infrequently, and where the number of cycles to which they are exposed during their intended use is less than 10^4.

10.2 Dynamic loading

Depending on the required minimum number of loading cycles without failure, N, a differentiation is made between:

a) springs with a limited fatigue life, i.e. those which are able to withstand $10^4 \leq N < 2 \times 10^6$ cycles;

b) springs with a high fatigue life, i.e. those which are able to withstand 2×10^6 cycles or more without failure.

Where springs are expected to withstand substantially more than 2×10^6 cycles, the manufacturer shall be consulted.

Bibliography

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DIN 4000-11, *Tabular layouts of article characteristics for springs*

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