BS ISO 19690-1:2017

BSI Standards Publication

Disc springs

Part 1: Calculation

National foreword

This British Standard is the UK implementation of ISO 19690-1:2017.

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.

Published by BSI Standards Limited 2017

ISBN 978 0 580 88622 5

ICS 21.160

This British Standard was published under the authority of the Standards Policy and Strategy Committee on 31 March 2017.

Amendments/corrigenda issued since publication

Date	Text affected

INTERNATIONAL STANDARD

ISO 19690-1

First edition
2017-03

Disc springs —

Part 1: Calculation

Ressorts à disques —

Partie 1: Calcul

Reference number
ISO 19690-1:2017(E)

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Foreword

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This document was prepared by Technical Committee ISO/TC 227, *Springs*.

A list of all the parts in the ISO 19690 series can be found on the ISO website.

Disc springs —

Part 1:
Calculation

1 Scope

This document 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 are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 16249, *Springs — Symbols*

ISO 26909, *Springs — Vocabulary*

3 Terms and definitions

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

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at www.iso.org/obp

— IEC Electropedia: available at www.electropedia.org

4 Symbols and units

For the purposes of this document, the symbols and units given in ISO 16249 and Table 1 apply.

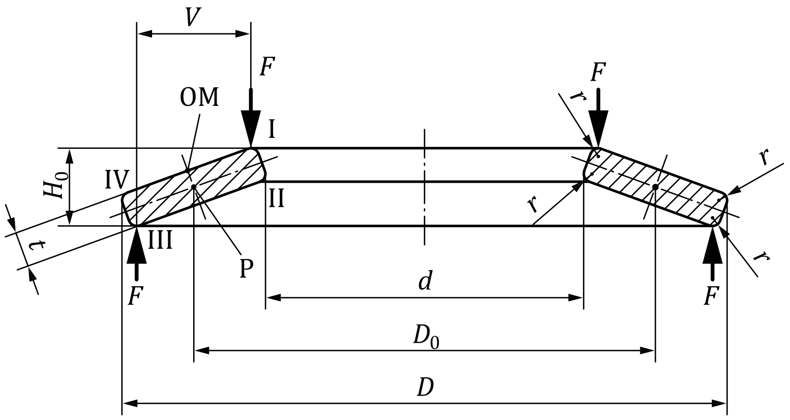
Table 1 — Symbols and units for design calculation

Symbol	Unit	Parameter
C_1, C_2, C_3, C_4	—	coefficients
D	mm	external diameter of spring
D_0	mm	diameter of centre of rotation
d	mm	internal diameter of spring
E	N/mm^2	modulus of elasticity of material (carbon steel and carbon alloy steel: 206 000 N/mm^2) (other materials: respective modulus of elasticity of material)
F	N	spring load
F_c	N	design spring load when spring is in the flattened position
F_G	N	spring load at the time of combining springs
F_t	N	spring test load at H_t
H_t	mm	height of spring when measuring spring load, $H_\mathrm{t} = H_0 - 0{,}75\ h_0$
H_0	mm	free height of spring
h_0	mm	initial cone height of springs without flat bearings, $h_0 = H_0 - t$
$h_{0,\mathrm{f}}$	mm	initial cone height of springs with flat bearings, $h_{0,\mathrm{f}} = H_0 - t_\mathrm{f}$
i	—	number of springs combined in series
k_1, k_2	—	coefficients
L_0	mm	free height at the time of combining springs
N	—	number of cycles for fatigue life
n	—	number of springs piled in parallel
OM	—	point at upper surface of the spring perpendicular to the centre line at point P
P	—	theoretical centre of rotation of disc cross section
R	N/mm	spring rate
r	mm	chamfer radius at edge
s	mm	deflection of spring
s_G	mm	deflection of stack
t	mm	thickness of spring
t_f	mm	reduced thickness of single disc spring with flat bearings
V	mm	length of lever arms
V_f	mm	length of lever arms with flat bearings
W	N·mm	energy capacity of springs
α	—	ratio of external diameter to internal diameter
ν	—	Poisson’s ratio of material
σ_OM	N/mm^2	stress at position OM
σ_I	N/mm^2	stress at position I
σ_II	N/mm^2	stress at position II
σ_III	N/mm^2	stress at position III
σ_IV	N/mm^2	stress at position IV
NOTE N/mm^2 = MPa		

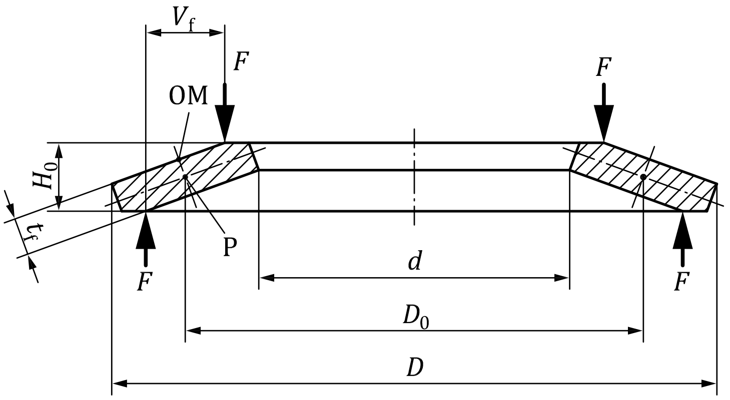
5 Dimensions and designation

5.1 General

Figure 1 illustrates a single disc spring, including the relevant positions of loading.



a) Without flat bearings: group 1 and group 2



b) With flat bearings: group 3

Key

D	external diameter of spring	t	thickness of spring
D_0	diameter of centre of rotation	V	length of lever arms
d	internal diameter of spring	V_f	length of lever arms with flat bearings
F	spring load	I	position I
H_0	free height of spring	II	position II
OM	point at upper surface of the spring perpendicular to the centre line at point P	III	position III
P	theoretical centre of rotation of disc cross section	IV	position IV
r	chamfer radius at edge		
t_f	reduced thickness of single disc spring with flat bearings		

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

5.2 Disc spring groups

Table 2 shows disc spring groups.

Table 2 — Disc spring groups

Group	t (mm)	With flat bearings and reduced thickness
1	$0{,}2 \le t < 1{,}25$	No
2	$1{,}25 \le t \le 6{,}0$	No
3	$6{,}0 < t \le 14{,}0$	Yes

5.3 Dimensional series

Table 3 shows the dimensional series.

Table 3 — Dimensional series

Dimensional series	h_0/t	t_f/t	D/t
A	approximately 0,40	approximately 0,94	approximately 18
B	approximately 0,75	approximately 0,94	approximately 28
C	approximately 1,30	approximately 0,96	approximately 40

6 Design formulae for springs

6.1 General

The following formulae apply to single disc springs with or without flat bearings, where $16 < D/t < 40$ and $1{,}8 < D/d < 2{,}5$. In the case of other designs or materials, it is recommended that the spring manufacturer should be consulted.

6.2 Test load

The test load of single disc springs, 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 height, H_t, as ones without, where the principal dimensions D, d and H_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.

6.3 Coefficients used in calculation

Coefficients can be given by Formula (1) to Formula (7):

$$\alpha = \frac{D}{d} \tag{1}$$

$$C_1 = \frac{1}{\pi} \times \frac{\left(\frac{\alpha - 1}{\alpha}\right)^2}{\frac{\alpha + 1}{\alpha - 1} - \frac{2}{\ln\alpha}} \tag{2}$$

$$C_2 = \frac{1}{\pi} \times \frac{6}{\ln\alpha} \times \left(\frac{\alpha - 1}{\ln\alpha} - 1\right) \tag{3}$$

$$C_3 = \frac{3}{\pi} \times \frac{\alpha - 1}{\ln\alpha} \tag{4}$$

$$C_4 = \sqrt{-\frac{k_1}{2} + \sqrt{\left(\frac{k_1}{2}\right)^2 + k_2}} \tag{5}$$

where

$$k_1 = \frac{\left(\dfrac{t_\mathrm{f}}{t}\right)^2}{\left(\dfrac{1}{4} \times \dfrac{H_0}{t} - \dfrac{t_\mathrm{f}}{t} + \dfrac{3}{4}\right)\left(\dfrac{5}{8} \times \dfrac{H_0}{t} - \dfrac{t_\mathrm{f}}{t} + \dfrac{3}{8}\right)} \tag{6}$$

$$k_2 = \frac{k_1}{\left(\dfrac{t_\mathrm{f}}{t}\right)^3}\left[\frac{5}{32}\left(\frac{H_0}{t} - 1\right)^2 + 1\right] \tag{7}$$

In the case of springs without flat bearings, $C_4 = 1$.

In the case of springs with flat bearings, C_4 shall be calculated using Formula (5) and, in all subsequent formulae, t_f shall be substituted for t and $h_{0,\mathrm{f}}$ (i.e. $H_0 - t_\mathrm{f}$) for h_0.

Guideline values for the reduction in disc spring thickness as a function of the dimensional series are given in Table 3.

6.4 Spring load

The load can be calculated using Formula (8). In the case of springs without flat bearings, $C_4 = 1$.

$$F = \frac{4E}{1-\nu^2} \times \frac{t^4}{C_1 \times D^2} \times C_4{}^2 \times \frac{s}{t} \times \left[C_4{}^2 \times \left(\frac{h_0}{t} - \frac{s}{t}\right) \times \left(\frac{h_0}{t} - \frac{s}{2t}\right) + 1\right] \tag{8}$$

In the case of springs where there is consideration of chamfer radius at edge, and without flat bearings, the load can be calculated using Formula (9):

$$F = \frac{D-d}{(D-d)-3r} \times \frac{4E}{1-\nu^2} \times \frac{t^3}{C_1 \times D^2} \times s \times \left[\left(\frac{h_0}{t} - \frac{s}{t}\right) \times \left(\frac{h_0}{t} - \frac{s}{2t}\right) + 1\right] \tag{9}$$

6.5 Design stresses

The design stresses can be calculated using Formula (10) to Formula (14). Positive stresses are tensile stresses and negative stresses are compressive stresses.

$$\sigma_\mathrm{OM} = -\frac{4E}{1-\nu^2} \times \frac{t}{C_1 \times D^2} \times C_4 \times s \times \frac{3}{\pi} \tag{10}$$

$$\sigma_\mathrm{I} = \frac{4E}{1-\nu^2} \times \frac{t}{C_1 \times D^2} \times C_4 \times s \times \left[-C_4 \times C_2 \times \left(\frac{h_0}{t} - \frac{s}{2t}\right) - C_3\right] \tag{11}$$

$$\sigma_\mathrm{II} = \frac{4E}{1-\nu^2} \times \frac{t}{C_1 \times D^2} \times C_4 \times s \times \left[-C_4 \times C_2 \times \left(\frac{h_0}{t} - \frac{s}{2t}\right) + C_3\right] \tag{12}$$

$$\sigma_{\mathrm{III}} = \frac{4E}{1-\nu^2} \times \frac{t}{\alpha \times C_1 \times D^2} \times C_4 \times s \times \left[C_4 \times (2C_3 - C_2) \times \left(\frac{h_0}{t} - \frac{s}{2t} \right) + C_3 \right] \tag{13}$$

$$\sigma_{\mathrm{IV}} = \frac{4E}{1-\nu^2} \times \frac{t}{\alpha \times C_1 \times D^2} \times C_4 \times s \times \left[C_4 \times (2C_3 - C_2) \times \left(\frac{h_0}{t} - \frac{s}{2t} \right) - C_3 \right] \tag{14}$$

6.6 Spring rate

The spring rate, which is not linear, can be calculated using Formula (15) by differentiating Formula (8) with respect to the deflection, *s*.

$$R = \frac{dF}{ds} = \frac{4E}{1-\nu^2} \times \frac{t^3}{C_1 \times D^2} \times C_4{}^2 \times \left\{ C_4{}^2 \times \left[\left(\frac{h_0}{t} \right)^2 - 3\frac{h_0}{t} \times \frac{s}{t} + \frac{3}{2} \left(\frac{s}{t} \right)^2 \right] + 1 \right\} \tag{15}$$

In the case of springs where there is consideration of chamfer radius at edge, the spring rate can be calculated using Formula (16):

$$R = \frac{dF}{ds} = \frac{D-d}{(D-d)-3r} \times \frac{4E}{1-\nu^2} \times \frac{t^3}{C_1 \times D^2} \times \left[\left(\frac{h_0}{t} \right)^2 - 3\frac{h_0}{t} \times \frac{s}{t} + \frac{3}{2} \left(\frac{s}{t} \right)^2 + 1 \right] \tag{16}$$

6.7 Energy capacity of springs

The energy capacity of springs can be calculated using Formula (17):

$$W = \int_0^s F \times ds = \frac{2E}{1-\nu^2} \times \frac{t^5}{C_1 \times D^2} \times C_4{}^2 \times \left(\frac{s}{t} \right)^2 \times \left[C_4{}^2 \times \left(\frac{h_0}{t} - \frac{s}{2t} \right)^2 + 1 \right] \tag{17}$$

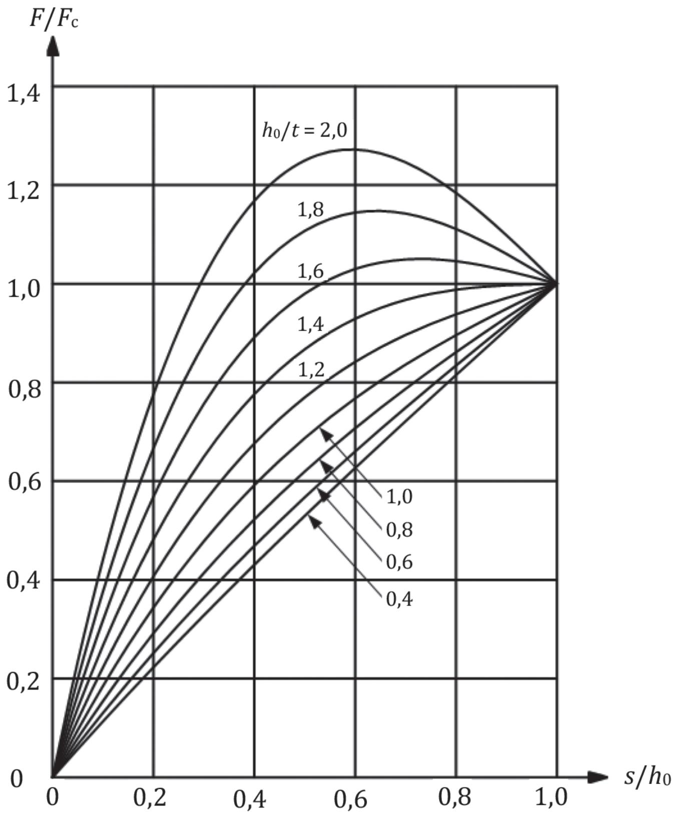
7 Load characteristics

7.1 Load characteristics for a single disc spring

7.1.1 Load/deflection curve

The load/deflection curve for a single disc spring is not linear, with its shape being rather a function of the ratio h_0/t.

Figure 2 illustrates load/deflection curves as a function of the ratio h_0/t or $C_4 \times h_{0,\mathrm{f}}/t_\mathrm{f}$.



Key

F/F_c	spring load ratio
h_0/t	ratio of initial cone height of spring to thickness
s/h_0	deflection ratio

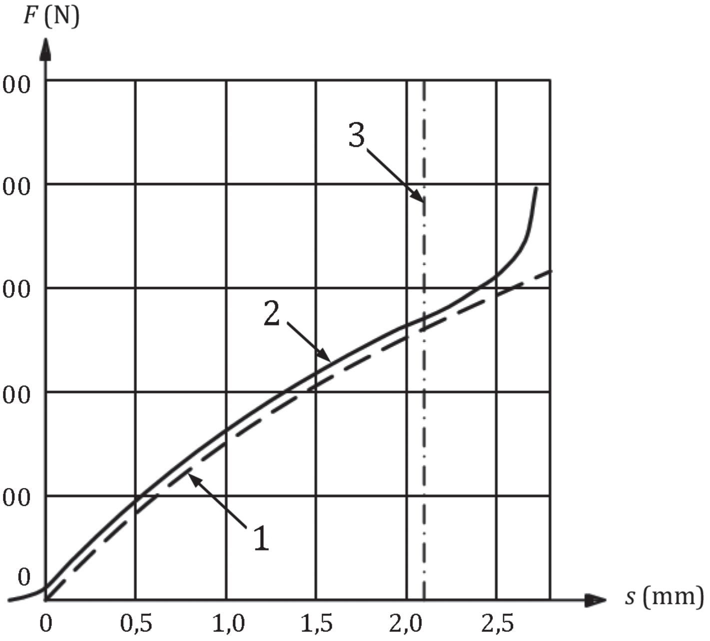
NOTE In the case of springs with flat bearings, $C_4 \times h_{0,f}/t_f$ is substituted for h_0/t.

Figure 2 — Spring load/deflection curves for various h_0/t ratios

7.1.2 Design and actual load characteristics

When measuring the spring load using a load tester, the spring load is, for example, as shown in Figure 3.

When $s/h_0 > 0,75$, the actual curve will deviate more and more from the design curve because 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.



Key

1	design curve
2	actual curve
3	$s = 0{,}75\ h_0$ (h_0 is the initial cone height of springs without flat bearings)
F	spring load
s	deflection of spring

Figure 3 — Example of actual and design spring load/deflection curves

7.2 Load characteristics for stacks of disc springs

7.2.1 General

For springs, various load characteristics can be obtained from the various combinations. When the spring is used in a stack and applied to a load, it should be guided by an inner guide or an outer guide to keep it in position. It is preferable to use an inner guide, but an outer guide is acceptable. When using the guide, a clearance between the spring and the guide shall be made. The amount of clearance should be agreed between customer and supplier.

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

7.2.2 Stacking in parallel

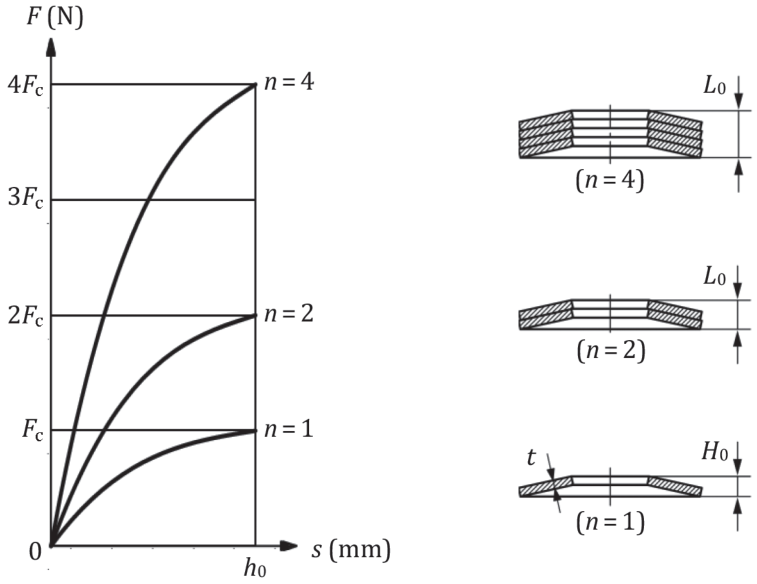
In the case of stacking disc springs in parallel as shown in Figure 4, the spring load will be in direct proportion to the number of single disc springs making up the stack. The spring load, the deflection and free height are calculated using Formula (18) to Formula (20):

$$F_G = n \times F \tag{18}$$

$$s_G = s \tag{19}$$

$$L_0 = H_0 + (n - 1) \times t \tag{20}$$

NOTE In the case of springs with flat bearings, t_f is substituted for t.



Key

F	spring load
F_c	design spring load when spring is in the flattened position
H_0	free height of spring
h_0	initial cone height of springs without flat bearings
L_0	free height at the time of combining springs
n	number of springs piled in parallel
s	deflection of spring
t	thickness of spring

Figure 4 — Variations in load/deflection curves when stacking springs in parallel

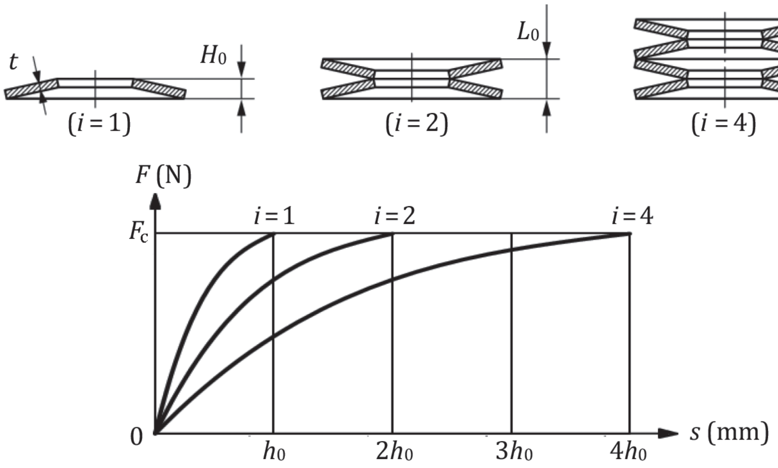
7.2.3 Stacking in series

In the case of stacking disc springs in series, as shown in Figure 5, the deflection will be in direct proportion to the number of single disc springs making up the stack. The spring load, the deflection and free height are calculated using Formula (21) to Formula (23):

$$F_G = F \tag{21}$$

$$s_G = i \times s \tag{22}$$

$$L_0 = i \times H_0 \tag{23}$$



Key

F	spring load
F_c	design spring load when spring is in the flattened position
H_0	free height of spring
h_0	initial cone height of springs without flat bearings
i	number of springs combined in series
L_0	free height at the time of combining springs
s	deflection of spring
t	thickness of spring

Figure 5 — Variations in load/deflection curves when stacking springs in series

7.2.4 Stacking in parallel and series

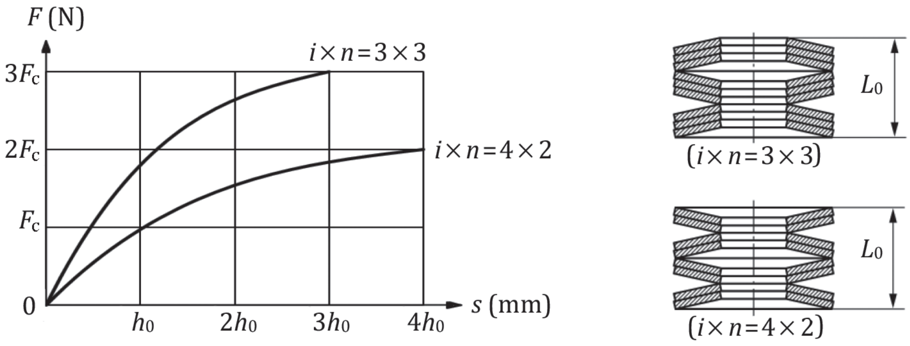
In the case of stacking disc springs in parallel and series, as shown in Figure 6, the spring load, the deflection and free height are calculated using Formula (24) to Formula (26):

$$F_G = n \times F \tag{24}$$

$$s_G = i \times s \tag{25}$$

$$L_0 = [H_0 + (n - 1) \times t] \times i \tag{26}$$

NOTE In the case of springs with flat bearings, t_f is substituted for t.



Key

F	spring load
F_c	design spring load when spring is in the flattened position
h_0	initial cone height of springs without flat bearings
i	number of springs combined in series
L_0	free height at the time of combining springs
n	number of springs piled in parallel
s	deflection of spring

Figure 6 — Variations in load/deflection curves when stacking springs in parallel and series

8 Design stresses

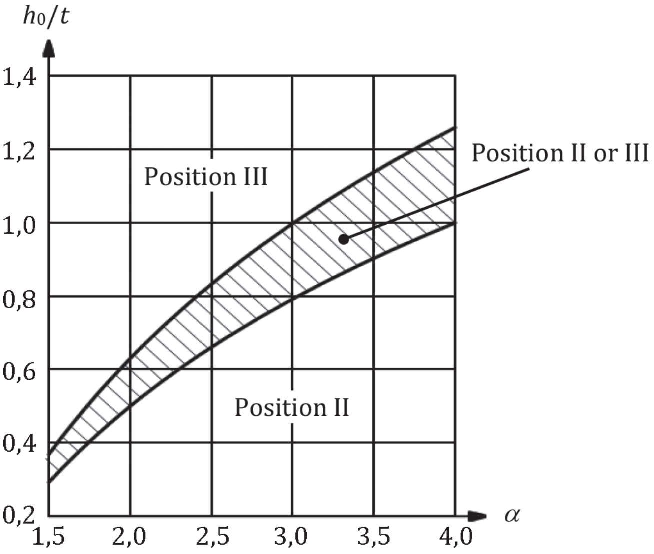
Since there are residual stresses in the spring as a result of the manufacturing process used, the results obtained from Formula (10) to Formula (14) do not reflect the actual values involved, but rather any nominal values. Thus, all information relating to stress in this document represents these nominal values.

An estimate of the permissible free overall height of the spring, H_0, may be based on a determination of the design stress, σ_{OM}, which should be about equal to the tensile strength.

The most important parameter for springs subjected to fatigue loading is the calculated tensile stress on the lower side of a single disc spring. The position most vulnerable to fatigue failure will be either the lower inner edge, position II, or the lower outer edge, position III (see Figure 1 and Figure 7), depending on the ratios $D/d = \alpha$, h_0/t and s/h_0.

This is illustrated in Figure 7 and applies to springs with or without flat bearings.

Since the ratio s/h_0 is a factor of influence with regard to the level of tensile stress at positions II and III, it is recommended, for the area between these positions, that σ_{II} and σ_{III} be determined in accordance with the formulae given in 6.5.



Key

h_0/t	ratio of initial cone height of spring to thickness
α	ratio of external diameter to internal diameter, $\alpha = D/d$

NOTE In the case of springs with flat bearings, $C_4 \times h_{0,\mathrm{f}}/t_\mathrm{f}$ is substituted for h_0/t.

Figure 7 — Relevant positions of loading for springs subject to fatigue loading

9 Types of loading

9.1 Static loading and moderate fatigue conditions

Springs shall be deemed to be subject to static loading

a) where this is the only type of loading and where it does not change, and

b) if they are 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.

9.2 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, and

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.

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[1] DIN 2092, *Disc springs — Calculation*

[2] DIN 2093, *Disc springs — Quality specifications — Dimensions*

[3] JIS B 2706, *Disc springs*

[4] GB/T 1972-2005, *Disc spring*

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