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Disc springs —

Part 1:
Calculation

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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.

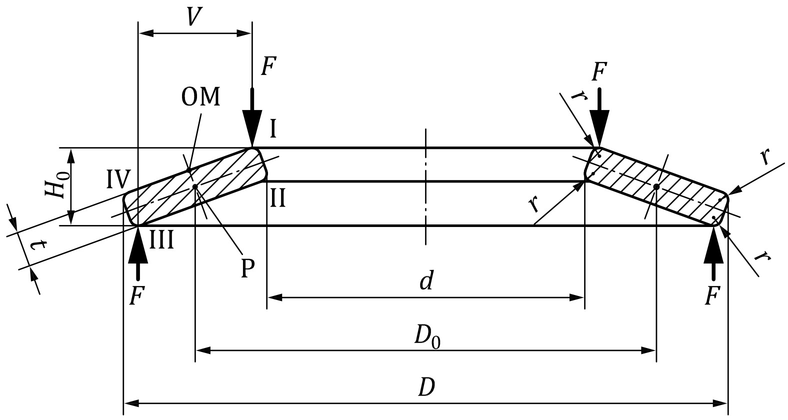
Table 1 — Symbols and units for design calculation

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, $H_t = H_0 - 0{,}75\ h_0$
H_0	mm	free height of spring
h_0	mm	initial cone height of springs without flat bearings, $h_0 = H_0 - t$
$h_{0,f}$	mm	initial cone height of springs with flat bearings, $h_{0,f} = H_0 - t_f$
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		

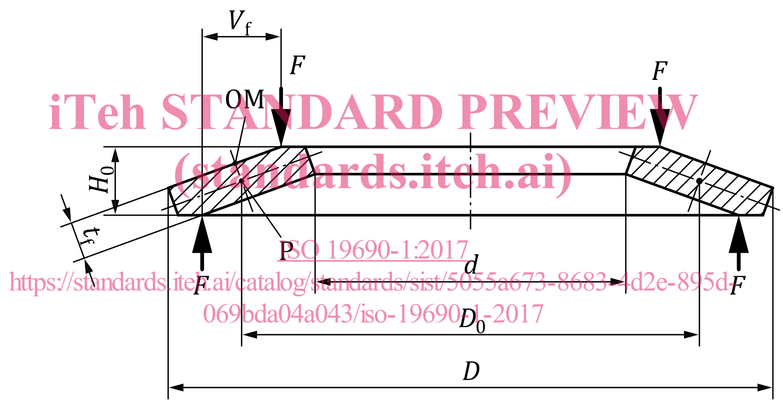
5 Dimensions and designation

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
D_0	diameter of centre of rotation
d	internal diameter of spring
F	spring load
H_0	free height of spring
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	chamfer radius at edge
t_f	reduced thickness of single disc spring with flat bearings
t	thickness of spring
V	length of lever arms
V_f	length of lever arms with flat bearings
I	position I
II	position II
III	position III
IV	position IV

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	$0{,}2 \leq t < 1{,}25$	No
2	$1{,}25 \leq t \leq 6{,}0$	No
3	$6{,}0 < t \leq 14{,}0$	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):

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

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

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

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

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

where

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

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

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 $h_{0,f}$ (i.e. $H_0 - t_f$) 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.

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

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

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

