
Disc springs —

**Part 1:
Calculation**

*Ressorts à disques —
Partie 1: Calcul*

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Contents

| | Page |
|---|-----------|
| Foreword | iv |
| 1 Scope | 1 |
| 2 Normative references | 1 |
| 3 Terms and definitions | 1 |
| 4 Symbols and units | 1 |
| 5 Dimensions and designation | 3 |
| 5.1 General | 3 |
| 5.2 Disc spring groups | 3 |
| 5.3 Dimensional series | 4 |
| 6 Design formulae for springs | 4 |
| 6.1 General | 4 |
| 6.2 Test load | 4 |
| 6.3 Coefficients used in calculation | 4 |
| 6.4 Spring load | 5 |
| 6.5 Design stresses | 5 |
| 6.6 Spring rate | 6 |
| 6.7 Energy capacity of springs | 6 |
| 7 Load characteristics | 6 |
| 7.1 Load characteristics for a single disc spring | 6 |
| 7.1.1 Load/deflection curve | 6 |
| 7.1.2 Design and actual load characteristics | 7 |
| 7.2 Load characteristics for stacks of disc springs | 8 |
| 7.2.1 General | 8 |
| 7.2.2 Stacking in parallel | 8 |
| 7.2.3 Stacking in series | 9 |
| 7.2.4 Stacking in parallel and series | 10 |
| 8 Design stresses | 11 |
| 9 Types of loading | 12 |
| 9.1 Static loading and moderate fatigue conditions | 12 |
| 9.2 Dynamic loading | 12 |
| Bibliography | 13 |

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

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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

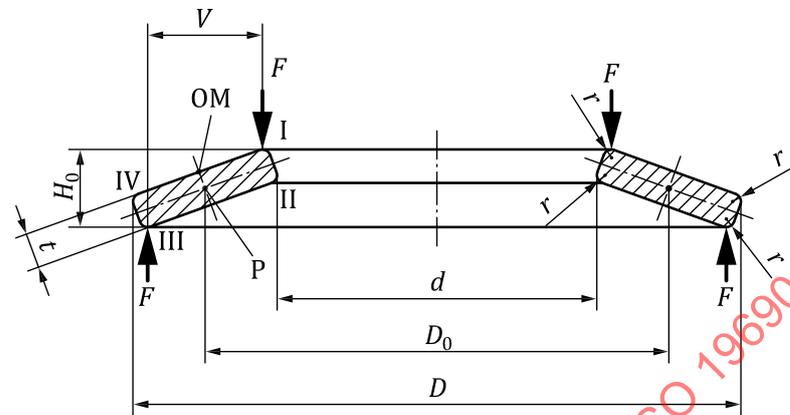
| Symbol | Unit | Parameter |
|----------------------|-------------------|--|
| C_1, C_2, C_3, C_4 | — | coefficients |
| D | mm | external diameter of spring |
| D_0 | mm | diameter of centre of rotation |
| d | mm | internal diameter of spring |
| E | N/mm ² | modulus of elasticity of material (carbon 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/mm² = MPa

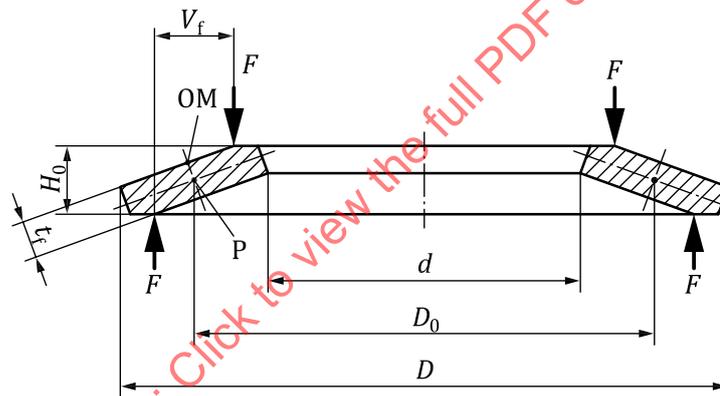
5 Dimensions and designation

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 | <i>t</i> (mm) | With flat bearings and reduced thickness |
|-------|-----------------------|--|
| 1 | 0,2 ≤ <i>t</i> < 1,25 | No |
| 2 | 1,25 ≤ <i>t</i> ≤ 6,0 | No |
| 3 | 6,0 < <i>t</i> ≤ 14,0 | Yes |

5.3 Dimensional series

Table 3 shows the dimensional series.

Table 3 — Dimensional series

| Dimensional series | <i>h</i> ₀ / <i>t</i> | <i>t</i> _f / <i>t</i> | <i>D</i> / <i>t</i> |
|--------------------|----------------------------------|----------------------------------|---------------------|
| 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):

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

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

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

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

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

where

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

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

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, $C_4 = 1$.

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

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 \(9\)](#):

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

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.

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

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

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

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

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

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 .

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

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

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

6.7 Energy capacity of springs

The energy capacity of springs can be calculated using [Formula \(17\)](#):

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

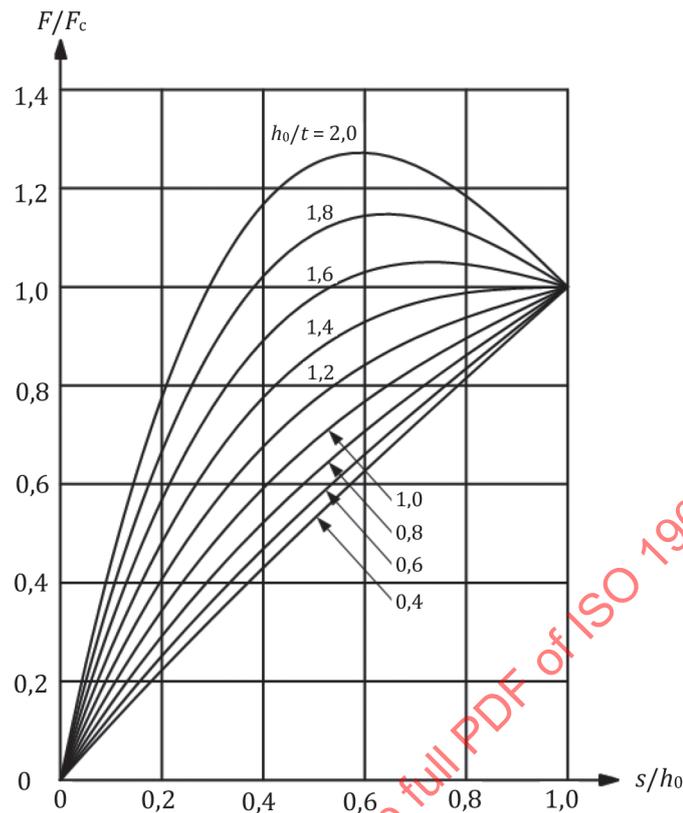
7 Load characteristics

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 $C_4 \times h_{0,t}/t_t$.

**Key**

F/F_c spring load ratio

h_0/t ratio of initial cone height of spring to thickness

s/h_0 deflection ratio

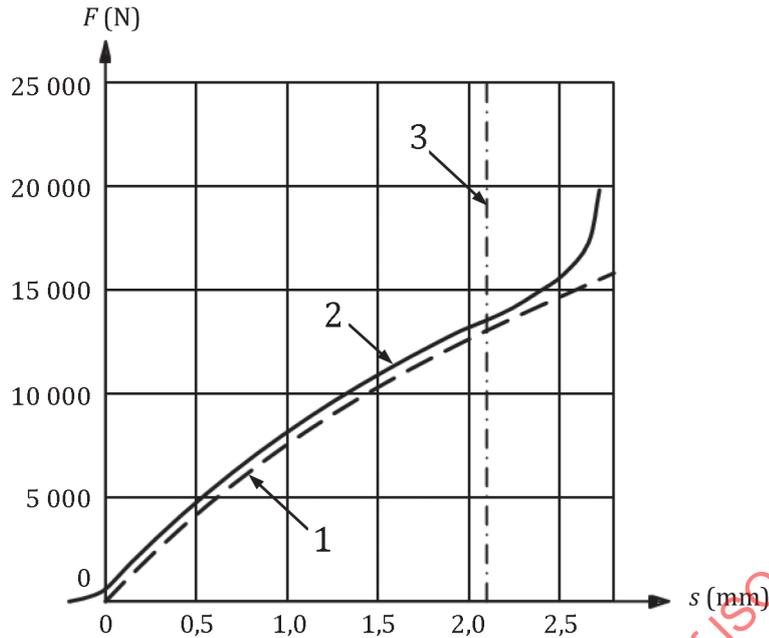
NOTE In the case of springs with flat bearings, $C_4 \times h_{0,t}/t_f$ is substituted for h_0/t .

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

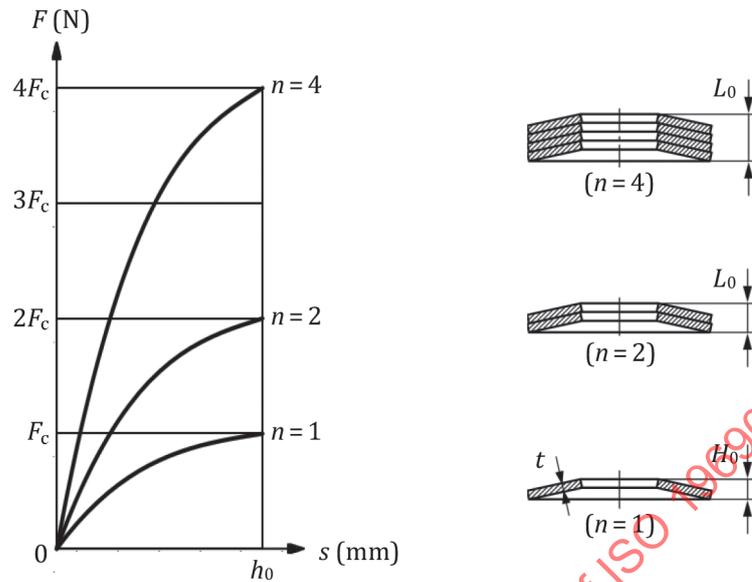
In the case of stacking disc springs in parallel as shown in [Figure 4](#), the spring load will be in direct proportion to the number of single disc springs making up the stack. The spring load, the deflection and free height are calculated using [Formula \(18\)](#) to [Formula \(20\)](#):

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

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

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

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

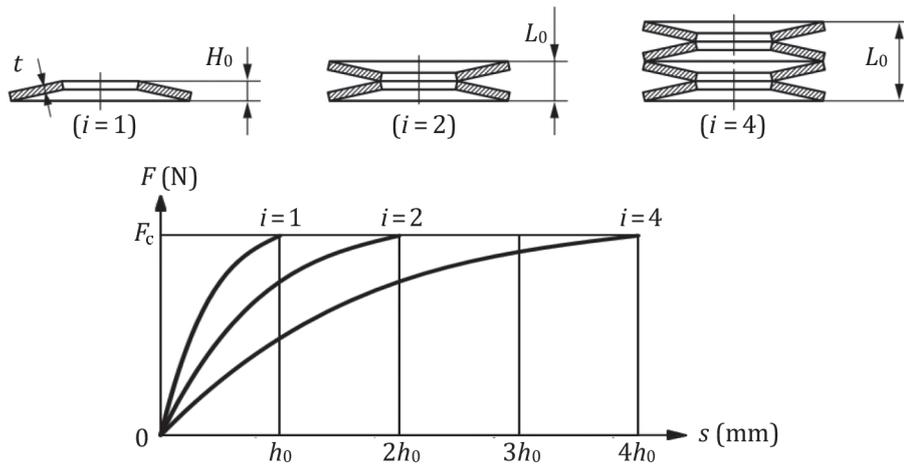
7.2.3 Stacking in series

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 .