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The Physics of Diaphragm Springs

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Diaphragm springs – General

Symbols and nomenclature

D_e	=	*Outside diameter*	*mm*
D_i	=	*Inside diameter*	*mm*
t	=	*Thickness of individual spring*	*mm*
h_o	=	*free cone height of the unloaded individual spring*	*mm*
l_o	=	*Overall height of the individual spring*	*mm*
		$l_o = h_o + t$	
F	=	*Spring force*	*N*
s	=	*Deflection*	*mm*

Note: All dimensions shown in the following charts are given in millimeters (mm) and Newton (N).

1 mm = 0.03937 in.

1 N = 0.1 daN = 0,22 lbf

Example: A diaphragm spring having 200 mm outside diameter (De), 160 mm inside diameter (Di), and 2.5 mm thickness, would be labelled: Diaphragm spring 200 x 160 x 2.5.

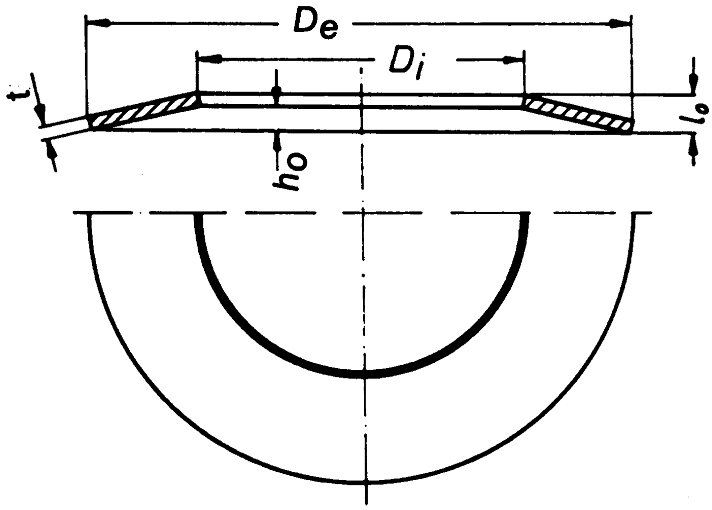

Fig. 1: Nomenclature of diaphragm springs

Spring force characteristics

No other spring type has load-deflection characteristics as adjustable as the diaphragm spring. Such a spring may have a linear characteristic, a progressive characteristic obtained by proper superimposition, a depressive characteristic, or even a negative characteristic. This unique performance makes this spring a very flexible element of machine design, and unequalled by any other.

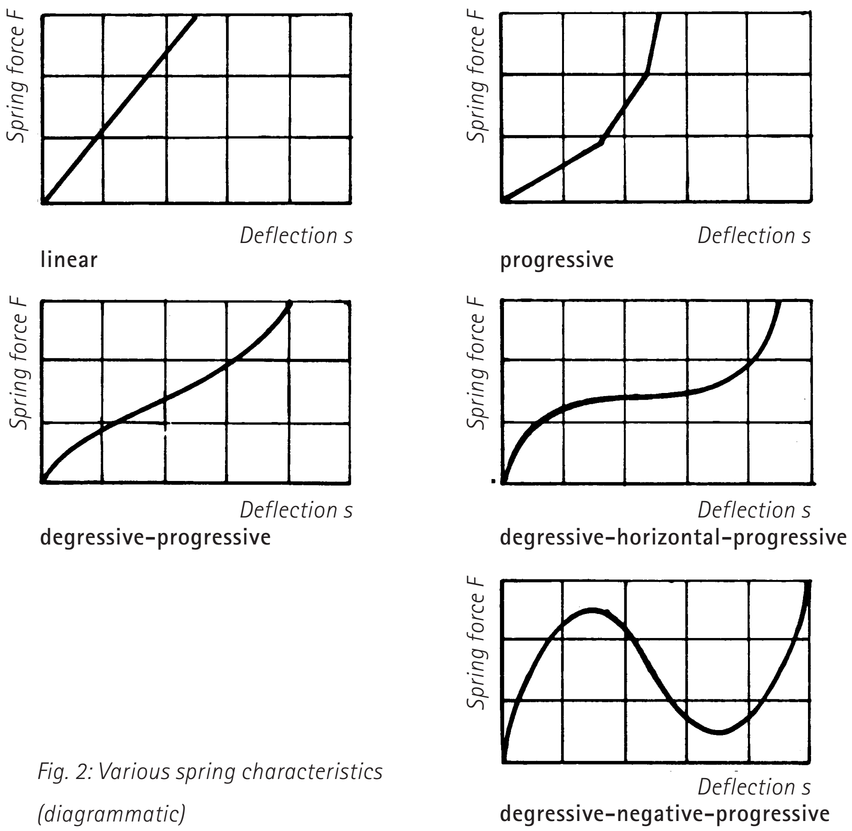

Fig. 2: Various spring characteristics (diagrammatic)

Dependence of Spring Characteristic on the h_o/t Ratio

The spring characteristic is varied within wide limits by altering the ratio of free cone height ho to thickness t. In fig. 3, height ho has been varied for a given constant thickness t, and in fig. 4 thickness t has been varied for a given constant ho. The point of inflection occurs when the spring is flattened out, and in figs. 3 and 4, it is at the intersection of the broken line with the spring characteristic.

Both figures are based on a 200 x 160 x 2.5 spring.

Fig. 5 again demonstrates the effect of the h_o/t ratio upon the spring characteristics. Here, however, the spring force F has been referred to the free height h_o. For any given diaphragm spring, the family of curves will supply the applicable h_o/t from the shape of the desired characteristic curve.

Example: A diaphragm spring is supposed to exert a maximum force of about 1.3 times the force applied in the flattened out position. Read off: $h_o/t = 2$.

Or: At what spring deflection will a diaphragm spring with ho/t = 2 have its minimum pressure? Find $s = 1.4\ h_o$.

$h_o/t = \sqrt{2} =$ 1.42 will give a partly horizontal pressure curve;

$h_o/t > \sqrt{2} =$ will yield a pronounced maximum and minimum force, with a negative spring rate between the maximum and the minimum.

$h_o/t > \sqrt{8} =$ 2.83 will make the spring stagnate in the minimum position, which means that a force opposite to the original one must be present in order to return the spring to its original Position.

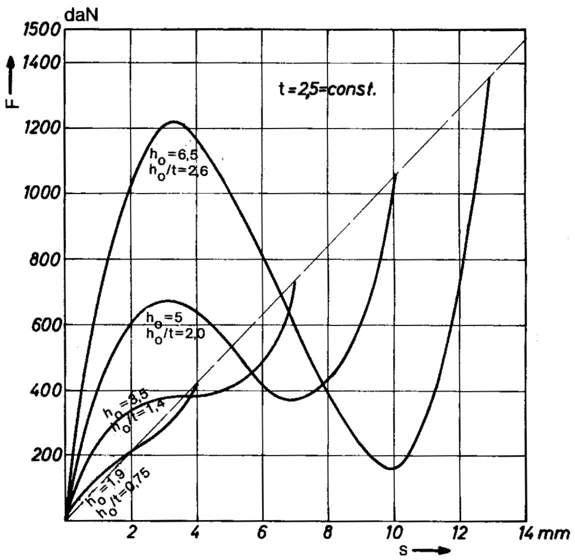

Fig. 3: Outline of characteristic as a function of h_o/t, where t = constant

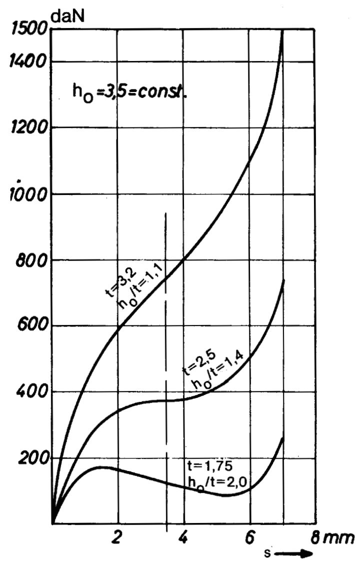

Fig. 4: Outline of characteristic as a function of h_o/t, where h_o = constant

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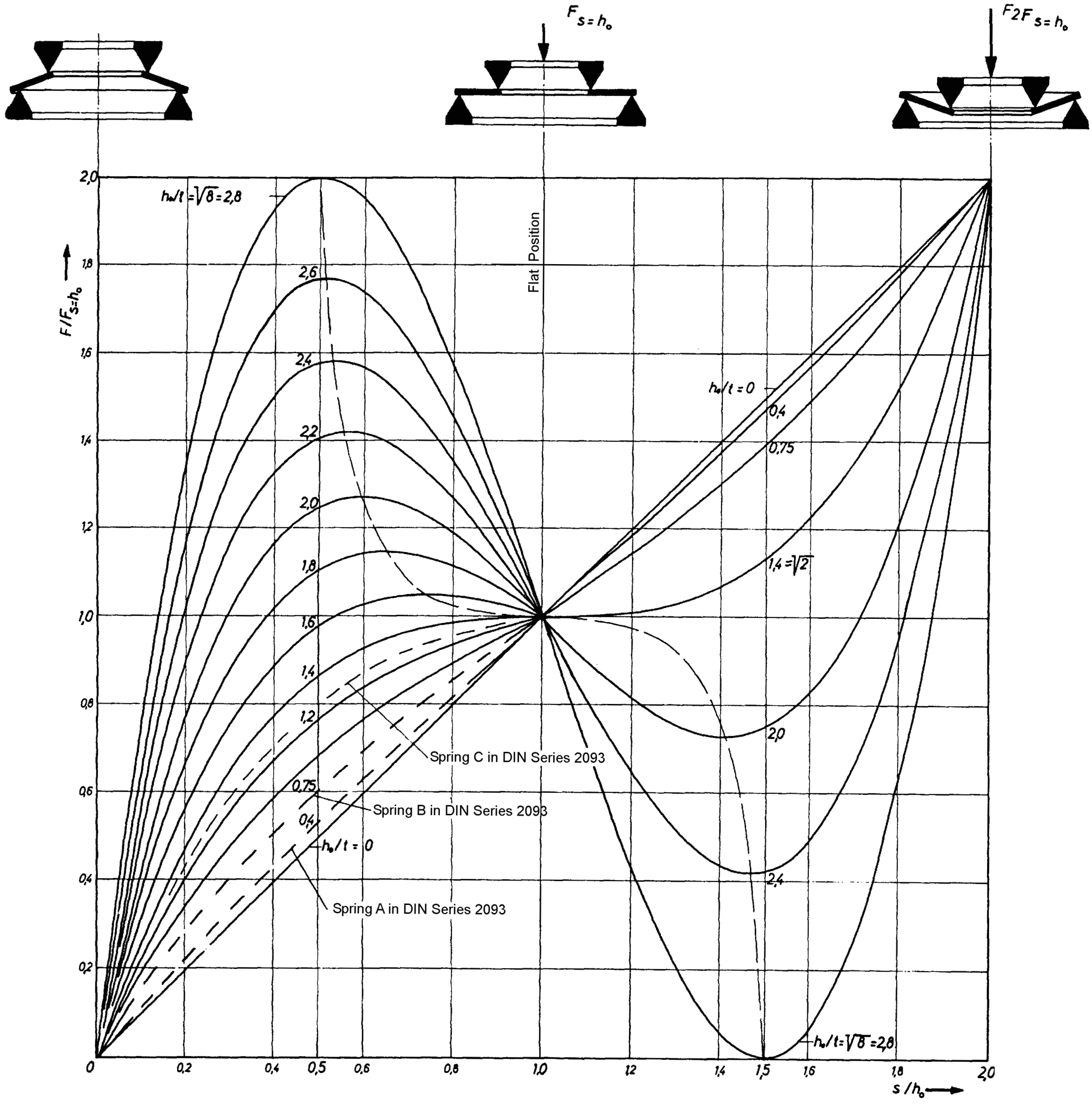


Fig. 5: Family of characteristics of the Diaphragm Spring, with variable h_0/t

Characteristics of Spring Combinations

Parallel stacking of springs will multiply the individual spring forces, while series stacking will multiply the individual deflections. In the latter case, the maximum deflection is reached when the individual springs become flat.

By suitably combining a number of springs (Fig. 7) stacks having a progressive characteristic can be obtained.

DIN Standard Disc Springs

This series is established by DIN Specification 2093, and is supplemented by products of various manufacturers. The outside diameters are from 8 to 250 mm. For the A series, the h_0/t ratio is 0.4, for the B series, h_0/t is about 0.75, and for the C series h_0/t is approximately 1.3.

Properties

1. Large spring forces with small deflections, hence "stiff" performance.
2. Designed to be depressed no further than the flattening-out point. Actually, the available deflection should not exceed 0.75 h_0, since the spring rolls off the support, which means a continuous reduction of leverage and hence a disproportionate increase in spring force (Fig. 8).

Since the deflection obtainable from an individual spring is usually insufficient, a series arrangement must be considered.

The spring force is increased by stacking discs in parallel; see Diaphragm Springs - General.

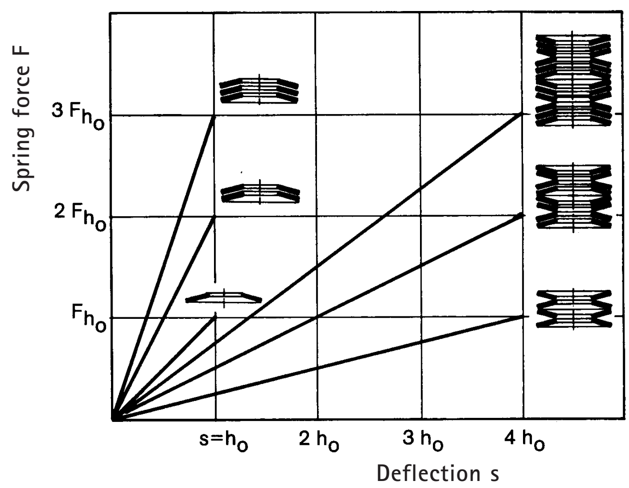


Fig. 6: Characteristics of different spring combinations (diagrammatic, disregarding friction)

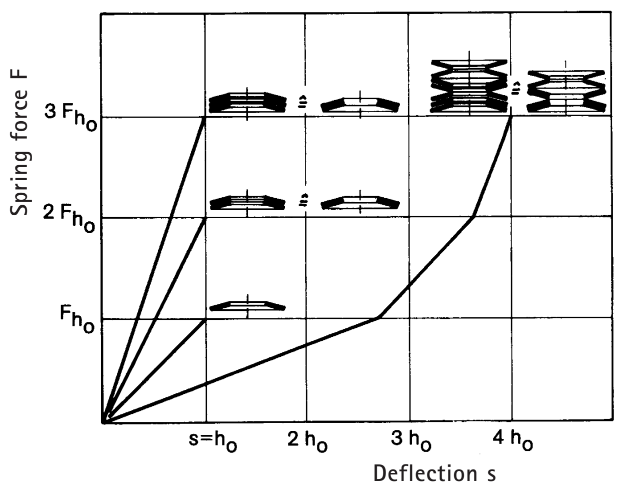


Fig. 7: Spring combinations with progressive characteristics (diagrammatic, disregarding friction)

Properties of Stacked Disc Springs

1. Great forces correspond to large axial and small radial extension of the elements employed.
2. Considerable damping (due to friction), especially for parallel stacking, by which friction increases progressively with a larger number of discs. Friction occurs mainly between the discs and along the guide rod in the center.

Depending on the number of discs and their arrangement, the spring forces are modified by the effects of friction which gives a hysteresis effect (see fig. 9).

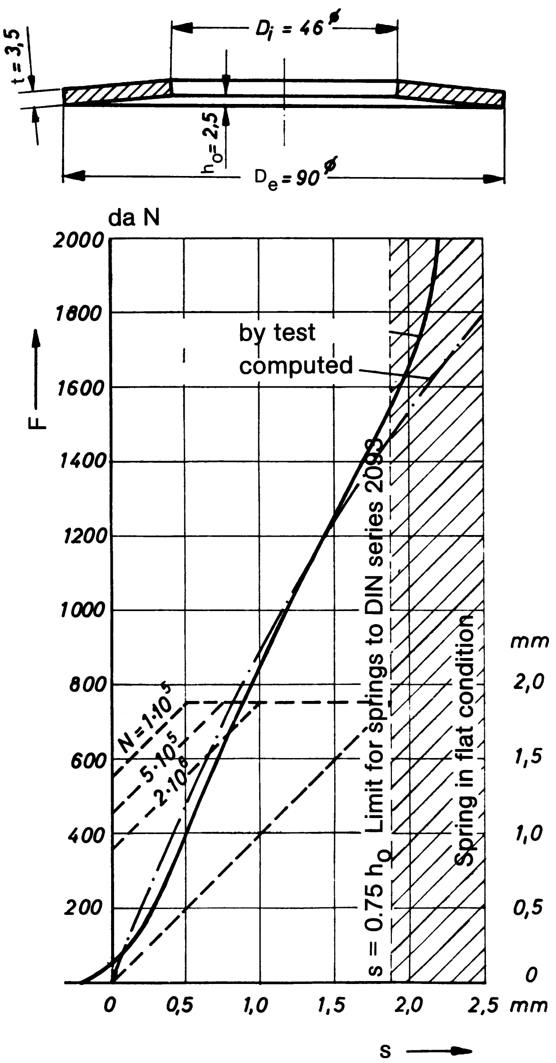


Fig. 8: Dimensions and spring characteristic of a B 90 DIN 2093 Standard disc spring

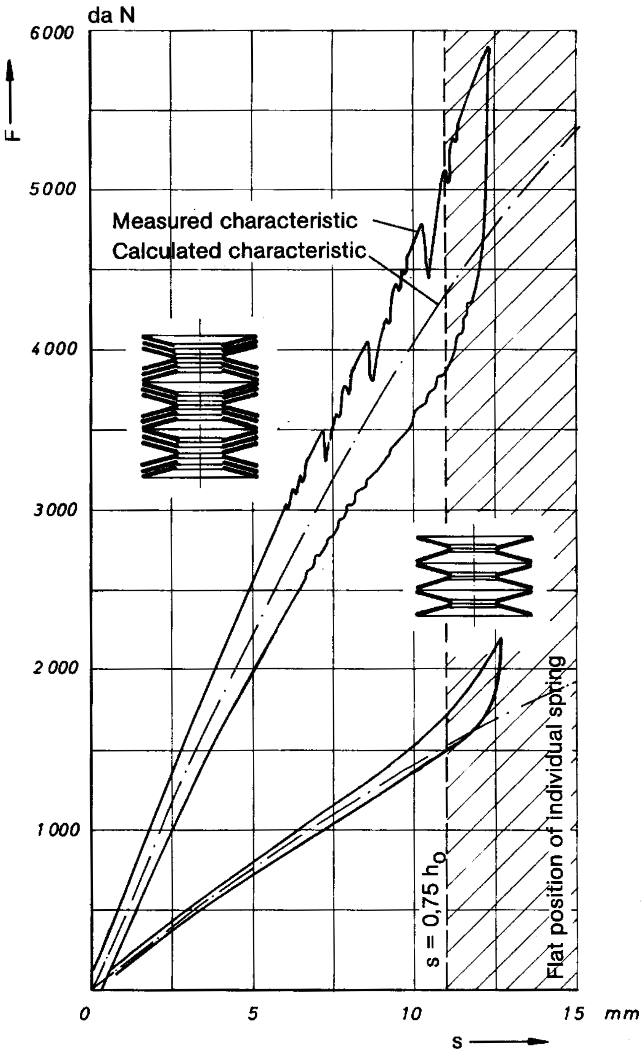


Fig. 9: Influence of friction (damping) upon the spring characteristics of two sets of parallel and series stacked spring combinations. (Springs B 90 DIN Series 2093)

The use of standard disc springs is limited by:

1. Spring characteristics. All standard springs have a more or less stiff performance. Horizontal or negative characteristics are not available.
2. Deflection. This is relatively small and for single springs limited to a maximum of 0.75 ho. To obtain larger deflections, series stacking is required. This demands more space and introduces friction.
3. Damping. The friction in a parallel stacked spring prevents accurate maintainence of specified load characteristics.
4. Fatigue strength. This will reduce considerably for more than six series stacked springs and for parallel arrangements.

HAUSSERMANN Special Diaphragm Springs

Compared with standard disc springs, HAUSSERMANN special diaphragm springs have the following properties:

1. Sizes and proportions may be selected at will; we can supply any desired configuration.
2. Any desired spring characteristic may be obtained.
3. The deflection may be extended since the spring may be depressed beyond its flat condition (see Fig. 10), and by the provision of fingers. Thus a stacking of springs can be avoided in most cases.
4. There is no increase in friction (or in damping) and it is easier to obtain relatively exact adherence to a specified force-deflection curve.
5. Excellent fatigue strength even for dynamical loading far beyond flat dependent on the individual spring design.

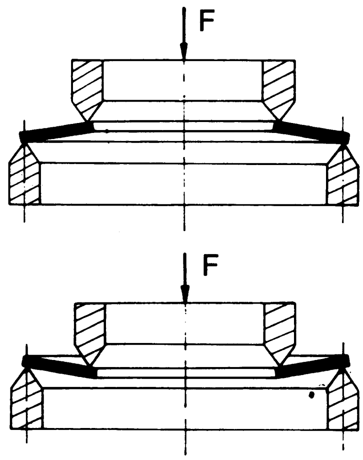


Fig. 10: Function of a diaphragm spring with extended deflection range.

Increasing Load or Deflection with Springs of Given Dimensions

Increasing the Spring Force Through Parallel Stacking

From Fig. 6 it will be noted that the spring force can be doubled, tripled, etc. by means of parallel stacking. To reduce friction between the springs, the surfaces may be lubricated. Also, the springs may be separated by spacers, such as wire rings, and thus the friction will not be much more significant than in the case of single springs.

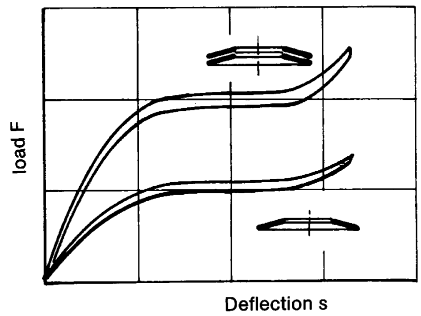


Fig. 11: Increasing the spring force by parallel stacking

Increasing Spring Force and Reducing Deflection by Decreasing the Leverage of the Spring Support

If the leverage between the loading ring and the supporting ring is reduced, the spring force will increase by

$$K_f = \frac{D_E - D_I}{D_{EF} - D_{IF}}$$

The deflection is reduced by

$$K_s = \frac{1}{K_f}$$

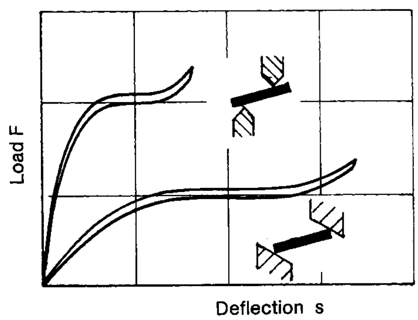


Fig. 12: How a reduction of support leverage affects the spring characteristic.

Increasing Deflection Through Series Stacking

As shown in Fig. 6, the deflection may be doubled, tripled, etc., by series stacking.

However, in view of the extended deflection range of the HAUSSERMANN diaphragm spring such stacking is frequently out of place, since:

1. The deflection of the individual spring then would be limited to $s = 0.75\ h_o$ and hence at least three series stacked springs would be needed to obtain the maximum deflection of a single spring;
2. The damping effect would be increased by the stacking;
3. The ratio h_o/t for single spring has to be limited to a maximum of 1.3 to eliminate the possibility of it deflecting more than others and snapping over centre when fully deflected. If this happened the performance of the stack assembly would be unpredictable.

Increasing Deflection and Reducing Spring Force by Increasing the Leverage of the Spring Support

By providing the annular disc with fingers of suitable length, the support leverage and hence the deflection can be extended considerably. The basic spring element is still the annular portion of the diaphragm spring; note Fig. 13. Again, the correction factors for spring force and spring deflection apply unchanged.

Diaphragm spring with short fingers (see curve 1)

Diaphragm spring ith long fingers (see curve 2)

Design of Diaphragm Spring Supports, and Centering

If springs are to be depressed beyond their flat position, they must be supported properly. When the spring is depressed, the support should not appreciably reduce the effective leverage in order to prevent an undesirable increase of the force applied. The greater the dynamic loading on the spring, the more carefully the support radius should be designed.

Centering the springs on their outer diameter is recommended especially for diaphragm finger springs, since the finger ends will undergo considerable radial movement in operation.

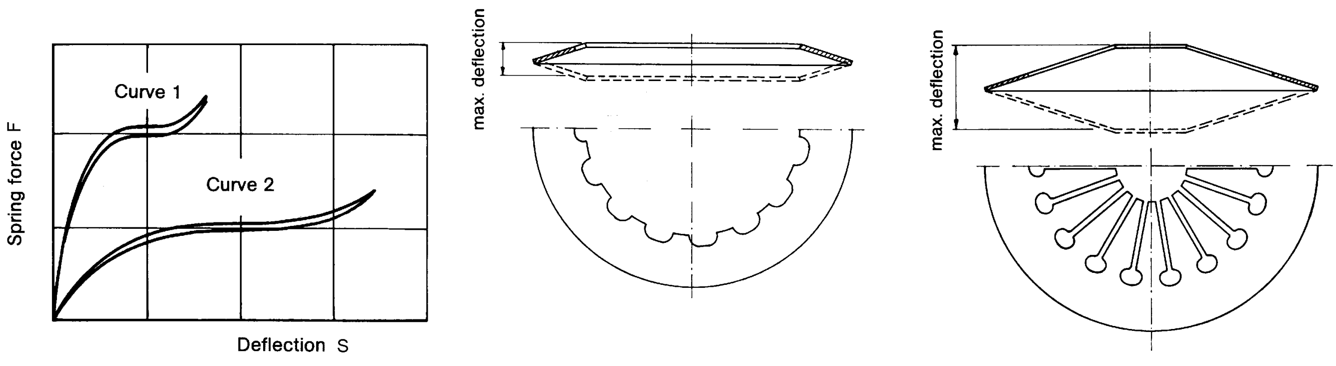


Fig. 13: How an extension of support leverage affects the spring characteristics

Some examples are shown below.

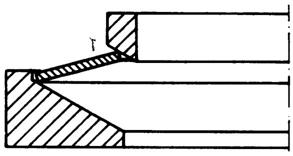
The figures show externally centered designs; the same principles may be applied for internal centering. In the case of high dynamic loads, the finger tips of the springs should be hardened additionally to reduce wear (patented).

Hysteresis

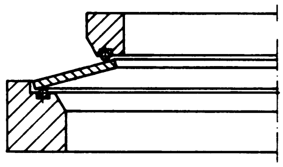
As already mentioned in Increasing Load or Deflection of Springs, springs show a difference in load called hysteresis between compression and release which is due to friction. If the spring supports are rounded, smooth and greased this hysteresis can be kept down to approximately 2 - 4% of the average spring load. In cases of higher spring loads and less care taken with the spring supports this hysteresis effect can go as high as 10%. However, in certain applications there are vibrations present which overcome the static friction and so reduce the hysteresis to a negligible amount.

Set in Diaphragm Springs

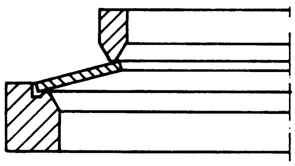
Due to the considerable gradient in tensile stress across the spring section, the diaphragm spring exerts an appreciable stiffening effort internally. This makes the diaphragm spring superior in endurance over all other spring types, even at elevated temperatures.



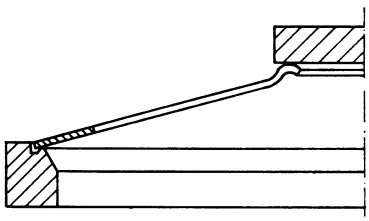
Diaphragm spring between inclined planes. In cases of high dynamic loading, it is recommended that the support edges of the spring be rounded off.



Pivot rings inserted in groove.



Supports rounded off.



With a flat compression piece, the finger tips will be cranked and hardened.

Fig. 14: Examples of spring support design

Depending on the spring material, hardness and layout a spring will tend to "set" during the first few cycles. This effect is taken into account in the design of diaphragm springs. In addition to that springs can be "scragged" before final inspection to ensure that as far as practical the possibility of setting is removed. Due to this attention to detail the HAUSSERMANN spring will give consistent characteristics over a long and severe service life.

Dynamic Loading of Diaphragm Springs

HAUSSERMANN springs for high dynamic loads are made from a carefully alloyed electric furnace steel of controlled sulphur and phosphorus content. They are accurately heat treated and shot peened for optimum service life.
An adequate life expectancy of a spring is based on a proper limitation of the service stresses. At the top of a diaphragm spring, compressive stresses will prevail, with tensile stresses at the concave side.
In the case of an annular disc spring, the critical region is the lower outside edge, which should be rounded off for best dynamic performance.
With slotted diaphragm springs, there is also a notch effect at the root of the fingers. In HAUSSERMANN diaphragm springs this is, however, greatly attenuated by the provision of oval holes (patented). Extensive research has revealed that this feature will greatly extend the life of the spring, as

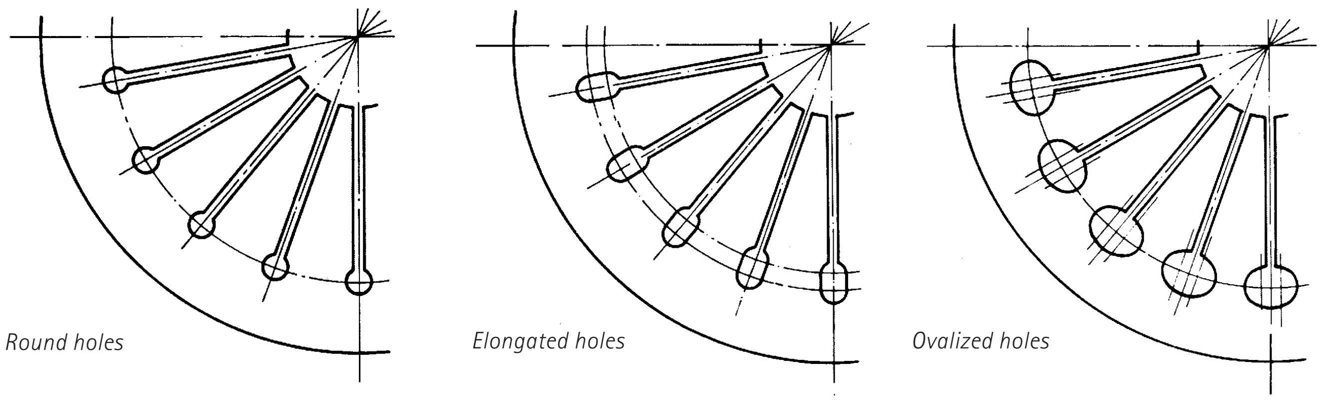


Fig. 15: Various hole patterns

will coining of the lower hole edges.

Further measures to reduce stress include:
Increasing the outside diameter, preserving all other dimensions as well as the shape of the characteristic.
Reduction of the overall height (and resulting change in the characteristic).
When these steps are impracticable, the load can be distributed over several diaphragm springs stacked in parallel.
In general diaphragm springs should be preloaded. The preload deflection should be at least equal to .15 h_o. This preload is to ensure that the residual tensile stresses at the inner upper corner are translated to compressive stresses to ensure maximum fatigue resistance.

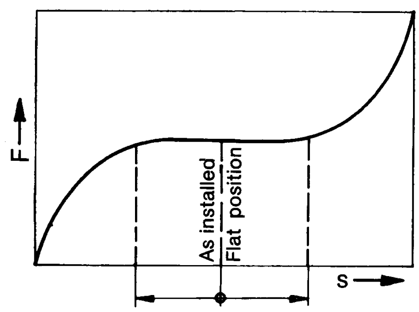
Torque Transmission with Diaphragm Springs

Diaphragm finger type springs can also transmit a torque. In that case, the driving torque is transmitted from the shaft through the spring fingers to the outer casing via driving dogs rivetted to the spring. In this way a verycompact assembly is possible.
This approach has been used for instance in the DAF Variomatic variable speed transmission.

Applications of Special Diaphragm Springs

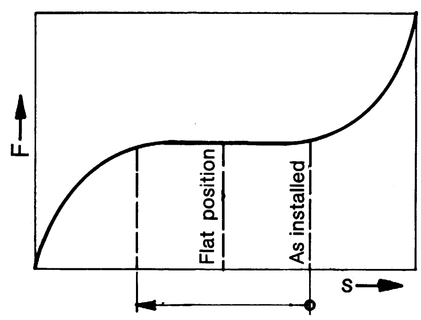
From the wide field of application offered by the HAUSSERMANN special designs, in view of the extended deflection range and variability of characteristics, some examples will be presented.
HAUSSERMANN Special Diaphragm Springs with Partly Horizontal Characteristics (h_o/t = 1.42)
The possibility of obtaining constant performance across deflections of variable length has created wide application, such as

- taking up the play in movable elements, for example ball bearings, seals and the like



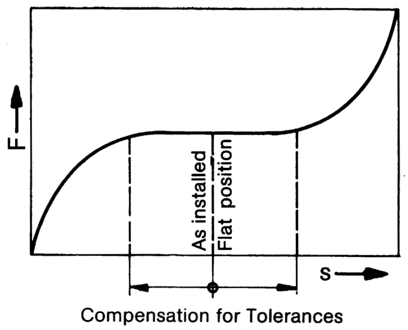
Compensation for Play

- compensation for heat expansion of screw joints for example

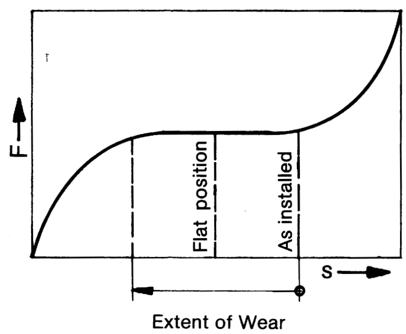


Compensation for Expansion

• compensation for play and assembly clearances

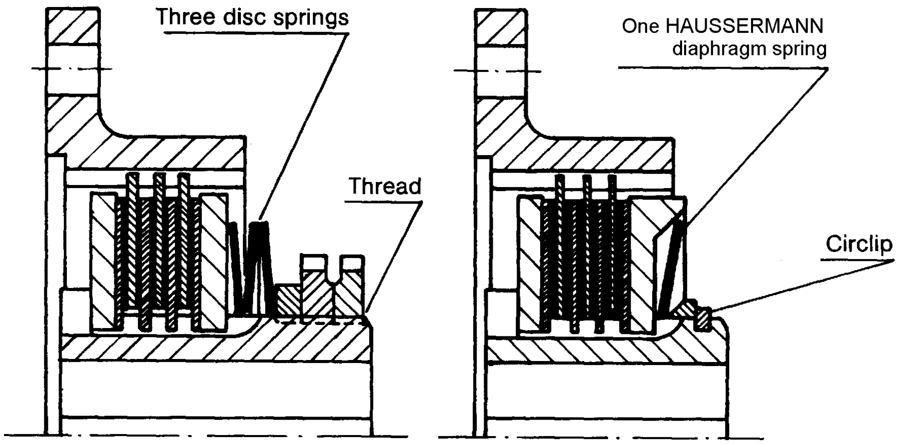


• automatic compensation for wear in overload clutches, multiple-disc clutches and brakes, etc.



Clutches so equipped require no readjustment other than renewal of friction elements, and thus are free of maintenance. Frequently disc springs with an h_0/t ratio of 1.3 are used in these cases. However, these springs do not actually have a horizontal portion and have to be stacked to give the required deflection. Therefore, as wear takes place, the load reduces with an increasing tendency for the clutch to slip.

Fig. 16 shows an application of a diaphragm spring with a part horizontal characteristic in a multiple-disc overload clutch.The design is straightforward and maintenance-free as opposed to the one shown above.



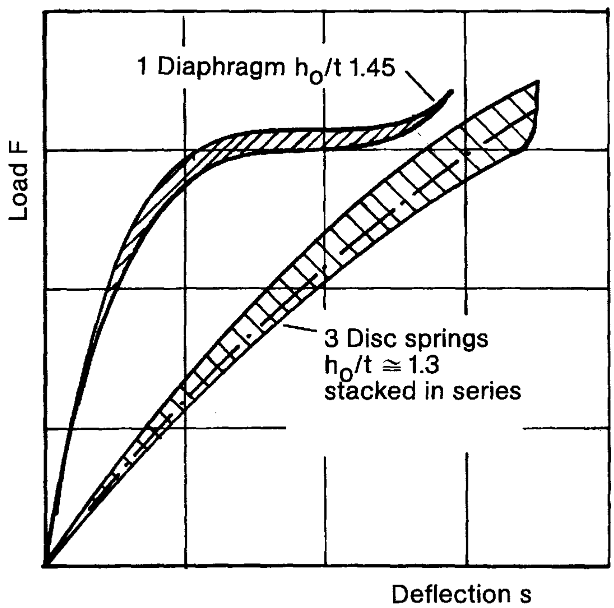


Fig. 16: Section (diagrammatic) of a multiple-disc overtorque clutch, employing (on top) three disc springs with h_0/t = 1.3, and (below) one HAUSSERMANN Special Spring with h_0/t = 1.4 - 1.5 depressed beyond flatness

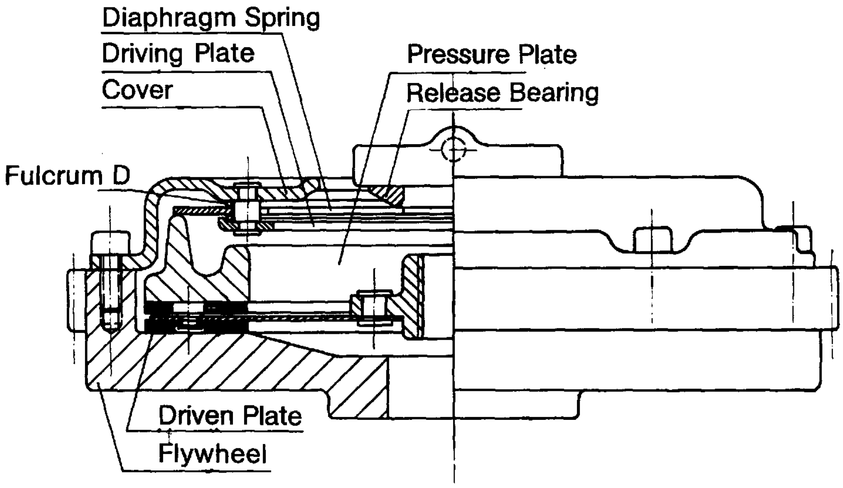
Special Springs with Partial Negative Characteristics

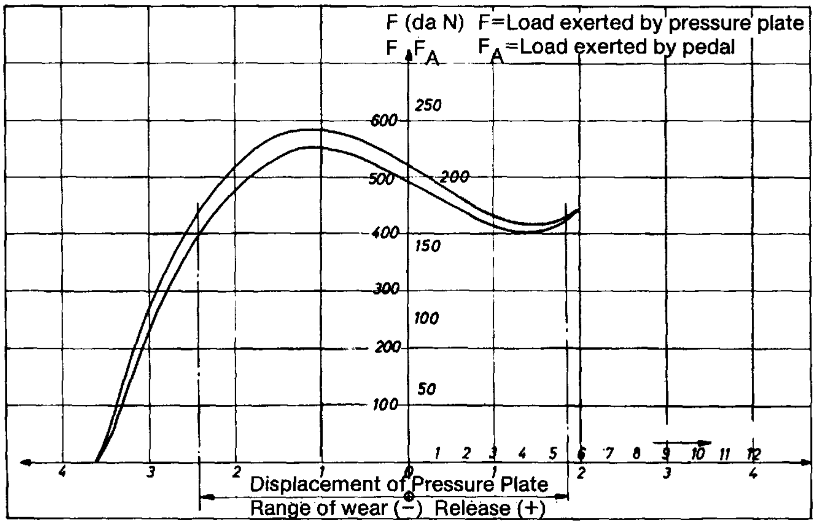
These diaphragm springs are popular in the automotive field.
In an automotive clutch equipped with a diaphragm finger spring, the clutch fingers reduce the releasing pressure, and simultaneously yield the leverage applied at fulcrum D for lifting the pressure plate.

Conversely to the performance of a conventional coil spring, upon declutching the compressive force of the diaphragm spring decreases; this reduces the effort required. As the friction linings gradually lessen, the spring pressure will not diminish; rather, it will increase. The diaphragm spring thus compensates forwear, rendering further resetting of the clutch unnecessary. In this particular application, other advantages of the dia- phragm spring include:

- Minimum overall length of the clutch.
- Due to the rotational symmetry of the element, the diaphragm spring will cause no unbalance.
- High speeds will not affect the function of the diaphragm spring, as would have been the case with a helical spring.

Another field in which HAUSSERMANN special diaphragm springs have been used to good advantage through featuring partly negative characteristics is that of stepless speed reducers. In a manually controlled primary variator pulley, the





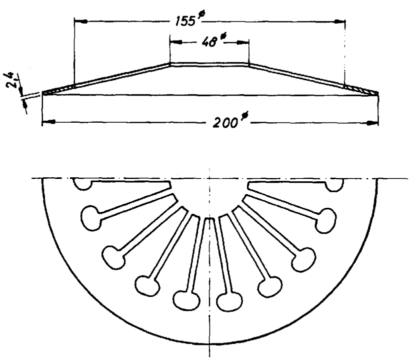


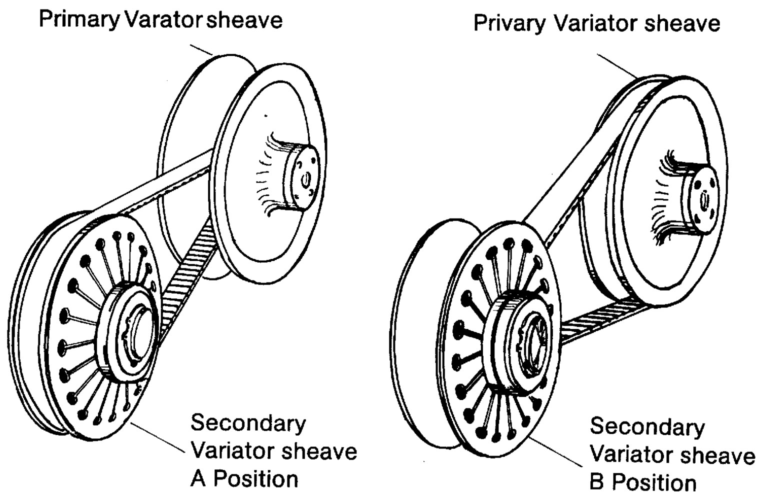
Fig. 17: HAUSSERMANN Diaphragm Spring with partly negative characteristic for use in passenger car clutches. Spring characteristic and section of clutch (diagrammatic)

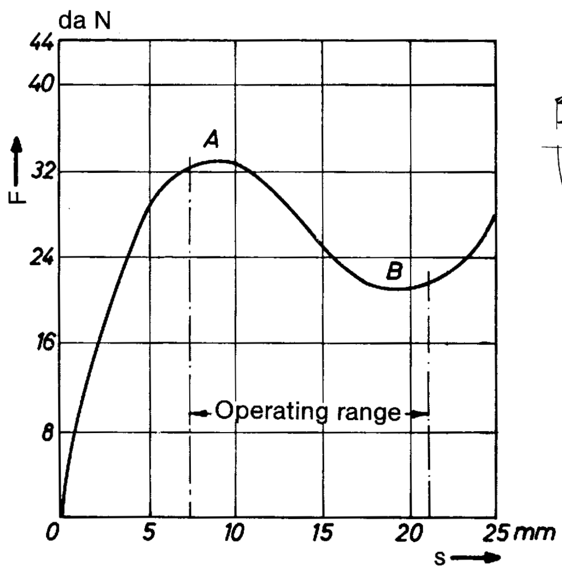
opening width is set, and the opening of the secondary pulley is adjusted automatically. Slotted diaphragm type springs provide the pressure required for the adhesion of V-belts. The large deflection range necessary for the ultimate variator setting is obtained by means of a diaphragm spring having extended fingers and a large conical height.

The load/deflection characteristic as shown in Fig. 18 is designed so that the variator power is constant over the whole speed range.
Again, a straight forward and compact mechanism is obtained with a HAUSSERMANN diaphragm spring. Other applications include the DAF Variomatic, the first V-belt drive for a car. Its high-capacity springs had been developed by HAUSSERMANN in collaboration with DAF, the Dutch car manufacturer.

Summary of the Properties of HAUSSERMANN Special Diaphragm Springs
The noteworthy attributes of these springs include the following:

1. Any useful characteristic of a diaphragm spring can be obtained. Only with this spring type can horizontal and negative characteristics be realized.
2. The deflection can be extended inasmuch as the spring may be deformed beyond the flat condition, and finger shaped levers may be provided for furt-





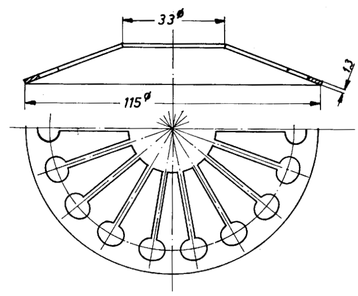


Fig. 18: HAUSSERMANN Diaphragm Spring with partly negative characteristic for use in V-belt transmission for stepless speed control

her extension of the deflection range.

3. Close quality control ensures consistent performance, good endurance, and long life.
4. Short overall lengths allow compact design having adequate bending and torsional resistance.
5. Rotational symmetry eliminates unbalance and vibration hazards.
6. Failures through internal collapse or buckling at elevated speeds as with helical springs are averted.

To save potential clients the effort involved in calculating a spring, we have prepared a Questionnaire that will give us preliminary information that our suggestions can be based on. Our Engineering Department then will be happy to study your problem and offer advice toward a final solution of your project.