TECHNICAL EXPLANATION

PROPORTIONAL SOLENOIDS

For use in hydraulic systems

Contents

1. Foreword

The technical explanation aims to clarify and define the expressions regarding proportional solenoids which are found in the solenoid or valve data sheets. Expressions occurring in the solenoid or valve data sheets which are not contained in this explanation may be found in the explanation for switching solenoids.

2. Type of solenoids

Direct-current proportional solenoids
Single stroke solenoid (compressing, longitudinal movement), whose armature performs a stroke movement, effected by electromagnetic force, from an initial stroke position to an end stroke position.
It differs from the switching solenoid, which, depending on its action, is a two-step displacement / current or force / current action.
To achieve low hysteresis and ideal linearity, the following points are also to be noted:

- Selection of good solenoid materials
  (low electromagnetic hysteresis; see 3.1)
- Ideal armature bearing system
  (low friction hysteresis)

3. Explanation of terms

3.1. Force

Solenoid force (F_M)
The usable proportion, i.e. minus friction, of the force that is generated in the direction of the stroke (movement direction 1); see Fig. 1.

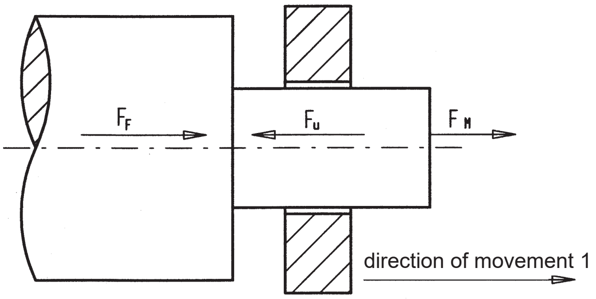
Rated force (F_{MN})
Solenoid force reached at rated current.

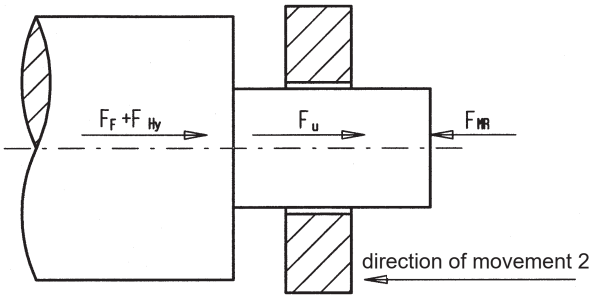
Restoring force (F_{MR})
The external force on the solenoid which must be applied in order to move the solenoid against the direction of stroke (movement direction 2). It is greater than the solenoid force by an amount that is twice that of friction force, plus the hysteresis force (see Fig. 2).

Induced force (F_F)
Mechanical force which is exerted on the armature by the electromagnetic field (see Figs. 1 and 2).

Friction Force (F_u)
The force occurring as a result of friction. It is always in the opposite direction to the direction of movement (see Figs. 1 and 2)

Hysteresis force (F_{Hy})
The force occurring as a result of electromagnetic hysteresis (see Figs. 1 and 2)





$F_M = F_F - F_u$ $F_{MR} = F_F + F_{Hy} + F_u$

Fig. 1Fig. 2

Force hysteresis (H_F) (differential force)
Difference between the solenoid restoring force and the solenoid force (see 3.8 Hysteresis)

$F_{MR} - F_M = 2F_u + F_{Hy} = H_F$

3.2. Electrical voltage

Voltage data refer to the arithmetical mean.

Reference voltage (U_B)
The voltage indicated on the solenoid, which generates the limiting current I_G when the maximum steady-state temperature is reached in the minimum. It must always be available as the supply voltage.

3.3. Resistance

Rated resistance (R_N)
Ohmic resistance of the solenoid coil at 20 C ambient temperature.

Hot-running Resistance (R_W)
Ohmic resistance of the solenoid coil which is set when a limiting current is continuously applied in a steady-state condition at maximum reference temperature.

3.4. Electrical Current

Current data refer to the arithmetical mean.

Rated current (I_N)
The given rated force is reached with the rated current F_{MN}

Limiting current (I_G)
The current with which the solenoid can be continuously loaded at maximum reference temperature without thermal overload occurring.

Linearity current (I_L)
The current at which the force-current curve becomes sufficiently linear.

Actuation current (I_A)
The current required to set the solenoid armature in movement against the effect of its friction forces.

3.5. Electrical power

Nominal wattage (P_N)
The product of rated current and rated resistance. $P_N = I_N^2 \times R_N$

Limiting power (P_G)
The product of limiting current and heat resistance. $P_G = I_G^2 \times R_W$

Linearity power
The product of linearity current and rated resistance. $P_L = I_L^2 \times R_N$

Actuation power
The product of actuation current and rated resistance. $P_A = I_A^2 \times R_N$

3.6. Expressions of time

The rise and fall times of a proportional solenoid which in practice must perform a specific stroke, depend, to a great extent, on its counter-load, which in most cases is not known, and on the controller used. These data can not therefore be included in the solenoid data sheets.

However the rise and fall times of proportional solenoids whose stroke in practice is constant or almost constant, is indicated on solenoid data sheets within the function F=f(t) with the current parameter, I (see 3.7 Functions).

3.7. Functions

Solenoid force - stroke (F=f (s); parameter current I)
The standard solenoid circuit of direct current proportional solenoids is designed so that the solenoid force - stroke curve is as horizontal and linear as possible around the working stroke s_A.

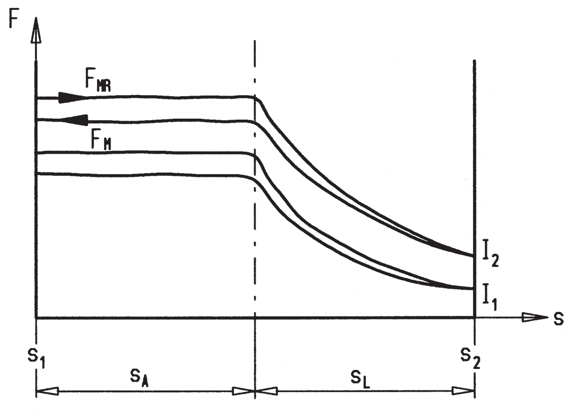


Fig. 3

Solenoid force - current (F=f(I); defined stroke s)
Optimum dimensioning of the solenoid circuit means that the solenoid force - current curve is almost linear. Only at very low currents ($I < I_L$) is no linearity achieved. This measurement is carried out with a fixed stroke (normally in the middle of the working stroke s_A).

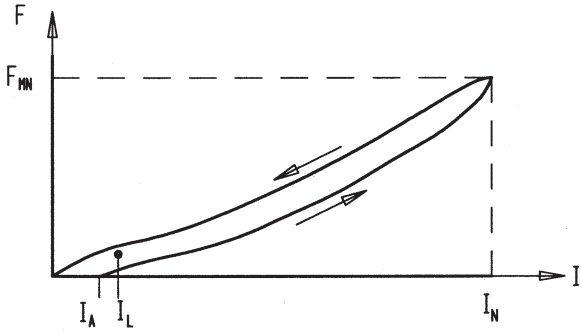


Fig. 4

Solenoid force - time (F=f(t); parameter current I, defined stroke s)
The solenoid force - time curve shows the rise and fall action of proportional solenoids. This measurement is carried out with a fixed stroke s (normally in the middle of the working stroke s_A) and is generated by a voltage jump.

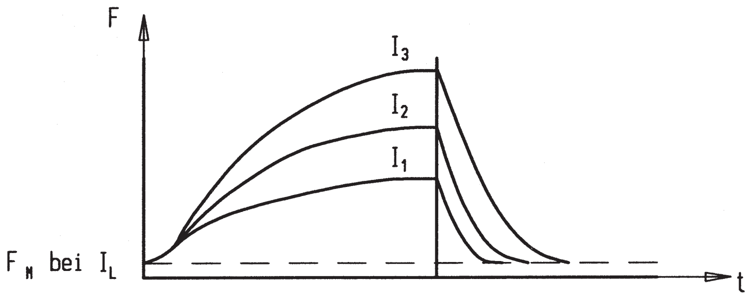


Fig. 5

3.8. Hysteresis

Force hysteresis (H_F)
The difference between the solenoid restoring force F_{MR} and the solenoid force F_R in the solenoid force - stroke curve at constant current (see also 3.1 Force)

Hysteresis of rated force (H_{FN})
The greatest difference between the solenoid restoring force and the solenoid force at rated current. I_N.

Percentage hysteresis of rated force (% H_{FN})
The hysteresis of rated force H_{FN} with respect to rated force F_{MN}.

$$H_{FN}(\%) = \frac{H_{FN}}{F_{MN}} \times 100$$

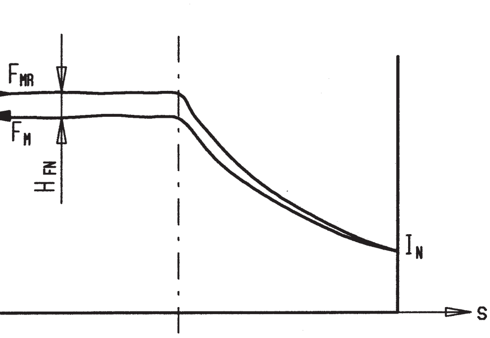


Fig. 6

Notes on force hysteresis
1)A distinction is made between two types of measurement of percentage hysteresis of rated force: static and dynamic measurements. Both are given on the solenoid data sheets; the dynamic measurement also states the measuring stroke speed used.

2)The force hysteresis value depends considerably on the wave from of the exciter current. For the data on the solenoid data sheets a direct current was chosen which was rectified from the alternating current network by means of a bridge rectifier.
The force hysteresis is greater with battery supply.
The force hysteresis can be minimised by superimposing a higher frequency alternating current (dither signal) or a pulse width modulation.

Current hysteresis (H_I)
The current difference between the magnetised and de-magnetised force - current curves.

Hysteresis of rated current (H_{IN})
The greatest current difference between the magnetised and de-magnetised solenoid force - current curves.

Percentage hysteresis of rated current (% H_{IN})
The hysteresis of rated current H_{IN} with respect to the rated current I_N.

$$H_{IN}(\%) = \frac{H_{IN}}{I_N} \times 100$$

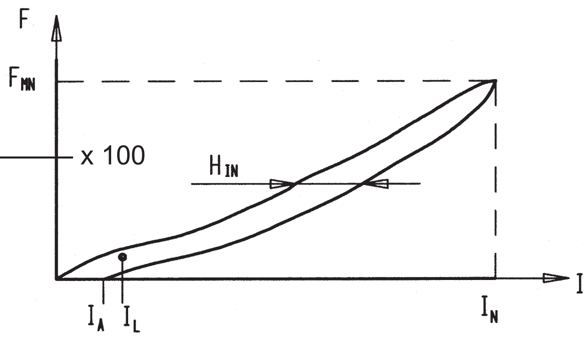


Fig. 7

3.9. Linearity

Deviation of linearity (L)
The current difference between the straight lines joining points 1 and 2 (ideal curve) and the mean curve of the solenoid force - current curve.

Rated deviation of linearity (L_N)
The greatest difference in current between the straight lines joining points 1 and 2 (ideal curve) and the mean curve of the solenoid force - current curve.

Percentage rated deviation of linearity (% L_N)
The rated deviation of linearity L_N with respect to the rated current I_N.

$$L_N(\%) = \frac{L_N}{I_N} \times 100$$

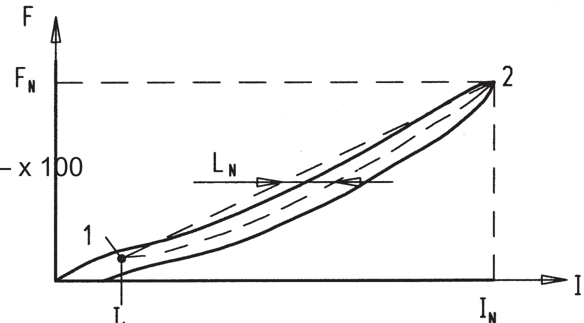


Fig. 8

4. Types of application

A distinction is generally made between three different types of application.

Working against a spring

By its combined action with a spring, the proportional solenoid demonstrates a proportional displacement - current action. It can be used for example in spring-loaded proportional hydraulic directional valves.

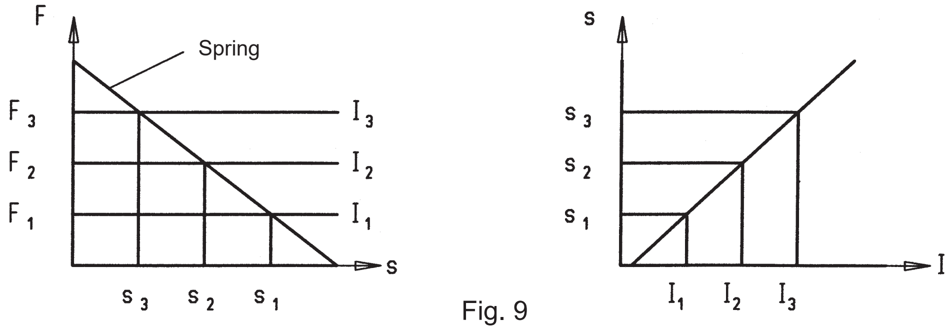


Fig. 9

Working against a fixed stopper

The counter-force curve is based on the operation of the proportional solenoid against a rigid stopper. The proportional solenoid demonstrates by its interaction, a proportional force - current behaviour. It can be used for example in hydraulic proportional pressure valves.

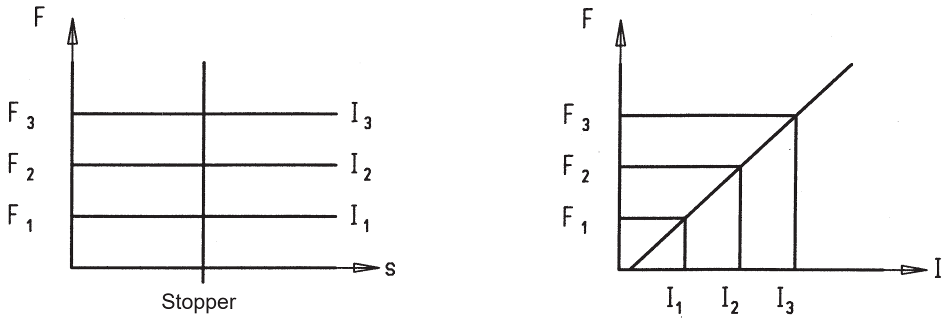


Fig. 10

Working against a constant counter - force

The proportional solenoid produces a special solenoid force - stroke curve (dropping rapidly towards the end stroke position); the solenoid demonstrates by its interaction with the constant counterforce, a proportional displacement - current behaviour. It can be used for example for displacing a weight.

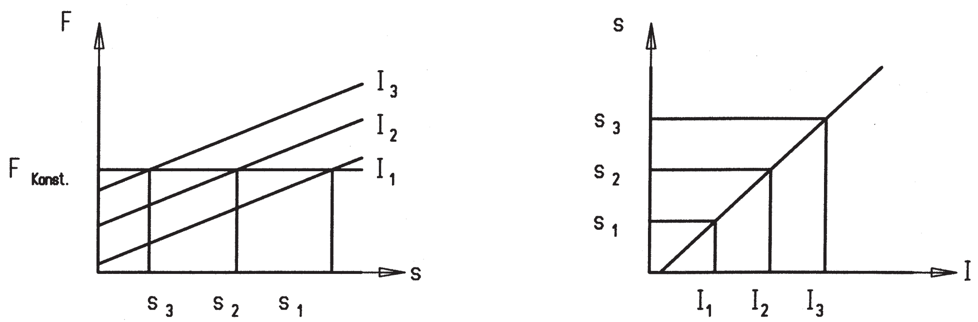


Fig. 11