Technical Introduction - Solenoids

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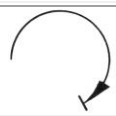
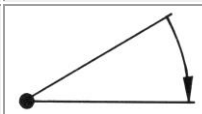
1. Indroduction

Since 1975 we have been successfully developing and producing electromagnets.
Over the course of time, proportional solenoids, linear solenoids, holding solenoids and clutches of all designs types and for special applications have been developed.

Over the course of time, a variety of proportional solenoids, linear solenoids, holding solenoids and clutches, valves and sensors of all design types and for special applications have been developed. The Schramme company has extraordinary competency in the area of proportional solenoids for hydraulic and pneumatic valves. We are the market-leader in this segment.

For decades, we have proven to be a reliable partner for automotive suppliers as well as for many other sectors in the industry and in medical engineering. And, of course, the Schramme Company is certified to ISO/TS 16949:2009 and DIN EN ISO 9001:2008.

Major types	**Operating characteristics**	**Operating symbols**
Linear solenoid	Linear working movement with adjustable stroke	
Rotary solenoid	Rotary working motion with adjustable stroke	
Pivoting rotary solenoid	Rotary working motion of a lever pivoted at one end, with adjustable angle of rotation	
Securing electromagnet	Attracts and secure ferromagnetic parts	
Special electromagnets	As need by the customer	

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3. Operation

Electromagnets transform electrical energy into mechanical work.
The highly simplified diagram below (Fig. 1) shows the major elements.

4. Direct-Current Solenoids (DC electromagnets)

Contrary to an alternating-current (AC) solenoid, the power consumption of a direct-current (DC solenoid ist independent of the position of the armature; DC solenoids are also characterized by softer- and harder-operation.

The inherently longer cycling times can be reduced by special circuitry measures. lt is also possible to modify the stroke-force characteristic. High switching frequencies do not cause dangerously high thermal loads in DC solenoids; maximal switching frequency is limited only by the pull- in and drop-out times.

5. Alternating-Current Solenoids (AC electromagnets)

Unlike DC solenoids, AC solenoids provide relatively high operating/cycling frequencies and low cycling times; this results in hardoperation which influences service life. Power consumption depends on the position of the armature.

High cycling frequencies can cause dangerously high thermal loading in AC solenoids, and the maximum permissible temperature is therefore the limiting factor for cycling frequency.

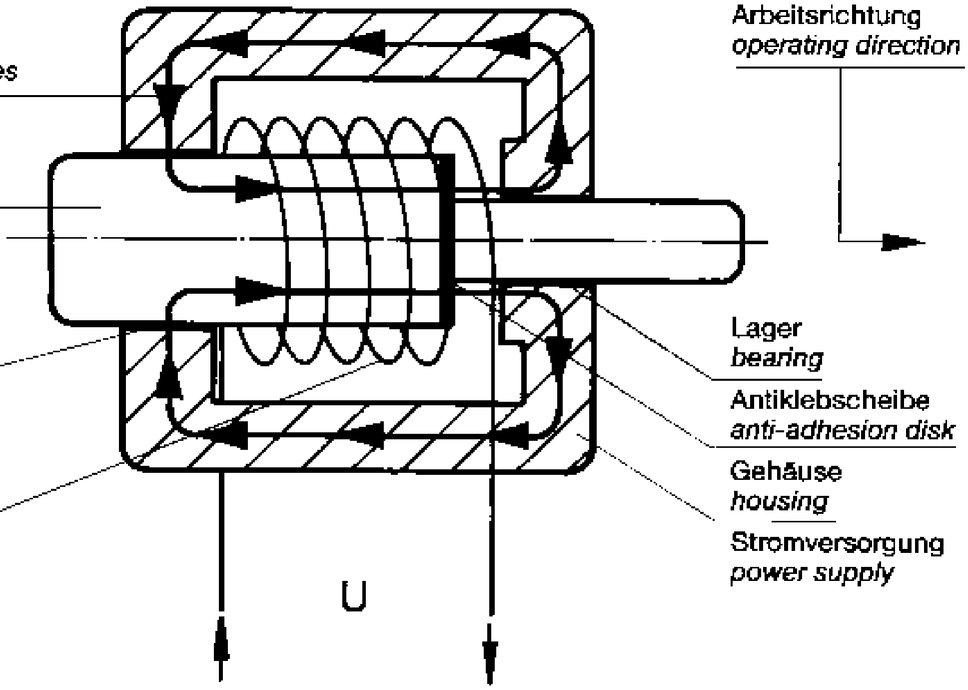

Abb. 1
Fig. 1

6. Force

Usually, the correct electromagnet for a given application is the smallest one which has adequate magnetic force.

6.1. Magnetic force

The magnetic force "FM", in Newtons, is the usable portion - i.e., that portion which is reduced by frictions - of the mechanical force which is produced in the electromagnet. It is measured at 90% of the rated voltage at operating temperature (9.2.).

6.2. Holding force

The holding force of an electromagnet is the force which is effective at the end of the stroke.

6.3. Residual force

The residual force, generated by remanent (residual) magnetism, is the holding force remaining after the electrical power has been interrupted. This force can be influenced by design features.

6.4. Return force

The return force is the force required to return the armature from the end of stroke to the start of stroke.

6.5. Magnetic force / stroke characteristic

There are three distance characteristic curves which indicated the armature movement toward the final (energized) position. (Fig.2).

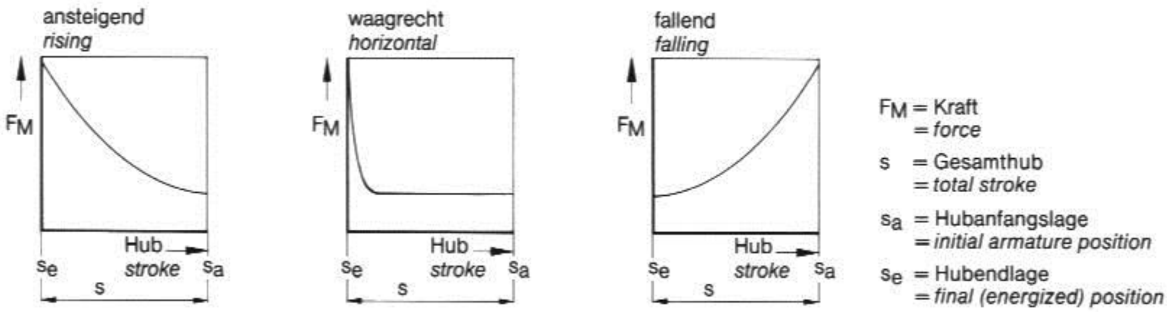

Abb. 2
Fig. 2

7. Stroke / Angle of Rotation

The stroke (angle of rotation with rotary solenoids) is the usable distance (angle) traveled by the armature from its initial position to the end of travel. If desired by customer - in most cases - distances/angles may differ from those listed in our descriptive material. As the stroke/angle is increased, the stroke/angle force is reduced, and vice versa.

7.1. Start of Stroke (sa)

This is the position of the armature before it starts its travel; it is also the position when it returns upon conclusion of the complete cycle.

7.2. End of Stroke (se)

This is the designed final position of the armature upon conclusion of the work portion of the complete cycle.

7.3. Stroke Work A

For the linear solenoid, the stroke work (in Newtons) is the self of the magnetic force (FM) over the magnetic stroke (s); for the rotary solenoid, the stroke work is the self of the magnetic (M) over the angle of rotation.
A solenoid has the correct size if the magnetic force (FM) exceeds the opposing force (F1) at all times, with only a slight amount of excess force to assure long service life (Fig.3).
A solenoid is too small if the magnetic force (FM) is less than the opposing force (F1) over a certain range (Fig.4).

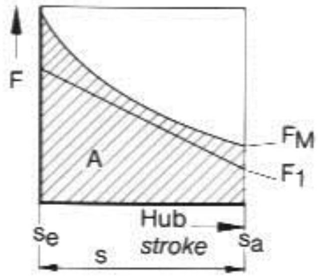

Abb. 3
Fig. 3

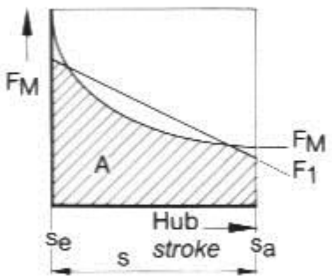

Abb. 4
Fig. 4

F_M = Kraft
= *Force*

s_a = Hubanfangslage
= *Initial stroke position*

s_e = Hubendlage
= *Final stroke position*

s = Gesamthub
Total stroke

8. Time terms

The use of electromagnets necessitates a certain chronological sequence best clarified with the following terms:

8.1. The power-off pause

The power-off pause (in sec.) is the time between switching off the exciter current and switching it on again.

8.2. ON period

This is the period (in sec.) between switching the exciter current on and off again

8.3. Cycle period

This is the sum of the ON period and the power-off pause.

8.4. Duty cycle in %

The ratio between the ON and the cycle period is the relative ON period (in %) The VDE provides for duty cycles of 5, 15, 25, 40 and 100 %.

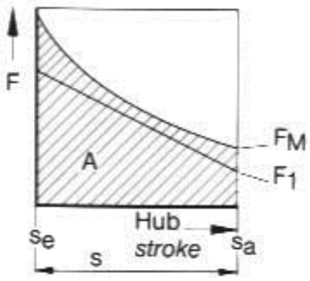

Abb. 3
Fig. 3

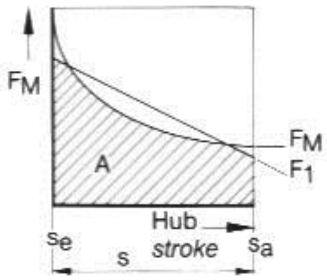

Abb. 4
Fig. 4

F_M = Kraft
= *Force*

s_a = Hubanfangslage
= *Initial stroke position*

s_e = Hubendlage
= *Final stroke position*

s = Gesamthub
Total stroke

8.5. Cycle-time diagram

The following diagram shows a typical operating cycle with the current rise, voltage cutoff and stroke as a function of time for a DC-operated solenoid (Fig.5).

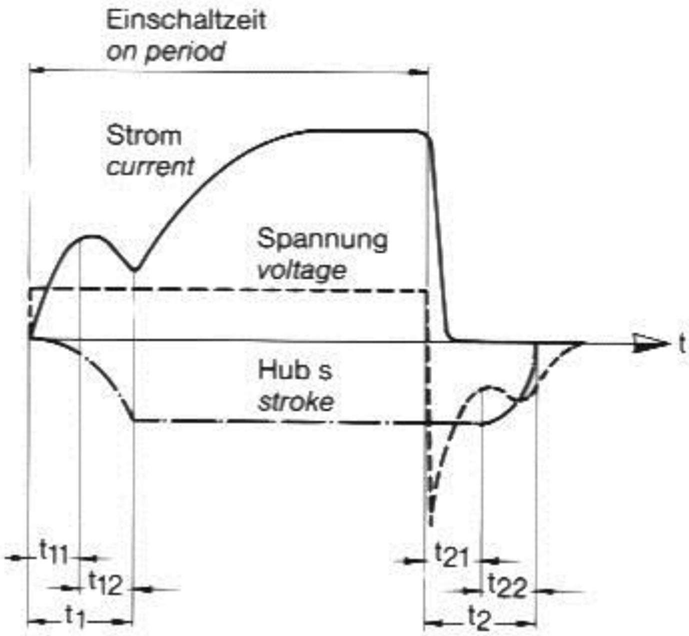

Abb. 5
Fig. 5

8.6. Cycling sequence

The cycling sequence (in sec.) is the single or periodically repeated joining of cycle period values of very different durations.

8.7. Reponse delay t11

The response delay (in sec.) is the time between application of the exciter current and initial movement of the armature.

8.8. Stroke time t12

This time (in sec.) starts when the armature begins to move from its initial position and ends when it reaches its limit of travel.

8.9. Pull-in time t1 = (t11 + t12)

Die Anzugszeit (in sec.) ist die Summe aus Ansprechverzug t11 und Hubzeit t12 Durch besondere Beschaltungsmaßnahmen kann die Anzugszeit verkürzt werden. Hierzu gehört die Schnellerregung.

8.10. Drop-out delay t21

Drop-out delay (in sec.) is the time from exciter current cutout until the armature starts to return to its initial position.

8.11. Rücklaufzeit t22

The return time (in sec.) is the time from the begin of armature return motion until it has reached its initial position.

8.12. Drop-out time t2 = (t21 = t22)

The sum of drop-out delay (t21) and return time (t22) is the drop-out time (in sec.).

9. Temperature terms and classes of insulating material

When selecting a suitable solenoid, the on-site temperatures must be considered.

9.1. Ambient temperature

The ambient temperature is the temperature (°C) surrounding the electromagnet when it is operating; the range restricted to +40 to -50 °C. Please consult us if values outside this range might be encountered

9.2. Permanent operating temperature

The permanent operating temperature (in °C) is equilibrium reached between the heat generated by the solenoid and that led away from it; equilibrium is considered to have been reached when the temperature has changed by no more than 1 °C during an operation period of 60 minutes. It is determined on a thermally nonconductive support in still air at the rated voltage.

9.3. Reference temperature

This temperature (in °C) is the constant temperature of the solenoid where there no at the operating site. This temperature may differ from the ambient temperature if, for example, the solenoid is mounted on a hydraulic valve which has warm hydraulic oil flowing through it.

9.4. Differential temperature

This is the number of degrees (°C) between the temperature of the solenoid (or a part thereof) and that of the cooling medium designated for the solenoid.

9.5. Limiting temperatures

The upper limiting temperature (in °C) is the highest temperature permitted for the solenoid or any part thereof.
The lower limiting temperature (in °C) is the lowest temperature permitted for the solenoid or any part thereof.

9.6. Max. temperature above normal

This is the maximum permissible number of degrees (°C) of differential temperature.

9.7. Thermal insulation classes

Thermal insulating materials are divided into the following classes based on their thermal resistance.

Thermal insulation classes	Limit temperature °C	Max. temperature
Y	90	50
A	105	65
E	120	80
B	130	90
F	155	115
H	180	140
C	> 180	> 140

10. Electrical terms

If solenoids are to operate reliably, they must be provided with suitable power; the following are a few terms to aid in understanding:

10.1 Nominal voltage

The nominal voltage is that with which a solenoid is normally operated;
the tolerance is +5 % to –10 %.

10.2. Nominal current

The nominal current given in the data sheets is always referenced to the rated voltage and a winding temperature of 20 °C.

10.3. Nominal power

The nominal power (in W) is calculated from the rated voltage and current
(at a winding temp. of 20 °C) given in the data sheets.

10.4. Test voltage

All solenoids are tested for electrical insulation and dielectric strength at a certain test voltage which lies considerably above the rated voltage. The test voltage is applied between the exciter winding and the metal parts of the unit which can be touched. The following table indicates the test voltage required for a given voltage rating. Voltage tests may be repeated with a maximum of only 80% of the test voltage (VDE regulation).

1		2	3	4	5	6	7	8	9	10
Series voltage	DCV	30	60	110	250	440	600	800	1200	1500
	AC	30	60	125	250	380	500	-	1000	-
Test voltage U_P	V	600	1000	1500	2000	2500	2500	3000	3500	5000

11. Protection classes

In an electromagnetic device in Class I, voltage-carrying parts have only an operating insulation and a connection for the neutral line.

An electromagnetic device in Class II has operating and protective insulation but no connection for the neutral line.

An electromagnetic device in Class III is designed for operation at less than 42 Volts and has no circuit designed for any higher voltage.

11.1. Types of protection

The following types of protection are standardized in DIN 400501.They concern protection against touching, foreign and humidity.

Using IP 65 as an example,
"IP"= code for the standardized type of protection;
the 1st digit following concerns touching and entry of foreign bodies; the 2nd digit concerns protection against penetration of water.
Refer to the following table:

1st digit	Protection against touching and foreign bodies
0	No protection
1	Protected against large foreign bodies
2	Protected against small foreign bodies
3	Protected against grain-sized foreign bodies
4	Protected against dust deposits

5	Protected against dust deposits
6	Protected against dust entry
2. Kennziffer	Protection against water
0	No protection
1	Protected against vertically falling water
2	Protected against water falling at an angle
3	Protected against sprayed water
4	Protected against splashing
5	Protected against water jets
6	Protected in case of flooding
7	Protected in case of immersion
8	Protected in case of submersion

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12. Sample circuits

Suitable circuity will influence the operating times and service life of the electromagnet.

In a circuit on the alternating-current side (Fig. 6), the overvoltage at cutoff is fully damped, however this severely delays the drop-out time.

In a circuit on the direct-current side (Fig. 7), the overvoltage at cutoff is not damped. This circuit is usually employed with magnetic units of low electrical power in order to shorten the drop-out time. Please use this circuit only after consulting us.

Contact wear of electromagnets on the direct-current side can be reduced by including a Varistor in parallel with the switch (Fig. 8).

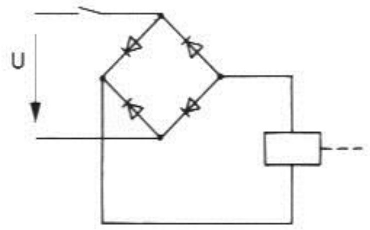

Abb. 6
Fig. 6

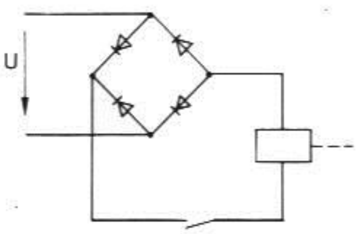

Abb. 7
Fig. 7

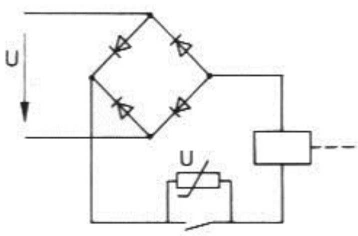

Abb. 8
Fig. 8

13. Damping

Damping by Ohmic resistance

A parallel resistor can be used to limit the voltage surge which occurs when the power to the solenoid is cut off; as a result however, the drop-out time increases, as does the power requirement. Both are reduced as the parallel resistance is reduced (Fig. 9).

Damping by Varistor (voltage-dependent resistor)

A Varistor may be used to damp the voltage surge at cutoff; this causes only a slight rise in power requirement (Fig. 10).

Damping by diode

Diodes will completely damp the cutoff surge voltage, however the drop-out time will be greater (Fig. 11).

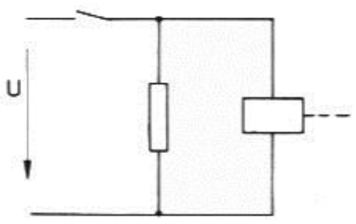

Abb. 9
Fig. 9

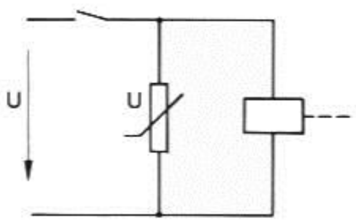

Abb. 10
Fig. 10

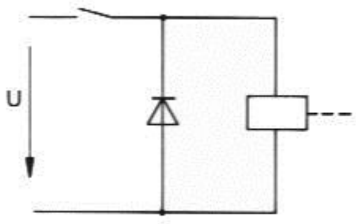

Abb. 11
Fig. 11

14. Economy circuit

(e.g. with an Ohmic resistor)

Employment of an economy circuit makes it possible to use a smaller solenoid. To prevent the winding from overheating, the current is limited by a resistor after the armature reaches the end of the stroke. This circuit can not be used with high operating frequencies. The size of the dropping resistor depends on the resistance of the exciter winding (Fig. 12).

15. Rapid excitation

With DC-operated solenoids, the pull-in time (8.9.) can be influenced by various means in the circuit.

This time depends primarily on the electrical constants of the exciter winding; a resistor can be used in series to shorten the pull-in time.

The size of the dropping resistor (Rv) depends on the resistance of the exciter winding (Rcu) at operating temperature (Fig. 13).

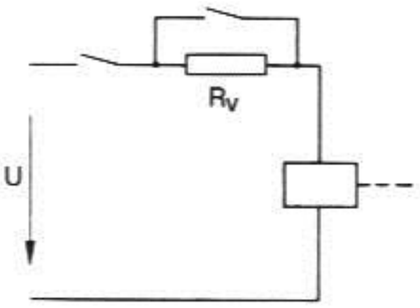

Abb. 12
Fig. 12

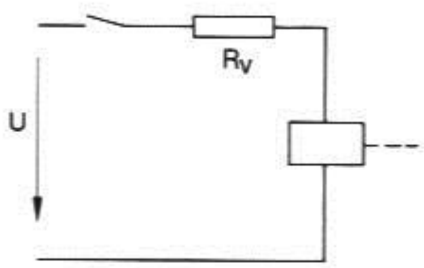

Abb. 13
Fig. 13

16. Installation Guidelines

DC electromagnets may be installed in any position. Ensure that forces are taken of only in the axial direction.

In order to achieve maximum service life, electromagnets should be loaded with at least 70% of the magnetic force.

lt is imperative that voltage, ON period, temperature and protection be checked before an electromagnetic device is operated.

If a neutral lead is required, it is to be provided by the customer in compliance with VDE 0100.

17. Ordering Information

Feel free to contact us by telephone, E-mail or fax.

Our team will help you – guaranteed.

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