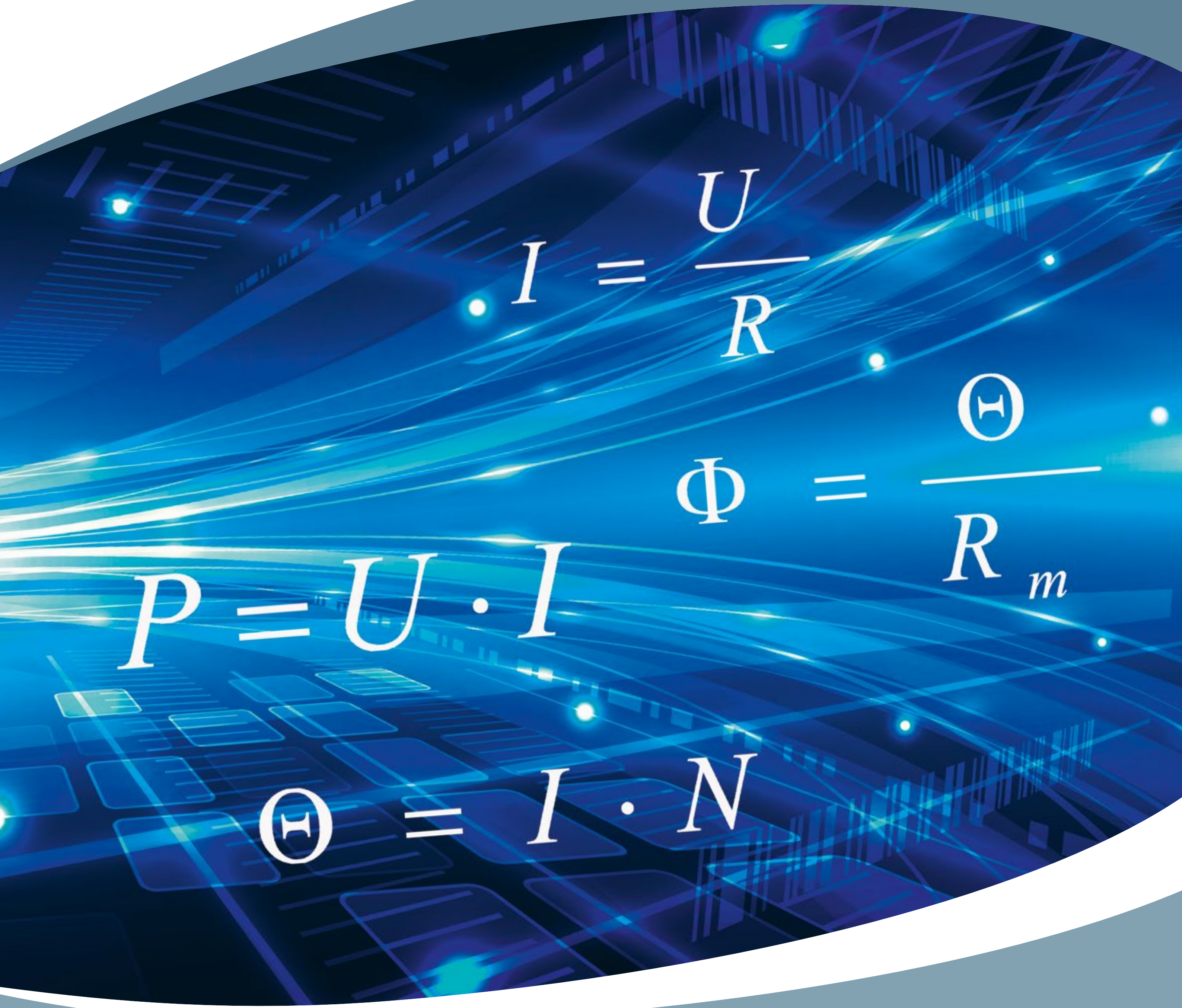
KENDRION

WE MAGNETISE THE WORLD



Technical definitions

INDUSTRIAL MAGNETIC SYSTEMS

BINDER

We develop solutions!

Kendrion develops, manufactures and markets highquality electromagnetic and mechatronic systems and components for industrial and automotive applications. For over a century we have been engineering precision parts for the world's leading innovators in passenger cars, commercial vehicles and industrial applications.

As a leading technology pioneer, Kendrion invents, designs and manufactures complex components and customised systems as well as local solutions on demand. Committed to the engineering challenges of tomorrow, taking responsibility for how we source, manufacture and conduct business is embedded into our culture of innovation. Rooted in Germany and headquartered in the Netherlands, our expertise extends across Europe to the Americas and Asia. Created with passion and engineered with precision.

In the business unit **Industrial Magnetic Systems (IMS)** the focus lies on electromagnetic actuators and mechatronic assemblies for applications in power engineering, safety engineering, machine building, automation technology and other industries. With the experience of our traditional brands Binder, Neue Hahn Magnet and Thoma Magnettechnik we are successful in our markets as an industry expert with a high technological competence.

We offer you both customer-specific and standardised products. Our assemblies are based on powerful and reliable single-stroke, holding, locking, spreader, control, rotary, vibratory solenoids and solenoid valves.
We always think in terms of solutions.

Our strength lies in new developments for our customers. Our engineers are specialists for innovative products with optimum technical properties. Furthermore, we develop mechanical assemblies, modern drive electronics and sensor systems to your requirements.

Our products are manufactured in Germany at the parent companies Donaueschingen and Engelswies as well as in the USA, China and Romania. This ensures efficient project management and a needs-oriented delivery for our internationally operating customers.

By means of segmented production areas we can implement both small quantities and large series with an optimum degree of automation.

We guarantee top quality.
All products are tested and developed in compliance with the norm DIN VDE 0580 for electromagnetic devices and components or according to industry-specific standards of our customers. In many cases our products are tested and certified by external associations. among others according to the CSA. VdS and ATEX guidelines. Our quality management system is certified according to DIN EN ISO 9001. and our environmental management system fulfils the norm ISO 14001.

With our subsidiaries in Austria, Italy, the USA, China and our worldwide distribution network we are your ideal partner on site.

Kendrion – We magnetise the world

www.kendrion.com

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1. General technical explanations and term definitions

1.1. What components comprise an electromagnet?

Solenoid body
Part that contains the excitation winding and conducts the magnetic flax (also: solenoid housing).

Excitation winding
Winding to create the magnetic field (also: magnetic coil, coil, winding).

Excitation system
Module consisting of magnet body and excitation winding.

Voltage winding
Excitation winding that receives current, which depends on the supply voltage and the excitation resistance.

Current winding
Excitation winding that determines the current of upstream equipment, i.e. which mainly depends on the excitation winding resistance (e.g. current regulation).

Armature
Magnetically conducting parts moved or held by the magnetic field.

1.2. What different types of solenoids are there?

Actuating solenoid
Component for affecting a limited lengthwise or rotating movement.

Linear solenoid
Actuating solenoid that triggers a stroke movement via the effect of a magnetic field created by the excitation winding (also: single stroke solenoid).

Rotating solenoid
Actuating solenoid that triggers a rotating movement via the effect of a magnetic field created by the excitation winding. With regard to their functionality, rotating solenoids may be designed as single stroke or reverse stroke rotating solenoids featuring single or double currentless limit positions (monostable-bistable).

Oscillating solenoid
Actuating solenoid that triggers a periodic back and forth movement via the effect of a magnetic field created by the excitation winding in a spring-mass system featuring an oscillating frequency, which is generally related to a fixed proportion of the frequency to the applied voltage.

Holding magnets, holding solenoid
Device or component for adhering ferromagnetic objects.

Reversing linear solenoid
An actuating solenoid with electromagnetic force effect in two movement directions. Depending on the excitation, the stroke movement takes place from the respective stroke start position to the associated stroke limit position. In this case, the stroke limit position of one direction is simultaneously the stroke start position of the opposite movement direction.

Single stroke spreader solenoid
A linear solenoid that is mainly used for ventilating block brakes due to its design and technical data.

Single stroke double spreader solenoid
A linear solenoid consisting of two single stroke spreader solenoids that is mainly used for ventilating block brakes due to its design and technical data.

Pulling and pushing design (Figure 1) Kendrion actuating solenoids may be divided into three variations with regard to the created movement:
pulling, pushing, and pushing and pulling. This refers to both linear stroke solenoids and rotating solenoids.

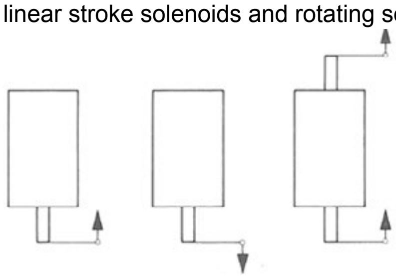


Figure 1 from left to right: Pushing, pulling, pushing and pulling designs of single stroke linear solenoids

Pulsing linear solenoid
A device featuring an armature stroke movement caused by electromagnetic forces from the stroke start position to the stroke limit position, whereby the armature is held by an integrated permanent solenoid while the current is switched off.

Control solenoid, proportional solenoid, regulating solenoid
Linear stroke solenoids that are mainly used to activate valves in hydraulic controls and regulating devices due to their design and technical data.

Valve solenoid
A linear solenoid that is mainly used for activating valves in pneumatic and hydraulic control devices due to its design and technical data.

Single stroke solenoid with pivoting armature
A linear solenoid featuring an armature that completes a pivoting movement around a pivot point.

1.3. What quantities define the characteristic curve of the electromagnet?

Magnetic force F
The useful part of the force produced in the stroke direction inside the actuating magnet, i.e. the force reduced by friction.

Stroke force F_{stroke}
The magnetic force that acts outwards in consideration of the associated component of the armature weight. The stroke force is equal to the magnetic force in case of horizontal installation.

Holding force F_H
In case of direct current actuating solenoids, this is the magnetic force in the stroke limit position. In case of alternating current solenoids, the average value of the magnetic force periodically fluctuating with the alternating current in the stroke limit position.

Residual holding force
The holding force remaining after deactivation.

Residual actuating force
The force required to return the armature to the stroke start position after deactivation. (in case of rotating solenoids, the force corresponds with the torque)

Solenoid stroke s
The path covered by the armature from the stroke start position and stroke limit position.

Stroke start position s_1
The position of the armature before starting the stroke movement or after completing the return movement.

Stroke limit position s_2
The designed position of the armature in the solenoid after completing the stroke movement.

1.4. How does a stroke-force characteristic curve of an electromagnet look?

Magnetic force stroke characteristic curve
The graphic display of the magnetic force depending on the solenoid stroke. There are three different characteristic curves in the direction of the stroke limit position (Figure 2).

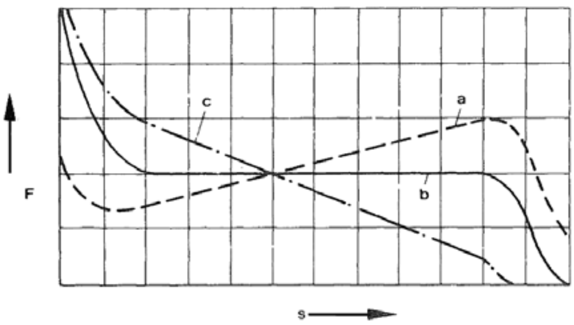


Figure 2 magnetic force stroke characteristic curves.
a dropping characteristic curve
b horizontal characteristic curve
c climbing characteristic curve
s solenoid stroke
F magnetic force

1.5. How is stroke work calculated?

Stroke work W
The integral of the magnetic force F above solenoid stroke s.

$$W = \int_{s_2}^{s_1} F ds$$

The stroke work comprises a potential stroke work component W_1 and a kinetic stroke work component W_2 (Figure 3).

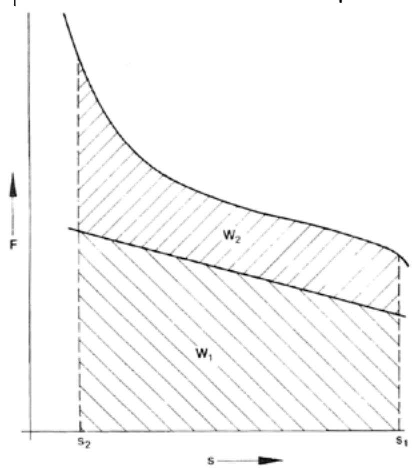


Figure 3 Stroke work with proportionally changed counter-force

F	magnetic force	s	solenoid stroke
s_1	stroke start position	s_2	stroke limit position
W_1	static stroke work component	F_{F1}	spring force
W_2	kinetic stroke work component	F_{F2}	spring force

1.6. What time definitions are relevant for operation of electromagnets?

Activation delay t_{11}
The time from activation of the excitation current until starting the armature movement.

Stroke time t_{12}
The time from the start of the armature movement from the stroke start position until reaching the stroke limit position.

Attraction time t_1
The time from activation of the excitation current until reaching the stroke limit position. The sum of the activation delay t_{11} and stroke time t_{12}.

Release delay t_{21}
The time from deactivation of the excitation current until starting the return movement of the armature.

Return time t_{22}
The time from the start of the return movement from the armature until reaching the stroke start position.

Release time t_2
The time from deactivation of the excitation current until reaching the stroke start position. The sum of the release delay t_{21} and return time t_{22}.

1.7. What electrical terms are relevant for the operation of electromagnets?

Activation current
In case of alternating current devices, this is the current that activates during excitation when the armature is held in the stroke start position and the compensation process is finished.

Nominal voltage U_N
The value of the electrical voltage that is indicated by the manufacturer for a device or a component and refers to the operating and performance aspects.

Preferred nominal voltage
The nominal voltage that devices are usually available with ex warehouse.

Nominal current I_N
In case of electrical devices, the supply current assigned by the manufacturer to the device or the component to designate or identify it. Generally, the current consumption of voltage windings under nominal conditions, as well.
In case of alternating voltage windings, the current that activates as the holding current under nominal current, when the armature in the stroke limit position.

Holding current I_H
In case of alternating voltage devices or components, this is the current that activates upon excitation of the nominal voltage, when the armature is in the stroke limit position and the compensation process has completed.

Activation current I_E
In case of alternating current devices and components, this is the current that activates during excitation with nominal voltage when the armature is held in the stroke start position and the compensation process is finished.

Nominal power P_N
Suitable rounded power value to designate and identify the device or the component. Also generally the power consumption under nominal conditions (20°C coil temperature).

Holding power
The product of the nominal voltage and holding power in case of alternating voltage device or components.

Insulating material class
The assignment of winding insulating materials to thermal classes with regard to their limit temperature according to DIN EN 60085.

Heat class	Limit temperature °C	Limit over temperature °C
Y	90	50
A	105	65
E	120	80
B	130	90
F	155	115
H	180	140

Table 1

Protection class
Classification of devices with regard to protection measures against electrical shock according to DIN EN 61140.

IP protection class
Scope of protection of the electromagnetic device against direct contact or penetration of solid objects or water.
Specification as an IP code according to DIN EN 60529.

1.8. What are the applicable standards for electromagnets

If nothing in particular has been agreed to, actuation magnets are generally tested and built according to DIN VDE 0580. The protection classes of the devices and the electrical connections correspond with DIN EN 60529. Requirements deviating from this or may be special and project-specific to the devices (corrosion protection, operating type, environmental conditions, etc.) must be agreed to separately.

Normal operating conditions
(DIN VDE 0580:2011-11, section 4.2. and 4.3.)
The environmental temperature does not exceed 40°C, and its average value does not exceed 35°C for a duration of 24 hours. The lower limit of the ambient temperature is -5°C. The altitude of the location of use does not exceed 1000 m above sea level. The relative humidity of the ambient air should not exceed 50% at 40°C. In case of lower temperatures, higher humidity levels may be permitted, e.g. 90% at 20°C. A moderate amount of condensate may form. The ambient air should not be significantly fouled by dust, smoke, aggressive gases, and vapours.

1.9. How are electromagnets supplied with power?

Electrical connection

The devices may only be connected to the specified power supply (direct or alternating current) featuring the voltage indicated on the type plate. There are different connection options, e.g. free wire ends, clamping terminals, or plug connections. In case of devices in protection class I, which do not provide a protectove conducor upon delivery, the protective conductor upon delivery, the protective conductor must be ensured by the user as per VDE 0100 on metal parts connected with the solenoid that conduct, as well. The preferred nominal voltage is provided in the individual catalogues.

Rectifier

Actuating solenoidsfor direct current must be connected to suitable direct voltage sources for safe operation. In particular, nominal voltage and nominal power of direct voltage sources must correspond with the required values. If half-wave rectifiers are used, humming noises can occur due to the current ripple resulting from high holding force requirements. In case of doubt, bridge rectifiers should be used. If switching power supplies are used, then they must be suitable for operation with inductive loads. Kendrion offers rectifiers with half-wave and/or bridge rectification (please check these conditions).

Activation of solenoids

The current supply for solenoids can be activated on the direct current side or the alternating current side. In case of alternating current-side activation of actuator solenoids (Figure 4), the long deactivation delay time t21 must be observed during deactivation. In case of direct current-side activation (Figure 5), only a low shut-off delay occurs, but short-term over-voltage certainly results. The level in this situation depends on the device’s nominal voltage, the electrical current supply and the opening speed of the switching device.
This may equal max. 0.6 kV for 24 V, or approx. 2 kV for 110 V, or approx. 4 kV for 230 V.
The user must ensure that the deactivation voltage peaks cannot cause any damage to the switching device (arc) or the solenoids.

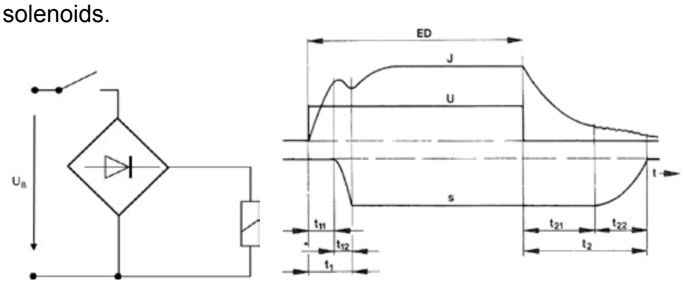


Figure 4 Alternating current-side activation

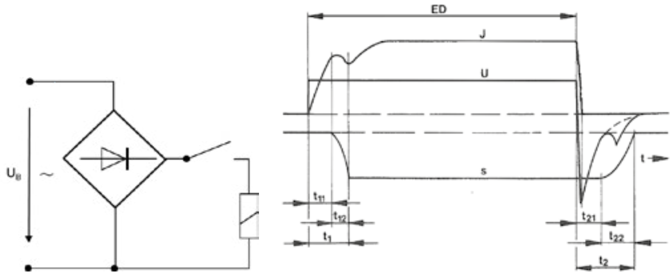


Figure 5 Direct current-side activation

ED	Activation duration	I	Current
U	Voltage	s	Solenoid stroke
t_1	Attraction time	t_{11}	Activation delay
t_{12}	Stroke time	t_2	Delay time
t_{21}	Release delay	t_{22}	Return time

Protection measures against deactivation voltage peaks

By limiting the deactivation over-voltage resulting during direct current-side deactivation to a level that is not hazardous for an actuating solenoid, safe and problem-free switching behaviour is ensured for the rectifier/switch. Ohmic resistors, varistors, diodes, Z diodes, etc. may be considered protective devices. See Figure 6, Figures a to d.

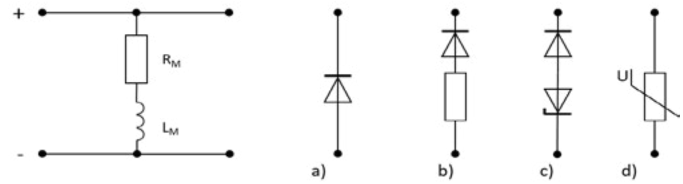


Figure 6 Suppressor circuit for electromagnets

a	Free-wheeling diode	b	Diode with resistance
c	Diode with Z diode	d	Varistor

L_M Inductance of the electromagnets
R_M Ohmic resistance of the electromagnet

The free-wheeling diode (Figure 6 a) completely prevents the development of deactivation voltage peaks. The decay time of the current t_0 (until the current in the coil has dropped to 5% of the value prior to deactivation) is calculated

$$t_0 \approx 3\tau_M \text{ ,with } \tau_M = \frac{L_M}{R_M} \text{ , the shut-off voltage peak is } U_{smax} \approx 0$$

This suppressor circuit is especially effective as interference suppression, but it significantly increases the deactivation time t2 of the magnet. The deactivation process approximately corresponds with the alternating current-side activation.
The **diode with resistance** (Figure 6 b) effectively limits the deactivation voltage peak, depending on the side of the resistance. This means: The larger the resistance is, the higher the remaining deactivation voltage and the faster the drop in power will be.

$$t_0 \approx \frac{\tau_M}{\left(1 + {}^{R}/_{R_M}\right)} \text{, with } \tau_M = \frac{L_M}{R_M} \text{ , } U_{smax} = -\frac{U_n R}{R_M}$$

The suppression effect is good and easily adjustable, so this variation is frequently applied.

If a **diode with a Z diode is used** (Figure 6 c), this limits the deactivation voltage $U_{smax} = -U_z$.
This also means: the higher the permitted deactivation voltage, the shorter the deactivation time will be. This type of switching is often used for small solenoids.
In case of activation with a **varistor** (Figure 6 d), a very good suppression effect is produced, and the voltage peak depends on the nominal value and the characteristic of the varistor

1.10. Why must the maximum activation duration of an electromagnet be observed?

Activation duration
The time that passes between activation and deactivation of the excitation current.

Currentless pause
The time that passes between deactivation and reactivation of the excitation current.

Cycle time
The sum of activation duration and the currentless pause.

Cycle sequence
A one-time or periodically recurring sequencing of cycle time values of different sizes.

Continuous operation
Operation during which the activation duration is so long that the steady-state temperature is reached.

Short-term operation S_2
Operation during which the activation duration is so short that the steady-state temperature is not reached and the currentless pause is so long that the device cools down to the ambient temperature (tolerance 2K).

Intermittent operation S_3
Operation during which the activation duration and the currentless pause alternate regularly, whereby the pauses are so short that the device does not cool down to the ambient temperature.

Relative activation duration

$$\textbf{rel. activation duration} = \frac{\textbf{activation duration}}{\textbf{duty cycle}} \cdot \textbf{100} \quad \textbf{in\%}$$

The catalogue specifications for the relative activation duration of Kendrion solenoids refer to a cycle time of 5 minutes, if not otherwise indicated. The maximum activation duration results from this for the various relative activation duration:

40%	Activation duration	max. 120 s
25%	Activation duration	max. 75 s
15%	Activation duration	max. 45 s
5%	Activation duration	max. 15 s

These maximum values may not be exceeded.
In case of doubt, application take places for the respective longer relative activation duration.

Switching operations z
Number of working cycles.

Switching frequency Z
The number of switching operations per hour.

Operating temperature condition
The over-temperature determined according to VDE 0580 increased by the ambient temperature. If nothing else is indicated the ambient temperature amounts to 35°C.

Deviating reference temperature
Our solenoids can also be used under deviating reference temperatures if the permitted activation duration is multiplied by the corresponding calculation factor. The stroke work completed by the winding at operating temperature is not influenced by this. The diagram (Figure 7) is used to determine the relevant activation duration in case of deviating reference temperatures.

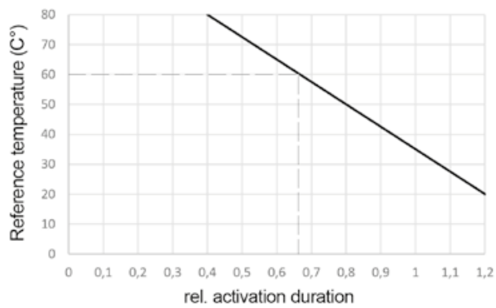


Figure 7 Relative activation in case of deviating reference temperatures

Heating
As a result of the input power of the excitation winding, heat is produced in the electromagnets. This can go up to the limit of the underlying insulating materials class, e.g. 120°C in case of class E, if the heat dissipation on the machine/system is disregarded. Force specifications in the Kendrion catalogues always refer to the operating temperature condition.
In normal cases, a part of the heat can be dissipated via the mechanical fastener to the machine/system, which leads to reduced internal heat.
If additional heat is introduced from other sources in the environment, then the maximum permitted coil temperature can be maintained according to the insulating material class.

1.11. What are the characteristics of magnetic circuits?

Magnetic remanence
When a ferromagnetic component is magnetised, a portion of the magnetisation remains in the material after deactivation of the excitation. This condition is referred to as remanence

or residual magnetism. Put simply, it may be expected that the majority of magnetising materials behave as if they were weak permanent magnets. The remanence determines the residual holding power. After pulling off the workpiece from the holding surface once, the remanence nevertheless disappears continuously. The greater the air gap δ_L, the lower the expected remanence and the residual holding force will be.

Permeabilität μ
This indicates the permeability of a material in case of magnetic fields. The relative permeability μ_{rel} μrel is the amplification factor related to the permeability μ_0 of the vacuum.

$$\mu_0=1,256*10^{-6}\frac{Vs}{Am}$$

$$\mu=\mu_{rel}\mu_0$$

In case of ferromagnetic materials: $\mu_{rel} \gg 1$

Magnetic flax Φ
In equivalence of the electrical circuit Φ is defined as the flow size of the magnetic field according to current I in the electrical circuit. The better the magnetic properties (permeability μ), the greater the magnetic flax Φ at otherwise equal parameters will be. Information is indicated in Weber (Wb) or Vs.

$$1Wb=1Vs$$

Magnetic flax density B
If the magnetic flax is related to the conducting cross-sectional area in the magnetic circuit, the magnetic flax density B that results is indicated in T (Tesla).

$$1T=1\frac{Vs}{m^2}=1\frac{Wb}{m^2}$$

1.12. What points need to be observed while using Kendrion electromagnets?

In general, Kendrion electromagnets are intended for use under the nominal operating conditions indicated in DIN VDE 0580.
In case of deviating operating conditions, coordination with the manufacturing plant is necessary.
For example, corresponding measures like a higher protection class and/or special surface protection must be taken.
Solenoids, armature plates, axes, and piston must be free of fouling, since otherwise, functionality could be impaired. The devices may not be exposed to any strong external magnetic fields.
The devices must be fastened in the application using the intended fastening devices, e.g. threaded drilled holes, fastening flanges, and similar equipment.
In case of devices in protection class I, the protective conductor line must be ensured by the user according to DIN VDE 0100.
If there is not protective conductor on the magnet side, then the device must be earthed via its electrically conductive housing.

Electro-holding magnets, permanent electro-holding magnets
During installation of devices, ensure that the exterior pole surface features at least 5 mm clearance to the side and above away from other magnetising materials to faults in the magnetic field. The installation position is irrelevant. The force reduction is planned exactly in the direction of the axis, since otherwise, reduced magnetic force can be expected.

Oscillating solenoids of the type OAC are drive components that may be integrated freely by the user according to the technical rules and parameters in his own drive system, which also affects all further technical parameters described here such as installation position, nominal voltage, and nominal frequency, equipment with springs, and adjustment of the mechanical resonance. The air gap must be measured so that so the nominal power of the coils is not exceeded on the one hand and the moved armature cannot collide with the excitation system on the other.

Oscillating solenoids with magnetic holding fasteners of the type OAB must be secured by the user against ‘unintentional wandering’ with suitable mechanical end stops. Furthermore, the system must be coordinated according to the formulas provided in the technical explanations.

Vibratory feeder drivers of type OMW must be matched with a corresponding support weight. The approach required for this is described in the technical explanations for oscillating solenoids. In general, the devices are suitable for a drive frequency (mains frequency) of 50 Hz. Other frequencies require coordination with the manufacturing plant. In particular, the leaf springs of the vibratory feeder drives must be protected against use during transport, assembly, and damage, since the device configuration could otherwise be altered. If the load and additional weights indicated in the device sheets are exceeded, the solenoids could be overloaded easily.

Installation position of oscillating solenoids and vibratory feeder driver. The preferred installation position for oscillating solenoids of type OSR is vertical, while vibrators of types OMW, OLV, and OAB should be horizontal.
Vibratory feeder drivers (type OMW) may be installed horizontally or inclined at an angle of 18° in the conveyor direction. In case of other installation positions, the deviating effective direction of gravity on the moving armature can impair the cycle stroke.

Actuating solenoids for precision mechanical and industrial applications. The installation position is irrelevant. It must nevertheless be ensured that the force reduction takes place directly in the axis direction, since otherwise, there is a danger that the bearing positions will seal prematurely due to one-sided loading. The solenoids are loaded with at least 2/3 of their nominal magnetic force. Under-loading causes premature wear on the support surfaces of the armature and solenoid housing due to severe impacting in the stroke limit position, as well as severe impacting noise. The armature axis is protected against damage. Bent or deformed axes will block the armature or damage the bearing positions.

Spreader solenoids, double spreader solenoids
In case of vertical installation, the armature weight must be taken into consideration. The armature axis is protected against damage. Deformed axes will block the armature and cause damage to the bearing positions.

1.13.Safe use and maintenance

The devices are built, tested, and designed according to the accepted rules of the technology, especially according to the provisions affecting electromagnetic devices (DIN VDE 0580). The devices may only be connected to the voltage type indicated on the type plate (direct current, alternating current) and the indicated voltage value.
During all maintenance work, it must be ensured that the devices are not connected to voltage. The current conducting parts like plug-in contacts or excitation winding of the device may not come into contact with water. The free wire or cable ends or the plug-in connections of devices may not be loaded mechanically (pulling, crushing, etc.). Devices may not be operated if: Electrical lines are damaged, the solenoid housing or the coverings exhibit damage, there is suspicion of defects and damage after falling, or similar. Repairs may only be completed by technicians in these cases. Incorrectly completed repairs can result in significant dangers to the user. If the devices are used for unintended purposes or connected incorrectly, then no liability can be accepted for possible damages. The user is responsible for suitable and safe use.
In case of doubt, the installation location, environmental conditions, and similar aspects must be confirmed with the manufacturer of the devices in good time.
The life cycle strongly depends on the external conditions (installation location, type of medium, height of load). Statements related to this shall require a separate agreement. The indicated magnetic forces are average values and may deviate from the listed values due to natural fluctuations. Depending on the use case, corresponding accident prevention measures must be observed.

Electro-holding magnets, permanent electro-holding magnets
Galvanised electro-holding magnets are maintenance-free. Painted devices do not have rust-protected pole surfaces. As required, the pole surfaces may be ground again to the wear limit level.

Oscillating magnets, vibratory feeders
Oscillating magnets and vibratory feeders, except for the type OLV, are maintenance-free in case of intended use. In case of devices that are operated permanently in the temperature threshold range of the excitation winding, the winding will exhibit a nominal life cycle of approx. 20,000 hours (DIN EN 60172). Exceeding the temperature threshold of the insulating material class that is used can lead to irreparable damage very quickly, e.g. shorted windings or deformation or destruction of the plastic that is used

Actuating solenoids for precision mechanical and industrial applications. Linear solenoids are maintenance-free in case of intended use. Exceeding the temperature threshold of the insulating material class that is used can lead to irreparable damage very quickly, e.g. shorted windings or deformation or destruction of the plastic that is used.
Solenoids produced by Kendrion are also maintenance-free with regard to storage. In particular, the slide bearings that are used are not oiled, greased, or treated in any other manner.

Spreader solenoids, double spreader solenoids
The damping buffer or damping bushings, if available, must be replaced after one to two years. The axes may not be greased or oiled. The hand ventilation lever may not be activated above the maximum indicated torque for ventilation, since otherwise, the hand ventilating bolt could be destroyed.

1.14. Guidelines – CE marking

The products from Kendrion are electromagnetic components and are only planned for use in electrical equipment. In most cases, our components fall under the Machinery Directive as an “incomplete machine”, depending on the connection voltage (0 V to 50 V AC/0 V to 75 V DC) or the Low-Voltage Directive (from 50 V AC/from 75 V DC). In addition to these directives, we also adhere to additional product-specific guidelines in the current version of RoHS, ATEX, Building Products Directive, etc

Machinery Directive
The products that involve incomplete machines within the context of the Machinery Directive 2006/42/EC do not receive labelling with the “CE” label. A Declaration of Incorporation can be issued for the requirements of the Machinery Directive. However, the Declaration of Incorporation is not automatically included in our deliveries. We are happy to provide this to you upon request.

Low-Voltage Directive
Products that are subject to the Low-Voltage Guideline 2014/35/EU are marked with the “CE” label. A corresponding Declaration of Conformity is not automatically a component of our deliveries, but we would be pleased to issue this to you upon request.

EMC Directive/requirements of German laws affecting electromagnetic compatibility of equipment (EMVG)
Electromagnetic compatibility according to EMVG must be

ensured regarding interference immunity from externally active electromagnetic fields and line-related interference. Furthermore, the emission of electromagnetic fields and line-related interference must be limited during operation of the device.

Adherence to the EMC Directive 2014/30/EU must be ensured by the user of our products together with the controls, mains devices, and switching equipment planned by the user for their operation. In case of use of the accessories recommended by us, the EMC Directive may be viewed in the respective individual catalogues.

On the basis of properties of the electromagnetic devices dependent on switching and operation, a Declaration of Conformity indicating adherence to the corresponding EMC standards is only possible in the context of switching devices is possible, but not for the individual devices. For this reason, switching recommendations are provided to adhere to the relevant standards. If no separate specifications about CE conformity for the electronic accessories are provided in the device sheets, standard-conforming threshold limits are indicated in the following sections.

Interference immunity

EN 61000-4-2 Electrostatic Discharge:
All electromagnetic devices correspond with at least severity level 3, without additional measures. The electronic accessories correspond with at least severity level 2.

EN 61000-4--3 Electromagnetic Fields:
All electromagnetic devices correspond with at least severity level 3, without additional measures. The electronic accessories correspond with at least severity level 2.

EN 61000-4-4 Transient Disturbances (Burst):
All electromagnetic devices correspond with at least severity level 3, without additional measures.
The electronic accessories correspond with at least severity level 2. In case of devices 33 43302..., 33 43303... and the series 32 17350 ... severity level 3 may occur for temporary periods with low voltage increases, but nevertheless do not result in functional interference.

EN 61000-4 -5 Surges:
All electromagnetic devices correspond with at least severity level 3, without additional measures. The electronic accessories correspond with at least severity level 2.

EN 61000-4-8 Power frequency magnetic fields, EN 61000-4-9 Impulse magnetic fields, EN 61000-4-10 Damped oscillatory magnetic fields:
Because the working magnetic fields of electromagnetic devices are many times stronger than the interference fields, no functional influences result. The devices correspond at least with severity level 4. The electronic accessories correspond with at least severity level 3.

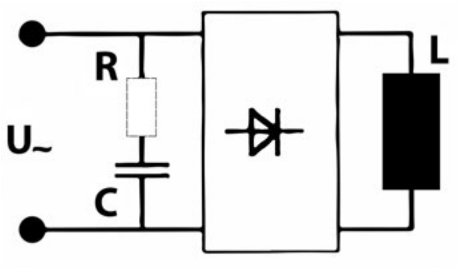
EN 61000-4-11 Voltage dips, short interruptions, and voltage variations:

a) Actuating solenoids, electro-holding magnets, locking solenoids, including electromagnetic closure systems: The electromagnetic devices change to the currentless switch state in case of voltage interruptions after the switching times indicated in the device sheets according to VDE 0580, whereby the switching time depends on the controls and mains conditions (e.g. generator effects of running motors), and voltage interruptions and voltage drops that are shorter than the release delay time indicated according to VDE 0580 do not cause any armature movement. The release delay time is nevertheless determined by the device and the respective counterforce, and in general, voltage drops below the continuously permitted tolerance threshold results in a reduction of holding force below the nominal values. The user must ensure that subsequent damages due to voltage-related drops in the holding force or failure of the magnets are able to be avoided. The functionality of the electromagnetic device and the electronic accessories remains available if the subsequent damages indicated above are avoided. Proportional and oscillating solenoids: Voltage fluctuations and interruptions can lead to deviations in the oscillating amplitude and the armature position, provided they are not able to be controlled by upstream regulating devices.
b) Locking solenoids, permanent electro-holding magnets, including electromagnetic opening systems:
c) Short voltage interruptions and drops can only cause unlocking or opening as a result of their functionality: This function may not be able to be executed at times.
d) The user must ensure that subsequent damages cannot result. If the opening function is executed permanently, the solenoid is able to change to the currentless state indicated in a). The user must avoid subsequent damage in a suitable manner.

Interference emissions

The electromagnetic devices and the electronic accessories belong to Group 1 according to EN 55011. The disturbance behaviour must be differentiated according to interference radiation and line-related interference voltage

a) *EN 55011 Interference field strength:* In case of operation with direct voltage or rectified 50/60 Hz alternating voltage, all devices correspond with the threshold values in class B. The electronic accessories correspond with at least class A.
b) *EN55011 Interference voltage:* In case of operation with direct voltage, the electromagnetic devices correspond at least with the threshold values of class A. In case of operation with electronic devices, smoothed direct voltage must be used (residual ripple < 10%). We recommend using capacitors featuring a capacity of at least 2200 µF/ADC and a nominal voltage of 40 V at 24 V DC or 25 V at 12 V DC. They must be installed as close to the consumer as possible. If the devices with the electronic accessories operate on 50/60 Hz alternating current mains, additional interference suppression measures are required to reach the threshold values of class A.



The use of interference suppression capacitors or suppressors is recommended, the dimensioning of which depend on the electrical connection data of the electromagnetic devices and the mains conditions. Table 1 summarises the recommended values. Interference suppression must be installed close to the consumer. Faults that result while switching electromagnetic devices generally depend on the inductive load. Depending on the requirements, a shut-off voltage limit can be implemented via anti-parallel diodes or components for limiting voltage like varistors, suppressor diodes (TVS), WD elements, or similar, although these have an influence on the switching times of the devices. Corresponding purchasing options are provided in the technical explanations of the devices.

If the operator uses the devices with other electronic accessories, then he must ensure adherence to EMC laws. Adherence to the corresponding standards using components or modules or used devices does not release the user or manufacturer of the complete device or the system from proof of conformity to standards for his complete device or his system.

Electronic device	Mains voltage (VAC)	Direct current at L load (ADC)	Capacitor (nF/VAC)
Half-wave rectifier 32 07 .02AO.. 32 07333HO	bis 230 bis 400	bis 2.0 bis 2.0	47/250 100/400
Bridge rectifier 32 07.03AO.. 32 07334HO 32 07350AOO	bis 230 bis 400	bis 1.5 bis 3.0 bis 5.2 bis 2.0 bis 4.0 bis 5.2	47/ 250- 100/ 250- 220/250- 100/400- 220/400- 330/400-
Over-excitation rectifier 32 17.5 . . . 2	bis 230 bis 400	bis 1.0 bis 3.0 bis 2.0 bis 3.0	47/ 250- 100/ 250- 100/400- 220/400-

Table 2: Dimensioning

2. Technical definitions for holding magnets

2.1. What are holding magnets?

Electro-holding magnets (holding solenoids) remain able to be magnetised. Workpieces in position due to magnetically created forces. Pieces that are unable to be magnetised are able to be held on a magnetisable armature plate. The specific design of the magnetic circuit maximises the holding force for the smallest possible air gap. The ideal attraction of the armature plate from a greater distance is not available for these devices.

The holding force is created by an electromagnetic field in case of electro-holding magnets, or by a permanent magnetic field in case of permanent electro-holding magnets.

In terms of construction, these magnets feature an open magnetic circuit (Figure 9), which is completed by the workpiece and the armature plate. The size of the resulting magnetic flax specifies the holding force.
The degree of magnetising ability of a workpiece is specified by the relative permeability μ_{rel} of the material.

The larger the magnetic flax Φ for a continuously steady holding surface that penetrates the workpiece, or the greater the magnetic induction B on the holding surface, the higher the holding force F_H.

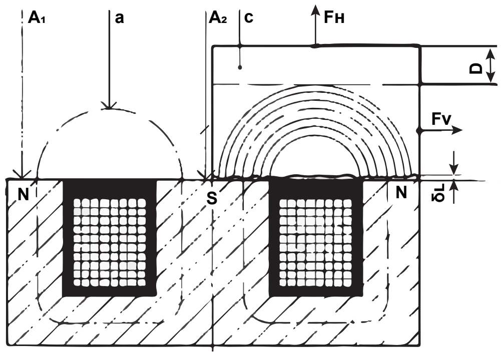


Figure 9 holding magnet

a	= open magnetic circuit	δ_L	= air gap
A_1/A_2	= magnetic holding surface	F_H	= holding force
c	= workpiece	F_V	= shifting force
N, S	= magnetic poles	D	= ideal workpiece density

2.2. How is holding force calculated?

Holding force

The holding force is the force that is required to remove the workpiece from the holding surface of the solenoid. Using ulling force formula, you may calculate:

$$F_H = \frac{B^2 A}{2\mu_0}$$

B...the median flow density in the air gap, A=A1+A2 (Figure 9)

In case of a magnetic **flax density of 1.6T, approx. 1N result from approx 1 mm² holding surface.**
The magnetic flax and therefore the flow density are specified by the overall resistance in the magnetic circuit.

Residual holding force F_R of electro-holding magnets
The holding force remaining due to the magnetic remanence after deactivation of the previously indicated nominal voltage of electro-holding magnets. Depending on the workpiece, this is between 20 and 40% of the holding force while the device is activated. In case of door holding solenoids (GTR types), the residual holding force on the armature is overcome by a spring-operated pin.

Shifting force F_v
The force required to shift a workpiece parallel to the holding surface while the device is switched on.
Depending on the texture of the workpiece surface, this amounts to 20... 33% of the holding force F_H while under current.

2.3 What factors influence the holding force?

Air gap δ_L
This indicates the average clearance between the holding surface of the magnet and the held workpiece surface. The shape of the surfaces facing each other and non-magnetic substances (e.g. galvanic overcoats, paint, soot) form its size. The roughness and unevenness of the surface acts as an additional air gap. Due to the low permeability of air (μ_0), the air gap is the relevant size for the magnetic flax.

Influences that affect the holding force:

- the air gap δ_L
- the thickness of the workpiece (armature plate)
- the material properties of the workpiece (μ_{rel})
- the configuration of the magnetic holding surface

Configuration of the holding surface
The configuration of the holding surface is the contact surface (in %) that the workpiece contacts the holding solenoids (surface A1+A2, see Figure 9). The holding force per surface unit of a holding solenoid is nearly the same across the complete holding surface. The configuration of the holding surface is at maximum (100%) when the complete magnetic holding surface is occupied by the workpiece.

Material properties
The holding solenoid housing, which guides the magnetic flax, consists of highly permeable steel.
For this reason, the high holding force indicated in the data sheets is able to be reached with armature plates or workpieces consisting of steel S235JR (formerly referred to as St37) or comparable materials. In any case, the actual holding force able to be reached is reduced by different application parameters, including the low permeability of the workpiece. This therefore

depends on the material type. Hardened materials also possess a lower permeability. The basic rule is: The higher the hardening degree, the lower the magnetic conductance and therefore also the achievable holding force.
The curves in Figure 10 indicate that in case of a specific the field strength H, which is created by the excitation winding of the holding solenoids, the magnetic induction is different for the various materials. B = f (H)
Workpieces with different magnetising characteristic curves produce different holding forces with the same holding solenoids.

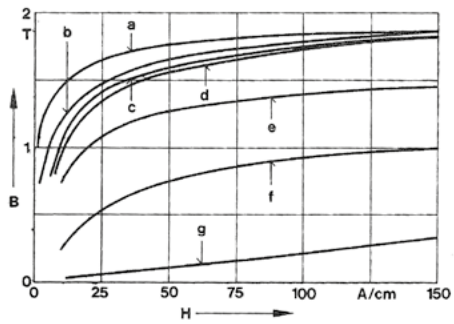


Figure 10 Magnetising curves of common materials

a	Armco (pure iron)	b	S235JR (St37)
c	E335 (St60)	d	GS (cast steel)
e	GT (malleable cast iron)	f	GG (grey cast iron)
g	HSS (Rc 64)	B	magnetic induction (T)
H	magnetic field strength (A/cm)		

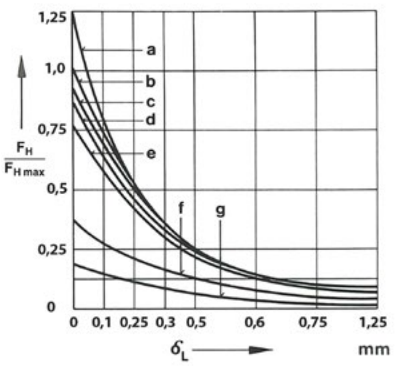


Figure 11 Influence of the material and the air gap δL on the holding force F_H

a	Armco (pure iron)	e	GT (malleable cast iron)
b	S235JR (St379)	f	G (grey cast iron)
c	E335 (St60)	g	HSS (Rc 64)
d	GS (cast steel)		

Thickness of the workpiece

For every size of device, there is an optimal workpiece thickness, which is indicated in the device sheets of the catalogue as “armature plate thickness”. The associated diagrams specify the influence of low workpiece thickness. An armature plate thickness larger than the indicated thickness, will not result in increased holding force.

Calculation instructions

The diagram in Figure 11 display the connection between the air gap and the achievable holding force in case of different materials (curves a to g). As a reference, S235JR (curve b) is provided for an air gap of 0 mm.
In this case, all other materials achieve relative holding force values, also in case of large air gaps. Furthermore, the reduced holding force can be calculated approximately for other materials.

Example: Calculation of holding force of an electro-holding magnet GT063B001

Boundary conditions:

- The workpiece to be held has a material thickness of 4 mm
- Air gap approx. 0.05 mm
- The holding surface is covered completely by the workpiece
- Workpiece material: S235JR

Holding force determination:
From the data sheet: Max. holding force according to the diagram: approx. 730 N According to the diagram in Figure 11 a correction factor of 0.9 results for curve b) at 0.05 mm.
The expected holding force is approx. 650 N

Reduction of input power

The input power may be reduced via upstream activation of a voltage regulator. The voltage reduction produces heat and holding force F_H of the individual devices according to the diagram in Figure 12.

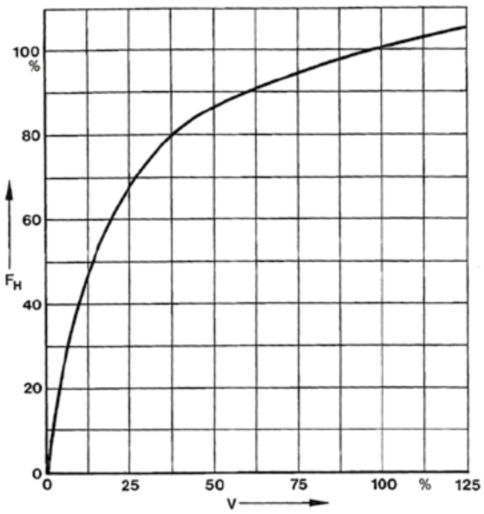


Figure 12 Holding force F_H of electro-holding magnet in % of the maximum value in case of a nominal voltage, this depends on the percent of input voltage V

2.4 Special applications

Use of multiple holding solenoids for a workpiece (group arrangement)

- Every holding solenoid must be fastened to be moveable so it is able to be adjusted (Figure 13).
- Every holding solenoid should hang flexibly on a traverse beam to ensure that the varying support force of the individual solenoids is not too high in case of uneven application surfaces (Figure 14). Furthermore, a flexible suspension is able to dampen the shuddering movements of the carrier.

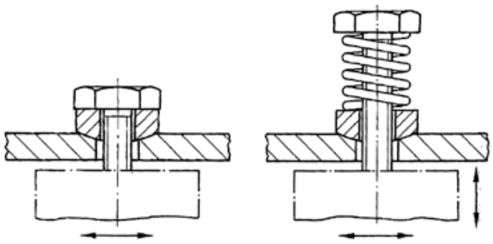


Figure 13 Figure 14

Figure 13 Individual fasteners

Figure 14 Ideal fastening in case of group arrangement

Holding especially thin materials

Equally distributed holding rods are recommended for holding thin metal sheets. Ensure that the holding forces are not able to be reached due to bending the metal sheets.

External fields

Permanent electro-holding magnets may not be exposed to another strong magnetic field to ensure that they are protected from irreversible loss of holding force.
In case of electro-holding magnets, strong external magnetic fields can lead to temporary changes in holding force.

2.5 Special characteristics of permanent electro-holding magnets

All of the statements made above apply to both electro-holding magnets and permanent electro-holding magnets, with the exception

- of dependence of the holding force F_H on the operating voltage, and
- the expression of residual holding force

In case of permanent electro-holding magnets, the permanent magnetically produced holding force F_H is neutralised by activation of the supply voltage. In any case, the quality of neutralisation depends on the applied voltage (tolerance) and the coil temperature. A holding force F_H = 0N can only be achieved for the exact nominal current.
Figure 15 displays the size of the holding force F_H of a permanent electro-holding magnet depending on the nominal current I_N at which the force equals 0 exactly. Depending on the operating conditions, the operating current differs slightly from the nominal current so that a residual holding force F_R remains. Ensure that if the current is increased above the nominal current, the holding force will also be too great.

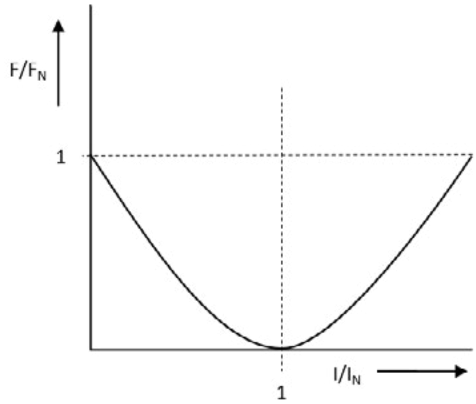


Figure 15 F_H=f(I/I_N) for permanent electro-holding magnets

3. Technical definitions for actuating solenoids

3.1. General

Neutral and polarised magnets

Neutral linear solenoids are characterised by the fact that they create their magnetic field exclusively via the current flow in the coil. In contrast to this, polarised linear solenoids feature one or more continuous magnets (permanent solenoids), which also create a magnetic field without electrical power. With the help of the coil current, the magnetic field of the permanent magnet is modified so that the desired effect is able to be achieved, e.g.

- currentless holding and/or
- reversing the movement direction or
- reduction of power consumption.

Linear solenoids and rotary solenoids

While *linear solenoids* are used to create linear actuating movements, rotary solenoids are used for rotary drive of a shaft (Figure 16). All explanations of linear solenoids apply to rotary solenoids accordingly. These analogies must be observed:

- path, stroke, s, s_1, s_2 → rotation angle, α,α_1,α_2,
- Fforce, magnetic force, holding force, spring force, F_x → Rotary torque, holding torque, spring torque, M_x
- $W_{mech} = \int_{s_1}^{s_2} F ds \quad \rightarrow \quad W_{mech} = \int_{\alpha_1}^{\alpha_2} M d\alpha$

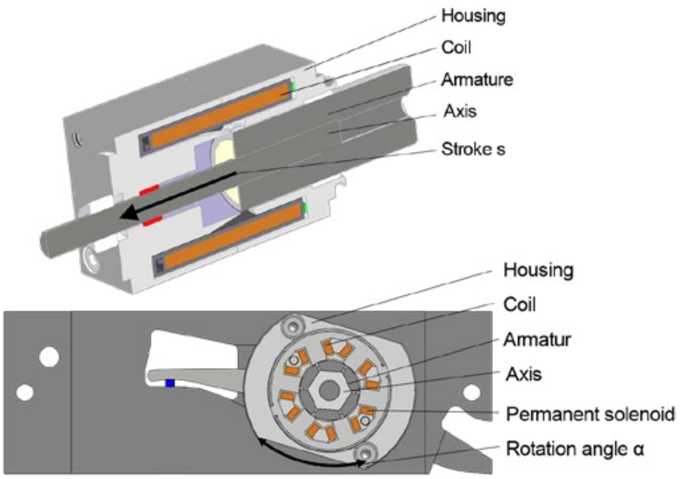


Figure 16 Neutral solenoid (Figure above), polarised rotary solenoid with main components and effective direction (Figure below)

Spring forces

If springs are used in actuating solenoids, they reduce or enhance the externally available mechanical forces.

Mechanical interface

Actuating solenoids must be integrated into the drive unit mechanically. For this purpose, the standard device features threaded holes, centring collars, and similar aspects. The exact position and size are indicated in our catalogue data. Please contact us in case of special adjustments. In particular, the customer may not implement any additional drilled holes, since the danger of damaging other components is very high in this case.

IP protection according to DIN EN 60529

The IP protection class of the respective solenoids is indicated in our technical data. Actuating solenoids possess relatively low protection against penetration of water or solid foreign objects due to their design. To increase the protection class, some additional components like folding bellows or scraper rings are offered. These components simultaneously increase abrasion and reduce the magnetic force available.

3.2. Function of actuating solenoids

Function

Actuating solenoids should shift a mechanically moveable part with a specified force along a specified path (stroke s) (Figure 17).

Holding forces

In the stroke start or stroke limit position, the armature of the solenoid is able to remain with holding force F_H (see Figure 17). One of these positions is usually held by magnetic forces, while the other forces are held by a spring or other external forces, respectively. Depending on the magnet configuration, the magnetically held position is held via current flow from the coil or by permanent magnets.

Armature return movement

Prior to executing a new working stroke, the armature must be returned to the stroke start position. This is completed via built-in or external springs or from outside by the mechanical drive that the solenoid is used in. In case of reversible solenoids, the stroke start and stroke end position change with the active working direction.

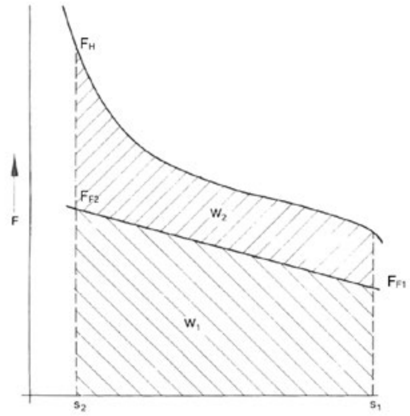


Figure 17 Function of an actuating solenoid with spring load:

s_1 Stroke start	s_2 Stroke stalimitrt
F_H Holding force (magnetic)	F_{F1} Spring force at stroke start
F_{F2} Spring force at stroke limit	W_1 Static stroke work
W_2 dynamic stroke work	

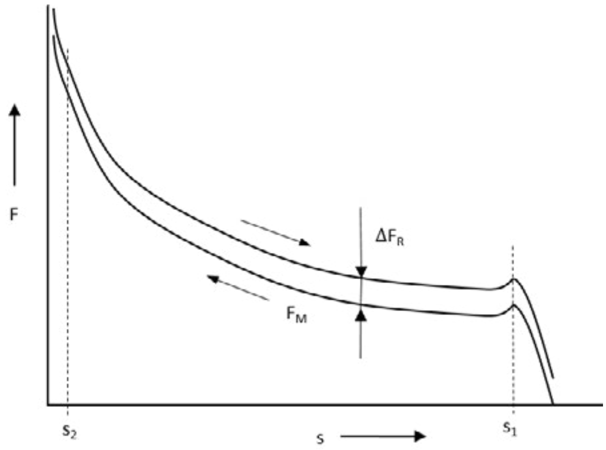


Figure 18 Abrasion on actuating solenoids. The arrows indicate the movement direction
F_m Magnetic force, ΔF_R Abrasive force hysteresis

Abrasion
The magnetic armature is never exposed to the same forces along its circumference due to geometric asymmetry. Unequally distributed magnetic flax, mechanical asymmetry, and external forces (e.g. gravity) cause bearing abrasion during the armature movement, which lowers the useful magnetic force (Figure 18 bottom curve).
For this reason, the magnetic force F_M for the solenoid stroke is given less the abrasive force. On the other hand, the return movement of the armature towards the attraction direction under current requires the force $F_M+\Delta F_R$ (Figure 18, upper curve). Simultaneously, the bearing abrasion amplifies the asymmetry, and abrasion leads to ageing, which limits the number of movement cycles that may be reached.

Heating of actuating solenoids
The functions of the actuating solenoids are ensured by the design, assuming standard ambient temperature in connection with internal heating (see table 1 and 3).
In case of increased ambient temperatures, reduction in achievable stroke work must be accepted, since the power consumption must also be reduced (Figure 19). This takes place to protect the insulating materials against damage.
Curve 1 depicts the respective voltage (in %) depending on the ambient temperature at which a solenoid may be operated, provided its excitation winding is designed for a normal ambient temperature (values provided in the
device sheets). Curve 2 depicts the permitted input power in % of the list values, provided the magnet needs to work at higher ambient temperature than 40°C.
Curve 3 indicates the stroke work of the magnet at an input power adjusted to the ambient temperature.

Additional heat sources
In addition to this, the temperature of the coil is specified significantly by the heat dissipation or addition from the machine components. The good mechanical contact (often metallic, good heat conduction) cause the temperature to be very severely influenced by other sources. In particular, the coil heating during operation must be checked in case of operation on hot components.

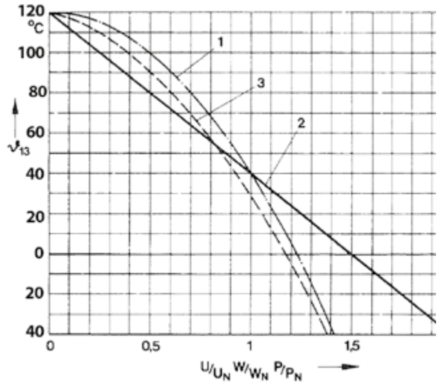


Figure 19 Reduction of permitted operating voltage or power consumption and achievable stroke work in case of increased ambient temperature, shown for insulation class E
ϑ_{13} Ambient temperature W_N Nominal stroke work
U_N Nominal voltage P_N Nominal input power

Curve 1: $U/U_N = f(\vartheta_{13})$

Curve 2: $P/P_N = f(\vartheta_{13})$

Curve 3: $W/W_N = f(\vartheta_{13})$

Optimal magnet design
To achieve the best ratio of electrical power to mechanical work for a given magnet volume, the ideal design for the underlying power consumption must be determined (in the warm state!).
The optimum level mainly consists of the correct ratio of the coil cross-section (A_{Cu}) to the magnetic circuit cross-section (A_{Fe}):
$$\max.\ \{W_{mech}(V, P_{el,\ warm})\}=f\left(\frac{A_{Cu}}{A_{Fe}}\right)$$
Furthermore, additional criteria play a role for the ideal configuration, which is why a solenoid is calculated comprehensively and adapted to the individual use case.

3.3. Activation process of actuating solenoids

Operation at the voltage source (normal operation)
Solenoids are normally operated with supply voltage so that the voltage tolerances or internal resistance of the voltage source and lines have an influence on the operating behaviour. In general, these are combined for tolerance-related nominal voltage. Note that the specified upper temperature limits of the coil must be maintained at maximum voltage (→ maximum power consumption) for functionality, but the projected power-force characteristic must be reached in case of minimal voltage and maximum coil temperature.

Heating and voltage tolerance lower the magnetic force of a solenoid significantly below the force at nominal conditions (table 3).

The magnetic force of the solenoid now amounts to approx. 50% of the force at nominal conditions (Figure 20b, curve 1 and 2). The consequences are clear differences in terms of force, switching time, and activation noise, depending on the level of heat and operating voltage.
The forces and switching times indicated in the data sheets are achieved by magnets at operating temperature

Relevant size	Depending on	Calculation/source	Example	Explanation
I_M	R_{warm}, U_{max},U_{min}	$I_M = U_{min}/R_{warm}$	$I_M \approx 0{,}67\ I_N$ at 155°C and $0{,}9U_N$	Solenoid current available for functionality
R_{warm}	$\vartheta_{Coilmax}$	$R_{warm} = R_{20}((\vartheta Spule-20°C)\ 0{,}0039+1)$	$R_{warm} \approx 1{,}5R_{20}$ at 155°C	Maximum value of the coil resistance in operation
Thermal class	Materials	DIN EN60085 (VDE 0301-1):2008-8	Class F: 155°C	Maximum temperature of the insulating materials
U_{max}, U_{min}	Application		±10%	Voltage tolerance at the solenoid
F_M	I_M	Non-linear magnetic circuit L = L(s,I)	$F_M \approx 0{,}5F_N$	Practical actual achievable force

Table 3: Dependence of magnetic force on other influencing factors

DC voltage controller
The tolerance of operating voltage is clearly limited. For the residual tolerance of ± 2%, for example, and a medium coil temperature of 155°C, the force drops to approx. 60% under warm conditions, compared to nominal conditions (Figure 20 b), curve 3).

DC current controller
This voltage is variable for the DC current controller. The maximum permitted current results from the thermal class and the quality of heat dissipation to the environment. The magnetic circuit is optimised to the calculated current.
This current can be applied in any operating condition. The supply-side always features a voltage reserve to compensate the increased resistance resulting from heating.
Advantages of current regulation:

- Accelerated activation process
- A maximum solenoid current is specified that is always able to be reached
- The magnetic force, the switching time, and the switching noise are the same in cold and warm states
- The magnet may be optimised for the desired force-path characteristic

A variable current regulation enables solenoids to be used together with a return movement element and/or a path measuring device as an actuator (proportional magnets).
In any case, the maximum coil resistance already included during specification of the nominal current, whereby the gained mechanical work is comparable with that of the DC voltage controller (Figure 20 b, curve 3).

Shortened activation duration
If actuating solenoids are used in continuous operation, the option of operating with shortened activation duration is available ("Short operation", see technical explanation, 1.10). Due to a changed coil configuration, the nominal power is increased compared to the permanent operation. The advantage related to increased stroke work related to the design size. Figure 20 a) shows the expected increase in mechanical work in case of shortened activation duration.

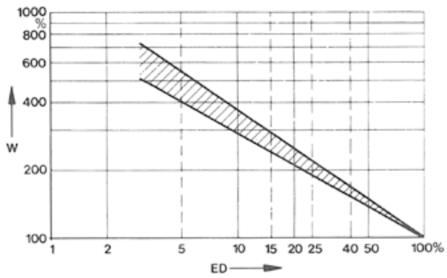


Figure 20 a) Stroke work W depending on the relative activation duration in case of actuating solenoids for direct current

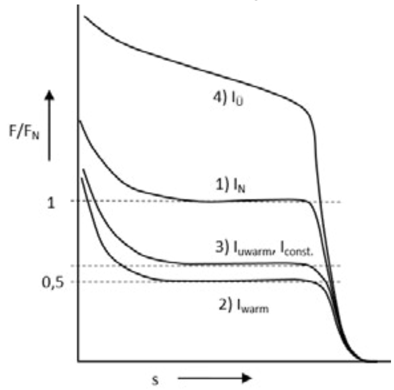


Figure 20 b) Force-path characteristic for nominal current I_N

I_{warm} Minimum current I_{uwarm} Warm current for voltage controller
I_{const} Current controller $I_{Ü}$ Over-excitation

High-speed excitation to shorten the attraction time t_1
During high-speed excitation (Figure 21) the overall resistance is increased via upstream activation of hmic resistance to the magnet, and the time constant is also reduced. The operating voltage U_B is clearly higher than the nominal voltage of the magnet U_N. During activation (I=0) via high voltage ($U_B >> U_N$) with a simultaneously reduced electric time constant,

$$T_{el}=\frac{L_M}{R_M+R_V}$$

the magnetic coil is excited faster than without resistance (Figure 23). The activation delay time and attraction times are reduced accordingly. In stationary operation with $I = I_N$ = const., the operating behaviour and the mechanical work of the magnets correspond with the normal operation.
Note that the preliminary resistance constantly consumes a power loss of $P_V=I_N^2R_V$ during stationary operation.

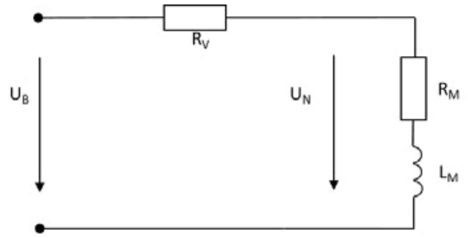


Figure 21 Actuator solenoid with high-speed excitation

U_B Operating voltage
U_N Nominal voltage of the magnet
R_V Preliminary resistance
R_M Ohmic resistance of the magnet
L_M Inductance of the magnet

Over-excitation
In case of over-excitation (Figure 22a), the solenoid receives increased voltage during the attraction process to

- shorten the switching time and/or
- to produce increased mechanical work.

Another form of over-excitation consists of initially applying the entire operating voltage to a partial coil (attraction coil (L_{M1})). After the end of the armature movement, this is connected in series with the so-called holding winding (L_{M2}), so that the nominal current is adjusted (Figure 22b).
The difference of "over-excitation" to the operating mode “shortened activation duration” consists of the fact that the power is reduced to a thermally safe value after the attraction process. The solenoid is also able to be operated like a 100% activation duration device. The voltage is reduced either time-controlled or via limit position detection. Because the holding force is present at nominal power by way of the magnet configuration, it is sensible to utilise the over-excitation as far as possible so that the attraction force corresponds with nominal operation (Figure 24 Item (b)). The increased attraction power causes additional heating during each attraction process, which is why a maximum number of activations Z (switching cycles per h) must be specified for this mode. Over-excitation enables the stroke work to be increased similarly well as by using shortened activation duration (Figure 20 a), however without the disadvantage of long shut-off phases. The over-excitation power is normally specified so that permanent operation is possible.

The theoretical maximum switching frequency therefore results in

$$f_{smax}=\frac{1}{t_1+t_2}$$

In case of increased over-excitation power, currentless pauses may be required to maintain the temperature thresholds, depending on the switching frequency. These are determined by application-specific tests. The statements regarding the influence of coil warming on solenoid current, force, and activation time apply analogously to over-excitation. Over-excitation can also be combined with current and voltage regulation to produce the advantages indicated above.

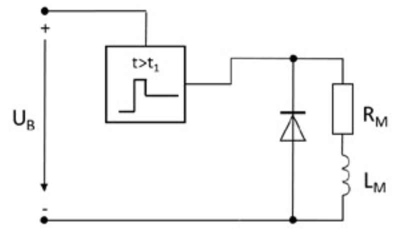


Figure 22a) Solenoids with over-excitation: Voltage reduction with PWM module

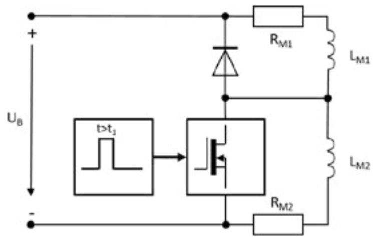


Figure 22b) Solenoids with over-excitation: Double winding solenoid with holding and attraction winding (R_{M1}, L_{M1}), the holding winding (R_{M2}, L_{M2}) is short-circuited during attraction

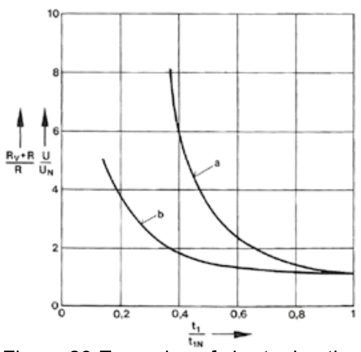


Figure 23 Examples of shortening the attraction time via high-speed excitation (a) with ($\frac{R_V+R}{R}$) and over-excitation (b) with U/U_N, t_{1N} activation time without high-speed/over-excitation, the switching time information is otherwise related to the same parameters (especially magnet geometry, counter-forces)

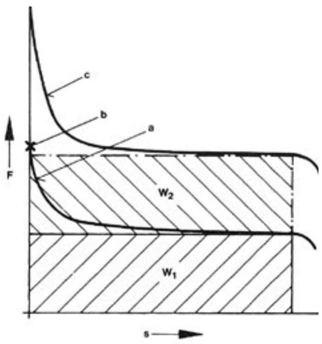


Figure 24 Influence of over-excitation on the stroke work characteristic curve of the magnet

a Characteristic curve in case of normal excitatio
b Holding force in case of Normal excitation
c Characteristic curve with over-excitation rectifier
W_1 Stroke work via normal excitation
W_2 Stroke work in addition to over-excitation
F Magnetic force
s solenoid stroke

3.4. Inspection of actuating solenoids

Test voltage

All of the actuating solenoids are tested for voltage stability prior to delivery. In this case, the test voltages as per VDE 0580 apply, provided nothing else has been agreed to, see table 4**.**

Repeated voltage testing

During the piece inspection, the voltage test should not be repeated if possible. Nevertheless, if a 2nd inspection is required, e.g. during acceptance processes, then this may only take place at 80% of the test voltage values indicated in table 3.

Nominal voltage / V	Test voltage for devices in protection class I, III with AC, U_{eff} / V
50	500
100	800
150	1400
300	2200
600	3300
1000	4300

Table 4: Test voltages (extract from DIN VDE 0580 :2011-11)

4. Technical definitions for oscillating solenoids

4.1. General description of oscillating solenoids

From a physical perspective, oscillating solenoids (for definitions, see item 1.2.) generate forced, damped oscillations within a spring-mass system.

Their oscillation frequency is specified by the pulsing electromagnetic force of the integrated solenoids (drive frequency). This is always equal to the frequency of the excitation force.

The frequency of the force pulse is determined by the pulsing current in the excitation coil:

- in case of pulsing direct current, this is equal to the pulse frequency of the current
- in case of alternating current, this is twice as large as the frequency of the alternating current.
- in case of alternating current with half-wave rectification or alternating current with field overlay by permanent magnets, this is equal to the frequency of the alternating current.

Oscillating drives feature several application specifics vis-a-vis other actuating solenoids. The resonance frequency (natural frequency) is the frequency at which a system would oscillate after one-time excitation due to the participating masses and springs alone.
If damping is disregarded, the natural frequency is a single degree of freedom:

$$f_0 = \frac{1}{2\pi}\sqrt{\frac{c}{m}}$$ c...spring constant, m...flywheel mass

If the units for f_0, c, and m indicated in section 4.3 are used, the following adapted size equation results:

$$f_0 = 5\sqrt{\frac{c}{m}} \quad [\text{Hz}]$$

If the drive frequency is too close to the resonance frequency, then an extremely large cycle stroke can result, which will damage the oscillating solenoids.
Further explanations for coordination of the drive with the application are provided in the following sections.

4.2. Terms

Oscillation frequency f
The frequency that the device oscillates at, which is normally 50 Hz = 3000 min^{-1}.

Maximum air gap a_{max}
The air gap indicated on the magnet in the static state (see Figure 25, air gap a).

Cycle stroke s

In case of oscillating solenoids, this is the difference between the reversing points of the armature movement in the drive direction. (the cycle stroke can be specified with self-adhering measuring wedges (Figure 26), which can be applied to the oscillating component.)

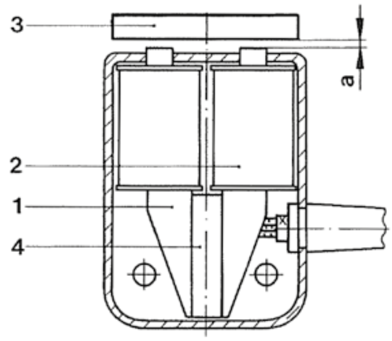


Figure 25 Oscillating drive OSR

a Air gap
2 Excitation winding
4 Permanent magnet
1 Magnet body
3 Armature

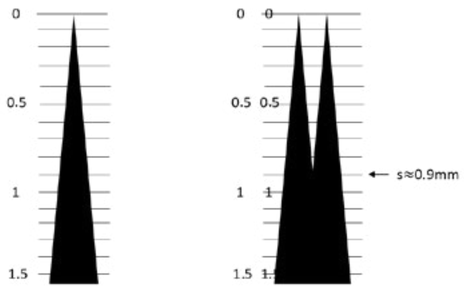


Figure 26 Measuring wedge for stroke measurement at oscillating solenoids, recording the measuring wedge movement: s=0.9 mm

Useful stroke, side, weight, mass
These relate to the part capable of oscillating that creates a useful effect.

Free stroke, side, weight, mass
These relate to the part capable of oscillating that does not create a useful effect. Ideal case: “Free of oscillations”.

Desired load weight
In case of vibratory feeder drivers as a channel weight, which make installation of a listed device possible.

Nominal power P_S, S
The apparent power in case of nominal voltage.

4.3. Designs and applications of Kendrion oscillating drives

Formula symbols and SI units used

f_0	Natural frequency	Hz
f_a	Drive frequency	Hz
c	Spring constant	N/mm
c_s	Spring constant of the rubber buffer in the direction of thrust	N/mm
d	Spring thickness (thickness)	mm
m_F	Weight of the free side of the double oscillator	kg
m_N	Weight of the useful side of the double oscillator	kg
m_r	resulting weight	kg
s_F	Cycle stroke of the free side	mm
s_N	Cycle stroke of the useful side	mm
s	Total cycle stroke s=sN+sF	mm
a	Air gap	mm
p	Resistance ratio	

Device types OAC…

These devices (Figure 27) are universally applicable oscillating solenoids for spring-mass systems in oscillating conveyors, linear conveyor drives, etc. to operate alternating voltage or pulsing direct voltage.

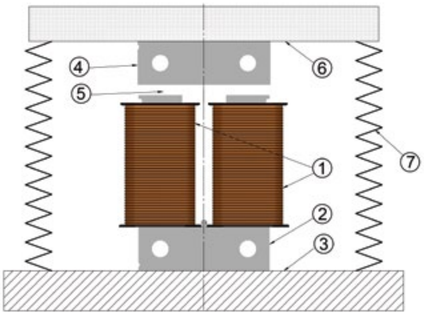


Figure 27 Oscillating solenoid OAC… built into the oscillating system

1	Excitation winding	5	Air gap
2	Iron core (yoke)	6	Useful mass
3	Free mass	7	Spring system
4	Amature		

The oscillating solenoids consist of the excitation winding, the yoke, and the armature (parts 1, 2, 4), whereby the excitation winding consists of two coils switched in sequence. The yoke and armature consist of magnetic steel sheet (UI section), whereby hysteresis losses in the iron core are kept low. The coils are coated in plastic.
In case of activation with 50 Hz AC, an attractive force is applied to the armature, which pulses with 100 Hz (6000 min^{-1}).
In case 50 Hz alternating voltage is used with additional half-wave rectification, a force pulse equal to 50 Hz (3000 min^{-1}) is applied. Both also apply if the electrical voltage is influenced with a phase angle control (OCS902.000703). With the help of pulse width modulating voltage, the frequency range of 5…200 Hz can be set for the oscillating frequency (frequency control device OCS902.000810).

The oscillation properties of the complete system must be set via the spring-mass system, in which case, the mechanical resonance frequency in particular must be observed. If the drive frequency is too close to the resonance frequency, there is a danger that the armature plate will collide with the excitation system, because the cycle stroke will be too large. For this reason, the drive frequency should be approx. 1-2 Hz below the resonance frequency. Theoretically, the free mass should be very large compared to the useful mass to prevent transfer of oscillations to the free side (substructure, chassis). Practically, only low

$^{m_F}/_{m_N} > 12$ oscillations are transferred for a ratio, so this may be considered a compromise. To specify the spring rigidity, only the useful mass must now be taken into account.

Therefore:

$$f_0 = 5\sqrt{\frac{c}{m}} \rightarrow c = \frac{f_0^2}{25}\, m_N \rightarrow m_N = \frac{25\,c}{f_0^2}$$

Although a drive frequencyz

$f_a = f_0-(1…2)Hz$ is desirable.

If the free weight cannot be achieved, then the resulting mass m_r must be used for calculation instead of m_N, since both masses are now set into motion.
The cycle stroke of both sides is formed in approximately the reverse relationship to its masses:

$$\frac{s_N}{s_F} \approx \frac{m_F}{m_N}$$

Device types OSR… (Figure 25) – "shaker coil"
This involves drives for "shaking" components, e.g. using funnels. The magnetic system of the oscillating solenoid is cast inside a plastic housing. This consists of two excitation windings and two halves of the magnet body, which are connected on the underside by a permanent magnet. The magnet body is comprised of magnetic steel sheets to reduce vortex flows. The magnetic circuit is closed by the body to be oscillated, which indicates the armature, via the air gap. If the body to be oscillated does not consist of magnetic material, a magnetising armature plate must be attached. Permanent magnets built into the magnet body pre-magnetise the system, and a constant attractive force results between the magnet body and the armature. If alternating voltage is applied to the excitation winding, the effective force of the electromagnetic alternating field overlays the effective force of the permanent magnet. The frequency of the resulting force therefore corresponds with the frequency of the applied alternating voltage, which moves the armature in the same rhythm.
In order to achieve the desired oscillating movement, the useful mass, i.e. the body to be oscillated must be fascinated with spring elements capable of oscillating on a base plate or a base. The calculation equations for the OAC drives apply analogously. The oscillating solenoid must be fastened stably on a free mass that is as heavy as possible.

An additional application option is to fasten the oscillating solenoid using flexible springing permanent magnet mounts (or angle brackets with screws) to a component to be vibrated (funnel, hopper, etc.) (Figure 28). The magnet body then oscillates independently from the mass ratios as a “free mass” and excites the “useful mass” to oscillate. Therefore:

$$\frac{s_N}{s_F} \approx \frac{m_F}{m_N}$$

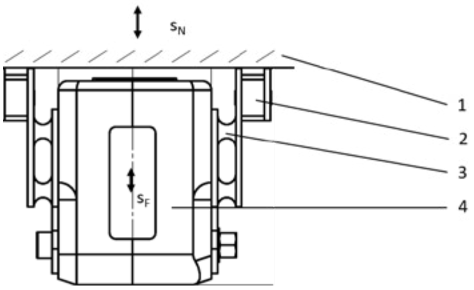


Figure 28 Device OSR as a vibrator with magnetic adhering fastener

1	component to be vibrated	3	elastomer
2	Adhering fastener (alternative to fastening bracket)	4	Vibrator OSR…

The device types OSR… are also suitable for operation with frequency control devices OCS902.000810 and phase angle controls (OCS902.000703) without additional half-wave rectification.

Device types OLV… (Figure 29) “Linear oscillating solenoid” The magnet body of the linear vibrator consists of a round steel housing. The inside of the magnet body features the excitation winding and the armature, which is guided centrally via a non-magnetic shaft and two springs, which are kept in the centre position.

A permanent magnet featuring guiding poles, which is positioned between both coils of the excitation winding, pre-magnetises the system. The forces affecting the armature in this case are compensated by the arrangement of the guiding poles.

If alternating voltage is applied to the excitation winding, the effective force of the electromagnetic alternating field overlays the effective force of the permanent magnet, whereby the positive current half-wave moves the armature in the one direction and the negative half-wave moves it in the opposite direction. Electromagnetic and spring forces complement each other in both movement directions.

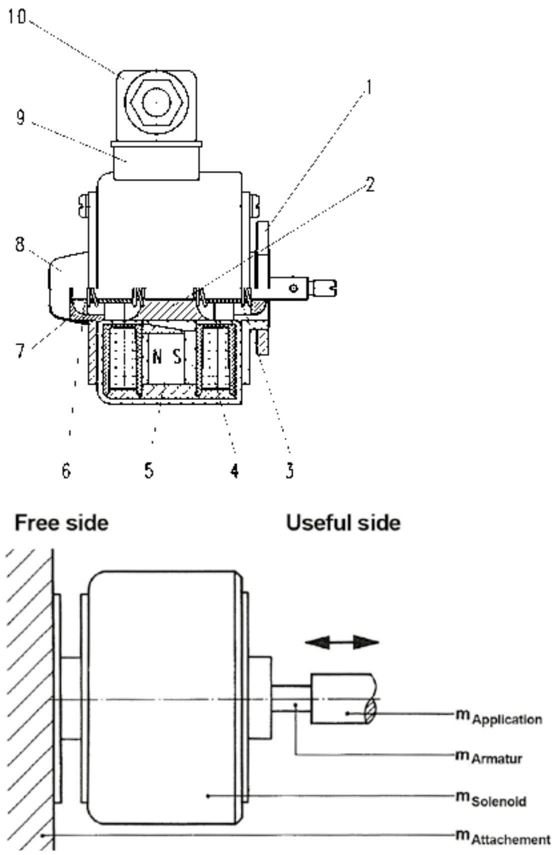


Figure 29 Linear oscillating drive, construction above, application principle below

1	Fastening flange	6	Spherical bearing
2	Amature	7	Spherical bearing shell
3	Spring	8	Sealing cap
4	Coil	9	Device plug connector
5	PE magnet	10	Device plug socket

The frequency of the resulting force on the armature corresponds with the frequency of the applied alternating voltage, which moves the armature linearly with the drive axis in the same rhythm. The linear vibrator may be used as an oscillating drive (OLV54...51) by fastening it to a large free mass using a fastening flange. This allows the axis to accept an oscillating movement (Figure 29 below).

In another form of application, a weight may be attached to the axis. In this case, the useful and free side are exchanged downwards in relation to Figure 29, and the drive works as a vibrator, similar to devices of type OSR….

Device types OMV… “Vibratory feeder driver”

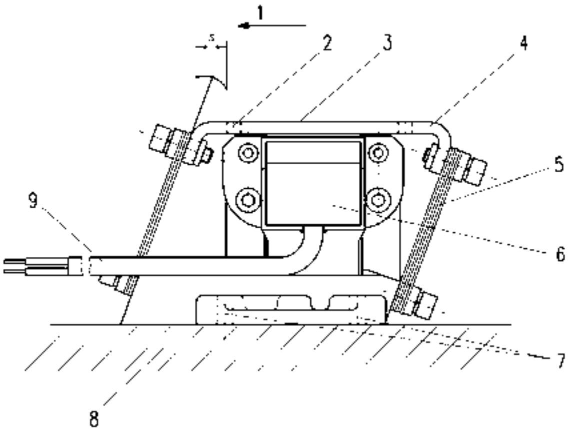


Figure 30 Vibratory feeder driver

1	Conveyor direction	6	Excitation system
2	Thread for fastening the conveyor trough	7	Fastener drilled hole
3	Useful side	8	Free side
4	Armature	9	Connection cable
5	Leaf spring package	s	Cycle stroke

In case of the vibratory feeder driver (Figure 30), the magnet body is fastened to a base with the excitation winding. The armature plate is positioned above this, which features pole surfaces separated by an air gap, which are parallel to the magnet body. The armature plate and the base are connected with each other by angled leaf springs (angle approx. 20°).
The coil features an integrated half-wave rectifier (types OMWxxxxx1 …OMWxxxxx3). The type OMWxxxxx4 is pre-magnetised by continuous magnets and works without half-wave rectification.
If alternating voltage is applied to the excitation winding, an attractive force pulsing at the mains frequency results in all types between the excitation system and the armature plate. Because the leaf springs are arranged at an angle, the armature plate with the conveyor trough fastened on top of it completes an oscillating movement and transports loose material in the conveyor direction. In case of larger or relatively broadly loaded conveyor trough, it is sensible to use multiple smaller devices in place of one large vibratory feeder driver.
Various leaf springs are available for all sizes of Kendrion vibratory feeder drivers, which enable the devices to be adjusted to the loading weight within their application limits. The corresponding characteristic curves are indicated in the data sheet. The cycle stroke is also able to be set using a frequency controller device or a phase angle controller without additional half-wave rectification. Take special care that the maximum cycle stroke is not exceeded, since this could result in severe damage or destruction of the device itself.

Device types OAB… (Figure 31) “Arc vibration generators”

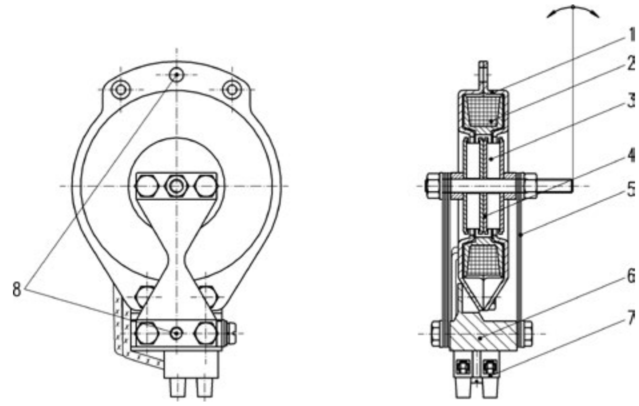


Figure 31 Arc vibration generator

1	Magnet body	4 Complete armature
2	Excitation winding	5 Spring
3	Permanent magnet	6 Device base
7	connector plug	8 Mounting

The magnet body of the arc vibration generator (Figure 31) comprises two ring shells, which contain the excitation winding. This is permanently connected to the device base. The armature consists of two round permanent magnets featuring axially inverted poles and two pole discs, and it is located between leaf springs that are fastened to the two opposite sides of the device base. The system is pre-magnetised by both permanent magnets. During inactivity, one ring pole is placed between two pole discs each of the armature. If alternating voltage is applied to the excitation winding, the unequal poles of the armature and magnet body attract. The frequency of the arc-shaped armature movement corresponds with the frequency of the applied alternating voltage.
The arc vibration generator may be used as an oscillating solenoid and as a vibrator with an additional weight on the armature shaft.

Sample applications (table 5)

Application	Device type
As a drive for diverse parts capable of oscillation on bearings (e.g. for spiral conveyors, linear conveyors, vibration tables, sieve technology), for hopper and chute vibration	OAC...
As a drive for linear movement	OLV…
As a substructure and drive for conveyor chutes, dosing, and filling devices	OMW…
For vibrating small chutes and hoppers; as a drive for sorting, dosing, vibrating	OAB… OSR... OLV..

Table 5: Sample applications of Kendrion oscillating drives

Electrical connection

The device sheets indicate the different connection types for

the individual devices. The devices may only be connected according to the specifications on the rating plate. Pay special attention to the voltage and frequency. It frequently occurs that multiple devices are operated parallel to a single control device. If the devices are intended to oscillate cophasal to increase the oscillating energy, then the devices must also be connected electrically cophasal.
If oscillation compensation is desired, the devices may be connected electrically inverted. In this case, the oscillating masses must be mechanically decoupled. The required free mass may be easily reduced using this method. However, exact coordination is required for this.
During operation, the amplitudes of all devices are controlled electrically (e.g. phase angle controls).

4.4. Coordination of device types with individual cases

Gerneral

Every oscillating system exhibits its own resonating frequency, which depends on its mass, spring constant, and the weight of the conveyed material.
If an oscillating conveyor is operated at its resonating frequency without damping, endlessly large amplitudes theoretically result, as well as the minimum energy requirement, however this system would not be controllable. A damped system that oscillates in its own resonance is unusable, since every change to the damping due to more or less conveyed material results in a change in the amplitude and therefore the conveyor speed. On the other hand, the oscillating frequency of the system should not be too far removed from the resonance frequency, especially since no or only a little oscillating movement would be created.

Using the curves in Figure 32, the connection between the damping and the resulting altered resonance frequency becomes clear. As damping increases, the f_{res} of the system drops.
By coordinating the system above (super-critical operation) or below (sub-critical operation) the resonance frequency, different properties of the conveyor are able to be reached.

Super-critical operation (Figure 32):

In case of super-critical operation, the drive frequency f_a is greater than the resonance frequency f_{res}.
Increased damping (b – c) caused by increased conveyed material, for example, increases the resonance distance and reduces the amplitude, i.e. the amplitude/conveyor output is subject to severe fluctuations. The force and vibration movement run inverted in this operating mode (the moment of the largest air gap coincides approximately with the maximum current), which requires a larger counter-mass and increased power consumption.

In practice, this type of coordination is used for smaller conveyors in assembly technology, since large counter-masses are present due to design reasons, and the resonance curve appears very flat because of high damping.

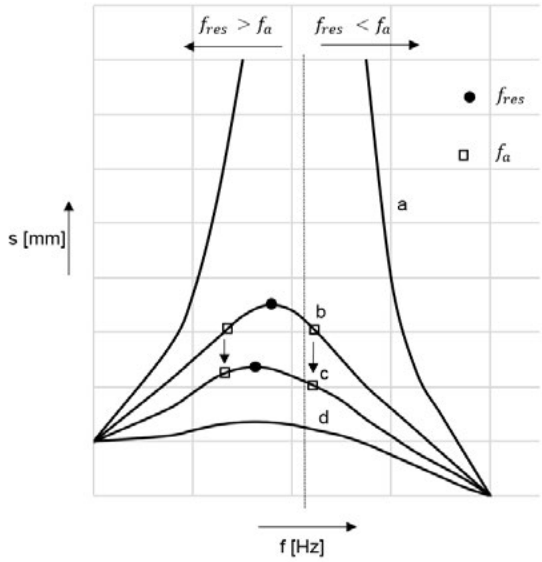


Figure 32 Cycle stroke s depending on the drive frequency ratio f_a to the natural frequency f_{res}

a	without damping (theoretical)
b,c,d	increasing damping
f_a	drive frequency
f_{res}	resonance frequency
$f_{res} > f_a$	sub-critical operation
$f_{res} < f_a$	super-critical operation

Sub-critical operation (Figure 32):

Increased damping (e.g. curve b – curve c) due to increased conveyed material, for example, reduces the resonance distance and the amplitude increases again. The reduction of the amplitude due to damping and the approach of drive and resonance frequency counteract each other, and the system is resistant to load fluctuations.
The force and oscillation movement run cophasal in this operating mode (the moment of the smallest air gap drops coincides approximately with the maximum current).
This type of coordination is selected in case of increased conveyed weight and to couple tilting conveyed materials.

Conveyed materials	Material that is conveyed through an oscillating system.
Traps	Sorting elements that are implemented in the conveyor and position the conveyed material correctly
Linear conveyor **Trough** **Conveyor rail**	The conveyed material is transported straight to an axial receptacle
Spiral conveyor Round Conveyor **Sorter**	The conveyed materials are moved upwards in a round conveyor on a spiral track, sorted by “traps” as required, and provided for further processing in a defined position (correct position).
Supply hopper **Hopper**	Elevator, conveyor belt, plate conveyor, or high-volume linear conveyor for automatic, sensor-controlled refilling conveyed material into the round conveyor
Accumulation sensor **Material sensor**	Sensor that determines if conveyed material is present/absent at a specified position and initiates measures for material flow
Accumulation switching **Fill level controls**	An (accumulation) sensor signal and adjustable time delays keeps the material level at a constant level to prevent unnecessary conveyor running times
Hopper controls	A sensor signal and adjustable time delays monitor the material level in the round conveyor and refill it from the bunker upon request (to ensure longer running times without personnel)
Min-max controls **Route controls**	Two accumulation sensors and adjustable time delays keeps the material level on a constant route to prevent unnecessary conveyor running times
t_{on} / t_{off}	Switch on or off delay of the conveyor drive
Cycle operation	The conveyor “cycles” over adjustable ON/OFF times to refill or separate parts
Umin / Umax	In order to adjust the target value range of different conveyor drives, the minimal and maximum output voltage of the control device may be specified. The adjustable target value range is between these two values
Gentle start	After activation, the conveyor increases to its set conveyor speed along a time-adjustable ramp to prevent previously sorted parts from tipping off/falling off or colliding with the solenoid armature
Gentle stop	After deactivation, the conveyor decreases to “zero” along a time-adjustable ramp to prevent the position of previously sorted parts from changing
Air gap **Idle air gap**	Clearance between the magnet and armature while the conveyor is idle
Conveyor speed **Conveyor output**	Conveyor quantity per time unit
Displacement	Movement of the conveyor relative to the idle air gap (2 x oscillation amplitude)
Oscillation frequency	The mechanical oscillation frequency of the conveyor, depending on the feed mains in case of triac/thyristor controls, independent of the feed mains in case of frequency control devices
Resonance frequency	Natural frequency of the system (min. power consumption, maximum, theoretical endless amplitude).
Operating frequency	The frequency specified by the mains (triac/thyristor controls) or by the frequency control device
Resonance distance	The difference between the resonance frequency and operating frequency
Super-critical operation	The operating frequency is above the resonance frequency Working stroke/displacement changes via load/damping.
Sub-critical operation	The operating frequency is below the resonance frequency Working stroke/displacement relatively independent under load/damping.
Half-wave operation **50 Hz – operation** **3000 min^{-1}.**	Oscillation frequency is equal to the mains frequency, only one half-wave is controlled Example: Mains frequency 50 Hz ≙ 3000 min^{-1}. Mains frequency 60 Hz ≙ 3600 min^{-1}.
Full-wave operation **100 Hz – operation** **6000 min^{-1}.**	Oscillation frequency is double the mains frequency, both mains half-waves are controlled Example: Mains frequency 50 Hz ≙ 6000 min^{-1}., Mains frequency 60 Hz ≙ 7200 min^{-1}

Table 6: Technical terms for oscillation drives

4.5. Activation devices for oscillating solenoids

Frequency control device (Figure 35)

A frequency inverter designed especially for oscillating feeder drivers creates a quartz-exact, adjustable drive frequency, independent of the mains frequency. This drive frequency can be adjusted in micro-steps of 0.1 Hz or 1 Hz to the resonance frequency of the oscillator, and the setting range spans from 5…200 Hz.
The output-side alternating voltage is sinusoidal, whereby clean oscillation generation is able to proceed in the oscillating drive, similar to mains supply.

For the user, this means that the complicated mechanical coordination and possibly the spring exchange is omitted, and the oscillator may be electronically specified to the running behaviour optimally. Basically, the adjustable drive frequency (Figure 33) ensures the technical oscillation adjustment of the spring-mass system (Figure 32), whereby the unwanted sub-critical or super-critical coordination is available.

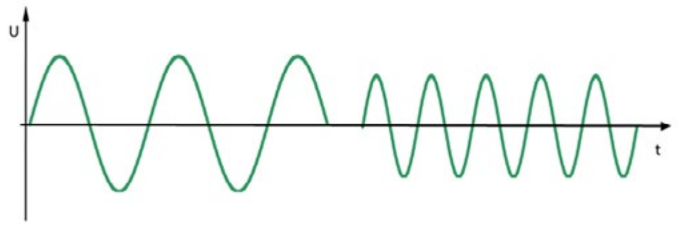


Figure 33 Various frequencies and voltages for activation of oscillating solenoids

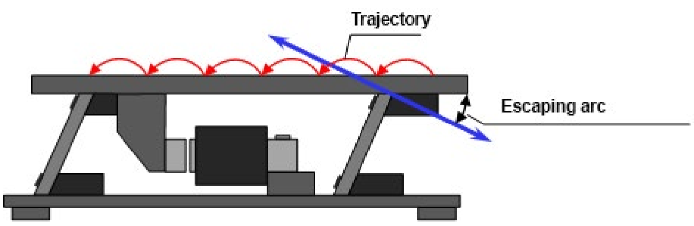


Figure 34 Function of a “micro-shot” oscillating conveyor

On the basis of abrasion behaviour, particle size, and specific weight, different materials behave very specifically as conveyed materials. The individual particles are provided to a “micro-shot” via a shot angle (= approx. oscillation angle α) specified by the positioning of the leaf springs (Figure 34). In this case, the frequency specification an exact adjustment to the optimum value for the respective material. In this case, mainly the oscillating frequency, but also the cycle stroke, are changed.
It is also possible to set the cycle stroke and therefore the conveyor power by changing the supplied solenoid voltage.
The frequency control device also possesses additional properties that are adjusted especially for operation with oscillating drives, for example remote control via potentiometer, half and full-wave operation, and gentle activation and deactivation.

Figure 35 Frequency controller device

Phase angle controls

Figure 36 Phase angle controls 33 43304B00 (left), 33 43303B00 (right)

Kendrion phase angle controls are used to create adjustable alternating voltage or pulsing direct voltage (half-wave operation) (Figure 37) to supply oscillating drives.

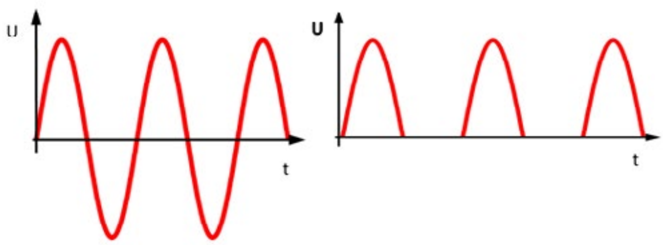


Figure 37 Full-wave operation (left) and half-wave operation by half-wave rectification (right)

The devices 3343303/04/B00 enables switching cabinet assembly on top-hat rails. The voltage can be set directly or via an external potentiometer. The devices possess a 24 V DC switch input and deliver maximum 2/3 A AC and voltages of 0 V to 0.95 U.

Suitability of Kendrion oscillating drives for half/full-wave operation of the frequency control device and phase angle control (table 7)

In case of drives that already possess pre-magnetisation, controls using sinus half-waves is not recommended. The result will not be satisfactory, since the overlap of the permanent magnet field and the solenoid field does not occur as intended. Furthermore, the result depends on the polarity.
The same applies if a half-wave rectifier is already integrated in the drive, as is the case with several OMW… types. Even at best, half-wave operation from the control device will not provide any advantage.

Type	Half-wave	Full-wave	Remark
OAC…	3000 min^{-1}	6000 min^{-1}	Complete frequency spectrum usable
OAB…	Not suitable	3000 min^{-1}	Integrated permanent magnets
OMW…	Not suitable	3000 min^{-1}	Permanent magnets or half-wave rectification integrated
OLV…	Not suitable	3000 min^{-1}	Permanent magnets integrated
OSR…	Not suitable	3000 min^{-1}	Permanent magnets integrated

Table 7: Possible uses and oscillation frequencies of Kendrion oscillating drives combined with Kendrion phase angle controls or frequency controls, oscillating frequencies related to 50 Hz working frequency

5. Formula symbols and SI units

Formula symbols	Size	Unit Symbol	Unit name
GEOMETRY			
A,S	Surface, surface area, Surface	m^2	Square metre
a	Distance	m	Metre
α,β,γ	Flat angle	rad	Radian
b	Width	m	Metre
d, δ	Thickness, layer thickness, diameter	m	Metre
δ_L	Air gap	m	Metre
h	Height	m	Metre
l	Length	m	Metre
r	Radius	m	Metre
s	Path length, curve length	m	Metre
V, τ	Volume, capacity	m^3	Cubic metre
τ_p	Pole pitch	m	Metre
TIME			
a	Acceleration	m/s^2	
α	Angular acceleration	rad/s^2	
f	Frequency	Hz	Hertz
g	Local gravitational acceleration	m/s^2	
n	Speed, rotation frequency	s^{-1}	
ω	Angular velocity	rad/s	
T, τ	Time constant	s	Second
t	Time, time span, duration	s	Second
v	Speed	m/s	
MAGNETISM			
B	Magnetic flax density, magnetic induction	T	Tesla
Φ	Magnetic flax	Wb	Weber
H	Magnetic field strength, magnetic excitation	A/m	
L	Inductance, Self-inductance, mutual inductance	H	Henry

Formula symbols	Size	Unit Symbol	Unit name
MECHANICAL			
E	Elasticity module	N/m^2	
F	Force	N	Newton
F_G	Weight force	N	Newton
J	Inertia moment 2nd moment of mass	kgm^2	Kilogram Square metre
M	Torque	Nm	Newton metre
m	Mass, weight as a result of weighing	kg	Kilogram
P	Power	W	Watt (1J/s=1W)
p	Pressure	Pa	Pascal
ρ	Density	kg/m^3	
σ	Normal, tensile, compressive, and bending stress	N/m^2	
W	Work	J	Joule
η	Degree of efficiency	1	
μ, f	Coefficient of friction	1	
HEAT			
α	Coefficient of resistance	1/k	
T, Θ	Temperature, thermodynamic temperature	K	Kelvin
t	Celsius temperature	°C	Celsius
ΔT = Δt = Δv	Temperature difference, over-temperature	K	Kelvin
ELECTRICITY			
C	Electrical capacity	F	Farad
G	Electrical conductance, conductance	S	Siemens
I	Electrical current	A	Ampere
P	Active power	W	Watt
R	Electrical resistance	Ω	Ohm
S, P_s	Apparent power	W	Watt
U	Electrical voltage, electrical potential difference	V	Volt
X	Reactance	Ω	Ohm
Z	Characteristic impedance, wave impedance, impedance	Ω	Ohm

6. References

The guideline VDE 0580:2011-11 is the basis of these technical explanations. It is quoted both directly and indirectly from this Directive.

Overview of Catalogue

Linear Solenoids

Classic Line

- single-stroke solenoids
- compact design
- individual fixing
- mono- and bistable version

High Performance Line

- square single-stroke solenoids
- high force with small installation space
- modular system
- short pull-in times

High Power Line

- round single-stroke solenoids
- high forces and stroke travels
- short switching times
- also reversible solenoids

Control Power Line

- control solenoids
- extremely fast switching
- short strokes
- precise switching

Electro Holding Magnets

Hahn CQ Line

- door holding magnet
- design and functionality
- VdS, CE, EN 1155, EN 14637 tested
- great variety

Industrial Line

- industrial holding magnets
- high holding force with low power consumption
- compact design
- variable connections

Oscillating Solenoids

Oscillating Line

- vibratory solenoids
- wide product range for transportation of bulk material
- low wear and tear
- compact design

Elevator Line

- spreader solenoids
- especially designed for elevator brakes
- extremely high forces
- any mounting position

ATEX Line

- explosion-proof solenoids
- prevent the occurrence of sparks and light arcs
- dynamic and reliable switching

Locking Line

- locking solenoids
- high transverse forces
- integrated feedback of locking function
- compact design

System Line

- operated by AC
- extremely short activation times
- very high pull-in forces

Custom Solutions

- **Rotary solenoids**
- **Assemblies**
- **Customer-specific solutions**

Please contact us for special or customer-specific solutions.

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WE MAGNETISE THE WORLD

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