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Commutation setting

.Commutation setting

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.Explanation

Three-phase a.c. motors are only operable if torque or force acts on the moving part of the motor due to the assignment of current in the motor windings (primary part) to the motor magnetic field (secondary part). The establishment of this assignment is called "commutation". It is implemented by a "commutation angle", or "commutation offset", that enables the suitable motor control in each possible position of the primary part with regard to the secondary part:

- Synchronous motors have a permanent motor magnetic field, that is why a specific value is required for the "commutation offset"
- Asynchronous motors have a magnetic field that is induced with neutral orientation, their commutation offset is a default value

.FOC operation (control with motor encoder)

For field-oriented current control (FOC), the position of the primary part with regard to the secondary part is acquired via a position encoder (motor encoder), and via the suitable "commutation angle" (commutation offset) the motor is controlled in such a way that the maximum possible torque or the maximum possible force is generated when current flows:

- Synchronous motors with motor encoder require a motor-specific "commutation offset" due to the stationary permanent magnets in the secondary part, if the position encoder was mounted without a defined orientation.
- For asynchronous motors with motor encoder, a default "commutation offset" takes effect. According to the default value, the magnetic field of the motor is induced with neutral orientation.

FOC operation is possible both for rotary motors and for linear motors!

.SVC operation (control without motor encoder)

In the case of motor control by sensorless current control, a commutation offset is also required. The commutation offset value is generated automatically when drive enable is set. However, the performance is limited as compared to FOC motor control with encoder!

Sensorless SVC operation is only possible for rotary motors!

.Relevance for the user

.Use case

For which cases is it relevant to have a look at the topic of "commutation setting"?

.Relevance of commutation setting for - motors and third-party motors

Relevance?	Type of construction of motor?	Rexroth motor ranges?	Motor encoder?	Additional Hall sensor component?	Commutation setting?
No	Rexroth housing motor	MSK, MS2N MAD, MAF	Integrated in the motor housing	None	No, already done by the manufacturer!
Yes	Rexroth synchronous kit motor	MLF, ML3	On axis side, third-party component	No, SHL02 cannot be used for MLF on device side with Rexroth linear motors	Yes, required! After the motor components were installed in the axis!
		MBS, MBT		No (not available for rotary motors)	
No	Rexroth asynchronous kit motor	1MB			No, not required!
Yes	Third-party synchronous motor	/	Third-party component	/	Yes, required!
No	Third-party asynchronous motor	/	Third-party component	/	No, not required!

. Rexroth housing motors

Rexroth housing motors do not require any commutation setting by the user! They are immediately operational at delivery if controlled with ctrlX DRIVE controllers:

- MS2N (synchronous motors)
- MSK (synchronous motors)
- MAD (asynchronous motors)

- MAF (asynchronous motors)

> - For Rexroth housing motors working according to the principle of synchronous motors, the motor-specific value of the commutation offset is determined during the production process and stored in their data memory in the motor encoder. The user does not need to set the commutation offset!
> - Rexroth housing motors working according to the principle of asynchronous motors do not require any unit-specific value of the commutation offset!

. Rexroth kit motors

For synchronous Rexroth kit motors, the user is required to set the commutation for FOC operation! These motors consist of individual components (primary part with motor winding, secondary part with permanent magnets). They are only assembled to form an operational motor when they are installed in the machine axis and completed by the customer with a motor encoder for FOC operation. **The commutation offset can only be determined by the user during commissioning after the motor unit has been completed. Only then the motor will be operational with ctrlX DRIVE controllers!**

The following Rexroth kit motors are manufactured according to the functional principle of a "synchronous motor":

- MLF, ML3 linear motors
- MBS and MBT rotary motors

> It has to be possible for ctrlX DRIVE to evaluate the motor encoder used (see ↘ “Supported motors and motor encoders”)
>
> The firmware and the commissioning tool support the determining of the commutation offset value.

.Third-party synchronous motors

For third-party synchronous motors, the user is required to set the commutation for FOC operation! The motor has to be equipped with a motor encoder. The motor-specific commutation offset has to be determined by the user during the commissioning of the motor. Only then the motor will be operational with ctrlX DRIVE controllers!

> It has to be possible for ctrlX DRIVE to evaluate the motor encoder used (see ↘ “Supported motors and motor encoders”)
>
> The firmware and the commissioning tool support the determining of the commutation offset value.

.Application-related information for project planning

. Rexroth kit motors

For FOC operation, Rexroth kit motors require an axis-side position encoder; it has to be possible for ctrlX DRIVE to evaluate the position encoder as a motor encoder.

.Motor encoder, absolute vs. relative

In most cases, the position encoder used as motor encoder and integrated in the axis mechanics is not supplied by Rexroth, but provided by the customer. It is a conventional product selected according to the mechanical conditions of the axis and the qualitative requirements.

With regard to their actual position values that can be displayed, position encoders used as motor encoders are distinguished as encoders that can be evaluated in **absolute** form or in **relative** form.

The motor encoder of a synchronous motor is particularly important for its fail-safe commutation. Ideally, only **absolute motor encoders** should be used for synchronous Rexroth kit motors. The advantage in this case is that the correct assignment of current in the primary part to the magnetic field in the secondary part is immediately ensured when drive enable is set, when the commutation offset had been determined and stored in the drive during the initial commissioning of the motor.

For some applications it is **necessary to use relative motor encoders** , because the available length of absolute motor encoders is limited, for example. The disadvantage in this case is that absolute detection of the motor position is impossible. Therefore, the commutation offset has to be set again each time the drive is switched back on or after a change of the communication phase from "CM" to "OM" ("bb" or "Ab").

For rotary motors, the disadvantage regarding commutation can be avoided by a single resolver encoder (analog, relative encoder), if the suitable resolution is selected: As motor encoders for rotary synchronous motors, they have the property to be an "absolute commutation initialization encoder", if the resolver has the same number of pole pairs as the motor or one pole pair.

For additional information on the resolver encoder, please see .

Concerning operationally reliable drives with third-party synchronous motors and ctrlX DRIVE controllers with regard to the selected motor encoder, the same principles apply as for Rexrothsynchronous kit motors (see above).

.Overview of the motor encoders to be used for FOC operation of synchronous motors

.Possible combinations of motor encoders and synchronous motors

Motor encoder	Rexroth synchronous kit motor (rotary, linear)	Rexroth synchronous kit motor (linear) with SHL02	Third-party synchronous motor
Absolute	+	--	+
Relative	o / +[1)]	/	o / +[1)]

Motor encoder	Rexroth synchronous kit motor (rotary, linear)	Rexroth synchronous kit motor (linear) with SHL02	Third-party synchronous motor
Legend: +: *advantageous combination* 1): *only applies to resolver encoders with the same number of pole pairs as rotary motor* o: *Combination possible, initial commissioning might possibly require especially trained staff* --: *Combination not useful and not possible / Combination not possible* SHL02: *Hall unit Additional Hall sensor component or option*			

.Additional Hall sensor component

For Rexroth MLF linear motors that are to be used with a relative motor encoder, it is not yet possible to use the SHL02 additional Hall sensor component intended for this purpose on the motor side. As an alternative, an absolute encoder can be used.

.Methods of commutation setting

For commutation setting, the drive firmware provides alternative methods. **Depending on the motor and motor encoder**, the following methods are **preferably used**:

- **Linear motor MLF, ML3 with absolute encoder**
  - Measuring method (without current): Distance measurement, access to the axis mechanics is required
  - a) Saturation method (with current) for MLF and ML3, if "measuring method" (1.) is not possible because no access to measuring distance [except for MCL, because ironless motor -> MCL see (2.b)].
    b) Sine-wave method or orientation method (with current) for MCL (ironless motor), if "measuring method" (1.) is not possible
- **Linear motor MLF, ML3 with relative encoder**
  - Saturation method (with current) for MLF and ML3
  - Sine-wave method or orientation method (with current), if "saturation method" (1) is not possible due to ironless motor (MCL) or because maximum controller current is not sufficient.
- **Motors MBSxx2, MBT and third-party motors with absolute or relative encoder**
  - Saturation method (with current): Controller needs to be able to provide the maximum motor current!
  - Sine-wave method or orientation method (with current), if "saturation method" (1) is not possible because, for example, maximum controller current is not sufficient or magnetic saturation of the motor is not sufficient.

.Specific characteristics depending on the motor encoder

For determining the commutation offset of synchronous kit motors and third-party motors there are the following specific characteristics to take into consideration, depending on the motor encoder used:

Absolute motor encoder

- In this case, the commutation offset is a motor-specific, static value. This value is determined during the initial commissioning of the motor with the preferred method mentioned for each case, and the value is permanently stored in the drive.
- Before it is stored, the commutation offset value should be checked for maximum possible performance and, if necessary, it should be optimized.

With the stored motor-specific commutation offset, the **motor with absolute motor encoder** is **immediately ready for operation** when drive enable is set, comparable to a housing motor with motor encoder memory! **Recommendation: Use absolute position encoders as motor encoders!**

Relative motor encoder

- In this case, the commutation offset is not a static value! It depends on the position of the motor shaft/moving motor component when the relative motor encoder is initialized.
- The relative motor encoder is initialized after the transition from CM to PM. When drive enable is set, the commutation offset is automatically determined with the preferred method with current mentioned for each case.
- This commutation offset value always has to be determined again after the encoder was initialized. The value can be of different qualities so that the drive performance may be significantly reduced.
- To maintain the best possible performance of the drive, an optimized reference value for the commutation offset can be generated during initial commissioning. After a motion procedure, this reference value can be taken into account as a corrective factor for the currently determined value (see ↘ “Commissioning”)

Since the commutation offset value always has to be determined again and might be of different qualities, using **relativeposition encodersas motor encoders for synchronous motors is not recommended**! There are risks with regard to the performance and operational safety of the drive!

.Restrictions in case a relative motor encoder is used

If a synchronous kit motor or third-party motor with a relative motor encoder is used, the preferred commutation method with current starts when drive enable is set and determines a commutation offset that matches the current position of the motor shaft/moving motor component.

There are the following restrictions for determining the optimum commutation offset value, depending on the commutation method:

.Restrictions for saturation method

. Typical applications and restrictions for saturation method

Applications of synchronous motors with relative motor encoder	Restrictions for saturation method

Applications of synchronous motors with relative motor encoder	Restrictions for saturation method
Rexroth MCL motors (ironless) and third-party motors without or with only little saturation effects (e.g. ironless motors or motors with high leakage flux)	Saturation method cannot be used for determining commutation offset!
Applications with relative motor encoder (without using the commutation offset correction by motion procedure)	Max. torque/force can be reduced by approx. 20% compared to the optimum value (autom. determination of the commutation offset with "AF")!
Applications with relative motor encoder for which the commutation offset correction by motion procedure is used	Max. torque/force until reference mark is passed can be reduced by approx. 20%!
Drives that may be in motion during the determination of the commutation offset, e.g. coasting spindles, printing roller drives etc.	Saturation method is only possible for motors in standstill!
Drives with a low degree of overload capacity	Saturation method only possible if amplifier current is sufficiently high: Twice the nominal motor current is typically required for commutation setting. Ideally, the drive should be able to supply the motor peak current.
Drives that are not permitted to move during determination of the commutation offset (low-friction axes with low inertia)	Saturation method (with current) can cause motor motion!

.Restrictions of sine-wave and orientation method

. Typical applications and restrictions of sine-wave and orientation method

Applications of synchronous motors with relative motor encoder	Restrictions of sine-wave and orientation method
Linear axis with single motor or parallel motor	Only balanced (e.g. horizontal) axes with little friction! Motors subject to cogging force may lead to problems! The axis must not be positioned at the limit stop, free movement is required!
Linear axes in Gantry arrangement	Only balanced (e.g. horizontal) axes with little friction! In addition, both drives have to carry out sequential commutation settings, "AF" should not be active at the other drive!
Axis with holding brake (e.g. vertical axis)	Holding brake must be released to determine the commutation offset successfully. Only possible for balanced axes!
Rotary axes with single drive	Only balanced axes with little friction; high inertia can cause problems! Motors subject to cogging torque may lead to problems!
Rotary axes, mechanically connected	See above "Linear axes in Gantry arrangement"!

.Commissioning

.Motor encoders to be evaluated in absolute form in a motor-related way

The ideal case of motor commutation is a **motor encoder to be evaluated in absolute form in a motor-related way**. In this case, the commutation offset is determined during motor commissioning with the preferred method depending on the motor, and it is stored in the drive.

Afterwards, the synchronous motor is fully operational. In the future, it will always be immediately ready for power output after restarting.

Designs of motor encoders to be evaluated in absolute form in a motor-related way (encoder directly attached):

- Single-turn combined encoders or digital single-turn encoders
- Multi-turn combined encoders or digital multi-turn encoders
- Resolvers with the same number of pole pairs as the motor

If axis-related, absolute evaluation of the motor encoder is not possible, motor-related, absolute evaluation of the motor encoder may nevertheless be possible!

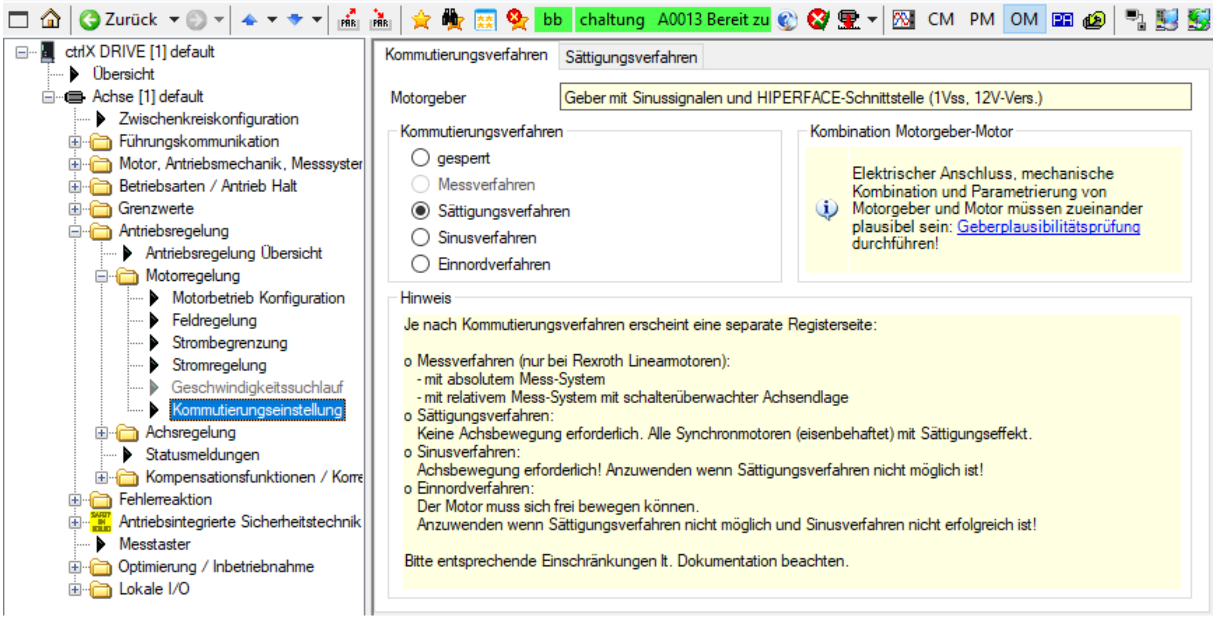

Fig. 309: ctrlX DRIVE Engineering basic dialog for commutation setting

.Relative motor encoders

If it is not possible, for implementation-related or cost-related reasons, to use a motor encoder to be evaluated in absolute form in a motor-related way, a motor encoder to be evaluated in relative form may be used. The disadvantage is the fact that after every motor encoder initialization [switching on, transition CM->OM (bb, Ab)] **the commutation offset has to be determined again**, because it is not a constant value.

To **maintain the best-possible motor performance** for switching on in the future, the commutation offset determined during initial commissioning is converted, after a motion procedure, to a fixed dedicated position on the motor side and stored as a reference value in the drive. When switching on in the future, a difference value is calculated from the stored reference value and the new commutation offset value currently determined. This is done by a repeated motion procedure (typically the motion for establishing the position data reference), and the difference value is added to the current value as a corrective factor.

Designs of relative motor encoders (encoder directly attached):

- 1Vpp encoders with sinusoidal signals and reference marker
- Resolvers with a number of pole pairs different from the motor and more than one pole pair

.Additional information and details

.Resolution of the commutation offset

The "commutation offset" refers to a motor pole pair that is assigned an electrical angle range of 360°. The electrical angle of 360° (one "electrical revolution" over one period of the sinusoidal control voltage of motor control) is standardized by the drive firmware to 1024 increments. For this reason, the value range of the commutation offset parameters (P-0-0508, P-0-0509, P-0-0515, P-0-0521) is 0...1023, corresponding to a resolution of up to 0.4°el.

The "commutation resolution" is determined by the controller in consideration of all mechanical transmission elements between motor encoder and motor. Depending on the resolution of the Basic encoder evaluation, the available position increments are calculated back to a pole pair of the motor and checked for the minimum resolution of 512 increments. This minimum resolution is already sufficient to realize the optimum torque/force constant.

In , the arrangement options of position encoders and the mechanical transmission elements acting in the drive mechanics are described in detail!

.Rotational direction motor - motor encoder

To successfully determine the commutation offset, it is imperative that the rotational direction of the motor matches the rotational direction of the motor encoder. This is the case if the position feedback value of the motor encoder (S-0-0051) shows increasing position feedback values at positive torque/force command value (S-0-0080 or P-0-0049) (take possible negations of the polarity parameters into account!).

If the rotational direction of the motor does not match the rotational direction of the motor encoder, the motor cannot follow the command value with the determined commutation offset. It moves to a close-by rest position or carries out uncontrolled movements. The error message F8010 might occur, but not necessarily!

The rotational direction is checked by starting the "encoder plausibility check" (command C3700, configured in P-0-0582), and for balanced axes it should always be carried out before the commutation setting. It requires motor motion over two revolutions or two pole pair distances. If a holding brake is present, it will be released for this process. When an axis is at the mechanical limit stop, an error message is likely to occur!

CAUTION!

. Check of the rotational direction

The check of the rotational direction is not suited for unbalanced, vertical axes! The axis will drop down when the holding brake is released after C3700 was started!

.Commutation methods

For determining the commutation offset, the drive firmware provides alternative methods that are preferably used, depending on the motor type and situation. Thus, an optimum, reliable value can be determined in the shortest possible time.

Methods without current:

- **Measuring method**
  → only with Rexroth linear kit motors with motor encoder to be evaluated in absolute form: distance measurement between primary and secondary part at a position in the axis setup, see documentations:
  - "Synchronous linear motors MLF"
  - "Self-cooled linear motors ML3"

Methods with current:

- **Saturation method** (motor in standstill or blocked)
  → with all iron motor types in combination with motor encoders that can be evaluated in absolute form or with relative

motor encoders; not with ironless motors. See ↘ “Restrictions for saturation method”
The "saturation method" is a commutation method for which the axis needs to be blocked or at standstill. Ideally, the motor should be blocked. If the motor has a braking device that is controlled by the drive controller, the braking device is actively blocked.

- **Sine-wave method** (requires unrestricted movement of the motor)
  → with all iron and ironless motor types in combination with motor encoders that can be evaluated in absolute form or with relative motor encoders; if the saturation method is not possible. See ↘ “Restrictions of sine-wave and orientation method”
- **Orientation method** (requires unrestricted movement of the motor)
  → with all iron and particularly ironless motor types in combination with motor encoders that can be evaluated in absolute form or with relative motor encoders; if the saturation method is not possible and the sine-wave method is not successful. See also ↘ “Restrictions of sine-wave and orientation method”

.Checking / subsequently optimizing the commutation offset

Optimizing the offset value by means of command

The value determined for "P-0-0521, Effective commutation offset" can be checked by the controller and subsequently optimized. "P-0-0518, Commutation: Factor current" is used for this purpose. The drive has to be in drive enable (AF) and in standstill. In addition, the axis has to be able to move sufficiently (motion range see table).

. Minimum required motion range for executing command C5600

Motor design	Motion range	Reference
Rotary	± 10 angular degrees	Motor shaft
Linear	± 0.1 × pole pair distance	Primary part

The controller optimizes the commutation offset which is already operational (value stored in P-0-0521) by transmitting test signals to the motor. The information for improving the commutation offset is taken from the motor motion (actual position value). Upon successful execution of command C5600, an improved value is available in parameter P-0-0521.

> It is always recommended to execute "C5600 Command subsequent optimization of commutation offset" if none of the restrictions mentioned for the "orientation method" (see above) exists!

Manually optimizing the commutation offset

The automatically determined value for the commutation offset is stored in parameter "P-0-0521, Effective commutation offset". If the initial commissioning mode is active (respective bit in P-0-0522), the value of P-0-0521 can also be manually optimized. Optimization should be carried out using a force measurement device.

$$(P\text{-}0\text{-}0521)_m = (P\text{-}0\text{-}0521)_a \pm 150$$

Fig. 310: Range of values for optimizing the commutation offset

m manually

a automatically determined

.Checking / subsequently optimizing the commutation offset

Manually optimizing the commutation offset

The automatically determined value for the commutation offset is stored in parameter "P-0-0521, Effective commutation offset". If the initial commissioning mode is active (respective bit in P-0-0522), the value of P-0-0521 can also be manually optimized. Optimization should be carried out using a force measurement device.

$$(P\text{-}0\text{-}0521)_m = (P\text{-}0\text{-}0521)_a \pm 150$$

Fig. 311: Range of values for optimizing the commutation offset

m manually

a automatically determined

.Mechanical arrangement options of the motor encoder

Evaluation of a position encoder as motor control encoder (motor encoder) depends on the arrangement of the position encoder within the drive mechanics and the type of coupling: The position encoder has to be connected to the motor without slip and with low elasticity.

In , the arrangement options of position encoders and possible applications are described in detail!

Effect of an encoder gearbox

If a motor encoder to be evaluated in absolute form is connected via an encoder gearbox in the case of a synchronous motor, in general there is no unambiguous assignment of electrical angle and absolute actual position value. Therefore, the motor encoder to be evaluated in absolute form now behaves like a relative motor encoder as regards commutation.

In two special cases, however, absolute commutation initialization is possible for synchronous motors with encoder gearbox:

- Case 1, single-turn (or multi-turn) encoder:
  - If an n-fold motor revolution (n is an integer) results in exactly one encoder revolution
- Case 2, multi-turn encoder:
  - If exactly one motor revolution results in an m-fold encoder revolution (m is an integer)

Effect of a load-side, absolute encoder

For synchronous motors with relative motor encoders and with slip-free drive mechanics, the load-side encoder can be used as commutation initialization encoder for the motor, if an additional encoder (encoder 2) that can be evaluated in absolute form is installed at the axis. In this case, the assignment is made in "P-0-0185, Encoder 2 control word". The specifications for synchronous motors with a motor encoder that can be evaluated in absolute form apply.

Axis with sensorless synchronous motor and load-side encoder 2

In confined spaces, position-controlled axes may require the use of a sensorless motor in combination with a load-side encoder. With slip-free drive mechanics, the load-side encoder (encoder 2) can be used as a motor encoder. In this case, the parameter "P-0-0515, Commutation offset 2" is used instead of "P-0-0508, Commutation offset":

- With absolute load-side encoder for motor-related commutation offset value.
- With relative load-side encoder as reference point-related value of "P-0-0521, Effective commutation offset", if the "optimum commutation setting with regard to reference point" is used.

Encoder 2 used as motor encoder (commutation initialization encoder), see also .

.Parameters involved

Besides the motor parameters (see overview of parameters in , other parameters are available for commutation setting:

- P-0-0506, Amplitude for angle acquisition
- P-0-0507, Test frequency for angle acquisition
- P-0-0508, Commutation offset
- P-0-0509, Commutation offset coarse
- P-0-0514, Amplitude for angle acquisition, sine-wave method
- P-0-0515, Commutation offset 2
- P-0-0517, Commutation: Required harmonics component
- P-0-0519, Commutation status word
- P-0-0520, Test frequency for angle acquisition, sine-wave method
- P-0-0521, Effective commutation offset
- P-0-0522, Control word for commutation setting
- P-0-0523, Commutation setting measured value
- P-0-0524, C1200 Commutation offset setting command

General information

General information

Explanation

Three-phase a.c. motors are only operable if torque or force acts on the moving part of the motor due to the assignment of current in the motor windings (primary part) to the motor magnetic field (secondary part). The establishment of this assignment is called "commutation". It is implemented by a "commutation angle", or "commutation offset", that enables the suitable motor control in each possible position of the primary part with regard to the secondary part:

- Synchronous motors have a permanent motor magnetic field, that is why a specific value is required for the "commutation offset"
- Asynchronous motors have a magnetic field that is induced with neutral orientation, their commutation offset is a default value

FOC operation (control with motor encoder)

For field-oriented current control (FOC), the position of the primary part with regard to the secondary part is acquired via a position encoder (motor encoder), and via the suitable "commutation angle" (commutation offset) the motor is controlled in such a way that the maximum possible torque or the maximum possible force is generated when current flows:

- Synchronous motors with motor encoder require a motor-specific "commutation offset" due to the stationary permanent magnets in the secondary part, if the position encoder was mounted without a defined orientation.
- For asynchronous motors with motor encoder, a default "commutation offset" takes effect. According to the default

value, the magnetic field of the motor is induced with neutral orientation.

FOC operation is possible both for rotary motors and for linear motors!

SVC operation (control without motor encoder)

In the case of motor control by sensorless current control, a commutation offset is also required. The commutation offset value is generated automatically when drive enable is set. However, the performance is limited as compared to FOC motor control with encoder!

Sensorless SVC operation is only possible for rotary motors!