Selection of a third-party motor driver

Summary

When deciding to use a third-party motor driver instead of a FAULHABER driver, this motor driver has to fulfill a few requirements to be compatible with FAULHABER motors.

There are three major aspects, two of them are related to thermal motor protection:

- **The PWM frequency of the motor driver**

  Most FAULHABER motors have a slotless design. This leads to an advantageous dynamic behavior without any cogging torque.

  The slotless design also results in motors which have a very low electrical time constant. When choosing a motor driver, the PWM frequency has to be selected accordingly. A high switching frequency (**at least 40 kHz**) is required to avoid thermal losses in the motor.

  Similar considerations apply when using third party slotless motors.

  FAULHABER controllers therefore operate at a very high PWM frequency of about 100 kHz.

- **The interpretation of the datasheet current of BLDC motors**

  The current of micro BLDC motors is not expressed as rms current but as a DC-equivalent current, instead. This is also true for most third-party micro BLDC motors.
  If a third-party driver is working with rms currents, which is usually the case, the current has to be converted into the required value (see page 4).
  This is especially relevant for any thermal motor protection.

  FAULHABER controllers provide thermal motor protection – using a I²t model for the Speed Controllers and sophisticated algorithms for Motion Controllers.

- **The hall sensor pattern and excitation sequence of BLDC motors**

  The three hall sensors of FAULHABER BLDC motors are phase shifted by 120°.
  Most FAULHABER digital hall sensors use an open collector topology, therefore requiring pullup resistors in the driver.
  A detailed excitation sequence is provided on page 5.
  The third-party driver needs to be adjustable accordingly, which most drivers are.

Applies To

FAULHABER BLDC and DC motors

Description

Background on PWM power losses

FAULHABER slotless motors have windings with very low electrical time constants typically in the range of 10..400 µs (= Inductance L / Resistance R).
When combined with a PWM driver this causes a current ripple, which leads to additional motor power losses.

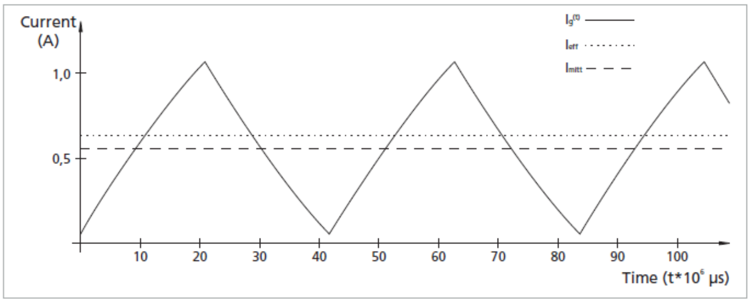

Figure 1: Motor current @ too low PWM frequency

The motor driver must be able to cope with the low electrical time constant – a high PWM frequency is required to reduce the current ripple and minimize the additional thermal losses.

Selecting a lower supply voltage, if applicable, also reduces PWM related losses.
The filtering provided by additional motor phase inductances does so as well.
When further interested in the last two measures see Application Note 178 for details.

Besides PWM frequency, PWM related losses also depend on the duty cycle of the operating point. The duty cycle reflects the percentage of voltage applied to the motor.

- At low and high duty cycles PWM losses are low.
- At a duty cycle in the range of 40..60% PWM related losses are highest.

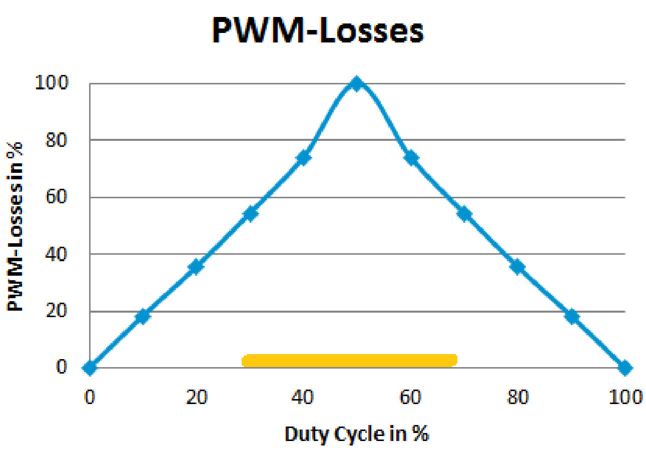

Figure 2: PWM Losses as function of duty cycle

Motor performance dependent on motor driver's PWM frequency

To get an impression on how important it is to select a PWM frequency fitting the motor type, the following tables are showing the performance of FAULHABER motors at different PWM frequencies The values in % express how much the torque has to be reduced in order not to thermally damage the motor operating continuously at the named worst case operating point.

Slotless DC motors — Feasible Torque @ **50 % duty cycle**, @nominal voltage

Motor name	Torque/speed@ half the nom-inal voltage, full modulation	@ 10 kHz	@ 20 kHz	@ 50 kHz	@ 100 kHz
1319 SR	1.5 mNm @ 500 rpm	- 9 %	- 3 %	☑	☑
2657 CXR	42 mNm @ 2000 rpm	- 34 %	- 12 %	- 5 %	- 5 %

Slotless BLDC motors — Feasible Torque @ **50 % duty cycle**, @nominal voltage

Motor name	Torque/speed@ half the nom-inal voltage, full modulation	@ 10 kHz	@ 20 kHz	@ 50 kHz	@ 100 kHz
2250 BX4	29 mNm@ 2000 rpm	- 17 %	- 7 %	- 5 %	- 5 %
3268 BX4	90 mNm @ 2000 rpm	- 29 %	- 16 %	- 8 %	- 8%

Slotted BLDC motors — Feasible Torque @ **50 % duty cycle**, @nominal voltage

Motor name	Torque/speed@ half the nom-inal voltage, full modulation	@ 10 kHz	@ 20 kHz	@ 50 kHz	@ 100 kHz
32 BXTH	39 mNm @2000 rpm	☑	☑	☑	☑

Recommendations:

For **slotless** motors a PWM frequency of **at least 40 kHz** 1) is highly recommended, when applying the nominal motor voltage to the driver. When operating the driver at voltages above the nominal motor voltage PWM losses significantly increase, therefore **at least 80 kHz** would be necessary to fully utilize the motor. **Slotted** motors on the other hand do not require such high frequencies, **10 to 20 kHz** is usually sufficient.

1) The PWM frequency is related to a center-aligned topology, drivers using an edge aligned topology need to use twice the recommended PWM frequency.

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Hints on thermal motor protection and motor torque monitoring

The correct interpretation of motor currents is relevant for

- thermal motor protection
- understanding the relation between motor current and motor torque

These two aspects are discussed here.

<u>For **thermal motor protection** some drivers offer a I^2t model:</u>

- The thermal time constant tau1 found in the motor datasheet is recommended to be used for this purpose.

- In addition, a current value which can be applied continuously under the ambient and mounting conditions must be parametrized.
  When the ambient temperature equals 22°C and the motor is mounted using an aluminum flange, the applicable current is usually the datasheets rated current. If the conditions differ the current has to be adjusted accordingly.

- Most third-party drivers interpret currents as rms values. Since the datasheet currents of FAULHABER **BLDC** motors are listed as DC-equivalent currents, they need to be converted to be used in such a third-party motor driver.
  Depending on the commutation type the conversion looks like this:
  - Sinusoidal commutation: **DC equivalent current * 0.78 = RMS Current**
  - Trapezoidal commutation: **DC equivalent current * 0.82 = RMS Current**

  If interested, the derivation of a DC-equivalent can be found in Application Note 183, as well as the explanation why the current supplying a driver does not equal the motor current.

<u>Monitoring the motor current can be used to estimate the **motor torque**:</u>

- Motor torque = motor current x torque constant km;

- Applied to **BLDC** motors:
  If the monitored current is a rms value, is has to be multiplied by 1.29 (sinusoidal commutation), respectively by 1.22 (trapezoidal commutation) before inserting it into above equation.

The excitation sequence and hall sensor pattern of FAULHABER BLDC motors

For clockwise rotation the following excitation sequence applies.

	Sensors			Phases		
Electrical Degrees	A	B	C	A	B	C
0 - 60°	1	0	0	High	x	Low
60 - 120°	1	0	1	High	Low	x
120 - 180°	0	0	1	x	Low	High
180 - 240°	0	1	1	Low	x	High
240 - 300°	0	1	0	Low	High	x
300 - 360°	1	1	0	x	High	Low

Figure 3: Hall sensor outputs and excitation sequence

- Commutation Sequence is C-B-A for clockwise rotation.
- There are three hall sensors phase shifted by 120°.
- Most FAULHABER hall sensors use an open collector topology and therefore require pull-up resistors in the motor driver.
- Back-EMF is phase shifted by 60° regarding the hall sensors.

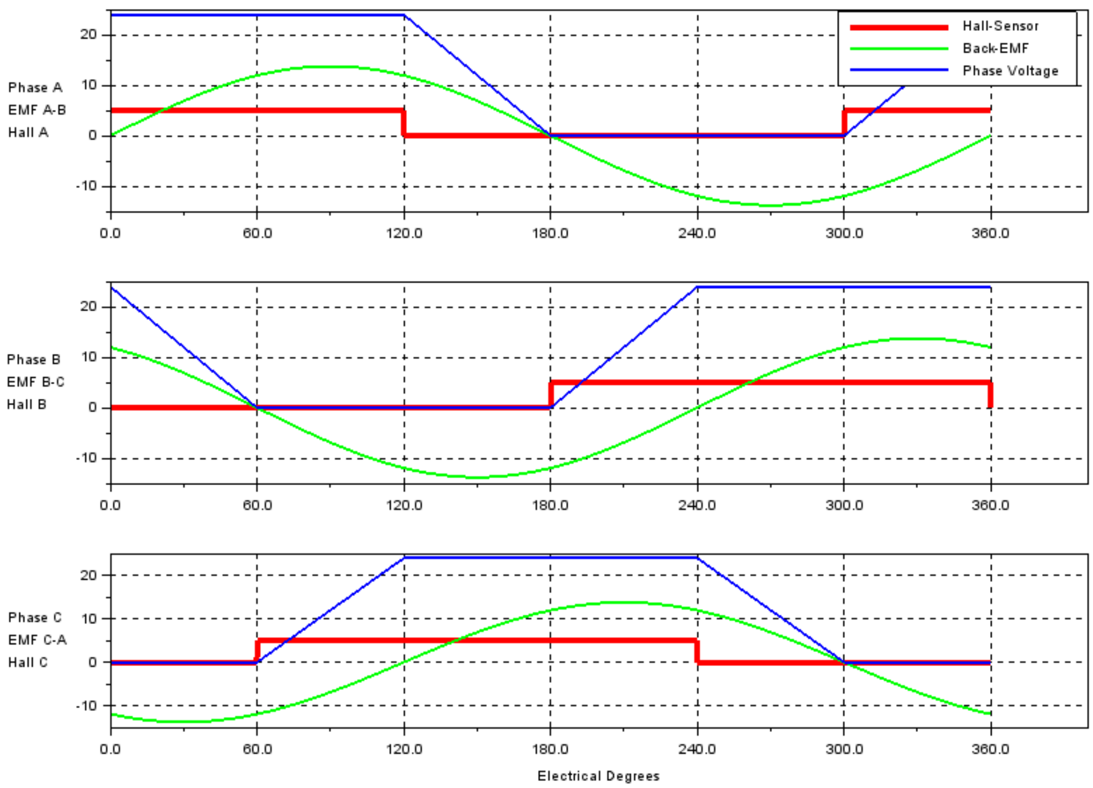

Figure 4: Phase-Voltages, Back-EMF(measured phase-to phase) and Hall-Sensor-Signals

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