Reduction of PWM motor power losses using additional inductances

Summary

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 – high switching frequencies are required.

FAULHABER controllers already operate at very high PWM frequencies of about 100 kHz to avoid thermal losses in the motor.
Nevertheless there exist conditions which require an additional inductance to reduce power losses.

Similar considerations apply to third party slotless motors.

This application note explains when to add an additional inductance to the motor phases, when using FAULHABER controllers.

Applies To

FAULHABER Motion Controllers MC5010, MC5005, MC5004, MCBL, MCDC and Speed Controllers SC5008, SC2804, SC1801 in combination with FAULHABER motors.

Description

Background

FAULHABER 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. The motor driver must be able to cope with the low electrical time constant – high PWM frequencies are required to reduce the current ripple and minimize the additional thermal losses.
Reducing the supply voltage is also a measure to significantly reduce PWM losses. Of course it is only applicable when the motor is operated at speeds of about half the achievable speed.

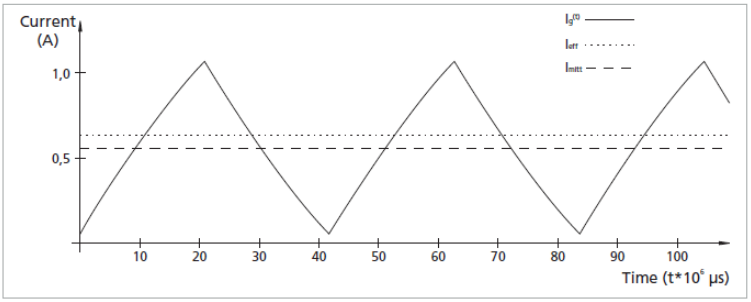

Figure 1: Motor current @ PWM

Measures to avoid additional PWM losses
Select a controller which operates at high PWM frequencies (about 100 kHz)
Reduce the supply voltage, if applicable
Add inductances or add a sine wave filter

Table 1: Summary of measures

Table 1 summarizes the measures to avoid thermal overheating. The next chapters explain when to add an inductance and how to dimension it.

If an additional inductance is used, see page 8 for control parameter settings of a FAULHABER Motion Controller MC50xx.

Overview

Motor type	Conditions	Inductance	Page
FAULHABER motors DC / BLDC	- in general	Not needed	-
FAULHABER motors DC / BLDC	- 2 x Unominal + - continuous operation in “critical” area (30..70% duty cycle)	Benefical for most motors	4 + 5
1660 BHT, 1645 BHS, 2264 BP4, 2057 BA	- Unominal + - Speed Controller	Recommended	6
1660 BHS	- Unominal + - continous operation - MC50xx or SCxxxx	Required	7

Table 2: Overview

Operation of slotless motors @ voltages above the nominal voltage

When the application requires to use a supply voltage above the nominal voltage of the motor, most FAULHABER motors will thermally benefit from an additional inductance.

This is especially applies to **continuous operation** in a critical operation area:

- an operation area which results in a PWM duty cycle between 30..70%

Figure 3 shows this critical operation area, when **double** the nominal voltage is applied.

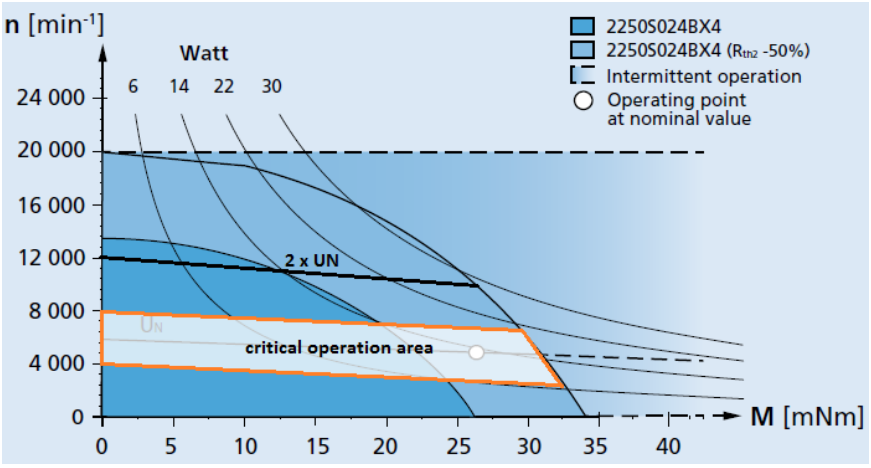

Figure 2: Critical Operation area @ Duty cycle 30..70% + 2 x U_N

In this duty cycle range the additional PWM losses are highest (see figure 3) with a maximum at a duty cycle of 50%.
A 50 % duty cycle means that the motor is operated at about half the achievable speed.

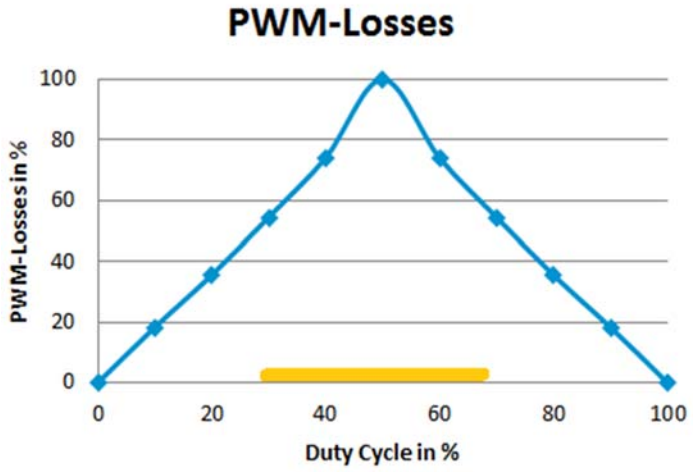

Figure 3: PWM Losses as function of duty cycle

Guideline for selecting an inductance

As a rule of thumb an additional inductance for the use case highlighted in figure 2 can be selected with the following formulas:

	Rule of thumb for additional inductances	Conditions
DC- Motor / BLDC-Motor	L_{add} = 1..2 x L_{motor}	@ 100 kHz PWM frequency + double the nominal supply voltage ($2 \times U_N$) is applied + continuous operation in “critical” area

Table 3: Rule of thumb

The additional inductance **should** have the following characteristics:

- Rated current >= **2 x motor continuous current** (to avoid saturation of the inductor)
- Low resistance value, compared to the motor resistance (20% or lower)

DC motors require only one additional inductance (see figure 4).

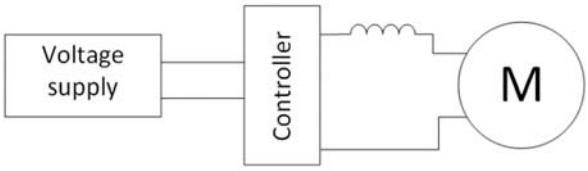

Figure 4: DC motor with an additional inductance

BLDC motors always require 3 additional inductances (see figure 5). The additional inductance L_{add} in table 2, 3 and 5 refers to one of these inductances.

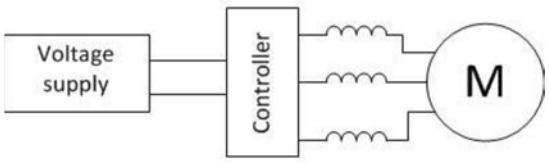

Figure 5: BLDC motor with three additional inductances

Alternative – Sine wave filter

Instead of a simple inductance, a choke in combination with X- and Y-capacitors could be used. Since this alternative requires a more sophisticated filter design it is not further discussed here.

Operation of 1660BHT, 1645BHS, 2264BP4, 2057BA @ FAULHABER Speed Controller

There are three BLDC motor types which highly benefit from additional inductances when operated at a FAULHABER Speed Controller, even when only the nominal voltage is applied.

Motor type	Rule of thumb for additional inductances	Conditions
1660 BHT **1645 BHS** **2264 BP4** **2057 BA**	L_{add} = 1..2 x L_{motor}	@ Speed Controller + nominal supply voltage U_N

Table 4: Rule of thumb for Speed Controller

The additional inductance **should** have the following characteristics:

- Rated current >= **2 x motor continuous current** (to avoid saturation of the inductor)
- Low resistance value, compared to the motor resistance (20% or lower)

Operation of 1660 BHS @ FAULHABER MC50xx or FAULHABER Speed Controller

The BLDC motor 1660 BHS requires measures to be operated continuously at any FAULHABER Controller.

If the speed range of the application allows, operate this motor type at half the nominal voltage. Consider choosing the 48V motor version and operate it at 24 V for instance. This will of course reduce the speed range to half the nominal speed of the motor.

Motor type	Recommended supply voltage
1660 024 BHS	12 V
1660 048 BHS	24 V

Table 5: Reduction of supply voltage

If the reduction of the supply voltage according to table 5 is not possible, an additional inductance is always highly recommended to avoid thermal motor overheating.

The rule of thumb for inductance selection is modified according to table 6.

Motor type	Rule of thumb for additional inductances	Conditions
1660 BHS	L_{add} = 3..4 x L_{motor}	@ 100 kHz PWM frequency + nominal supply voltage U_N

Table 6: Modified rule of thumb for 1660 BHS

Table 7 shows two example inductors valid only for the mentioned motor types.

Motor type	Additional Inductance - L_{add}	Example Inductors
1660 024 BHS	100 µH *	2200HT-101-RC, Bourns
1660 048 BHS	330 µH *	2200HT-331-RC, Bourns

Table 7: Example inductors

* Do not select any inductances which have values larger than recommended, since this could cause poor commutation at high motor speeds (> 10000 rpm). This would be due to a resulting electrical time constant over 1 ms.

The additional inductance **sould** have the following characteristics:

- Rated current >= **2 x motor continuous current** (to avoid saturation of the inductor)
- Low resistance value, compared to the motor resistance (20 % or lower)

Control parameter settings

When using a MC5005, MC5010 or MC5004 and an additional inductance make sure to create a new motor via Motion Manager Software, which incorporates the additional inductance. Only then dynamic control parameter settings will be preset.

Manipulation of the terminal inductance:

- DC motor: $L = L_{motor} + L_{add}$
- BLDC motor: $L = L_{motor} + 2 \times L_{add}$

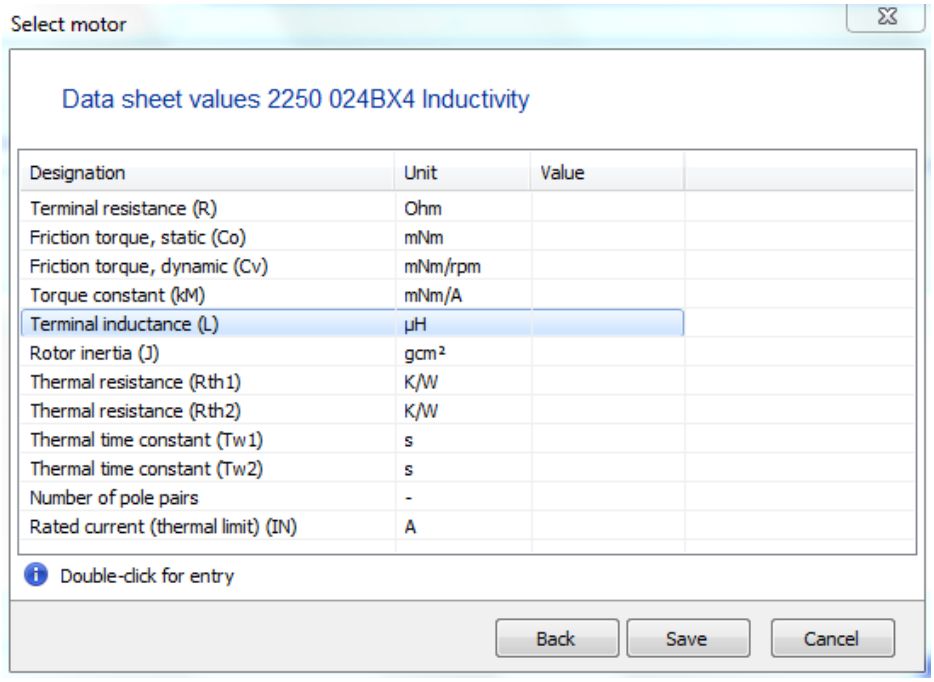

Figure 6: Motor creation @ Motion Manager

Be aware that the additional inductance must be selected carefully according to the guidelines presented in this application note, especially to avoid any saturation. Otherwise the new parameter settings will lead to a noisy motor operation or will even cause instability of the system.

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