

# 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.

If you want to use a PWM filter from the shelf, for the purpose of power loss reduction, there are products available fitting the Motion Controllers MC5005, MC5010 and MC5004 and the FAULHABER Speed Controllers, see [EFM 5001/5003/5008](#).

## 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  $\mu$ s (= 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.

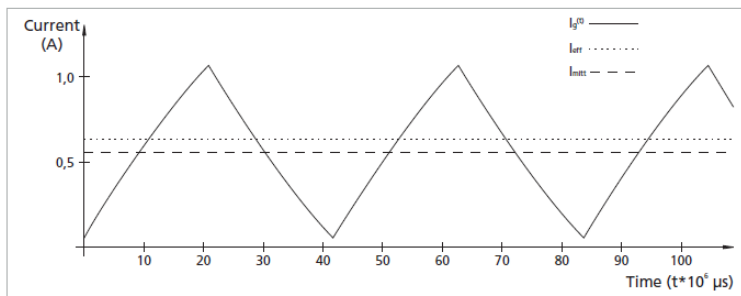


Figure 1: Motor current @ PWM

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
<b>FAULHABER motors DC / BLDC</b>	- in general	Not needed	-
<b>FAULHABER motors DC / BLDC</b>	- 2 x Unominal + - continuous operation in "critical" area (30..70% duty cycle)	Beneficial for most motors	4 + 5
<b>1660 BHT, 1645 BHS, 2264 BP4, 2057 BA</b>	- Unominal + - Speed Controller	Recommended	6
<b>1660 BHS</b>	- Unominal + - continuous 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 applying 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.

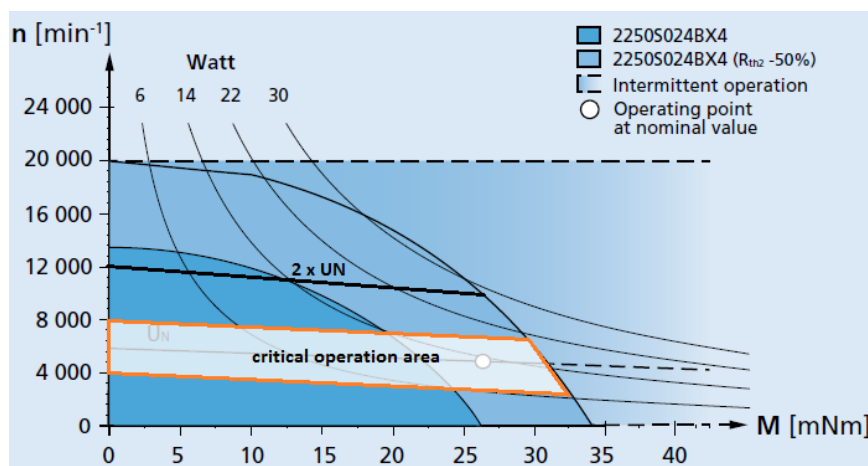


Figure 2: Critical Operation area @ Duty cycle 30..70% + 2 x  $U_N$

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.

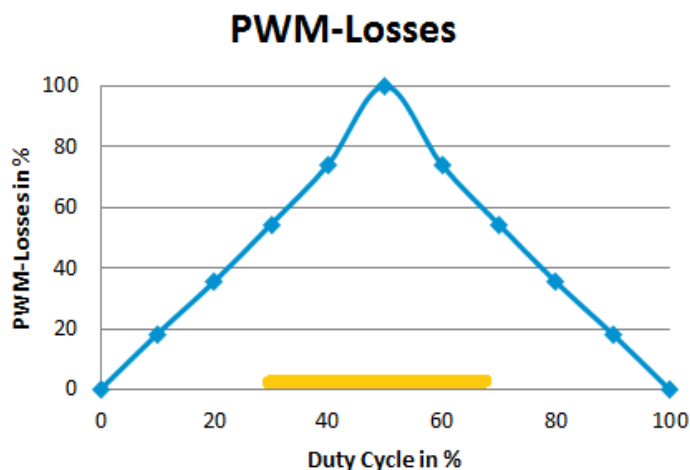


Figure 3: PWM Losses as function of duty cycle

## 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	$L_{add} = 1..2 \times L_{motor}$	@ 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  $\geq 2 \times$  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).

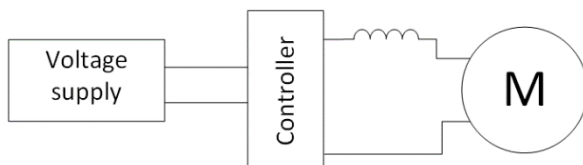


Figure 4: DC motor with an additional inductance

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.

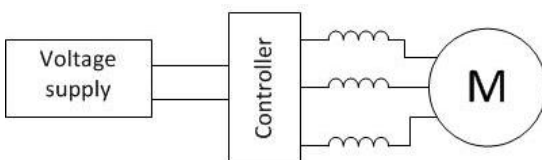


Figure 5: BLDC motor with three additional inductances

## FAULHABER PWM filter

If you want to use a PWM filter from the shelf there are products available fitting the Motion Controllers MC5005, MC5010 and MC5004 and the Speed Controllers, see [EFM 5001/5003/5008](#).

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

There are four 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	$L_{add} = 1..2 \times L_{motor}$	@ 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  $\geq 2 \times$  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 <b>024</b> BHS	<b>12 V</b>
1660 <b>048</b> BHS	<b>24 V</b>

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	$L_{add} = 3..4 \times L_{motor}$	@ 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 <b>024</b> BHS	<b>100 <math>\mu</math>H</b> *	2200HT-101-RC, Bourns
1660 <b>048</b> BHS	<b>330 <math>\mu</math>H</b> *	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 **should** have the following characteristics:

- Rated current  $\geq 2 \times$  motor continuous current (to avoid saturation of the inductor)
- Low resistance value, compared to the motor resistance (20 % or lower)

## Inductance configuration

When using a MC5005, MC5010 or MC5004 and an additional inductance make sure to configure it using Motion Manager 6. Only then dynamic control parameter settings will be preset.

The configuration panel can be found here:

Configuration / Initial Startup / Additional Inductance

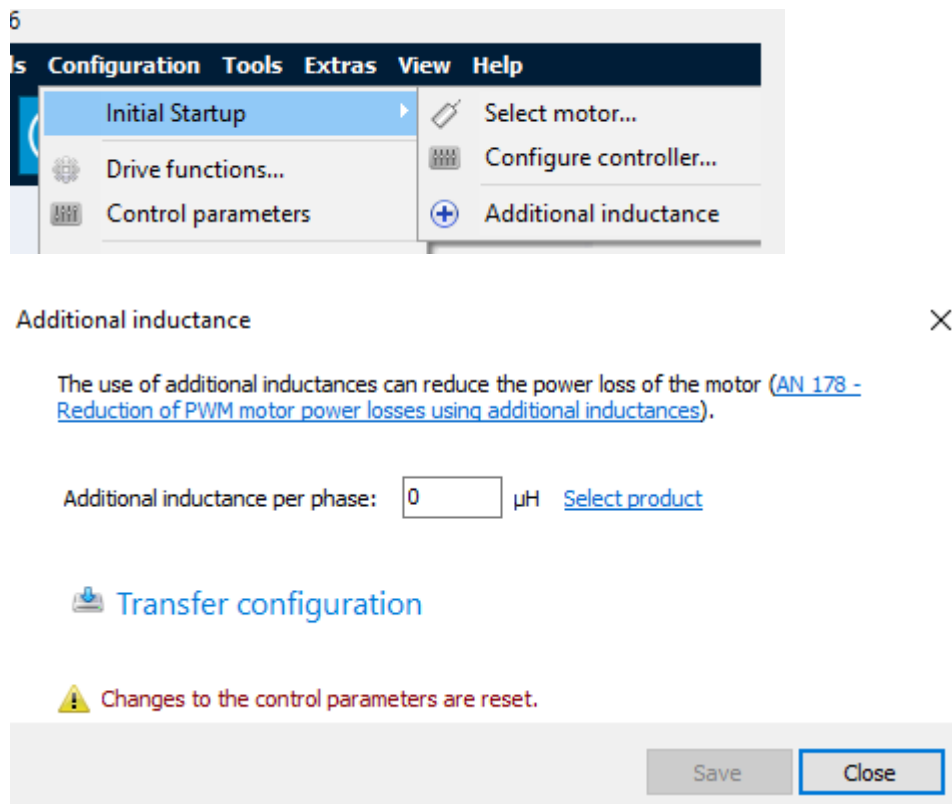


Figure 6: Filter configuration @ Motion Manager 6



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.



## Rechtliche Hinweise

**Urheberrechte.** Alle Rechte vorbehalten. Ohne vorherige ausdrückliche schriftliche Zustimmung der Dr. Fritz Faulhaber & Co. KG darf diese Application Note oder Teile dieser unabhängig von dem Zweck insbesondere nicht vervielfältigt, reproduziert, gespeichert (z.B. in einem Informationssystem) oder be- oder verarbeitet werden.

**Gewerbliche Schutzrechte.** Mit der Veröffentlichung, Übergabe/Übersendung oder sonstigen Zurverfügung-Stellung dieser Application Note werden weder ausdrücklich noch konkludent Rechte an gewerblichen Schutzrechten, übertragen noch Nutzungsrechte oder sonstige Rechte an diesen eingeräumt. Dies gilt insbesondere für gewerbliche Schutzrechte, die mittelbar oder unmittelbar den beschriebenen Anwendungen und/oder Funktionen dieser Application Note zugrunde liegen oder mit diesen in Zusammenhang stehen.

**Kein Vertragsbestandteil; Unverbindlichkeit der Application Note.** Die Application Note ist nicht Vertragsbestandteil von Verträgen, die die Dr. Fritz Faulhaber GmbH & Co. KG abschließt, und der Inhalt der Application Note stellt auch keine Beschaffenheitsangabe für Vertragsprodukte dar, soweit in den jeweiligen Verträgen nicht ausdrücklich etwas anderes vereinbart ist. Die Application Note beschreibt unverbindlich ein mögliches Anwendungsbeispiel. Die Dr. Fritz Faulhaber GmbH & Co. KG übernimmt insbesondere keine Gewährleistung oder Garantie dafür und steht auch insbesondere nicht dafür ein, dass die in der Application Note illustrierten Abläufe und Funktionen stets wie beschrieben aus- und durchgeführt werden können und dass die in der Application Note beschriebenen Abläufe und Funktionen in anderen Zusammenhängen und Umgebungen ohne zusätzliche Tests oder Modifikationen mit demselben Ergebnis umgesetzt werden können. Der Kunde und ein sonstiger Anwender müssen sich jeweils im Einzelfall vor Vertragsabschluss informieren, ob die Abläufe und Funktionen in ihrem Bereich anwendbar und umsetzbar sind.

**Keine Haftung.** Die Dr. Fritz Faulhaber GmbH & Co. KG weist darauf hin, dass aufgrund der Unverbindlichkeit der Application Note keine Haftung für Schäden übernommen wird, die auf die Application Note und deren Anwendung durch den Kunden oder sonstigen Anwender zurückgehen. Insbesondere können aus dieser Application Note und deren Anwendung keine Ansprüche aufgrund von Verletzungen von Schutzrechten Dritter, aufgrund von Mängeln oder sonstigen Problemen gegenüber der Dr. Fritz Faulhaber GmbH & Co. KG hergeleitet werden.

**Änderungen der Application Note.** Änderungen der Application Note sind vorbehalten. Die jeweils aktuelle Version dieser Application Note erhalten Sie von Dr. Fritz Faulhaber GmbH & Co. KG unter der Telefonnummer +49 7031 638 688 oder per Mail von [mcsupport@faulhaber.de](mailto:mcsupport@faulhaber.de).

## Legal notices

**Copyrights.** All rights reserved. This Application Note and parts thereof may in particular not be copied, reproduced, saved (e.g. in an information system), altered or processed in any way irrespective of the purpose without the express prior written consent of Dr. Fritz Faulhaber & Co. KG.

**Industrial property rights.** In publishing, handing over/dispatching or otherwise making available this Application Note Dr. Fritz Faulhaber & Co. KG does not expressly or implicitly grant any rights in industrial property rights nor does it transfer rights of use or other rights in such industrial property rights. This applies in particular to industrial property rights on which the applications and/or functions of this Application Note are directly or indirectly based or with which they are connected.

**No part of contract; non-binding character of the Application Note.** The Application Note is not a constituent part of contracts concluded by Dr. Fritz Faulhaber & Co. KG and the content of the Application Note does not constitute any contractual quality statement for products, unless expressly set out otherwise in the respective contracts. The Application Note is a non-binding description of a possible application. In particular Dr. Fritz Faulhaber & Co. KG does not warrant or guarantee and also makes no representation that the

processes and functions illustrated in the Application Note can always be executed and implemented as described and that they can be used in other contexts and environments with the same result without additional tests or modifications. The customer and any user must inform themselves in each case before concluding a contract concerning a product whether the processes and functions are applicable and can be implemented in their scope and environment.

**No liability.** Owing to the non-binding character of the Application Note Dr. Fritz Faulhaber & Co. KG will not accept any liability for losses arising from its application by customers and other users. In particular, this Application Note and its use cannot give rise to any claims based on infringements of industrial property rights of third parties, due to defects or other problems as against Dr. Fritz Faulhaber GmbH & Co. KG.

**Amendments to the Application Note.** Dr. Fritz Faulhaber & Co. KG reserves the right to amend Application Notes. The current version of this Application Note may be obtained from Dr. Fritz Faulhaber & Co. KG by calling +49 7031 638 688 or sending an e-mail to [mcsupport@faulhaber.de](mailto:mcsupport@faulhaber.de).