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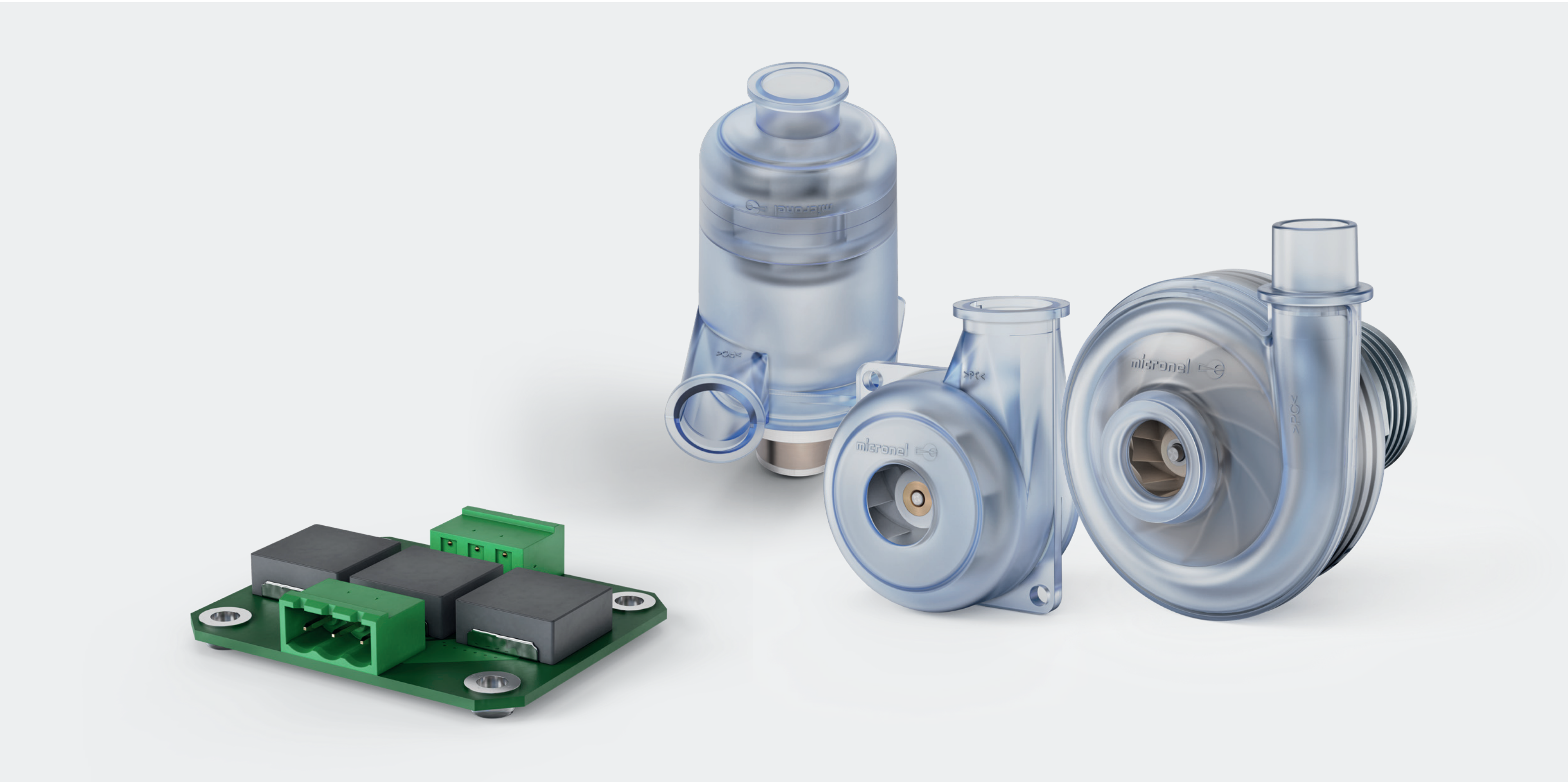
Application Note

Improving Blower Efficiency with MCM-33/10



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1. Introduction

To achieve a high speed, electric blowers such as the U65HN-024KS-6 often utilize slot less motors in their design. These motors usually have a very low phase inductance and resistance. In combination with a PWM (Pulse Width Modulation) driven phase voltage of low frequency and high amplitude, this will cause a high current ripple to flow in the blower, which causes significant losses. These losses diminish the efficiency of the blower operation, potentially leading to substantial motor heating. Figure 1 shows the phase current of a U65HN-024KS-6 operated free blowing at 30 kRPM and 24 V_{DC}. The current ripple is quite large, and causes the power consumption to be around 29.8 W in total. A good portion of which can be attributed to unwanted losses.

Figure 1: Phase Current Without Motor Choke

Adding the Micronel Motor Choke Module (MCM-33/10) to the blower reduces the current ripple significantly, as displayed in Figure 2. The power consumption is reduced by approximately 44%, falling from 29.8 W to 16.7 W, without reducing flow or pressure in the chosen operating point. It is noteworthy, however, that the motor choke reduces the maximum motor speed and increases the ohmic losses of the overall system. These drawbacks arise due to the additional resistance that the choke introduces to the motor phase. For a more detailed discussion of all mentioned phenomena, please refer to chapter 3.

Figure 2: Phase Current With Motor Choke

2. Examination of Micronel Blowers

As discussed in the introduction, using a blower in conjunction with the MCM-33/10 may have a positive influence on its power consumption at a given operating point. To give a comparative overview over which Micronel products benefit from the MCM-33/10, several blowers have been compared regarding power consumption with and without the additional motor choke. All tests are conducted for maximum flow operation at 25%, 50% and 75% of the blower's maximum speed.

2.1 Experimental Conditions

The following equipment and devices have been used to conduct the experiments:

Laboratory Equipment	
Power Supply	TTi CPX400P
Multimeter	Fluke 289 True RMS Multimeter
Motor Driver	
Driver type	MDB 48-10 (BEMF driven)
Max. power output	24 V_{DC}, 10 A RMS max.
Motor Choke	
Type	MCM-33/10
Inductance	33 µH
Resistance	42 mΩ
Continuous Current	10.7 A

2.2 Power Consumption

Figure 3 shows the reduction of power consumption for a selection of common Micronel blowers. For each blower a measurement was performed at 25%, 50% and 75% of their maximum achievable RPM at maximum flow operation (free blowing).

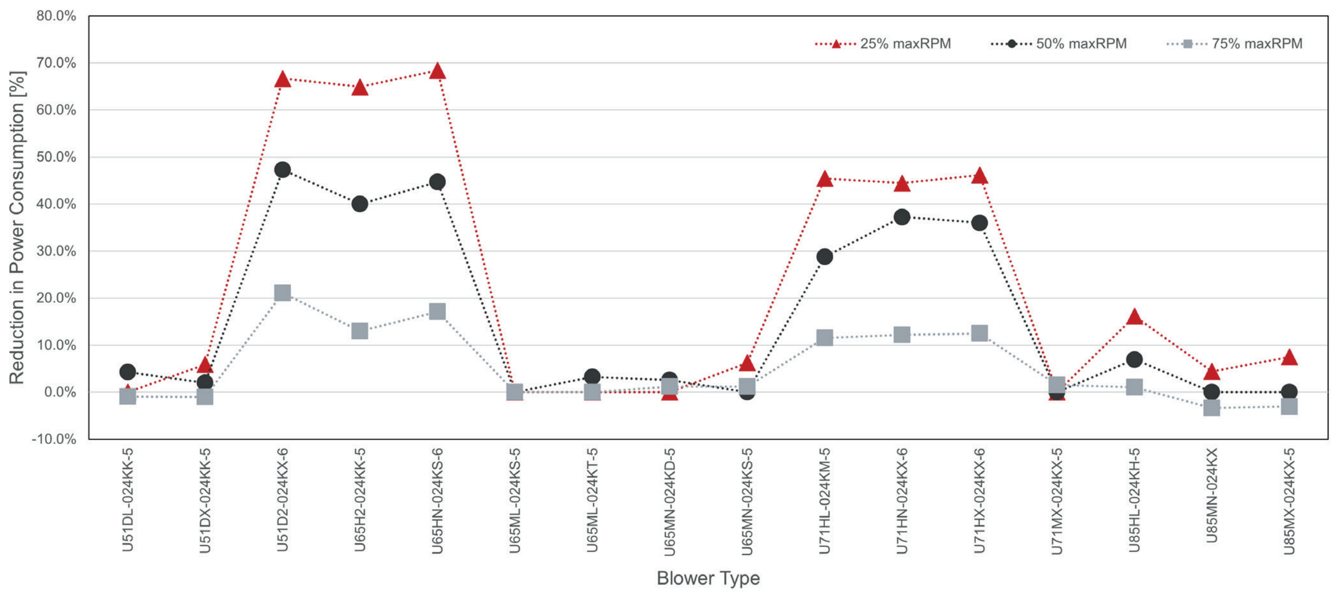

Figure 3: Reduction in Power Consumption With MCM-33/10

2.3 Loss of Max RPM

While the MCM-33/10 may reduce the power consumption of a blower, it also decreases the blower's maximum motor speed. Figure 4 shows the approximate loss of maximum speed between operation with and without the MCM-33/10 for a selection of common Micronel blowers.

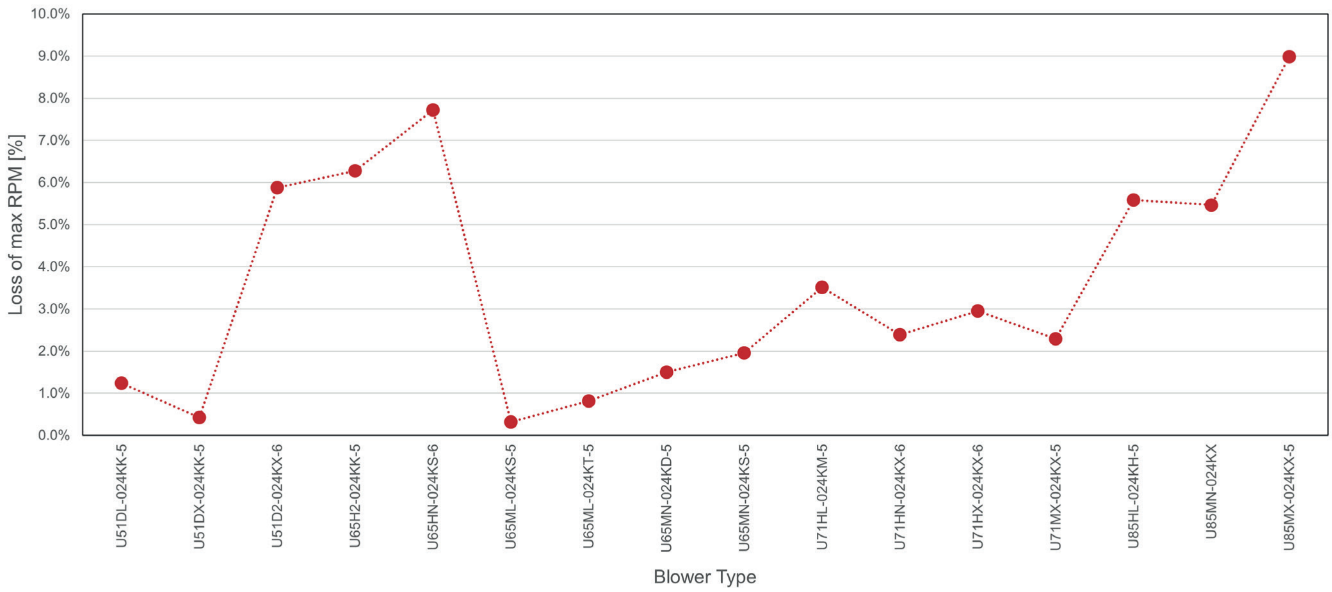

Figure 4: Loss of Max. RPM with Motor Choke

2.4 Conclusion

The MCM-33/10 helps to significantly reduce the power consumption of various Micronel blowers. The experimental results show that the application of the motor choke is most beneficial to the blowers shown in Table 1. All measurements were conducted at maximum flow operation at 24 V_{DC}.

	Operating point as percentage of maximum motor speed (freeblowing)			
	25%	50%	75%	
Blower	Reduction of power consumption [%]			Loss of max. RPM [%]
U51D2-024KX-6	66.7	47.3	21.1	1.2
U65H2-024KK-5	64.9	40.0	13.0	5.9
U65HN-024KS-6	68.4	44.7	17.1	6.3
U71HL-024KM-5	45.5	28.8	11.6	3.5
U71HN-024KX-6	44.4	37.3	12.2	2.4
U71HX-024KX-6	46.2	36.0	12.5	2.9

Table 1: List of Micronel Blowers That Benefit Most From the MCM-33/10

2.5 Raw Data

Table 2 contains the raw data from the experiment for further inspection or operation point estimation.

		Motor Speed [% of max RPM]							
		25		50		75		100	
Blower	Choke	w[RPM]	I [ARMS]	w[RPM]	I [ARMS]	w[RPM]	I [ARMS]	w[RPM]	I [ARMS]
U51DL-024KK-5	No	15000	0.16	28000	0.47	39000	1.05	48400	1.92
	Yes	15000	0.16	28000	0.45	39000	1.06	47800	1.87
U51DX-024KK-5	No	15000	0.17	28000	0.50	38000	1.00	47000	1.85
	Yes	15000	0.16	28000	0.49	38000	1.01	46800	1.78
U51D2-024KX-6	No	13000	0.51	26000	1.10	39000	1.90	51000	3.08
	Yes	13000	0.17	26000	0.58	39000	1.50	48000	2.66
U65H2-024KK-5	No	13000	0.57	25000	1.30	37000	2.62	47800	4.80
	Yes	13000	0.20	25000	0.78	37000	2.28	44800	3.97
U65HN-024KS-6	No	15000	0.57	31000	1.32	46000	2.45	59600	4.28
	Yes	15000	0.18	31000	0.73	46000	2.03	55000	3.36
U65ML-024KS-5	No	8000	0.11	16000	0.20	24000	0.40	30900	0.70
	Yes	8000	0.11	16000	0.20	24000	0.40	30800	0.69
U65ML-024KT-5	No	10000	0.13	20000	0.31	29000	0.65	36800	1.19
	Yes	10000	0.13	20000	0.30	29000	0.65	36500	1.16
U65MN-024KD-5	No	11000	0.16	21000	0.39	31000	0.84	40000	1.55
	Yes	11000	0.16	21000	0.38	31000	0.83	39400	1.49
U65MN-024KS-5	No	11000	0.16	22000	0.39	32000	0.86	40800	1.56
	Yes	11000	0.15	22000	0.39	32000	0.85	40000	1.48
U71HL-024KM-5	No	10000	0.33	21000	0.80	30000	1.47	39800	2.80
	Yes	10000	0.18	21000	0.57	30000	1.30	38400	2.52
U71HN-024KX-6	No	9000	0.27	17000	0.51	25000	0.82	33500	1.48
	Yes	9000	0.15	17000	0.32	25000	0.72	32700	1.40
U71HX-024KX-6	No	9000	0.26	17000	0.50	25000	0.80	33900	1.52
	Yes	9000	0.14	17000	0.32	25000	0.70	32900	1.43
U71MX-024KX-5	No	8000	0.13	16000	0.31	23000	0.65	30500	1.25
	Yes	8000	0.13	16000	0.31	23000	0.64	29800	1.21
U85HL-024KH-5	No	8000	0.31	20000	1.15	29000	2.95	37600	6.15
	Yes	8000	0.26	20000	1.07	29000	2.92	35500	5.27
U85MN-024KX	No	13000	0.45	24000	1.75	35000	5.05	43900	10.08
	Yes	13000	0.43	24000	1.75	35000	5.22	41500	8.80
U85MX-024KX-5	No	13000	0.40	25000	1.90	35000	4.95	44500	10.12
	Yes	13000	0.37	25000	1.90	35000	5.10	40500	8.02

Table 2: Raw Data for Current Consumption of Experiments

3. Additional Information

3.1 Current Ripples in Inductive Components

Ripple current is the term used to describe fluctuations in the current flowing through an electrical component. In the case of a PWM voltage applied to coils, ripple current refers to the alternating high and low levels of current that occur as the voltage rapidly switches on and off. This chapter aims to illustrate, how ripple currents are caused in the coils of a motor.

While the current in an ohmic resistor follows a change in the applied voltage almost instantaneously, in an inductor, the change of current takes time. This is due to its property known as ‚inductance', which inhibits a change of the flowing current. The greater the inductance, the slower the current can change, and vice versa. Figure 5 shows the resulting current buildup, when a voltage of 1.0 V_{DC} is applied to a coil of 0.1 Ω resistance and different inductances. It can be observed, that with increasing inductance, the current reaches its final value of 10 A with a greater delay. This illustrates how an increase in inductance leads to a reduction in the change rate of the current.

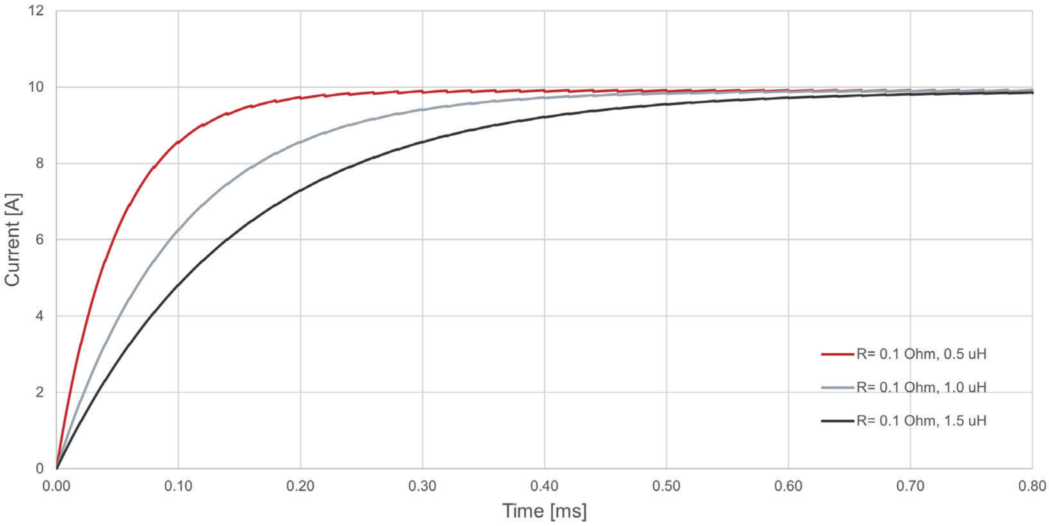

Figure 5: Current Behavior Depending on Inductance

This illustrates the coil currents behavior, if the voltage applied to it is held constant, but the coils inductance is altered. To illustrate the influence of an alternating voltage on the coil currents behavior, Figure 6 compares the coils different reaction to DC and AC (such as PWM) voltage.

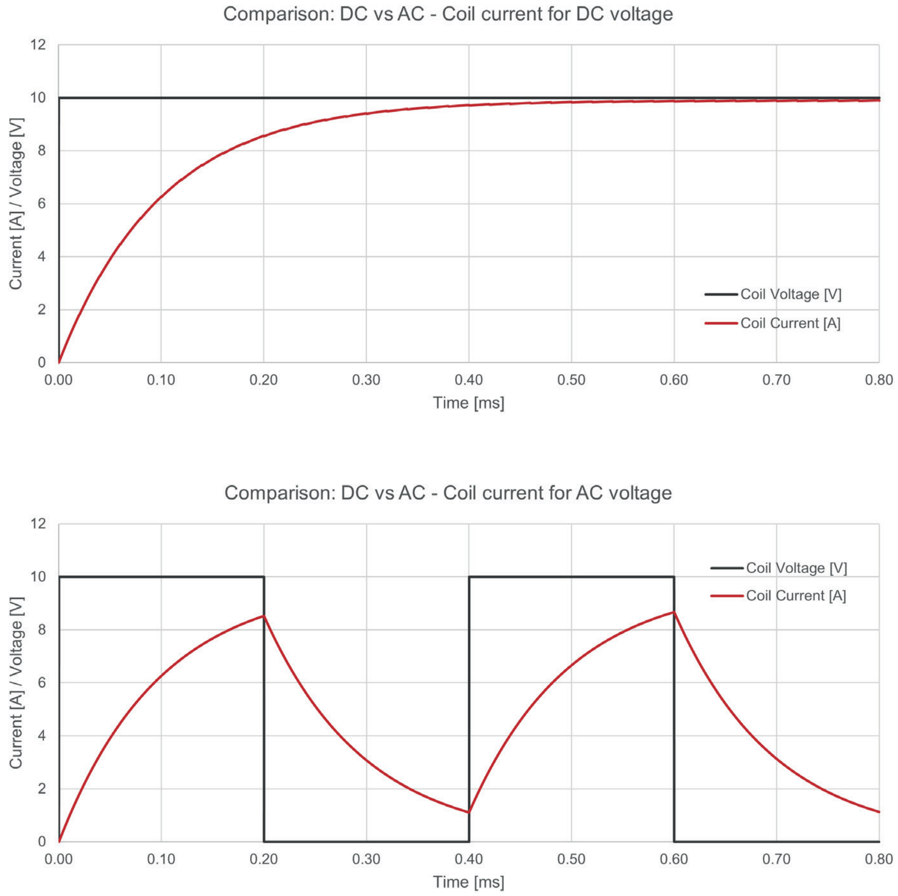

Figure 6: Current Behaviour Depending on Voltage Form

The top graph depicts the application of a constant voltage of 10 V_{DC} to a coil, resulting in a gradual increase in the current with a limited rate of change, just like in Figure 5. The bottom graph shows the application of an AC voltage, that switches between 10 V_{DC} and 0 V_{DC}, to the same coil. The alternating voltage levels cause the current through the coil to repeatedly increase and decrease.

When the voltage is at 10 V_{DC}, the current buildup appears the same as in the case depicted in the top graph. However, when the voltage is switched off, the current decreases in reversed manner. If the voltage is switched on again before the current diminishes to zero, the current will increase to a higher level than it did in the cycle before. Repeating this process several times will cause a gradual buildup of a current offset, until the currents repeated increase and decrease will reach an equilibrium and form a stable AC waveform akin to a sawtooth signal. How high the current rises and falls in each half of the PWM voltages cycle ultimately depends on the inductance of the coil. A low inductance will cause a faster rise in current and therefore a larger current ripple. On the other hand, a high inductance will lower the change rate of the current and therefore flatten the current ripple.

Since high speed motors typically utilize coils with a low inductance, the ripple current in its phases will likely be high. Chapter 3.2 ‚Losses caused by Current Ripples' will go into greater detail about the negative effects of large ripple currents, as they may cause significant losses and subsequent heating in the motor. Depending on the motor used in a blower's design, it may therefore be beneficial to increase the motor's phase inductance by adding a MCM-33/10 to the blower.

3.2 Losses Caused by Current Ripples

Ripple currents introduce additional losses in various ways. Generally, a current ripple with a larger amplitude has a higher root mean square (RMS) value compared to a ripple with a smaller amplitude. Since ohmic losses increase proportionally to the square of the RMS current, a higher current ripple leads to increased heat losses in the conducting material of the motor, such as the coil wires or additional motor chokes.
Moreover, significant current fluctuations in the motor coils result in corresponding fluctuations in the magnetic field they generate. Consequently, this causes the occurrence of eddy currents in the conductive core material of the motor, including the laminated cage and rotor magnet. These eddy currents further contribute to losses and heating. In extreme cases, these phenomena can lead to severe damage to the blower, such as an increased risk of demagnetization of the rotor magnet due to significantly elevated core temperatures.

Ohmic losses increase with:

- The square of the motor current
- The resistance of the conducting material (e.g. coil wires)

$$P_{Ohmic} \propto I_{RMS}^2 \cdot R_{Mot}$$

Eddy Current Losses increase with:

- The square of the magnetic field strength
  (By extension, this also means that the eddy current losses increase in direct proportion to the square of the motor current, as the magnetic field strength in the coil directly correlates with the current.)
- The square of the change rate in the magnetic field
  (By extension, this also means that the eddy current losses increase in direct proportion to the square of the PWM frequency, as the magnetic field in the coil changes in unison with the PWM signal)

$$P_{Eddy} \propto B^2 \cdot f_B^2 \rightarrow P_{Eddy} \propto I_{Motor}^2 \cdot f_{PWM}^2$$

3.3 Reducing Current Ripples in BLDC Motors

In general, the current ripple in an inductor is proportional to the following factors:

$$\Delta I_{PP} \propto \frac{V_{Mot}}{f_{PWM} \cdot L_{Mot} \cdot R_{Mot}}$$

Consecutively, the ripple current can be adjusted by altering any of these factors internally or externally of the motor. However, not all approaches are practical or advisable, as changes that seem beneficial in one aspect may have negative consequences in others.

One possible approach to limit ripple current is to decrease the motor‘s supply voltage, which would restrict the maximum peak current flowing in the motor coil. However, this is often impractical, as power supplies typically have fixed voltages and cannot be easily modified during operation. Additionally, the motor voltage directly determines the maximum speed of the motor, so reducing the voltage would also limit the blower‘s ability to generate its maximum rated flow and pressure.

Deliberately increasing the motor‘s phase resistance to decrease the ripple current is generally considered poor practice, as increased resistance also means higher ohmic losses. Furthermore, the additional resistance would lead to a higher voltage drop across the phase and/or supply line. This means that the motor is effectively being operated at a lower voltage than what the power supply offers. Consequently, this leads to a decrease in the motor‘s maximum speed and, subsequently, a reduction in overall output performance. It is important to keep the ohmic resistance in the motor phases to a minimum to optimize motor performance and efficiency.

The current ripple can also be decreased by increasing the frequency of the PWM voltage. As the frequency increases, the on and off periods of phase signal become shorter (compare Figure 6 with a higher PWM frequency). This results in reduced time available for the current to rise or fall, leading to a smaller current ripple amplitude. However, it is important to note that increasing the PWM frequency can have drawbacks. While it effectively reduces the amplitude of the current ripple, it also leads to increased eddy current losses. These losses are proportional to the square of the change rate in the magnetic field, as discussed in chapter 3.2. Additionally, higher PWM frequencies result in more frequent switching of the motor driver's output stage, leading to increased switching losses in the electronic motor driver.

The most practical method to reduce the current ripple in a BLDC is therefore to increase the phase's inductance. This limits the rate of change that can occur in the current, as explained in chapter 3.1. This can be achieved by adding an additional inductance in the path of the motor current, commonly referred to as a motor choke.

It's worth mentioning that the motor choke introduces a small amount of additional resistance into the phase. As discussed earlier, this will lead to a slight decrease in motor efficiency and maximum blower speed. However, motor chokes are designed to minimize resistance while providing the desired inductance. When applying a motor choke to Micronel blowers, the benefits significantly outweigh the drawbacks in many cases.

Revision Table

Revision	Date	Name	Remarks
01	23.06.2023	BA / KE	Creation of document

Micronel AG
Zürcherstrasse 51
CH - 8317 Tagelswangen

T +41 52 355 16 16
info@micronel.com
www.micronel.com