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Motor current measurement of a PWM power amplifier

Version: 1.12 (Eng.)
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Date: 2018-11-23

Motor current measurement in case of a PWM power amplifier

Topic:

- How to measure the current draw of motors which are controlled by a PWM power amplifier?

Situation:

Almost any modern motor controller (like the maxon product lines EPOS, ESCON, MAXPOS) use a so-called chopped PWM power amplifier to drive the motor, i.e. to provide the required motor current depending on the operating mode, the controller state, and working point.

- maxon controllers measure the motor current directly in the power amplifier.
  - ⇨ The motor current can be monitored by the corresponding maxon software (e.g. “EPOS Studio”, “ESCON Studio”, “MAXPOS Studio”) or it can be read out by the object dictionary (in case of an EPOS or MAXPOS).
  - ⇨ Maxon controllers use the measured motor current not just as the “Current Actual Value” for current (or torque) control but also for overload protection of the motor winding based on the configured “Nominal Current” and the “Thermal Time Constant of the Winding”.
- If a (3rd-party) motor controller does not offer the possibility of motor current measurement and monitoring, it might be required to measure the motor current directly in the motor wires.
  - ⇨ The motor current measurement by the motor wires is quite demanding concerning the required measurement equipment and procedure.
  - ⇨ The different possibilities, typical procedures, and the required measurement equipment is explained by the following paragraphs.

Solution:

Technical background:

- A PWM amplifier can be considered as some sort of electronic DC transformer. If the power losses of the electronic components, the motor itself, as well as the power consumption of peripheral components like sensors and actuators are neglected, the following simple power formula is valid:

  The **input power** (Supply voltage $V_{CC,}$ Supply current I_{Supply})
  equals the **output power** (Motor voltage U_{Mot}, Motor current I_{Mot})

  ⇨ $P_{In} = P_{Out}$

  ⇨ $V_{CC} * I_{Supply} = U_{Mot} * I_{Mot}$

- The supply voltage V_{CC} of the controller's input power is constant but the motor voltage U_{Mot} depends on the current working point (= speed and torque). The motor controller adapts the motor voltage (i.e. the PWM duty cycle) depending on the mode of operation and commanded set value. The actual motor voltage U_{mot} is always smaller than the voltage V_{CC} supplied to the motor controller. This is mainly due to the following two reasons:

  ⇨ Depending on the working point the commanded motor speed will typically correspond to a remarkable lower motor voltage (-> speed constant of the motor) than the supply voltage level of the motor controller.

  ⇨ Due to the limited "Max. PWM duty cycle" of PWM amplifiers of typical 90-98% of the supply voltage the full supply voltage can never be provided to the motor even not in case of the maximum possible speed operation (-> "Max. output voltage" specification of the motor controller).

- Based on the fact that the motor voltage U_{Mot} is always lower than the supply voltage V_{CC}, the motor current I_{Mot} will be typically higher than the supply current I_{Supply} (-> power transformer $P_{In} = P_{Out}$).

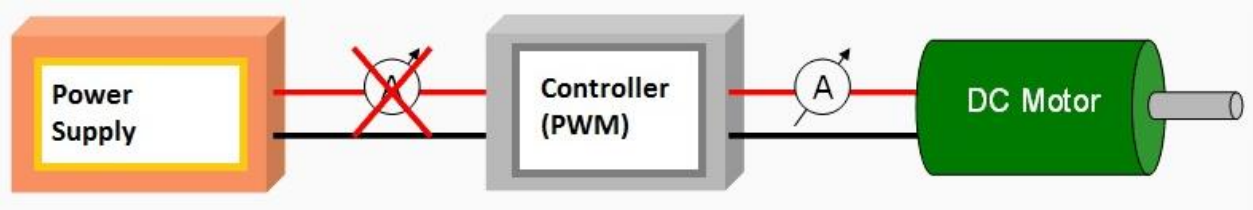
  ⇨ The motor current I_{Mot} (and motor voltage) depends on the torque and speed of the motor, i.e. the currently valid working point of the motor.

  ⇨ The supply current I_{Supply} of the motor controller is no direct indication for the motor current I_{Mot}.

  ⇨ The supply current I_{Supply} includes all typically minor currents required by the electronics (microprocessor, memory, …) and peripheral components (sensor, encoders, actuators, …) too.

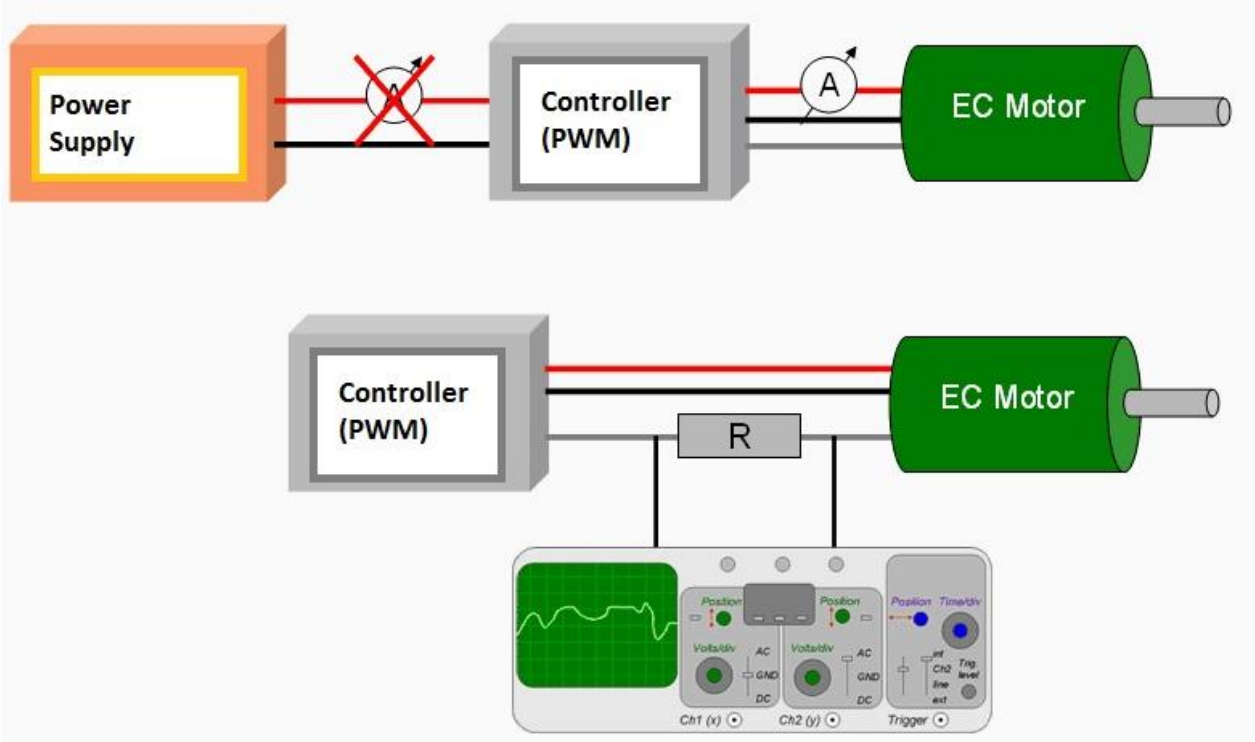
- maxon controllers use the internal motor current measurement data for current control and overload protection of the winding.

Motor current measurement of DC motors (= brush motors):



- The motor current of a DC motor can be measured directly in the motor wire.
- It is required to **use a "True RMS" multimeter** to measure the motor current due to the chopped PWM motor voltage.
  - ⇨ **A "simple" and commonly in use multimeter with AC or DC selection cannot(!!) measure the motor current properly.** The current measurement by such a multimeter will be completely wrong.
  - ⇨ **Important:**
    Please take care of the note at the end of this article about the **specific technical requirements of a "True RMS" multimeter** in use to measure currents of chopped PWM power amplifiers.

Motor current measurement of EC motors (= brushless motors):



- Concerning EC motors there is the additional challenge of three phases which are not being powered at the same time. Thus it is more elaborate to measure the motor current when the motor is running. The measurement of a single phase current does not correspond to the motor current then.
- Some motor controllers (and all maxon controllers) have an analog or digital current monitor. This is the simplest way of determining the motor current.
- The current within one phase of an EC motor can be determined with a “True RMS” current multimeter. One drawback is that such multimeters are often slow in measuring the current and require a stable motor condition for several seconds to get a correct and stable measuring result.

  ⇨ **Important:**
  Please take care of the note at the end of this article about the **specific technical requirements of a “True RMS” multimeter** in use to measure currents of chopped PWM power amplifiers.

- It is also possible to measure the current with an oscilloscope (instead of a multimeter) in one (or more) motor phases. A shunt resistor (e.g. 0.1 Ohm) has to be mounted in series to the motor phase then. The voltage across the resistor is proportional to the phase current (U = R * I) and can be recorded by the oscilloscope. The RMS motor current can be evaluated by such a measurement.
- **Important: Phase current does not equal the motor current!**
  Please note that a measured single phase current does not correspond to the specified motor current I_{Mot} which has to be taken into account concerning torque. This is due to the fact that the measured phase is not powered up in each shaft position, i.e. the measured phase current is lower than the actual motor current.

  ⇨ In case of a **block commutation**:
  Motor current = Measured **phase current multiplied by 1.22** (= square root of (3/2))

  ⇨ In case of a **sinusoidal commutation**:
  Motor current = Measured **phase current multiplied by 1.41** (= square root of 2)

General hints:

- **Current clamp / current probe**
  One more option is to use a suitable current clamp and a “True RMS” multimeter or oscilloscope. The advantage is that there is no need to cut the motor phase wire to insert a shunt resistor. The drawback is that these expensive precise current clamps (or current probes) for phase currents of up to 10A or even more and 100 kHz PWM are often not part of the standard measurement equipment.
- **Motor current measurement in case of a blocked motor shaft**
  If a motor current limitation has to be checked or a maximum torque in relation to the current has to be evaluated, it is easiest to measure the phase current when the motor shaft is blocked.
  - ⇨ Please note that the **motor shaft has to be blocked in a position which results in the maximum measured value** of the phase current. In case of a block commutation this position can be recognized easily. In case of a sinusoidal commutation this gets more demanding.
  - ⇨ It is important that a "True RMS" multimeter is in use for these measurements too which fulfills the following requirements.

Important: Requirements of a “True RMS” Multimeter!

- Please make sure to use a so-called **“True RMS” multimeter only** for all mentioned measurements!
  - ⇨ “**True RMS**” means that the multimeter is capable to measure any signal type (e.g. PWM) properly independent of its wave form.
  - ⇨ Standard “RMS” multimeters (without the add-on term “True”) can measure voltage and current values properly just in case of a sinusoidal waveform (which is not present by a PWM amplifier output).
- The controller’s motor output voltage is a rectangular PWM signal with frequencies up to 100 kHz (depending on the power amplifier’s specification of the controller in use).
  - ⇨ Take care that the **selected voltage and current measurement range** of the **“True RMS” multimeter in use is actually specified for frequencies at least up to 100 kHz.** Take a look into the details of the multimeter’s data sheet because this requirement is often NOT or NOT for all measurement ranges fulfilled.
  - ⇨ Many “True RMS” multimeters are just designed and capable to measure currents with a frequency of 1 kHz or 10 kHz. Such multimeters cannot be used to measure the output current of a PWM amplifier although the label “True RMS” is present. The high PWM frequencies up to 100 kHz will distort the measurement result which cannot be used for the evaluation of a motor current then.