Brushless Motor Controller Report

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I. Introduction

In the world of robotics, there are only a finite number of ways to actuate a robot. When the goal is to minimize the cost of transport and improve the energy efficiency, the most logical selection for actuation is electric motors. Other methods of actuation, like hydraulics or pneumatics, have major issues preventing energy efficiency. A hydraulic engine is extremely powerful, but consumes large amounts of energy and requires continuous running, even if the robot is not moving. Pneumatic systems require large, heavy storage tanks for compressed air, necessitating large air compressors to fill up the tanks and often the energy consumed compressing the air is not considered in the cost of transport. Conversely, electric motors are capable of large amounts of power, and are relatively light weight. A typical electric motor is capable of 200 watts per kilogram, while a typical human muscle is only capable of about 50 watts per kilogram of power.

Electric motors come in two major varieties: brushed and brushless. Brushed motors are the most common and the easiest to use. Brushed motors work by having two magnets in the stator and an electromagnet in the rotor. The motor continues to spin by the electromagnet changing orientation, which is controlled by the brushes that act as contact switches. Brushed motors are very easy to use, and will run by simply applying a dc voltage across the motor leads. The current Ranger robot is the laboratory uses exclusively brushed motors, with motor controllers set up for the brushed motors.

There are several issues with brushed motors. The constant contact of the brushes will limit the top speed of the motor and eventually the brushes wear out, necessitating replacement. The brushes also result in sparking and electrical noise, which leads to variation in the motor constants, as observed by the laboratory. Another disadvantage is that the component of the motor that heats up, the electromagnet, is in the rotor and is nearly impossible to cool without opening the motor to blow air through it.

Conversely, brushless motors do not contain brushes. The electromagnet for the motor is in the stator and does not rotate, while the rotor contains rare earth magnets. The changing of the polarity to continue to make the motor spin is controlled by a computer, making the control more precise and efficient, since the computer can factor in

the speed of the motor. Without the brushes, the motor has less frictional losses and less variable motor constants and properties. Also, with the electromagnets in the stator the motor will be much easier to cool, which means the motor will be able to run longer at higher power values without overheating.

The major drawback of the brushless motor is that they are much more difficult to control. A brushless motor requires a computer to sense the position of the rotor and apply the appropriate voltage across the appropriate electromagnet to force the motor to spin. Hence, the goal of this project is to modify a motor controller board to enable control of a brushless motor and create a motor controller to run the motor.

II. Methods and Results

A. Motor Description

The motor used is a Maxon EC32, 32 mm, brushless, 80 Watt order number 118888, corresponding to the 18 volt motor. The spec sheet for the motor is located in the appendix. A picture of the motor is displayed below in Figure 1. The motor is approximately 2.5 inches long, 1.25 inches across, and 270 grams.
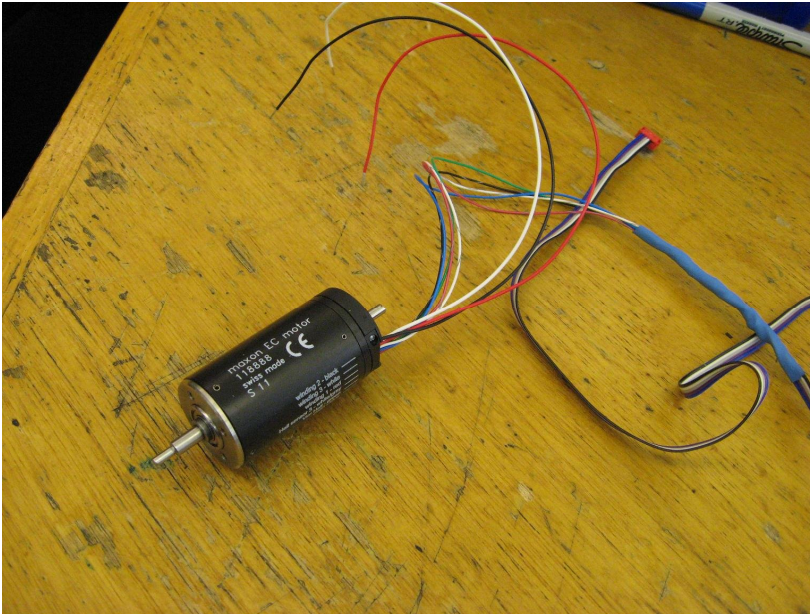

Figure 1: Picture of the brushless motor supplied.

As depicted in the figure, the motor has eight wires attaching to it. There is one power wire for each of the three windings, one power wire for the Hall effect sensors, one ground wire for the Hall effect sensors, and one power wire for each of the three Hall effect sensors. The Hall sensors are built into the motor to detect the position of the rotor. The Hall sensors return a high value when rotor is in one orientation and a low when the rotor is 180 degrees away from the high. In actual use, the Hall sensor returns a high for the 180 degree section while the rotor is closest to the sensor and a low voltage of zero for the rest of the time. The motor uses three Hall sensors, and by determining which sensors are on at any given time, the appropriate orientation of the electromagnetic field can be applied.

B. The Motor Controller Board

In order to implement a controller for the brushless motor, it is necessary for the H-bridge to have control over the three motor winding; this means that the motor controller board H-bridge must have a total of six MOSFETs, with each of the windings connected to the board between two of the MOSFETs. The current motor controller boards used on the Ranger only contain four MOSFETs, because they were built for brushed motors. The simplest method to reach the necessary number of MOSFETs, without redesigning an entire board, is to build a pseudo-motor controller board. The pseudo board is incapable of being used by itself; it contains no processor, it only contains the motor controller portion of the board, but when connected to the old motor controller boards, it is successfully used as a brushless motor controller.

i. Building the board

Although the pseudo motor controller only requires an additional two MOSFETs, the set of four were used on the board. This means the board has all the motor controller parts necessary to run a brushless motor, and the board is capable of being used as a backup for the current motor controller boards if necessary.

A picture of the finished product is depicted below in Figure 2, as described above only the motor controller components are on the board, so only approximately half the board is populated. The board was populated by a process called surface mount soldering. Using the procedure outlined in the wiki entry entitled: "How-to guide for surface mount soldering" compiled by Emily McAdams, the parts are soldered onto the empty circuit board.
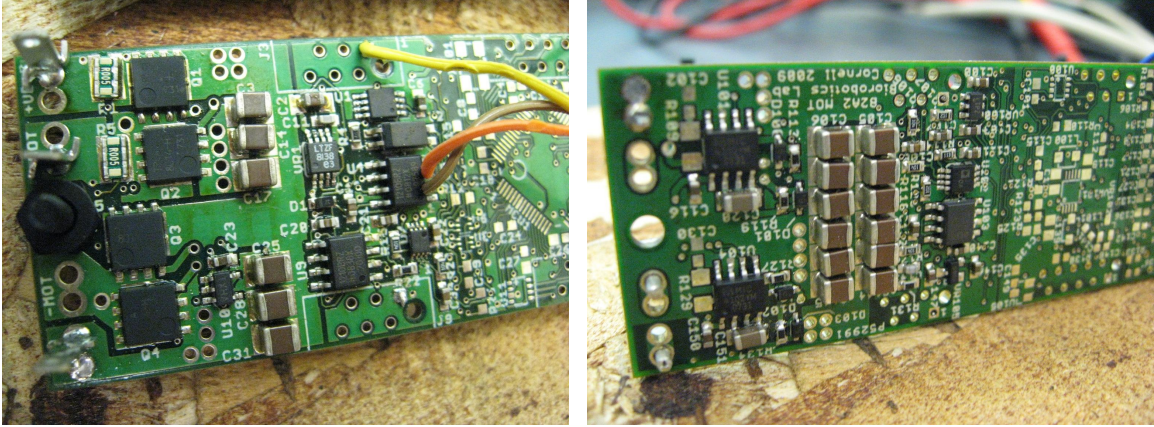
Figure 2: The top (left) and bottom (right) sides of the competed pseudo motor controller board.

ii. Connecting Boards

Upon completion of the pseudo motor controller board, it is necessary to connect the two boards together, relaying the appropriate information or power between the boards. To connect the boards, a four pin and a six pin connector were used to relay information to unused jacks on the original board, as well as an additional wire that was directly soldered to each board. This is depicted in Figure 3 below.
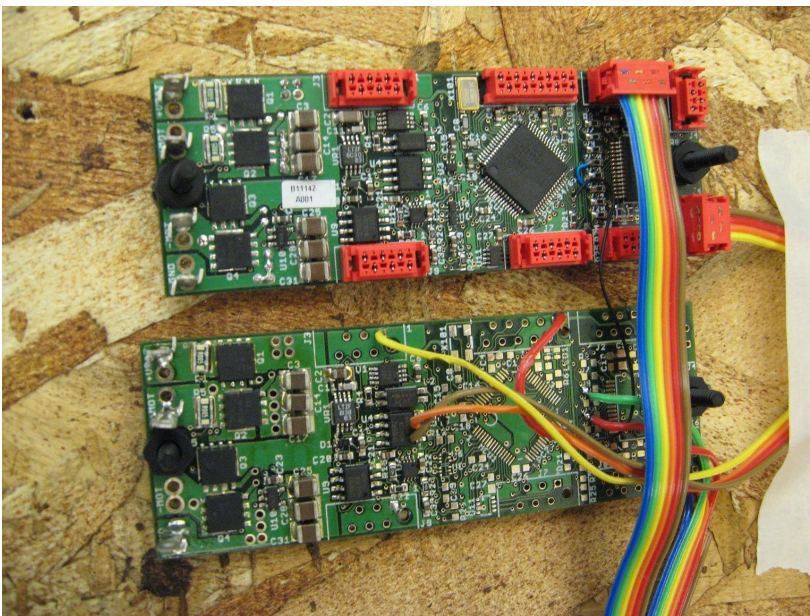

Figure 3: Displays the connections between the two motor controller boards.

The four pin connector is largely used to power the new pseudo board, and connects to the new board at the serial port at J6. The power supplied to the board is 3V3D, and is applied through pin three of the jack. Pin one of the jack supplies a reference ground, referred to as GND-C. The PWM for the board is supplied through pin four, and LSA is supplied through pin two. Pin one connects to the pseudo board at pin one of J3, pin two connects at pin 3 of U4, pin three connects at pin 1 of J1, and pin four connects at pin 2 of U4. Each of these connections is soldered onto the appropriate place on the pseudo board. The four pin connector required a small modification of the old board. At pin four, there was a resistor connecting a 5 volt reference voltage to the output. This resistor was removed because the reference voltage is unnecessary. The exact technical modification was that resistor R105 and resistor R24 were removed and R105 was placed across R111.

For the six pin connector, only two of the pins are utilized. Pin two is the battery current output, and pin five is the motor current output. This information is supplied back to the old motor controller board. The six pin connector attaches to the old motor controller board at J2. Pin two of the six pin connector is soldered directly to the resistor pad R11 and pin 5 is soldered directly to the resistor pad at R9 on the pseudo board.

The final board to board connection was the watchdog timer (WDT). The WDT was connected by attaching a small magnet wire between the two boards at the necessary points. This magnet wire was soldered directly to the boards by a via at pin 30 of the MCU on both boards.

The final connection necessary is to connect the Hall effect sensors to the old motor controller board. This requires three free digital inputs. Therefore, the Hall effect sensors are set up with a connector into J9 on the old motor controller board. The Hall sensors require a reference voltage applied to the signal across a resistor. Therefore, the available 5 volts at pin four of J9 were used as the reference voltage. This process involves soldering three resistors to pin four and then attaching one of the resistors to each Hall sensor output. The entire apparatus was covered with heat shrink to make it look more appealing. Schematics of the boards and connections are displayed below.
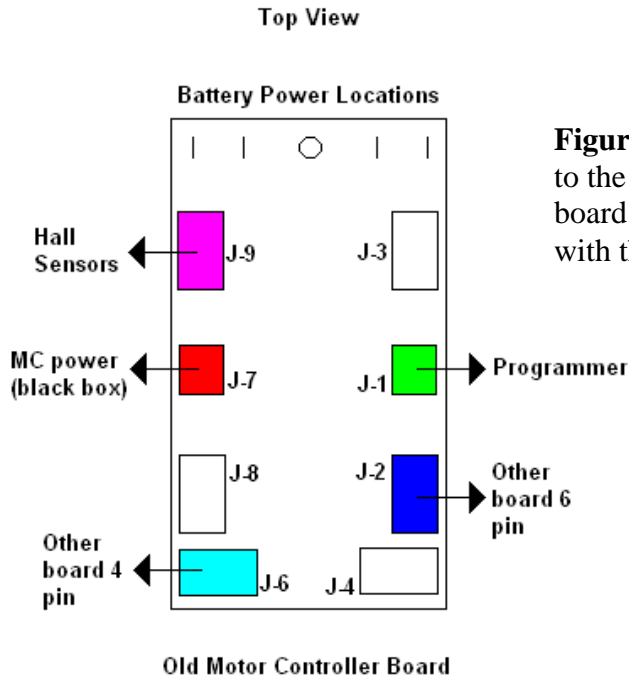
Top View

Battery Power Locations

Old Motor Controller Board

Figure 4: Depicts the connections to the original motor controller board. Specifically the interactions with the pseudo board.

It is also important to setup the motor power correctly. The power supply at J7 shown in Figure 4 is the power supply for the motor controller board. The motor itself must be powered. This configuration is depicted in Figure 5 below. In the figure, the blue, black, and red wires coming from the motor correspond directly with the actual white, black, and red winding power wires of the motor.
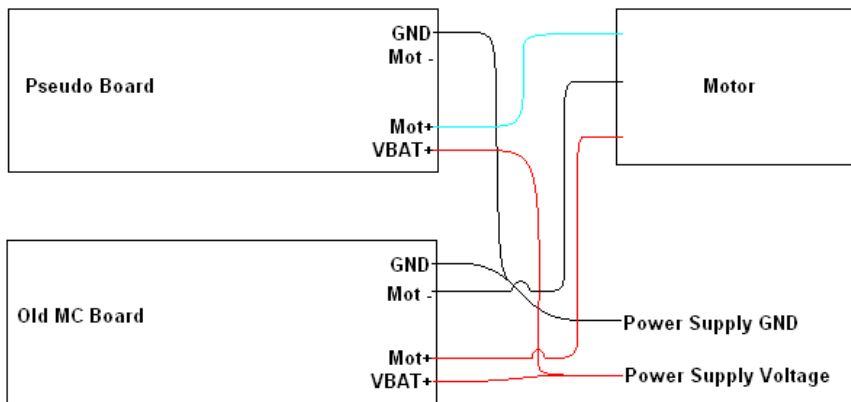

Figure 5: Depiction of motor power connections.

D. Motor Controller

The basic principal of the motor controller is to use the Hall effect sensors to determine the orientation of the rotor and apply a magnetic field perpendicular to the rotor magnets. To control the speed of the motor, the voltage applied is Pulse Width Modulated (PWM). It is also necessary to determine the speed of the motor, which can be accomplished by measuring the time for the Hall sensors to go through one full rotation, corresponding to one revolution of the motor. The diagram below shows the possible sequence of MOSFET activity to achieve one full rotation of the rotor. In the diagram, each winding is attached between two MOSFETs, and by controlling which MOSFETs are active controls the flow of current into the motor and ultimately the direction of the magnetic field.
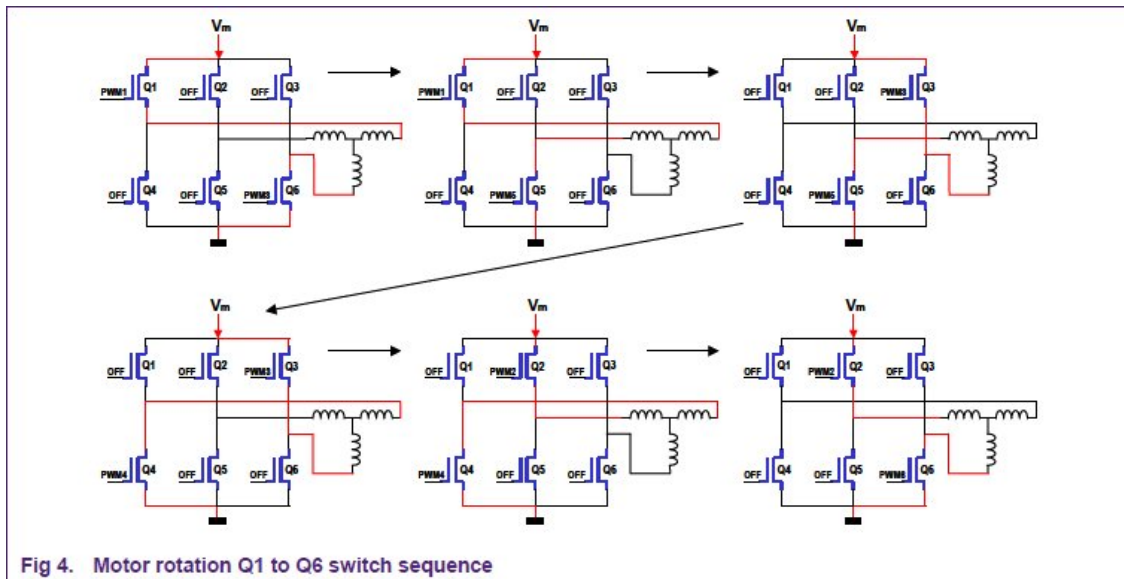

Fig 4.   Motor rotation Q1 to Q6 switch sequence

Figure 6: Depicts the flow of current through the MOSFETs and motor windings, as a progression of the rotation of the motor. The figure is from the **Brushless DC motor control using the LPC2141** article from the NPX website.

The actual implementation of this strategy utilizes a block commutation scheme provided in the Maxon EC motor guide, included in the appendix. This strategy is depicted in Figure 7, below. As depicted below there are six cases, where the high sensor is: 1, 1 and 2, 2, 2 and 3, 3, 3 and 1. In the code, the variable hall_sensor_code is comprised of three bits: sensor 3 is assigned bit 0, sensor 2 is assigned bit 1, and sensor 1 is assigned bit 2. The actual motor code takes on a switch-case structure, which allows

for the six cases listed above, as well as the potential to go in the reverse direction. In each case, it is first determined which winding is getting the voltage applied to it. Next, it is determined which two MOSFETs are set to the on position. For example, phase 1 in the diagram below has Hall sensors 1 and 3 set to on. This gives a value of 101 for hall_sensor_code, in binary, or 5 in decimal. In the diagram, U_{1-2} is on, with the shaded portion on the positive side. This means that the lowside MOSFETs for windings 1 and 2 are set to on, and the lowside MOSFET for winding 3 is off. Also, since the top is shaded, the first number of the subscript has the voltage applied to it, so in the code, winding 1 gets the voltage. This example is depicted as the second state in Figure 6. The specific section of code is as follows:

```
//***************************
case 5:   //0b101 Phase I
  {
   PWM_PHASE_A = pwm;
   PWM_PHASE_B = 0;
   PWM_PHASE_C = 0;
   LOWSIDE_PHASE_A_ON
   LOWSIDE_PHASE_B_ON
   LOWSIDE_PHASE_C_OFF
   break;
  }
//***************************
```
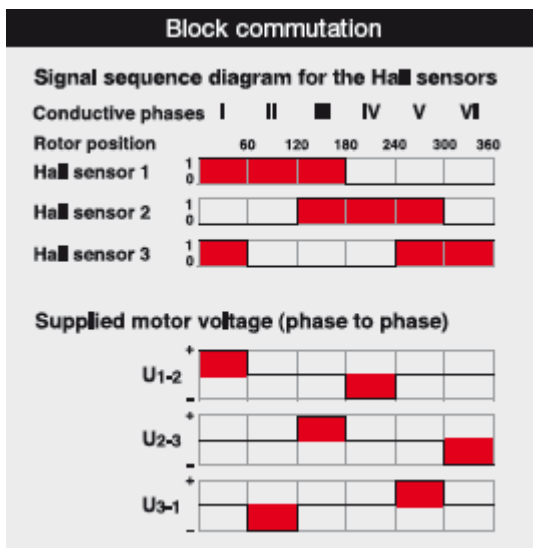

Figure 7: Block commutation scheme from Maxon's motor guide.

III. Discussion

Upon the completion of the project, I have a working motor controller for a brushless dc motor; however, the motor controller can be improved. Currently all of the code for the motor controller is in the main loop of the c file. This may cause a problem at high speed, since the motor may be turning faster than the main loop can keep up with. This problem could be solved by putting the code into an interrupt; let the motor run until a hall sensor switches on, then apply the necessary voltage to the necessary windings. This would also be useful for determining the speed of the motor by counting the interrupts. A working motor controller has been made, but many modifications are necessary before the code is good enough to use on a robot.

IV. Appendices

Motor Controller Code:

```
#include <includes.h>

void FIQ_Handler(void) __irq
{
}

int main (void)
{
signed short hall_sensor_code = 0;
signed short motor_forward = 0;
unsigned short pwm = 100;
unsigned long watchdog_counter = 0;

#define LOWSIDE_PHASE_A_OFF FIO0CLR = (1<<11);      // turn off low side A enable output
#define LOWSIDE_PHASE_B_OFF FIO1CLR = (1<<17);      // turn off low side B enable output
#define LOWSIDE_PHASE_C_OFF FIO0CLR = (1<<10);      // turn off low side C enable output

#define LOWSIDE_PHASE_A_ON FIO0SET = (1<<11);       // turn on low side A enable output
#define LOWSIDE_PHASE_B_ON FIO1SET = (1<<17);       // turn on low side B enable output
#define LOWSIDE_PHASE_C_ON FIO0SET = (1<<10);       // turn on low side C enable output

#define PWM_PHASE_A PWMMR6
#define PWM_PHASE_B PWMMR2
#define PWM_PHASE_C PWMMR5

  init_hardware();
 //init_interrupts();
  while(1)
  {

//Set up the Hall effect sensor code. This could be way shorter,
//but this way is easy to fiddle with until the phases are right.
  hall_sensor_code = 0;

  if (FIO0PIN & (1<<5))
  {
   hall_sensor_code |= (1<<0);  // Hall effect sensor 3 (C), bit zero
  }
  if (FIO0PIN & (1<<16))
  {
   hall_sensor_code |= (1<<1); // Hall effect sensor 2 (B), bit one
  }
```

```c
if (FIO0PIN & (1<<29))
{
 hall_sensor_code |= (1<<2); // Hall effect sensor 1 (A), bit two
}
if (!motor_forward)
{
 hall_sensor_code = - hall_sensor_code;  // Let's try making it go backward too
}


switch(hall_sensor_code)
{
 case 5:    //0b101 Phase I
 {
  PWM_PHASE_A = pwm;
  PWM_PHASE_B = 0;
  PWM_PHASE_C = 0;
  LOWSIDE_PHASE_A_ON
  LOWSIDE_PHASE_B_ON
  LOWSIDE_PHASE_C_OFF
  break;
 }
 case 4:    //0b100 Phase II
 {
  PWM_PHASE_A = pwm;
  PWM_PHASE_B = 0;
  PWM_PHASE_C = 0;
  LOWSIDE_PHASE_A_ON;
  LOWSIDE_PHASE_B_OFF;
  LOWSIDE_PHASE_C_ON;
  break;
 }
 case 6:    //0b110 Phase III
 {
  PWM_PHASE_A = 0;
  PWM_PHASE_B = pwm;
  PWM_PHASE_C = 0;
  LOWSIDE_PHASE_A_OFF;
  LOWSIDE_PHASE_B_ON;
  LOWSIDE_PHASE_C_ON;
  break;
 }
 case 2:    //0b010 Phase IV
 {
  PWM_PHASE_A = 0;
  PWM_PHASE_B = pwm;
```

```c
    PWM_PHASE_C = 0;
    LOWSIDE_PHASE_A_ON;
    LOWSIDE_PHASE_B_ON;
    LOWSIDE_PHASE_C_OFF;
    break;
}
case 3:    //0b011 Phase V
{
    PWM_PHASE_A = 0;
    PWM_PHASE_B = 0;
    PWM_PHASE_C = pwm;
    LOWSIDE_PHASE_A_ON;
    LOWSIDE_PHASE_B_OFF;
    LOWSIDE_PHASE_C_ON;
    break;
}
case 1:    //0b001 Phase vI
{
    PWM_PHASE_A = 0;
    PWM_PHASE_B = 0;
    PWM_PHASE_C = pwm;
    LOWSIDE_PHASE_A_OFF;
    LOWSIDE_PHASE_B_ON;
    LOWSIDE_PHASE_C_ON;
    break;
}
//Backwards      counterclockwise
case -5:    //-0b101 Phase I R
{
    PWM_PHASE_A = 0;
    PWM_PHASE_B = pwm;
    PWM_PHASE_C = 0;
    LOWSIDE_PHASE_A_ON;
    LOWSIDE_PHASE_B_ON;
    LOWSIDE_PHASE_C_OFF;
    break;
}
case -4:    //-0b100 Phase II R
{
    PWM_PHASE_A = 0;
    PWM_PHASE_B = 0;
    PWM_PHASE_C = pwm;
    LOWSIDE_PHASE_A_ON;
    LOWSIDE_PHASE_B_OFF;
    LOWSIDE_PHASE_C_ON;
    break;
```

```c
    }
    case -6:    //-0b110 Phase III R
    {
     PWM_PHASE_A = 0;
     PWM_PHASE_B = 0;
     PWM_PHASE_C = pwm;
     LOWSIDE_PHASE_A_OFF;
     LOWSIDE_PHASE_B_ON;
     LOWSIDE_PHASE_C_ON;
     break;
    }
    case -2:    //-0b010 Phase Iv R
    {
     PWM_PHASE_A = pwm;
     PWM_PHASE_B = 0;
     PWM_PHASE_C = 0;
     LOWSIDE_PHASE_A_ON;
     LOWSIDE_PHASE_B_ON;
     LOWSIDE_PHASE_C_OFF;
     break;
    }
    case -3:    //-0b011 Phase V R
    {
     PWM_PHASE_A = pwm;
     PWM_PHASE_B = 0;
     PWM_PHASE_C = 0;
     LOWSIDE_PHASE_A_ON;
     LOWSIDE_PHASE_B_OFF;
     LOWSIDE_PHASE_C_ON;
     break;
    }
    case -1:    //-0b001 Phase VI R
    {
     PWM_PHASE_A = 0;
     PWM_PHASE_B = pwm;
     PWM_PHASE_C = 0;
     LOWSIDE_PHASE_A_OFF;
     LOWSIDE_PHASE_B_ON;
     LOWSIDE_PHASE_C_ON;
     break;
    }
    default: //all off
    {
     PWM_PHASE_A = 0;
     PWM_PHASE_B = 0;
     PWM_PHASE_C = 0;
```
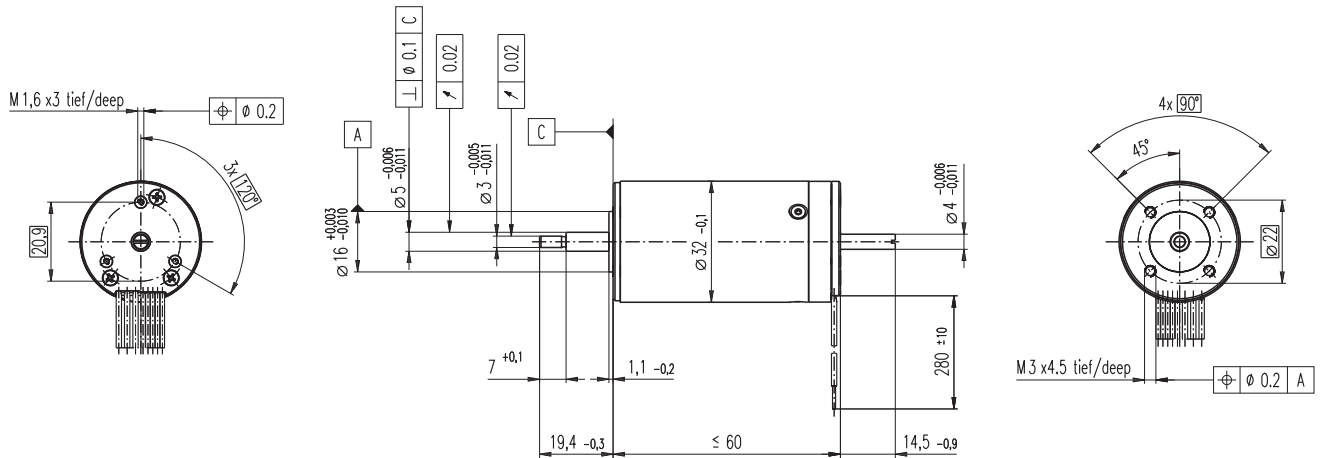
```c
    LOWSIDE_PHASE_A_OFF;
    LOWSIDE_PHASE_B_OFF;
    LOWSIDE_PHASE_C_OFF;
    break;
  }
}

PWMLER= (PWMLER|0x65) & ~PWMLER_RB;  //update PWM values.

if (watchdog_counter++ > 1000)
{

  watchdog_counter = 0;
}
else if (watchdog_counter++ > 500)
{
 FIO0SET = (1<<6);     // turn on watchdog timer output
}
else
{
 FIO0CLR = (1<<6);     // turn off watchdog timer output
  watchdog_counter++;
}
}
}
```

EC 32 ⌀32 mm, brushless, 80 Watt, CE approved

M 1:2

	Stock program
	Standard program
	Special program (on request)

Order Number

		118891	118892	118888	118889	118893	118890		
Motor Data									
	Values at nominal voltage								
1	Nominal voltage	V	12.0	18.0	18.0	24.0	36.0	48.0		
2	No load speed	rpm	15000	14300	13000	11000	14700	11300		
3	No load current	mA	901	555	487	286	289	148		
4	Nominal speed	rpm	13600	12800	11600	9510	13200	9790		
5	Nominal torque (max. continuous torque)	mNm	37.5	40.1	41.2	43.6	39.7	42.6		
6	Nominal current (max. continuous current)	A	5.82	3.88	3.61	2.37	1.98	1.19		
7	Stall torque	mNm	428	443	407	355	454	353		
8	Starting current	A	57.2	37.4	31.4	17.3	19.7	8.84		
9	Max. efficiency	%	77.0	77.6	77.1	76.4	77.7	76.2		
	Characteristics								
10	Terminal resistance phase to phase	Ω	0.21	0.481	0.573	1.39	1.83	5.43		
11	Terminal inductance phase to phase	mH	0.03	0.0752	0.09	0.226	0.285	0.856		
12	Torque constant	mNm / A	7.48	11.8	13.0	20.5	23.1	40.0		
13	Speed constant	rpm / V	1280	806	737	465	414	239		
14	Speed / torque gradient	rpm / mNm	35.8	32.7	32.6	31.5	32.8	32.5		
15	Mechanical time constant	ms	7.49	6.86	6.82	6.59	6.87	6.8		
16	Rotor inertia	gcm^2	20.0	20.0	20.0	20.0	20.0	20.0		

Specifications

Thermal data
17 Thermal resistance housing-ambient 5.4 K / W
18 Thermal resistance winding-housing 2.5 K / W
19 Thermal time constant winding 15.4 s
20 Thermal time constant motor 1180 s
21 Ambient temperature -20 ... +100°C
22 Max. permissible winding temperature +125°C

Mechanical data (preloaded ball bearings)
23 Max. permissible speed 25000 rpm
24 Axial play at axial load < 8 N 0 mm
   > 8 N max. 0.14 mm
25 Radial play preloaded
26 Max. axial load (dynamic) 5.6 N
27 Max. force for press fits (static) 110 N
   (static, shaft supported) 1200 N
28 Max. radial loading, 5 mm from flange 28 N

Other specifications
29 Number of pole pairs 1
30 Number of phases 3
31 Weight of motor 270 g

Values listed in the table are nominal.

Connection motor (Cable AWG 22)
red Motor winding 1
black Motor winding 2
white Motor winding 3
Connection sensors (Cable AWG 26)[1]
green V_{Hall} 4.5 ... 24 VDC
blue GND
red / grey Hall sensor 1
black / grey Hall sensor 2
white / grey Hall sensor 3
Wiring diagram for Hall sensors see page 27

1) Not lead through in combination with resolver.

Operating Range
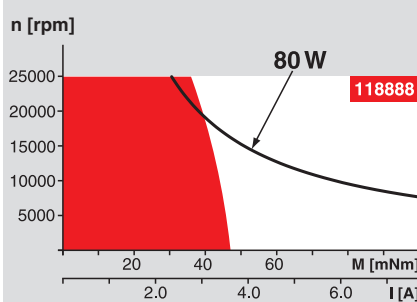
Comments

	Continuous operation
	In observation of above listed thermal resistance (lines 17 and 18) the maximum permissible winding temperature will be reached during continuous operation at 25°C ambient. = Thermal limit.
	Short term operation
	The motor may be briefly overloaded (recurring).
	Assigned power rating

maxon Modular System
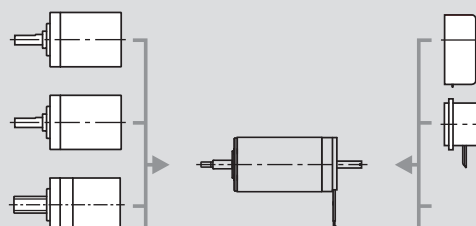Overview on page 16 - 21

Planetary Gearhead
⌀32 mm
0.75 - 4.5 Nm
Page 232

Planetary Gearhead
⌀32 mm
0.75 - 6.0 Nm
Page 234 / 236

Spindle Drive
⌀32 mm
Page 251 / 252 / 253

Encoder HED_5540
500 CPT,
3 channels
Page 269 / 271

Resolver Res 26
⌀26 mm
10 V
Page 278

Recommended Electronics:
DECS 50/5 Page 288
DEC 50/5 289
DECV 50/5 295
DEC 70/10 295
DES 50/5 296
EPOS2 24/5 303
EPOS2 50/5 303
EPOS 70/10 303
EPOS P 24/5 306
Notes 20

May 2009 edition / subject to change

maxon EC motor ironless winding
Technology – short and to the point

Characteristics of **maxon EC motors**
– Brushless DC motor
– Long service life
– Speeds of up to 50 000 rpm and higher
  are possible
– Highly efficient
– Linear motor characteristics, excellent
  control properties
– Ironless winding system maxon®
  with three phases in the stator
– Lowest electrical time constant and
  low inductance
– No detent
– Good heat dissipation, high overload
  capacity
– Rotating Neodymium permanent magnet
  with 1 or 2 pole pairs.
– Lowest residual unbalance

Characteristics of the **maxon EC-max** range
– attractive price/performance ratio
– robust steel casing
– speeds of up to 20 000 rpm
– rotor with 1 pole pair

Characteristics of the **maxon EC powermax**
range
– Highest power density thanks to rotor
  with 2 pole pairs
– Knitted winding system maxon® with optimi-
  sed interconnection of the partial windings
– Speeds of up to 25 000 rpm
– High-quality magnetic return material to
  reduce eddy current losses
– Mechanical time constants below 3 ms

Bearings and service life

The long service life of the brushless design can
only be properly exploited by using preloaded
ball bearings.
– Bearings designed for tens of thousands
  of hours.
– Service life is affected by maximum speed,
  residual unbalance and bearing load.

Program

– **EC-Program**
– *EC*-max-Program
– *EC*-powermax

– **with Hall sensors**
– **sensorless**
– **with integrated electronics**

Electronical commutation

Block commutation
Rotor position is reported by three in-built Hall
sensors. The Hall sensors arranged offset by
120° provide six different signal combinations
per revolution. The three partial windings are
now supplied in six different conducting phases
in accordance with the sensor information. The
current and voltage curves are block-shaped.
The switching position of each electronic com-
mutation is offset by 30° from the respective
torque maximum.

Properties of block commutation
– Relatively simple and favorably priced
  electronics
– Torque ripple of 14 %
– Controlled motor start-up
– High starting torques and accelerations
  possible
– The data of the maxon EC motors are
  determined with block commutation.

Possible applications
– Highly dynamic servo drives
– Start/stop operation
– Positioning tasks

Sensorless block commutation
The rotor position is determined using the
progression of the induced voltage. The electro-
nics evaluate the zero crossing of the induced
voltage (EMF) and commute the motor current
after a speed dependent pause (30° after EMF
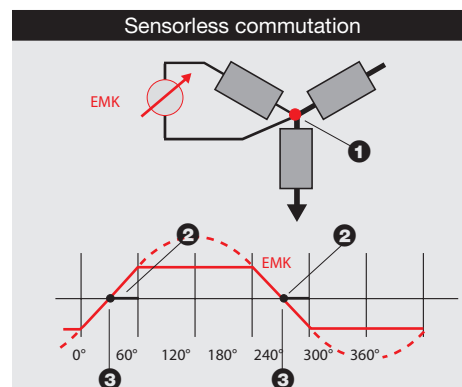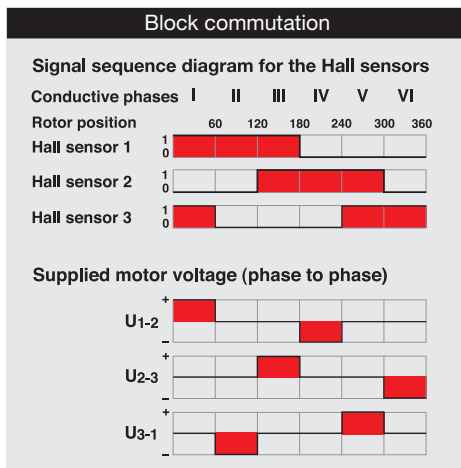zero crossing).
The amplitude of the induced voltage is
dependent on the speed. When stalled or at low
speed, the voltage signal is too small and the
zero crossing cannot be detected precisely. This
is why special algorithms are required for star-
ting (similar to stepper motor control). To allow
EC motors to be commuted without sensors in
a △ arrangement, a virtual star point is usually
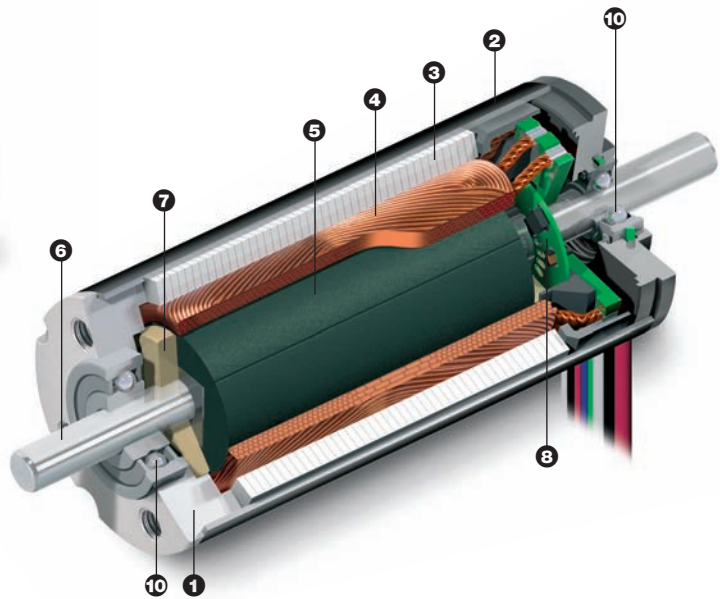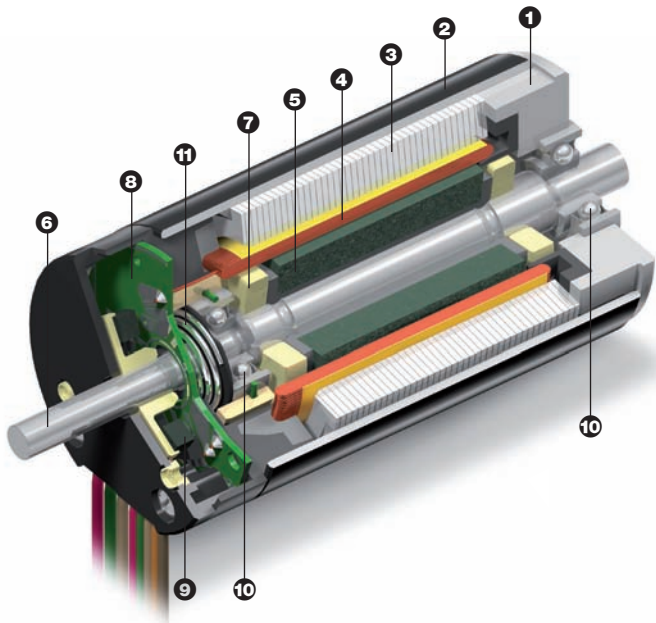created in the electronics.

Properties of sensorless commutation
– Torque ripple of 14 % (block commutation)
– No defined start-up
– Not suitable for low speeds
– Not suitable for dynamic applications
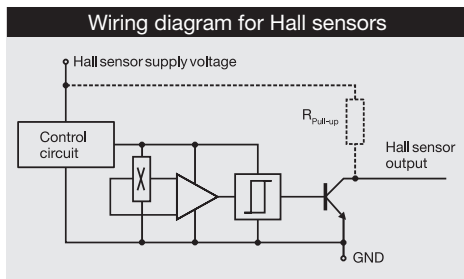
Possible applications
– Continuous operation at higher speeds
– Fans

Legend
The commutation angle is based on the length
of a full commutation sequence (360°e). The
length of a commutation interval is therefore
60°e.
The commutation rotor position is identical to
the motor shaft position for motors with 1 pole
pair.
The values of the shaft position are halved for
motors with 2 pole pairs.

❶ Flange
❷ Housing
❸ Laminated steel stack
❹ Winding
❺ Permanent magnet
❻ Shaft
❼ Balancing disks
❽ Print with Hall sensors
❾ Control magnet
❿ Ball bearing
⓫ Spring (bearing preload)

Block commutation

Signal sequence diagram for the Hall sensors

Conductive phases   I   II   III   IV   V   VI

Rotor position   60   120   180   240   300   360

Hall sensor 1
Hall sensor 2
Hall sensor 3

Supplied motor voltage (phase to phase)

U1-2
U2-3
U3-1

Sensorless commutation

EMK
EMK

0°   60°   120°   180°   240°   300°   360°

Sinusoidal commutation

The high resolution signals from the encoder or resolver are used for generating sine-shape motor currents in the electronics. The currents through the three motor windings are related to the rotor position and are shifted at each phase by 120 degrees (sinusoidal commutation). This results in the very smooth, precise running of the motor and, in a very precise, high quality control.

Properties of sinusoidal commutation
– More expensive electronics
– No torque ripple
– Very smooth running, even at very low speeds
– Approx. 5% more continuous torque compared to block commutation

Possible applications
– Highly dynamic servo drives
– Positioning tasks
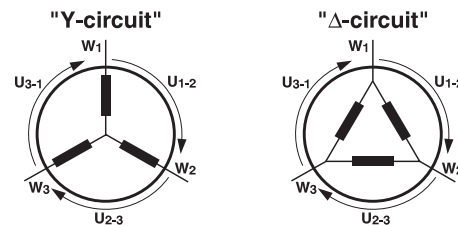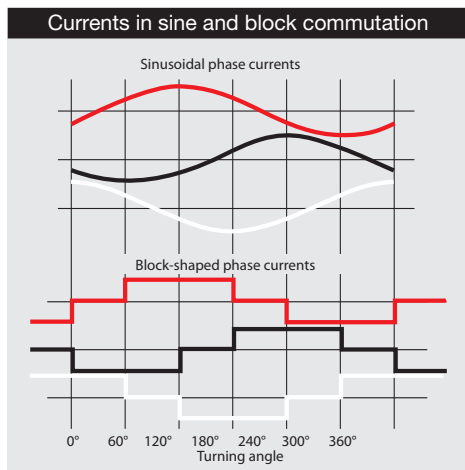
Hall sensor circuit

The open collector output of Hall sensors does not normally have its own pull-up resistance, as this is integral in maxon controllers. Any exceptions are specifically mentioned in the relevant motor data sheets.

Wiring diagram for Hall sensors

Hall sensor supply voltage

$R_{Pull-up}$

Control circuit

Hall sensor output

GND

Winding arrangement

The maxon rhombic winding is divided into three partial windings, each shifted by 120°. The partial windings can be connected in two different manners - "Y" or "Δ". This changes the speed and torque inversely proportional by the factor $\sqrt{3}$.

However, the winding arrangement does not play a decisive role in the selection of the motor. It is important that the motor-specific parameters (speed and torque constants) are line with requirements.

"Y-circuit"

W_1
U_{3-1}
U_{1-2}
W_3
W_2
U_{2-3}

"Δ-circuit"

W_1
U_{3-1}
U_{1-2}
W_3
W_2
U_{2-3}

The maximum permissible winding temperature is 125°C. (EC-max and EC-powermax 155°C).

For further explanations, please see page 141 or "The selection of high-precision microdrives" by Dr. Urs Kafader.

Currents in sine and block commutation

Sinusoidal phase currents

Block-shaped phase currents

0° 60° 120° 180° 240° 300° 360°
Turning angle

Legend
❶ Star point
❷ Time delay 30°
❸ Zero crossing of EMF