Electronic Instrumentation

Students Micro-Projects-Brushless motor (16)

GROUP NUMBER #6

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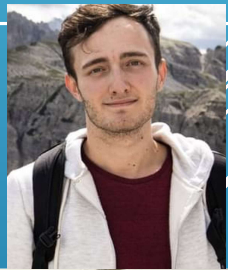
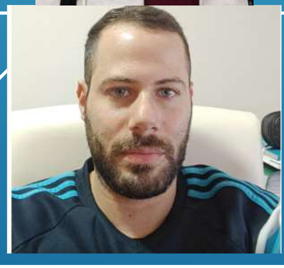
Student #2	**316146836**	**Steve Reznikov**	
Student #3	**313601866**	**Or Salganik**	

Lecturer Dr. Samuel Kosolapov

P16.11 MECHANICAL AND ELECTRICAL ELEMENTS OF THE MOTOR (DRAWINGS AND EXPLANATIONS)

A brushless motor, also known as a Brushless DC motor (BLDC) or as an electronically commutated motor, is a type of electric motor that **doesn't rely on carbon brushes to transfer current to the rotor coils.**

Instead, it uses electronic commutation **to determine which coil receives current at what time, precisely aligning with the rotor's position.**

Unlike traditional brushed DC motors, which use physical brushes and a commutator to contact the rotor and switch the current, **BLDC motors use permanent magnets and a rotating electronic circuit board to achieve the same effect.**

P16.11 MECHANICAL AND ELECTRICAL ELEMENTS OF THE MOTOR (DRAWINGS AND EXPLANATIONS)

TWO GENERAL TYPES OF DESIGNS OF BLDC MOTORS

Outrunner BLDC Motor:

- In an outrunner design, the rotor is located on the outer side of the motor assembly, surrounding the stator.
- The rotor rotates around a fixed stator, and the outer casing of the motor remains stationary during operation.
- Outrunner motors typically have a lower rotational speed compared to inrunners. They are often used in applications where torque is more important than speed, such as in electric vehicles, model aircraft, and wind turbines.

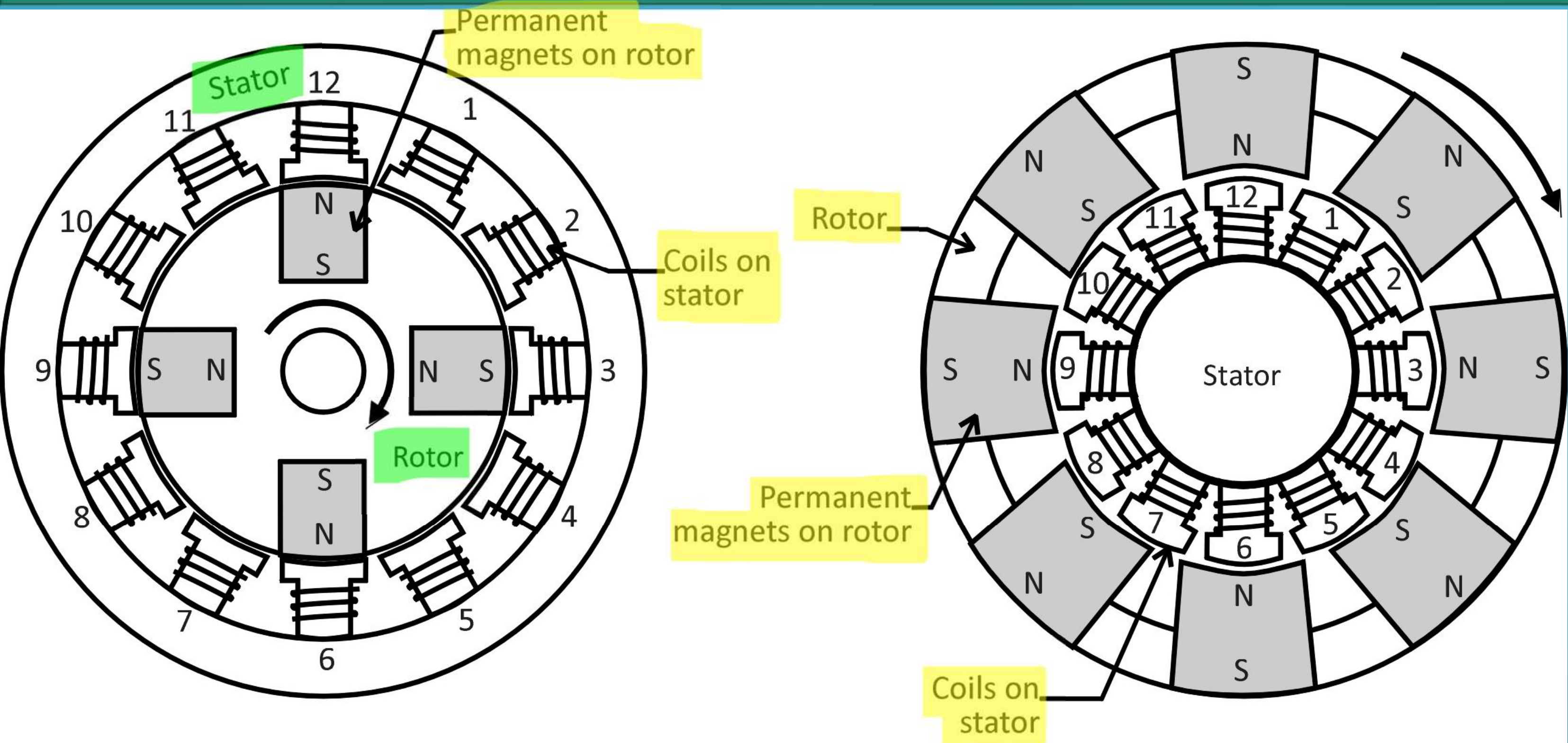
Inrunner BLDC Motor:

- In an inrunner design, the rotor is located inside the stator.
- The stator surrounds the rotor, and both rotate together as a single unit during operation.
- Inrunner motors usually have a higher rotational speed compared to outrunner motors.
- They are commonly used in applications where high rotational speeds are required, such as in RC cars, drones, and small appliances.

https://en.wikipedia.org/wiki/Brushless_DC_electric_motor

P16.11 MECHANICAL AND ELECTRICAL ELEMENTS OF THE MOTOR (DRAWINGS AND EXPLANATIONS)-CONTINUE

magnets are fixed to the rotor and the stator is wound with a specific number of poles. Current is commutated around the stator poles by using an electronic commutator. In the left image an inrunner design is presented and in the right image an outrunner design is presented:



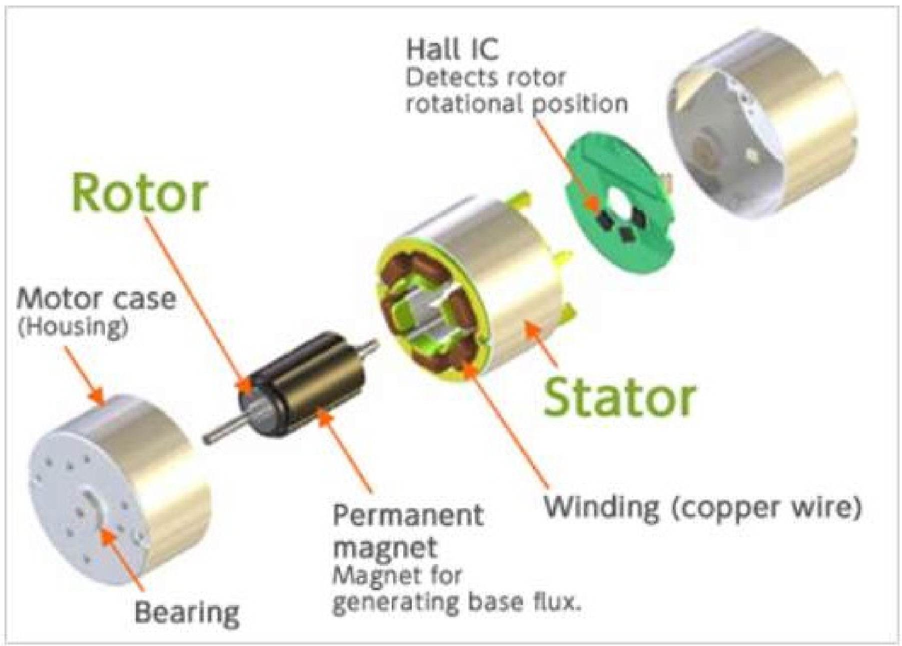
(a): Rotor inside stator (inrunner design) (b): Rotor outside stator (outrunner design)

https://www.quora.com/What-is-the-reason-my-brushless-permanent-magnet-DC-motor-is-hard-to-be-rotated-by-hand-while-the-bearings-the-stator-and-the-rotor-have-no-mechanical-problems

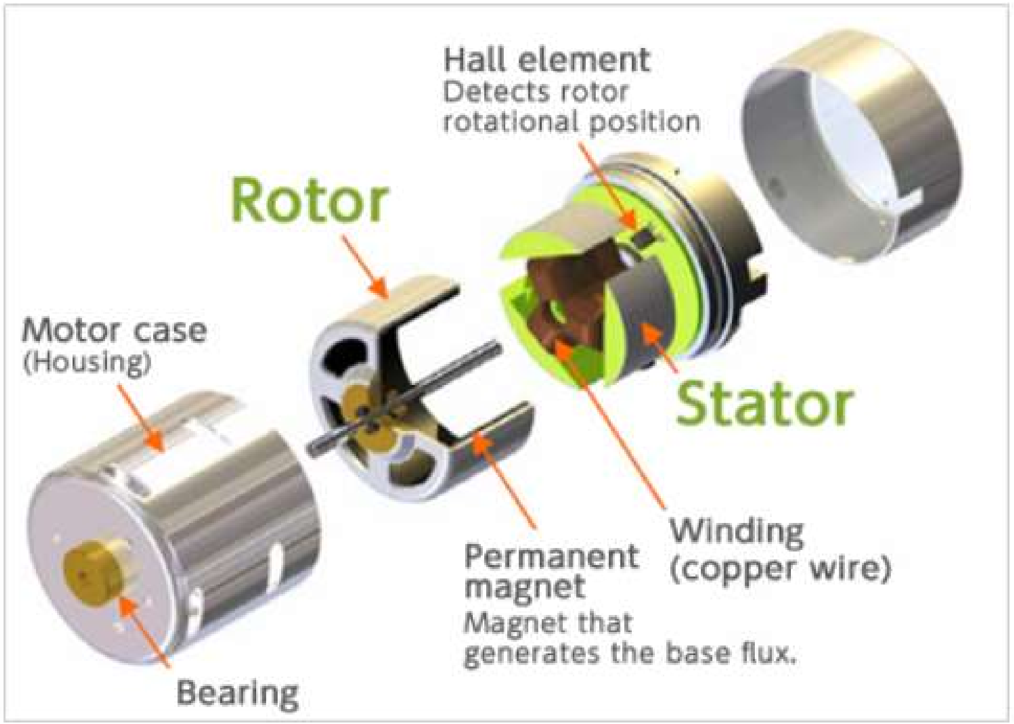
P16.11 MECHANICAL AND ELECTRICAL ELEMENTS OF THE MOTOR (DRAWINGS AND EXPLANATIONS)-CONTINUE

In the images below one can see few mechanical components of the Brushless DC motor. We can see the stator, rotor, Hall sensor and the case of the motor.

In an Inrunner design:



In an outrunner design:



https://www.nidec.com/en/technology/capability/brushless/

P16.11 MECHANICAL AND ELECTRICAL ELEMENTS OF THE MOTOR (DRAWINGS AND EXPLANATIONS)-CONTINUE

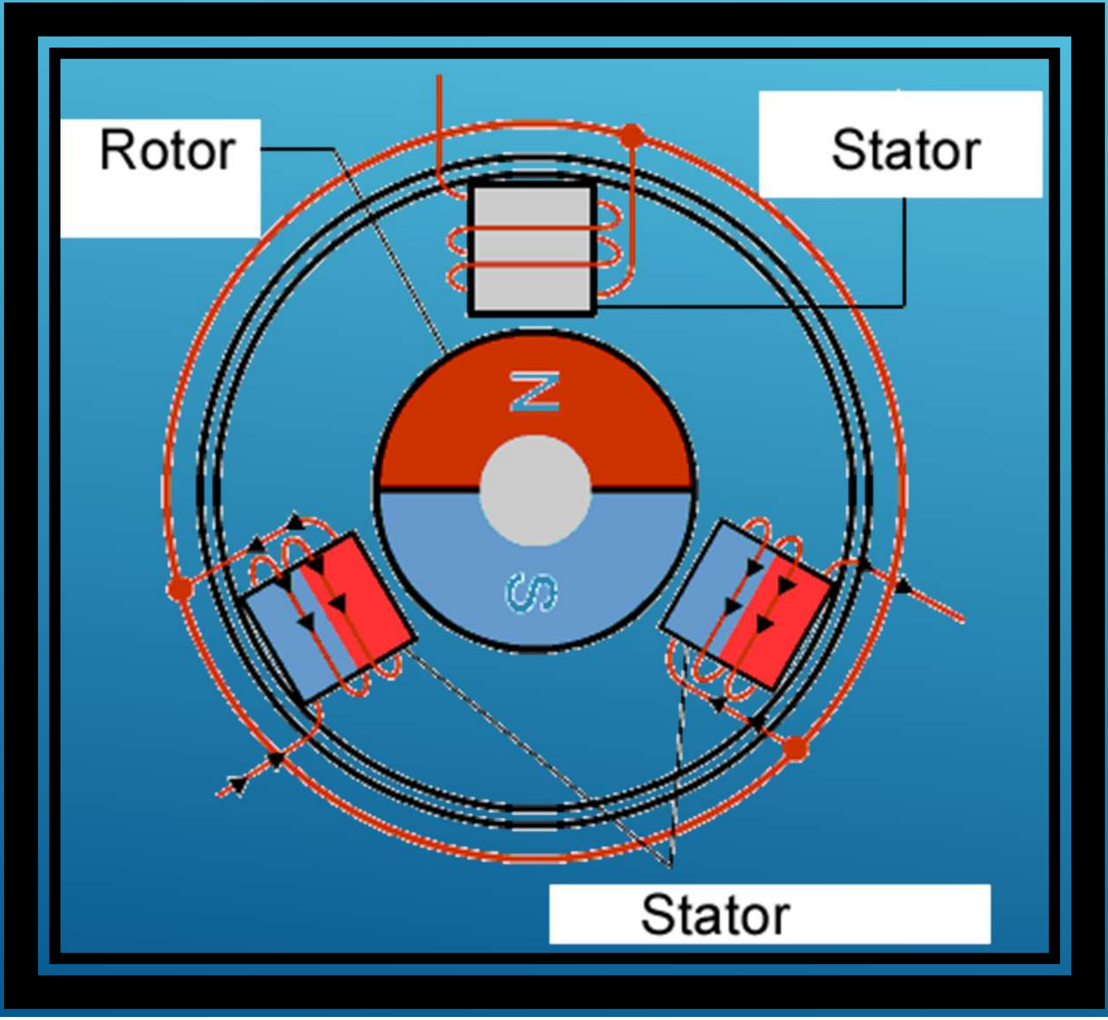
while BLDC motors draw DC power, **their internal operation and speed control mechanism resembles AC synchronous motors.**

BLDC is a **synchronous motor**-it means that the rotation of the permanent magnet rotor is synchronized with the changing magnetic field produced by the stator windings.
This synchronization allows for efficient and precise control of the motor's speed and torque.

https://www.motioncontroltips.com/faq-whats-the-difference-between-bldc-and-synchronous-ac-motors/

P16.11 MECHANICAL AND ELECTRICAL ELEMENTS OF THE MOTOR (DRAWINGS AND EXPLANATIONS)-CONTINUE

Inrunner animation:



In a **brushed DC motor**, the rotor spins 180-degrees when an electric current is run to the armature.

In **brushless DC motors**, the permanent magnets are on the rotor, and the electromagnets are on the stator. A computer then charges the electromagnets in the stator to rotate the rotor a full 360-degrees.

https://www.renesas.com/us/en/support/engineer-school/brushless-dc-motor-overview-01

P16.11 MECHANICAL AND ELECTRICAL ELEMENTS OF THE MOTOR (DRAWINGS AND EXPLANATIONS)-CONTINUE

The use of permanent magnets together with a rotating electronic circuit - eliminates the need for brushes, which can wear out and create **sparks**

Conclusion of P16.11 : brushless dc motors are more efficient, quieter, and longer-lasting than brushed DC motors. BLDC motors are also more controllable, as the electronic circuit board can be used to precisely adjust the speed and torque of the motor.

P16.11 MECHANICAL AND ELECTRICAL ELEMENTS OF THE MOTOR (DRAWINGS AND EXPLANATIONS)-CONTINUE

Rotor- The rotor of a typical BLDC motor is made of permanent magnets. Increasing the number of poles does give better torque but at the cost of reducing the maximum possible speed.

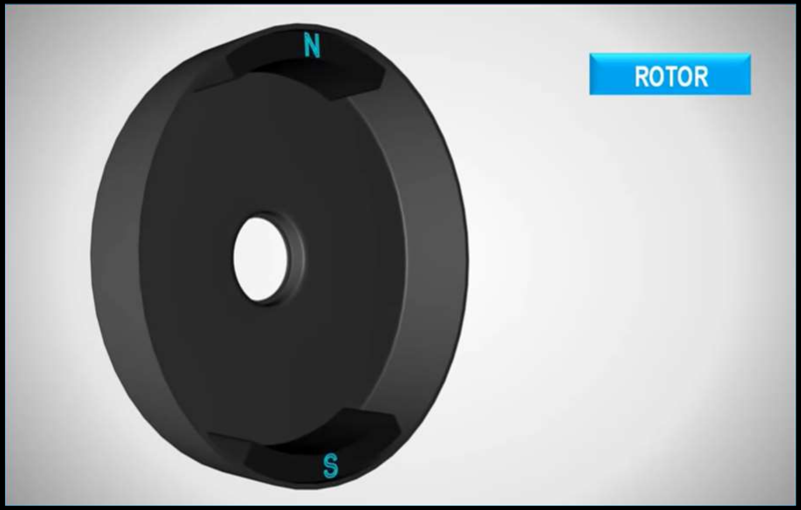
Stator - The stator windings are fed with currents controlled in magnitude and sequence (commutated) to effect rotation of the rotor

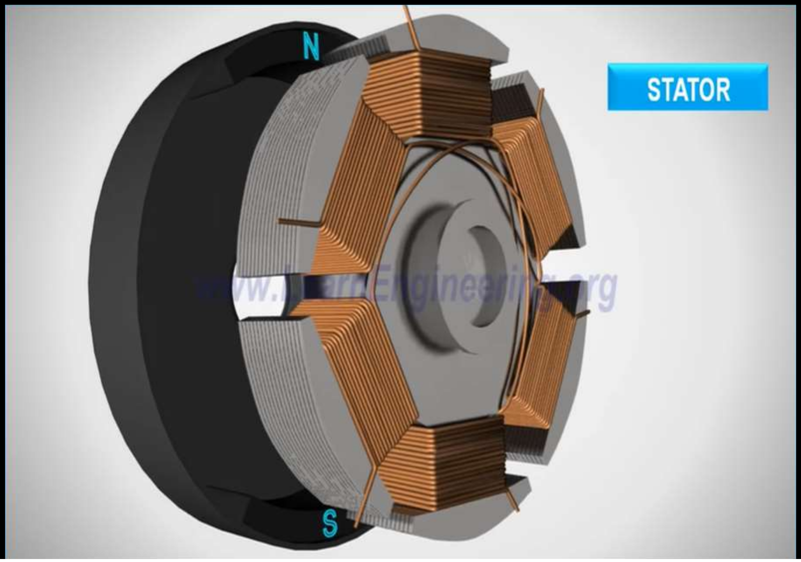
Sensor-the sensor give feedback to the system indicating when the rotor has reached the desired position. If commutation is done faster than this, the rotor magnets go out of sync with the stator magnetic field and the rotor vibrates instead of rotating.

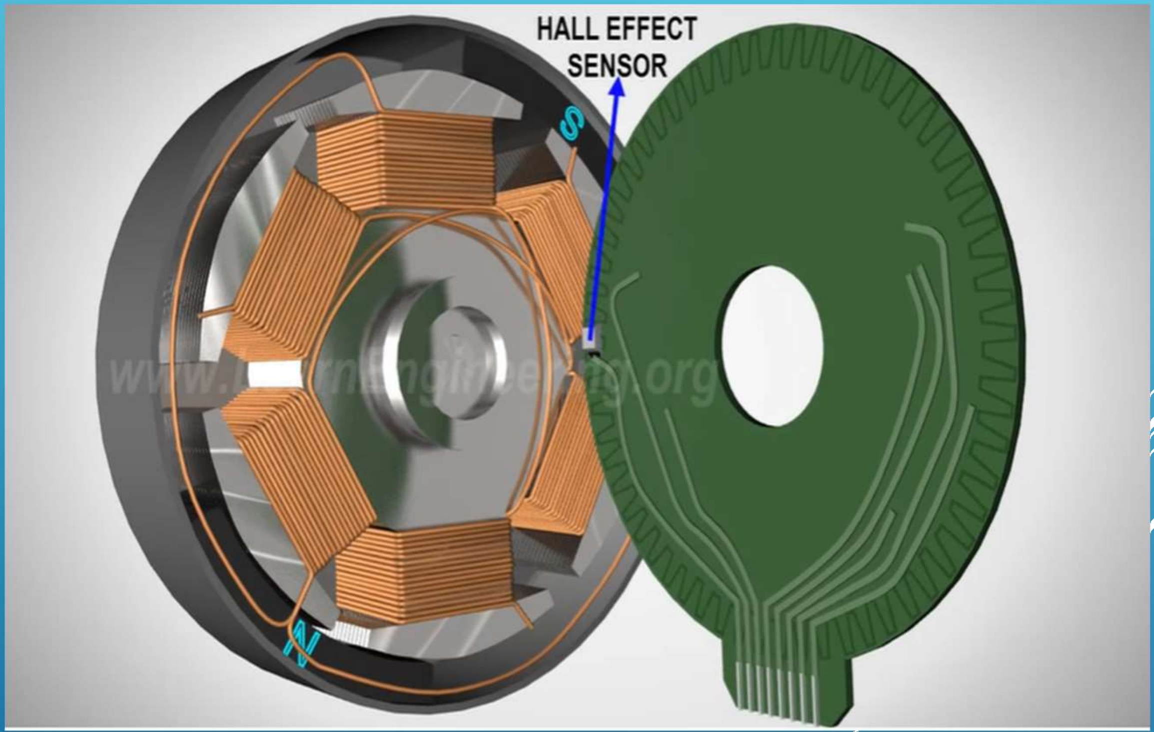
Brushless Motors are available in three configurations: single phase, two phase and three phase. Out of these, the three phase BLDC is the most common one.

https://www.electronicshub.org/brushless-dc-motor-bldc-motor/

P16.11 MECHANICAL AND ELECTRICAL ELEMENTS OF THE MOTOR (DRAWINGS AND EXPLANATIONS)-CONTINUE







https://www.quora.com/How-does-a-BLDC-motor-collect-the-current-without-brushes

P16.11 MECHANICAL AND ELECTRICAL ELEMENTS OF THE MOTOR (DRAWINGS AND EXPLANATIONS)-CONTINUE

Position Sensors (Hall Sensors):

Since there are no brushes in a BLDC Motor, the commutation is controlled electronically.
In order to rotate the motor, the windings of the stator must be energized in a sequence and the position of the rotor must be known to precisely energize a particular set of stator windings.

A Position Sensor, which is usually a Hall Sensor (that works on the principle of Hall Effect – will be explained in **P16.12**) is generally used to detect the position of the rotor and transform it into an electrical signal. Most BLDC Motors use three Hall Sensors that are embedded into the stator to sense the rotor's position.
The output of the Hall Sensor will be either HIGH or LOW depending on whether the North or South pole of the rotor passes near it.
By combining the results from the three sensors, the exact sequence of energizing can be determined.

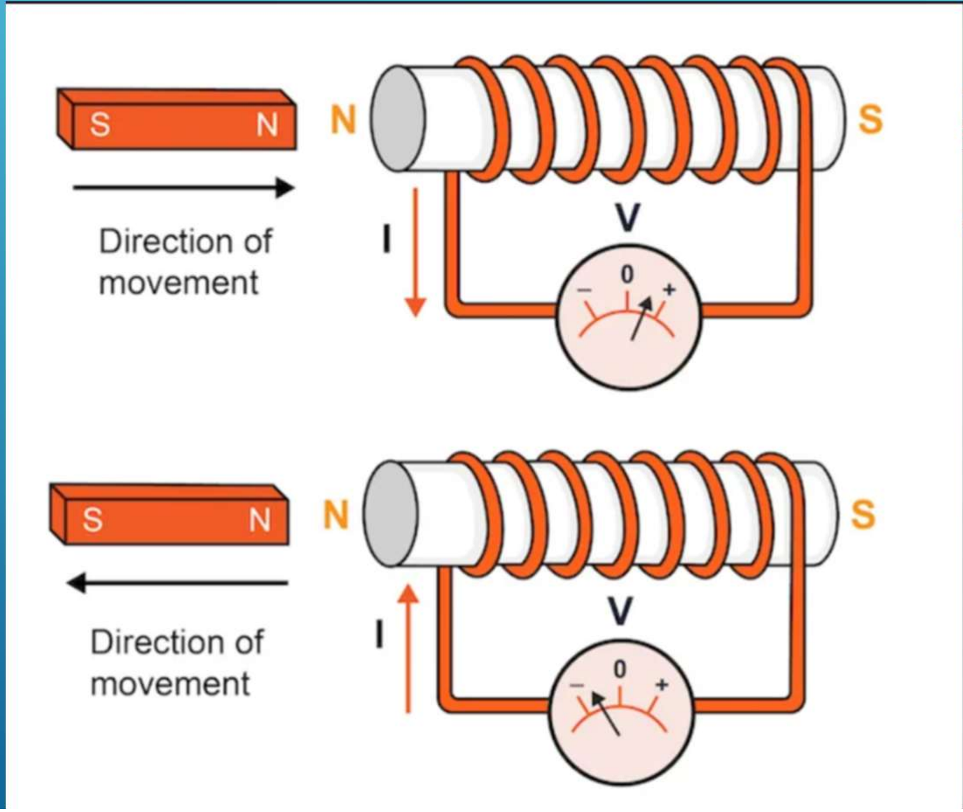
P16.12 PHYSICAL LAWS EXPLAINING OPERATION OF THE MOTOR

Faraday Law of Electromagnetic:

A voltage is induced in a conductor which is exposed to a time-varying magnetic field.

Equation: $E = -\frac{Nd\Phi_B}{dt}$

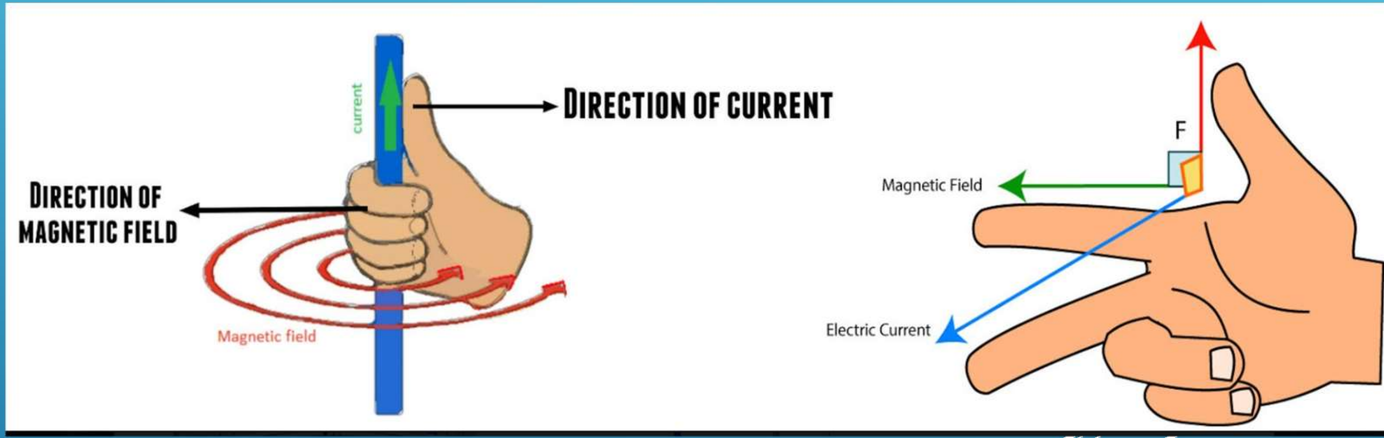
Explanation: In a BLDC motor, the rotating magnetic field produced by the stator induces a current in the rotor.
E is the induced electromotive force (EMF) in volts, N is the number of turns of wire, and $\frac{d\Phi_B}{dt}$ is the rate of change of the magnetic flux Φ_B through one turn of the wire.



P16.12 PHYSICAL LAWS EXPLAINING OPERATION OF THE MOTOR - CONTINUE

Lorentz Force: A particle of charge q, moving with velocity V in an electric (E) and magnetic field (B), experiences a force.

Equation: $\vec{F} = q(\vec{E} + \vec{v} \times \vec{B})$



Explanation: In BLDC motors, the current-carrying conductors (wires) in the presence of a magnetic field experience a force. This force acts perpendicularly to both the direction of the current and the magnetic field, creating torque that turns the rotor.

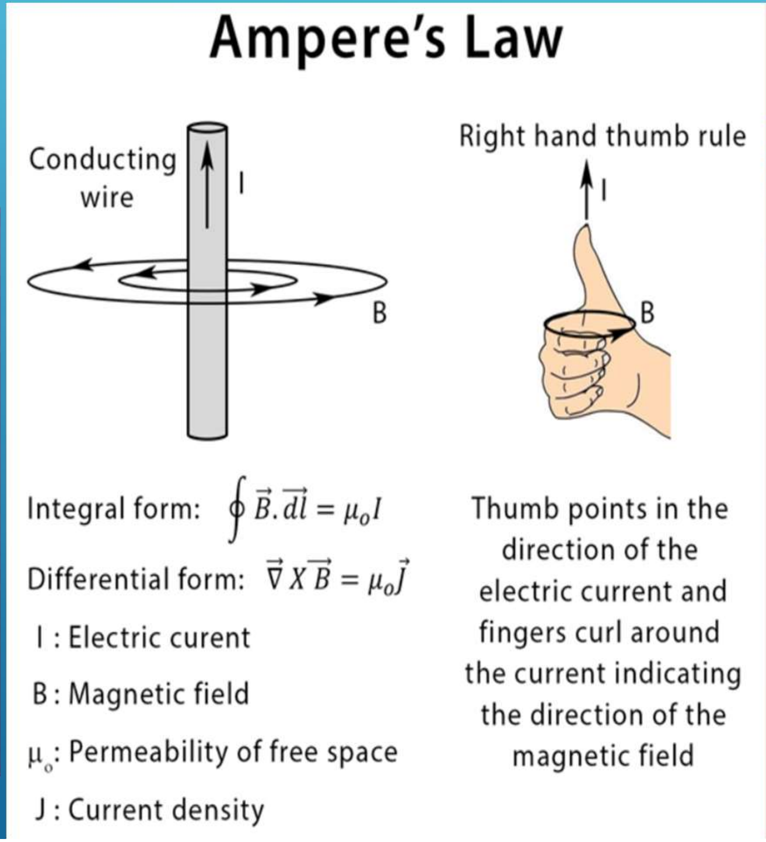
P16.12 PHYSICAL LAWS EXPLAINING OPERATION OF THE MOTOR - CONTINUE

Ampere's Law: The integrated **magnetic field** around a **closed loop** is proportional to the electric current plus the displacement current (rate of change of electric field) through the enclosed surface.

Equation: $\oint \vec{B}\,\overrightarrow{dl} = \mu_0 I$

Explanation: This principle explains how the magnetic field is generated by the stator windings in a BLDC motor. The current through the windings creates a magnetic field, which interacts with the permanent magnets on the rotor to produce motion.

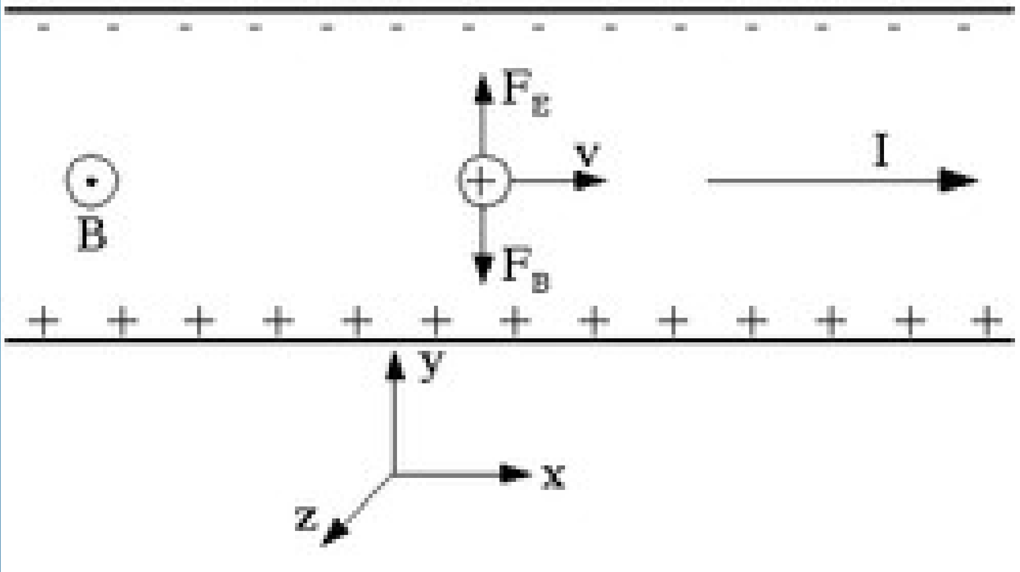
$\oint \vec{B}\,\overrightarrow{dl}$ is the line integral of the magnetic field B around a closed loop. μ_0 is the magnetic permeability of free space , I is the total current passing through the surface enclosed by the loop.



P16.12 PHYSICAL LAWS EXPLAINING OPERATION OF THE MOTOR - CONTINUE

In order to understand the working principle of the hall sensor – we need to understand the physical law in the center of it: **hall effect**

Hall effect is a physical phenomena in which an electrical voltage is created in the perpendicular direction of the flowing current in a conductor. The effect occurs when a magnetic field is applied on the conductor.



https://he.wikipedia.org/wiki/%D7%90%D7%A4%D7%A7%D7%7%94%D%_%98D7%95%D7%9C

P16.12 PHYSICAL LAWS EXPLAINING OPERATION OF THE MOTOR - CONTINUE

https://he.wikipedia.org/wiki/%D7%90%D7%A4%D7%A7%D7%94%D7%_7%98D7%95%D7%9C

hall effect- thorough explanation:

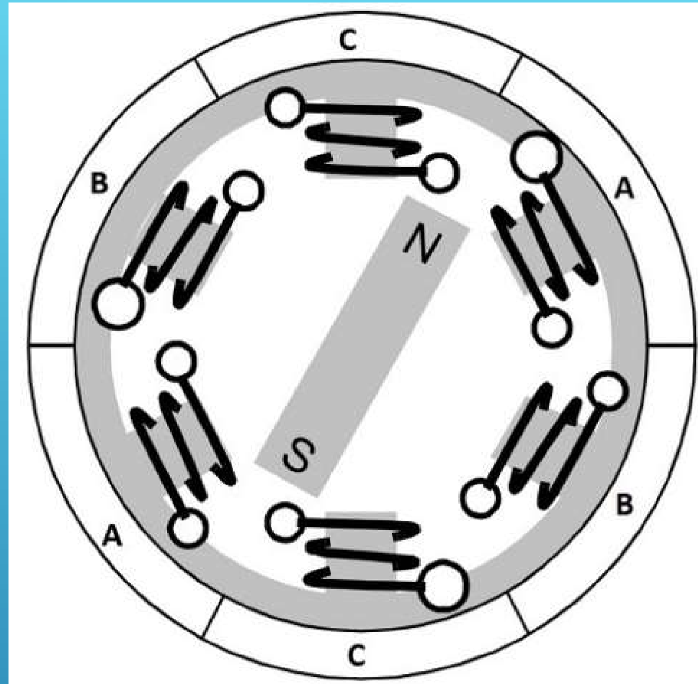
1) A current I flows in the conductor along the X-axis. We assume that the current is due to the movement of positive charges.
2) A magnetic field $\vec{B}$ acts on the conductor in $\hat{z}$ direction.
3) Due to the magnetic field, a Lorentz force $\overrightarrow{F_B}$ will act on the charges in the $-\hat{y}$ direction.
4) The positive charges will deflect towards the $\hat{y}$ direction, creating an excess of positive charge on the lower side of the conductor and an excess of negative charge on the upper side.
5) The charge separation will create an electric field $\vec{E}$ in the $\hat{y}$ direction.
6) The electric field will exert a force $\overrightarrow{F_E}$ on the charges in the $\hat{y}$ direction.
7) After a short time, the system will reach an equilibrium state where the magnetic force $\overrightarrow{F_B}$ and the electric force $\overrightarrow{F_E}$ balance each other.
8) As a result of the charge separation, the lower side of the conductor will be at a higher potential than the upper side. This potential difference is called the Hall voltage.

P16.12 PHYSICAL LAWS EXPLAINING OPERATION OF THE MOTOR - CONTINUE

Consider the following setup of three windings in the stator designated A, B and C. For the sake of understanding, let us replace the rotor with a single magnet.

According to ampere law - when a current is applied through a coil, a magnetic field is generated.

Then, the orientation of the field lines, which means that the poles of the generated magnet , will depend on the direction of the current flowing through the coil.



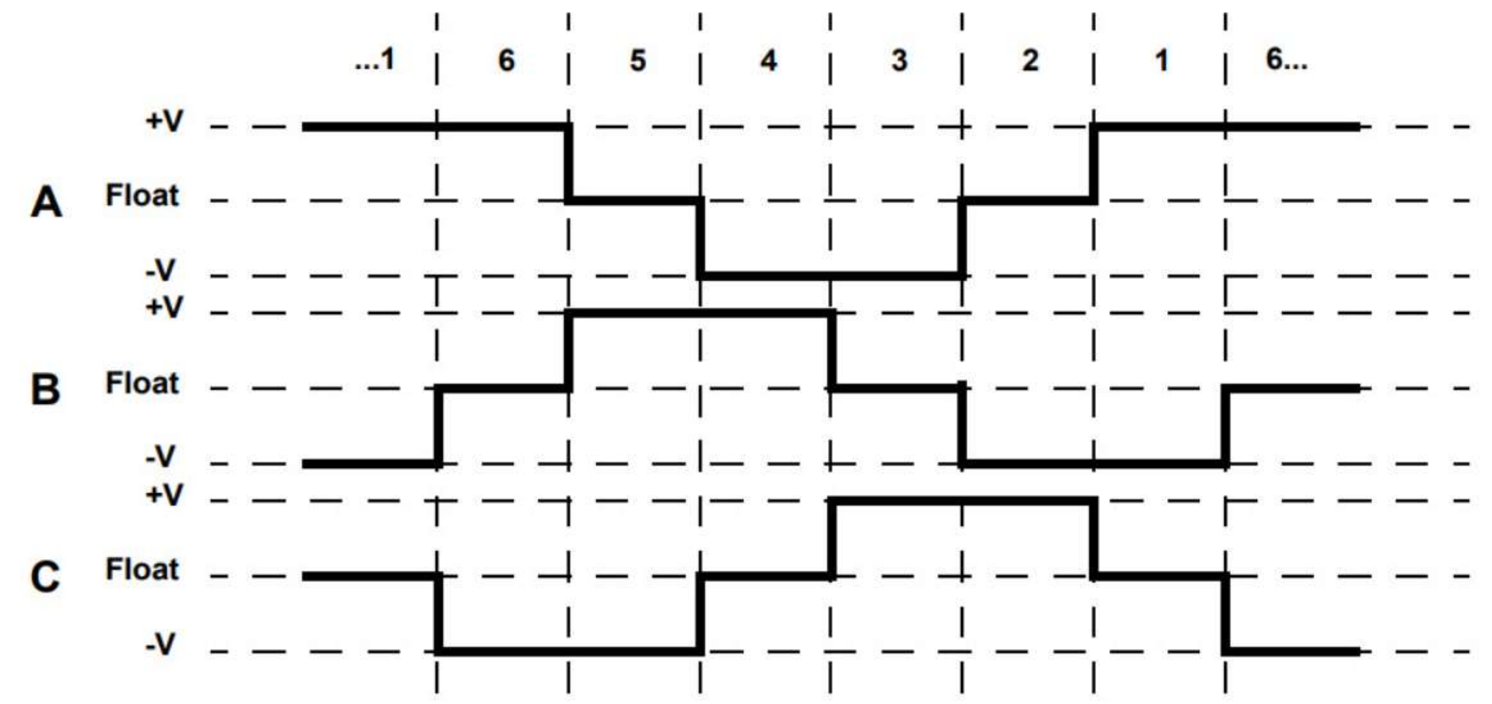
https://www.electronicshub.org/brushless-dc-motor-bldc-motor/

Using this principle, if we supply current to the coil A - it will generate a magnetic field and attract the rotor magnet. The position of the rotor magnet will shift slightly clockwise and will align with A.

Then, If we will pass current through coils B and C **one after the other (in that order),** the rotor magnet will rotate in clockwise direction.
That is the deep relation between the “physicality” (ampere law) and the “reality” in the motor

P16.12 PHYSICAL LAWS EXPLAINING OPERATION OF THE MOTOR - CONTINUE

For a complete 360^0 rotation of the rotor magnet, six possible combinations of the coils A, B and C are applicable and are shown in the following timing diagram.



Base on the diagram, we can confirm that at any time:

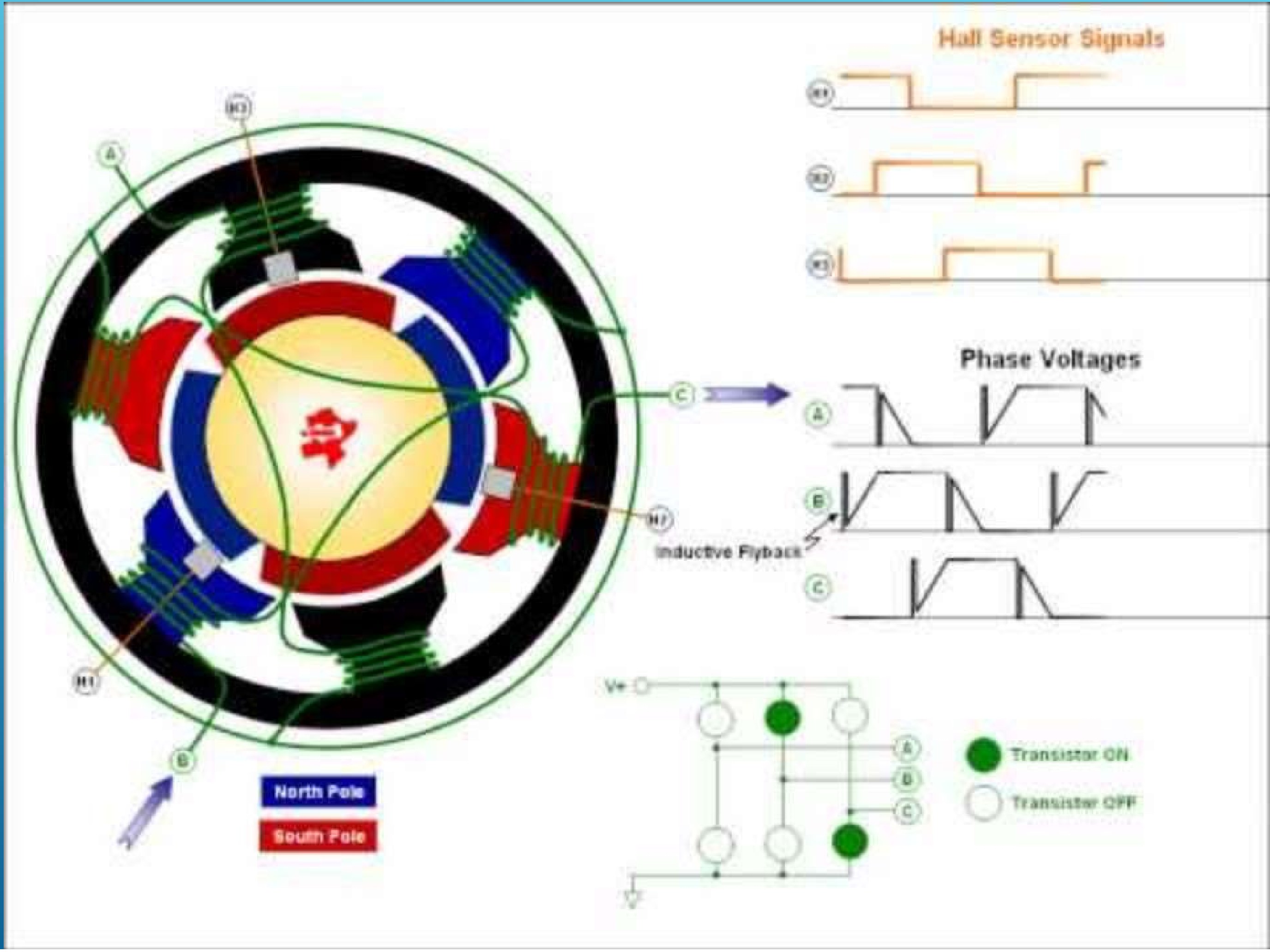
1) one phase is positive
2) one phase is negative
3) the third phase is idle (or floating).

So, based on the inputs from the **Hall Sensors**, we have two switch the phases as per the above diagram.

https://www.electronicshub.org/brushless-dc-motor-bldc-motor/

P16.12-PHYSICAL LAWS EXPLAINING OPERATION OF THE MOTOR - CONTINUE

SHORT YOUTUBE DEMONSTRATION OF BLDC ACTION – INCLUDING THE PHASE VOLTAGES AND THE HALL SENSORS SIGNALS



https://www.youtube.com/watch?v=43JMIuwVrY4

P16.13 – PHOTOS OF COMMERCIALLY AVAILABLE MOTORS WITH PIN EXPLANATIONS-PART 1

Brushless DC Motors with Integral Drive KinetiMax 42 EB Series

KinetiMax 42 EB – Electrical Connections

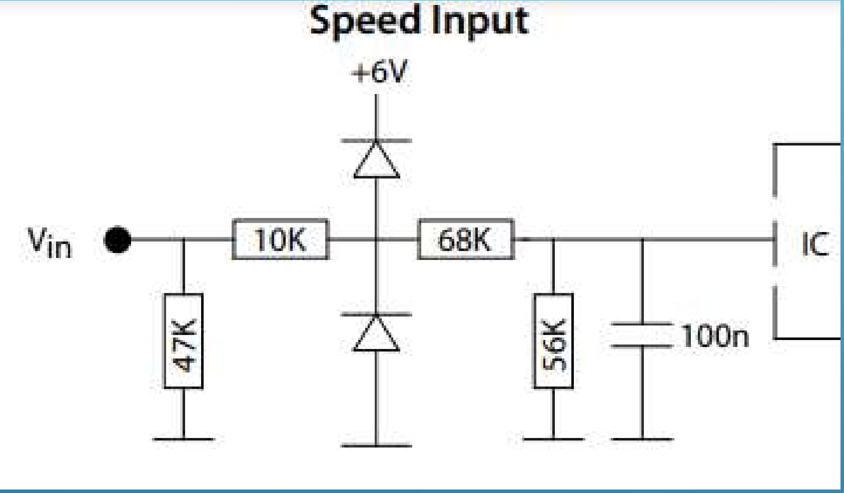
Version		Description	Wire Color (AWG 24)
6-Wire	1	Supply Voltage	Red
	2	Ground	Black
	3	Tachometer Output (FG)	Green
	4	Speed Control Input (V_{in})	White
	5	Direction Input (CW/CCW)	Brown
	6	Shield	Yellow

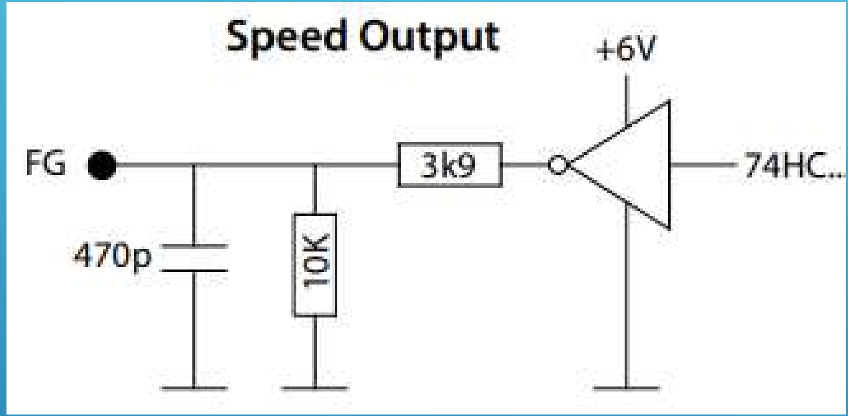
- 42 mm diameter outer rotor, brushless DC motor with integrated drive and robust bearing system.
- 70 mNm max. torque, up to 31 W output power

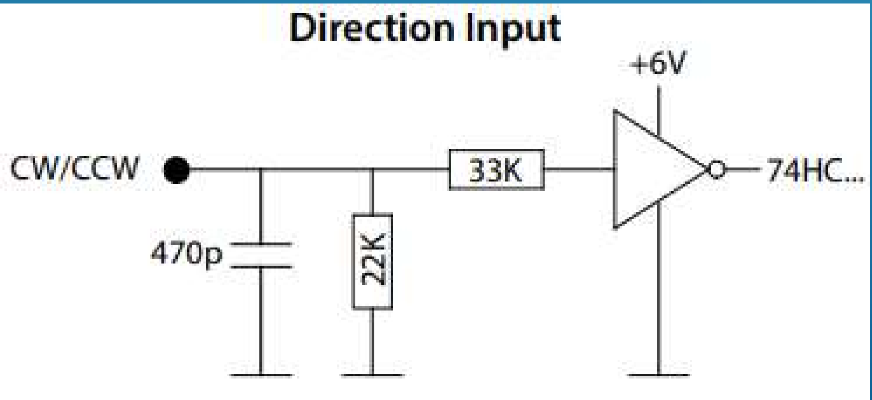
https://www.color-technik.net/wp-content/uploads/pdf.0418CT_42KMX-Allied_Motion_Datasheet/2018/02

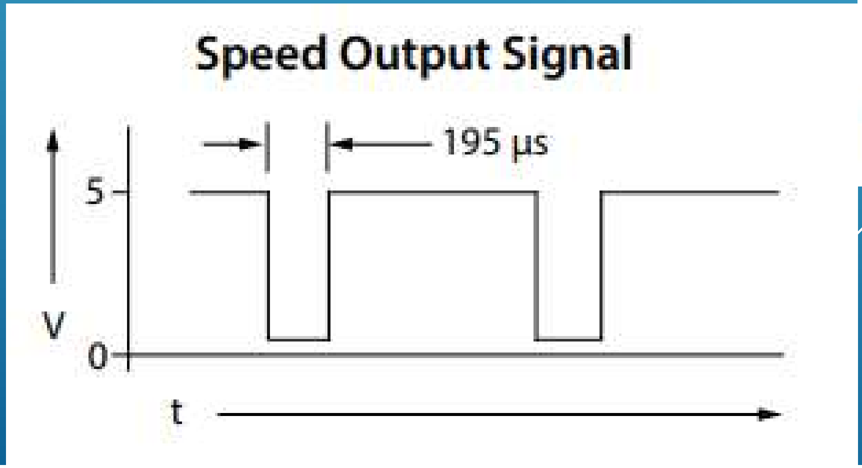
P16.13 – PHOTOS OF COMMERCIALLY AVAILABLE MOTORS WITH PIN EXPLANATIONS-PART 1-CONTINUE

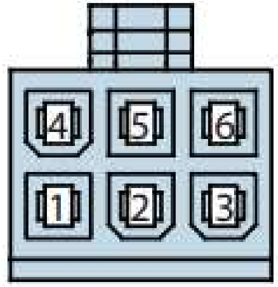
Speed input and speed output of the motor. In addition direction input and speed output signals.







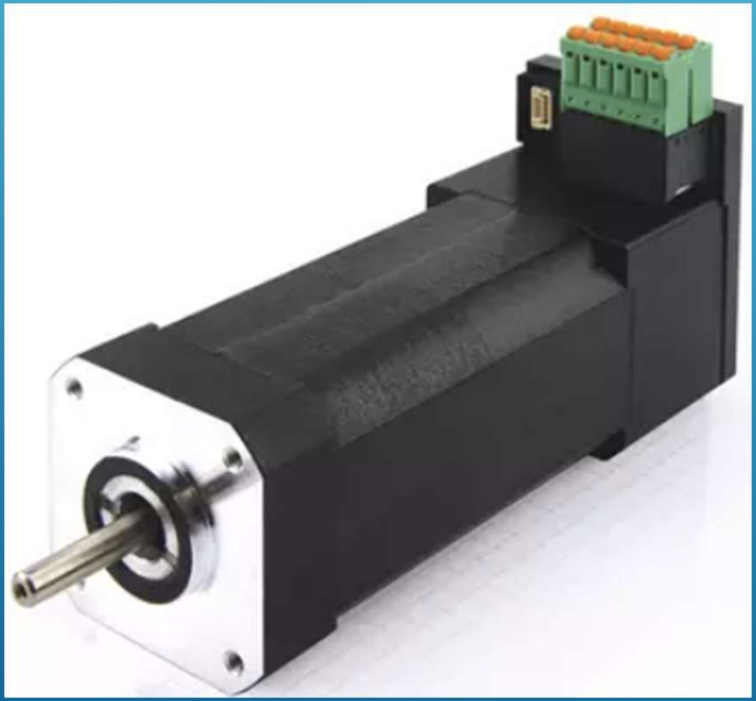




Mating Connector

P16.13 – PHOTOS OF COMMERCIALLY AVAILABLE MOTORS WITH PIN EXPLANATIONS-PART 2

PD2-C – BRUSHLESS DC MOTOR WITH INTEGRATED CONTROLLER – NEMA 17



https://en.nanotec.com/fileadmin/files/Handbuecher/Kurzanleitungen/EN/pd2c-usb-quick-guide.pdf

Smart BLDC motor with integrated controller and encoder. Ideally suited for highly dynamic applications with space constrictions, such as in laboratory automation.

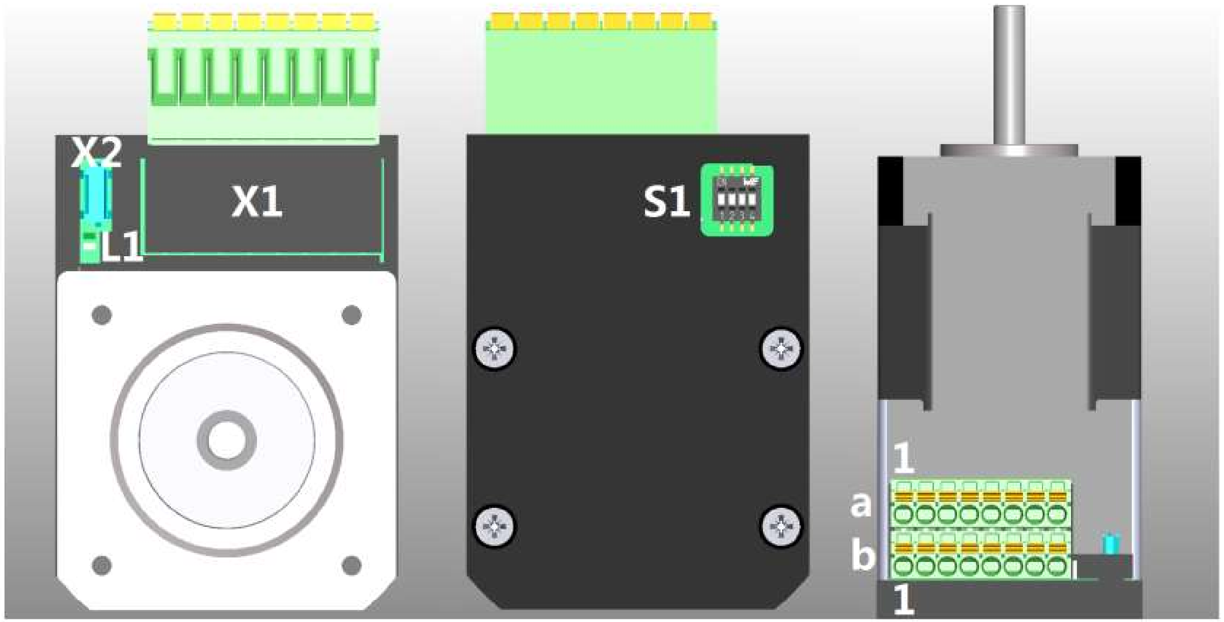
Inputs	3 digital inputs (+24 V) 3 inputs, single-ended or differential, +5 V / +24 V, switchable by means of software 1 analog input, 10-bit resolution, 0-10 V or 0-20 mA (switchable by means of software, default setting is 0-10 V)
Outputs	2 outputs, max. 24 V, 100 mA, open drain

	Operating voltage	Phase current rms	Peak current for 1 s
PD2-C	12 V to 48 V	1.8 A	Max. 3 A RMS

P16.13 – PHOTOS OF COMMERCIALLY AVAILABLE MOTORS WITH PIN EXPLANATIONS-PART 2-CONTINUE

Pin assignment

Pin 1 is marked.



Connector	Function	Pin assignment / description
X2	USB connection	Micro USB
S1	Dip switches for the selection of the *special drive modes* (Clock-direction/ Analog-speed)	See *Commissioning*

Pin No.	Function
a1	GND
a2	+UB (12–24V)
a3	INPUT 1 (24V)
a4	INPUT 2 (24V)
a5	INPUT 3 (24V)
a6	ANALOG INPUT (0–10V/0–20mA)
a7	OUTPUT 1 (open drain)
a8	OUTPUT 2 (open drain)
b1	GND
b2	+10V VOLTAGE SUPPLY
b3	–INPUT4/–ENABLE (5V/24V)
b4	INPUT 4/ENABLE (5V/24V)
b5	–INPUT 5/–DIRECTION (5V/24V)
b6	INPUT 5/DIRECTION (5V/24V)
b7	–INPUT 6/–CLOCK (5V/24V)
b8	INPUT 6/CLOCK (5V/24V)

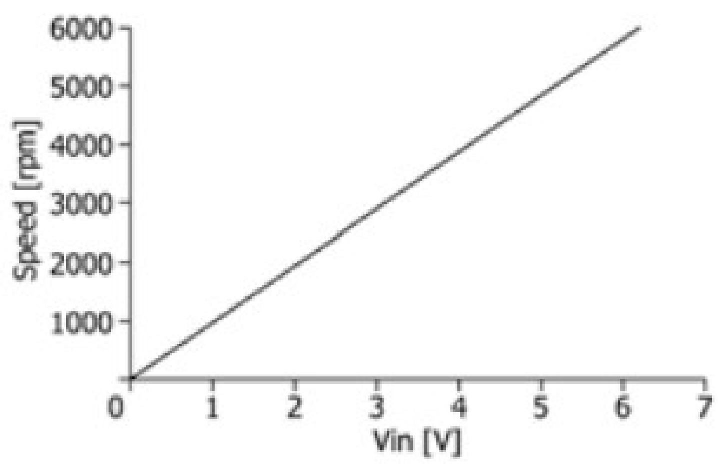
P16.14 IMPORTANT PARAMETERS OF ABOVE TWO MOTORS + EXPLANATIONS & COMPARISONS; RECOMMENDATIONS WHICH MOTOR TO SELECT WHEN AND WHY.

≫ FIRST MOTOR-PART 1

Important parameters of KinetiMax 42 EB

Voltage VDC		Nominal	12	24
		Range [1]	10 – 18	10 – 28
Rated Output Power		W	29	32
Torque mNm (oz.in.)		Rated	70 (9.9)	
		Max	72 (10.2)	100 (14.2)
Speed RPM		Rated	4300	
		No-load	5200	5300
Current	Rated	A	3.5	1.75
	Max	A	3.6	2.3
	No-load	mA	460	250

First important graph of KinetiMax 42 EB – speed[rpm] as a function of the V_{in}



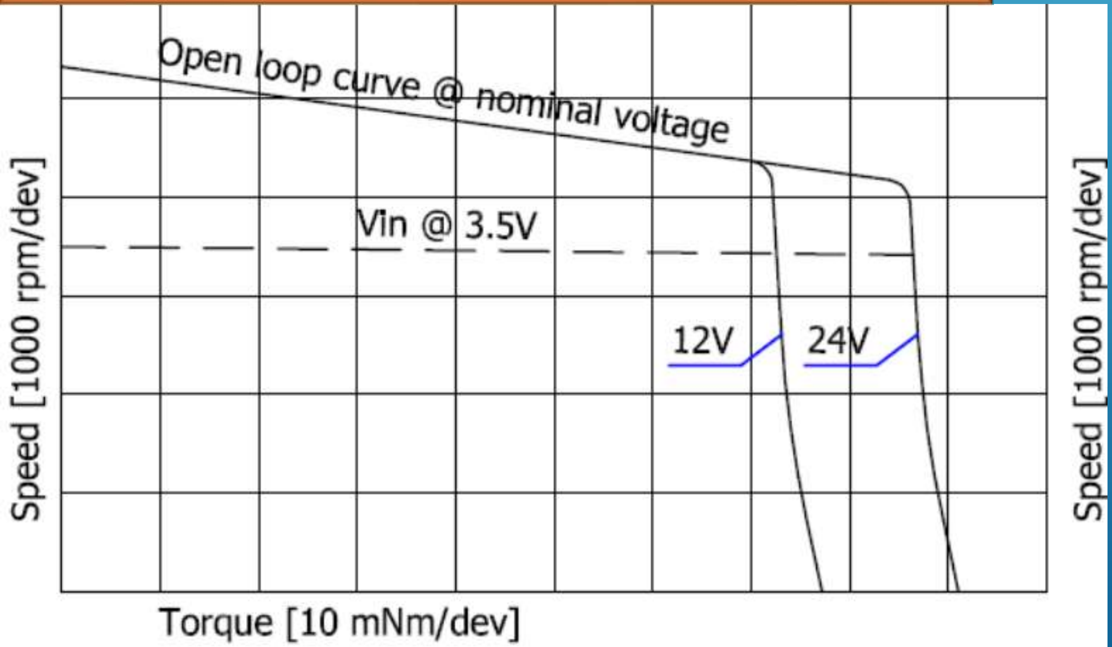
The conclusions from the graph:

1) As the voltage applied to the motor increases, the motor's speed will also increase.
2) The torque produced by the motor is related to its speed. At low speeds, the motor may be able to produce a high torque, but as the speed increases, the torque will typically decrease

P16.14 IMPORTANT PARAMETERS OF ABOVE TWO MOTORS + EXPLANATIONS & COMPARISONS; RECOMMENDATIONS WHICH MOTOR TO SELECT WHEN AND WHY.

>> FIRST MOTOR-PART 2:

Second important graph of KinetiMax 42 EB – speed[1000* rpm\dev] as a function of the created torque [10* mNm/dev]



The graph shows the relationship between the motor's torque and speed at different voltages. It is called an open-loop curve, which means the motor is operating without any feedback control. The conclusions from the graph:

1) The three curves in the graph correspond to three different voltages: 3.5 V, 12 V, and 24 V. As the voltage increases, the curves shift upwards, indicating that the motor can achieve higher speeds and torques at higher voltages.

2) The graph can be divided into two regions: a constant torque region and a constant power region. In the constant torque region, the torque remains relatively constant as the speed increases. In the constant power region, the product of torque and speed remains constant, so as the speed increases, the torque decreases.

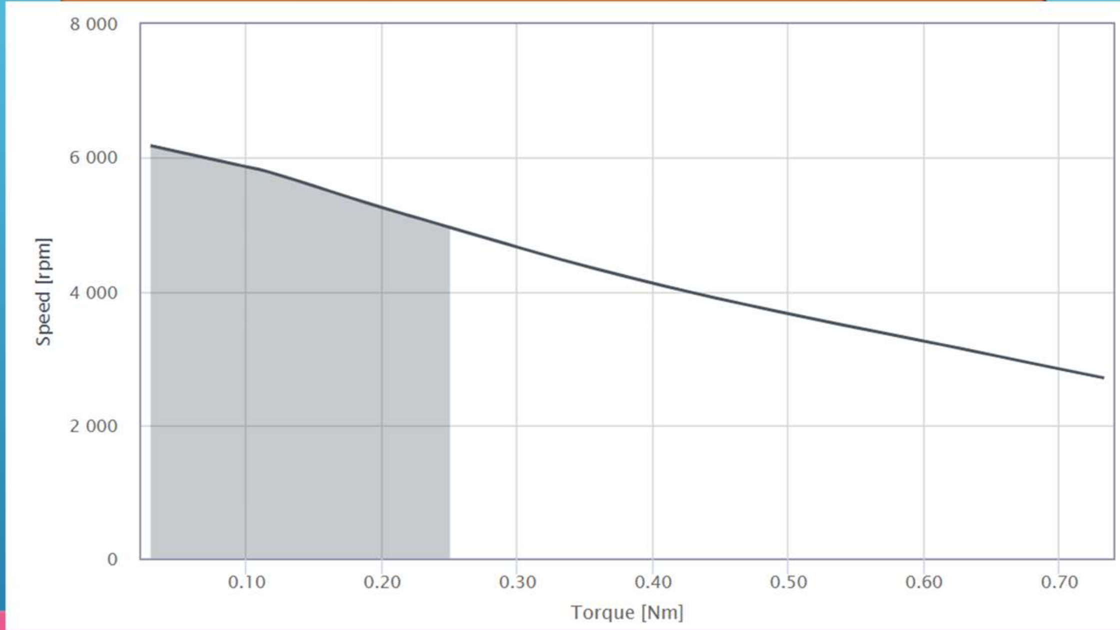
P16.14 IMPORTANT PARAMETERS OF ABOVE TWO MOTORS + EXPLANATIONS & COMPARISONS; RECOMMENDATIONS WHICH MOTOR TO SELECT WHEN AND WHY.

>> SECOND MOTOR-PART 1:

IMPORTANT PARAMETER OF THE "PD2-C"

- Rated Current (RMS) >> 1.8 A
- Number of Digital Inputs >> 6
- Number of Analog Inputs >>1
- Number of Digital Outputs >> 2
- Encoder Resolution >> 1024 CPR
- Operating Voltage >> 12 VDC - 48 VDC
- Peak Current (RMS) >> 3 A
- Type of Digital Inputs >> 24 V, 5/24 V (switchable)
- Type of Analog Input >> 0 - 20 mA / 0 - 10 V (switchable)
- Type of Digital Output >> open-drain (max. 24 V/100mA)

important graph of **PD2-C** – speed[rpm] as a function of the torque [Nm]



The graph shows a linear relationship between speed and torque, with speed decreasing as torque increases. This is a typical characteristic of BLDC motors, which are known for their high efficiency and wide speed range.

P16.14 IMPORTANT PARAMETERS OF ABOVE TWO MOTORS (NAMES AND TYPICAL VALUES AND GRAPHS WITH VALUES) + EXPLANATIONS & COMPARISONS; RECOMMENDATIONS WHICH MOTOR TO SELECT WHEN AND WHY.

≫ COMPARISONS AND RECOMMENDATIONS:

	Nanotec	Kinetimax
Output power	105W	29W
Torque	25Ncm	7.2Ncm
Speed	4000rpm	4300rpm
Current	10A	3.6A
Weight	0.85Kg	0.225Kg

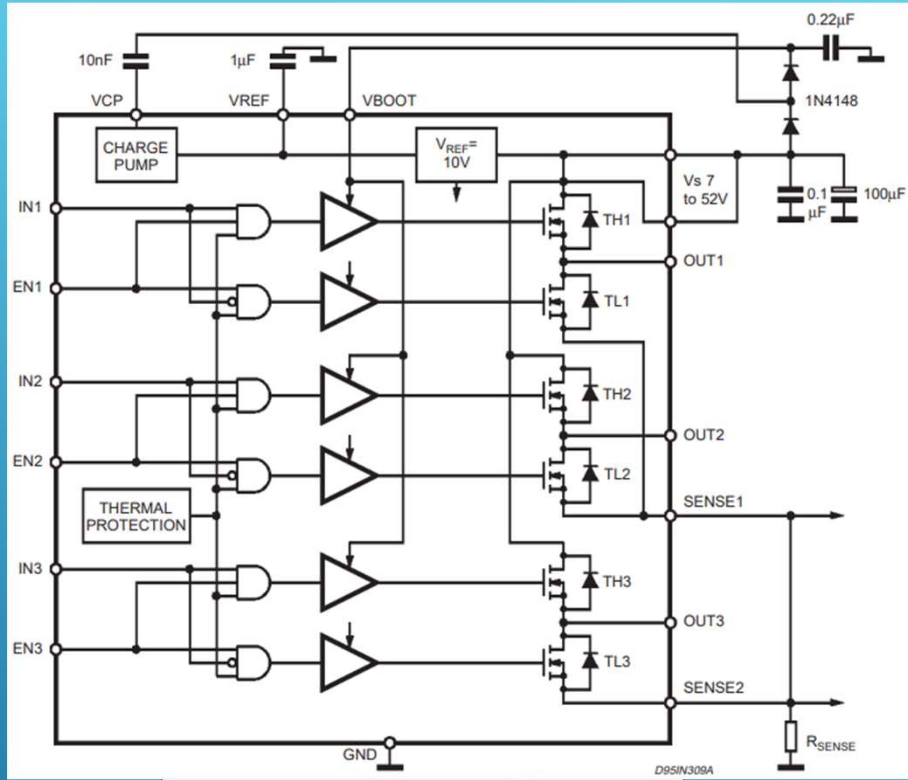
Pay attention- when we write ‘Nanotec’ we refer to the **PD2-C**

The Nanotec motor is a stronger motor with higher maximum power and it can produce far more torque than the Kinetimax. However, Kinetimax weights much less.
As it seen in the speed/torque graph (slide 26) , Nanotec’s torque curve is more linear, thus it is more stable. If heavy load is needed and weight is not an issue and than the Kinetimax is the more suitable motor, otherwise, Nanotec can be sufficient.

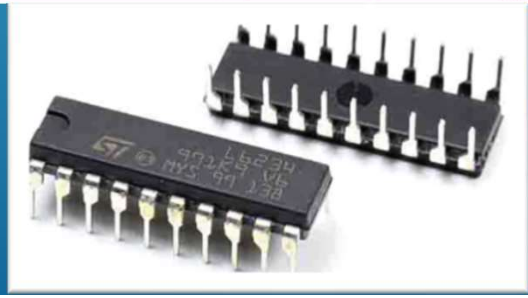
P16.21 – FULL ELECTRICAL CIRCUIT OF A MOTOR CONTROLLER (IN CASE OF IC – WHAT EXACTLY IS INSIDE IC)

L6234 - THREE PHASE BRUSHLESS **MOTOR DRIVER**-produced by STMICROELECTRONICS

- SUPPLY VOLTAGE FROM 7 TO 52V
- 5A PEAK CURRENT
- 4A DC OUTPUT CURRNT
- Reference Voltage up to 12V
- OPERATING FREQUENCY TO 50KHz
- The L6234 is a triple half bridge to drive a brushless DC motor.



Two motor controllers will be presented in P16.21 as a background (necessary one) for P16.22

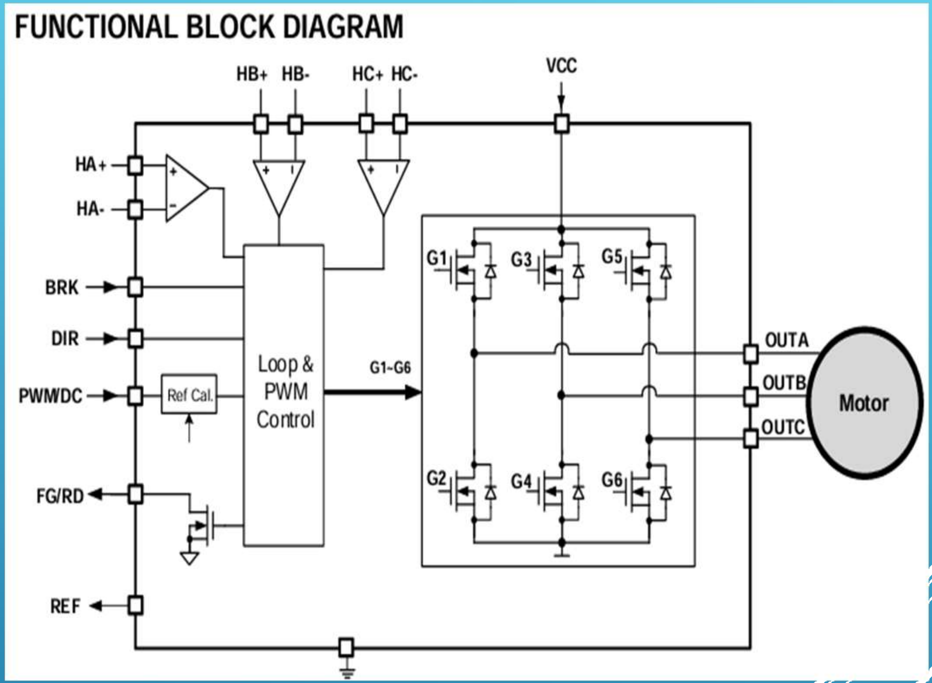


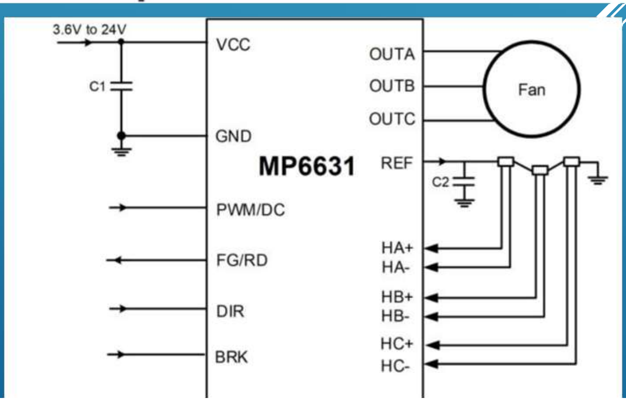
https://www.st.com/resource/en/datasheet/l6234.pdf

P16.21 – FULL ELECTRICAL CIRCUIT OF A MOTOR CONTROLLER (IN CASE OF IC – WHAT EXACTLY IS INSIDE IC)

MP6631 - a three-phase brushless DC (BLDC) **motor driver** with integrated power MOSFETs. The device supports a single external Hall-effect sensor or triple external Hall-effect sensors to drive a three-phase BLDC motor. Produced by **MPS COMPANY**

- SUPPLY VOLTAGE FROM 3.6 TO 24V
- 3A PEAK CURRENT
- Reference Voltage up to 5V
- OPERATING FREQUENCY TO 100KHz

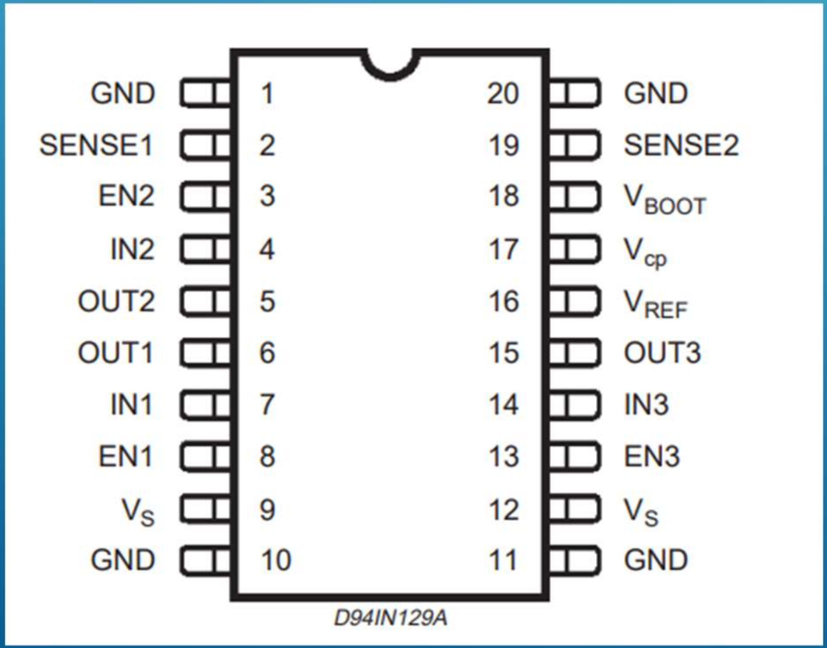




https://www.monolithicpower.com/en/documentview/productdocument/index/version/2/document_type/Datasheet/lang/en/sku/MP6631GL/

P16.22 – PHOTOS (FROM INTERNET) OF AT LEAST TWO COMMERCIALLY AVAILABLE MOTORS CONTROLLERS WITH PINS EXPLANATIONS-PART 1

L6234 - THREE PHASE BRUSHLESS MOTOR DRIVER-produced by STMICROELECTRONICS (was presented in slide 27 as part of P16.21)

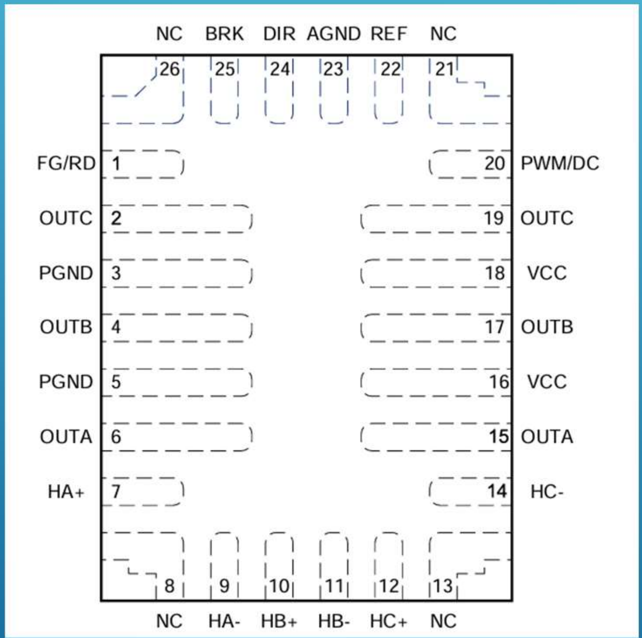


PowerSO20	Name	Function
6 5 15	OUT 1 OUT 2 OUT 3	Output of the channels 1/2/3.
7 4 14	IN 1 IN 2 IN 3	Logic input of channels 1/2/3. A logic HIGH level (when the corresponding EN pin is HIGH) switches ON the upper DMOS Power Transistor, while a logic LOW switches ON the corresponding low side DMOS Power.
8 3 13	EN 1 EN 2 EN 3	Enable of the channels 1/2/3. A logic LOW level on this pin switches off both power DMOS of the related channel.
9, 12	V_s	Power Supply Voltage.
19	SENSE2	A resistance Rsense connected to this pin provides feedback for motor current control for the bridge 3.
2	SENSE1	A resistance Rsense connected to this pin provides feedback for motor current control for the bridges 1 and 2.
16	V_{ref}	Internal Voltage Reference. A capacitor connected from this pin to GND increases the stability of the Power DMOS drive circuit.
17	V_{cp}	Bootstrap Oscillator. Oscillator output for the external charge pump.
18	V_{BOOT}	Overvoltage input to drive the upper DMOS
1,10 11,20	GND	Common Ground Terminal. In Powerdip and SO packages these pins are used to dissipate the heat forward the PCB.

https://www.st.com/resource/en/datasheet/l6234.pdf

P16.22 – PHOTOS (FROM INTERNET) OF AT LEAST TWO COMMERCIALLY AVAILABLE MOTORS CONTROLLERS WITH PINS EXPLANATIONS-PART 2

MP6631

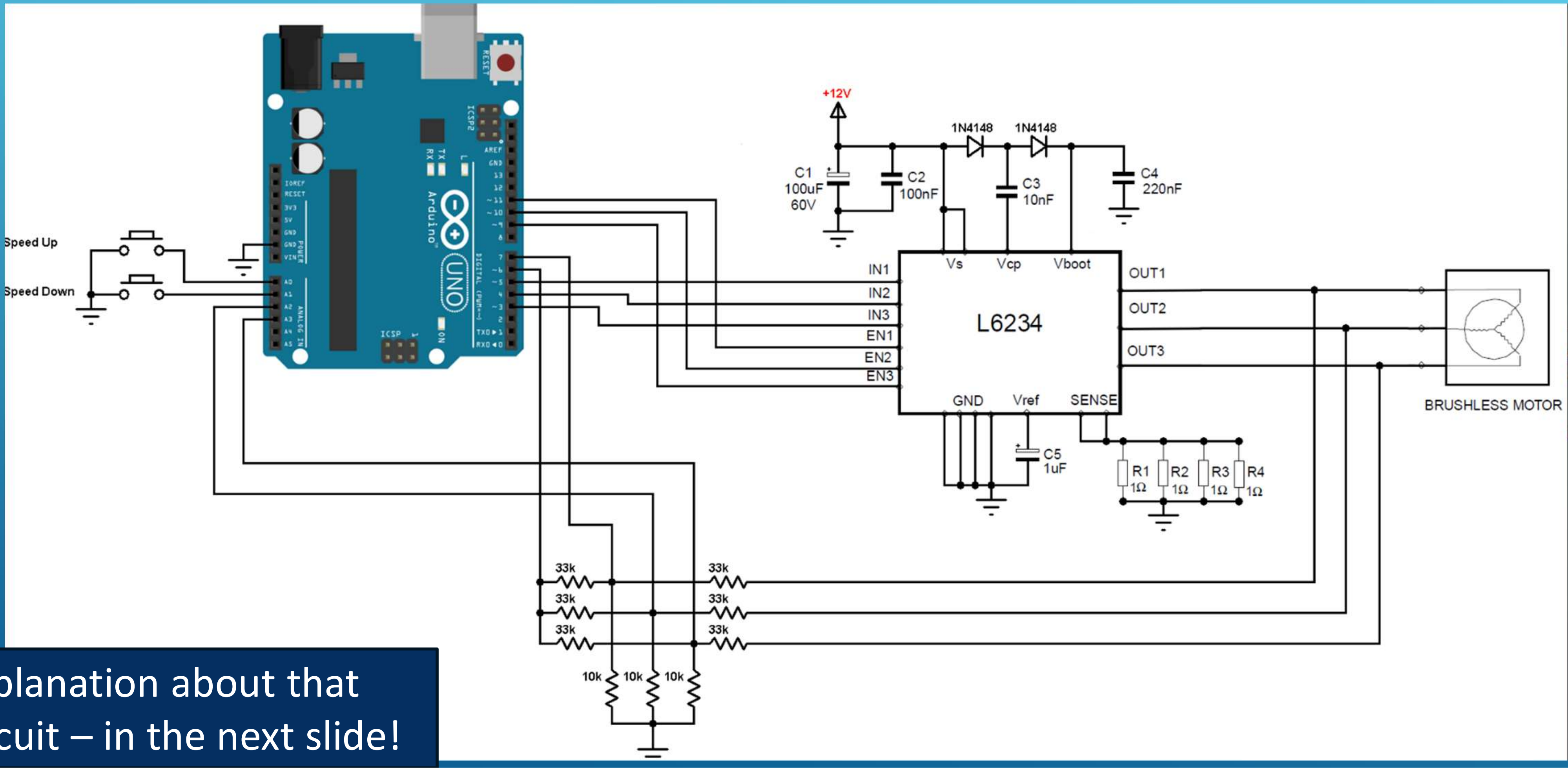


PIN FUNCTIONS

Pin #	Name	Description
1	FG/RD	**Speed or rotor lock indication.** Open-drain output. FG/RD can be used for speed indication (FG) or rotor lock indication (RD). Pull up this pin externally.
2, 19	OUTC	**Phase C terminal.**
3, 5	PGND	**Ground.**
4, 17	OUTB	**Phase B terminal.**
6, 15	OUTA	**Phase A terminal.**
7	HA+	**Phase A positive Hall input terminal.**
9	HA-	**Phase A negative Hall input terminal.**
10	HB+	**Phase B positive Hall input terminal.**
11	HB-	**Phase B negative Hall input terminal.**
12	HC+	**Phase C positive Hall input terminal.**
14	HC-	**Phase C negative Hall input terminal.**
16, 18	VCC	**Input voltage supply pin.** The VCC pin must be locally bypassed.
20	PWM/DC	**Rotational speed control input pin.** Supports the pulse-width modulation (PWM) input signal or the DC input signal. When DC_PWM = 0, apply a 1kHz to 100kHz PWM signal for speed control. When DC_PWM = 1, apply a 0V to 1.2V DC voltage for speed control.
22	REF	**Reference output pin.** The REF pin must be locally bypassed.
23	AGND	**Analog ground.**
24	DIR	**Direction control pin.** Pull this pin low for forward rotation (A → B → C); pull it high for reverse rotation (A → C → B). Internally pull down by resistor.
25	BRK	**Brake pin.** Pull this pin high to brake the motor; pull it low internally using a resistor.
8, 13, 21, 26	NC	

The MP6631 is a three-phase brushless DC (BLDC) motor driver with integrated power MOSFETs. The MP6631 controls the motor speed through the pulse-width modulation (PWM) signal or the DC signal on the PWM/DC pin with closed /open-loop speed control.

P16.23 – FULL ELECTRIC CIRCUIT OF THE WORKING MOTOR SYSTEM: CONTAINING ARDUINO, CONTROLLER, MOTOR, EXTERNAL POWER SUPPLY – PART 1



Explanation about that circuit – in the next slide!

P16.23 – FULL ELECTRIC CIRCUIT OF THE WORKING MOTOR SYSTEM: CONTAINING ARDUINO, CONTROLLER, MOTOR, EXTERNAL POWER SUPPLY – PART 2

Arduino UNO: This is a microcontroller board based on the ATmega328P.

L6234 Driver: our motor driver (was introduced in slide 28) – it is a three-phase motor driver . It's specifically designed to control the speed and direction of a brushless DC motor.

Power Supply: We have two indicated:
1) 12V source
2) 60V source

Arduino Pins: The Arduino is connected to the L6234 driver with pins labeled "Speed Up", "Speed Down", IN1, IN2, IN3, EN1, EN2, EN3. These likely control direction, speed (likely using PWM), and enable/disable signals for the motor.

Diodes (1N4148): for protection against reverse voltage or back EMF (electromotive force) that can be generated by the motor.

Capacitors (C1, C2, C3, C4): Capacitors of various values are used to smooth out voltage fluctuations, protect components, and potentially act as filters for noise in the circuit.

Resistors (10k, 33k): These resistors could be serving multiple purposes including limiting current, creating voltage dividers for signal adjustment, or as pull-up/pull-down resistors to maintain defined logic states on the Arduino pins.

P16.24 – EXPLANATION: HOW SPEED AND DIRECTION OF A ROTATION CAN BE CHANGED BY ARDUINO COMMANDS-PART 1

PWM (Pulse Width Modulation): Arduino can control the speed of a motor by adjusting the average voltage using PWM. PWM rapidly switches the power on and off during each cycle, and the duty cycle (percentage of time the signal is high) determines the average voltage. The higher the duty cycle, the faster the motor spins.

```
int motorPin = 9; // Example motor pin
int speed = 128; // Speed value between 0 and 255
void setup() {
pinMode(motorPin, OUTPUT); }
void loop() {
analogWrite(motorPin, speed); }
```

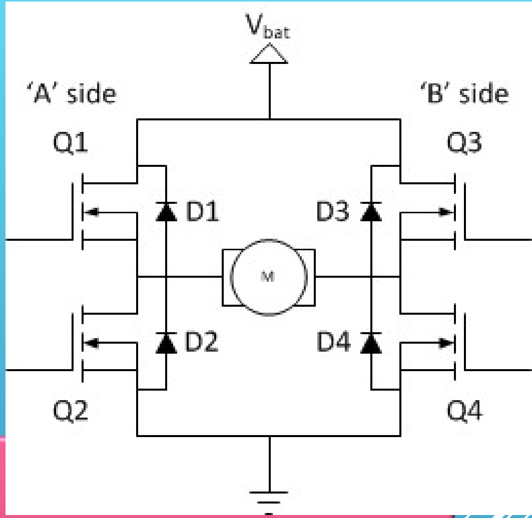
In analogWrite() function the parameter (speed in this case) ranges from 0 to 255.

0: This corresponds to a 0% duty cycle. This would mean it's not receiving any power, and hence, it's not moving.

128: This corresponds to a 50% duty cycle. In the case of a motor, it will receive power for half of the time and will rotate at approximately half of its maximum speed.

255: This corresponds to a 100% duty cycle. This would mean it's receiving continuous power, and it will rotate at its maximum speed.

P16.24 – EXPLANATION: HOW SPEED AND DIRECTION OF A ROTATION CAN BE CHANGED BY ARDUINO COMMANDS-PART 2



The direction of rotation of a motor can be changed using an H-Bridge motor driver in conjunction with Arduino commands.
An H-Bridge allows the current to flow through the motor in either direction, enabling you to control the motor's rotation.

What is an H-Bridge Motor Driver?
An H-Bridge is a circuit that enables a motor to rotate in both directions. It typically consists of four switches (transistors or relays) arranged in an "H" shape. By controlling the states of these switches, you can change the direction of the current flow through the motor.

- If you activate the top switches (let's call them A and B), the current flows from the motor's positive terminal to the negative terminal, causing the motor to rotate in one direction (e.g., clockwise).
- If you activate the bottom switches (let's call them C and D), the current flows in the opposite direction, causing the motor to rotate in the other direction (e.g., counterclockwise).

P16.24 – EXPLANATION: HOW SPEED AND DIRECTION OF A ROTATION CAN BE CHANGED BY ARDUINO COMMANDS-PART 3

```
int in1 = 2;  // Connect to input 1 of the H-Bridge
int in2 = 3;  // Connect to input 2 of the H-Bridge

void setup() {
  pinMode(in1, OUTPUT);
  pinMode(in2, OUTPUT); }
void loop() {
  // Clockwise rotation
  digitalWrite(in1, HIGH);
  digitalWrite(in2, LOW);

  // Counterclockwise rotation
  digitalWrite(in1, LOW);
  digitalWrite(in2, HIGH); }
```

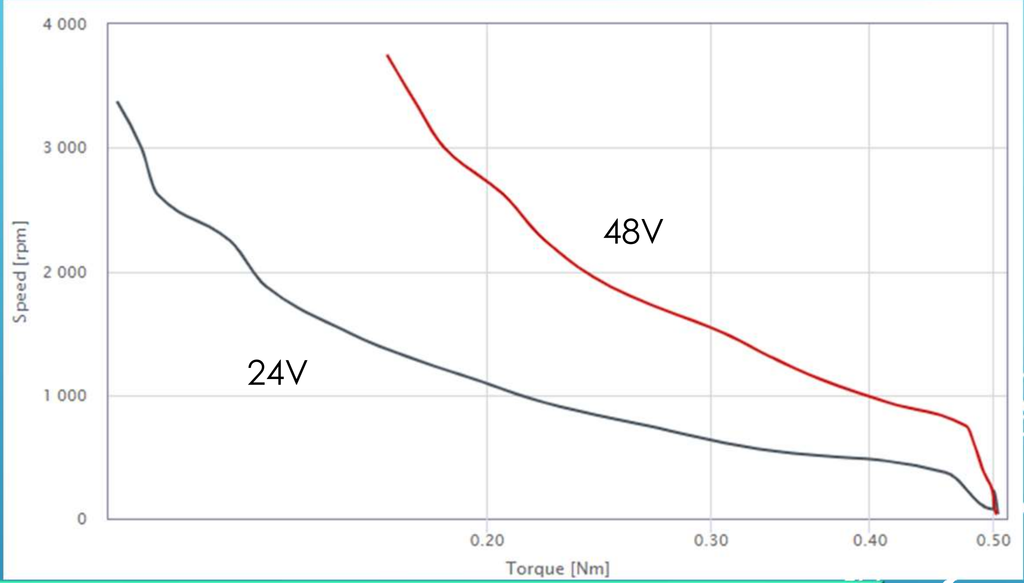
In this code example, when in1 is set to HIGH and in2 is set to LOW, the motor will rotate in one direction. When in1 is set to LOW and in2 to HIGH, the motor will rotate in the opposite direction.

The driver we used in this project is not H bridge motor driver, so it cannot be rotated

P16.25 EVALUATION OF SPEED (RPM) LIMITS. EXPLANATION OF A TYPICAL TORQUE BEHAVIOR-**PART 1**

Speed limits of a BLDC motor are primarily **determined by the supplied voltage and the motor's electrical characteristics**.
At the highest level, the maximum speed of the motor is limited by the maximum voltage that can be applied. Generally, the higher the voltage, the higher the speed (in RPM).

Speed Torque Curve of PD2-C BLCD motor



Give the equation $rpm = kv * V_{in}$

kv stands for KV constant, which is a specific characteristic of a brushless DC motor (BLDC motor). It essentially relates the rotational speed (rpm) of the motor to the applied voltage (volts).

rpm is the Revolutions per minute, a unit measuring the rotational speed of the motor.

V_{in} is the Voltage applied to the motor, measured in volts.

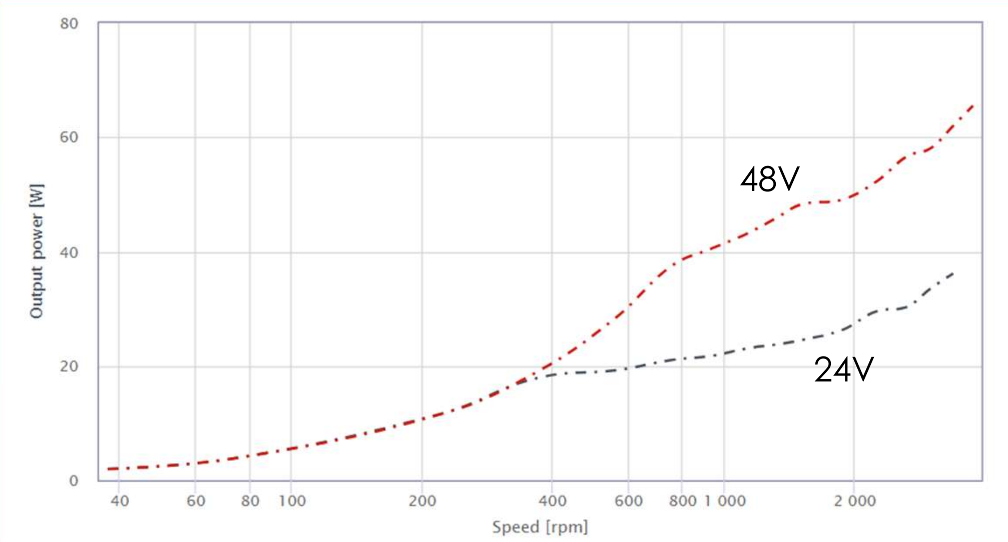
Another factor is the torque – it will be explained in the next slide!

https://us.nanotec.com/products/-2pd-18924118cl01-e-1804

P16.25 EVALUATION OF SPEED (RPM) LIMITS. EXPLANATION OF A TYPICAL TORQUE BEHAVIOR-PART 2

The equation $\boldsymbol{\tau = Kt \times I}$ describes the relationship between the torque produced by an electric motor and the current flowing through its windings. The τ (torque) is the rotational force produced by the motor, typically measured in Newton-meters (Nm) , Kt (Torque Constant) is a specific constant for the motor that relates how much torque the motor will generate per unit of current , and the I (Current) is the electrical current flowing through the motor's windings, measured in amperes (A)

Speed Vs Output power of PD2-C BLCD motor



The output power is described by the equation: $P = \tau * \omega$

- P is the power in watts (W),
- τ is the torque in Newton-meters (Nm)
- ω is the angular velocity in radians per second (rad/s) defined as $\omega = \frac{2\pi * RPM}{60}$

P16.3 BIBLIOGRAPHY

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