FRA231: Robotics Modelling & Experimentation (RMX)

By Narongsak Tirasuntarakul

Lecture 10: Actuator 2

Lecture Contents

- Working Principles of a Stepper Motor
- Stepper Motor Specification
- Stepper Motor Driver
- Working Principles of a Solenoid
- Types of Solenoid
- Solenoid Driver
- Solenoid Specification

Lecture Objectives

- Answer these following questions
  1. What are the advantages and disadvantages of a stepper motor comparing with brushed DC motor?
  2. What are the key specification of a stepper motor, and what are their effects?
  3. How to control the direction and speed of a stepper motor?
  4. What are the advantages and disadvantages of each drive mode for a stepper motor?
  5. What are the advantages and disadvantages of a solenoid comparing with other actuators?
  6. How to drive a solenoid?
  7. What are the key specification of a solenoid, and what are their effects?

Stepper Motor

Example applications

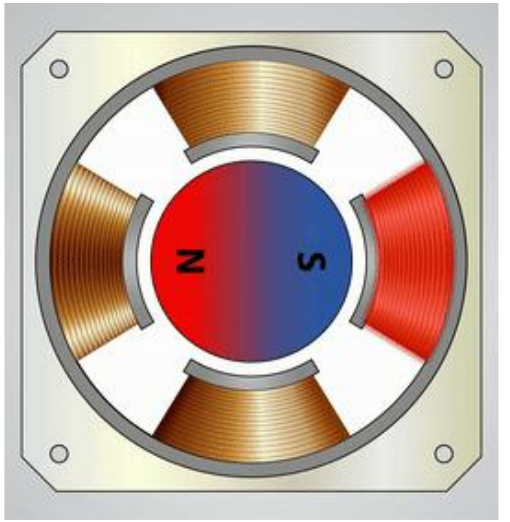
[VMC650 CNC Milling Machine - Vertical machining center manufacturer -]

CNC milling machine

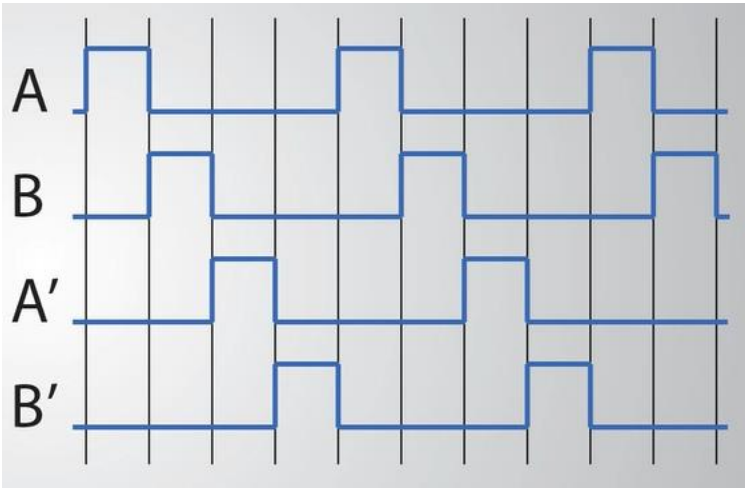
[Original Prusa MK4S 3D Printer MMU3 Bundle | Original Prusa 3D printers directly from Josef Prusa]

3D printer

Stepper Motor – Overview



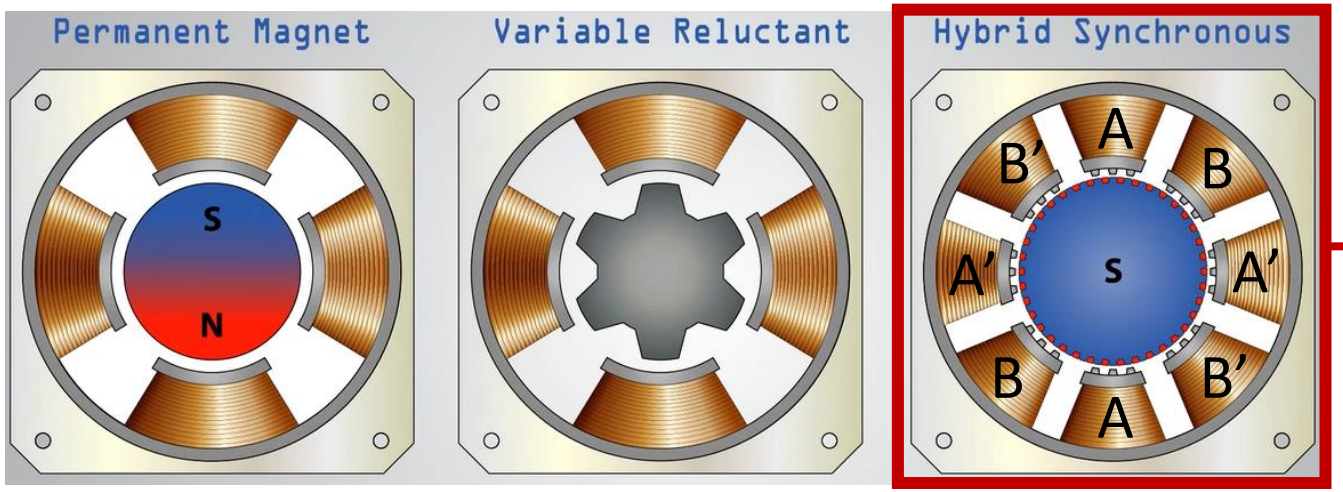
Wave Drive



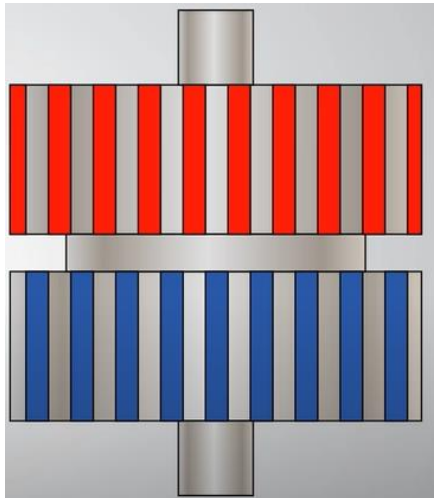
Open loop control system

https://www.youtube.com/watch?v=TWMai3oirnM&ab_channel=HowToMechatronics

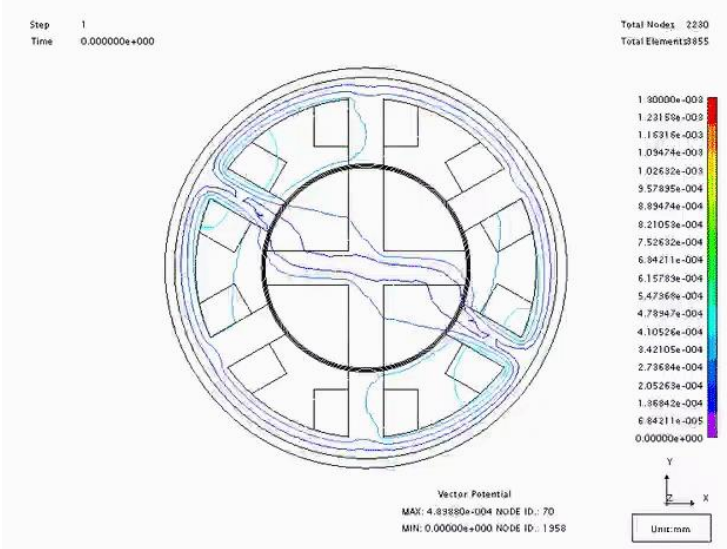
Stepper Motor – Rotor Types

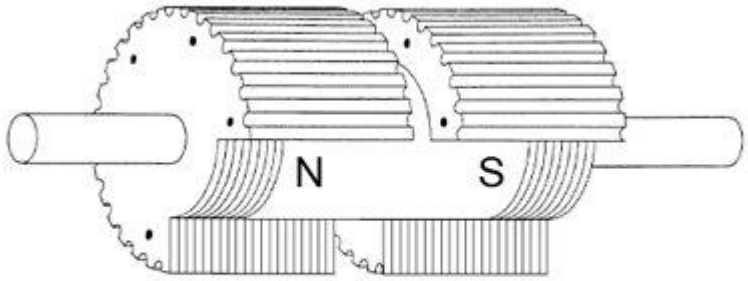


Top View



https://www.youtube.com/watch?v=TWMai3oirnM&ab_channel=HowToMechatronics



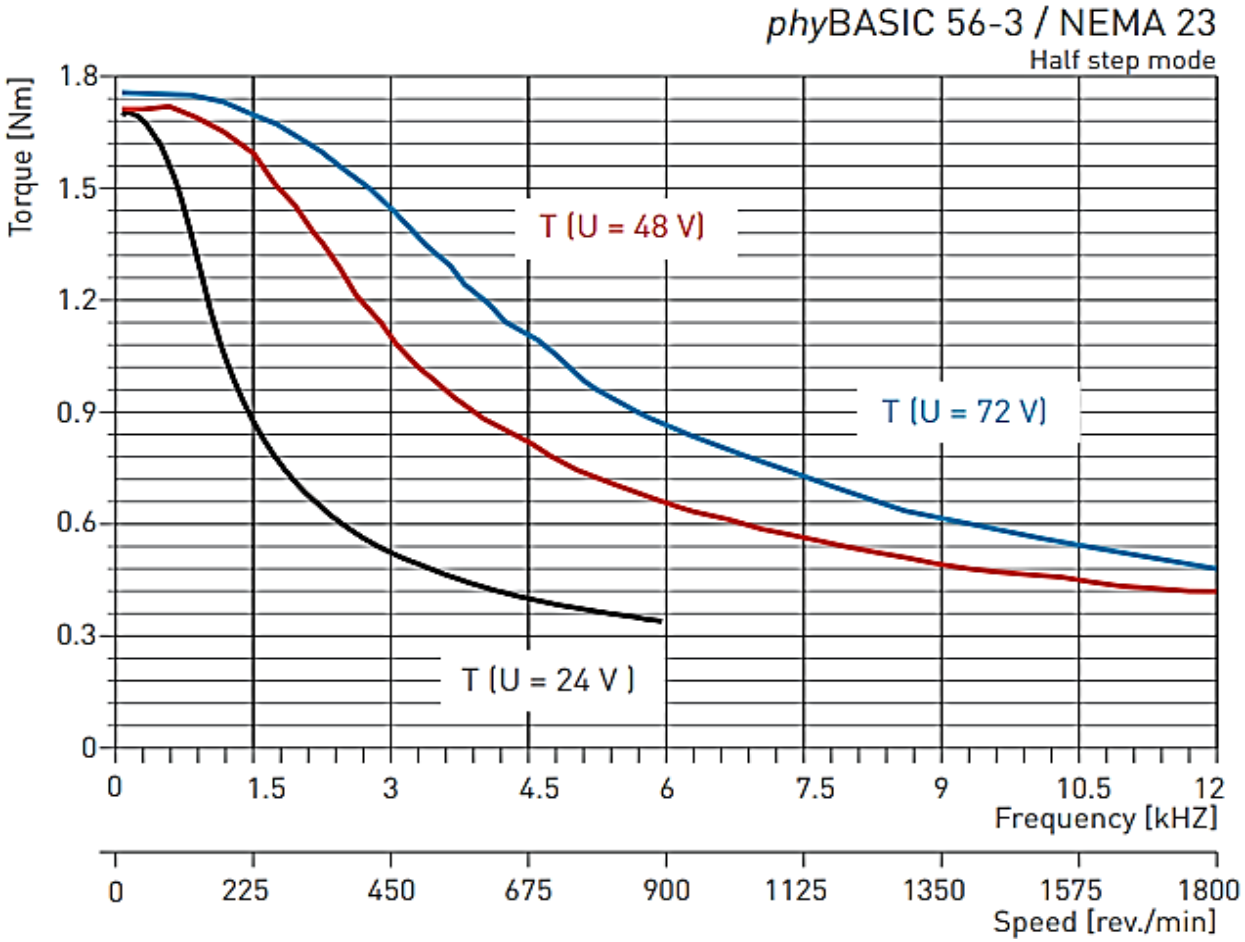


Hybrid Stepper Motor Rotor

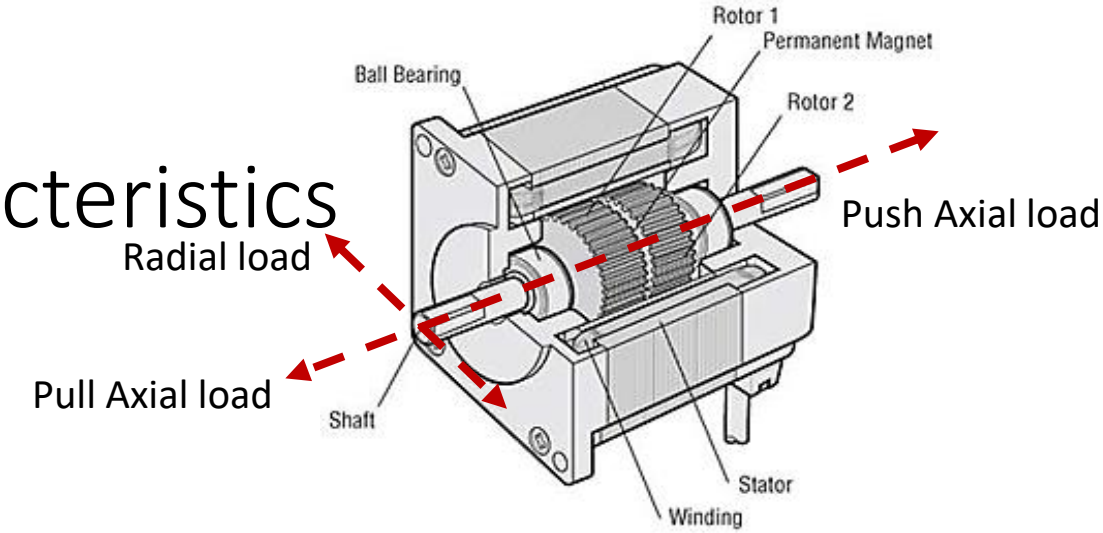
https://www.orientalmotor.com/stepper-motors/technology/hybrid-stepper-motors-v-hybrid-control.html

Stepper Motor – Motor Characteristics

Basic Specifications



Katalog-Deckblatt-SM_April_2015.indd



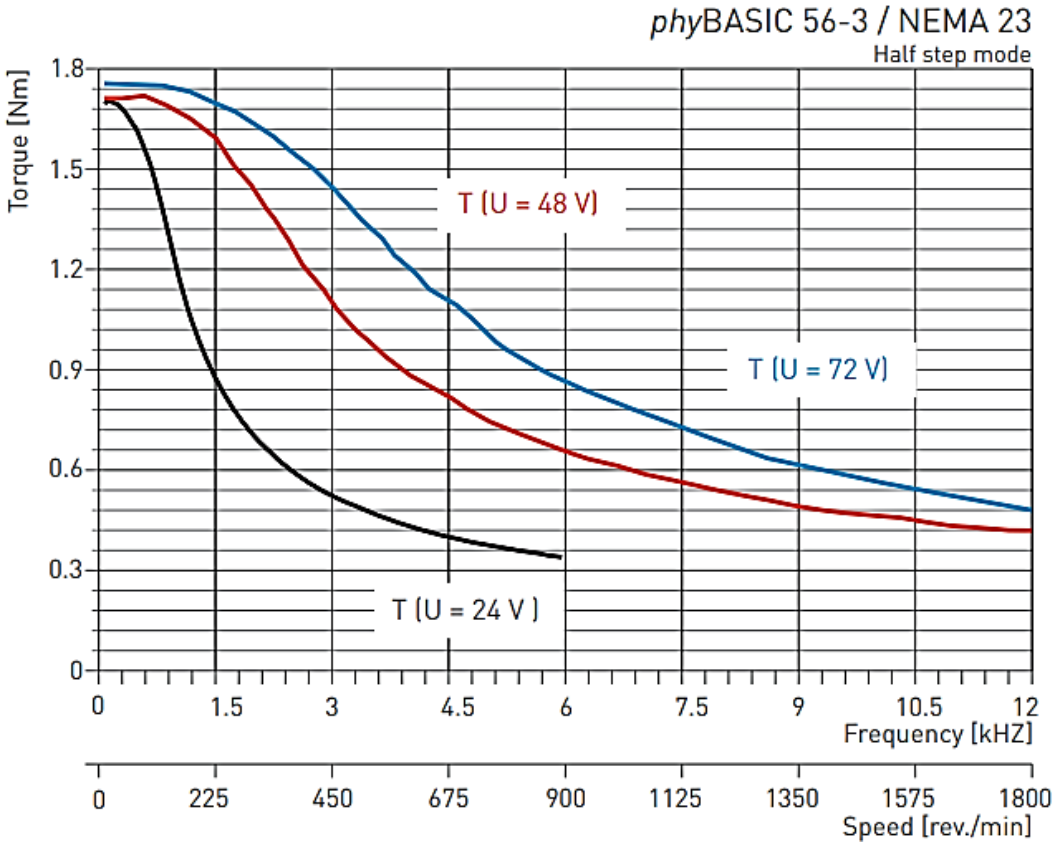
Motor Structural Diagram: Cross-Section Parallel to Shaft

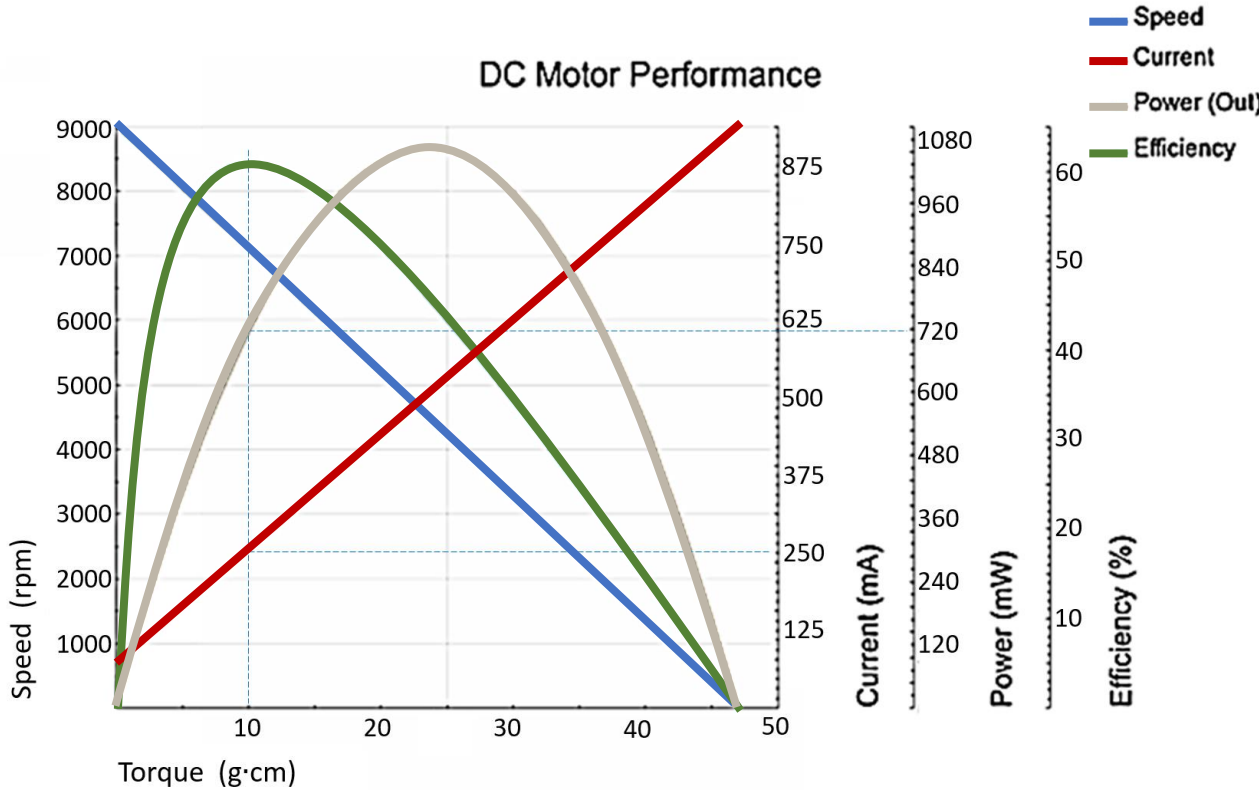
Stepper Motor Specifications

- **NEMA:** 23
- **Size:** 56-3
- **Current/Phase:** 2.0 A
- **Resistance/Phase:** 2.3 Ohm
- **Inductive/Phase:** 9.3 mH
- **AWG:** 26
- **Max Voltage:** 72V
- **Holding Torque:** 2300 mNm
- **Detent torque:** 75 mNm
- **Rotor Inertia:** 0.39 kg cm^2
- **Bearing Load:** Axial (push) 40 N/(pull) 130 N
- **Bearing Load:** Radial 70 N
- **Mass:** 1 kg

Stepper Motor – Motor Characteristics

Stepper – DC motor characteristics comparison

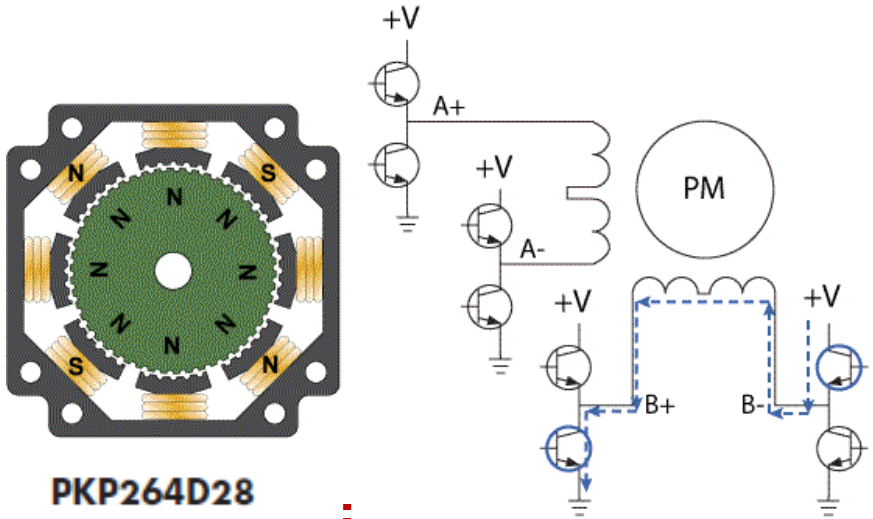




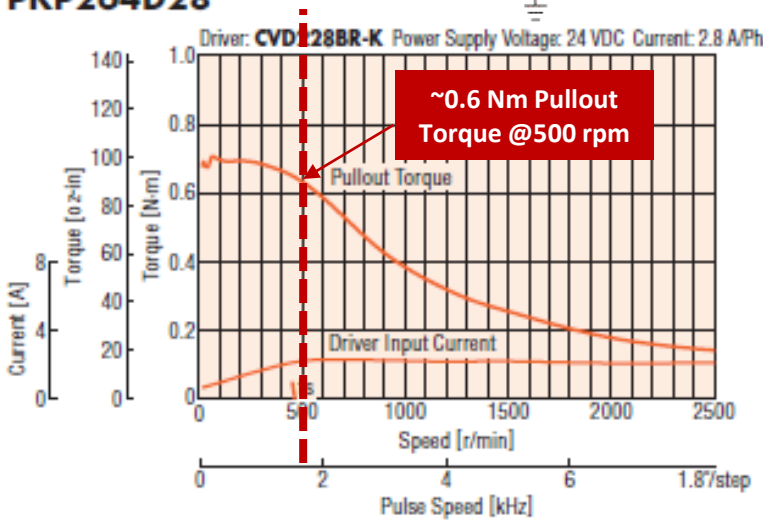
DC and stepper motor have differences in motion generation and motor driving method. This cause a difference in characteristics.

Stepper Motor – Stepper Driver Types

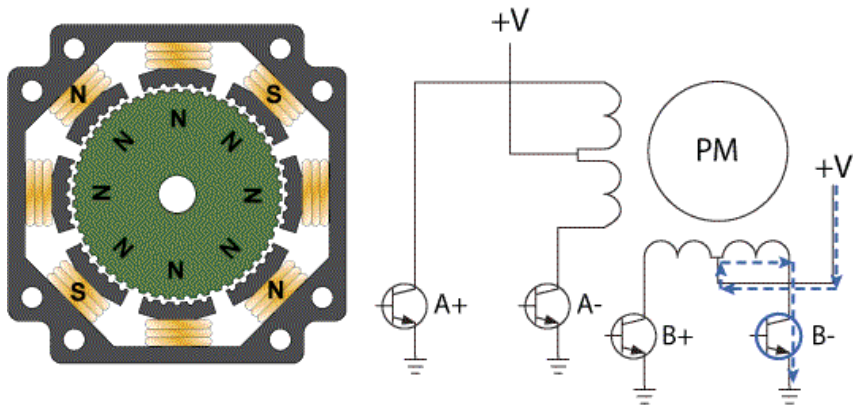
Bipolar Stepper Motor



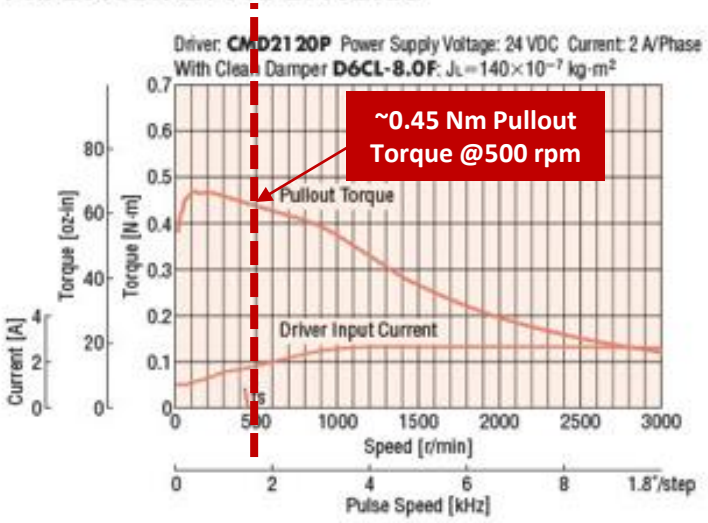
PKP264D28



Unipolar Stepper Motor



PKP264U20A2 / PKP264U20B2



- **Bipolar** driver **is more efficient** than unipolar
- **Bipolar** driver **is more complicated** to drive than unipolar
- **Bipolar** has a **better ability to send current** to a coil.

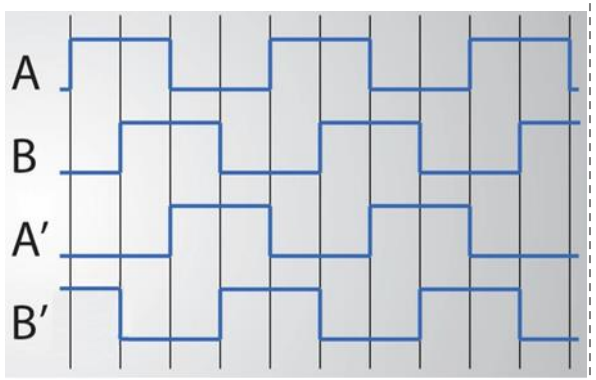
** By changing from driver types, we are changing the torque characteristics of the motor.

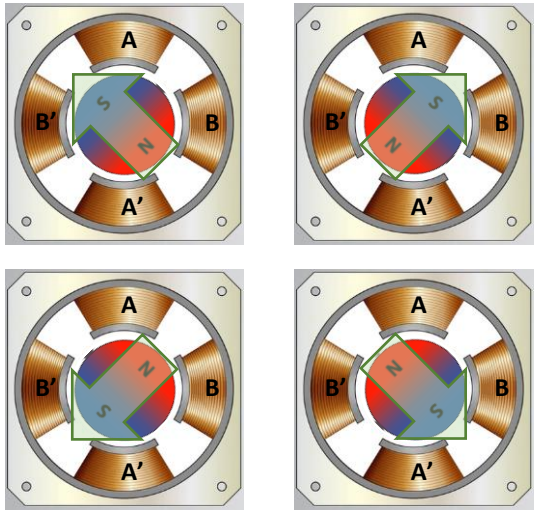
[Stepper Motor Wiring Basics: Unipolar vs Bipolar]

https://www.applied-motion.com/news/2015/10/what-unipolar-step-motor-drive

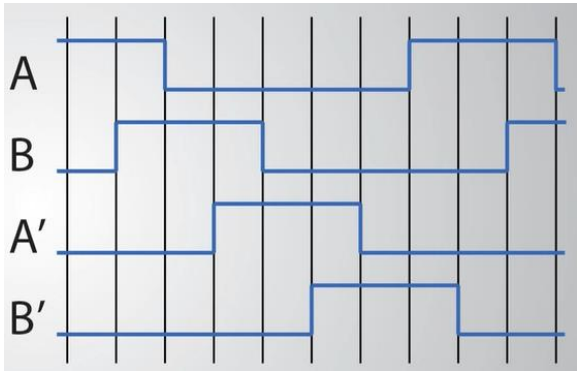
Stepper Motor – Drive Modes

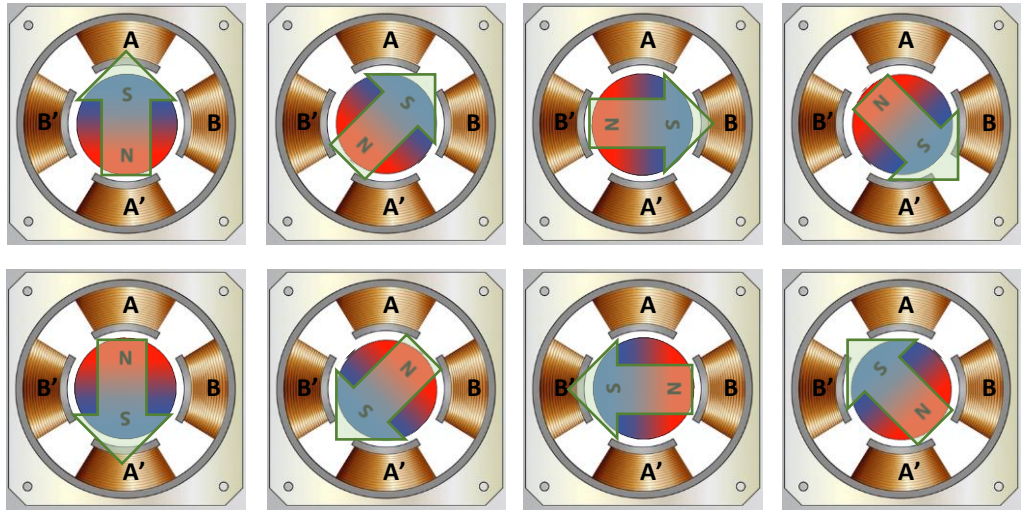
Full Step Drive



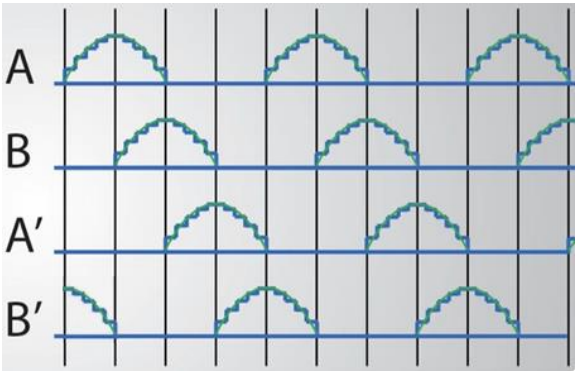


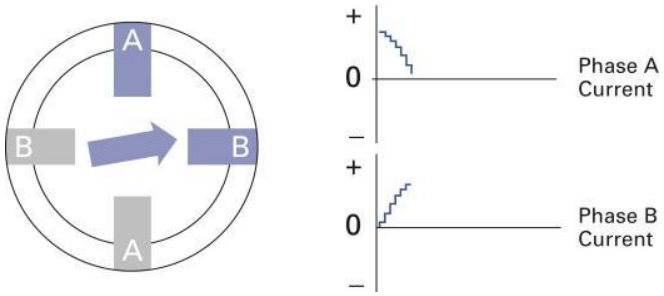
Half Step Drive





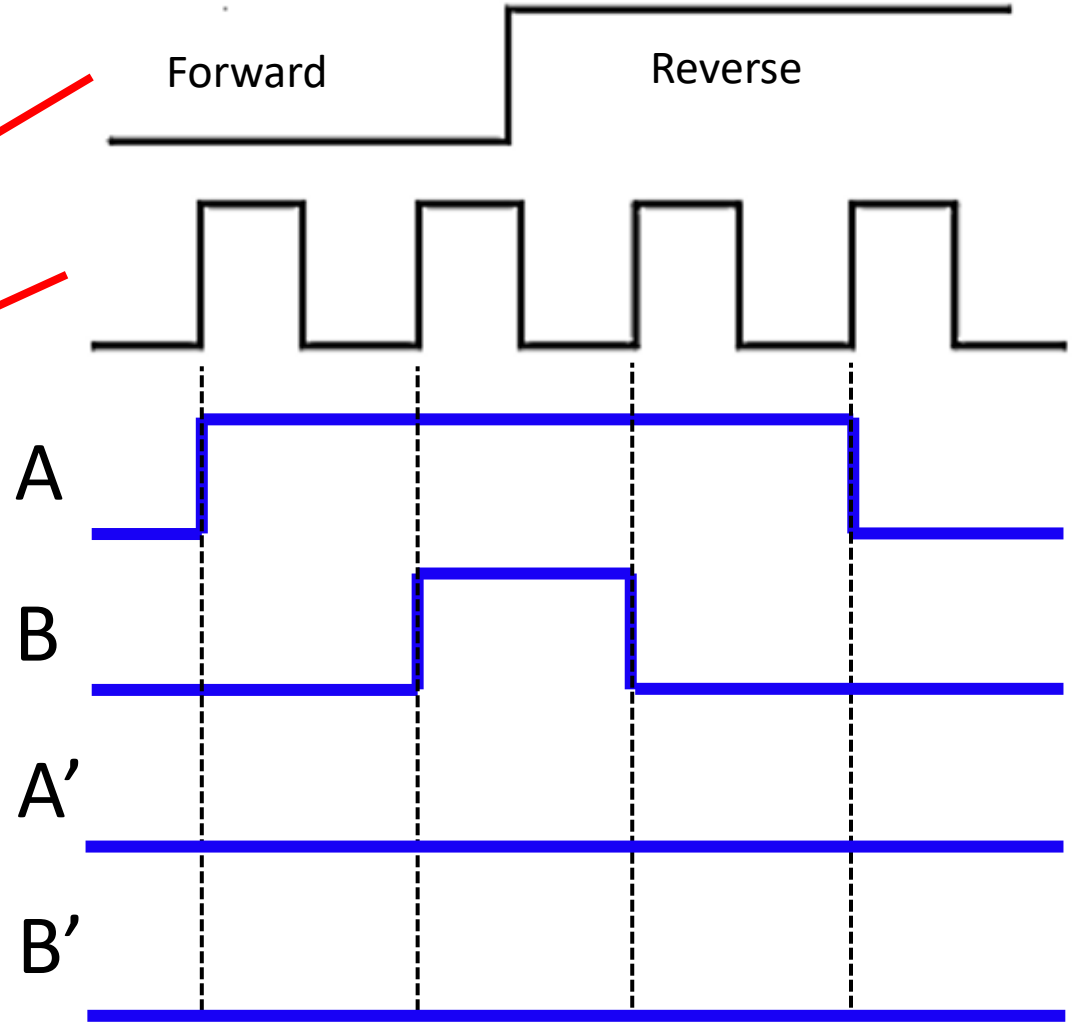
Micro Step Drive





[Stepper Motor Stages / Stepper Motors for Precision Motion, Positioning | PI]

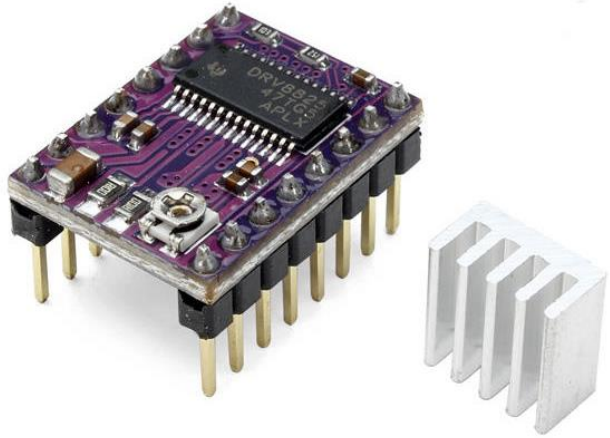
Stepper Motor – Stepper Driver



https://knowledge.ni.com/KnowledgeArticleDetails?id=kA00Z0000019ZTySAM&l=en-US

Stepper Motor – Stepper Driver

DRV 8825



MODE0	MODE1	MODE2	Microsteps
Low	Low	Low	Full step
High	Low	Low	Half step
Low	High	Low	1/4 step
High	High	Low	1/8 step
Low	Low	High	1/16 step
High	Low	High	1/32 step
Low	High	High	1/32 step
High	High	High	1/32 step

EN = Enable - Active LOW, (default state)
Leave unconnected if always enabled

M0 = Mode 0 (Set microstep size)
Leave unconnected for full Step Mode

M1 = Mode 1 (Set microstep size)
Leave unconnected for full Step Mode

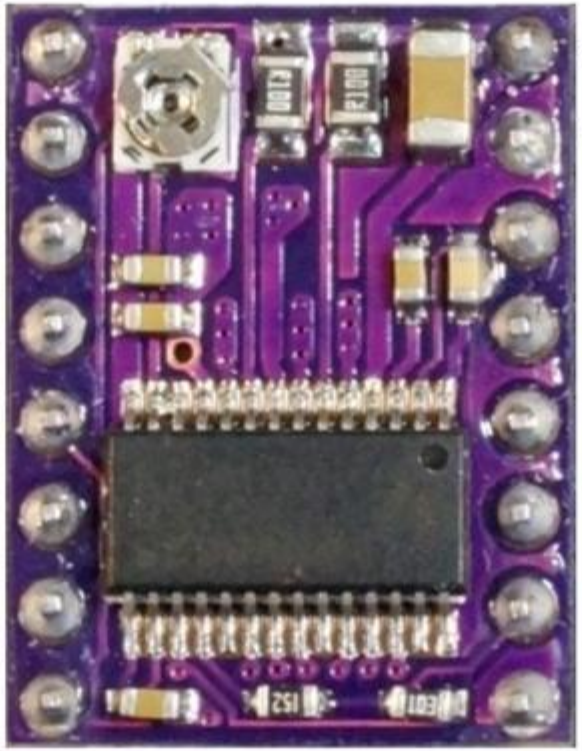
M2 = Mode 2 (Set microstep size)
Leave unconnected for full Step Mode

RST = Reset - Active LOW (default state)
Must pull high to take out of reset

SLP = Sleep - Active LOW (default state)
Must pull high to take out of sleep

STP = Step Input (pulse increments step)
Driven by microcontroller

DIR = Direction Input (rotation direction)
Driven by microcontroller



VMOT = Motor Voltage (8.2 - 45V)

GND = Motor Power Supply Ground

2B = Stepper Coil B (leg 2)

1B = Stepper Coil B (leg 1)

1A = Stepper Coil A (leg 1)

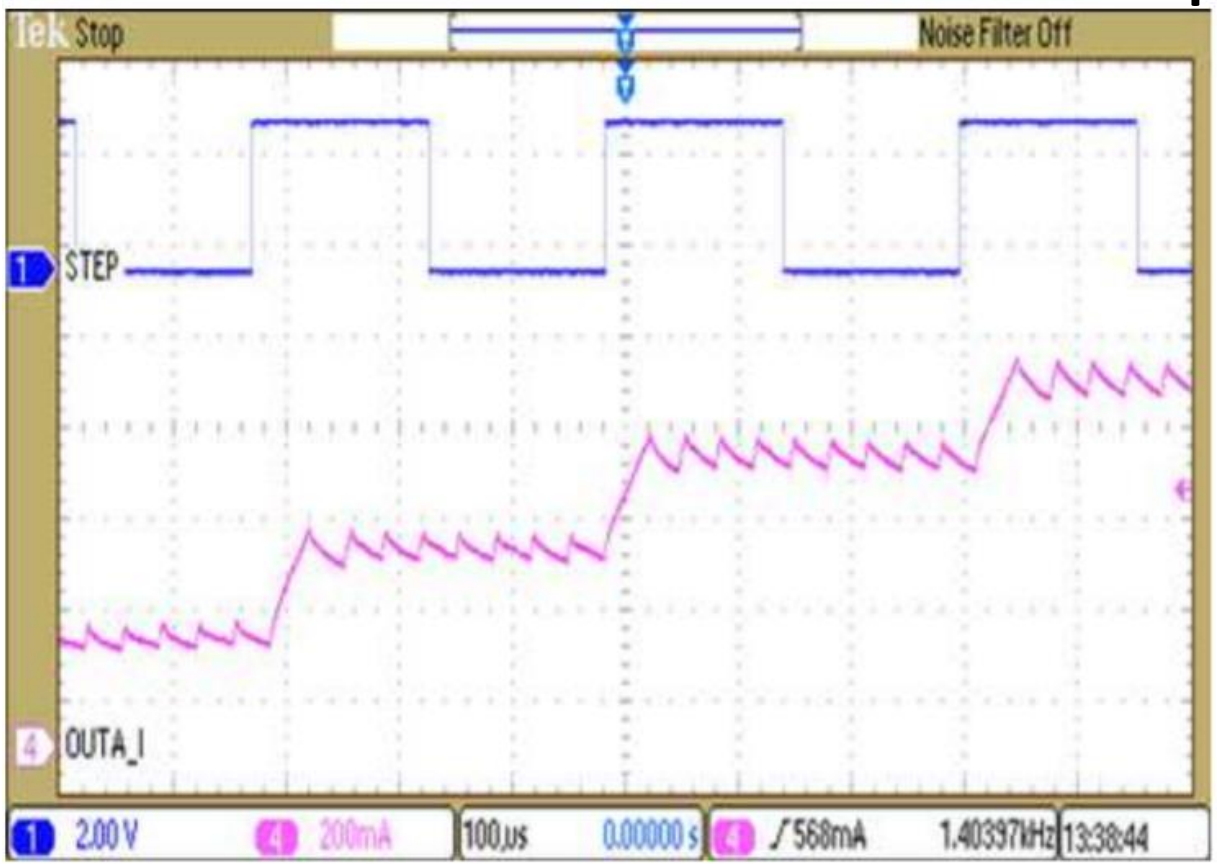
2A = Stepper Coil A (leg 2)

FLT = Fault Output - Active LOW when fault detected

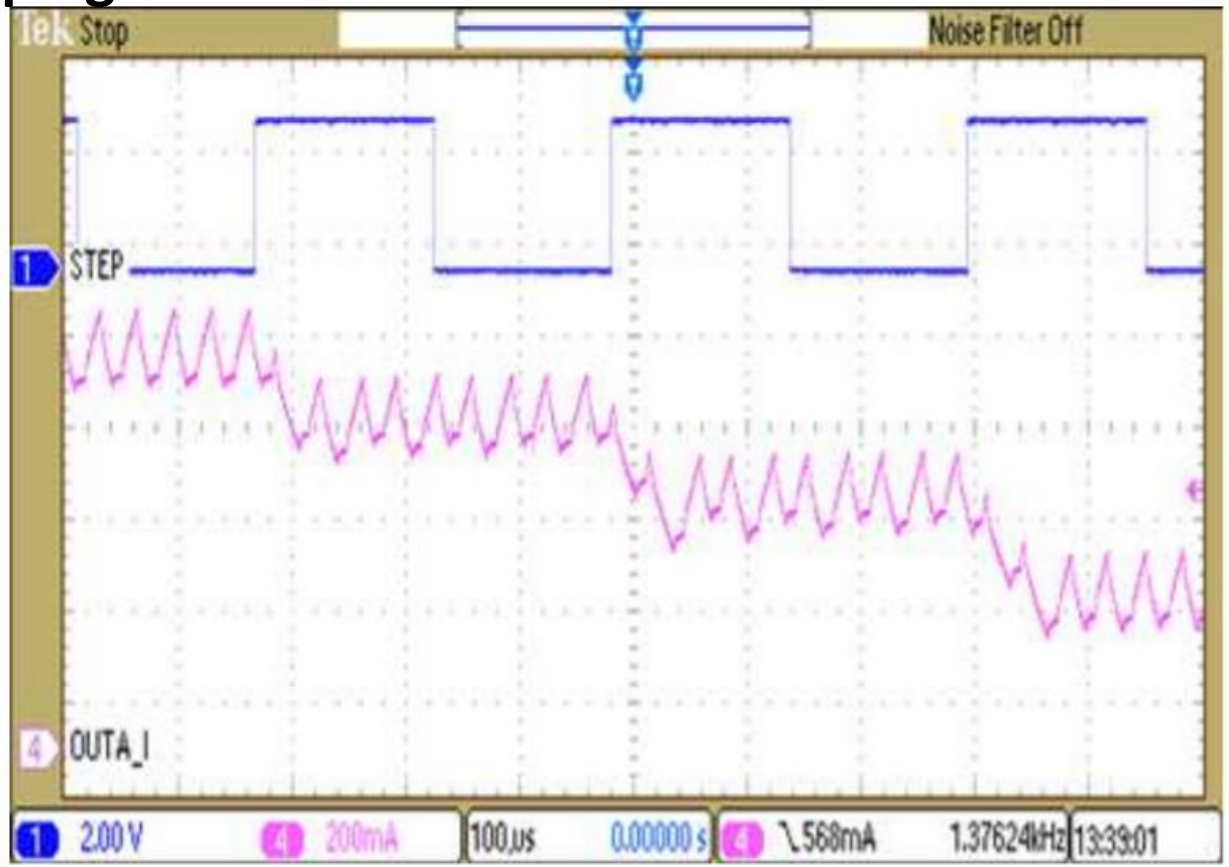
GND = Microcontroller Ground

Stepper Motor – Stepper Driver

DRV 8825 current draw from microstepping



Microstepping Current (Phase A) vs
STEP Input, Slow Decay on Increasing Steps



Microstepping Current (Phase A) vs
STEP Input, Mixed Decay on Decreasing Steps

Solenoid

Example applications

[TAILONZ PNEUMATIC 1/4"NPT Solenoid Valve DC12V Single Coil Pilot-Operated Electric 2 Position 5 Way Connection Type]

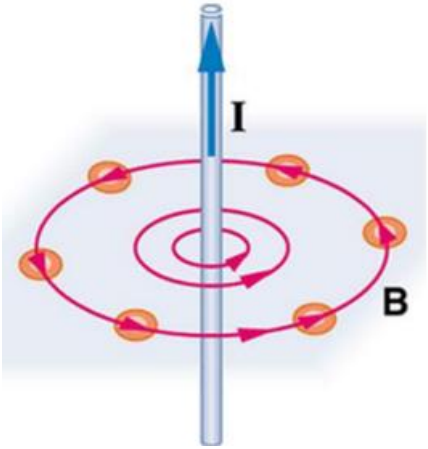
Solenoid Valve

[GD004 กลอนไฟฟ้า กลอนแม่เหล็กไฟฟ้า กลอนประตูไฟฟ้า LY-03 DC12V 0.3A 3.6W Electromagnetic Lock โซลินอยด์ล็อค Solenoid lock]

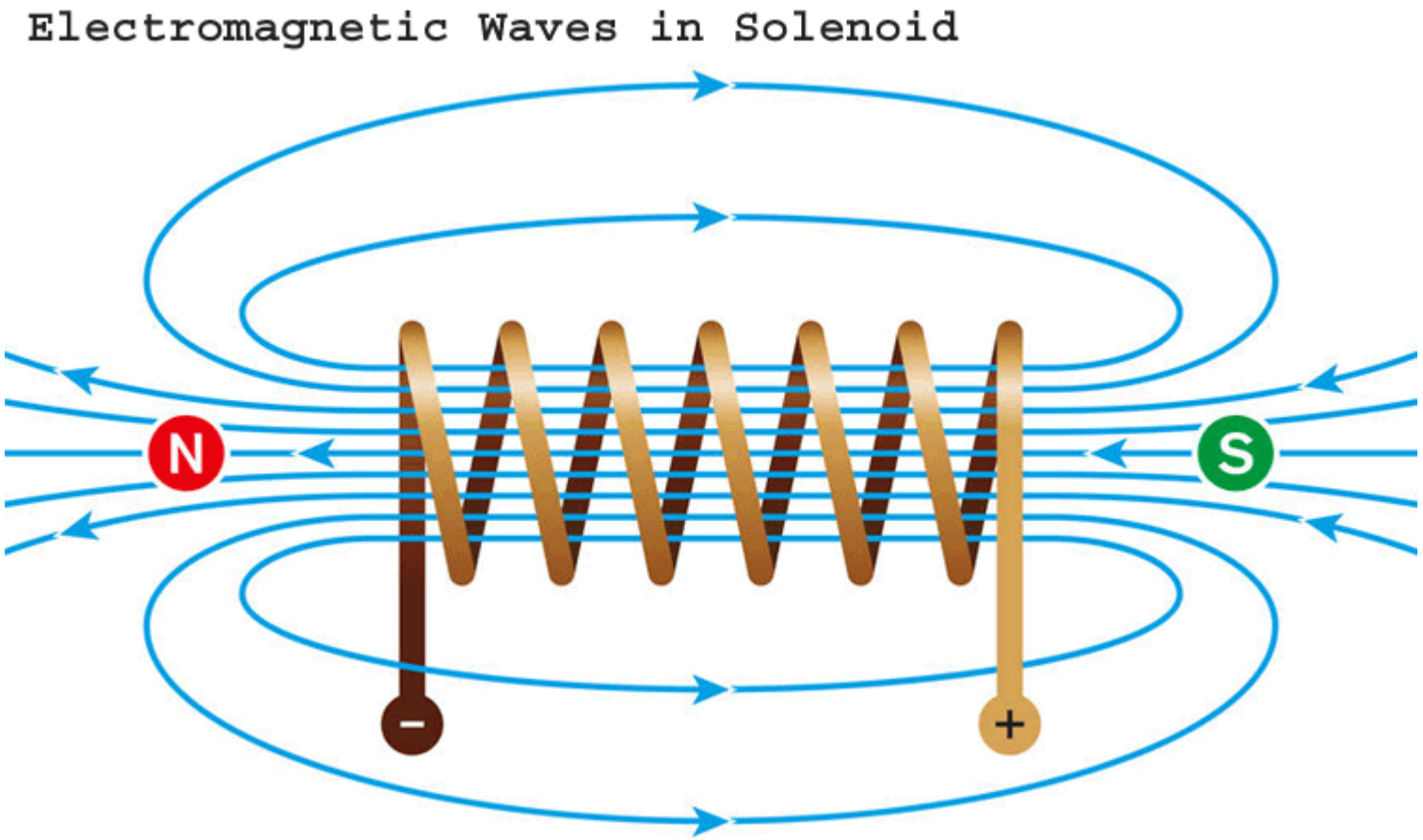
Solenoid Lock Door

Solenoid – Basic Principle

Ampere's Law

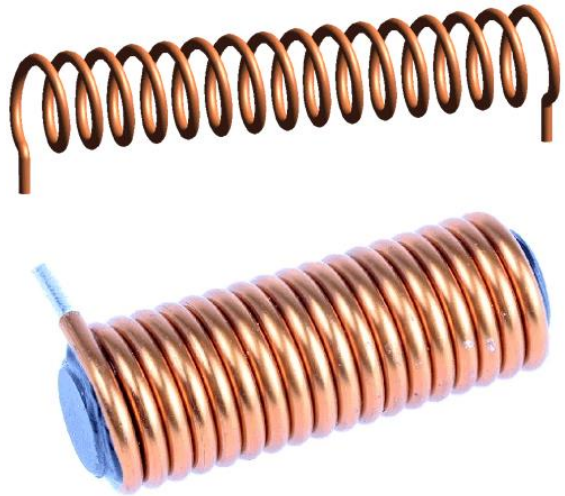


$$B = \frac{\mu_0 I}{2\pi r}$$



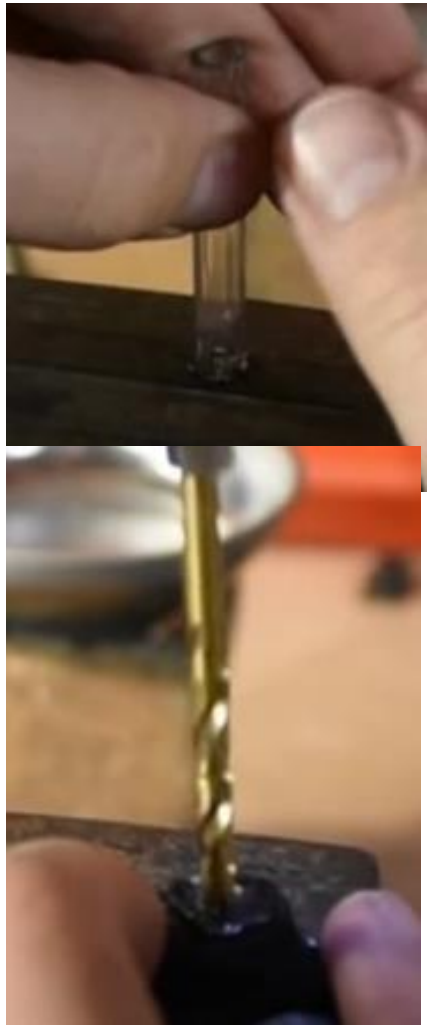
https://circuitdigest.com/article/what-is-solenoid-its-working-principle-and-types

$$B = \mu_0 \frac{NI}{l}$$



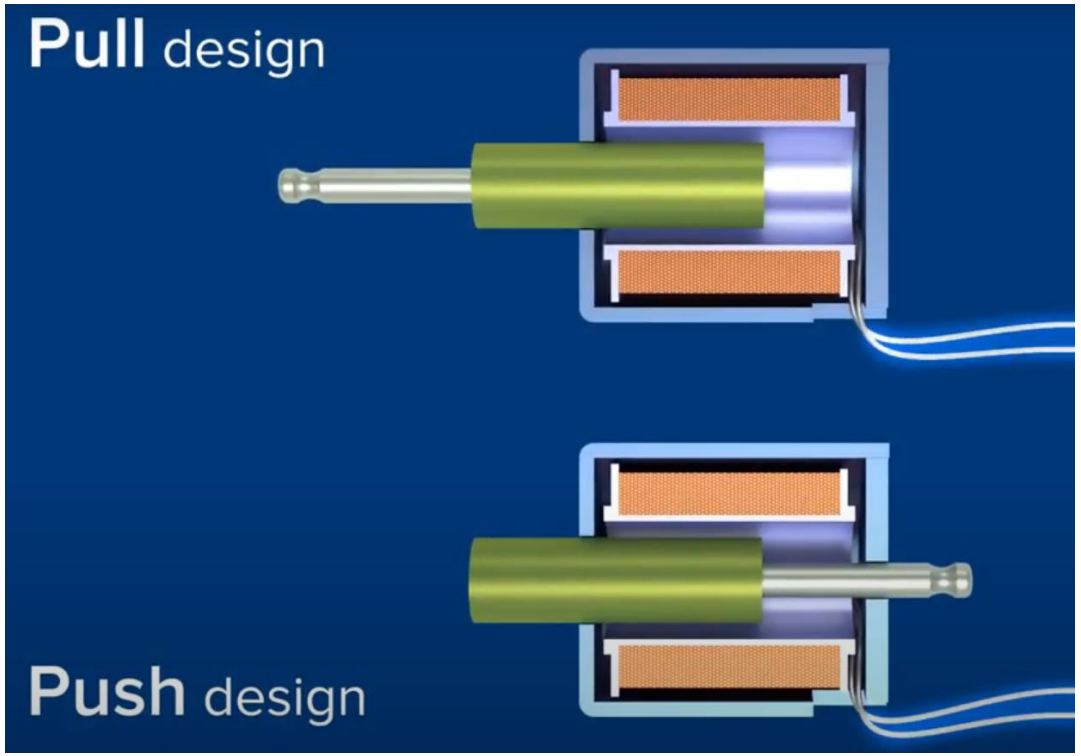
$$\mu_0 = 4\pi \times 10^{-7} T \cdot m/A \quad permeability\ of\ free\ space$$

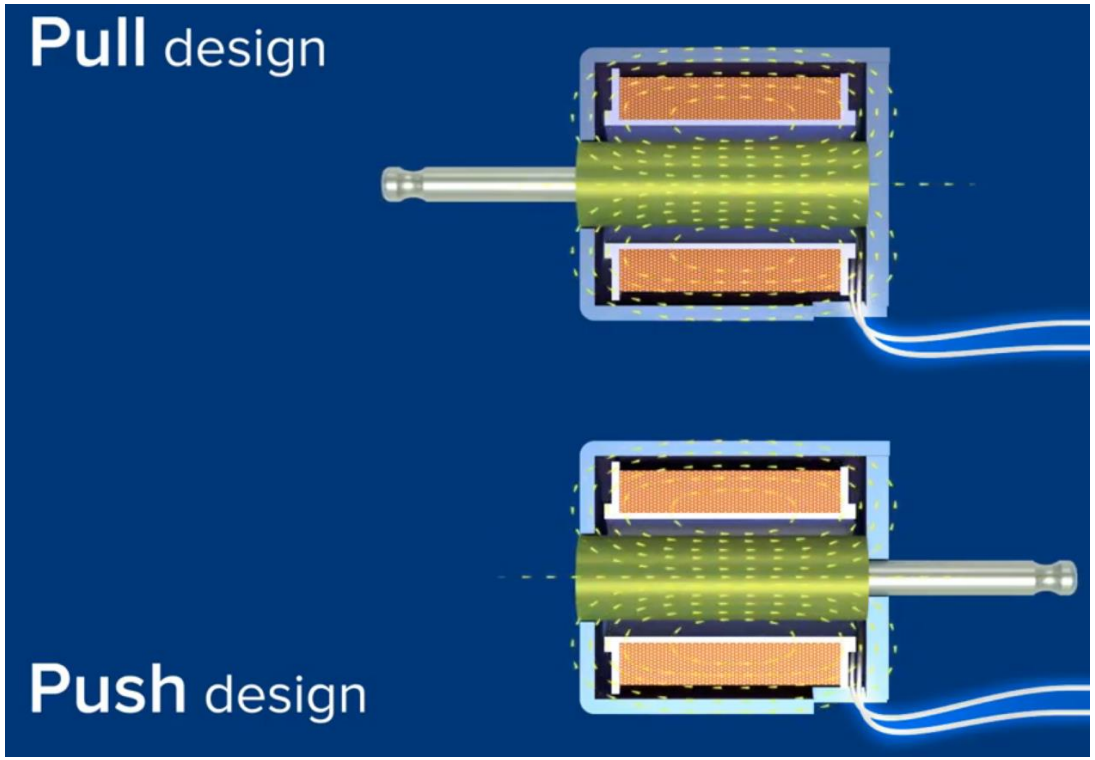
Solenoid – DIY Solenoid



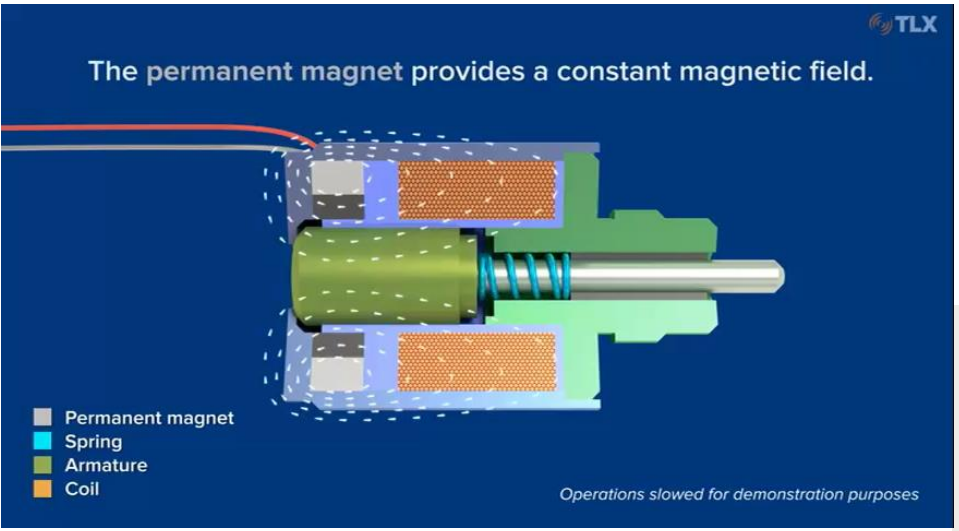
https://www.youtube.com/watch?v=BbmocfETTFo

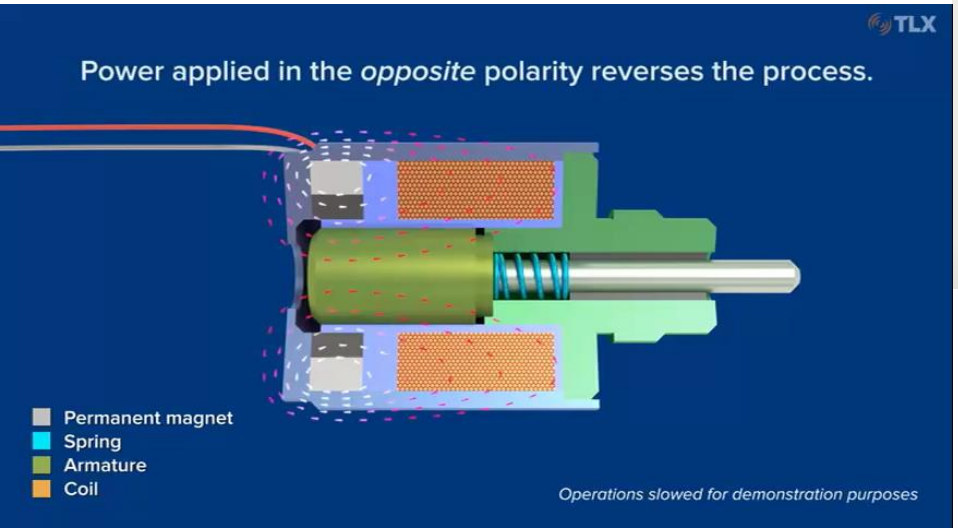
Solenoid – Basic design of solenoid

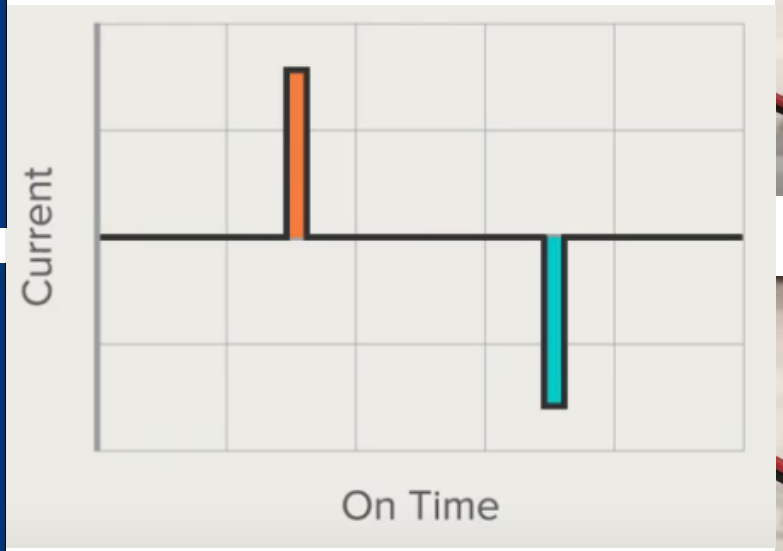


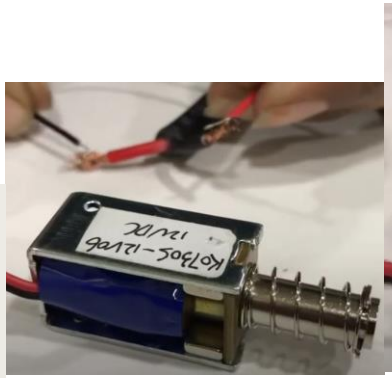


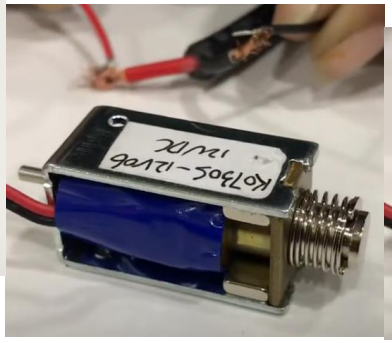
Solenoid – Latching Solenoid







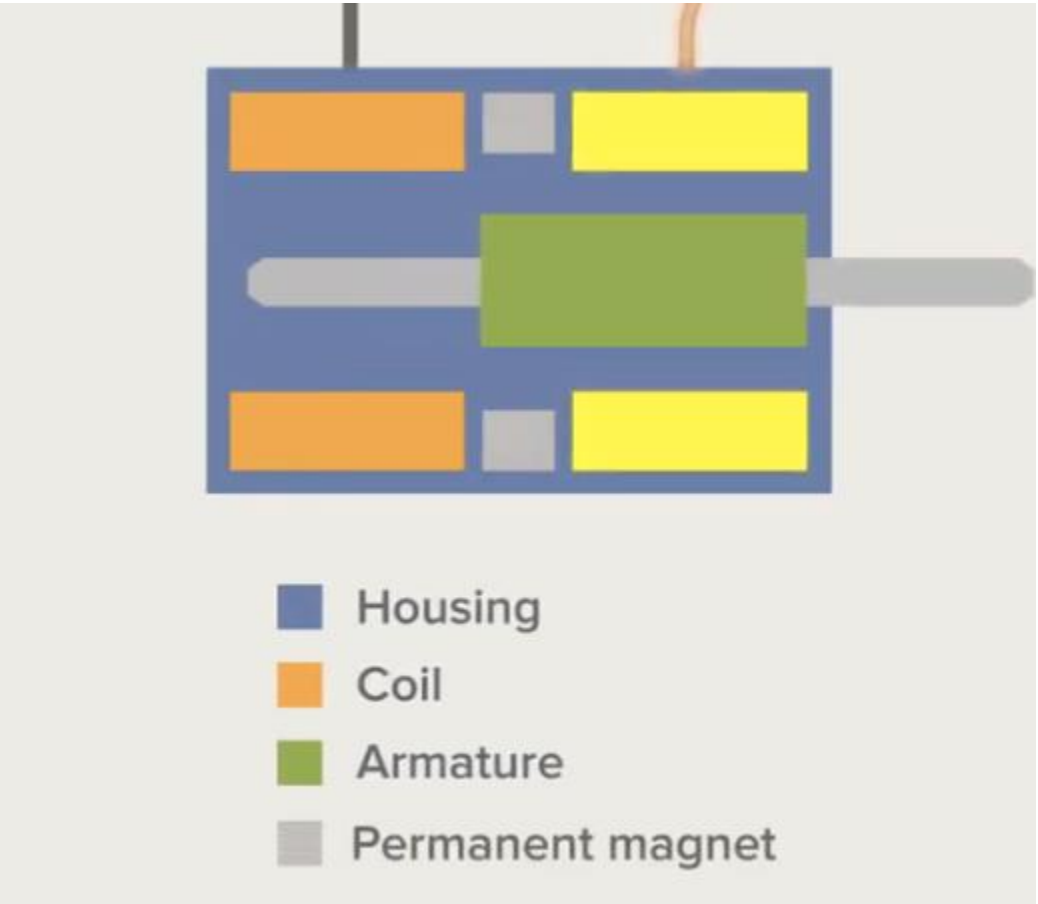


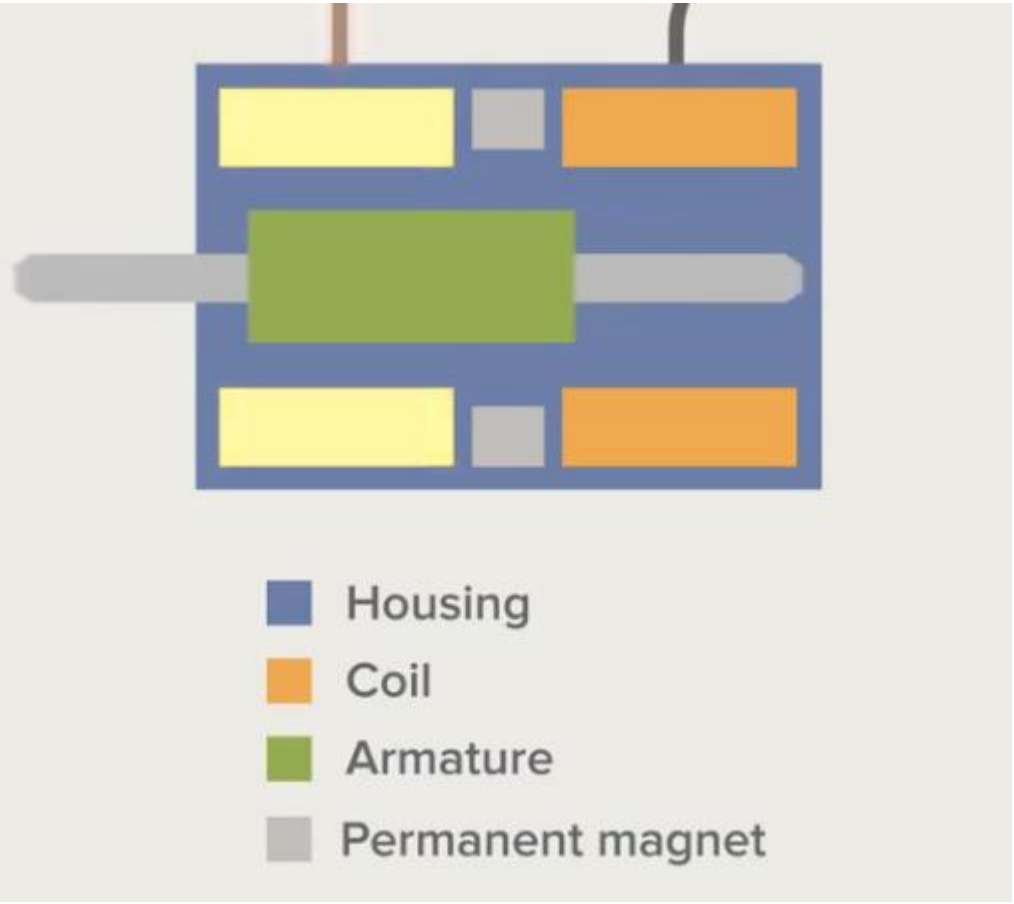


The advantage of latching solenoid

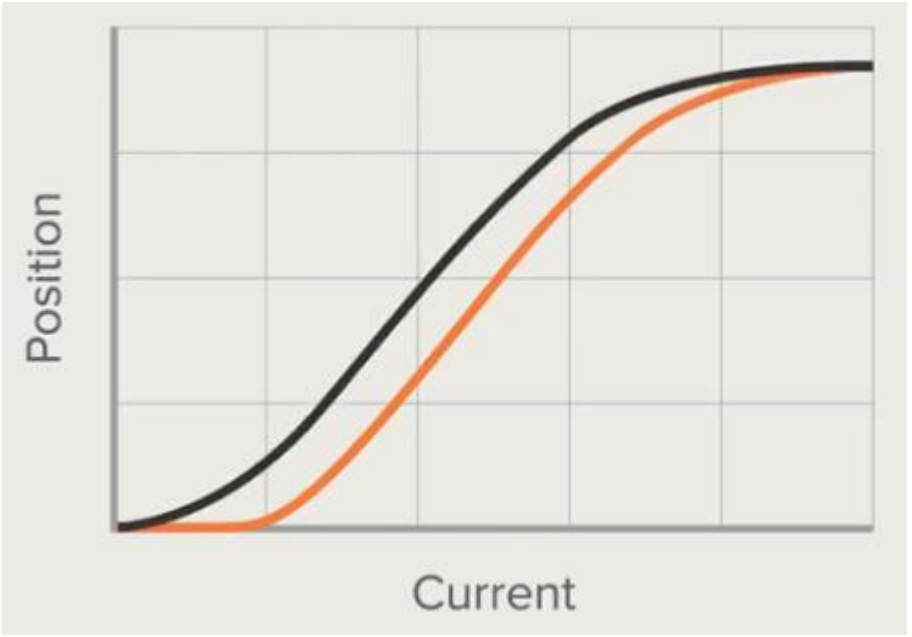
Low frequency application
Low power consumption

Solenoid – Bi-Stable Linear Solenoid





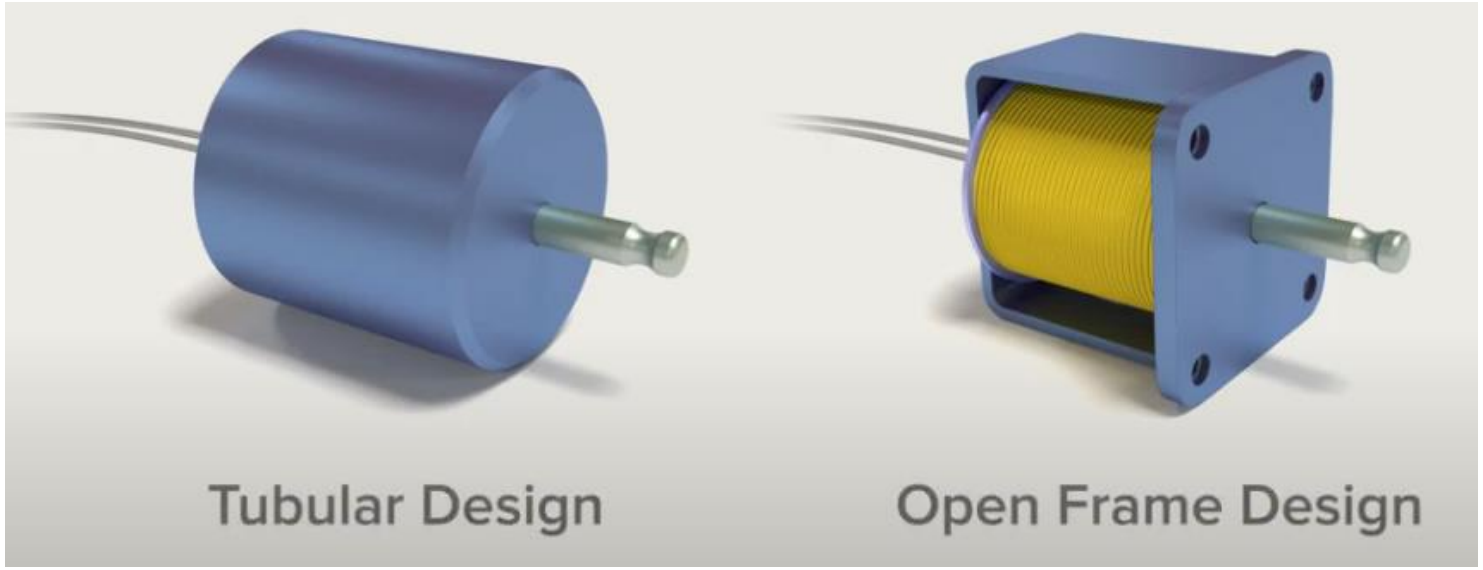
Solenoid – Proportional Solenoid



https://www.youtube.com/watch?v=Sq-CYfp9t4c

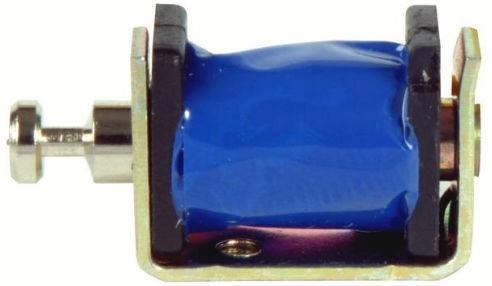
https://www.youtube.com/watch?v=xVk1CT3FWlo

Solenoid – Frame of Solenoid

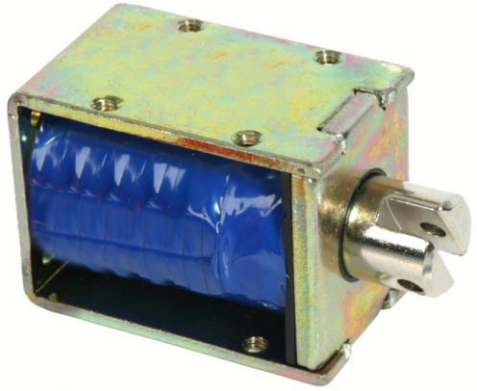


Minimize flux leakage
Reduce operational noise

Simplest design
Low cost



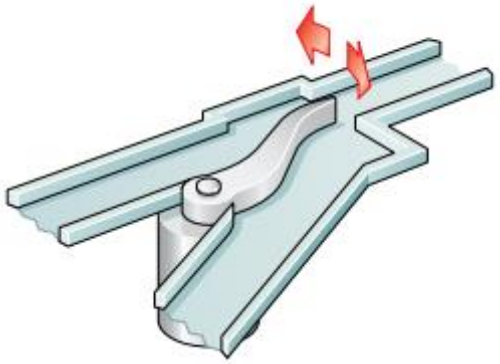
C Frame (U Frame) solenoid



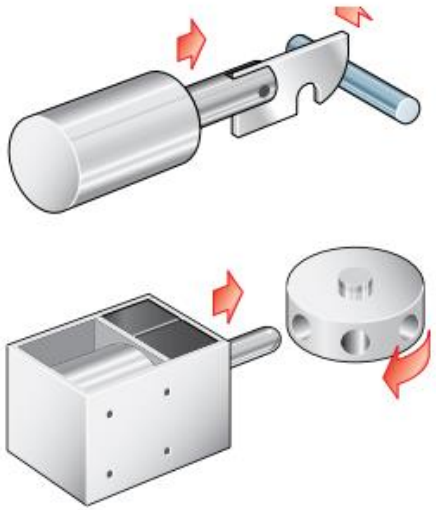
D Frame (Box Frame) solenoid

Solenoid – Linear Solenoid Application

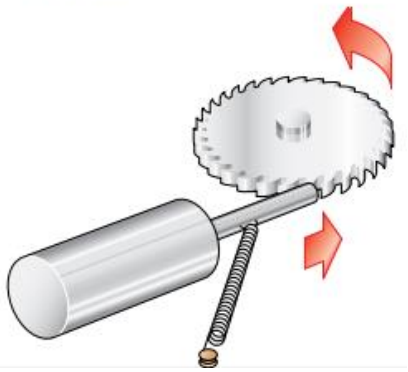
Divert



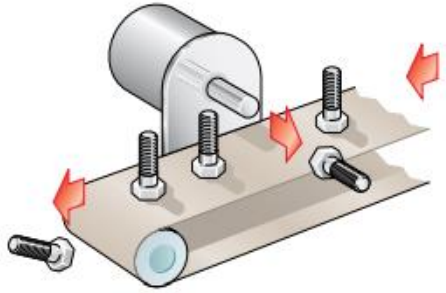
Lock/Latch



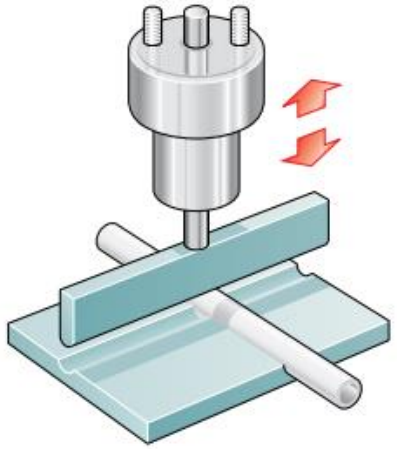
Position



Kick



Pinch



https://www.johnsonelectric.com/-/media/files/resources-for-engineers/solenoids/solenoids-principle-of-operation.ashx?la=ja&hash=AC01ABA5B2C47B338B55850084FD17FE1237EB33

Solenoid – Rotary Solenoid

Bi-stable rotary solenoids

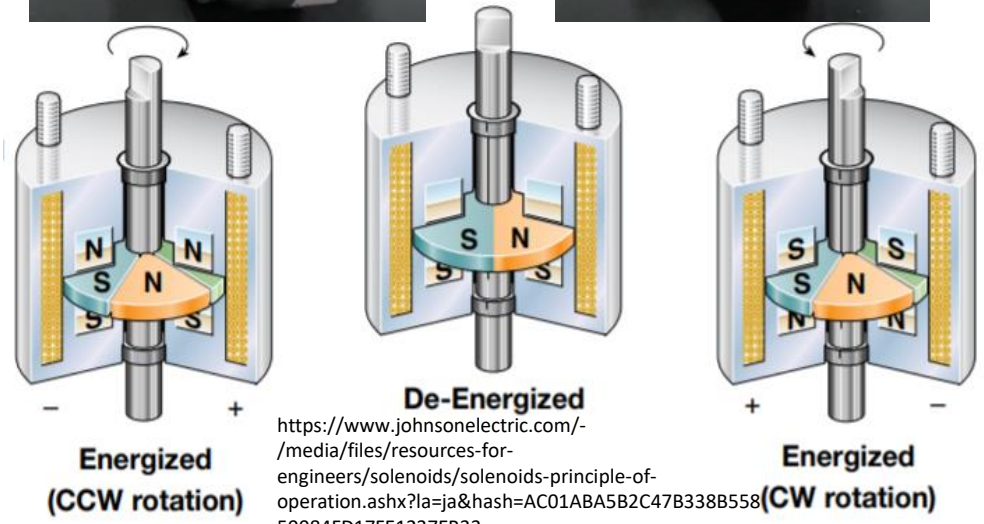
fast response times
holds the position even when power is not applied

Step rotary solenoids

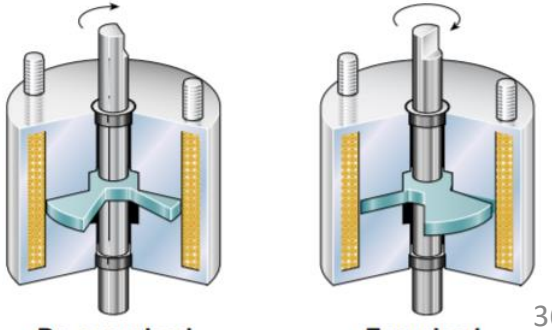
multiple position control
durable, high-torque
holds the position even when power is not applied

Latching solenoids

low duty cycle
negative electrical pulse unlatches the plunger



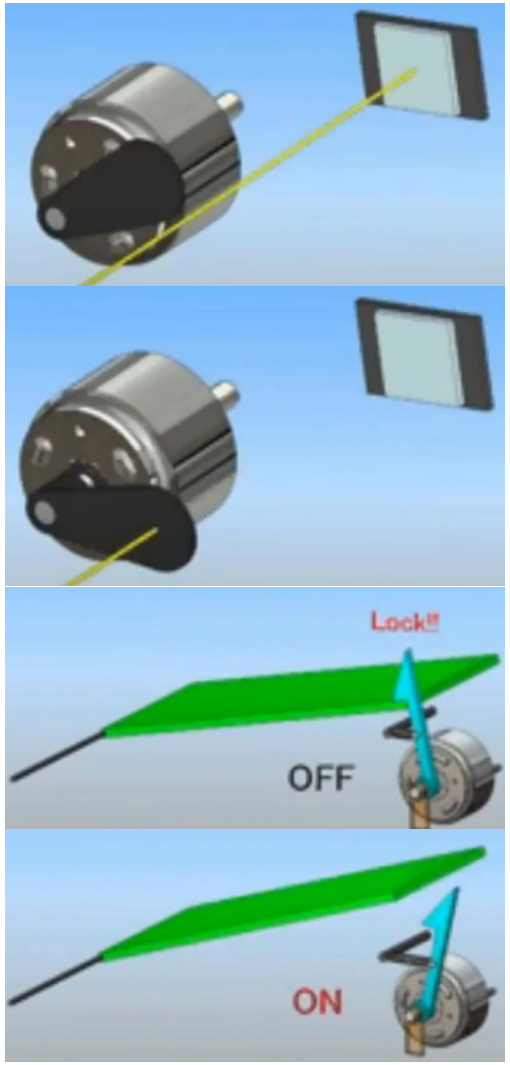
https://www.johnsonelectric.com/-/media/files/resources-for-engineers/solenoids/solenoids-principle-of-operation.ashx?la=ja&hash=AC01ABA5B2C47B338B55850084FD17FE1237EB33

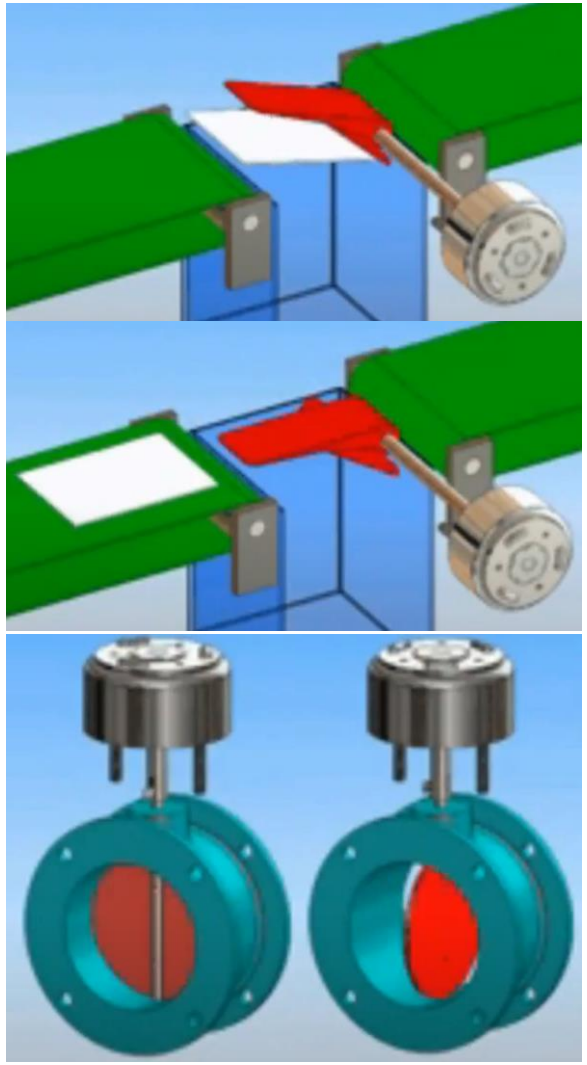


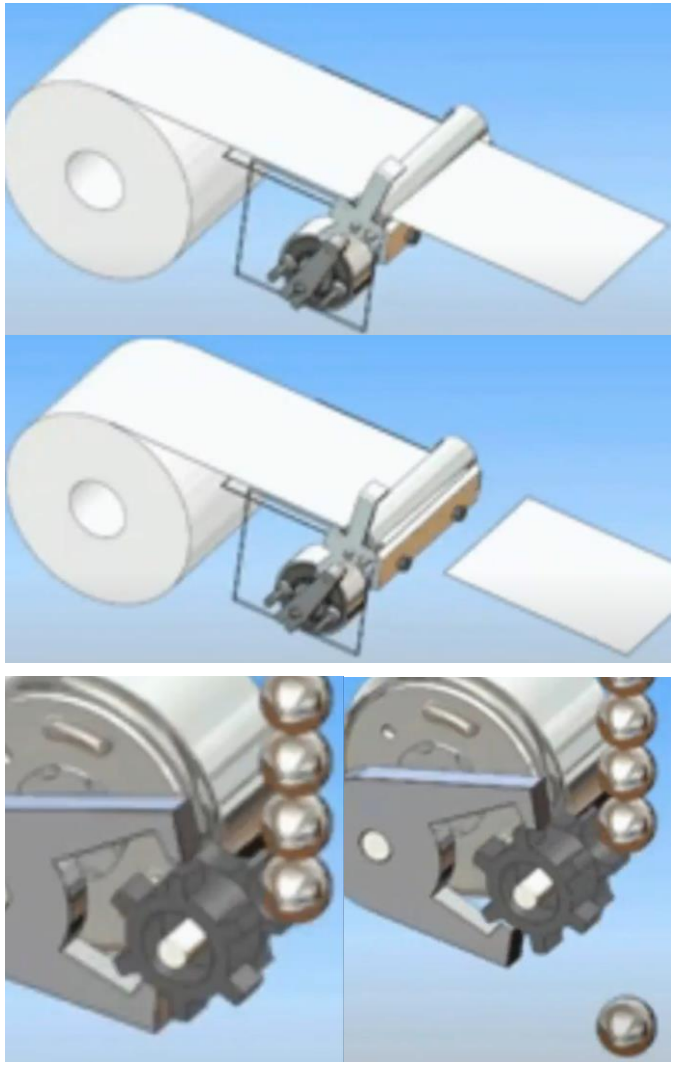
https://www.bicronusa.com/solenoid-applications/rotary-dc

https://www.globalspec.com/learnmore/mechanical_components/solenoids/rotary_solenoids

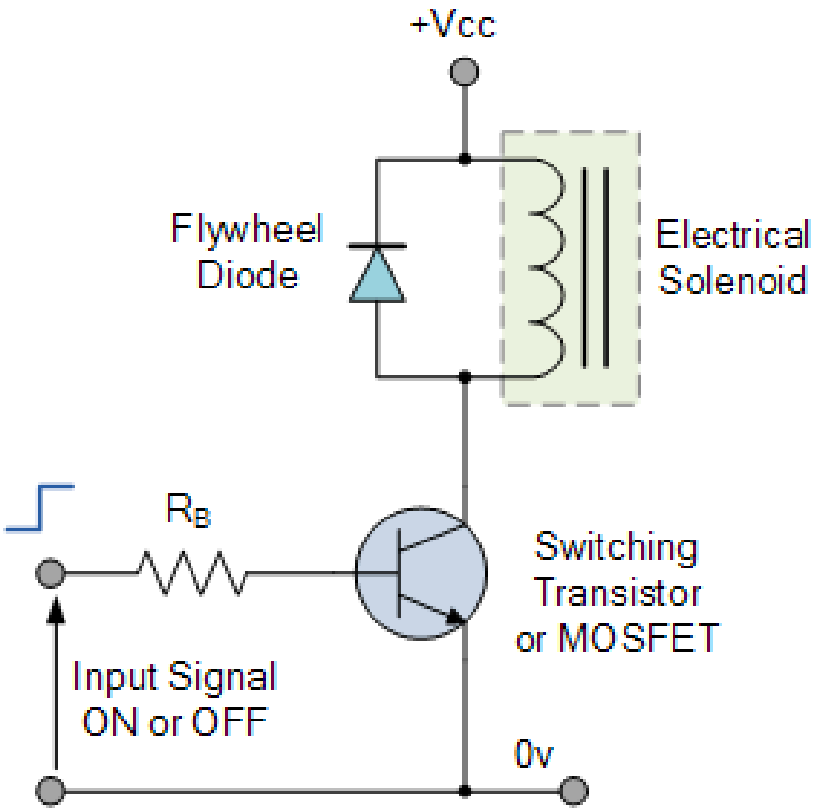
Solenoid – Rotary Solenoid Application



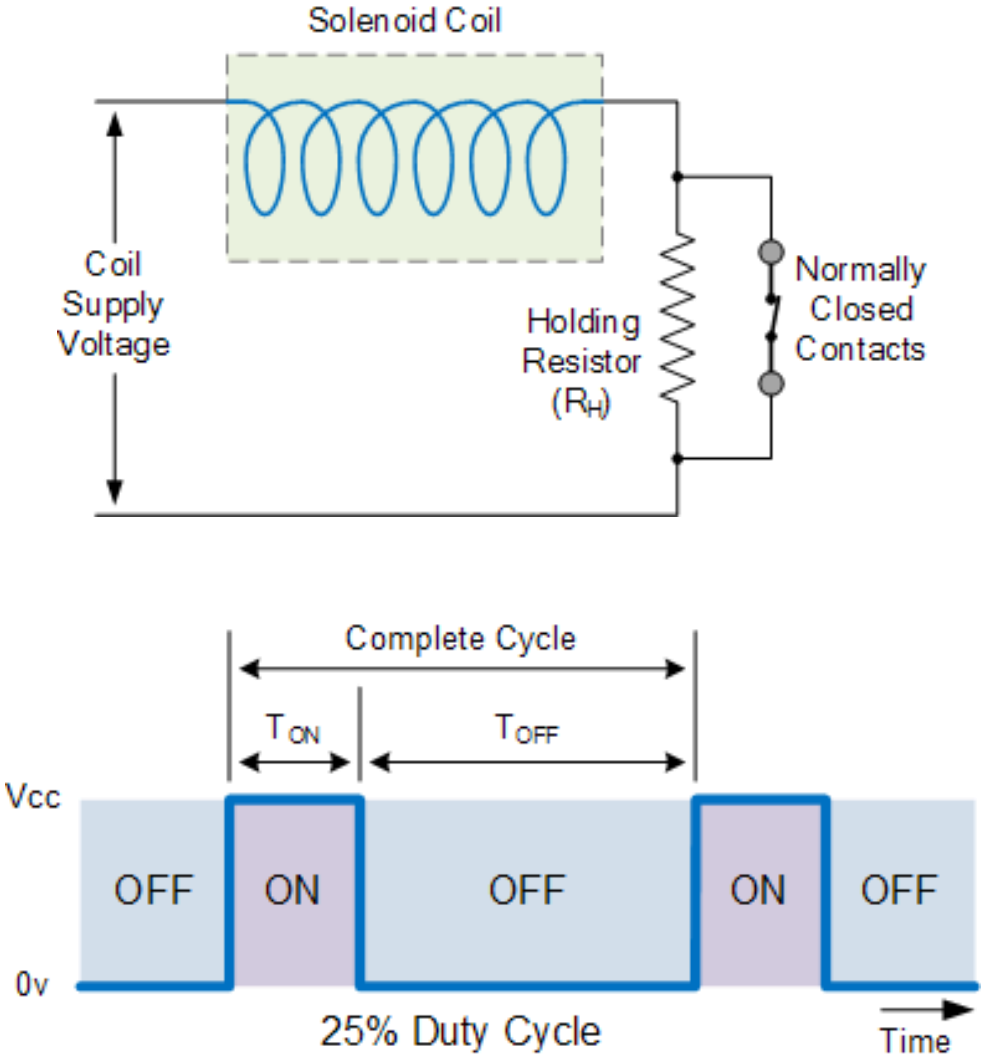




Solenoid – Driver

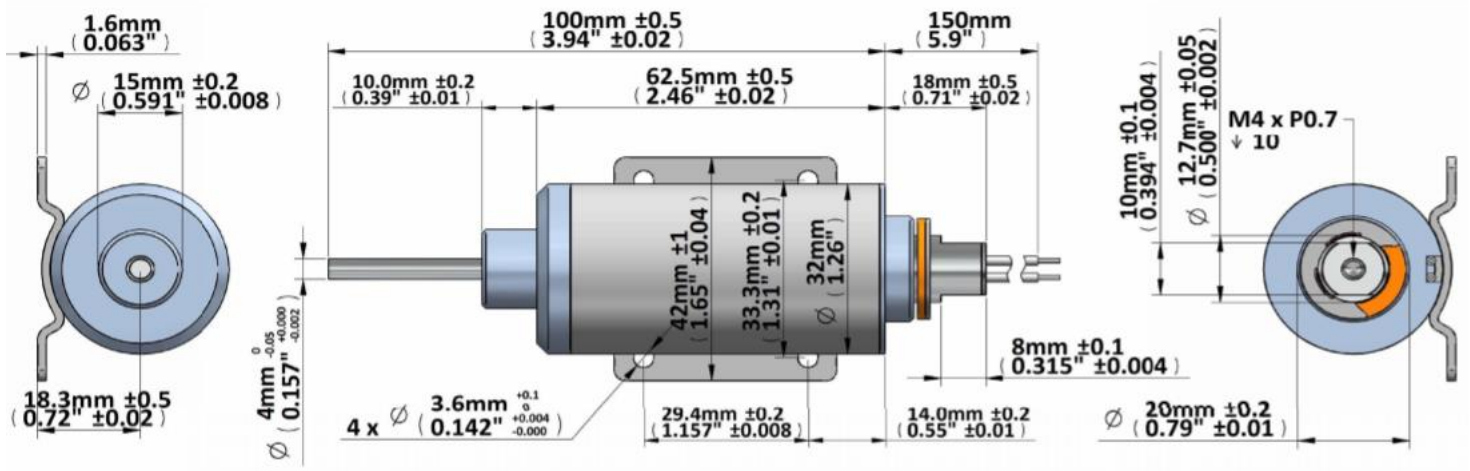


Protection



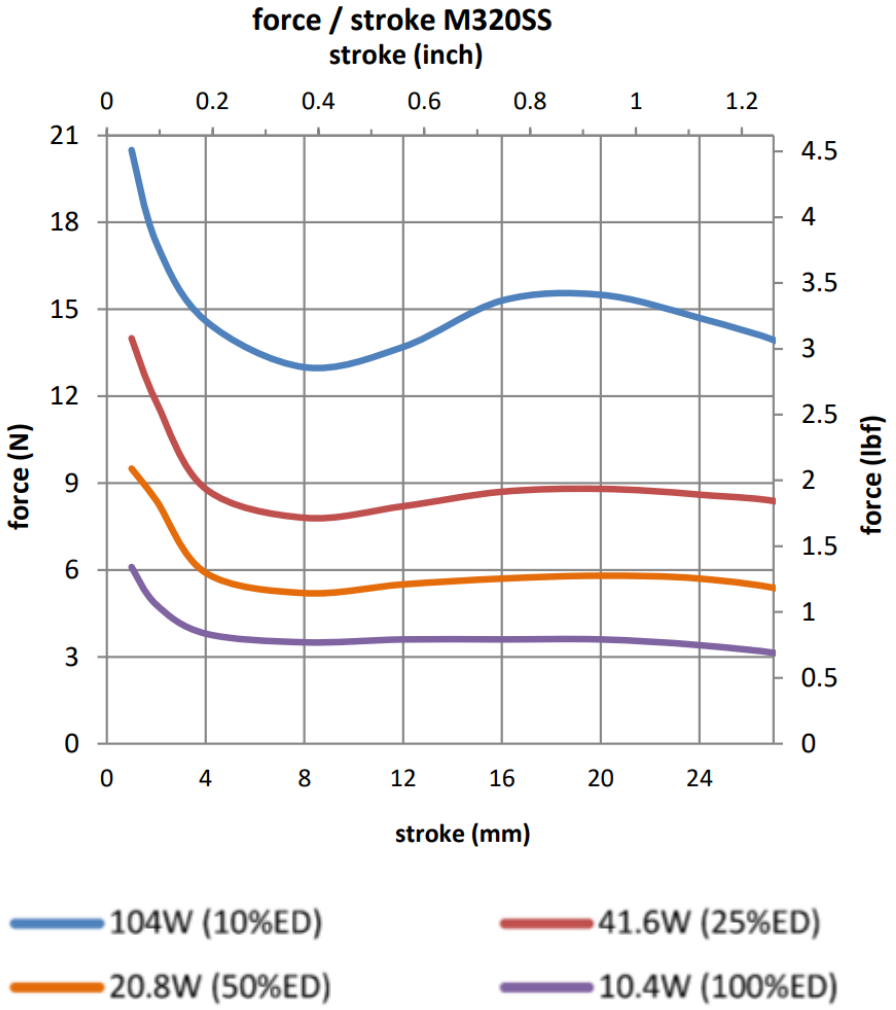
Reduce Heat

Solenoid – Specification



Data at 20°C , device performance measured without heat sink

duty cycle = "on" time / ("on" time + "off" time) x 100%			100% cont.	50% or less	25% or less	10% or less
Max. "on" time in seconds			∞	310	48	14
watts at 20°C			10,4	20,8	41,6	104
ampere-turns at 20°			1335	1888	2670	4222
AWG no.	resistance Ω±10% (at 20°C)	number of turns	volts DC			
M320SS-12v	14	1541	12,0	17,0	24,0	38,0
M320SS-24v	55	3060	24,0	34,0	48,0	76,0
M320SS-48v	214	5992	48,0	68,0	96,0	152,0
M320SS-96v	900	12200	96,0	136,0	192	304



https://www.geeplus.com/wp-content/uploads/2019/08/Super_Stroke_solenoid_M320SS.pdf