Wrocław University of Science and Technology

Relays

References

- S. L Herman, Industrial motor control, Clifton Park, 2014
- T. R. Kuphaldt, Lessons In Electric Circuits, Volume II – AC, 6th Edition, 2007 (http://www.faqs.org/docs/electric/AC/index.html)
- J. Przepiorkowski, Silniki elektryczne w praktyce elektronika, BTC

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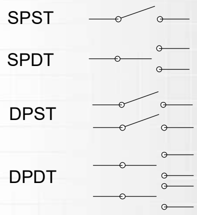
Outline

- relays
  - mechanical
  - electronic relay (SSR)
- Electric motors

3

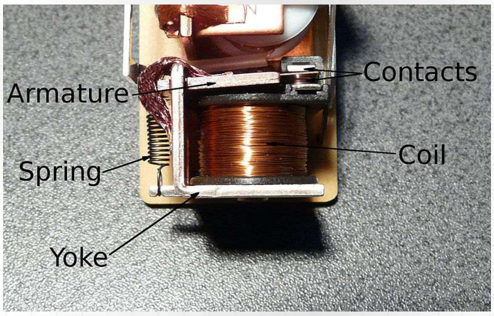
Relays



Single(Double)Pole
Single(Double;Triple)Throw

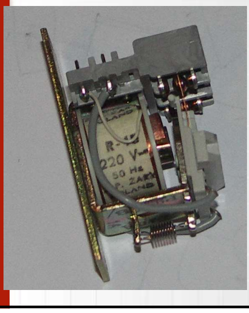
CO – centre off/change over
example
SPTT=SPCO

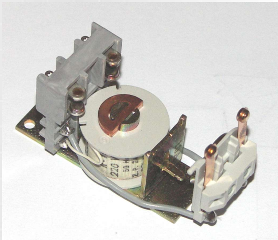
Relay



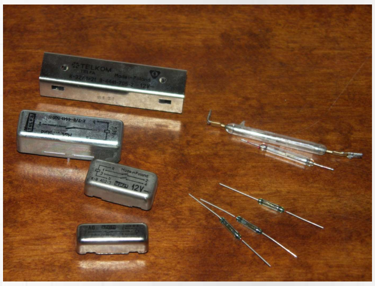
Relays

AC relay





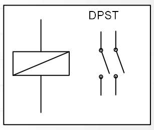
reed relay

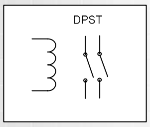


Relays - types

- Regular
- Latching (bistable)
- Polarized relay
- Reed relay
  - (mercury wetted)
- Contactor
- Solid state relay
  - transistor
  - triac
  - Thyristor
- Other (safety switches, over current,……)

Relay - diagram symbol





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Ohm's low for inductance

$$U_L = L\frac{dI}{dt}$$

$$U_L = X_L I_L = \frac{1}{i\omega C} I_L$$

TIPS:
•higher voltage applied – faster changes of current
•fast changes in current – higher voltage induced
•when current change „slope direction" – voltage change polarity:
    •positive voltage applied – current increased
    •current decreased – negative voltage induced

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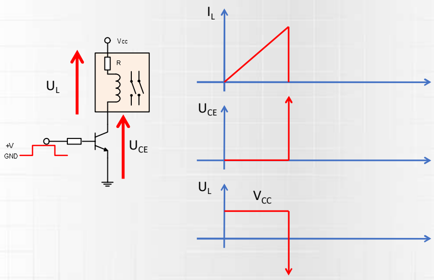
Switching on and off an inductor



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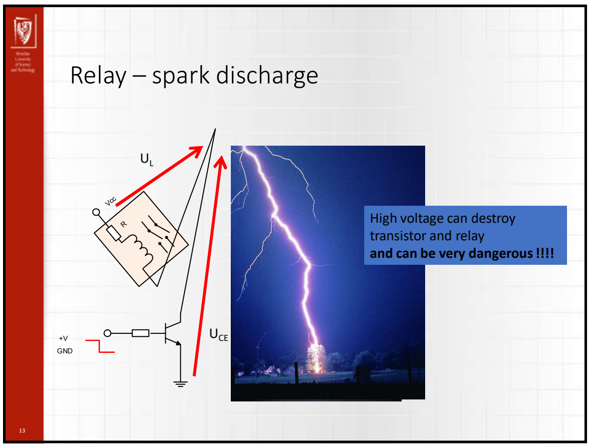
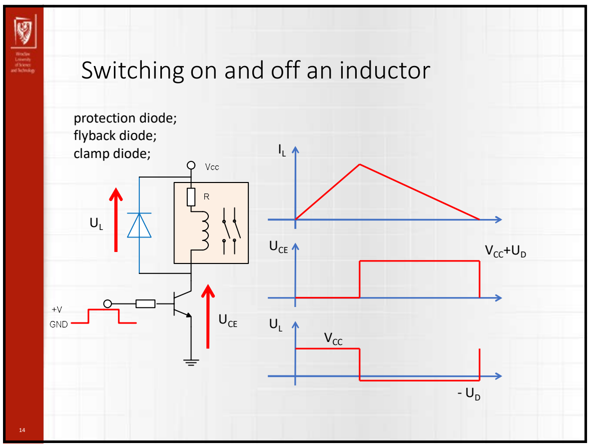
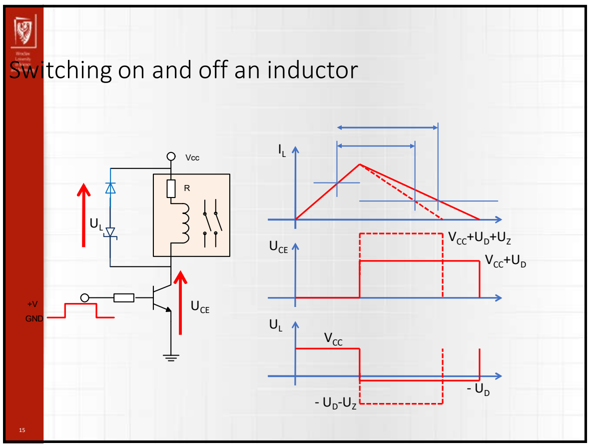
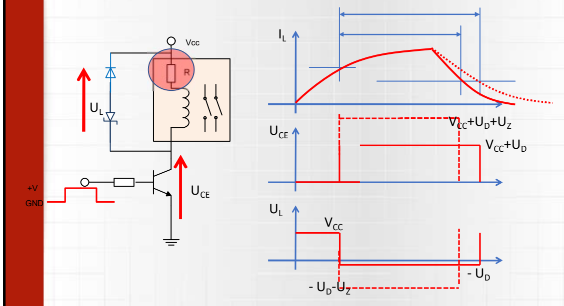

Relay – spark discharge
U_L
Vcc
R
+V
GND
U_CE
High voltage can destroy transistor and relay
and can be very dangerous !!!!


Switching on and off an inductor
protection diode;
flyback diode;
clamp diode;
Vcc
R
U_L
+V
GND
U_CE
I_L
U_CE
V_CC+U_D
U_L
V_CC
- U_D

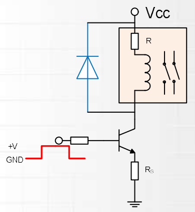

Switching on and off an inductor
Vcc
R
U_L
+V
GND
U_CE
I_L
U_CE
V_CC+U_D+U_Z
V_CC+U_D
U_L
V_CC
- U_D-U_Z
- U_D

Switching on and off an inductor

- series resistor influance

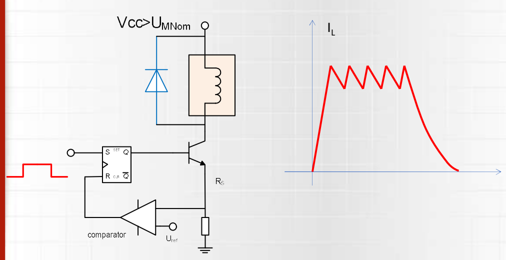


Decreasing rise time (off to on time)

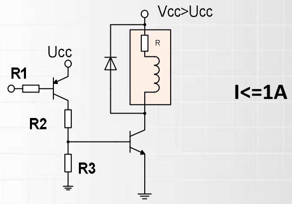


1. **Increase Vcc**
2. **add Rs to preserve Imax**
3. **result=> higher power dissipation**

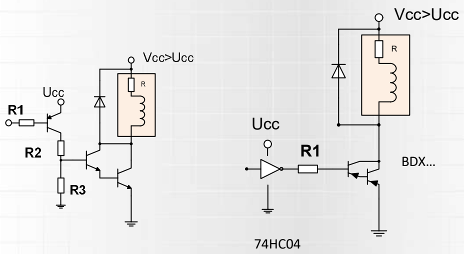
Decreasing rise time with current limit



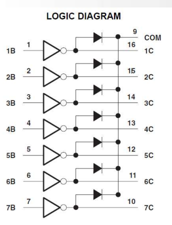
Driving relays and motors

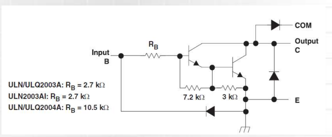


Driving relays and motors



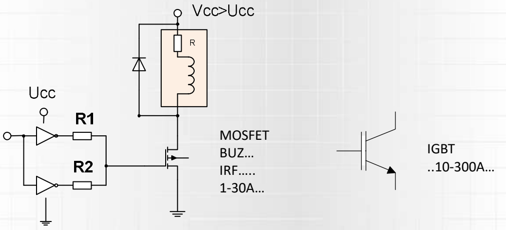
Darlington array ULN2004





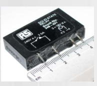
http://focus.ti.com/lit/ds/symlink/uln2004a.pdf

Driving relay/motor with MOSFET and IGBT



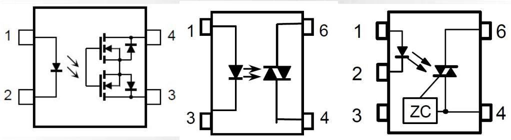
Sterowanie NPN, PNP

Solid State Relays (SSR)
Solid State Contactor (SSC)



SSR of different types

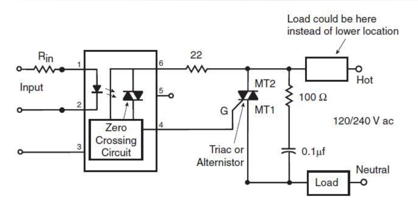
can be used for AC driven mechanical relays



•Usually small power but can drive any type of load (including induction)
•AC and DC applications

•Be carfull with inductive load – the load can be not switched off !!!
•AC applications only

High power SSR



BT136 data

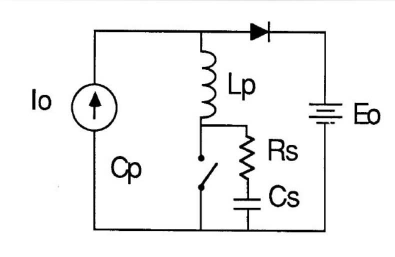
Absolute maximum ratings

Parameter	Symbol	Value	Unit	Test condition
peak repetitive off-stage voltage	V_{DRM}, V_{RRM}	600	V	
on-state RMS current	I_T(RMS)	4	A	TL≤66°C
NON repetitive surge peak on-state current	I_{TSM}	25	A	Tp=20ms, Tj=25 °C
critical rate of rise on-state current	dI/dt (Q_{1-3})	50	A/µs	I_{TM}=20A, T_G=0.2A
peak gate current	I_{GM}	2	A	
average gate power dissipation	P_G(AV)	0.5	W	
storage temperature range	Tstg	-40 to +150	°C	
operating junction temperature range	Tj	125	°C	

Electrical characteristics (Tj=25°C) unless otherwise specified

Parameter	Symbol	Value	Unit	Test condition
gate trigger current	I_{GT}	≤10	mA	T2+G+ V_D=12V, I_T=0.1A
		≤10	mA	T2+G- V_D=12V, I_T=0.1A
		≤10	mA	T2-G- V_D=12V, I_T=0.1A
		≤25	mA	T2-G+ V_D=12V, I_T=0.1A
gate trigger voltage	V_{GT}	≤1.5	V	V_D=12V, I_T=0.1A
hold current	I_H	≤30	mA	V_D=12V, I_T=0.1A
critical rate of rise off-state voltage	dv/dt	≥50	V/µs	V_D=67%V_{DRM}
on-state voltage	V_{TM}	≤1.7	V	I_T=5A
off-state leakage current	I_{DRM}	≤0.5	mA	V_D=V_{DRM}; Tj=125°C
thermal resistance	Rth(j-a)	60	°C/W	
	Rth(j-c)	≤3.7		

RC snubber



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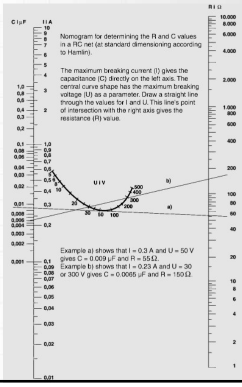
RC snubber



<30V – other load
>30V – over contacts

Protection elements:
- capacitive load
  - chock
  - NTC,
  - PTC(in series)
- induction load
  - surge arrester
  - varistor
  - transil

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Motors

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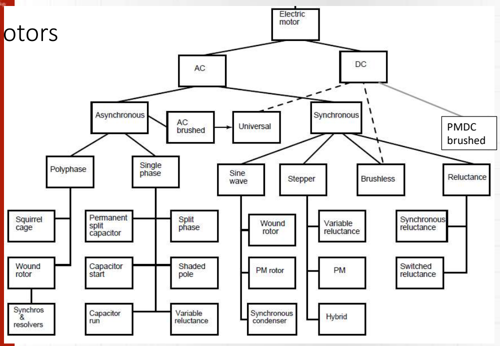
Motors



Electric motors

- AC motors
  - squirrel cage (3 phase, 1 phase -shade pole, cpacitor, split phase)
  - synchronous
- DC motors
  - Permanent magnet DC
  - Universal motors
    - series
    - shunt
    - compound wound
- BrushLess DC (BLDC)
  - 2 phase
  - 3 phase
- Stepper motors
  - reluctance
  - permanent magnet
  - hybrid
- Linear (Voice Coil Motor – VCM)

Type	Advantages	Disadvantages	Typical Application	Typical Drive
AC Induction (Shaded Pole)	Least expensive Long life lowpower	Rotation slips from frequency Low starting torque	Fans	difficult tocontrol
AC Induction (split-phase capacitor)	Medium power high starting torque	Rotation slips from frequency	Appliances Stationary Power Tools	Uni/Poly-phase AC
AC Squirrel cage 3ph	High power	Rotation slips from frequency	Industry/ hp.mashines	Inverter frequency Vector controll (fr/current)
Brushed DC	Low initial cost Simple speed control	Maintenance (brushes) Medium lifespan	Treadmill exercisers automotive motors (seats, blowers, windows)	Direct DC or PWM
BL DC	Long lifespan low maintenance High efficiency	High initial cost Requires a controller	Hard drives CD/DVD players electric vehicles	DC switching, Pwm
Universal motor	High starting torque, compact, high speed	Maintenance (brushes) Medium lifespan	Portable tools Grid powered	Uni-phase AC or Direct DC
Stepper DC 1ph/2ph	Precision positioning High holding torque	High initial cost Requires a controller	Positioning in printers and floppy drives	DC switching
AC Synchronous	Rotation in-sync with freq - hence no slip long-life	More expensive	Industrial motors Clocks Audio turntables tape drives	Uni/Poly-phase AC

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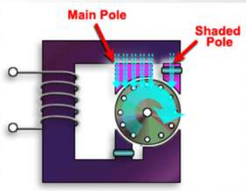
Shaded pole induction motor



advantages
- •Very cheap and reliable
- •Extremely rugged in nature
- •Easy to construct

disadvantages
- •Low starting torque
- •Low efficiency

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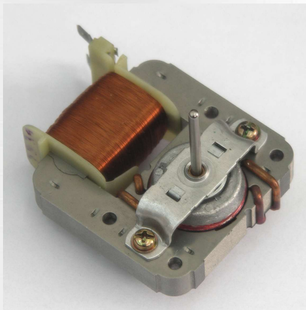
Shaded pole induction motor



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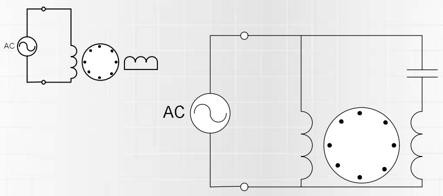
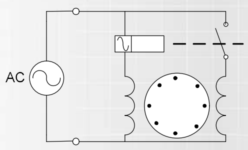
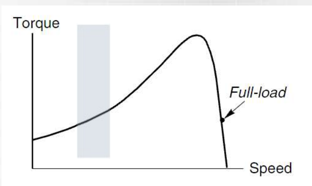
Capacitor Run
Permanent Split Capacitor(PSD Motor)



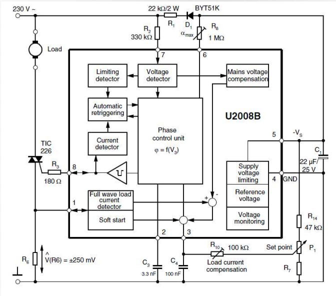
Split Phase Induction Motor



Induction Motor control by means of slip control



Induction Motor control by means of slip control



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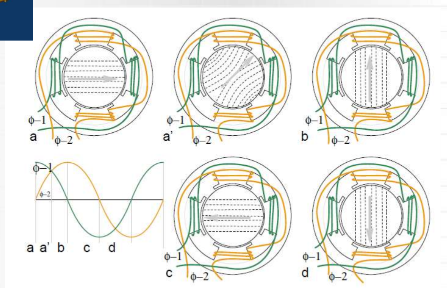
Squirrel cage



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Squirrel cage – drivig inverter

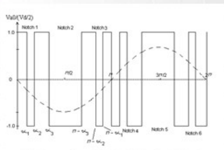

Fig 2 Programmed Harmonic Elimination of Fifth and Seventh Harmonics

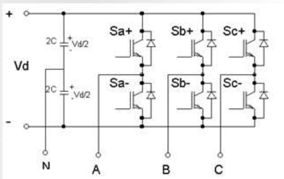

Fig 1 A Three Phase Inverter Circuit

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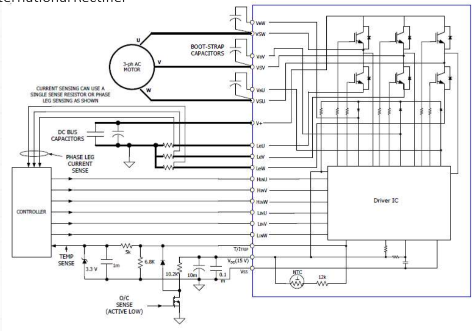
Inverter

IRAMS10UP60A
by International Rectifier



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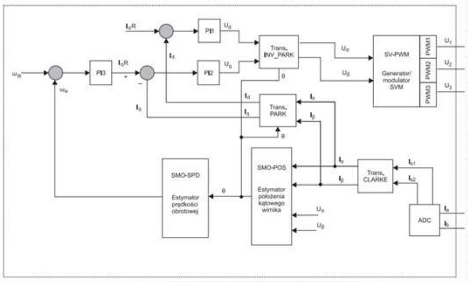

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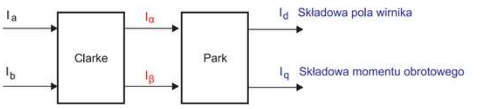

$I_\alpha = I_a$
$I_\beta = 0{,}577\,(I_a + 2I_b)$

$I_d = I_\alpha \cos\Theta + I_\beta \sin\Theta$
$I_q = I_\alpha \cos\Theta + I_\beta \sin\Theta$

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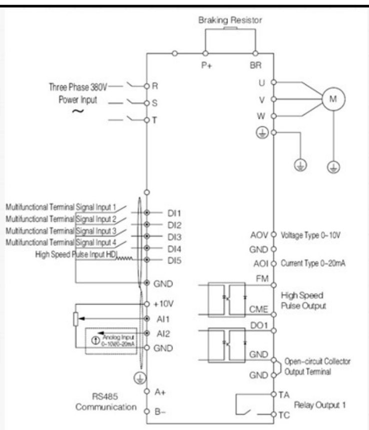
Braking resistor

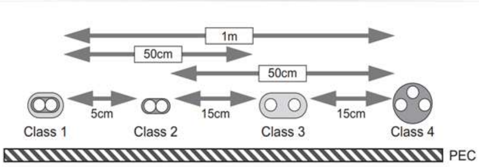
$$J = J_{Motor} + J_{Load}$$ inertial momentum

$$P_B = \frac{J\omega_B(\omega_B - \omega_0)}{t}$$ Braking power

$$R = \frac{V_{DC}^2}{P_B}$$ Resistor

$$P_{Res} = 1.30 * (P_B - P_{Inv})$$ Resistor power





The cables from adjustable **speed inverter** drives to their motors may be specified by the drive manufacturers to have 600mm or more spacing from any other parallel run of cable (**drives are perhaps the noisiest devices on the planet!).**

Figure from: Tim Williams, „EMC for Product Designers", Fifth edition, Elsevier, 2017

Class 4 Noisy: AC power and return, chassis ground, high-power RF and wideband signals; power inputs, outputs and DC links of adjustable speed motor drives, welding equipment, and similar electrically noisy equipment

Class 3 Slightly Noisy: DC power, suppressed switched loads, filtered AC; externally supplied low-voltage AC or DC power which does not also supply other noisy equipment, contactor and solenoid coil circuits

Class 2 Slightly Sensitive: low-power low frequency signals, low bit rate digital data; analogue instrumentation (e.g. 4–20 mA, 0–10V) and slow digital bus communications (e.g. RS232, RS422, RS485, Centronics); switched I/O such as limit switches, encoders, and the outputs of internal DC power supplies

Class 1 Sensitive: low-level analogue signals such as thermocouples, thermistors, RTDs, strain gauges, load cells, microphones; also wideband digital and analogue communications such as Ethernet, video, RF receiver inputs; and all other signals with full-scale range less than 1V or 1mA, or with a source impedance > 1kΩ, or signal frequency > 1MHz

Figure from: Tim Williams, „EMC for Product Designers", 5th edition, Elsevier, 2017

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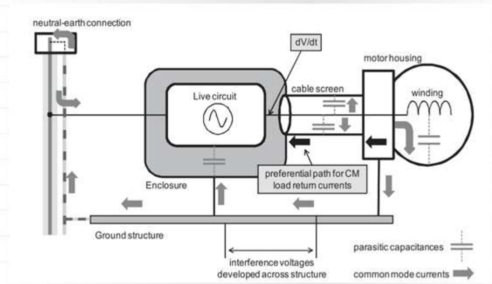

Parasitic common mode paths from a VSD

Figure from: Tim Williams, „EMC for Product Designers", Fifth edition, Elsevier, 2017

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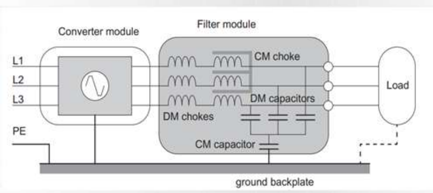

Filtering a VSD output

Figure from: Tim Williams, „EMC for Product Designers", Fifth edition, Elsevier, 2017

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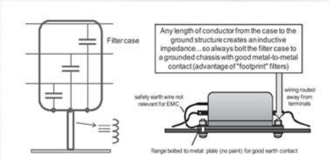
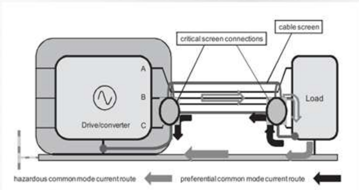


Grounding of CM filters

Figure from: Tim Williams, „EMC for Product Designers”, Fifth edition, Elsevier, 2017



Converter-to-load cabling

Figure from: Tim Williams, „EMC for Product Designers”, Fifth edition, Elsevier, 2017

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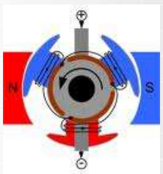
DC motors

PMDC – Permanent Magnet DC

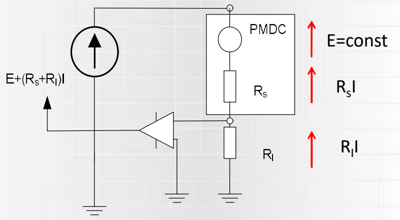


High starting torque,
compact,
high speed,
easy to controll,
cheap

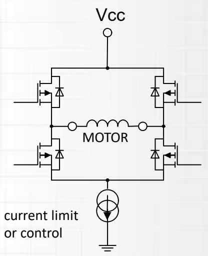
Maintenance (brushes)
Medium lifetime,
Noisy
EMI emission

DC motors

PMDC – Permanent Magnet DC - control circuit

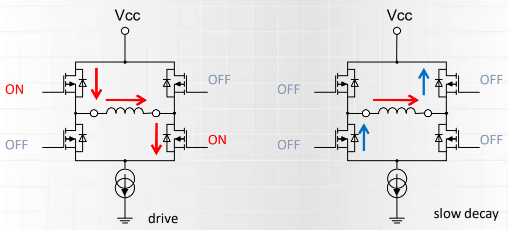


Direction controll - H bridge

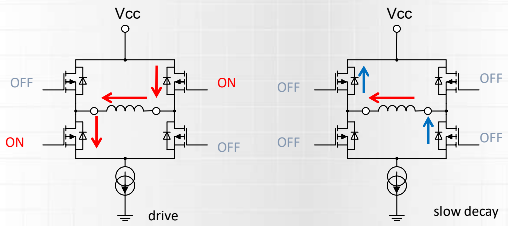


TIPS:
BJT, MOSFET, IGBT transistors can be used,
diodes cunduct self inductance currents

H bridge operation 1

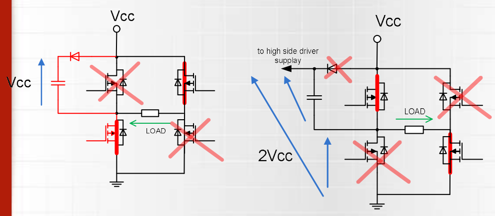


H bridge operation 2



61

Bootstrapping



62

DC motors

PMDC – Permanent Magnet DC -ironless (coil and disc) -pancake

TIP:
very little momentum – fast start

http://www.designworldonline.com/ArticleDetails.aspx?id=1973

http://www.kurz-motor.de/eproduktefametextgleichstromscheibenlaeufer.htm

63

Type	Advantages	Disadvantages	Typical Application	Typical Drive
AC Induction (Shaded Pole) (31)	Least expensive Long life lowpower	Rotation slips from frequency Low starting torque	Fans	difficult tocontrol
AC Induction (split-phase capacitor) (34)	Medium power high starting torque	Rotation slips from frequency	Appliances Stationary Power Tools	Uni/Poly-phase AC
AC Squirrel cage 3ph (40)	High power	Rotation slips from frequency	Industry/ hp.mashines	Inverter frequency Vector controll (fr/current)
Brushed DC (41)	Low initial cost Simple speed control	Maintenance (brushes) Medium lifespan	Treadmill exercisers automotive motors (seats, blowers, windows)	Direct DC or PWM
BL DC (49)	Long lifespan low maintenance High efficiency	High initial cost Requires a controller	Hard drives CD/DVD players electric vehicles	DC switching, Pwm
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Stepper DC 1ph/2ph (66)	Precision positioning High holding torque	High initial cost Requires a controller	Positioning in printers and floppy drives	DC switching
AC Synchronous (82)	Rotation in-sync with freq - hence no slip long-life	More expensive	Industrial motors Clocks Audio turntables tape drives	Uni/Poly-phase AC

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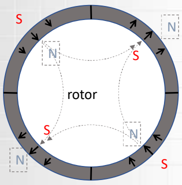
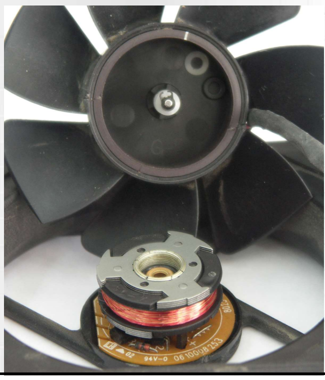
BLDC (BrushLess DC) motors



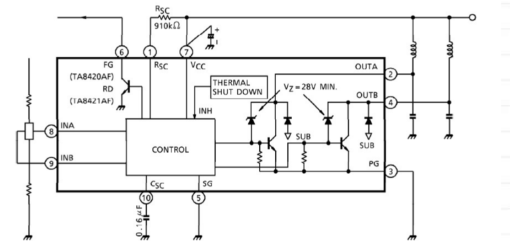
65

BLDC
1 phase

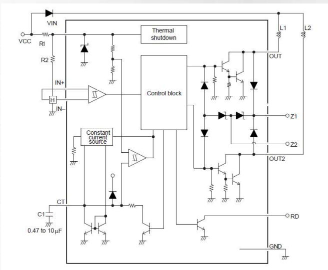


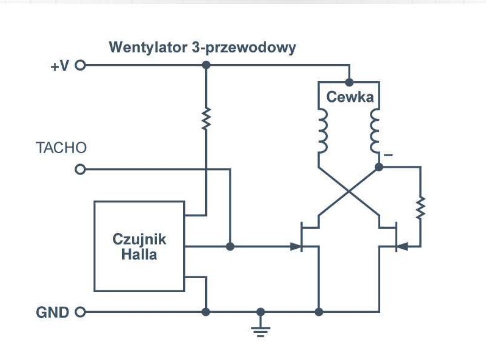
66

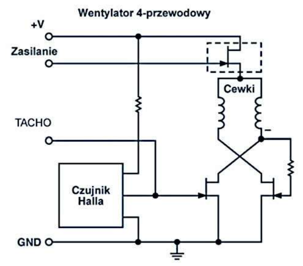
TA8420/21 BLDC 2 phase driver



LB1864 2 phase BLDC driver

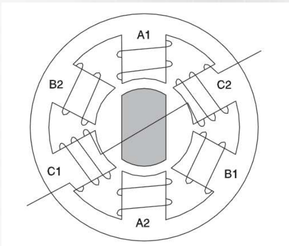






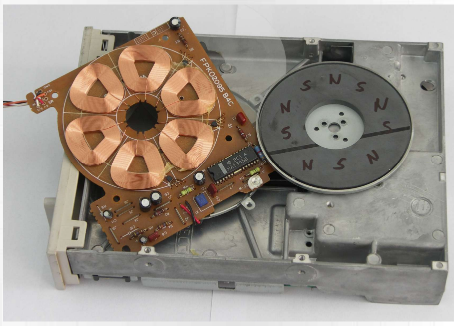
70

3 phase BLDC



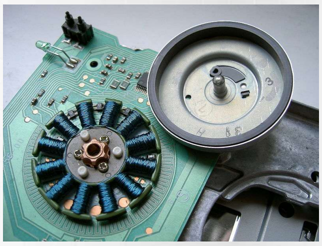
71

BLDC

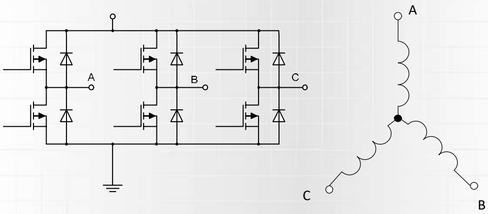


72

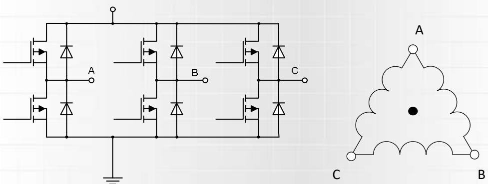
BLDC



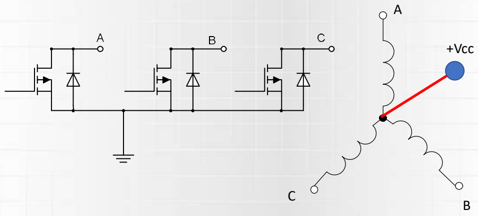
BLDC – bipolar driving - star



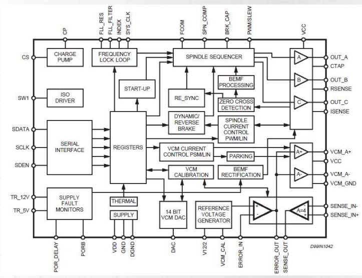
BLDC – bipolar driving - triangle



BLDC – unipolar driving - star



L6268 driver BLCD + VCM(voice-coil-motor) (ST)



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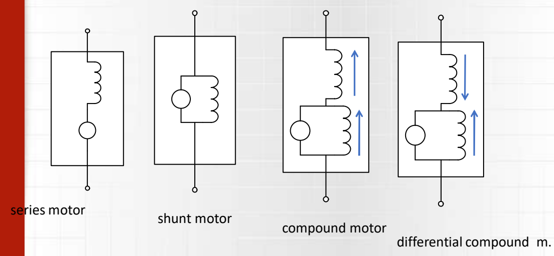
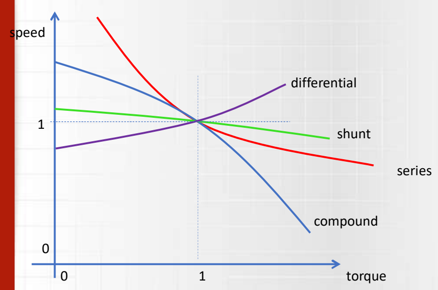
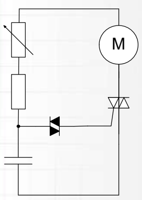
Permanent magnet replaced by electromagnet – universal motor



Torque vs. speed

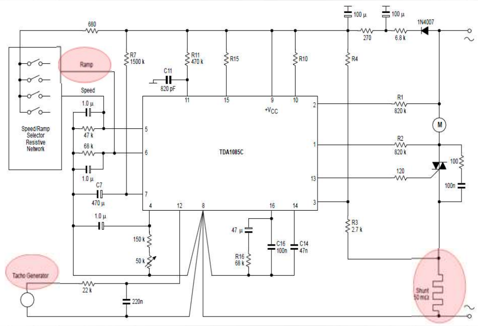


Universal motor – driver / controller



Tips:
1. voltage controlled
2. direction can be changed by switching stator or rotor winding
3. the example shown is the most simple

Universal motor – driver/controller more sophisticated example



From Motorola materials (now ON Semiconductor)

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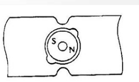
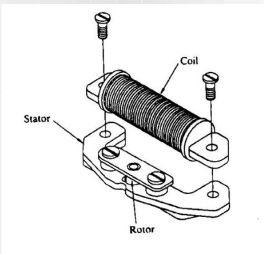
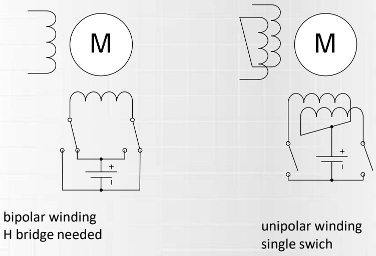


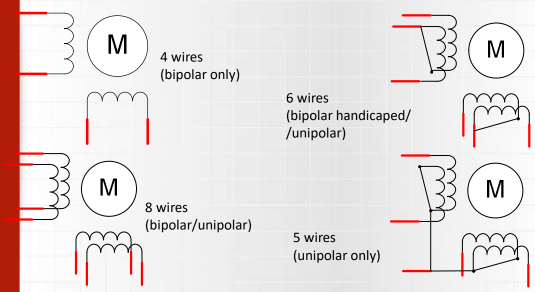
Silnik napędu zegarków (Quartz)



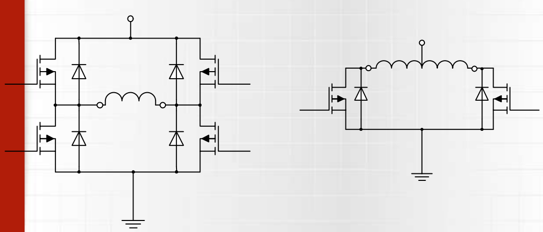
stepper motors- bi/uni-polar



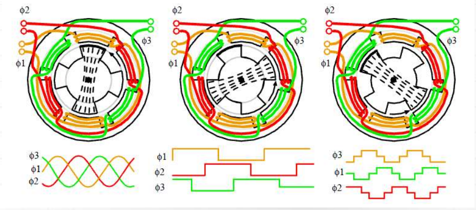
(2 phase) steppper motor internal conections



Unipolar/Bipolar stepper motor driving



Steppper motor – reluctance motor



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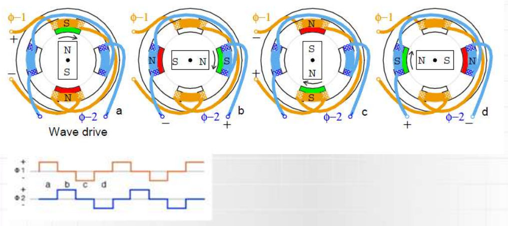
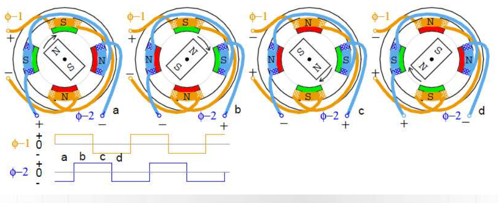
Permanent magnet motor
wave driving



lessons In Electric Circuits, Volume II – AC By Tony R. Kuphaldt, Sixth Edition, last update July 25, 2007

Permanent magnet motor
full step driving



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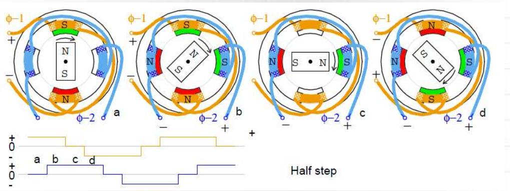
Permanent magnet motor half step driving



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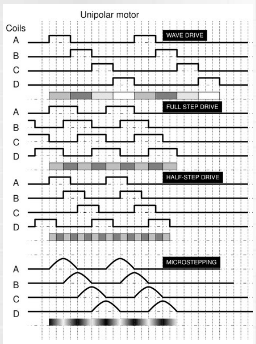
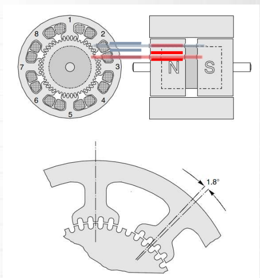
Full/microstep driving



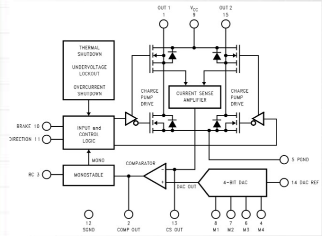
Hybrid motor

1,3,5,7 – phase A
2,4,6,8 – phase B

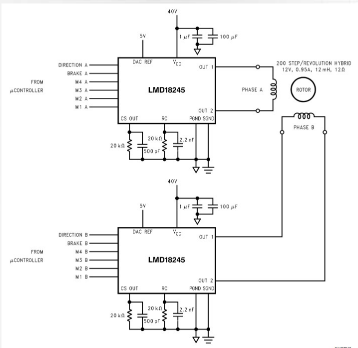


$$Step = \frac{360\deg}{N_{teeth} \cdot N_{phases}}$$

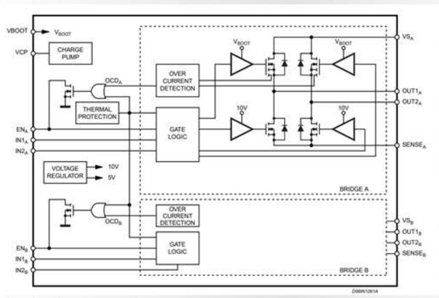
LMD18245 3A, 55V DMOS Full-Bridge Motor Driver – National Instrument

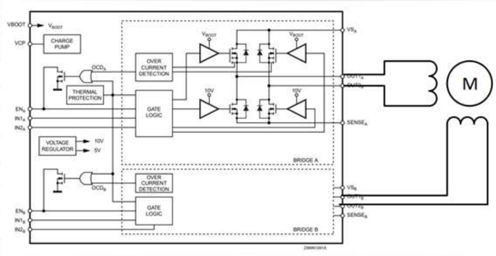


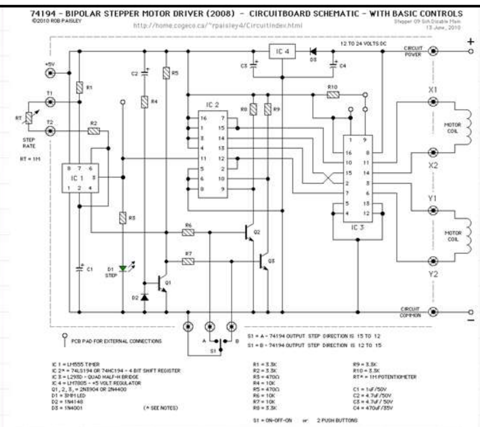
LMD18245 application



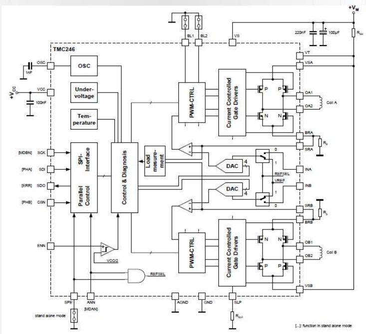
L6205



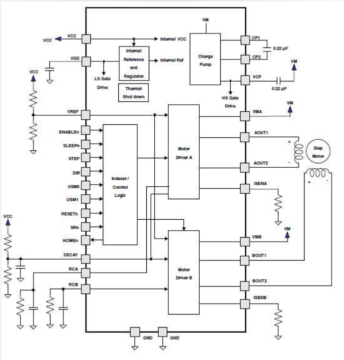

VBOOT
VCP
CHARGE PUMP
OVER CURRENT DETECTION
THERMAL PROTECTION
GATE LOGIC
VOLTAGE REGULATOR
10V
5V
BRIDGE A
OVER CURRENT DETECTION
GATE LOGIC
BRIDGE B
M


74194 - BIPOLAR STEPPER MOTOR DRIVER (2008) - CIRCUITBOARD SCHEMATIC - WITH BASIC CONTROLS
12 TO 24 VOLTS DC
IC 4
IC 2
IC 1
IC 3
MOTOR COIL
MOTOR COIL
X1
X2
Y1
Y2

TMC246


TMC246
OSC
Under-voltage
Tem-perature
SPI-Interface
Parallel Control
Control & Diagnosis
PWM-CTRL
Current Controlled Gate Drivers
DAC
DAC
PWM-CTRL
Current Controlled Gate Drivers

DRV8811
TI



100

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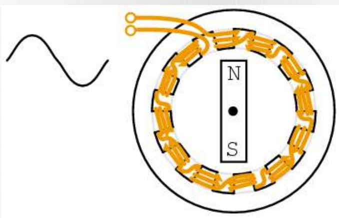
Synchronous motor



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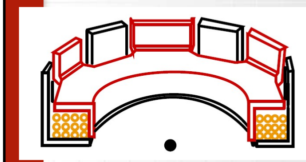
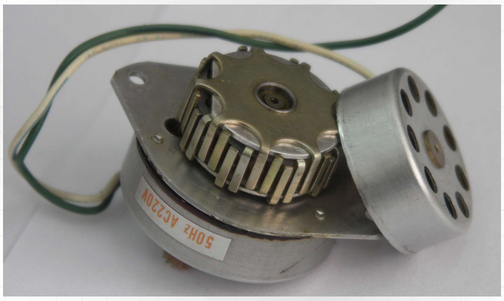
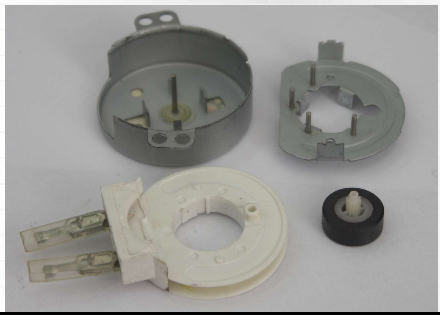
Multipole synchronous motor

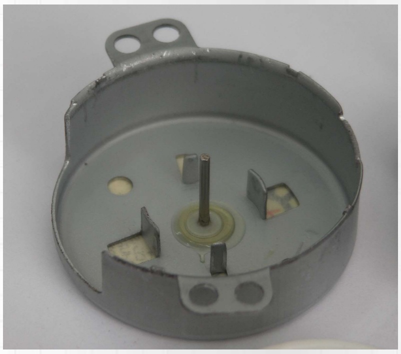


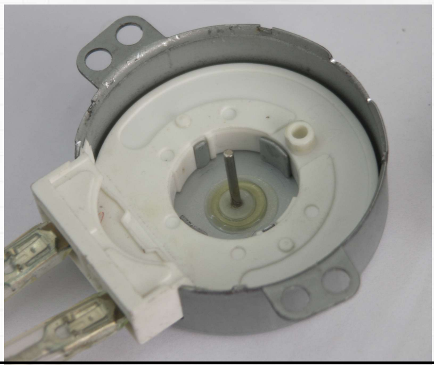
The inductionf or self starting and the bar magnet as synchronous motor

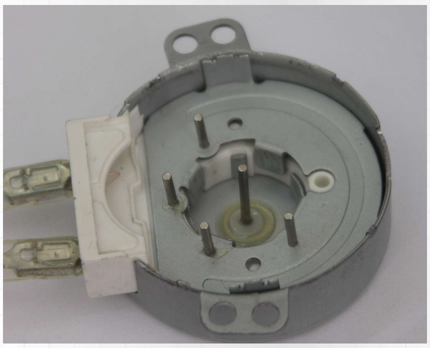


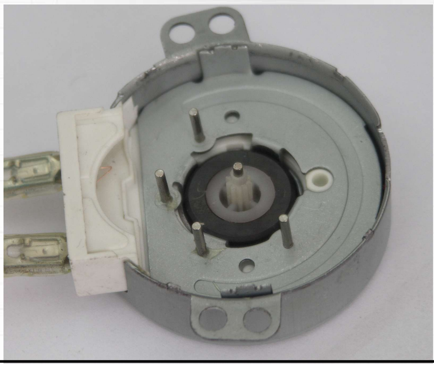
Synchronous motor







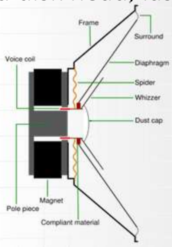




Synchronous motor
plat drive of microwave

VCM
Voice Coil Motor

VCM motors (actuators)
(hard disk head, laser positioner in CD)



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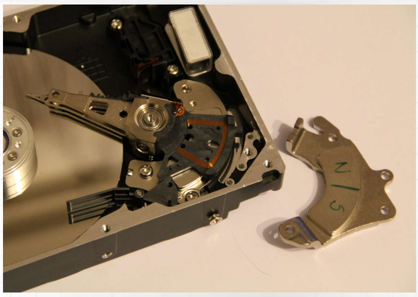
Linear motor



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Summary

- Electromechanical relays
- SSR
- AC motors
  - squirrel cage (3 phase, shade pole, capacitor, split phase)
  - synchronous
- DC motors
  - Permanent magnet DC
  - Universal motors
- Brushless DC (BLDC)
- Step motors
- Linear (Voice Coil Motor – VCM)

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Test questions example:

- What are the basic types of relays ?
- What is the role of a protection (flyback) diode in an electromechanical relay control circuit??
- Compare types of motors there basic features and way of control them:
  - AC Induction (Shaded Pole),
  - AC Induction (split-phase capacitor/inductor),
  - AC Squirrel cage(3 phase),
  - Brushed DC
  - Brushless DC
  - Universal motor,
  - Stepper motor,
  - AC Synchronous motor.

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