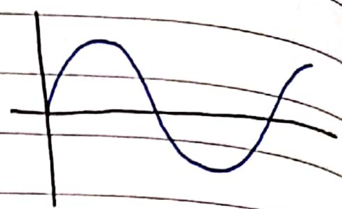
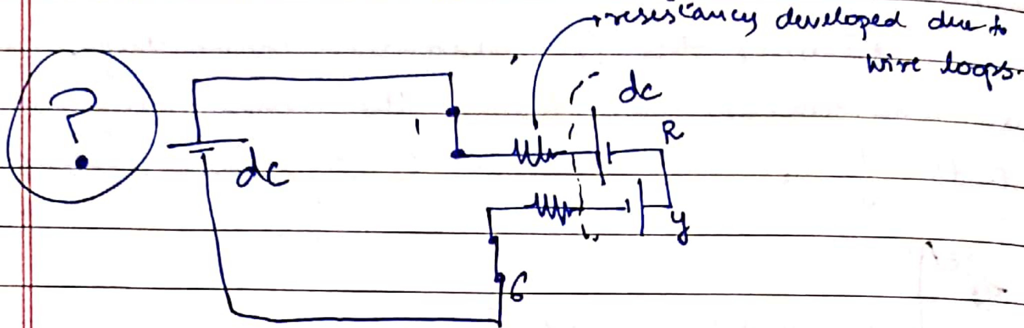
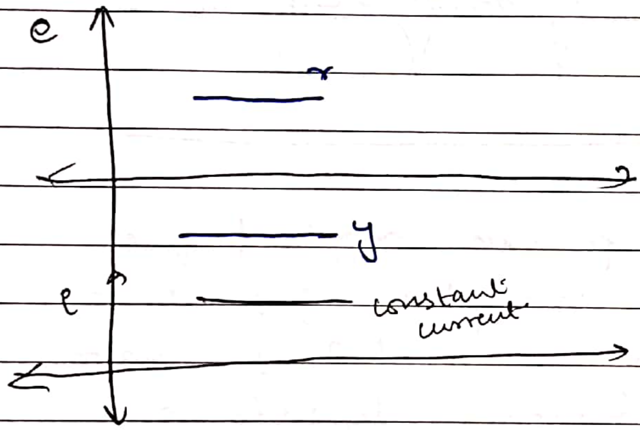
Permanent Magnet Synchronous Machines (PMSM)

- Sinusoidal EMF



BLDC 1, 6 are ON

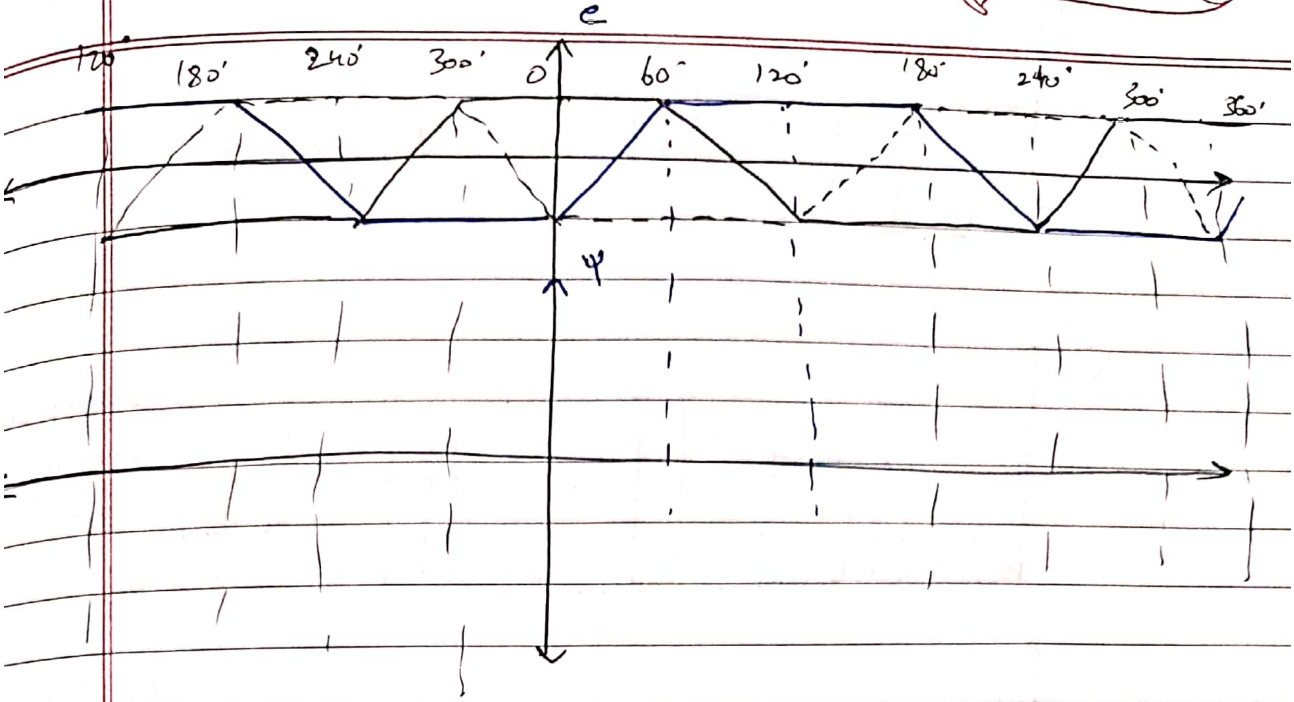



→ During any the interval, when any two switches are ON ⇒ Eq circuit can be represented as by a DC circuit.

$$e = \frac{d\psi}{dt} = \frac{d\psi}{d\theta}\frac{d\theta}{dt}$$

$\psi \rightarrow$ unique function of $\theta$




→ Ripple Torque
→ Need rotor angle info once in 60°

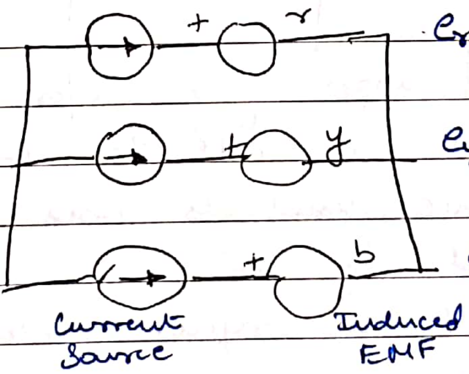
## PMSM :

→ EMF is sinusoidal
→ Sinusoidal flow of current into the motor
→ Inverter should be operated under sinusoidal PWM (or SPWM)

$i_r = I\cos(\omega t+\phi)$ $\qquad e_r = E\cos\omega t$

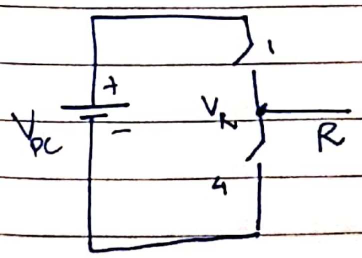
$i_y = I\cos(\omega t+\phi-120°)$ $\qquad e_y = E\cos(\omega t-120°)$

$i_b = I\cos(\omega t+\phi-240°)$ $\qquad e_b = E\cos(\omega t-240°)$




$P = e_r i_r + e_y i_y + e_b i_b = \text{const}$ (Active power flow)

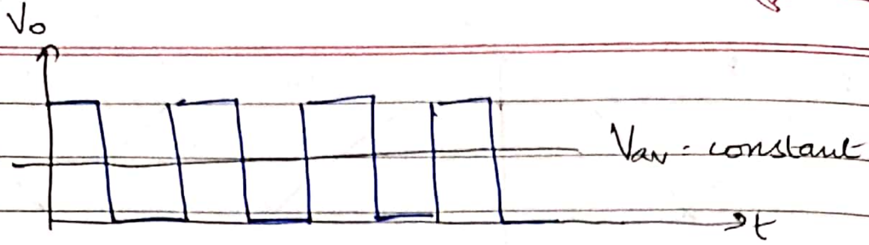
⇒ All 3 phases should be energized all the time.

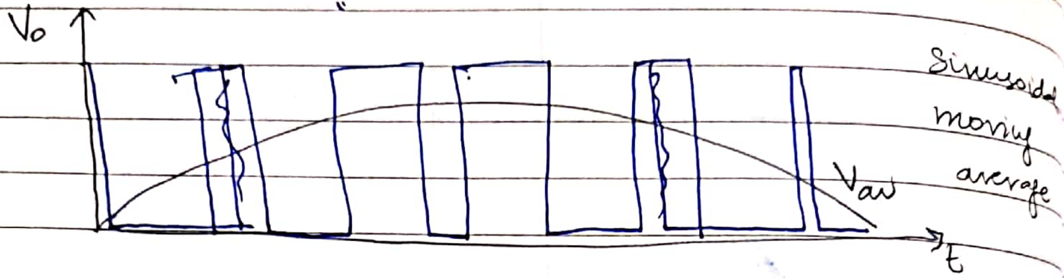


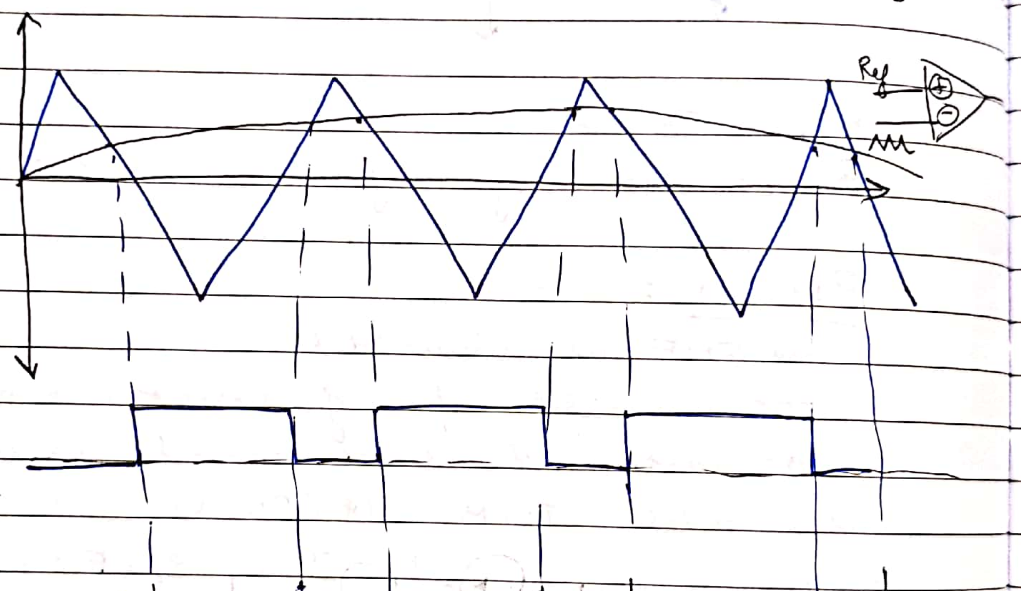

1 ON, 4 OFF ⇒ $V_R = V_{DC}$

1 OFF, 4 ON ⇒ $V_R = 0$

(We need $V_R$ well-defined hence exactly one of 1 & 4 is ON)




→ used for upper leg of inverter

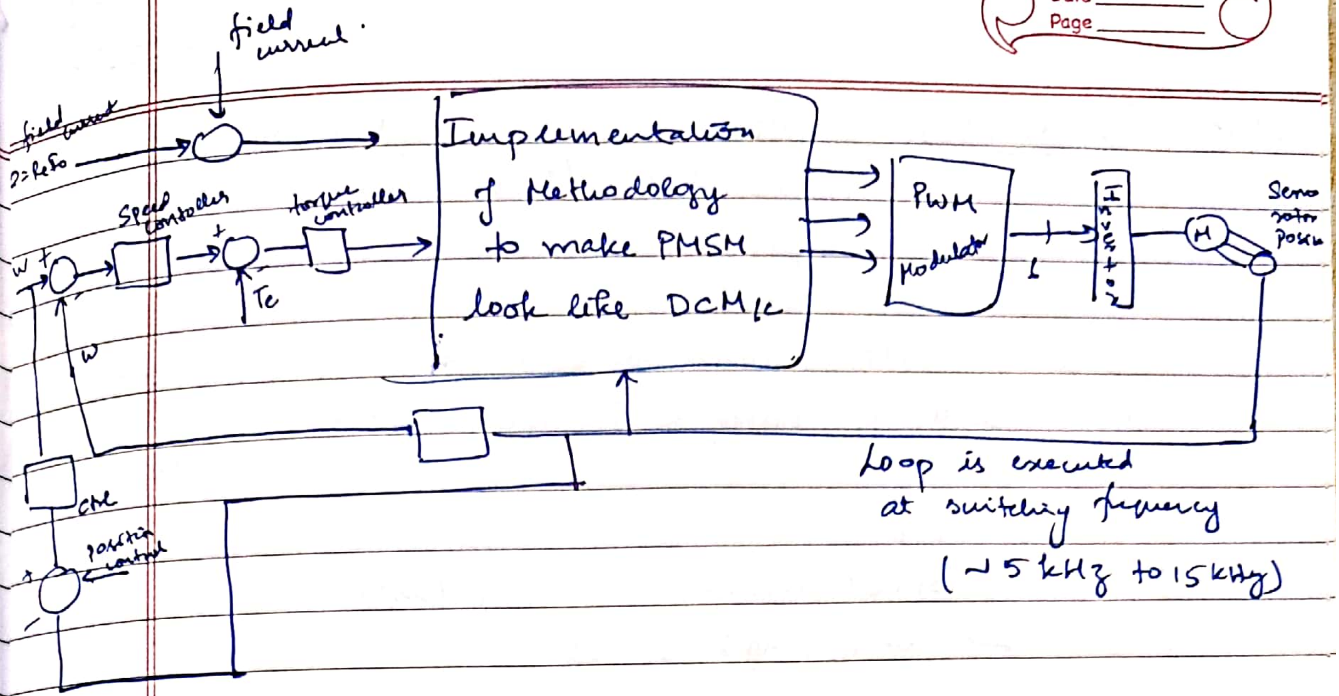
Compliment is used for lower.

→ The reference sinusoids used for R, Y & B phases are shifted by 120°

→ For PMSM, we require continuous rotor angle info, hence we use a rotor position sensor.

MOSFET → 100kHz

MOSFET, IGBT } Silicon →




Loop is executed at switching frequency (~5 kHz to 15 kHz)

## DC Machines

Advantages: (i) Simple to operate
(ii) Just connect R to armature circuit
(iii) Closed loop control is easy

Disadvantages: (i) Brush + Commutator
(ii) Larger size
(iii) Maintanence
(iv) Anciry ?

## BLDC

Adv: (i) Brushless, hence
(ii) no disadvantages of brushed DCM
(ii) Smaller size

Disadv: (i) AC machine, hence inverter is reqd
(ii) Ripple torque
(iii) Not for high performance/precision
(iv) Expensive (magnets)

## PMSM

Adv: (i) "Smooth Torque"
(ii) Hence suitable for high precision
(iii) Smaller in size

Disadv: (i) Complex control structure required
(ii) Expensive (magnets)

11/2/20

# Induction Motor. [Most robust]

- Wound field / Rotor motor → no magnet
- Squirrel cage motor

Size: PMAC machine < Inductor < DC motor.

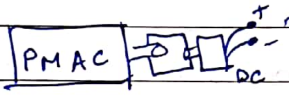
Cost : Induction motor < DC motor < PMAC machines (BLDC / PMSM)

for feedback,

→ Speed sensor
→ rotor angle sensor } Motor

## ☆ Speed

→ Tachogenerator ⇒ AC/DC




→ speed as $e = k\omega$

or AC tacho


ac induced emf amplitude & frequency are speed dependent

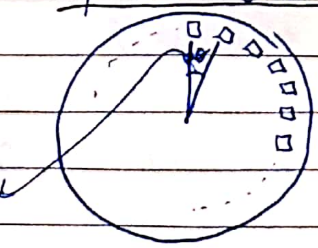
and sequence of R, Y, B will tell direction of rotation.

→ Rotor angle $\frac{d\theta}{dt} = \omega \Rightarrow \theta = \int \omega dt + c$

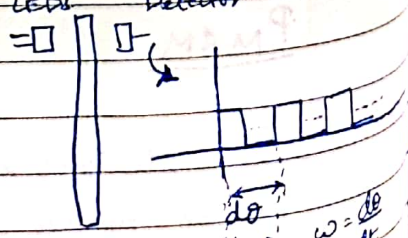
Encoder → incremental encoder ⇒ incremental angle
absolute encoder ⇒ absolute position

### Optical Encoder

(affected by environment)




LEDs Detector



$d\theta$

$dt$

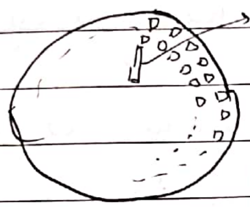
$\omega = \frac{d\theta}{dt}$

- Can be used as an incremental angle detection
- Speed, wait for a certain duration, count no. of edges

thus $\dfrac{\text{Total angle traversed}}{\text{duration of acquisition}} = \text{speed}$

Number of pulses per revolution (ppr) → ppr = 2500

For obtaining exact position, the encoder is made to undergo certain changes.

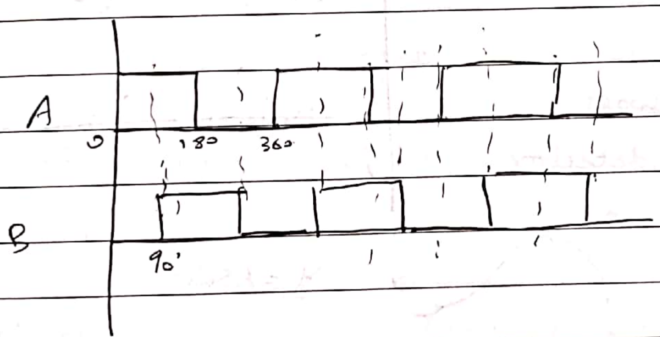


→ occurs once in every 360°

varied but sequential pulse

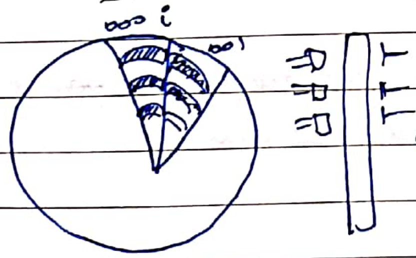
↳ index pulse.

· here: index pulse: one per revolution → angle 0°




| AB |
|---|
| 1 0 |
| 1 1 |
| 0 1 |
| 0 0 |

12/2/20 **Absolute Encoders**




Eg: for an 8 bit encoder,

positions available $= 2^8$.

angle width → $\dfrac{360°}{2^8}$

Eg: for a 3 bit encoder

0 0 0
0 0 1
0 1 1
⋮
1 1 1

When going from 1 state to the next state, It is best if only one code changes.

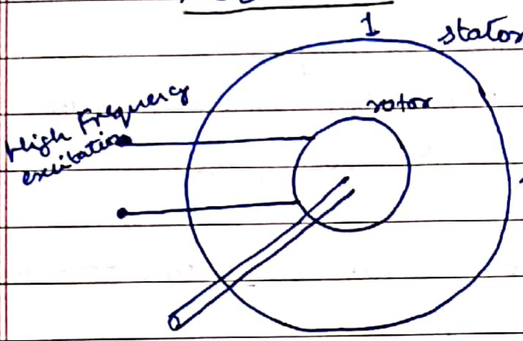
While manufacturing 011 → 100 here all three has to change and might not coincide due to manufacturing errors and that might lead to undesired state signals being generated inbetween target state signals.

Goal → Not more than 1 slot changes from one sector to another.

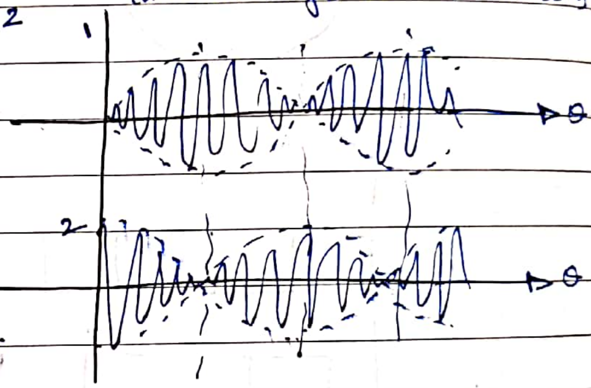
↳ 'Gray - Code'

## Resolver

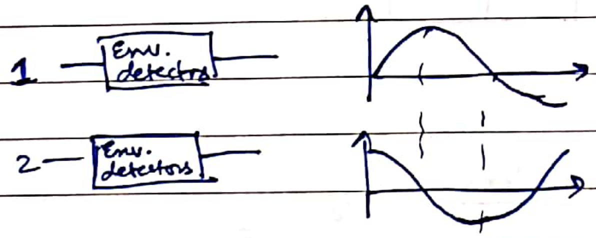
stator has two windings displaced by 90° (1 & 2)




induced emfs in 1 & 2 coils




these generated sinusoidal envelopes are sent to detectors.



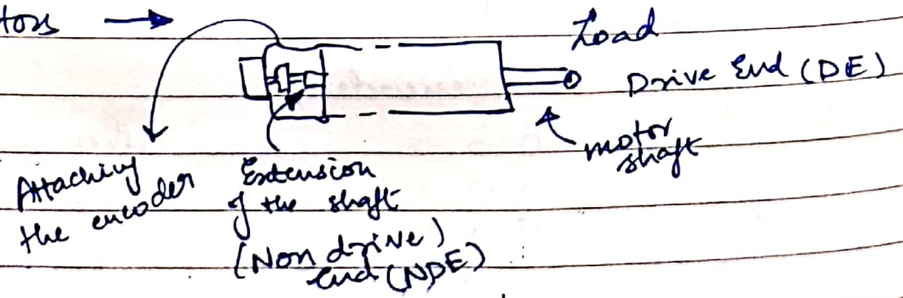

$y_1 = A\sin\theta$

$\theta = \tan^{-1}(y_1/y_2)$

$y_2 = A\cos\theta$

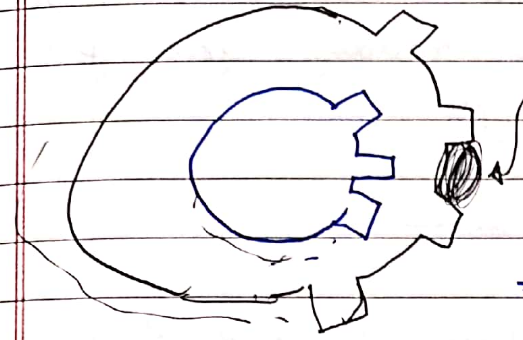
thereby, from the feedback, 'θ' / ~~posn~~ orientation can be calculated.

Motors →

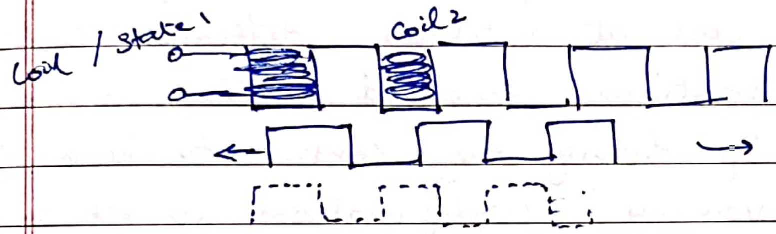


# Stepper Motor

↳ Moves in well-defined steps.




Magnetic circuit / flux path will realign in such a way that inductance becomes maximum.
⇒ air gap is minimum

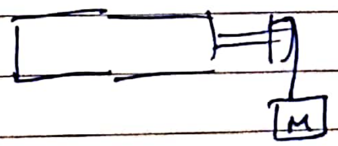



The gaps are uneven. Therefore → energizing coil 1, it will lock to that arrangement but that results in the next one (along coil 2) to be misaligned. Now, energizing coil 2 and not coil 1, makes it go to the next configuration.

The rotor does not have any coils, and is generally made of iron / iron + magnet.

Now, that it gets fixed to specific orientations, it gives enough stall torque (Holding torque) at any fixed orientation, and as the movement is well defined, it does not require position sensing.

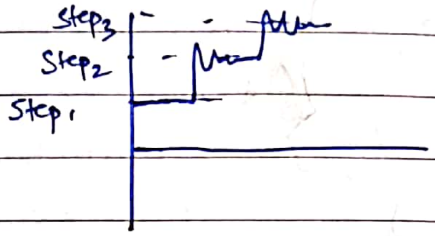
For instance,




using any other type of actuator would require a control system and feedback. But,
A stepper instructed to go to a certain configuration does the job, provided it is strong enough to hold it.

disadvantages →

- There should be no slip
- A rotor ~~to~~ going from one step to another might develop some momen and thereby osilates mildly before going to the step.




Therefore, instead of exciting only one coil at a time, different coils could be partially excited (called microsteppi and , by having the control to hold the rotor at various configurations in between, we can make the transition between steps very smooth (but must be done slow to prevent slipping).

- Restricted to low torque, low p
<1

X — X — X — X — X