EPFL

# Introduction to the Design of Space Mechanisms

Theme 6 part 3:

Components

Actuators, …

© NASA

Gilles Feusier

# Motors and Actuators

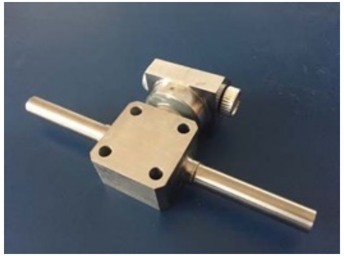
- Actuator: component transforming energy into a driving force in order to generate a movement (energy ⇒ work).
  - Rotary motors
    - Slow or rapid continuous rotation (antennae, solar arrays, …)
    - Positioning (detectors, telescopes, antennae, …)
    - Robotics (positioning, gripping, sampling …)
  - Linear motors
    - Deployment (antennae …)
    - Robotics
    - Breaking, damping (solar array deployment, locking …)
    - Clamping devices (stiffening of mobile elements during launch phase, launch locks, …)

# Motors and Actuators: Force generation (active components)

- Electromagnetic
  - Stepper motor, torque motor, brushless motor
    - Often combined with a gear reducer
    - Complex control electronic
    - High reliability
    - Widely used in space mechanisms
  - Brushed motors
    - Many issues in vacuum (contact wear) or in sealed, pressurized housing
    - Useful for ground support equipment (laboratory testing …)
    - Simple control electronic
  - Reluctance actuators
    - For simple safety applications (brake, locking finger …)
    - Low cost, high speed applications
    - May cause reliability issues
  - Brushless linear actuator
    - Limited use in space: high mass for high force, free in case of power failure, complex control electronic
    - Voice coil actuator widely used in space, however position control maybe complex (stability)

# Motors and Actuators: Force generation (active components)

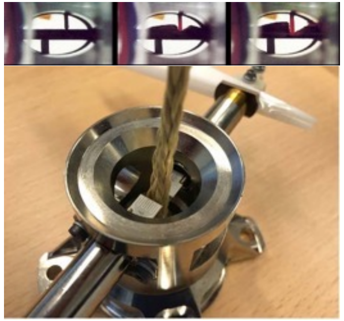
- Other principles
  - Paraffin actuators
  - Shape memory alloys (SMA) actuators
  - Piezo-electric actuators
  - Electrostatic actuators
  - Pyro-actuators
  - Thermal cutters and knifes
  - Hydraulic actuators (limited us in space: leakage, high pressure)



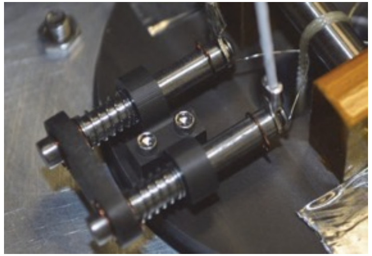
Pyro-valve

Dassault pyro initiator

Arquimea pin-puller
(reusable – manually resettable)



Thermal knife



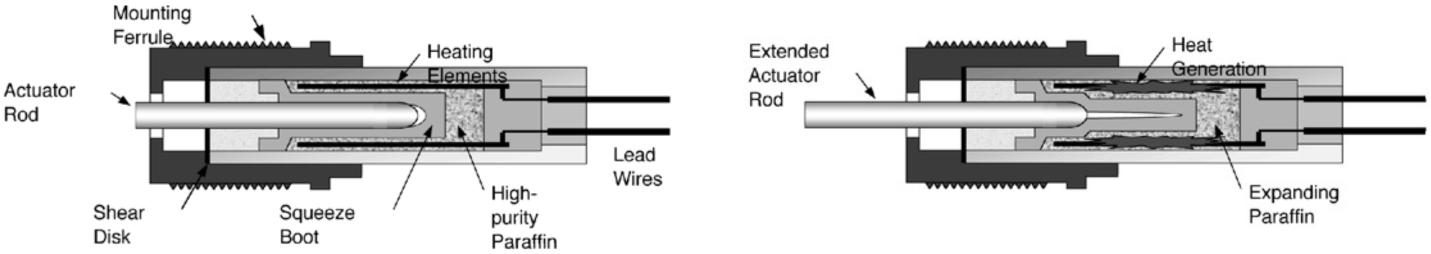
Source: A. Thurn et al., 41st Aerospace Mechanisms Symposium, 2012

Source: ECSS-E-HB-20-21A - Guidelines for electrical design and interface requirements for actuators

# Paraffin actuator

Source: Sierra Nevada Corporation


Source: Sierra Nevada Corporation




Source: Starsys/J. F. Cuttino et al. Journal of Engineering Design, 11:1, 31-53, DOI: 10.1080/095448200261171

# Motors and Actuators: Force generation (passive components)

- **Springs**: helical torsion spring, spiral torsion spring, leaf spring, torsion bar, membrane …

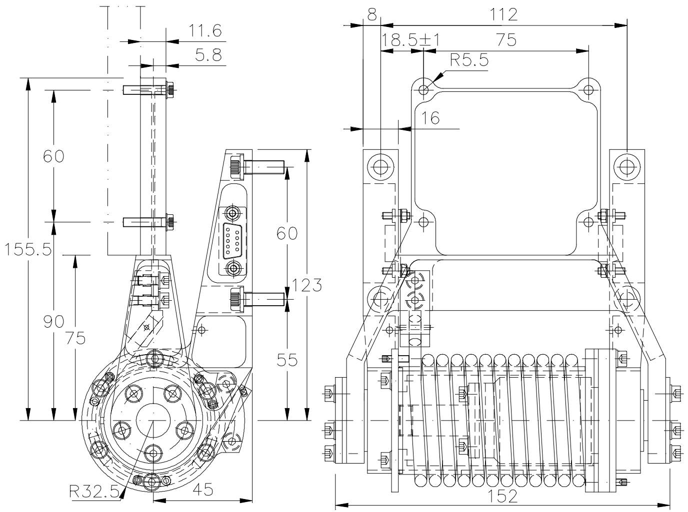
- **Osmotic actuators**: very little use in space: requires seals and fluids. Can be used of micro-g applications (in space lab, biology, …)

- **Differential expansion**: bimetals

- **Passive Shape Memory Alloy (SMA)**: Pseudoelasticity

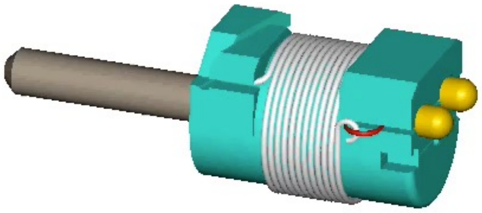
# Motors and Actuators: Force generation (passive components)



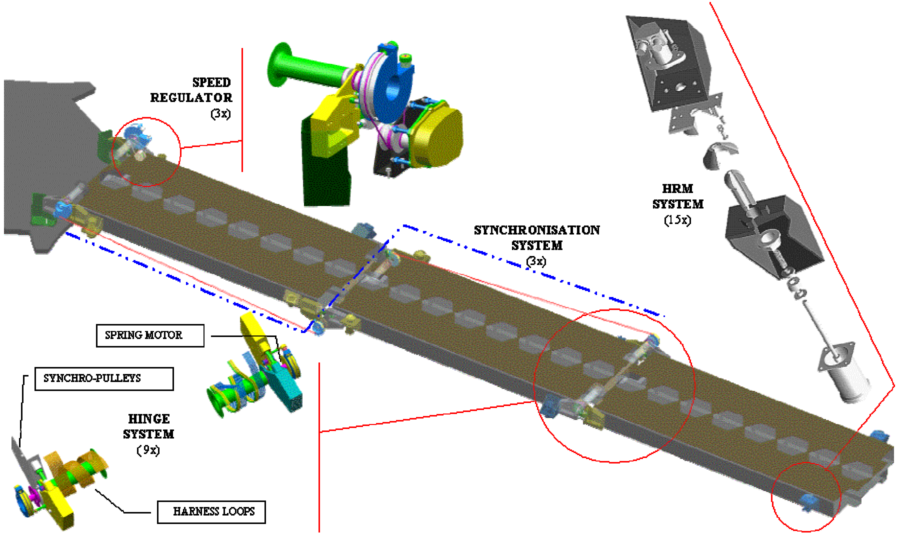



Source: Bueno et al. Proceedings of the 9th European Space Mechanisms and Tribology Symposium (ESMATS 2001),

Source: Sidz et al. Proceedings of the 18th European Space Mechanisms and Tribology Symposium (ESMATS 2019),



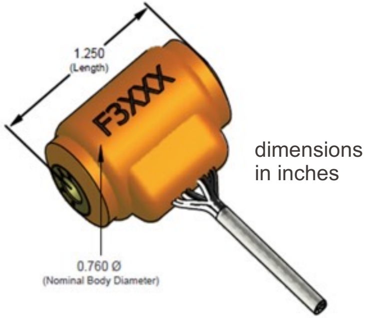
Source: NEA split spool. Ensign-Bickford Aerospace & Defense Company

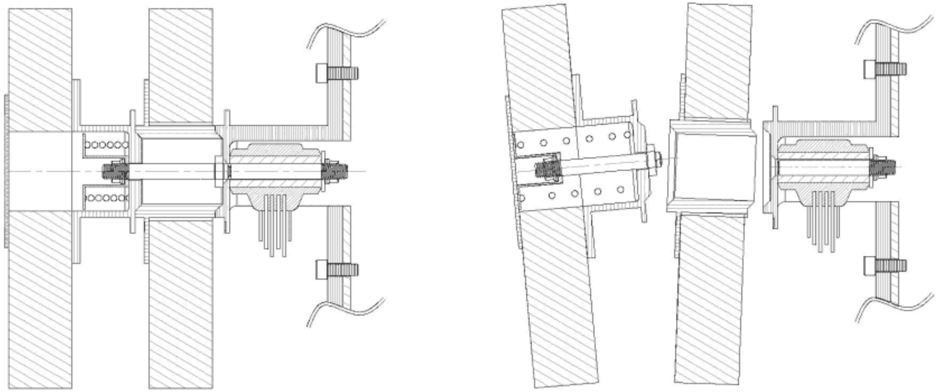



Source: Plaza et al. Proceedings of the 10th European Space Mechanisms and Tribology Symposium (ESMATS 2003),

# Active SMA Actuator

- Example: Ensign-Bickford Aerospace & Defense TiNi™ Frangibolt®

# Active SMA Actuator



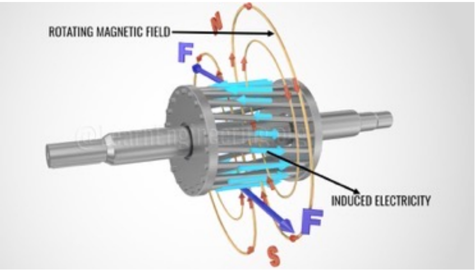
- Example: Pin puller, valve, cable cutter …




Source: Ensign-Bickford Aerospace & Defense TiNi™

# Motors and Actuators

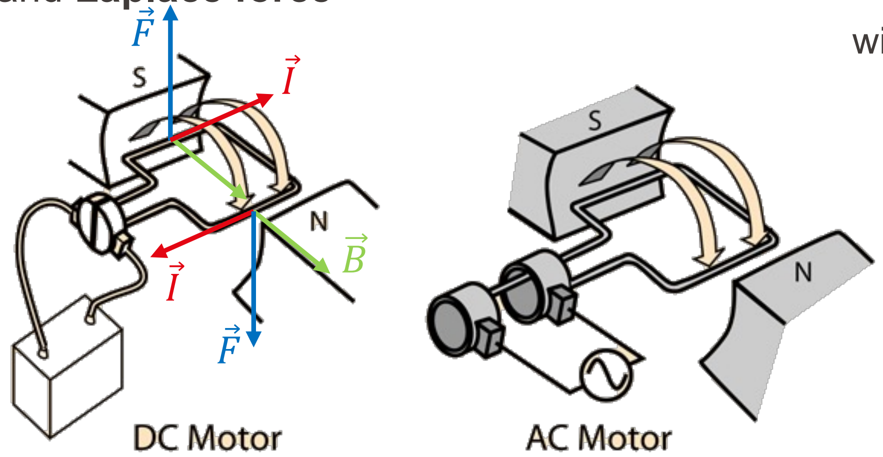
- Working principle of electric machines:
  - Based on
    - **Faraday's law of induction** $$e = -\frac{d\phi}{dt}$$




© Lesics Engineers Pvt.Ltd

with $e$: electromotive force (EMF) [V]
$\phi$: magnetic flux [Wb] (Weber = 1 V·s)

- **Lorentz force** (magnetic force only) and **Laplace force** $$\vec{F} = q \cdot \vec{v} \times \vec{B} = \vec{I} \cdot l \times \vec{B}$$

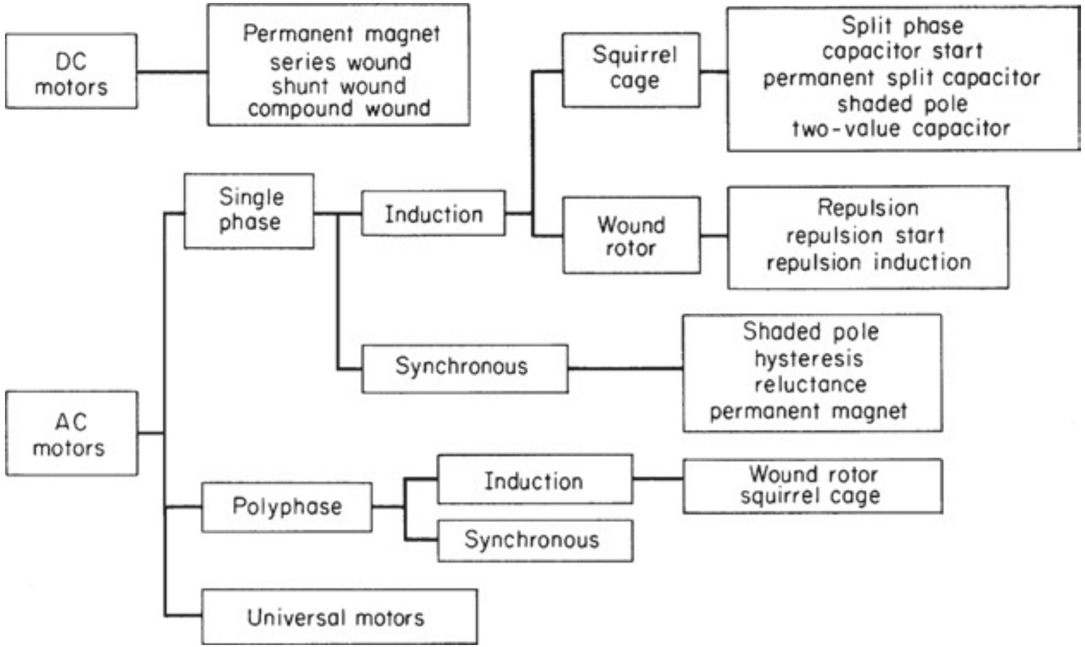



with $q$: charge [C]
$\vec{v}$: velocity of the particle [m/s]
$\vec{B}$: magnetic field [T]
$\vec{I}$: current [A]
$l$: conductor length [m]

Source of drawings: http://hyperphysics.phy-astr.gsu.edu/hbase/magnetic/elemot.html

# Motors and Actuators

## Classification of Electrical Motors.




Source: Standard Handbook for Electrical Engineers - Surya Santoso and H. Wayne Beaty editors, McGraw-Hill Education (2018) ISBN 978-1-25-964259-3, p.920

# Stepper Motor

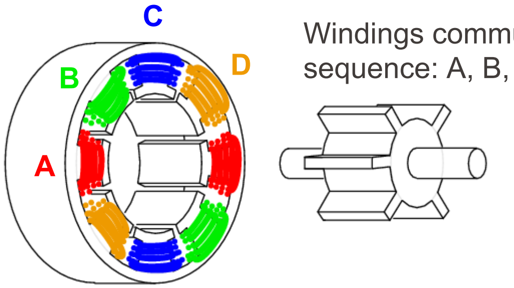
- Variable-reluctance (no permanent-magnet)
  - Very low (no) detent torque
  - Low torque
  - Coarse step angle
  - Low cost
- Permanent-magnet
  - High detent torque
  - Better torque than variable-reluctance motor
  - Limited rotation speed
  - Medium cost
- Hybrid
  - Detent torque depending on design
  - Best torque and speed performances
  - High resolution (100-400 steps per rev.)
  - High cost

*w/o electric power*

*≠ holding torque*

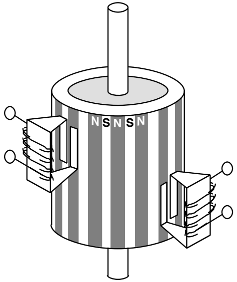
*with electric power*

➢ Requires a complex electronic control



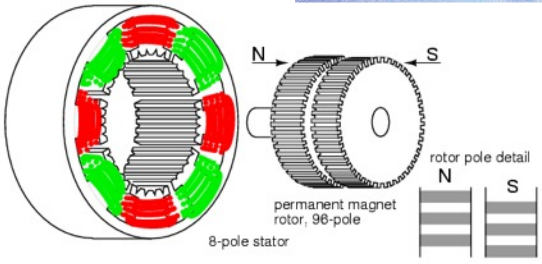

Windings commutation sequence: A, B, C & D

Source: [1]




Source: [2]

Source: SAGEM

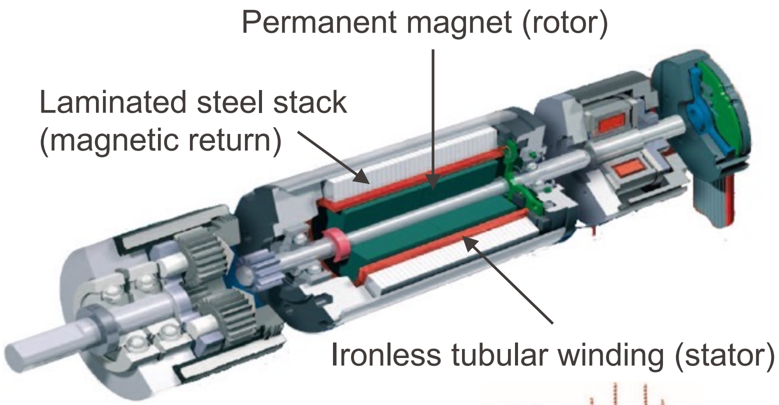



Source: [1]

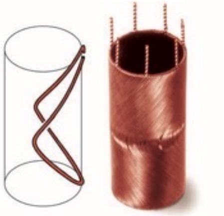
[1] https://www.ibiblio.org/kuphaldt/electricCircuits/AC/AC_13.html
[2] http://solarbotics.net/library/pdflib/pdf/motorbas.pdf

# Brushless DC motor

- Permanent magnet of the rotor side
- Stator composed of two or more pole pairs, electronically commutated in order to generate a rotating field
- If the stator does not contain any ferromagnetic component the detent torque is equal to zero
- Specific windings permit to get very compact size motors or large diameter frameless torque motors




Source: Maxon Motor AG

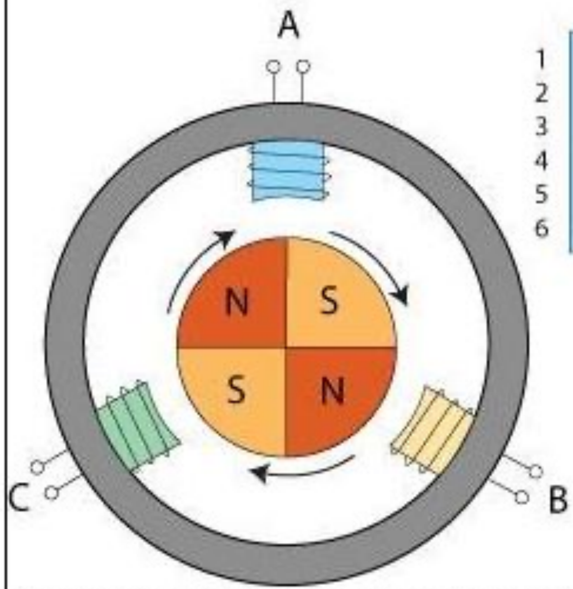


Source: Avior Contol Technologies, Inc.

Source: Soterem

# Brushless DC motor

- Permanent magnet of the rotor side
- Stator composed of two or more pole pairs, electronically commutated in order to generate a rotating field




| | Coil A | Coil B | Coil C |
|---|---|---|---|
| 1 | + | - | off |
| 2 | + | off | - |
| 3 | off | + | - |
| 4 | - | + | off |
| 5 | - | + | off |
| 6 | off | - | + |

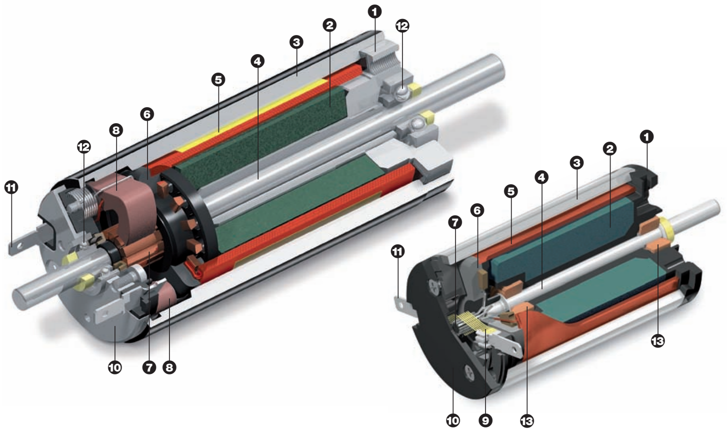
Six commutation phases "move" the electromagnetic field, which causes the permanent magnets on the rotor to move the motor shaft.

Source of the picture:
https://mae.ufl.edu/designlab/Class%20Projects/Background%20Information/Electric%20DC%20motors.htm

# Brushed DC Motor

- Similar build as brushless motor, but mechanical commutation is performed through the use of brushes and commutator slip ring
- Mechanical commutation:
  - Windings
  - Rupture of the circuit (Faraday's law)

→
- Sparking
- Electrical erosion
- Rapid wear
- Reliability problems



Source: Maxon Motor AG


Source: Soterem

# Theme 6 Part 3 Summary

- Actuators
  - Passive
    - Spring based …
  - Active
    - Electromagnetic: brushless DC motors, stepper motors, brushed motors …
    - Others: paraffin actuators, SMA actuators …
  - Electromagnetic actuators
    - Working principles
    - Classification

# Next session (in two weeks)

- Theme 6 – Part 4: Components (continued)
  - Actuators (continued)
  - Gear boxes
  - Angular encoders
  - Sensors and gauges
  - Cables

- Mini-project part 3: deadline May 4th, 2025.

- Readings:

[6.7] NASA/CR-2005-213424 Lubrication for Space Applications

[6.8] M. LoSchiavo et al. "Mars 2020 maxon Commercial Motor Development from Commercial-Off-the-Shelf to Flight-Qualified Motors, Gearboxes, and Detent Brakes", Proceedings of the 45th AMS, 2020