# LA MOTORISATON ELECTRIQUE

*Description, principes de fonctionnement et exemples*

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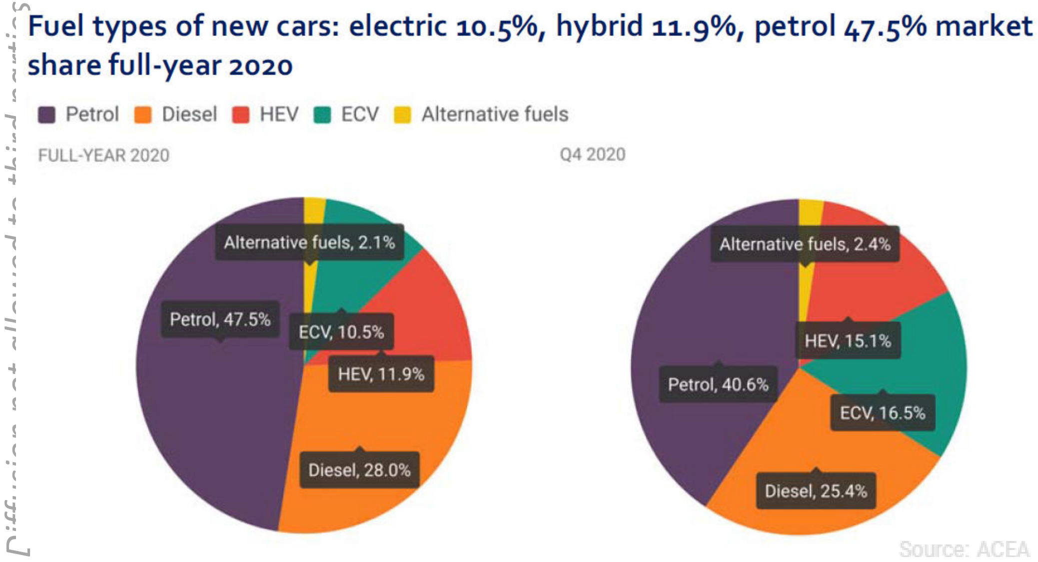
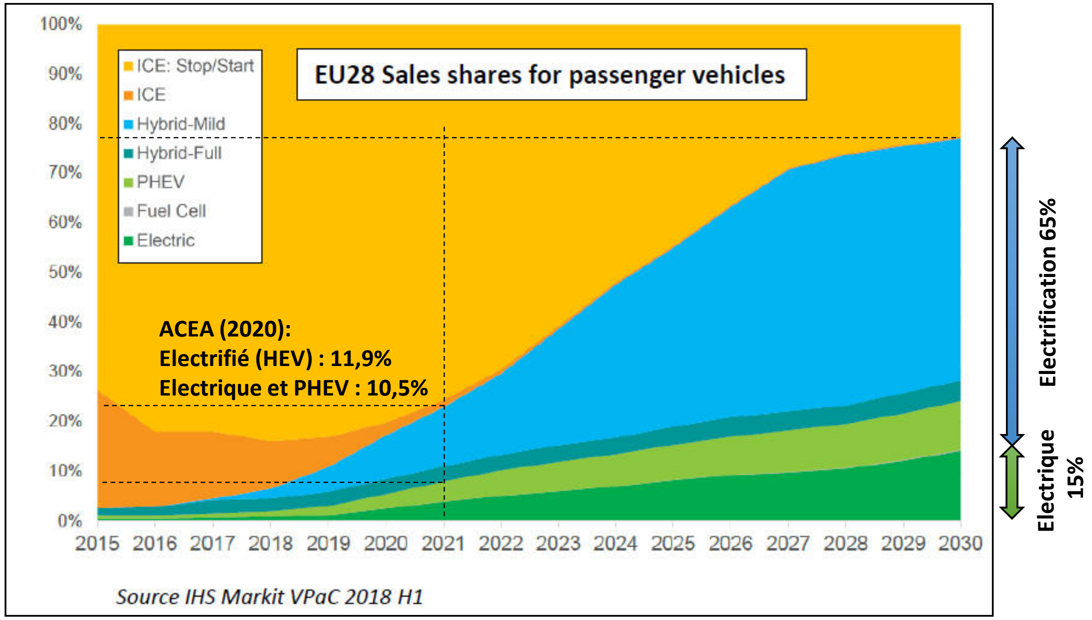
# MARCHÉ AUTOMOBILE
*CONTEXTE*

SUSTAINABLE MOBILITY

- Contexte :
  - Le marché de la mobilité électrifiée bénéficie d'un cadre mondial propice à la croissance
  - L'automobile électrifiée est tirée par les objectifs d'électrification de masse du parc automobile




- Les chaînes de traction hybrides devraient avoir une part importante du marché sur 10 ans
- La prise des parts du marché du véhicule 100% électrique s'accélère fortement à l'horizon 2030





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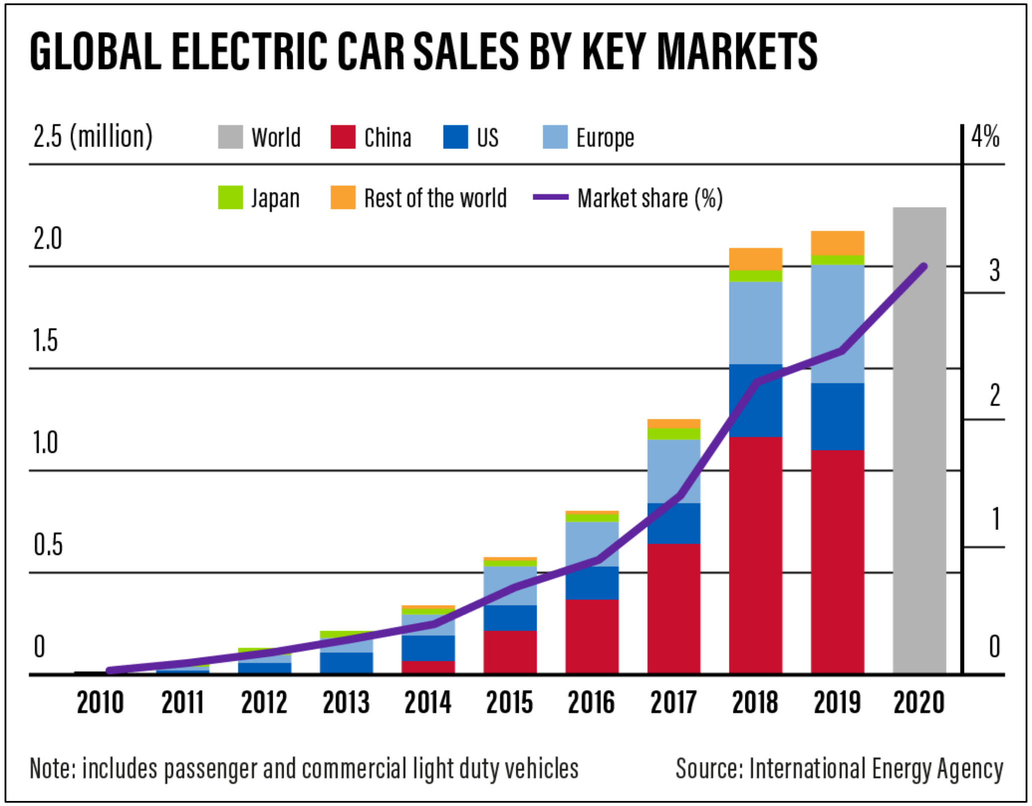
# INTRODUCTION

A global increase of electric systems sold all over the world



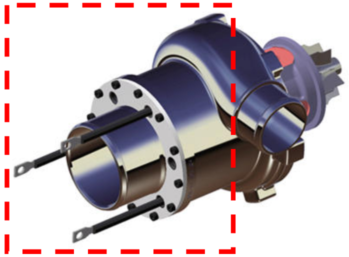
# Introduction
## *Electric system*

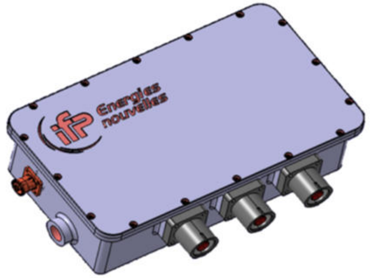


- **Advantages of electro-mechanical conversion**
  - Capability to obtain a rotational mechanical movement
  - Simple and reliable
  - The energy conversion is often reversible
  - The global efficiency of the conversion chain is excellent

- **Efficiency**
  - Theoretical efficiency limits are very close to real efficiency
  - Alstom Turbogenerator of 1150 MW: 98,88 % efficiency
    - ➔ still more than 1 MW of heat losses to dissipate
    - Maximum thermal engine efficiency : 50% (heavy duty engines)

*3-phase electric motor (coupled with a turbocharger)*





*Power electronics for 3-phase electric motor*

*3-phase electric motor for électric vehicle (with power electronics)*

# Introduction
## *Electric system*

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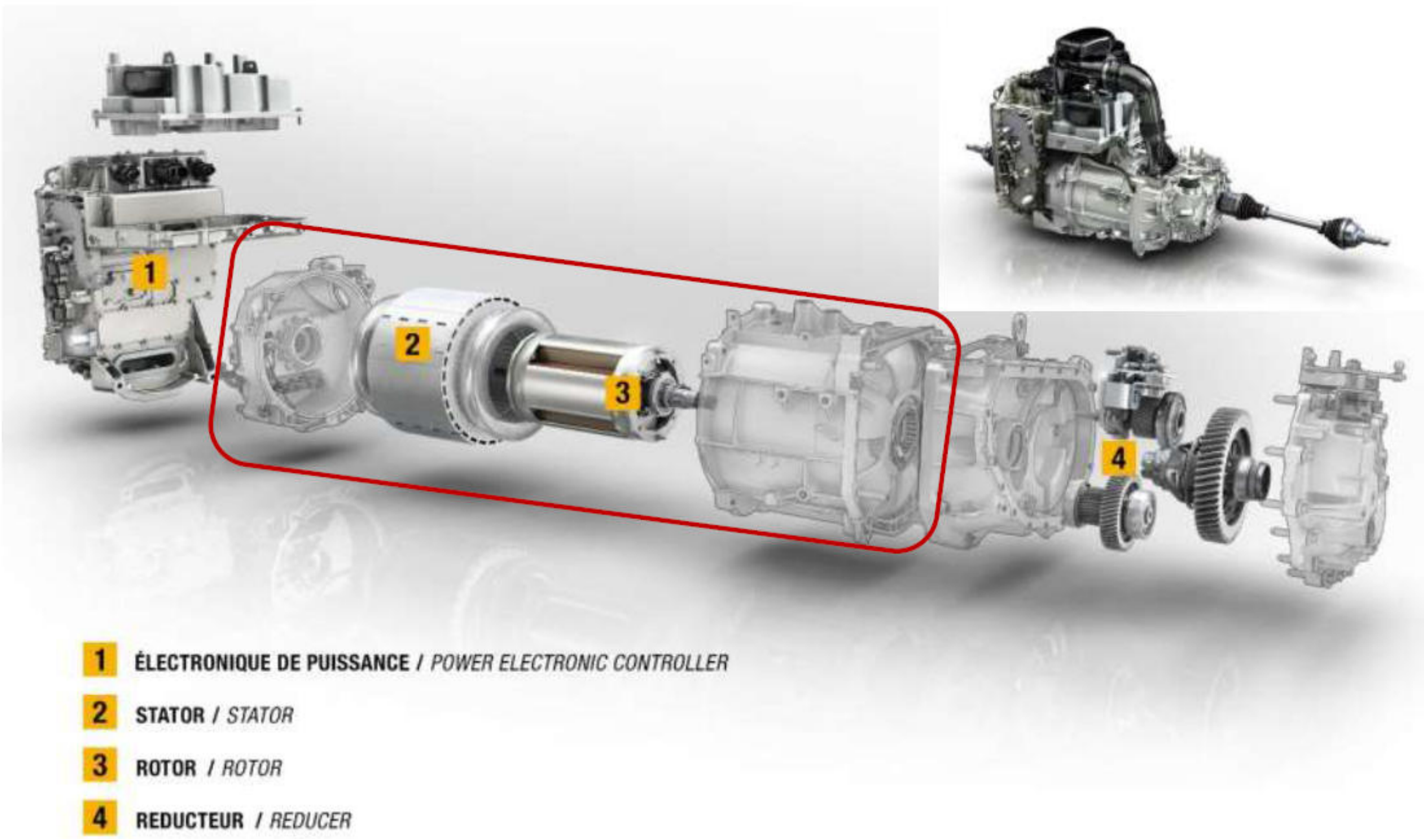
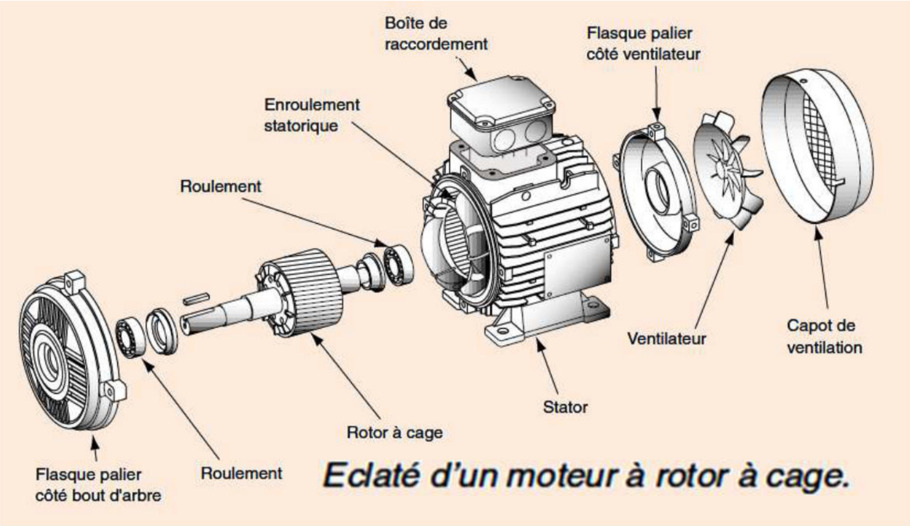
- **Composition of an electric drive :**
  - Electric Motor / Generator
    - Stator
    - Rotor
  - Power electronics
  - Control Laws
  - Reducer / mechanical transmission



# Introduction
## *Electric system vs. thermal engine*

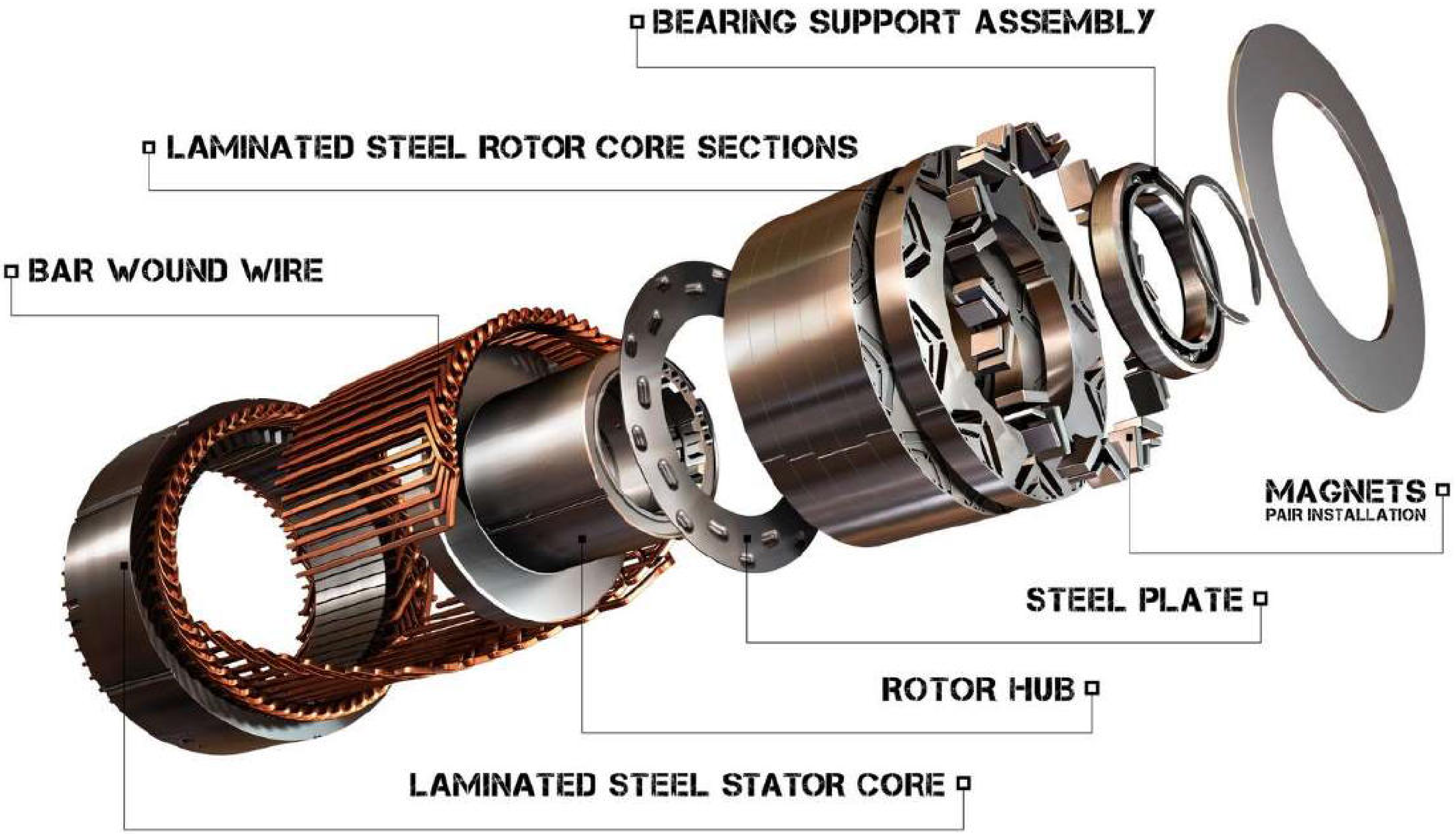



***Electric motor parts and components***

***Thermal engine parts and components***

**Compared to electric motor manufacturing, thermal engine industrial manufacturing is much more complex**

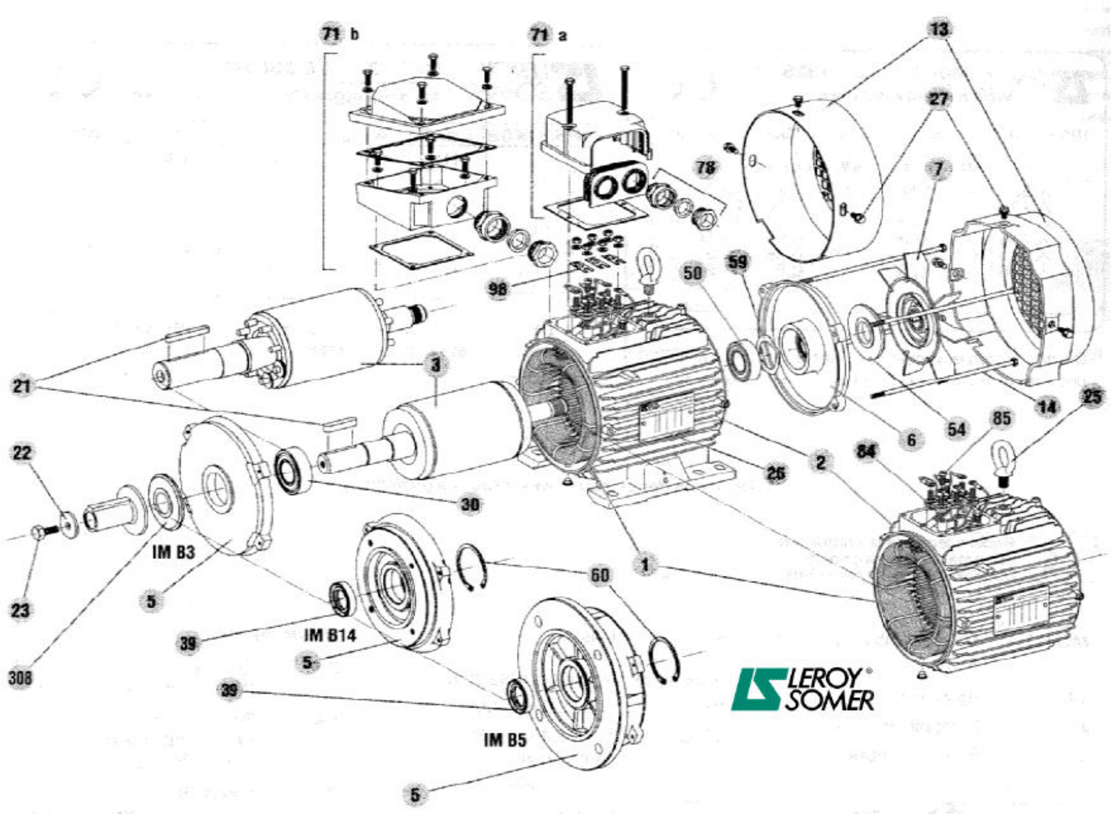
# Introduction
## *Active parts*



# Introduction
*Mechanical parts*

- **Mechanical parts**
  - Bearings
  - Flanges
  - Casing
  - …

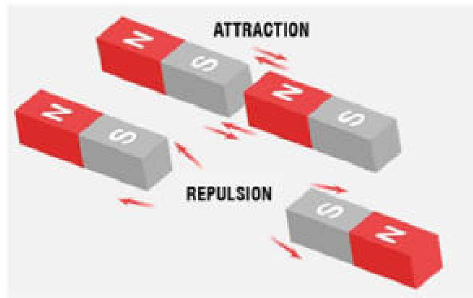
- **Specific parts**
  - Magnets
  - Sensors
  - Squirrel cage
  - Wounded rotor,…



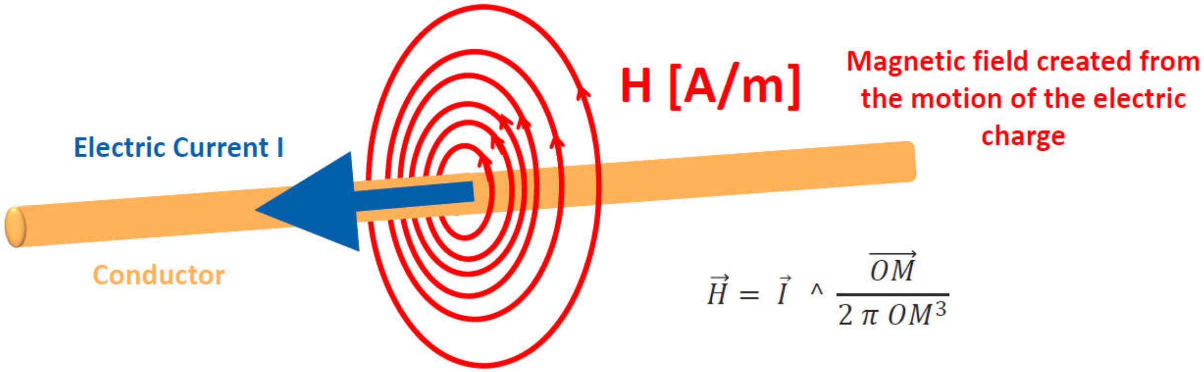

*Example of an industrial asynchronous machine*

# Introduction
## *Magnetism*

- **Forces generated by a magnet**
  - Magnets attract parts composed of iron and steel
  - Generally, magnets attract iron, cobalt, nickel and their alloys
  - Identical poles of two magnets repel each other; opposite poles attract each other




- **An electric current flowing through a conductor will create a magnetic field**
  - This is linked to the movement of electrons through the conductor




$$\vec{H} = \vec{I} \wedge \frac{\overrightarrow{OM}}{2\,\pi\, OM^3}$$





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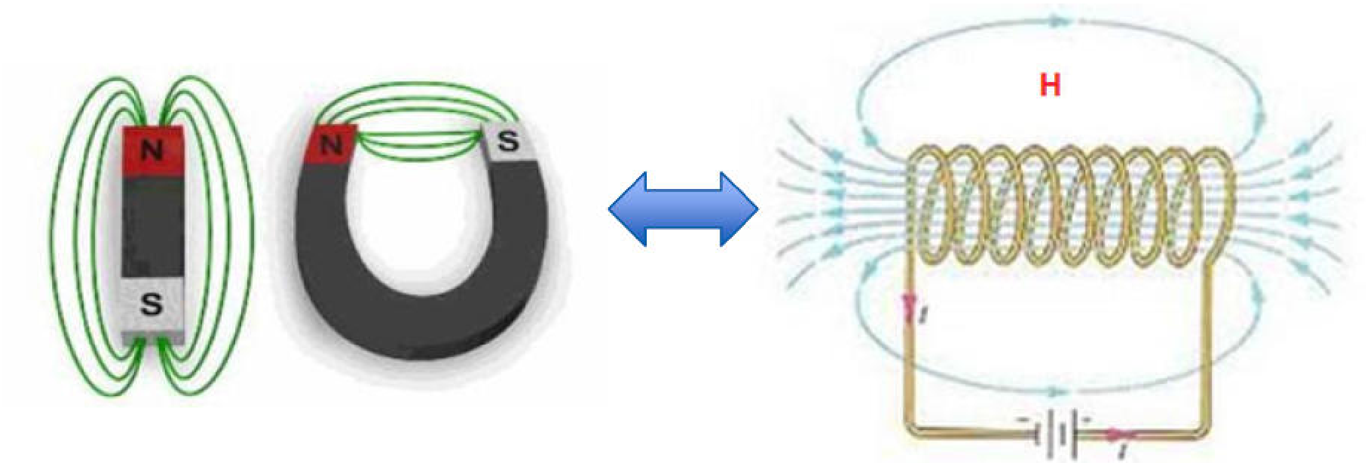
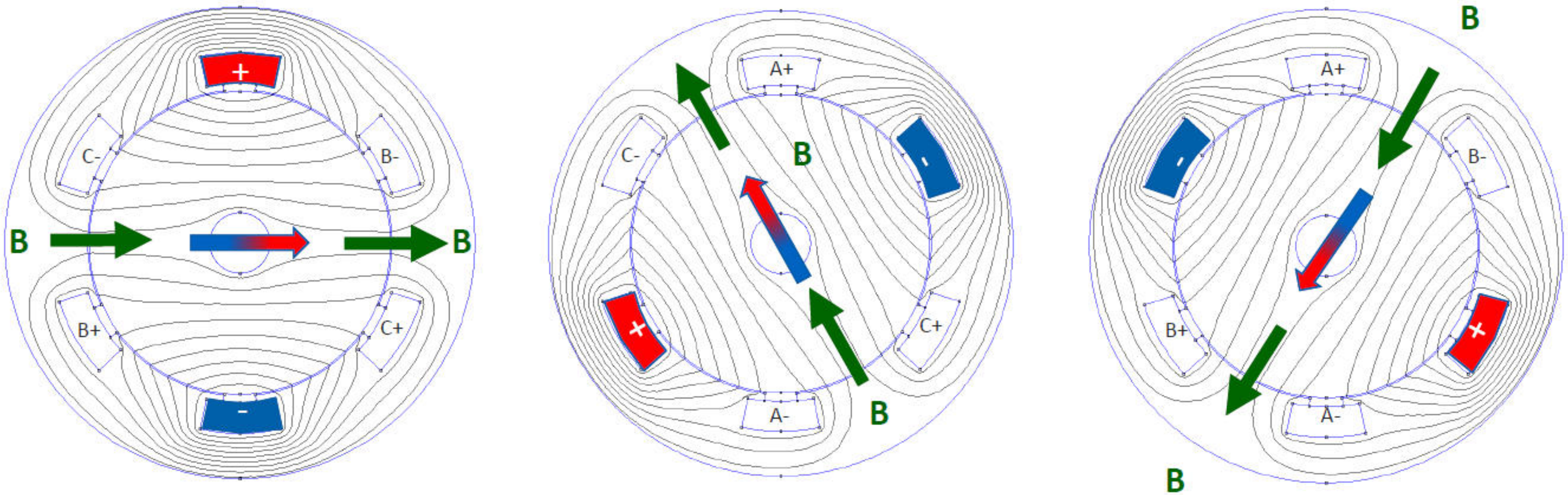
- **Thus, to create a magnetic field, it is possible to use:**
  - A magnet
  - A winding

- **Magnet and electro-magnet are equivalent**
  - To create a constant magnetic field in an electric machine, we find a number of technological options to choose from:
    - Either the magnetic field is created by a winding
    - Or the magnetic field is created by a magnet



# 3 phase stator winding
## *Principles*

- **3 coils encased in 6 slots ➔ Coils A, B and C**
- **The coils have a phase angle shift of 120 °**



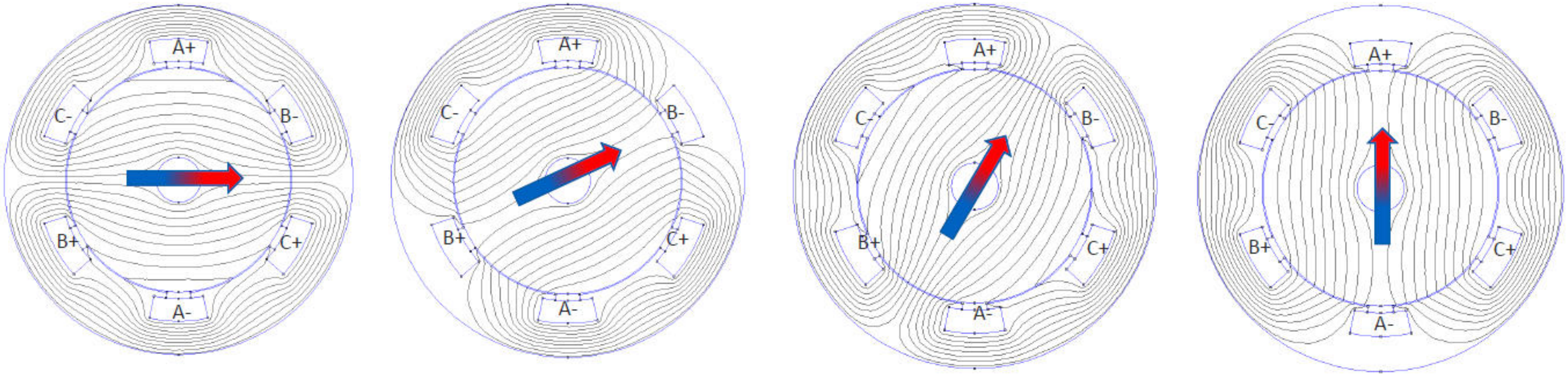

Coil A powered alone — Coil B powered alone — Coil C powered alone

- **Each coil is fed by a sinusoidal current form** $I = I_0 \cos(\omega t + \phi)$

# 3 phase stator winding
## *Rotating field*



- **Field for different angles  = 0°,  = 30°,  =60,  = 90°**




| | | | |
|---|---|---|---|
| $\alpha = 0$ | $\alpha = \frac{\pi}{6}$ | $\alpha = \frac{\pi}{3}$ | $\alpha = \frac{\pi}{2}$ |
| $i_a = \hat{I}$ | $i_b = \frac{\sqrt{3}}{2}\hat{I}$ | $i_a = \frac{1}{2}\hat{I}$ | $i_a = 0$ |
| $i_b = -\frac{1}{2}\hat{I}$ | $i_b = 0$ | $i_b = \frac{1}{2}\hat{I}$ | $i_b = \frac{\sqrt{3}}{2}\hat{I}$ |
| $i_c = -\frac{1}{2}\hat{I}$ | $i_c = -\frac{\sqrt{3}}{2}\hat{I}$ | $i_c = -\hat{I}$ | $i_b = -\frac{\sqrt{3}}{2}\hat{I}$ |

# Structure of electric motors



- **Stator**
  - Fixed part of the motor
- **Rotor**
  - Rotating part
  - By extension, moving part in the case of a linear motor
- **Inductor**
  - Magnet and or winding generating the magnetic flux in the machine
  - It is part of the excitation circuit
- **Armature**
  - Electrical windings in which the inductor flux generates an electromotive force
- **Many different machines exist**
  - The rotor can be internal or external
  - The armature can be in the rotor or stator, likewise for the inductor
  - It is not necessary that all motors have a separate inductor and a separate armature

# Structure of the rotor
*Example*

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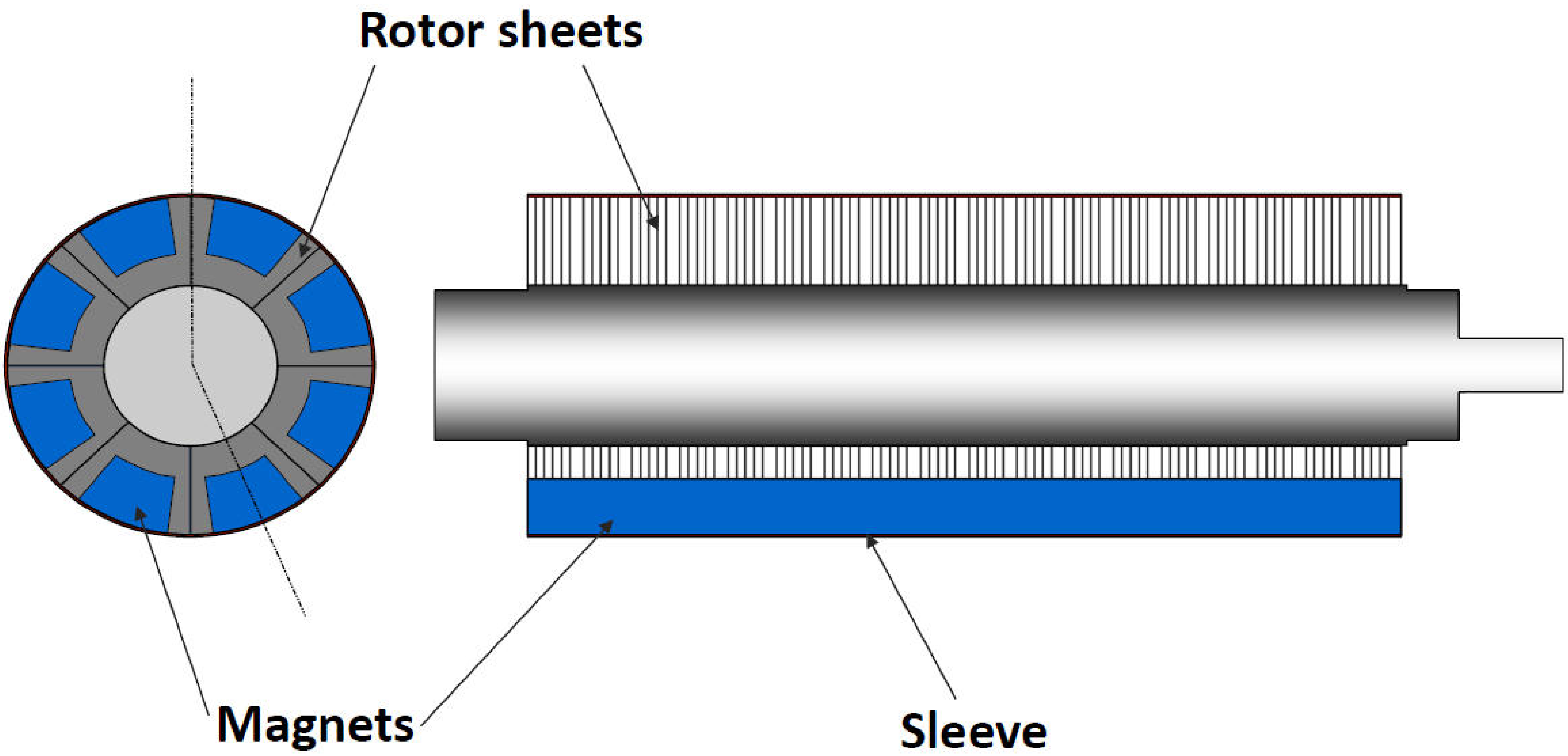
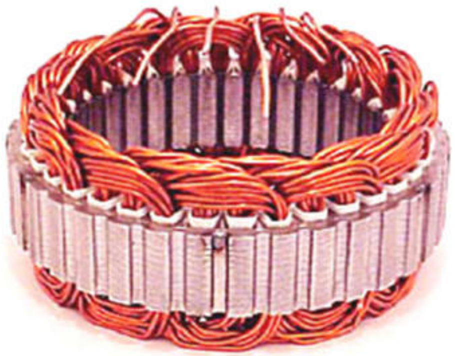
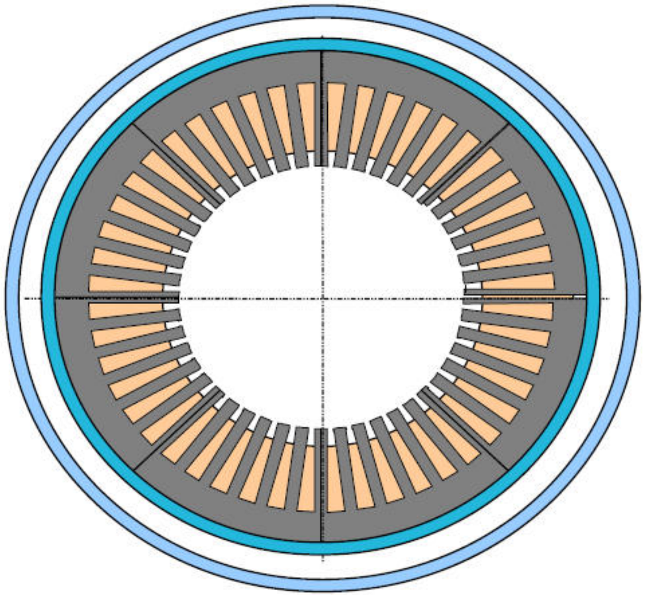
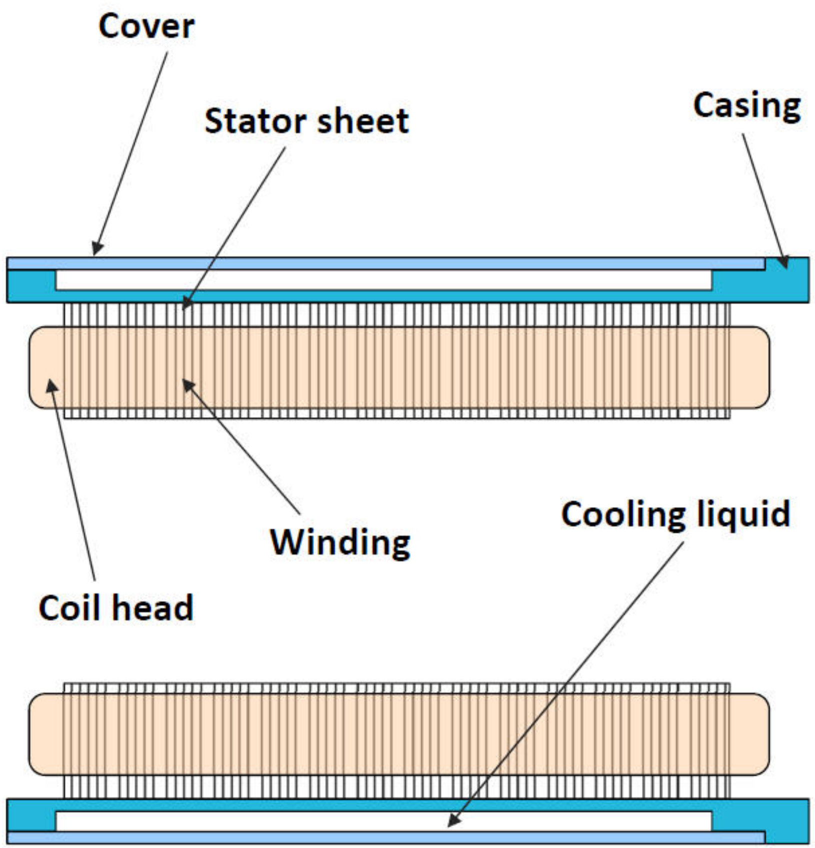


# Structure of the stator
*Example*







# General structure
*Example*

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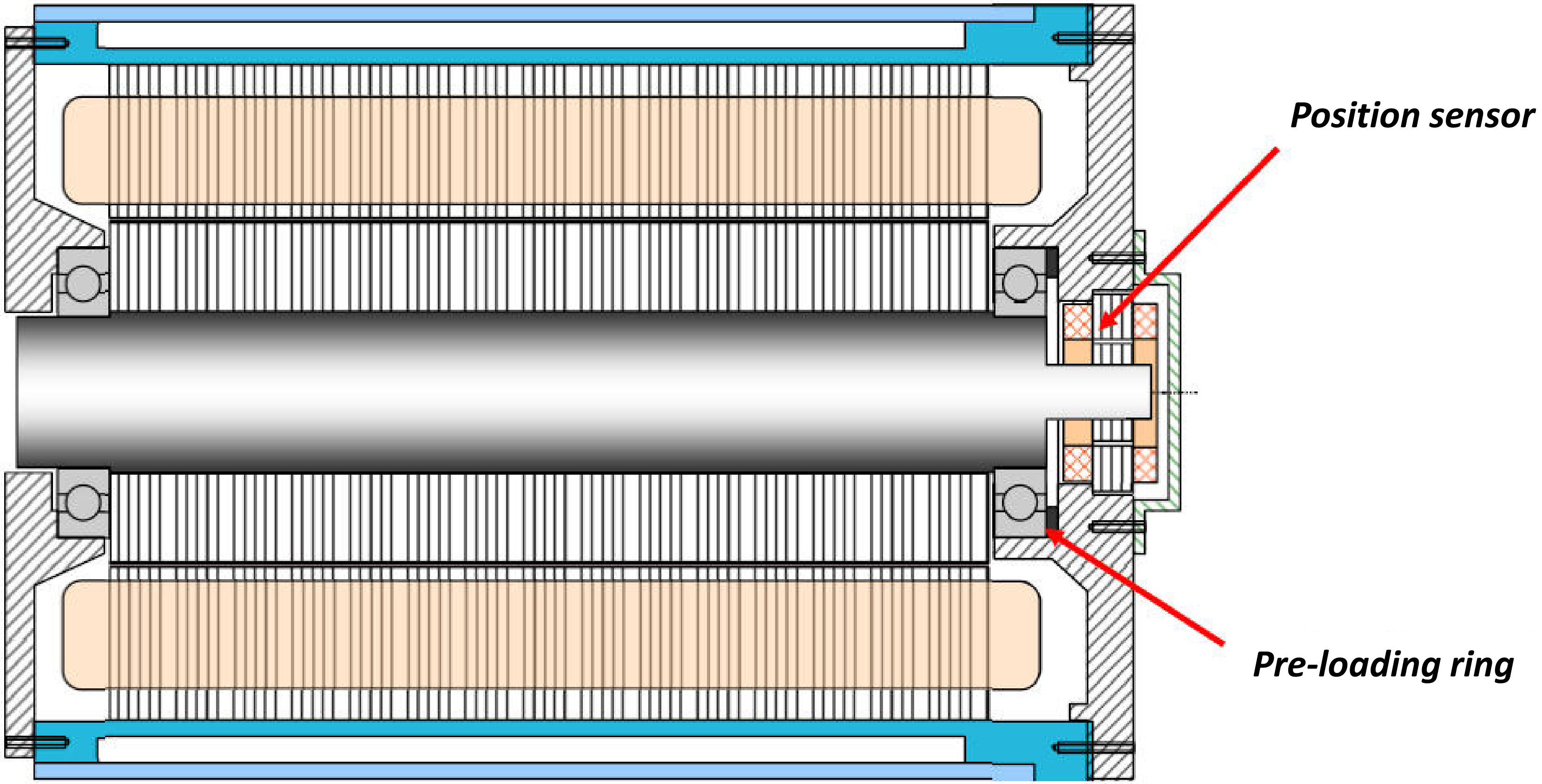






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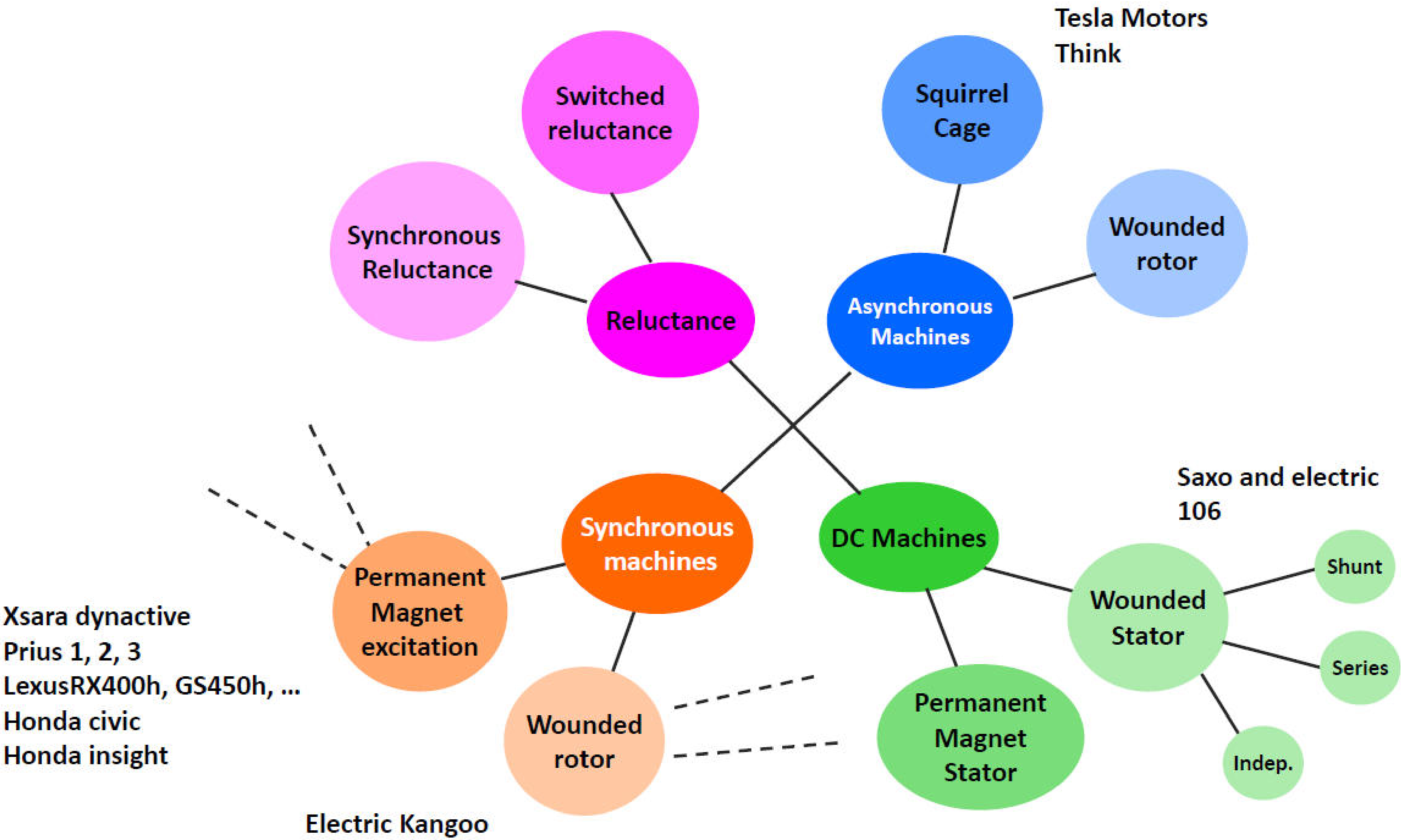
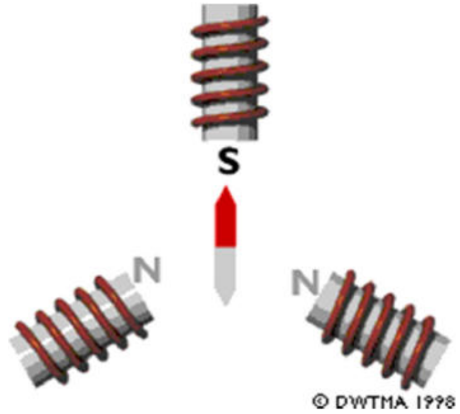
# Electric motors
## *Main families*



# Asynchronous (induction) motors
## *Principle*

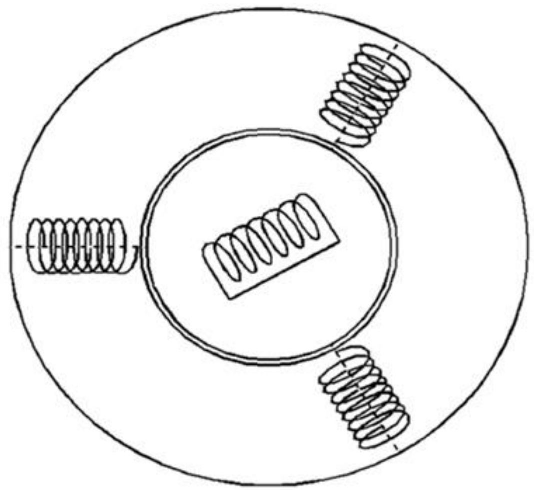


- **Three windings phased by 120° in the stator and individually powered generate a rotating field**
  - By modulating the intensity in each winding, we can generate a magnetic field with a constant amplitude but with a continuously varying angle
- **The rotating stator filed induces current in short circuit rotor winding**
  - Rotor field and stator field interaction will produce torque




Induction

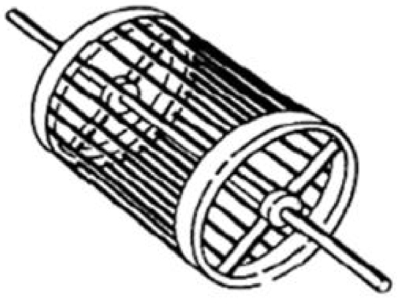
Stator field → Rotor current → Rotor field → Torque

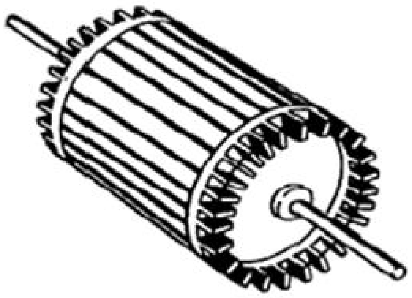


# Asynchronous (induction) motors
## *Rotor structure*

- **Wounded rotor structure**
- **Squirrel cage structure**
  - Made with aluminum or copper

- **Asynchronous motor**
  - Simple to product, limited cost
  
  ➔ One of the most widespread motor in the world

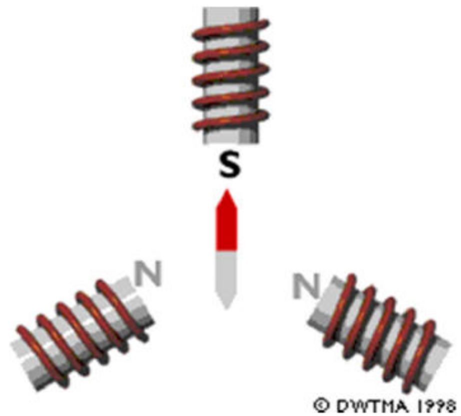




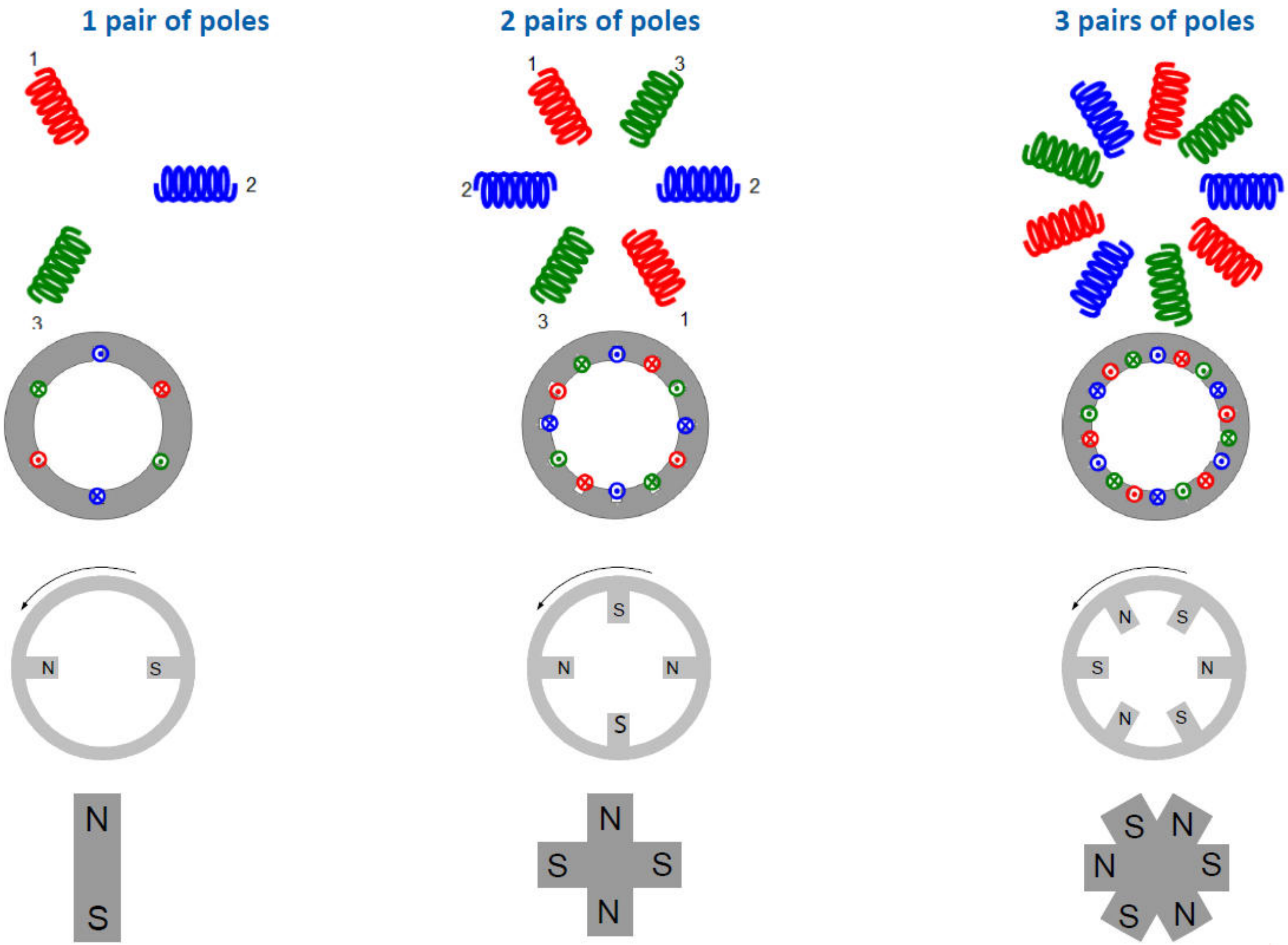

# Synchronous motors
## *Principle*

- **Three windings phased by 120° in the stator and individually powered generate a rotating field**
  - By modulating the intensity in each winding, we can generate a magnetic field with a constant amplitude but with a continuously varying angle

- **In the rotor's frame of reference, it has a constant magnetic torque**
  - The rotor aligns itself with the stator magnetic field
  - This results in a mechanical rotation of the rotor

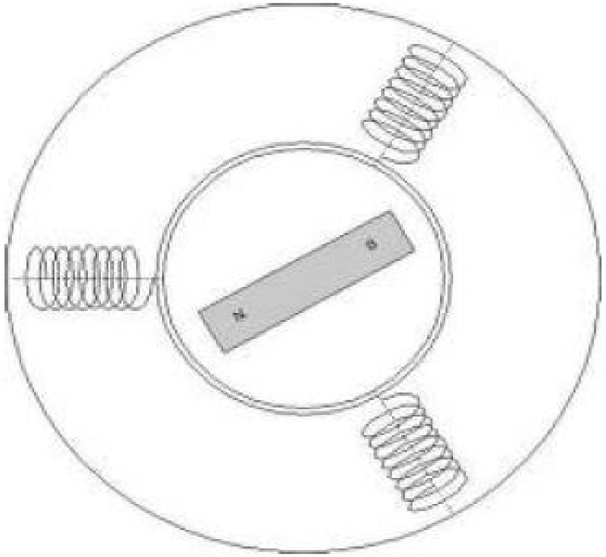


# 3 phase windings and pole numbers
## *Principle*



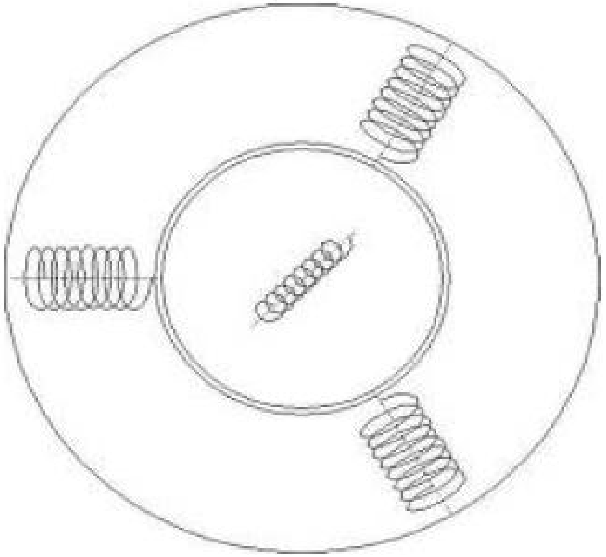
# Synchronous motor
## *Excitation*





**Excitation by permanent magnet**

*Electric machine with double excitation: permanent magnets and rotor windings*



**Excitation by a winding flowing with a continuous current (classic automotive alternator)**

**Advantages: less magnets & flux control using the inductor**
**Disadvantages: the rotor needs to be powered (Brushes and clamping rings that increase machine length)**

# Synchronous motor
## *Rotor topologies (examples)*

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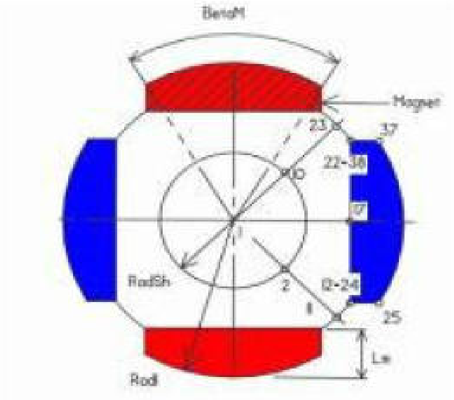
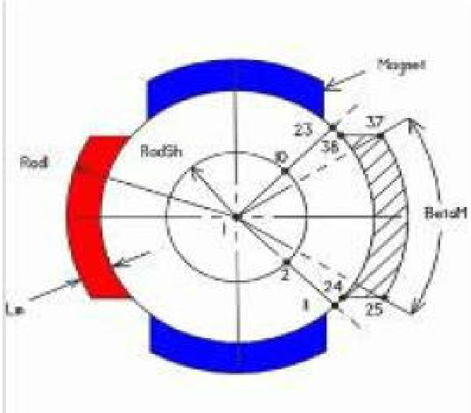
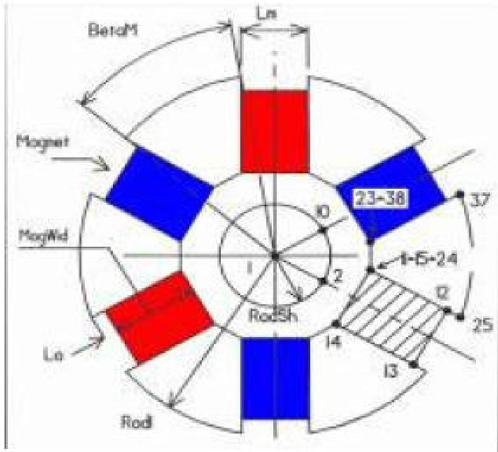
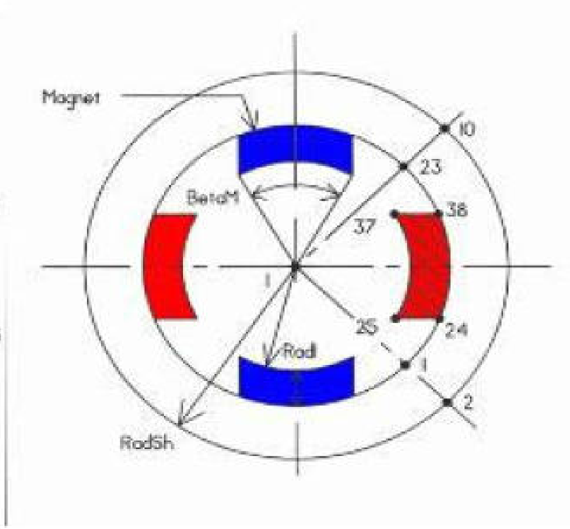


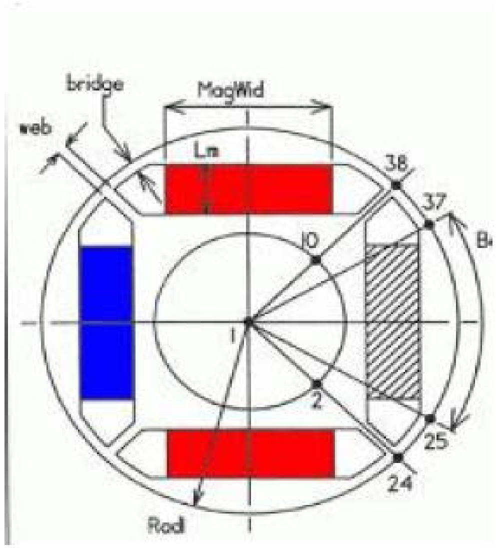

**Surface mounted magnets (non salient poles)**




**Flux concentration**




**Buried magnets**




**Interior magnets (ex prius)**

## Synchronous motor
## *Structure of permanent magnet machines*

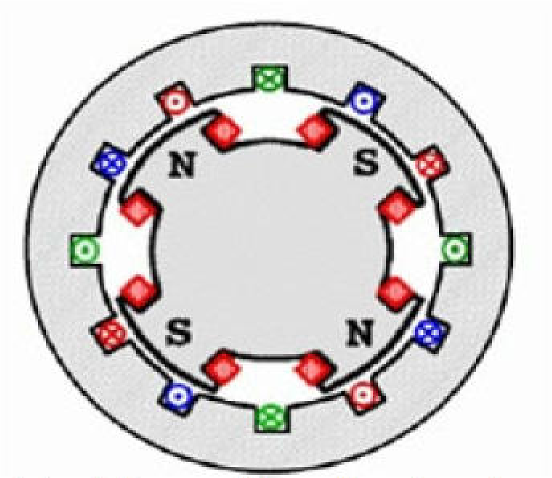
SUSTAINABLE MOBILITY

**Rotor of a permanent magnet machine**

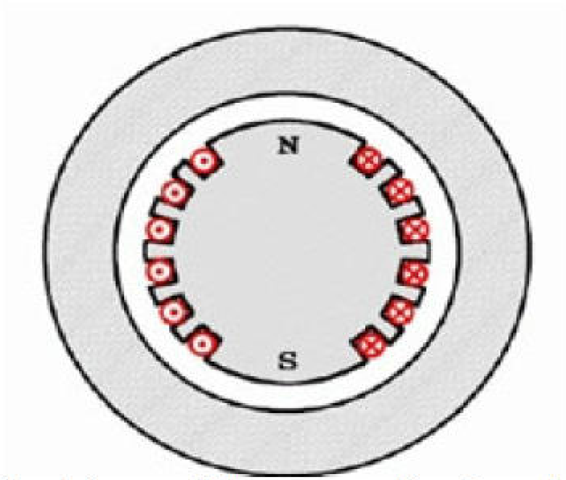
**Corresponding stator (hand winding ongoing)**

# Synchronous motor
## *Structure of wonded rotor machines*



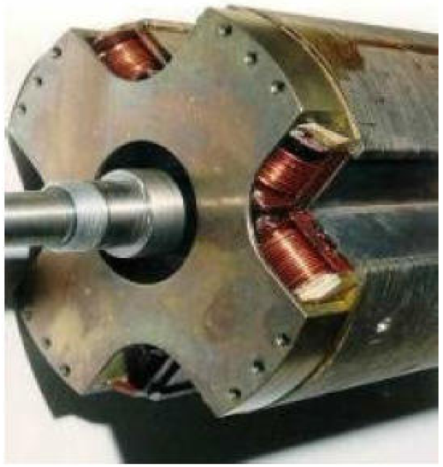


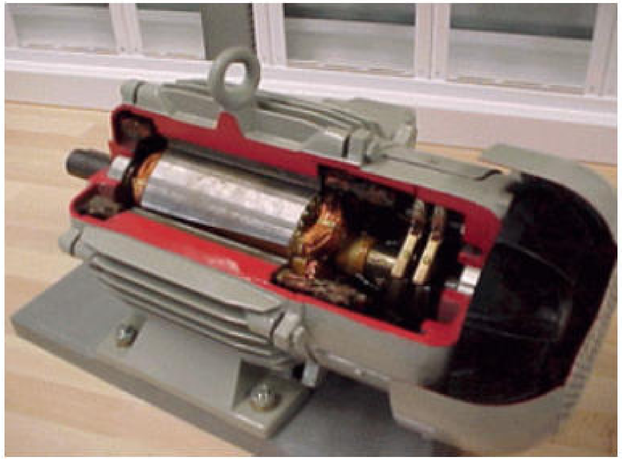

Machine with salient poles

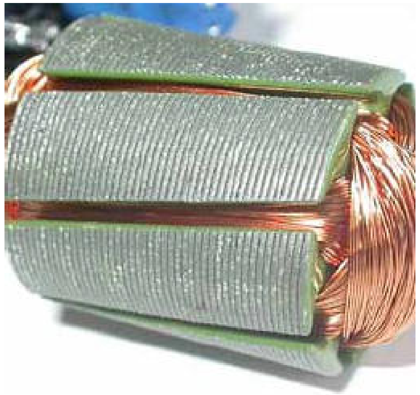



Machine with non-salient poles

***Remark: the stator has the same look and feel as that of permanent magnet machines***







***Some motors with salient poles are twisted to smoothen out the torque***

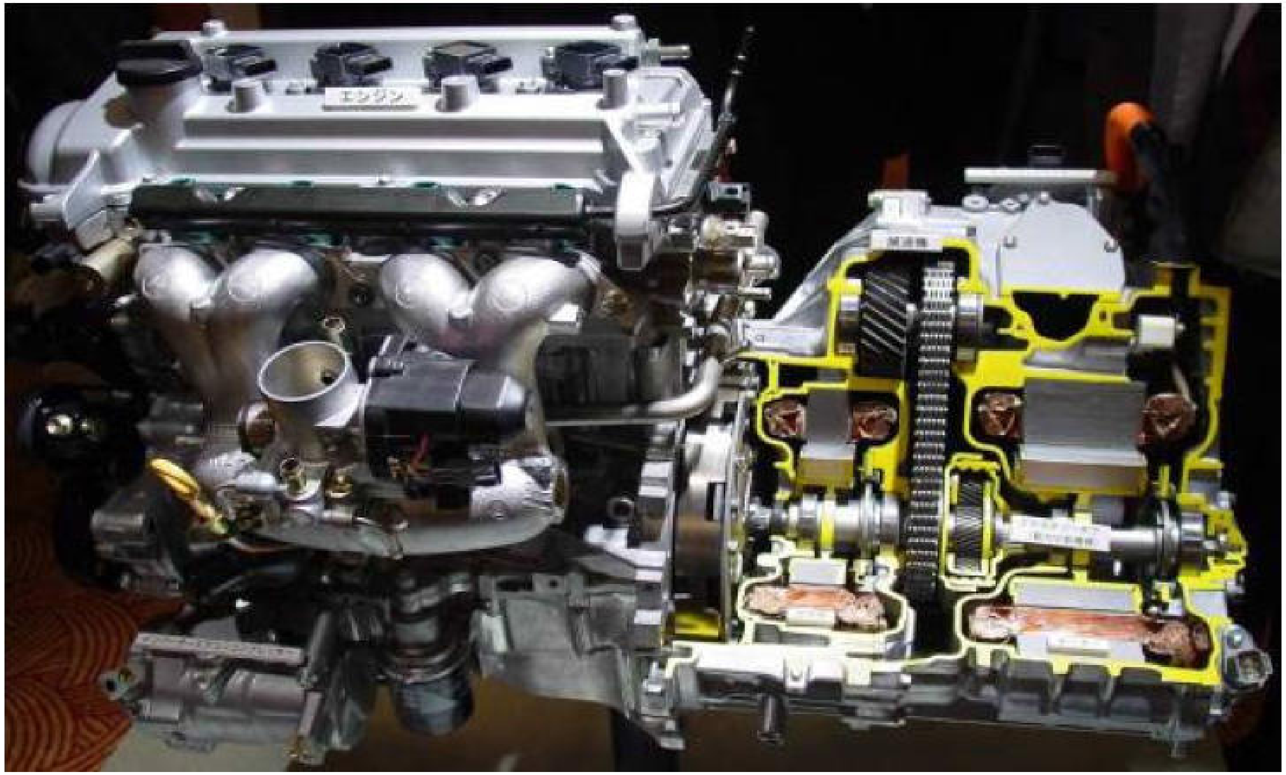
 

# Synchronous motor
*Examples*



- **1st generation of Toyota Prius**

**Inverter in Toyota Prius**



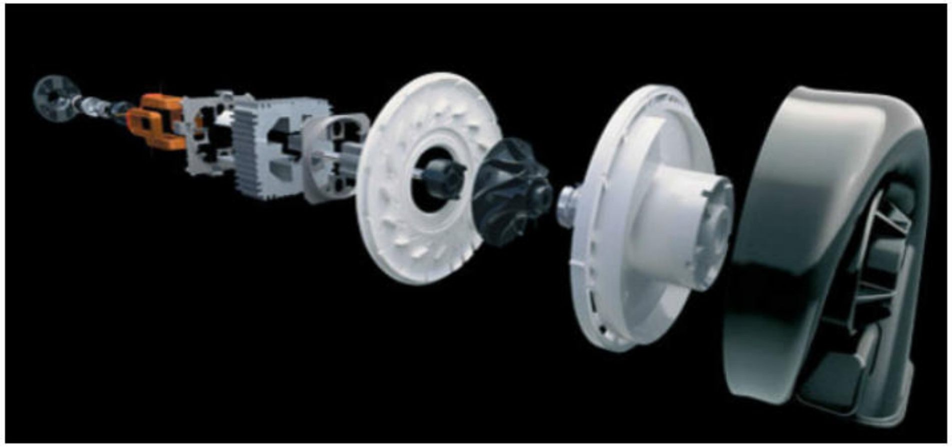
**Powertrain of Toyota Prius**

# Reluctance motor
## *Examples*




- **Switched reluctance motor for a commercial vacuum cleaner**
  - 100 000 rpm
  - 400 W
  - Machine weight of 1kg

- **The manufacturing simplicity of the rotor of a reluctance machine makes it a great fit for high speed applications**



# Reluctance motor
## *Principle*

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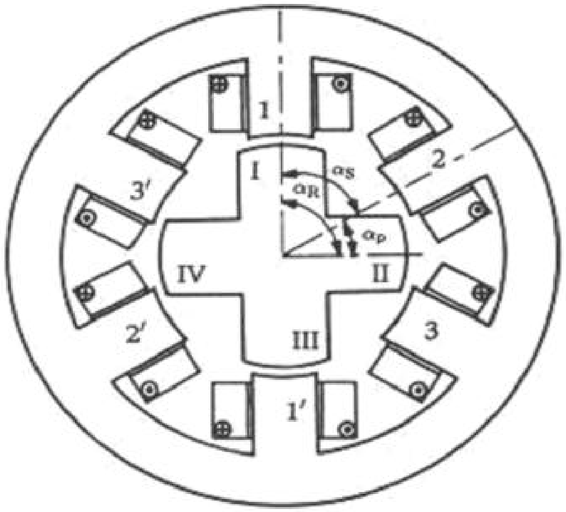
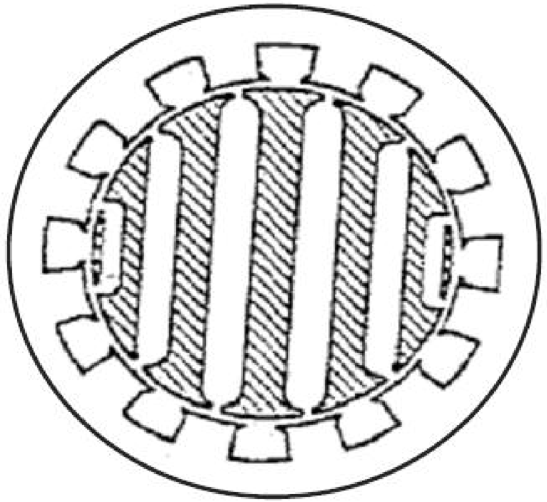
- **The concept of the reluctance machine is based on the fact that the machine rotor has a tendency to choose a stable equilibrium position that minimizes the passage of field lines in the air**
- **We distinguish two families**
  - Switched reluctance : in this case, we sequentially power three coils with a current (whose direction has no effect)
  - Synchronous reluctance : in this case, we create a rotating field using a classical three phase winding




Switch Reluctance



Synchronous reluctance

# Conclusion
## *Electric motors comparison*

SUSTAINABLE MOBILITY

| | Advantages | Disadvantages |
|---|---|---|
| Direct current machine | Can be used without power electronics<br>Simple to control<br>Low cost (if power electronics are not used) | Design (commutator and rotor losses to be evacuated<br>Mediocre durability<br>Limited efficiency (wounded rotor)<br>Reduced maximum speed (commutator) |
| Wounded rotor synchronous machine | No magnets<br>Limited losses at high speed<br>Higher degree of freedom for control | Design (sliprings, brushes and rotor losses to be evacuated)<br>Sliprings and brushes = maintenance<br>Temperature sensitivity (rotor conductors) |
| Permanent magnet synchronous machine | Compactness<br>Low speed efficiency | Cost (magnets)<br>High speed losses<br>Complex to control<br>Difficult handling of failure modes<br>Temperature sensitivity (magnets) |
| Asynchronous machine | Cost<br>Losses at zero torque and high speed<br>No magnets<br>Robust design and well-established process for aluminum cage | Design<br>Losses in normal operating range (rotor leaking current)<br>Limited ratio of base to maximum speed<br>Reduced air-gap |
| Variable reluctance machine | Cost (no magnets, rotor in sheets only)<br>Low rotor sensitivity to temperature<br>No mechanical sensitivity (heavy rotor) | Nose<br>Design<br>Low industrial maturity<br>Complex electronics (for switched reluctance) |

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