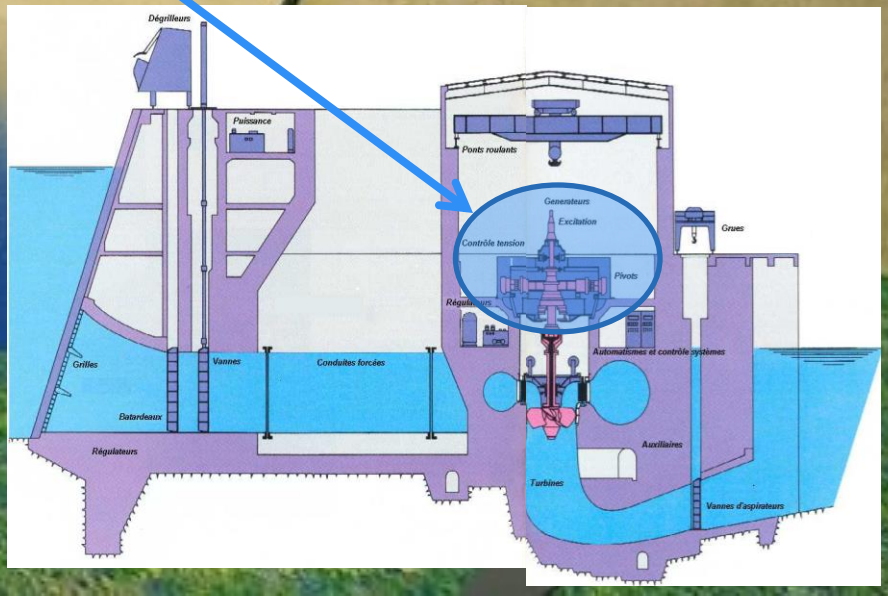
HydroGenerators

Hydraulic Generators - Generalities

Generator view



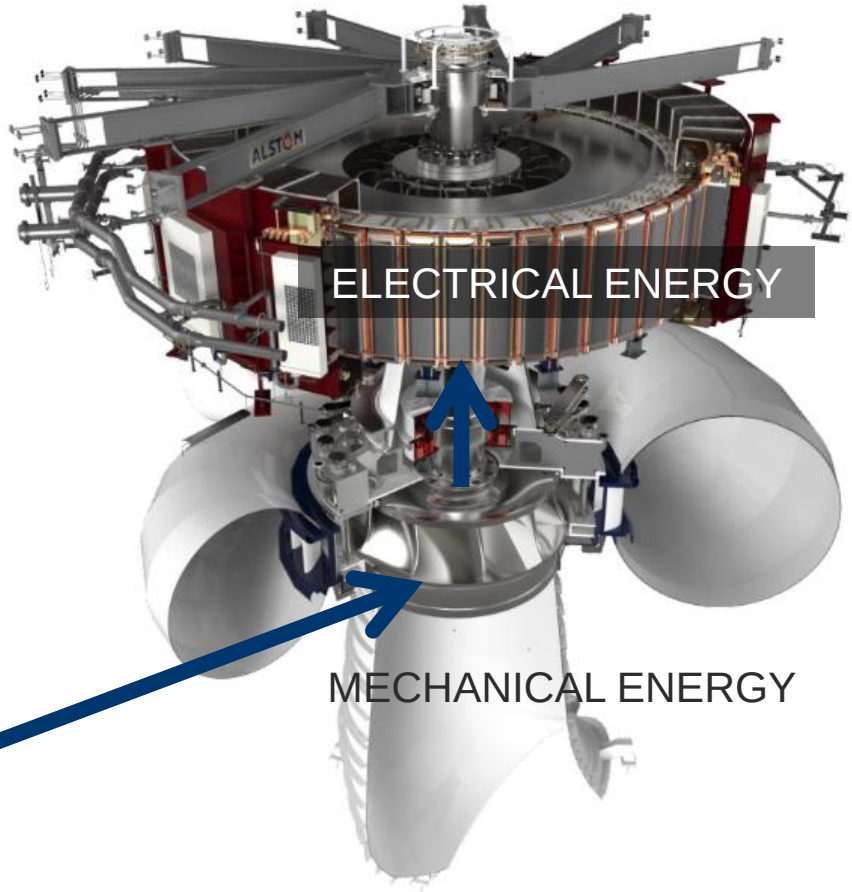
Hydraulic Generators - Generalities

Agenda

- Introduction / Generalities
- Electrical concept
- Electrical Components
- Mechanical Components
- Auxiliaries
- Varspeed machines

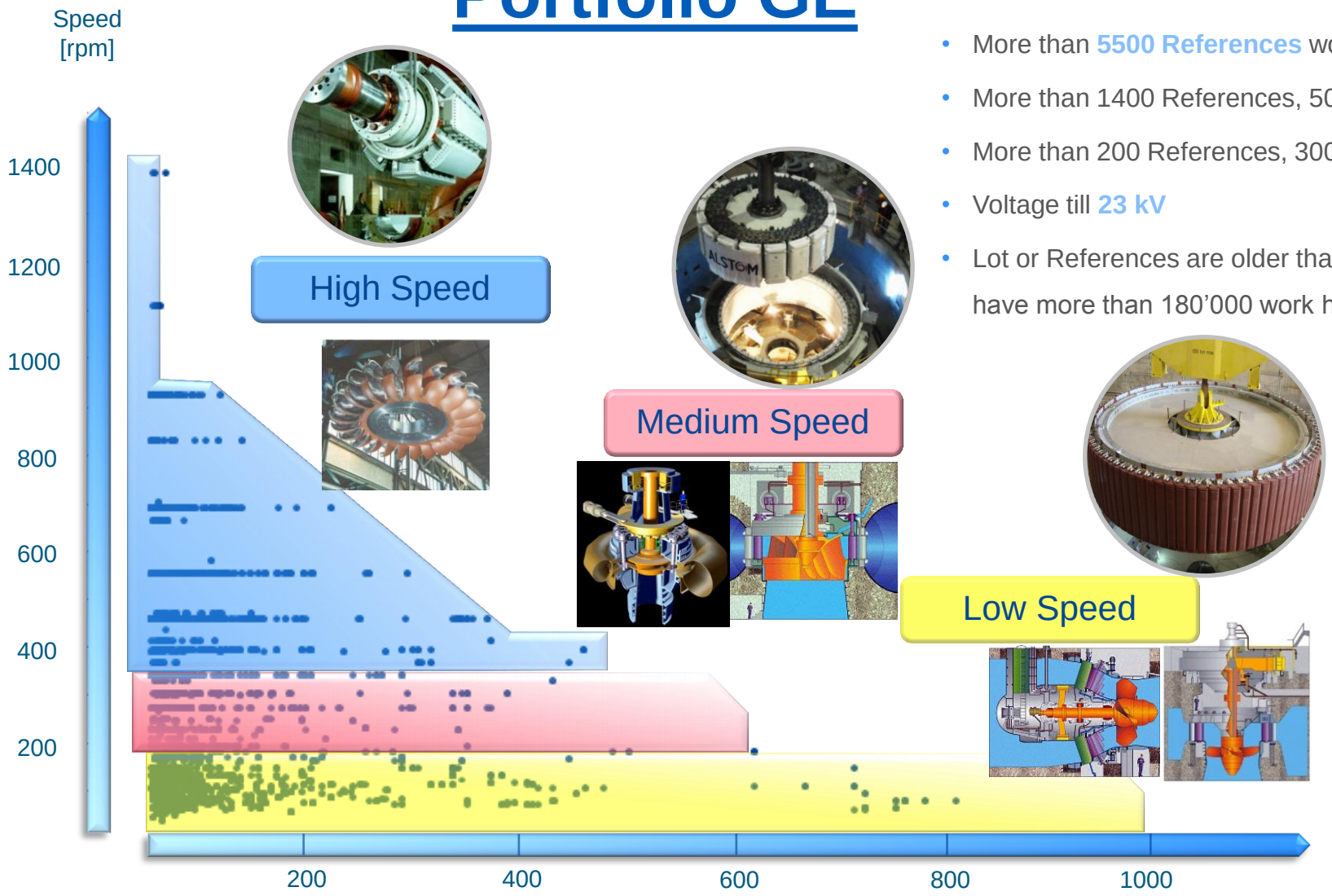
Introduction / Generalities

Why hydraulic generator ?



PRESSURE and KINETIC ENERGY

Portfolio GE

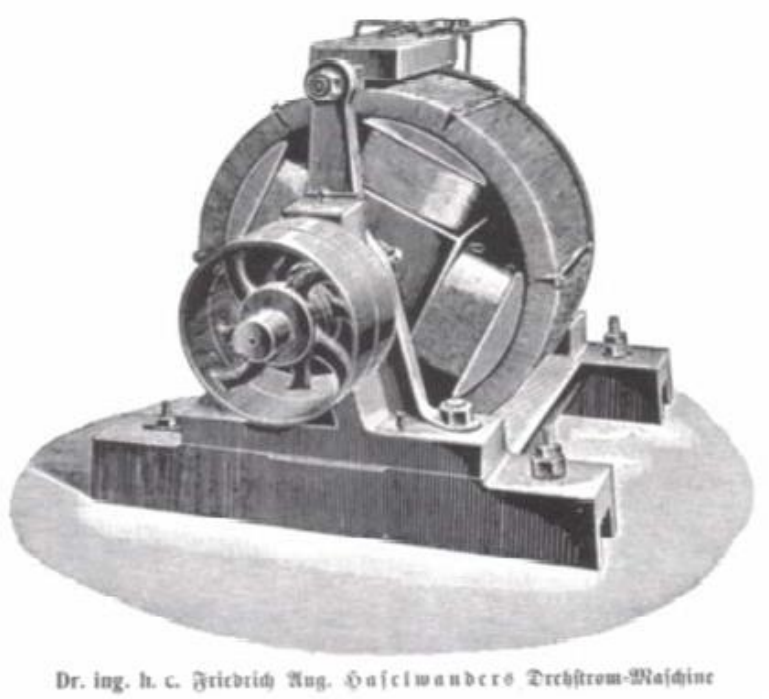


- More than **5500 References** worldwide
- More than 1400 References, 50 – 300 MVA
- More than 200 References, 300 – 889 MVA
- Voltage till **23 kV**
- Lot or References are older than **60 Years** and have more than 180’000 work hours

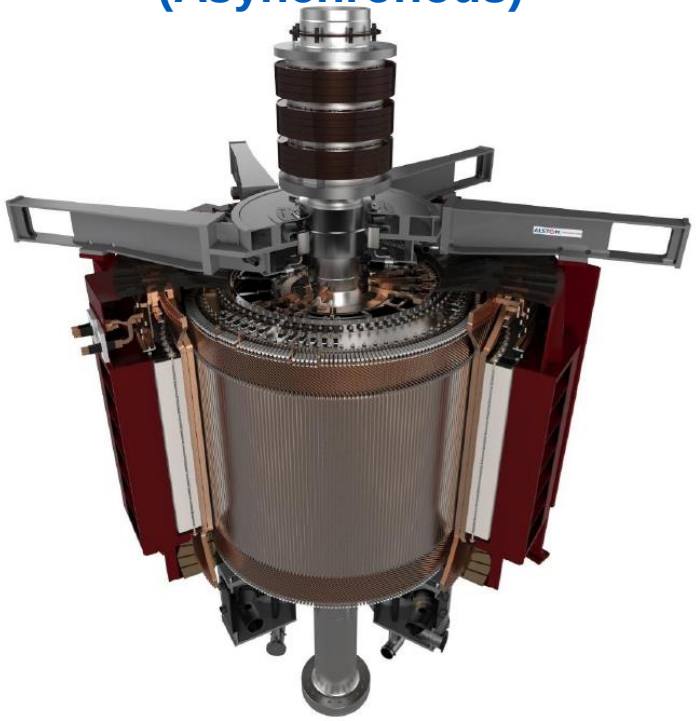
From First Synchronous generator

1887 : 1st Synchronous Generator

- 2’800 W, 960 rpm at 32 Hz
- Friedrich A. HASELWANDER



to High Power Induction machine (Asynchronous)



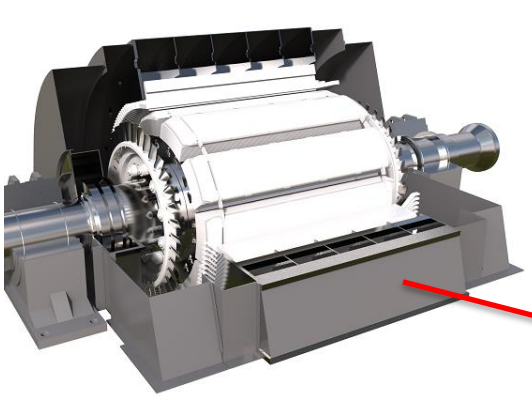
- **2015** : 1st Run of GE VARSPEED (Asynchronous)
  - LINTHAL
    - 250 MVA – 50 Hz
    - From 461 rpm to 530 rpm

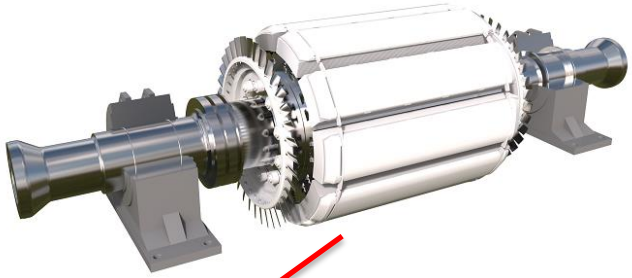
Electrical concept

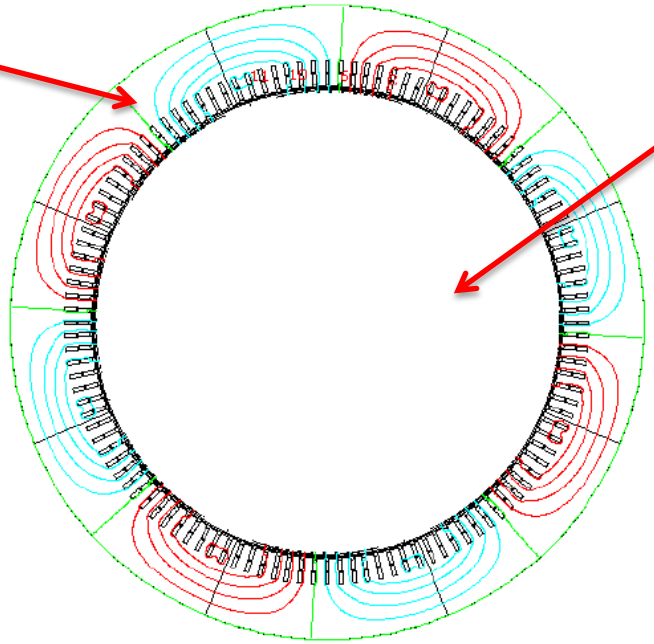
Electrical concept of synchronous machines

1 stator (fixed)

1 rotor (rotating)



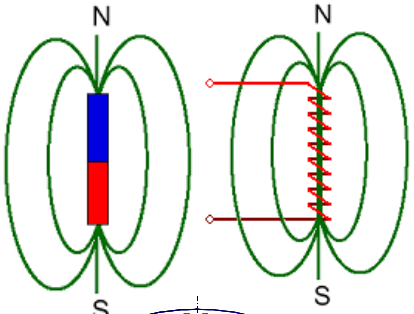


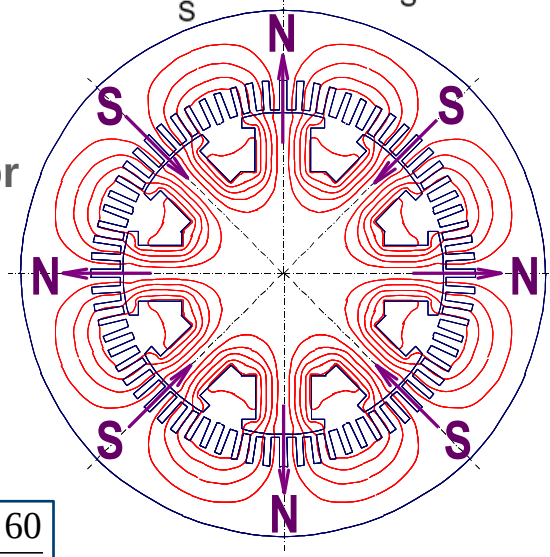


Electricity generation principle (discovered in 1830's)

Rotor – Poles circulated by DC current acting as magnets

- Poles by pair => ***2p*** poles/ ***p*** pair of poles around the circumference
- Magnetic Field (red lines) is driven through stator and rotor in circular field lines from pole to pole





Stator

- When the poles are rotating (rotor rotating at ***n*** rpm), the stator winding (fixed) see a time-varying magnetic field
- A voltage is generated (example: two coils U1, U2) with the Lentz's law $EMF = -\frac{\partial \phi_{rotor}}{\partial t}$

Speed and Frequency

- An observer on the stator will see a field variation with a frequency ***f***, the relation with the rotor speed ***n*** *(rpm)* is $n = \frac{f \times 60}{p}$

p	1	2	3	4	5	6	7	8	9	10
n	3000	1500	1000	750	600	500	429	375	333	300

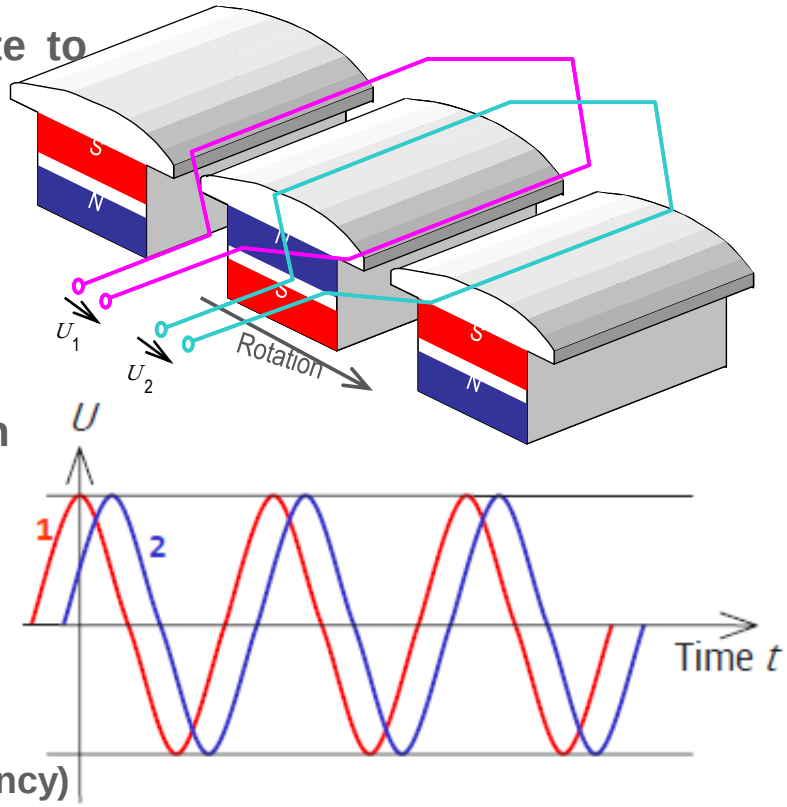
Example for 50Hz

STATOR

$$EMF = -\frac{\partial \phi_{rotor}}{\partial t}$$

- When the poles are rotating, stator is seeing variable magnetic fields
- Each turn of the stator winding will contribute to create a voltage at the end-winding
  - *U1 for the mauve circuit*
  - *U2 for the blue circuit*
- Usually, there are 3 circuits on the stator (three-phase generator)
- Circuits could be connected in parallel (for each phase) in order to respect the Stator voltage requirement

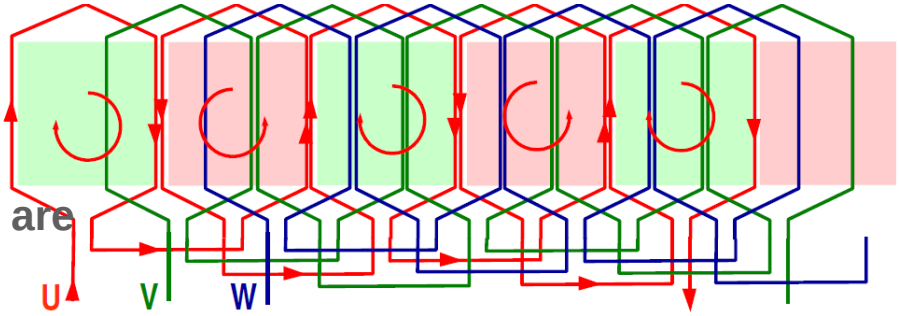
$$U = -w\frac{d\Phi}{dt}$$



=> Voltage depends on

- Size (area A) of the winding
- Number of turns ***w*** of the winding (doing a coil)
- Magnetic flux density and time variation (frequency)

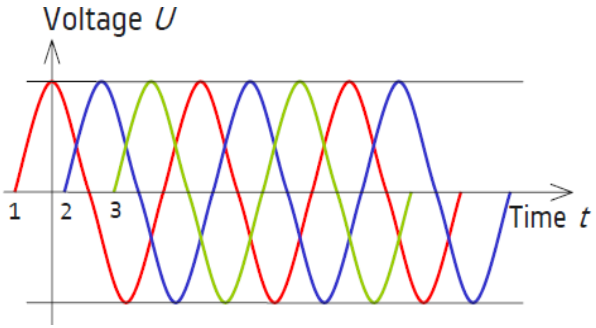
EMF : Electromotive Force following LENZ-FARADAY Law



3 Phase Stator Winding

- Stator windings has 3 phases (U,V,W) which are
  - Distributed symmetrically around the circumference
  - Shifted by 2/3 of the pole path

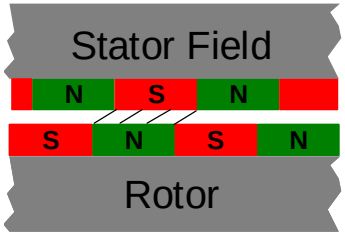
  => Goal is to get three sinusoidal time depending phase shifted by 120°

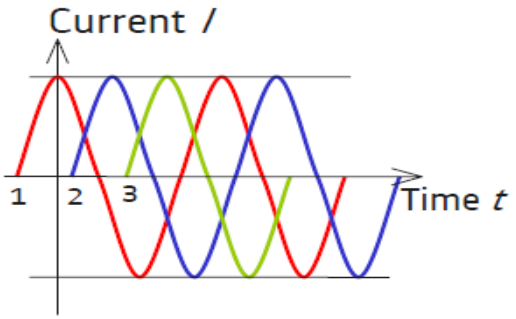


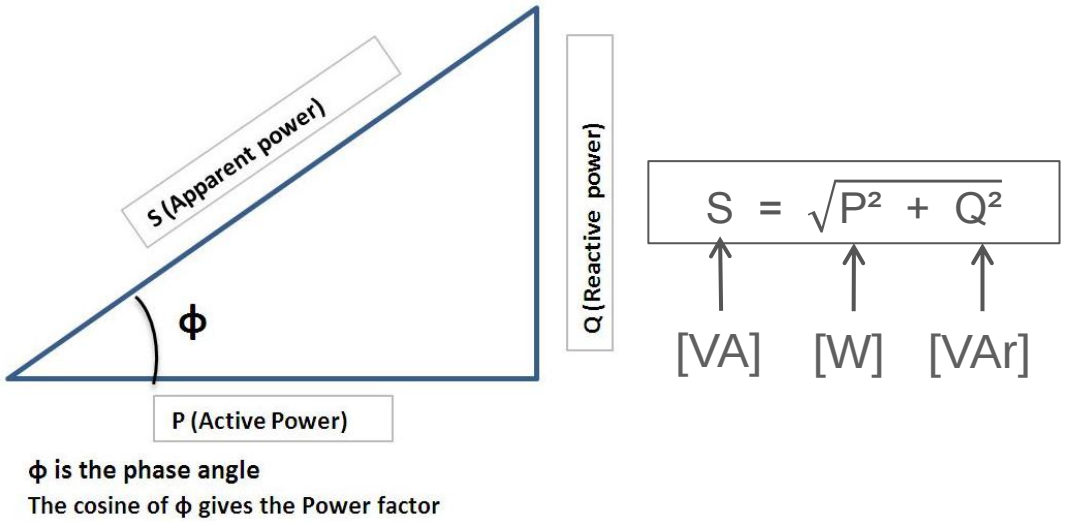
Induction in Stator Winding *(closed circuit – Load)*

- When the machine is connected to the grid, current is circulating in the stator windings which are :
  - Shifted by 120°
  - generate magnetic field wave running around with synchronous speed

    ⇒ Torque is generated



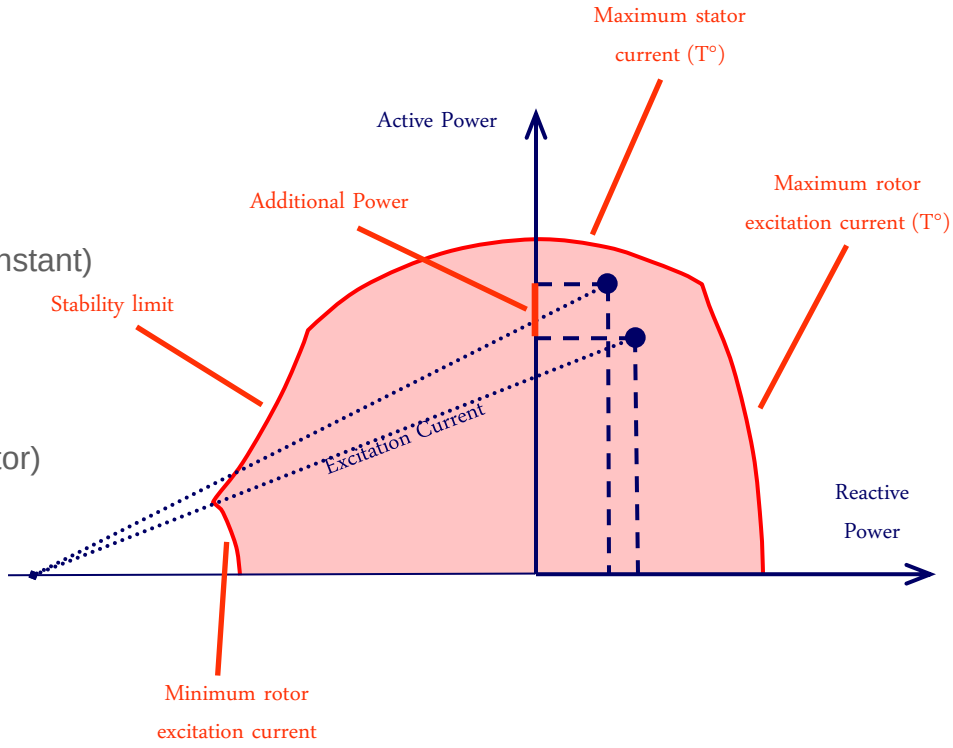




- Active Power [KW] → This is the power that creates work (given from turbine)
- Reactive Power [KVAr] → Grid characteristic
  - Does not create work
  - Characterized by a phase displacement between voltage and current
    - Reactive power is created by capacitors (I in front of U, phi>0)
    - Reactive power is consumed by inductances (I is behind U, phi<0)
- Normally the grid (consumers) consume reactive energy, therefore the generators must be able to compensate this demand. Synchronous machines in overexcited mode are able to deliver this reactive power.

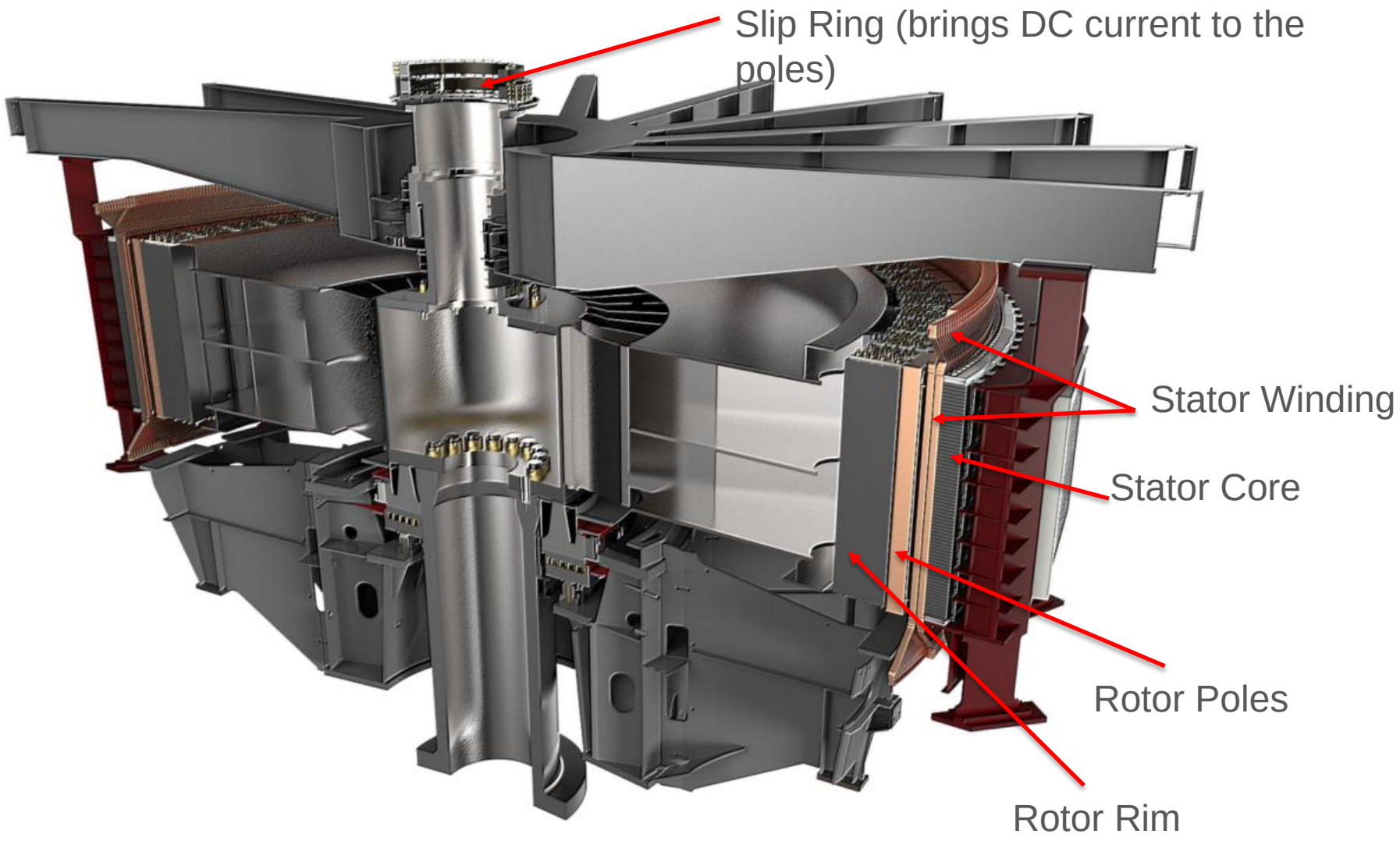
Automatic Voltage Regulation (AVR) – Electromagnet control

- **Active Power**
  Regulated by turbine only
- **Reactive Power**
  Regulated by excitation current
- **Example**
  - More power (“additional power”) from the turbine side
  - Reactive power decrease (excitation current keeps constant)
- **Operational limits are defined by**
  - The maximum rotor excitation current (T°)
  - The maximum stator current (T°)
  - The stability limit (magnetic angle between rotor & stator)
  - The minimum rotor excitation current



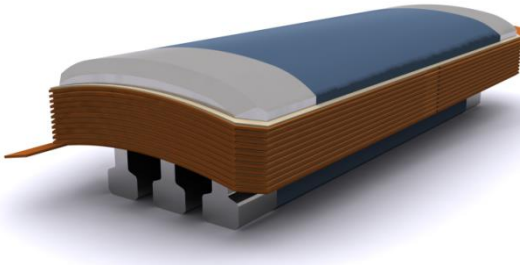
AVR allows the control of Grid Voltage and Reactive Power (Grid Interface)

Electrical Components


Slip Ring (brings DC current to the poles)
Stator Winding
Stator Core
Rotor Poles
Rotor Rim

POLES

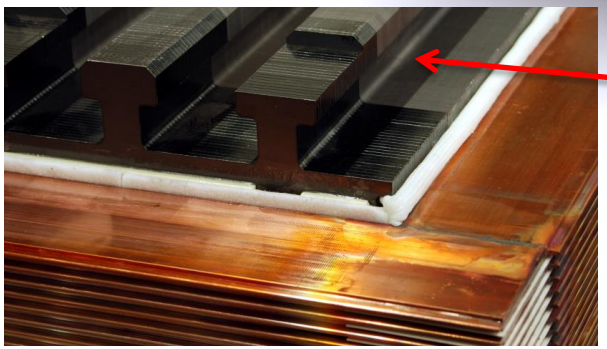
Pole is composed of



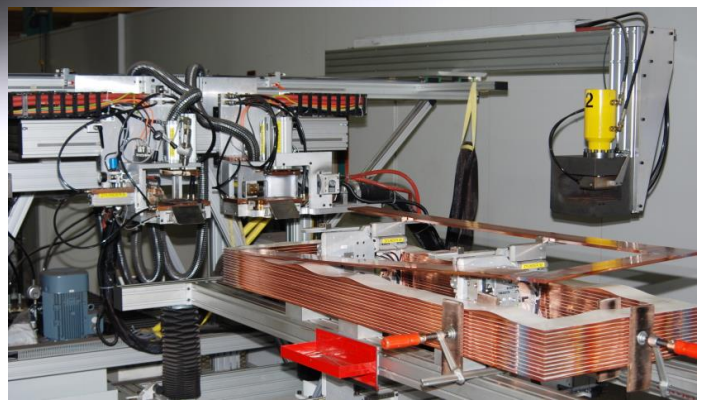
End Plates
& Tension Rods

Pole sheets (magnetic sheets which are stacked)

Coils with Insulation

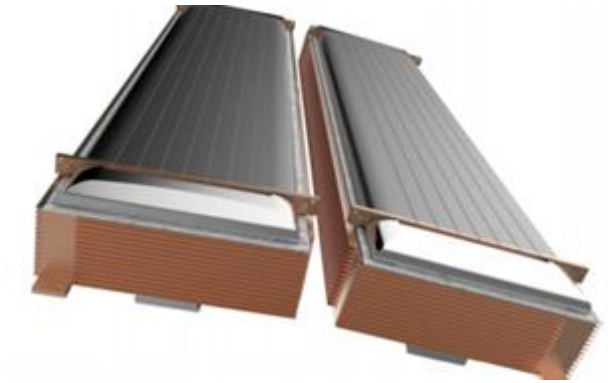


Claws (which are used to be connected to the rotor rim)

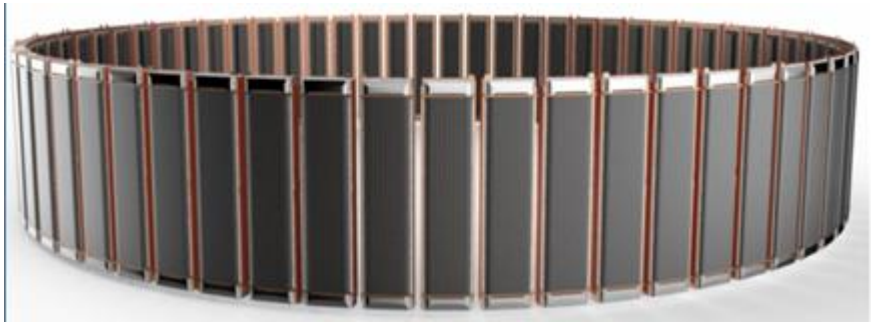


POLES

Poles alone

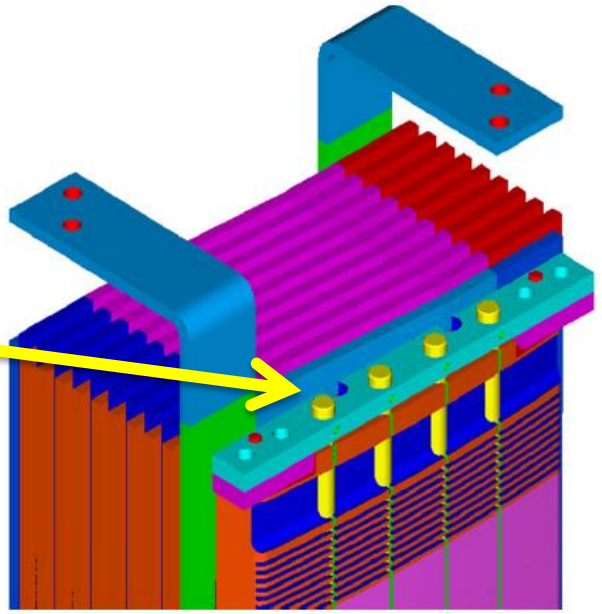


Poles creating a circle (rotating around the stator)



Damper bars

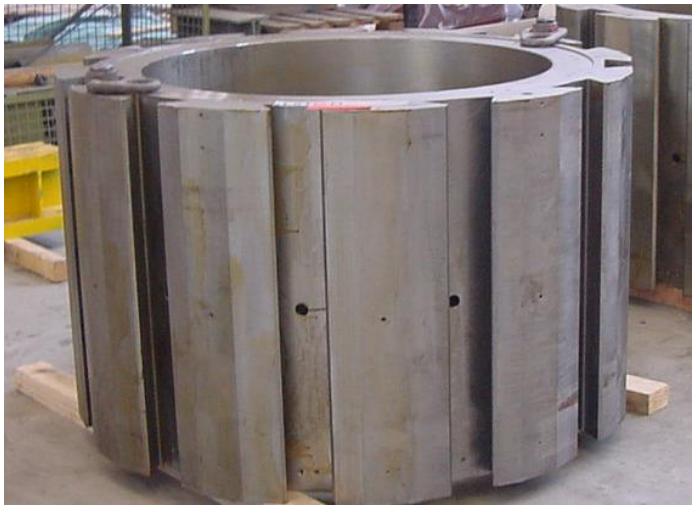
- Synchronization:
  - Helps to synchronize smother
  - Allows to start up as induction motor (squirrel cage)
- Reduces overvoltage when sudden stator sort circuits
- Reduces rotor oscillations



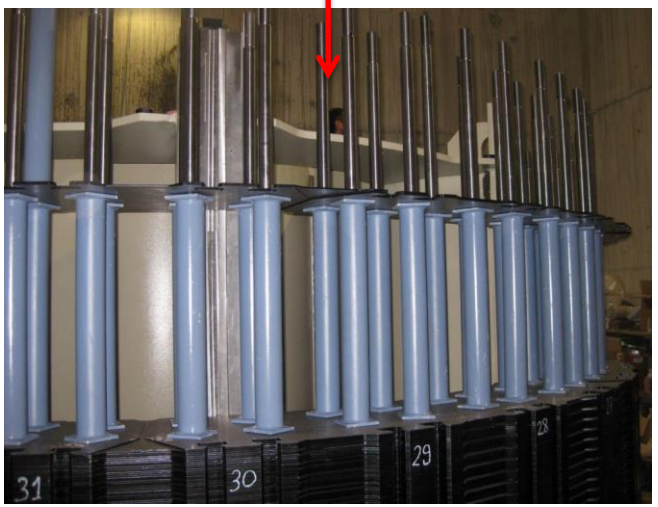
ROTOR RIM

Magnetic material used to conduct the magnetic field

Forged (solid)



Laminated (stacked)



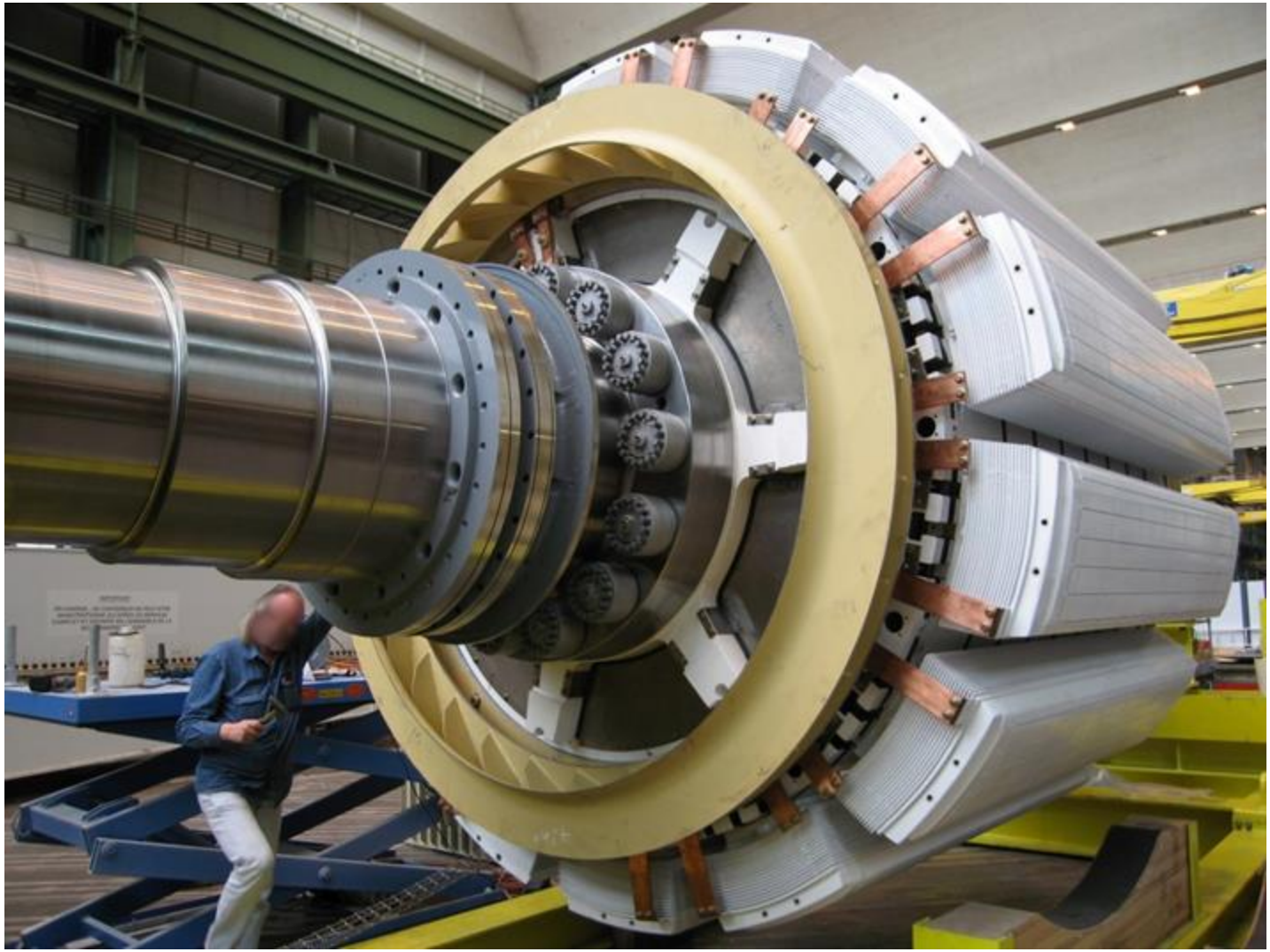
ROTOR RIM - Laminated

SEQUENCE

Stacked with the studs/bolts

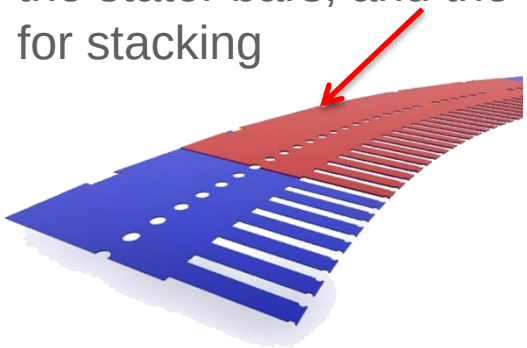
Stacked and pressed with the pressplates

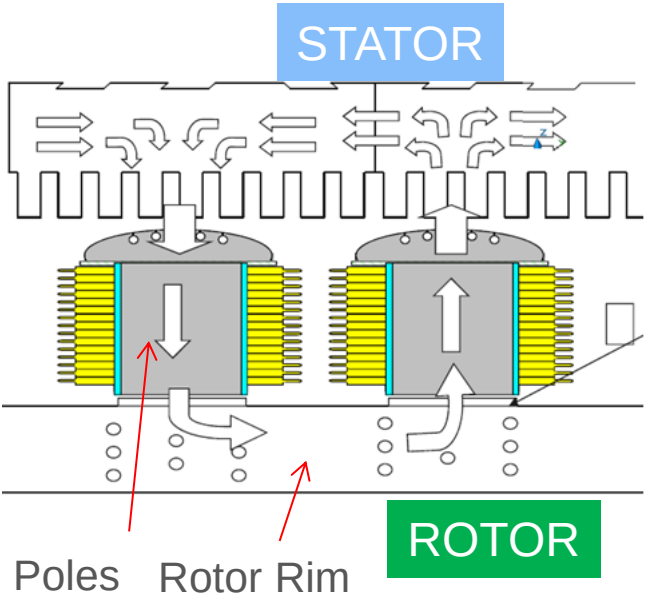
ROTOR COMPLETE



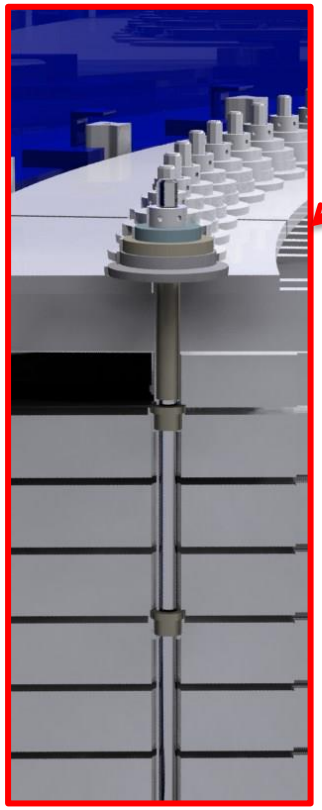
STATOR CORE

Stator Core with Slots where will be inserted the stator bars, and the holes for the key bars for stacking

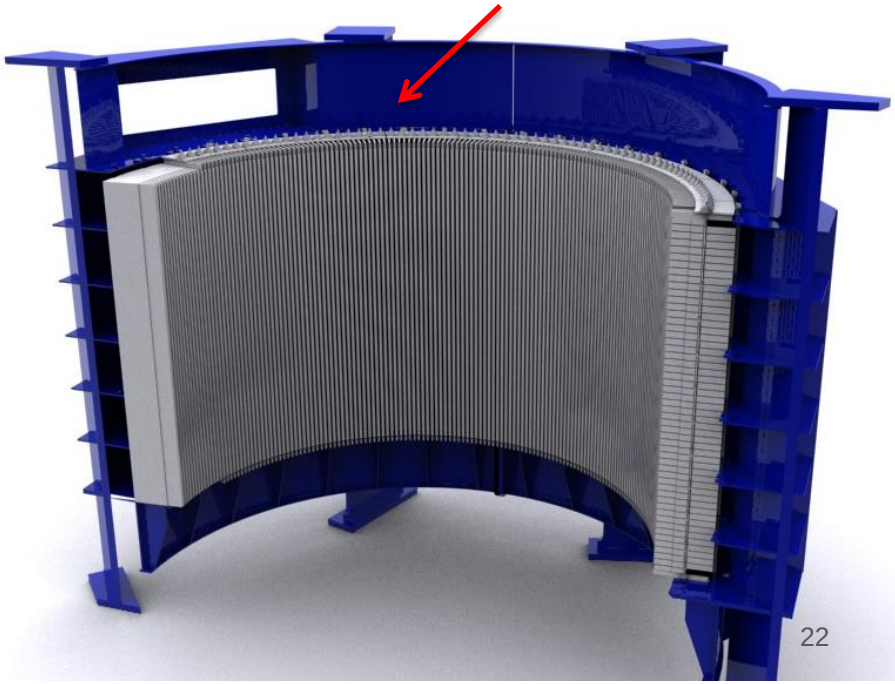




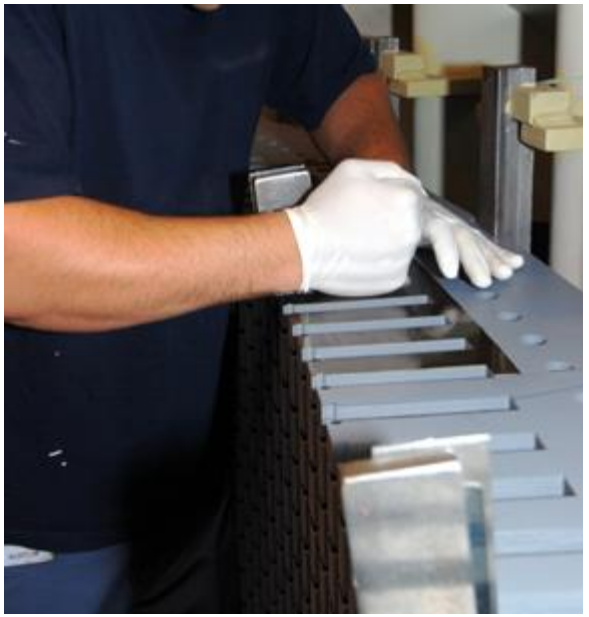
Stator Core at final stacking stage, using an non magnetic pressfingers for the final tightening (pressplate and pressfingers)



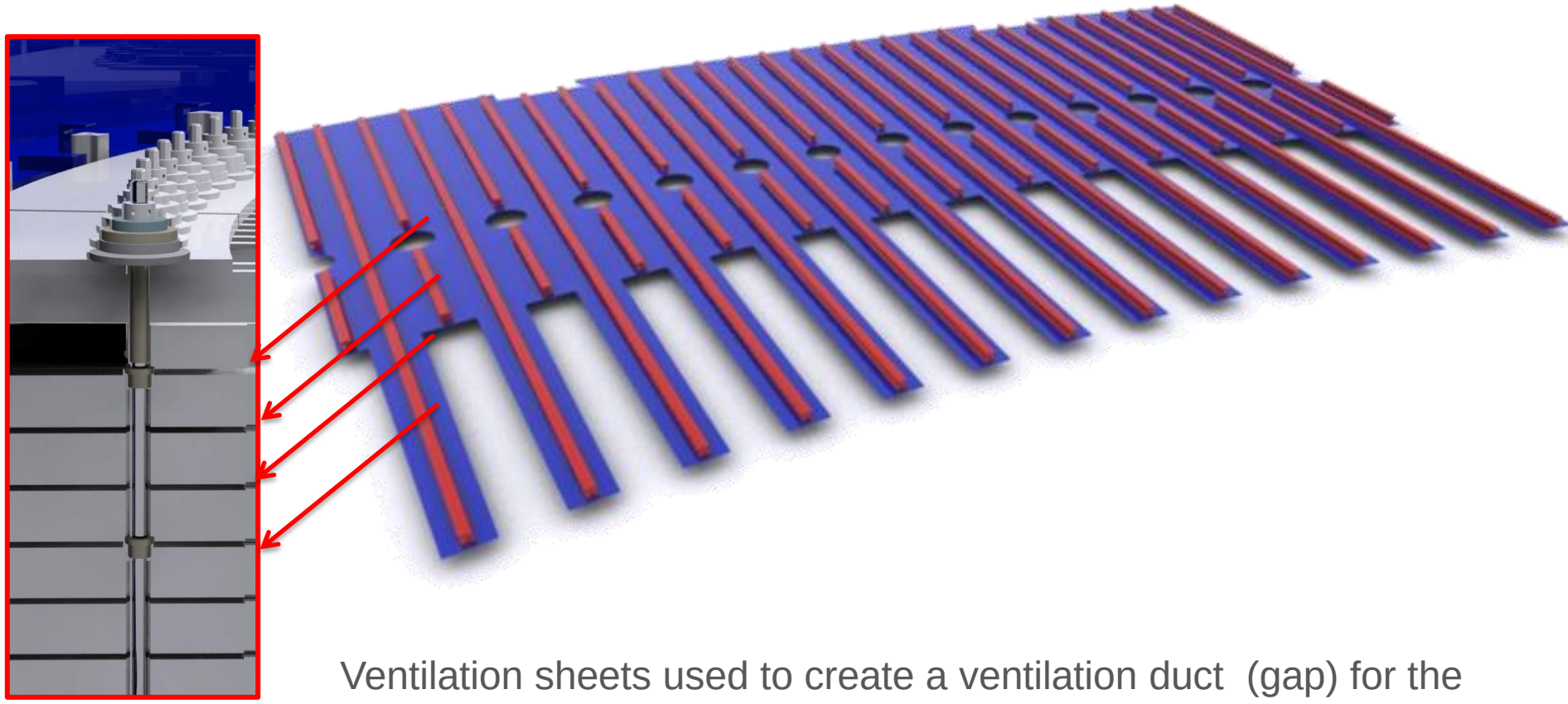
Complete stator core stacked



STATOR CORE



STATOR CORE VENTILATION



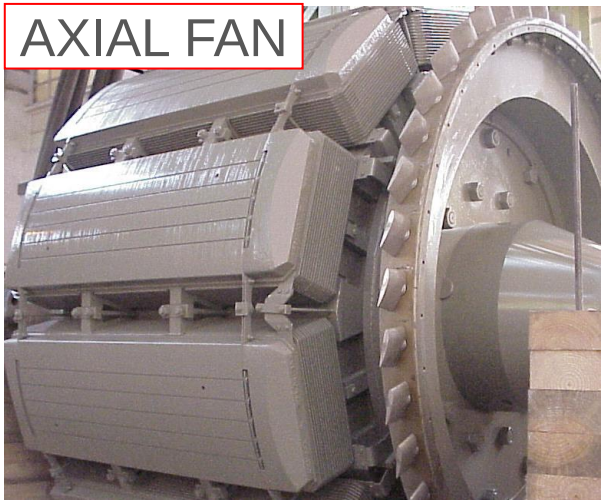
Ventilation sheets used to create a ventilation duct (gap) for the air

GENERATOR VENTILATION

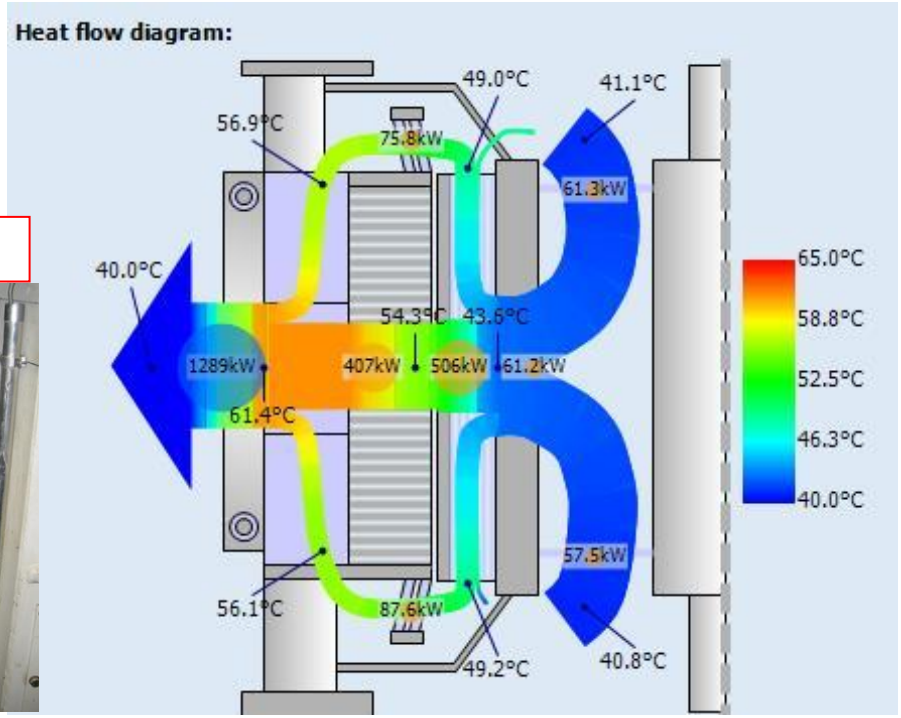
A lot of different ventilation principles could be imagined (guide the air)– high investigation for optimization :

- through the rotor rim (or not)
- through the air gap (via the rim or/and top & bottom)
- Through the end-windings (top and/or bottom – or not)
- Through the stator core and through the air coolers

AXIAL FAN

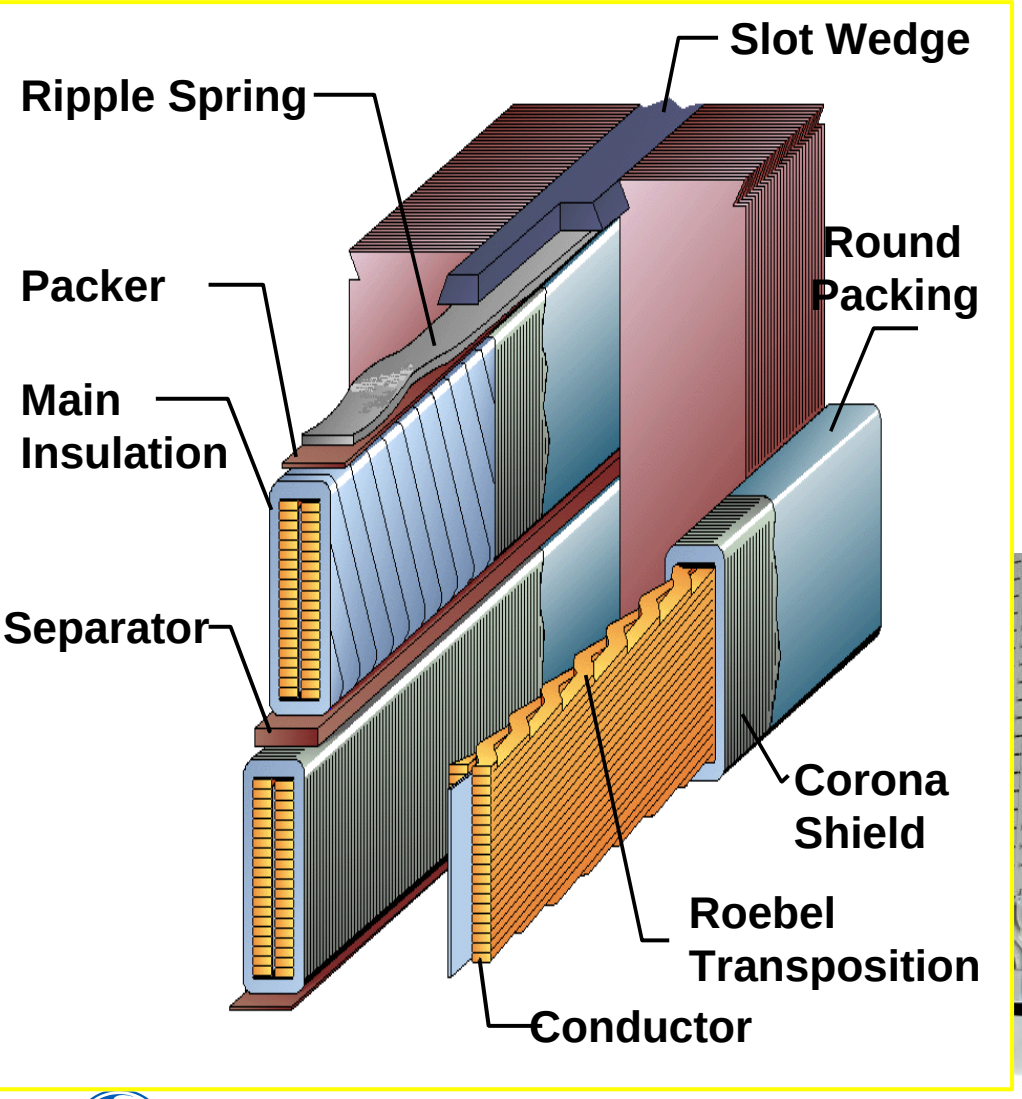


AIR COOLERS



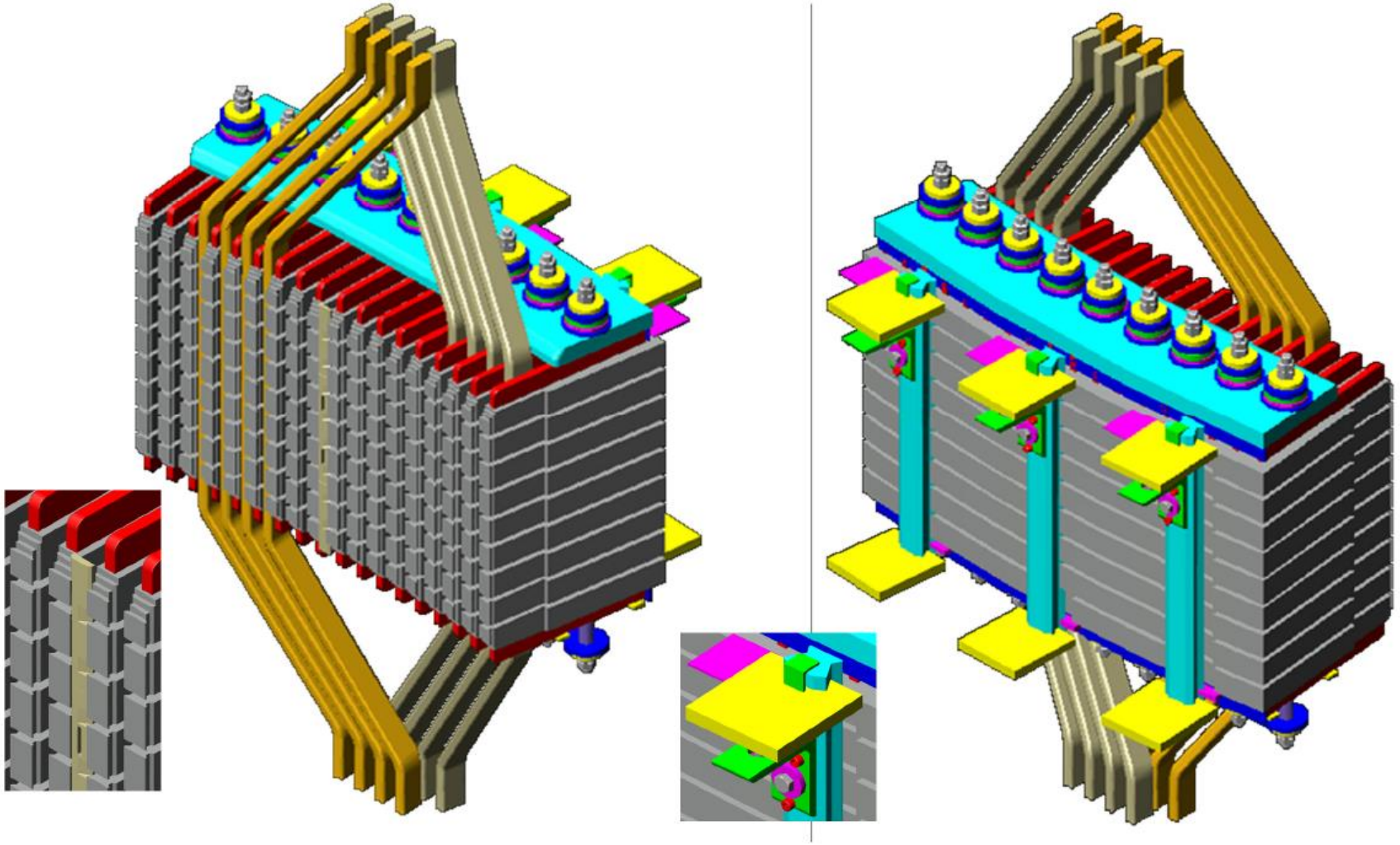
RADIAL/CENTRIFUGAL FAN

STATOR BARS

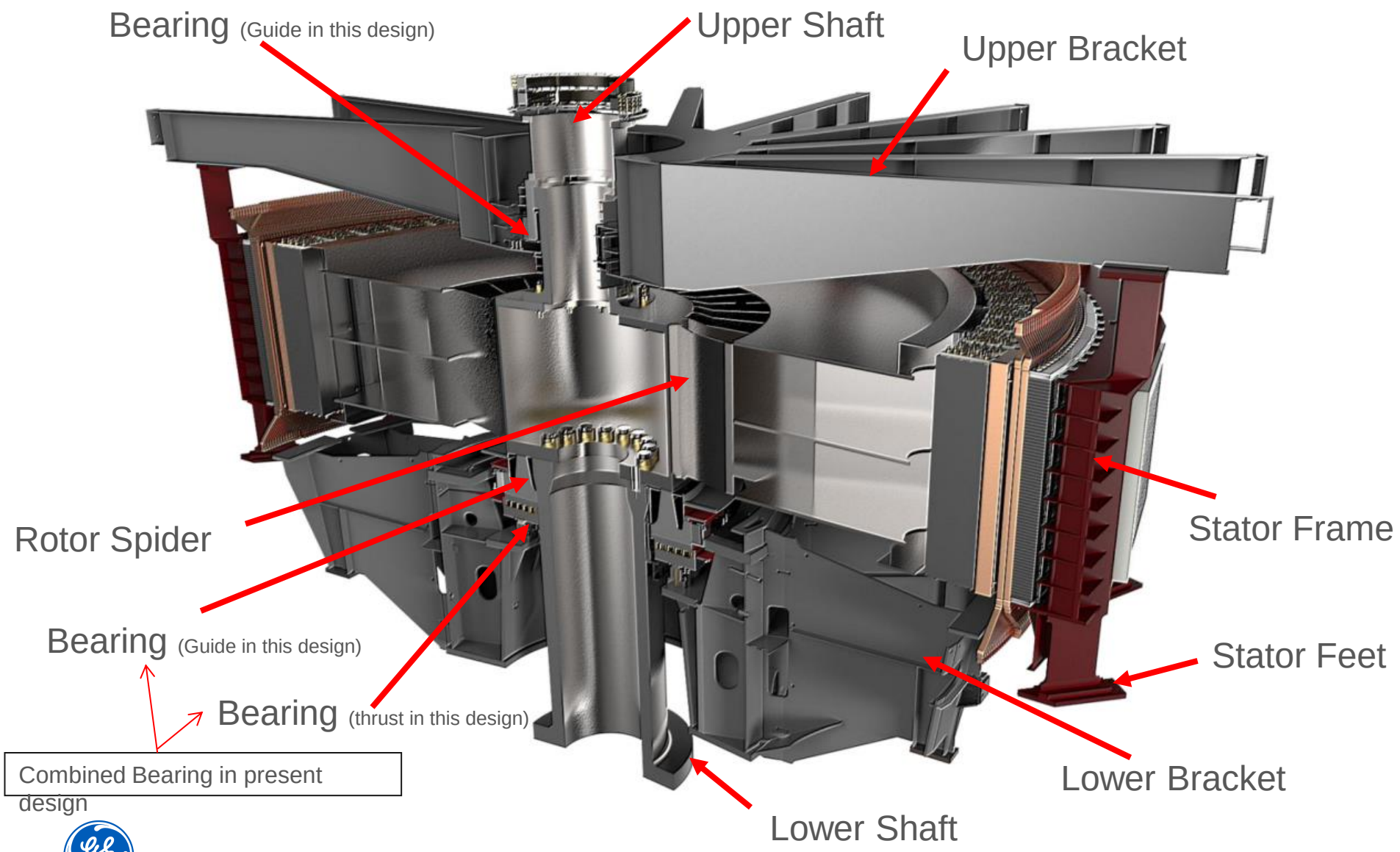


- BARS : Mainly Roebel bars used (Roebel is the technic to shift the strands each to another / transposition)
- INSULATION : used to control the main electrical field and avoid corona effect between adjacent bars (lightening)

STATOR BARS



Mechanical Components



Combined Bearing in present design

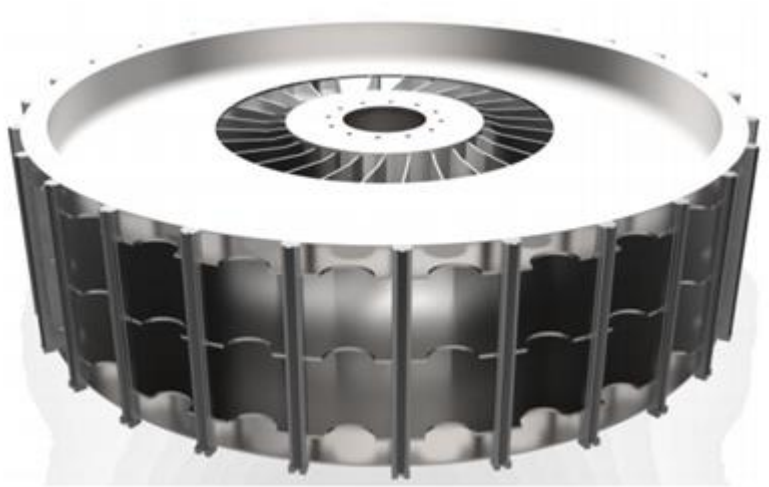
SHAFT

Two shafts : Upper and lower shafts bolted to solid rim or spider hub

Passing through going shaft without central disc
Rotor rim/spider shrink fitted to the central part

ROTOR SPIDER

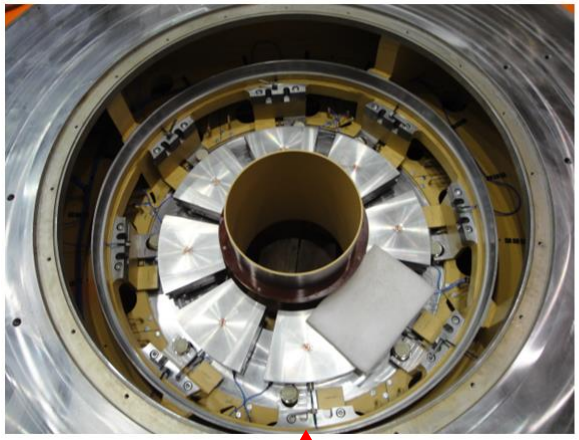
Rotor Spider shrink fitted to the Shaft
&
Rotor Rim shrunk on Rotor Spider

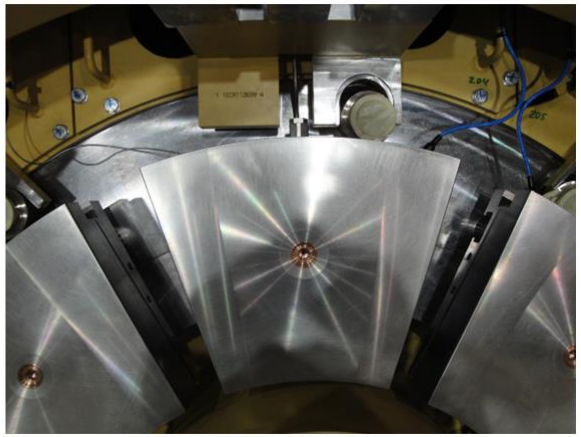


Rotor Spider usually welded at site

Rotor Rim is stacked on the Rotor Spider (wedge carriers), also followed by shrinking the rim on the spider

THRUST AND GUIDE BEARINGS





Thrust bearings are used to support all axial forces/load :

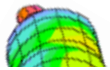
- weight of all rotating parts (turbine, generator rotor)
- Axial thrust from the turbine
- Any defaults (i.e. : electrical for generator)

Guide bearings are used to support all Radial forces/load :

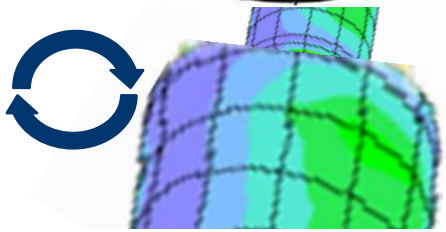
- dissymmetry of rotation/Shaft
- Thermal expansion
- Run out of shaft
- Any defaults (i.e. : electrical)

Thrust and Guide bearings are composed of pads (transmit the load to the bracket and foundations) and a fluid (oil) which allows the rotation (Hydro-dynamics). Fluid is circulating to be cooled.

BRACKETS

Guide bearing Bracket  *– radial Forces + bending*

Radial Forces



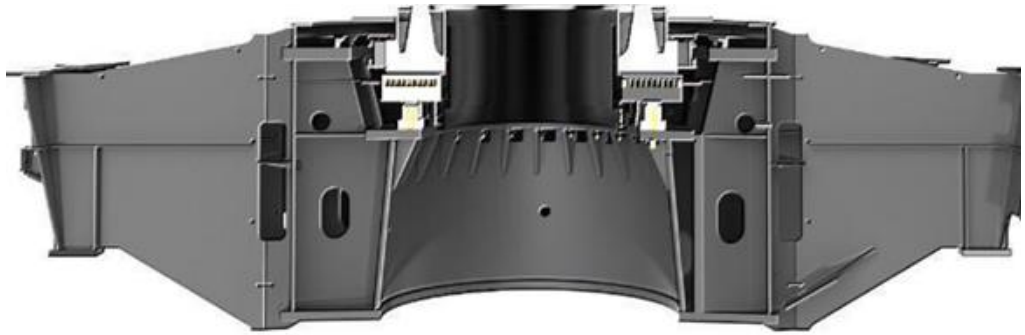
Critical Bending Speed

Oblique elements to allow thermal expansion, reduces foundations loads/stresses

Radial arms for small machine and when there is no connection to foundations

Thrust Bearings Bracket

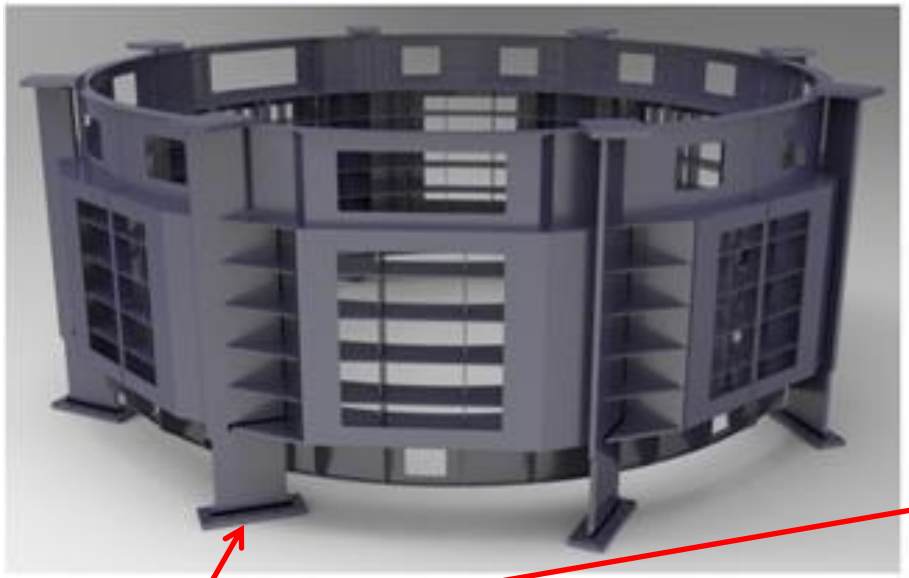
Rotor weight + Axial load from turbine

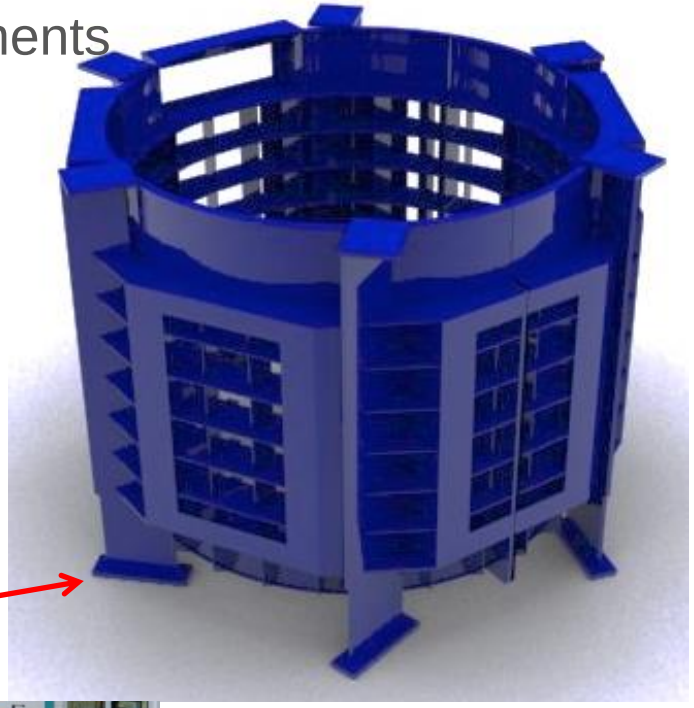


Combined Bearings Bracket

STATOR FRAME

Stator Frames – also done with Oblique Elements

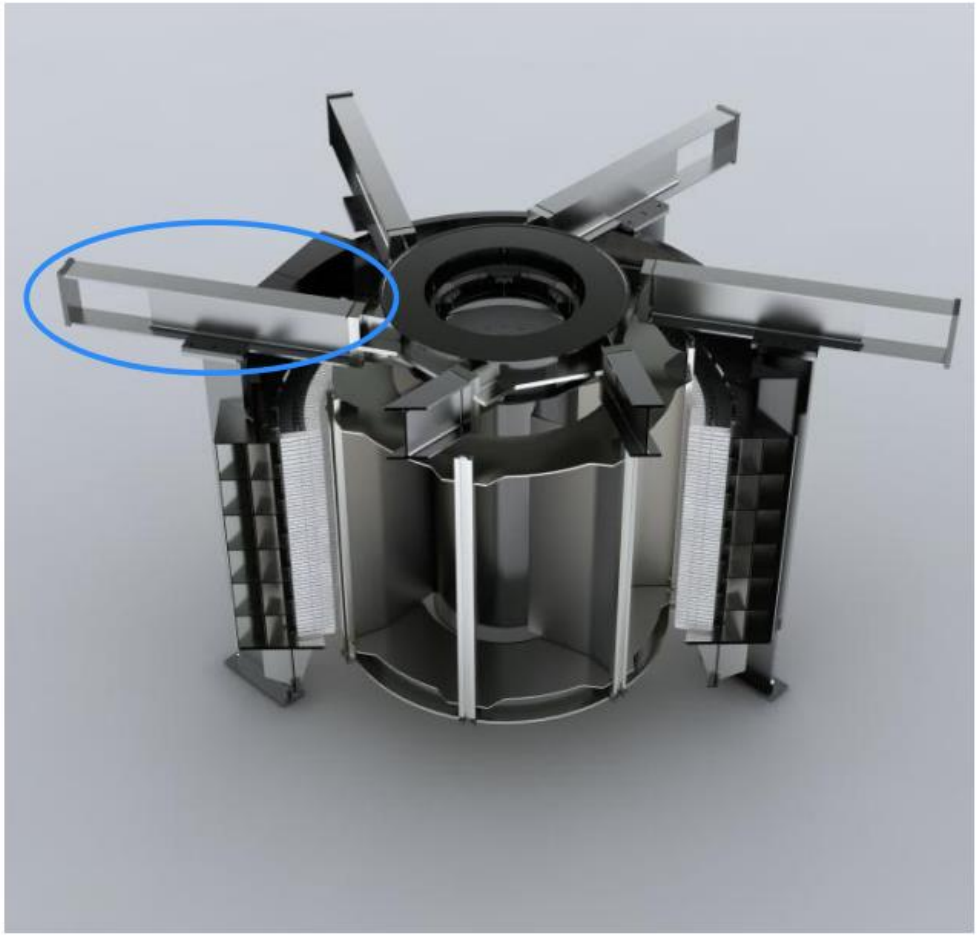




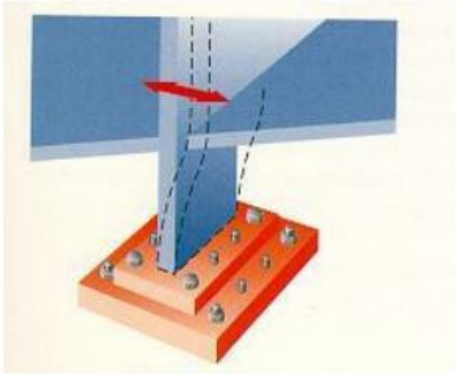
Oblique feet

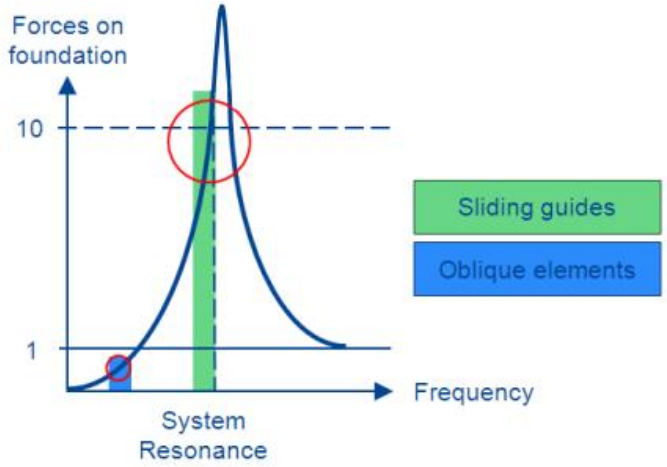
OBLIQUE ELEMENTS

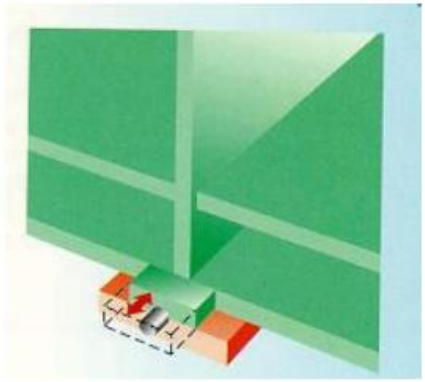
- There are more than 100 power plants or 300 machines in operation, starting from 1957, without any single notice of cracks in the stator frame due to low frequency vibration.



OBLIQUE ELEMENTS



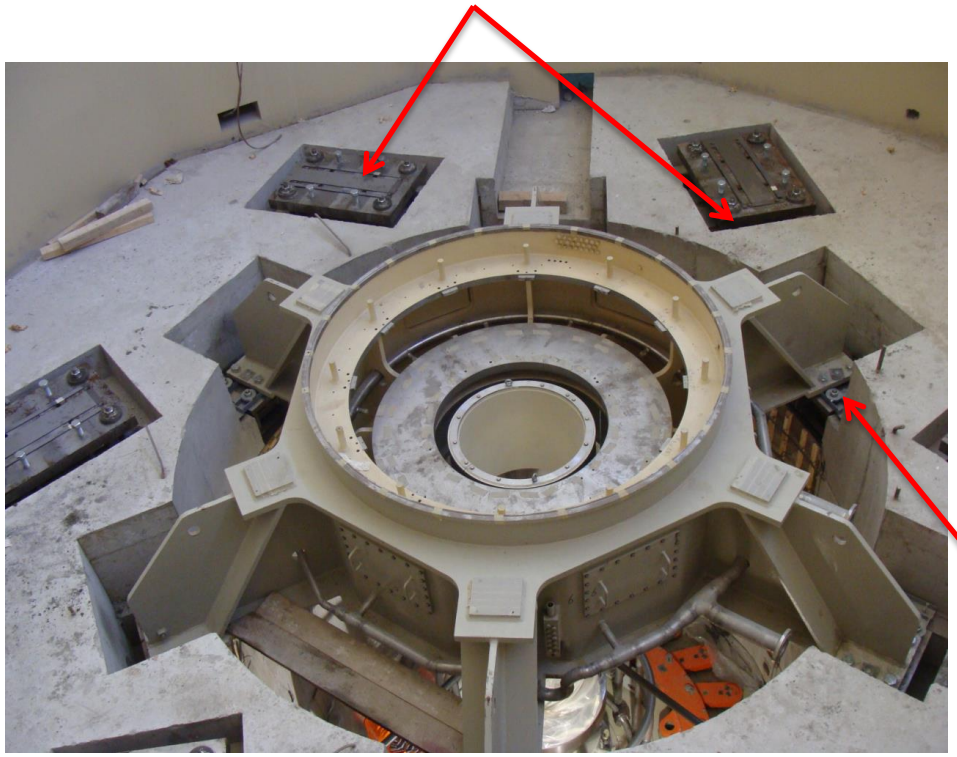




Oblique feet with fixed base	Radial guides with sliding base
High annular stability	Low inherent annular stability
High control of natural torsion frequency	No control of natural torsion frequency
No need for maintenance	Regular maintenance required
Lower transversal stiffness	High transversal stiffness
Lower foundation loads	Higher foundation loads
Low buckling risk	Higher buckling risk

FOUNDATION / PIT

Sole Plates to fix the Stator Frame (Feet)



Fixation of the Bracket to the foundation to transmit loads

PIT CLOSING

Pit cover are used to close the air inside the generator, and also limit the propagation of any fore inside the generator

PIT COVER– part where we can walk and make maintenance of the slip rings/brushes

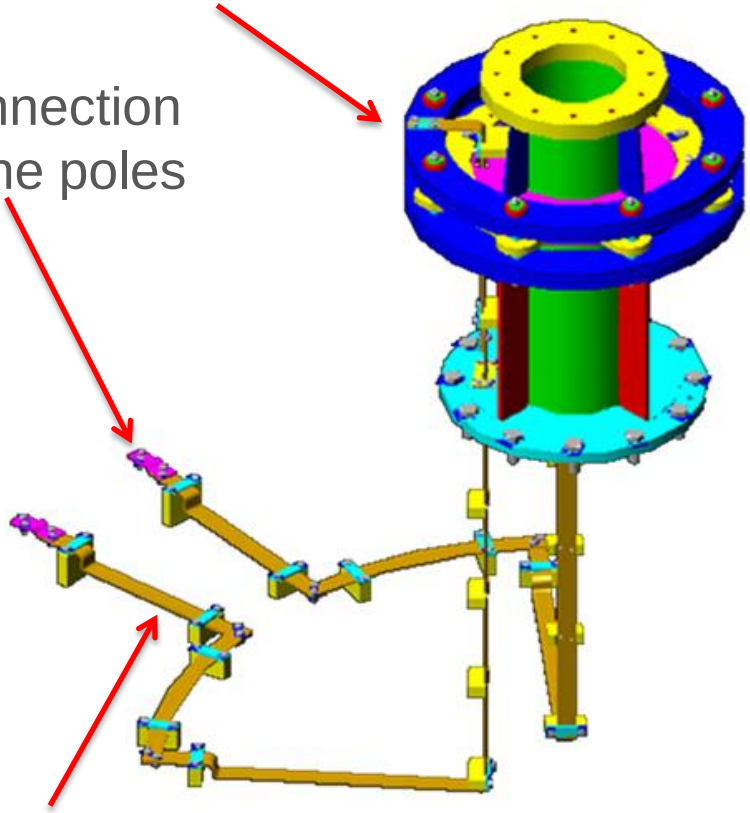
LOWER PIT COVER – part to isolate the Turbine parts from the generator parts

Auxiliaries

DC CURRENT TO POLES

Slip ring

Connection to the poles



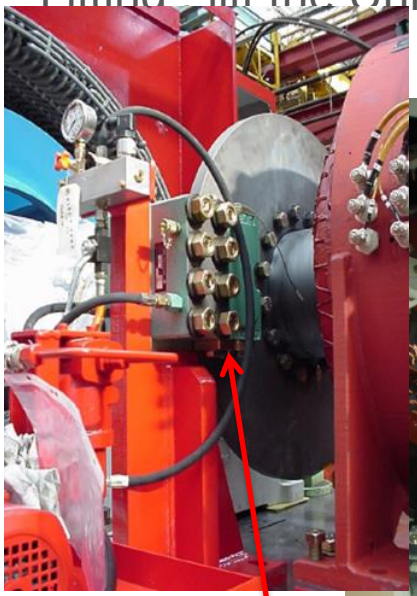
DC Bars – coming from Excitation System

Carbon Brushes

Springs for brushes

BRAKING & LIFTING

- Braking (disc) : Stop the Unit in after 30% of nominal speed (emergency) - jacks or calipers
- Lifting : lift the Unit for maintenance or for the start sequence



Brake disc (Vertical or Horizontal)

Combined jack for braking and oil for lifting

Jack alone
(when only brake disc)

Varspeed machines

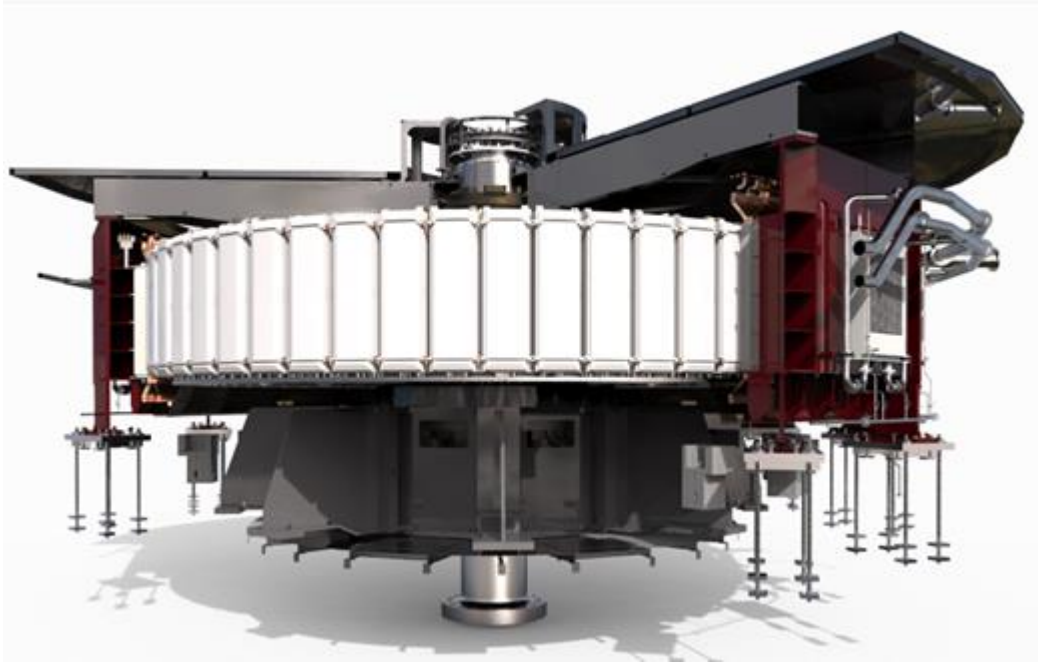
Asynchronous Machine – General Concept

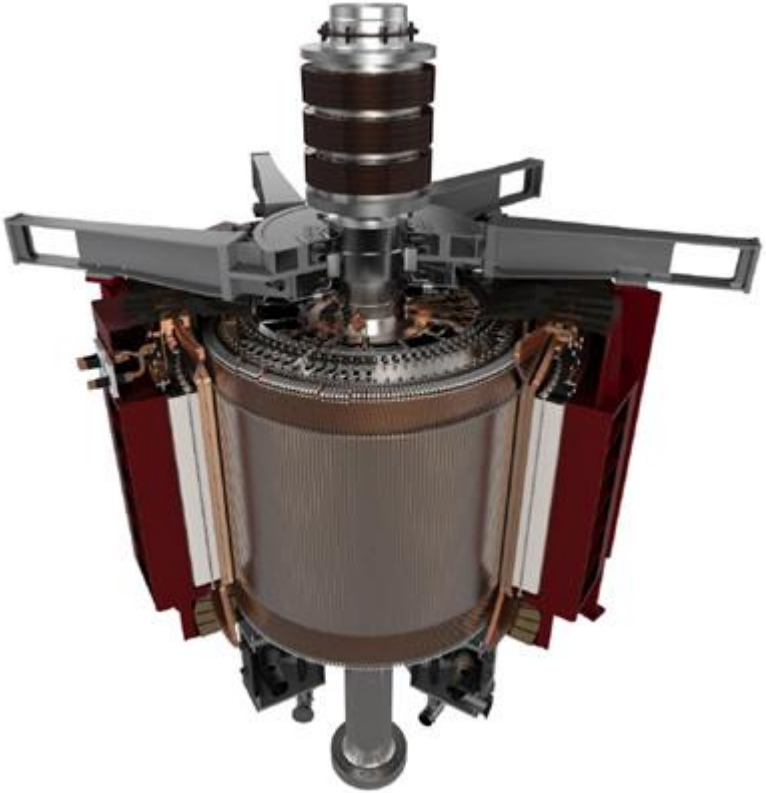
What is the difference between

standard hydraulic machine (synchronous – salient pole)

AND

next generation for PSP (Pump Storage Power Plant)

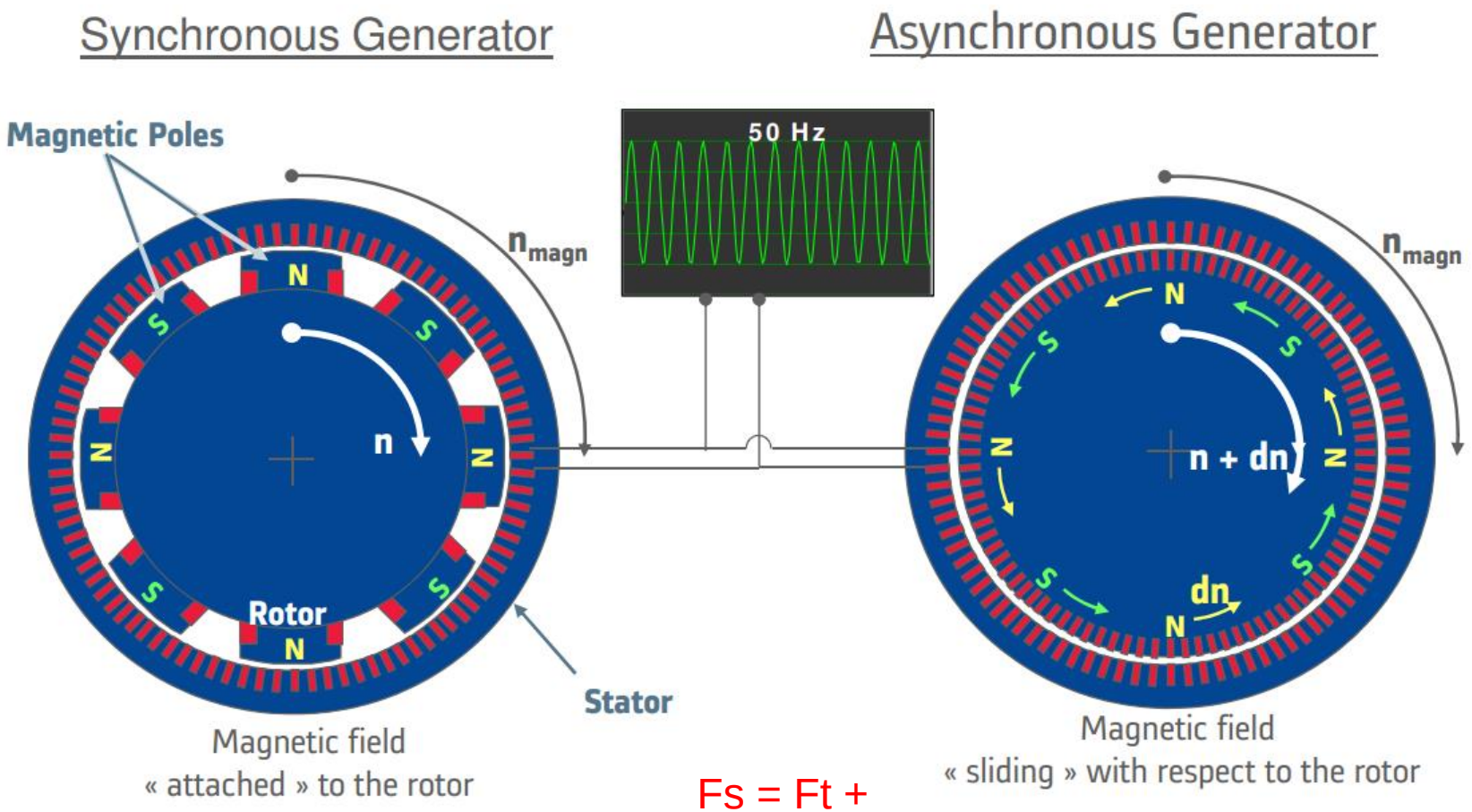




SYNCHRONOUS MACHINE

DOUBLE FED ASYNCHRONOUS MACHINE - DFAM

Asynchronous Machine – General Concept

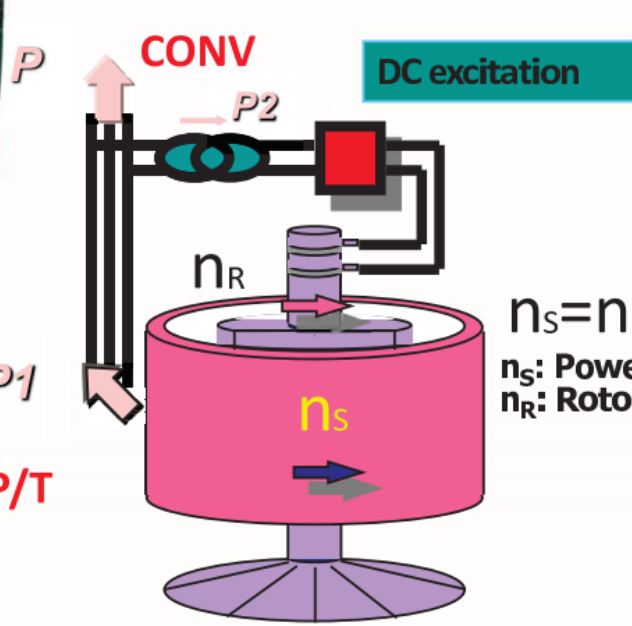


$Fs = Ft + Fr$

Fr → Excitation frequency (current on the rotor)
Fs → Stator frequency (Grid frequency)
Ft → Rotor frequency (rotation of the shaft)

Asynchronous Machine – General Concept

[1] System output/input is not equal to G/M terminal output/input.

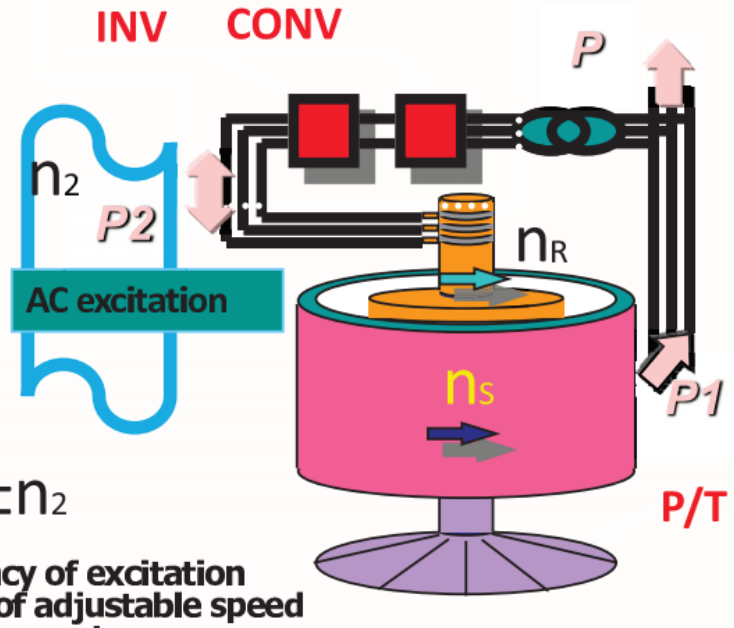


$n_S = n_R$

n_S: Power system frequency
n_R: Rotor rotational frequency

Constant speed machine

Excitation system of adjustable speed generator-motor



$n_S = n_R \pm n_2$

n_2: Slip Frequency of excitation system of adjustable speed generator-motor

Adjustable speed machine

P>>P2 ∴P≒P1

P : System output
P1: Generator terminal output
P2: Power to exciter

Value and/or direction of "P2" is changed due to the value of "n2".

∴ P≠P1