1. Manufacturing of Large Electrical Machines

1.1 History and significance of electric machinery

1.2 State-of-the art of medium and high power machines

1.3 Trends in large generators and high power drives

Source: Andritz Hydro, Austria

1. Manufacturing of Large Electrical Machines

1.2.1 Manufacturing of a big hydro generator

Source: Andritz Hydro, Austria

Manufacturing the stator of a hydro generator with vertical shaft

Welded stator housing of synchronous hydro generator

Source:

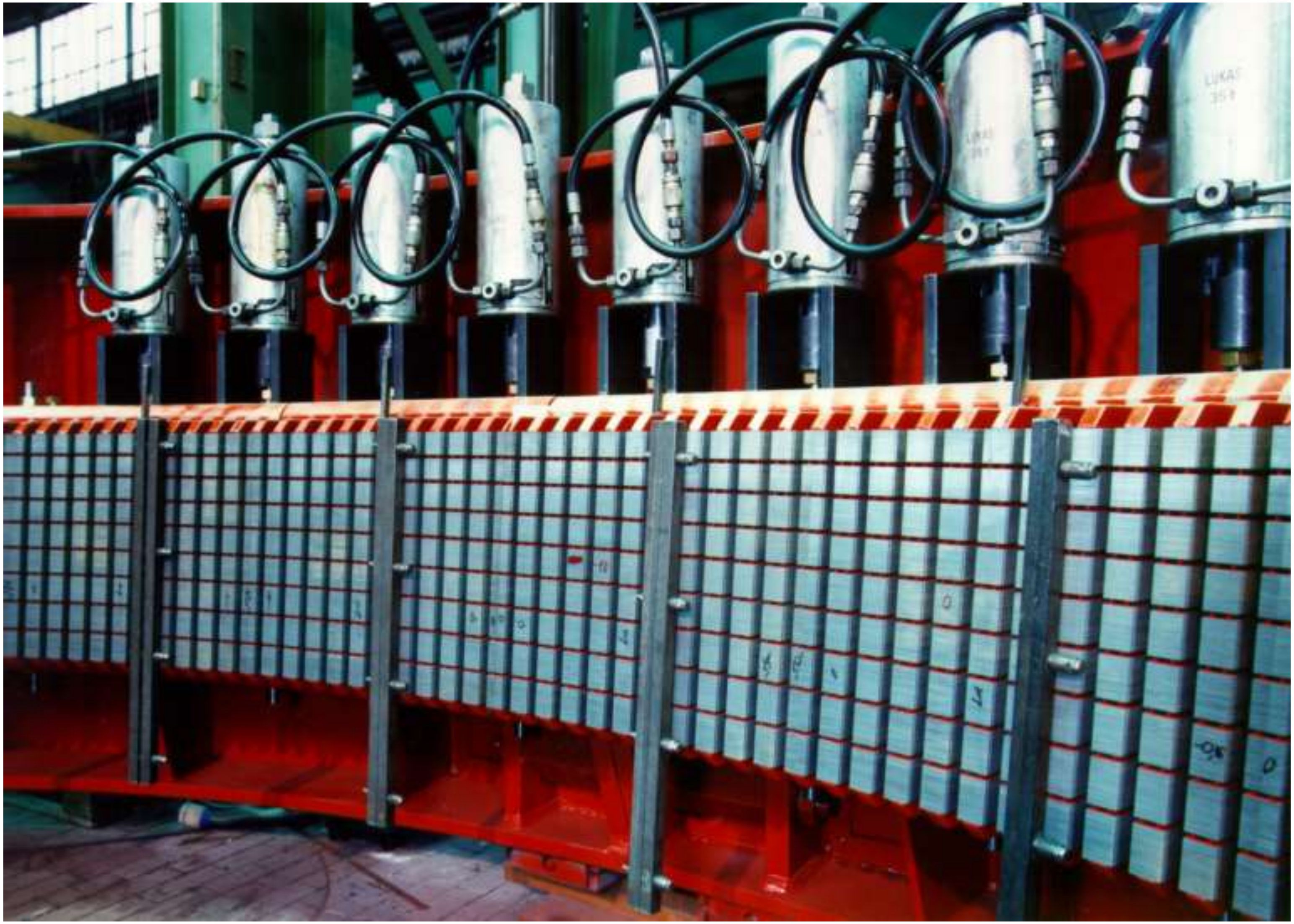
Andritz Hydro, Austria

Stacking of stator iron sheets of synchronous hydro generator

Source:

Andritz Hydro, Austria

Pressing of laminated stator iron core with hydraulic cylinders



Source:

Andritz Hydro, Austria

Insulation of high voltage stator winding (one turn = stator bar) with insulation robot

Big generators:

Only one turn per coil. Coil is split into 2 halves = 2 bars.

Here visible: Insulating one bar for a 2-pole turbine generator with glass-fibre band with mica layer for high voltage insulation.

Source:

Andritz Hydro, Austria

Insulation of high voltage stator winding (one turn = stator bar) with insulation robot

Source:

Andritz Hydro, Austria

Resin impregnated coils are heated in the oven to dry and harden the insulation

Source:

Andritz Hydro, Austria

High voltage form wound stator coil with several turns N_c for two-layer winding

Winding overhang

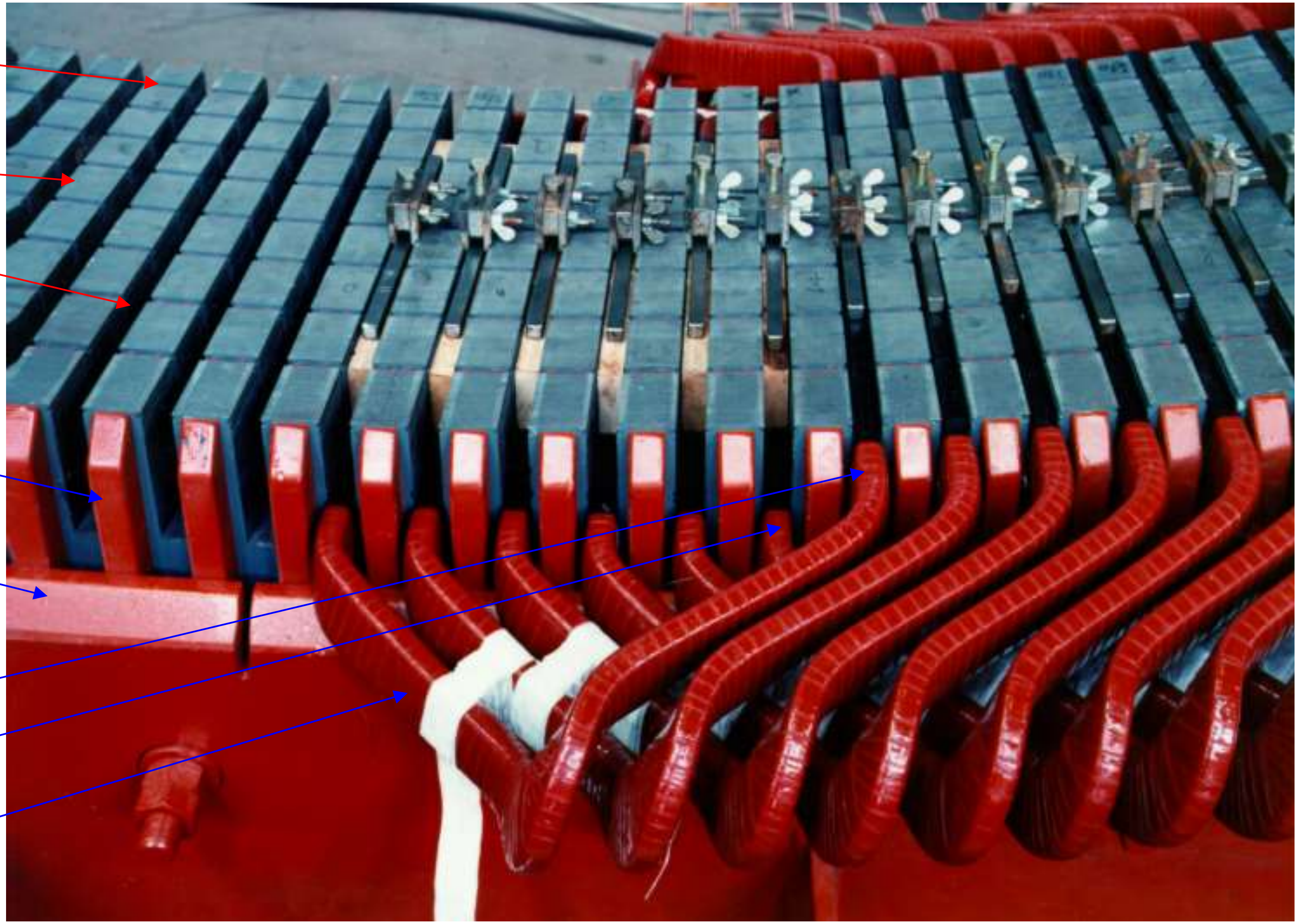
coil side, inserted in slot

coil terminals

Source:

Andritz Hydro, Austria

Inserting of impregnated form wound coils in the stator slots of a synchronous hydro generator with high pole count



Source:

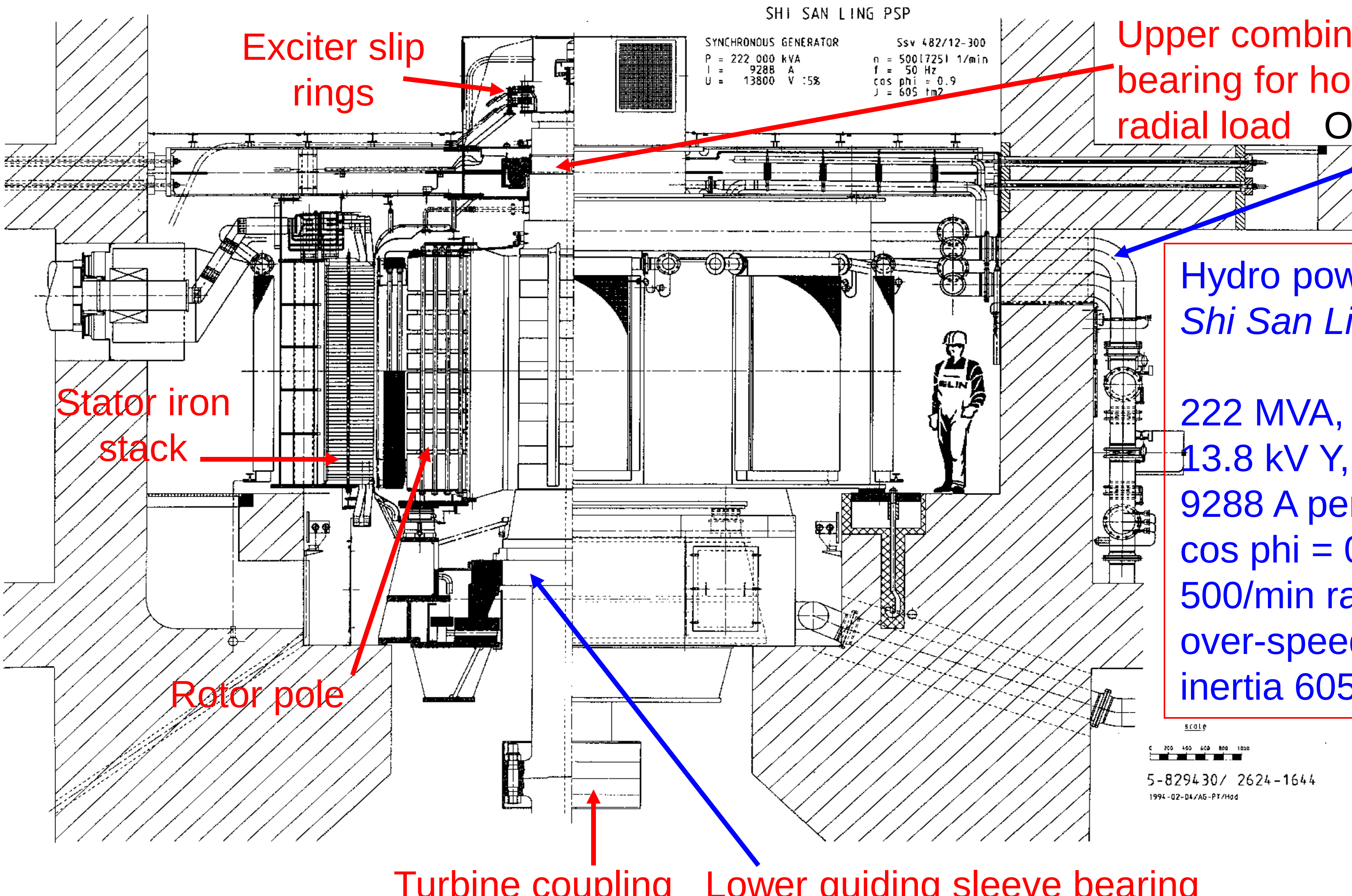
Andritz Hydro, Austria

High voltage stator winding of synchronous hydro generator - Pressing of winding bars in the slots

Source:

Andritz Hydro, Austria

Vertically mounted salient pole “big hydro” generator



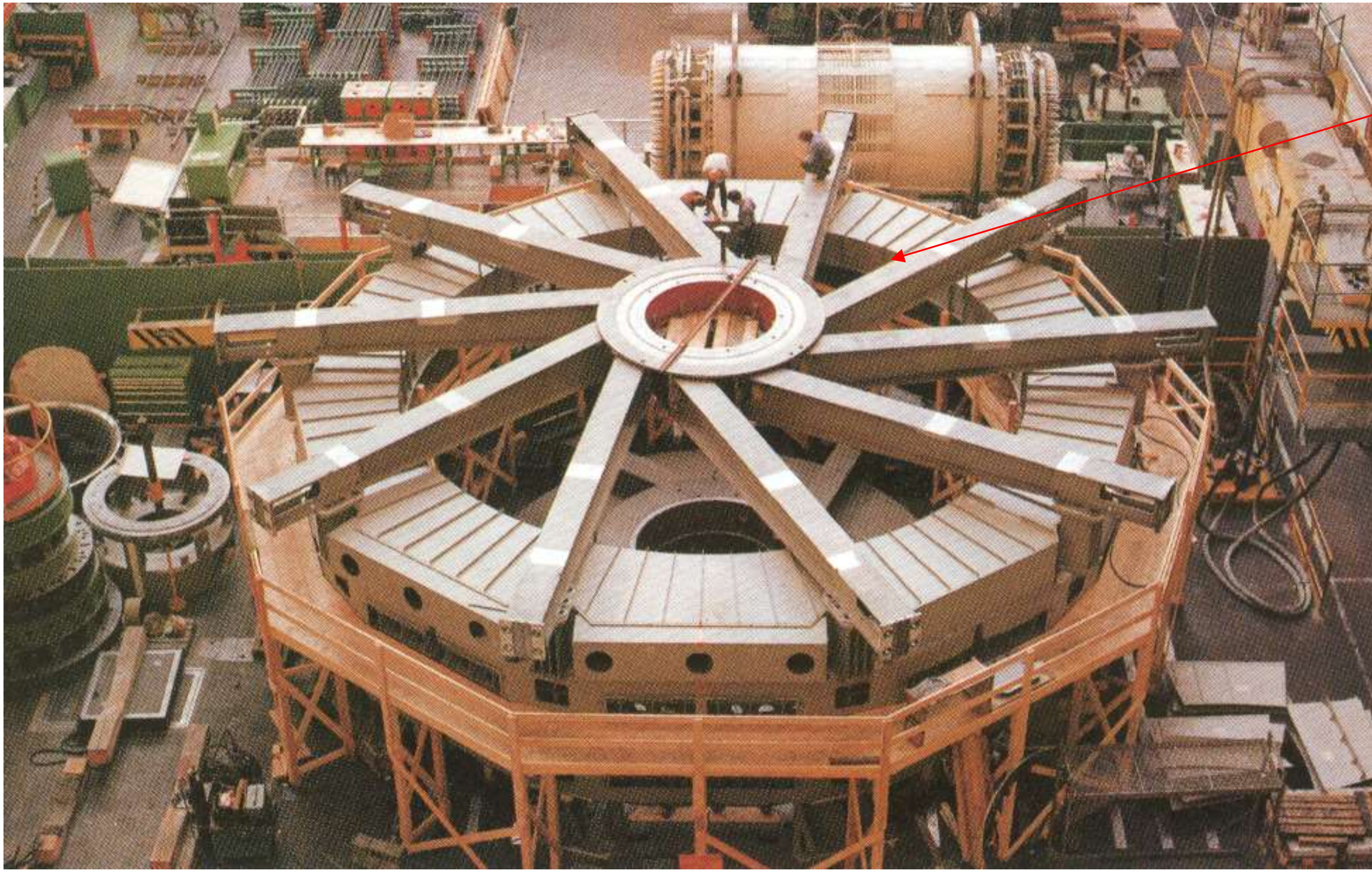
Hydro power plant
Shi San Ling / China

222 MVA, $2p = 12$
13.8 kV Y, 50 Hz
9288 A per phase
cos phi = 0.9 over-excited
500/min rated speed
over-speed 725/min
inertia 605 000 kg·m^2

Source:

VATech Hydro, Austria (now Andritz Hydro)

Upper spider for the bracket of a vertically mounted salient pole hydro generator



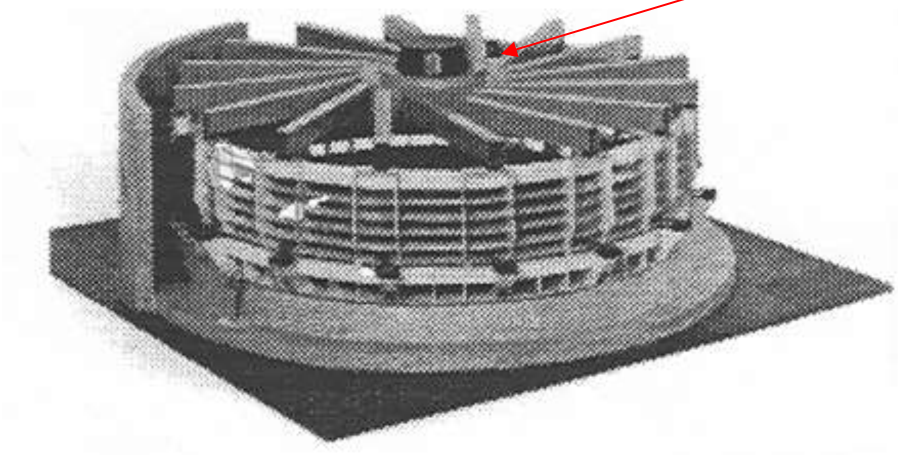
Skewed spider to equalize better the thermal expansion

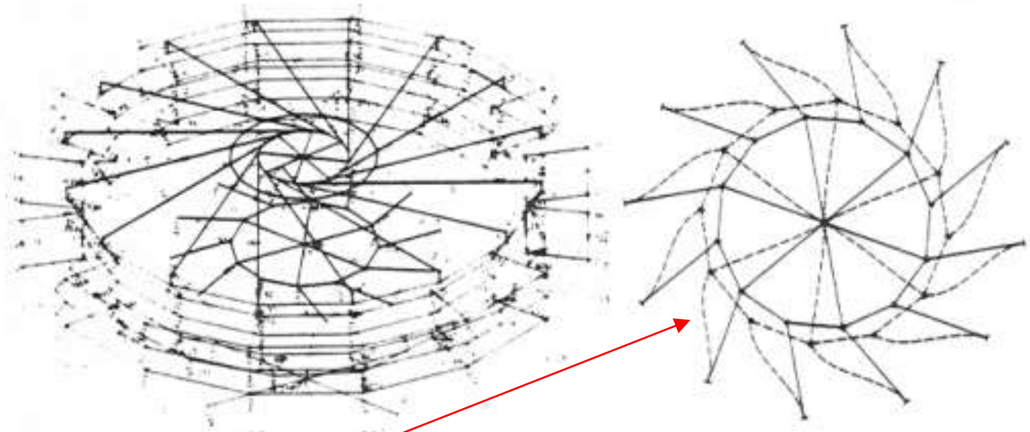
Source:

Alstom power (former BBC, Switzerland)

Skewed spider for the bracket of a vertically mounted salient pole hydro generator

Skewed spider to equalize better the thermal expansion





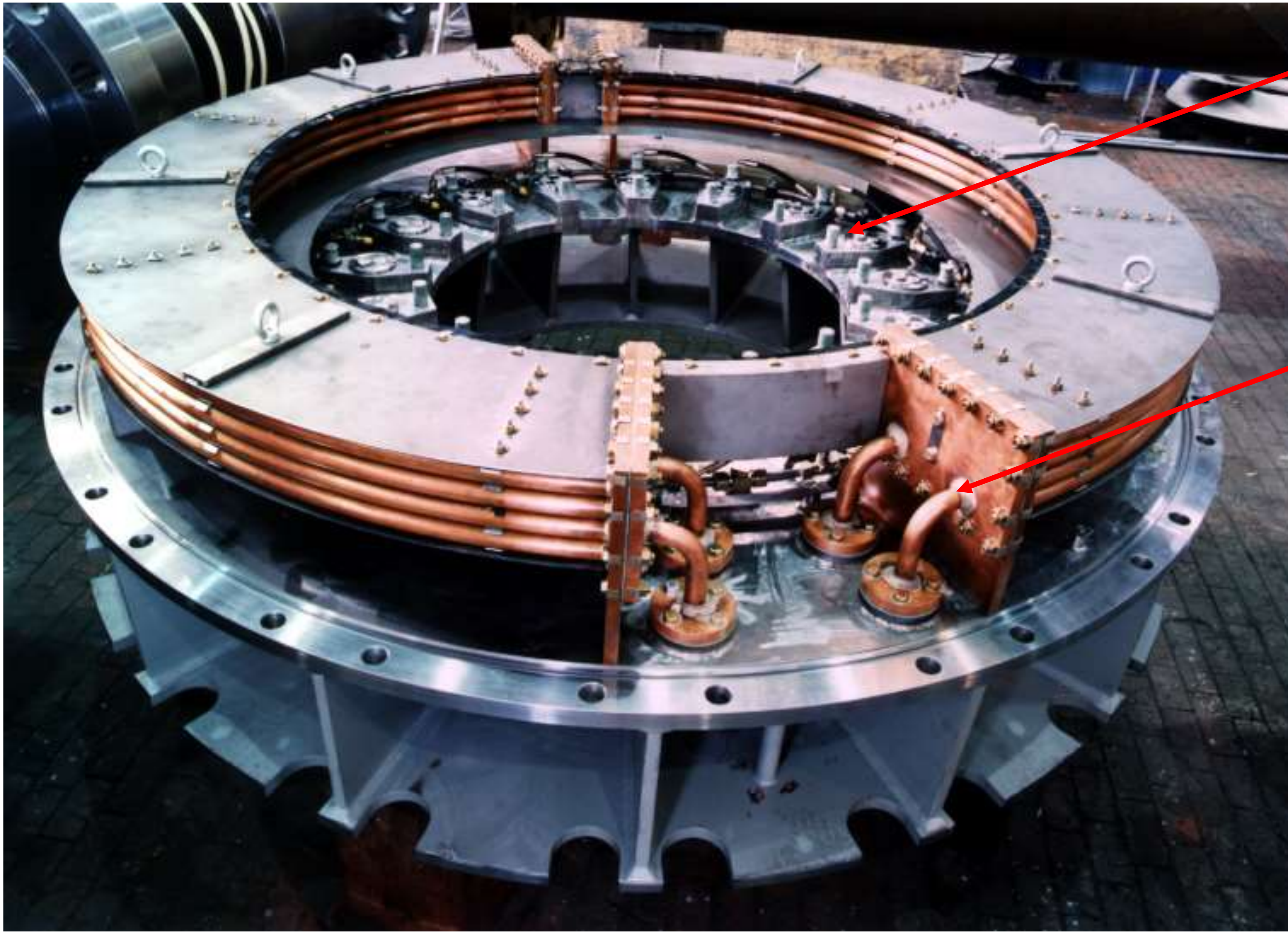
Due to skewed spider arms the centre of the shaft keeps better aligned also under thermal expansion

Source:

Alstom power (former BBC, Switzerland)

Manufacturing of the segmented sleeve bearings

Segment sleeve bearing for vertical load



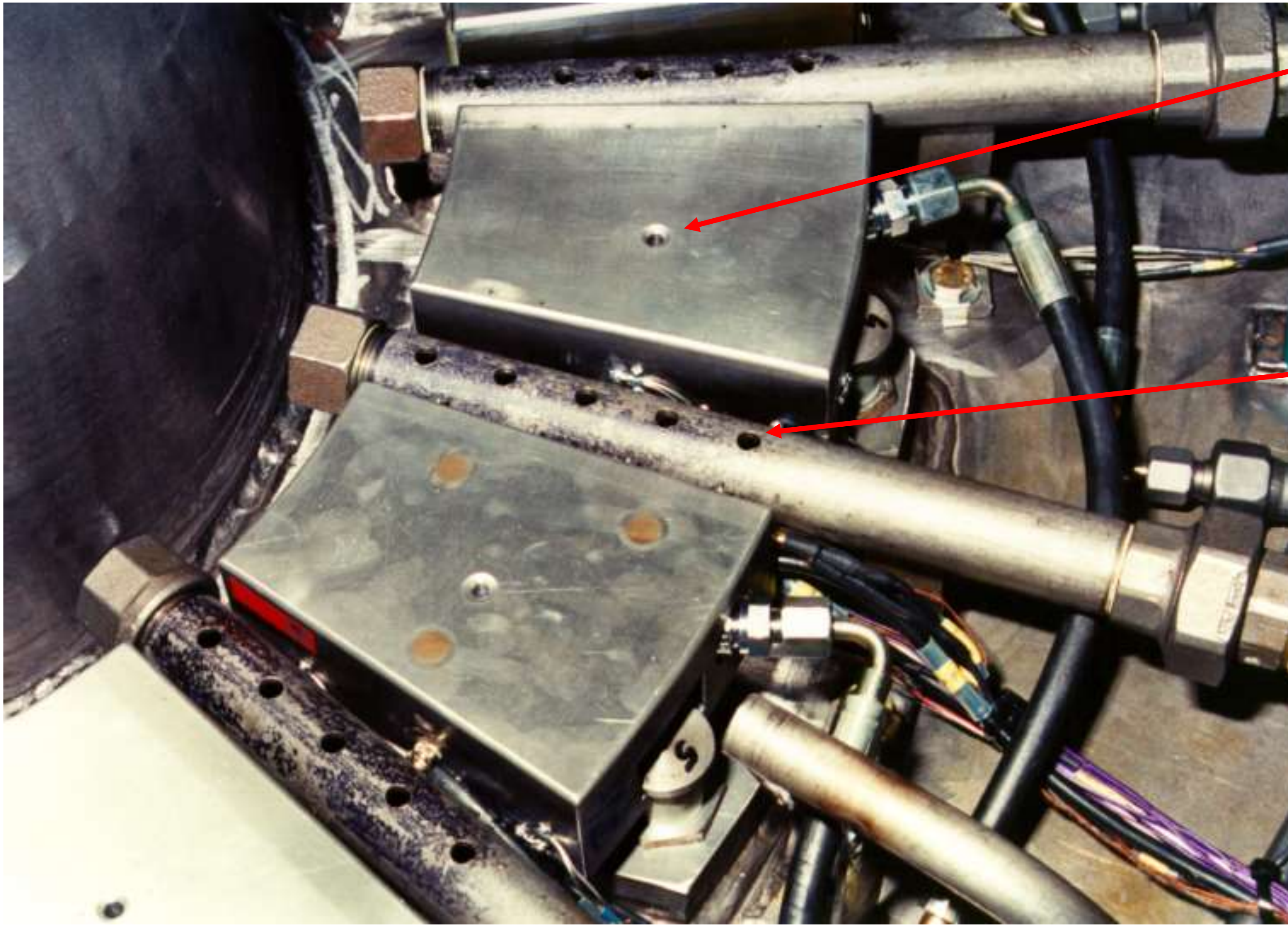
Bolts for bearing segments

Oil supply for lubrication and cooling

Source:

VATech Hydro, Austria (now Andritz Hydro)

Segment sleeve bearing for vertical load



Bearing segments for vertical load

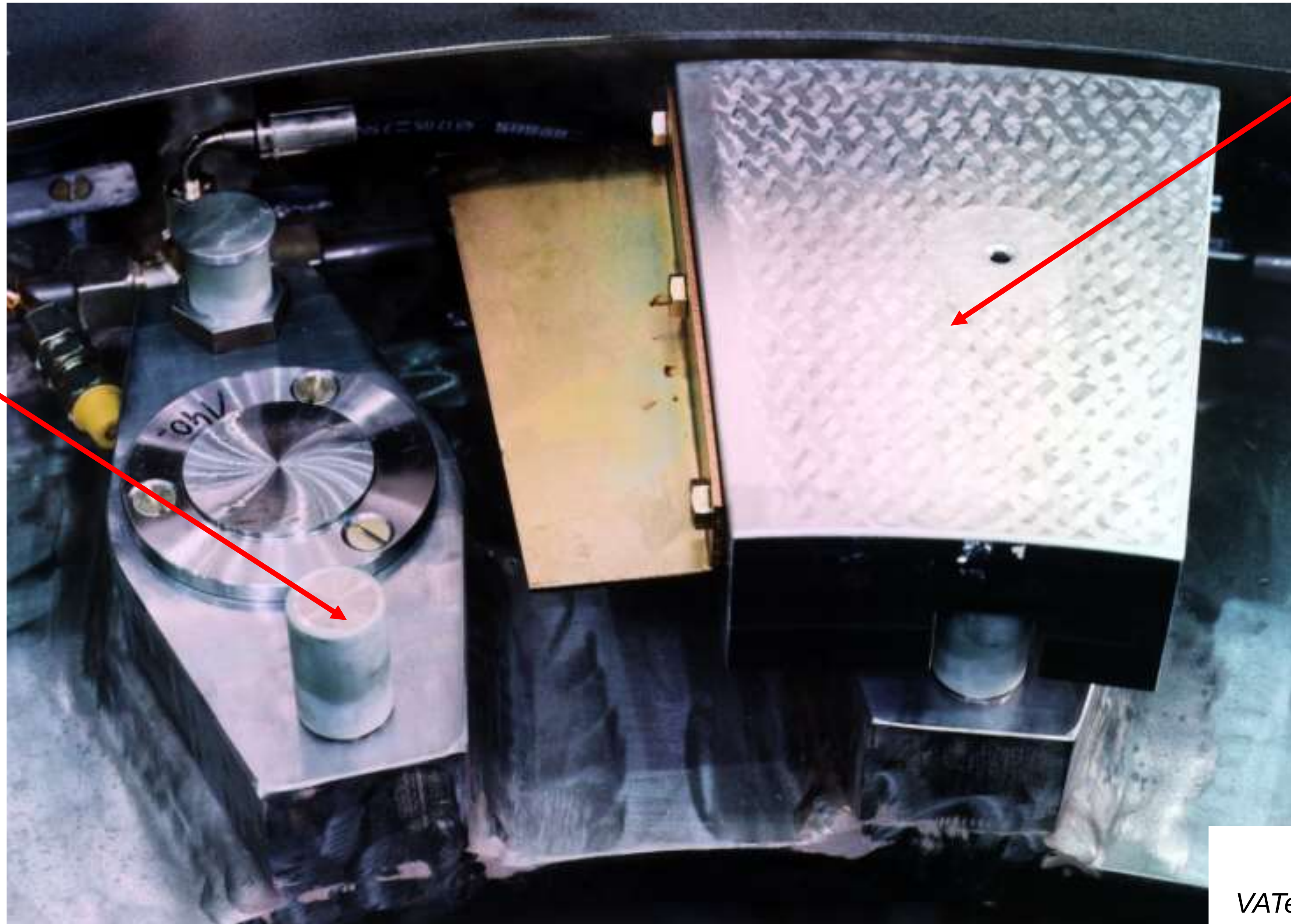
Oil outlet for lubrication

Source:

VATech Hydro, Austria (now Andritz Hydro)

Mounting of sleeve bearing segments for vertical load

Bolts for segments

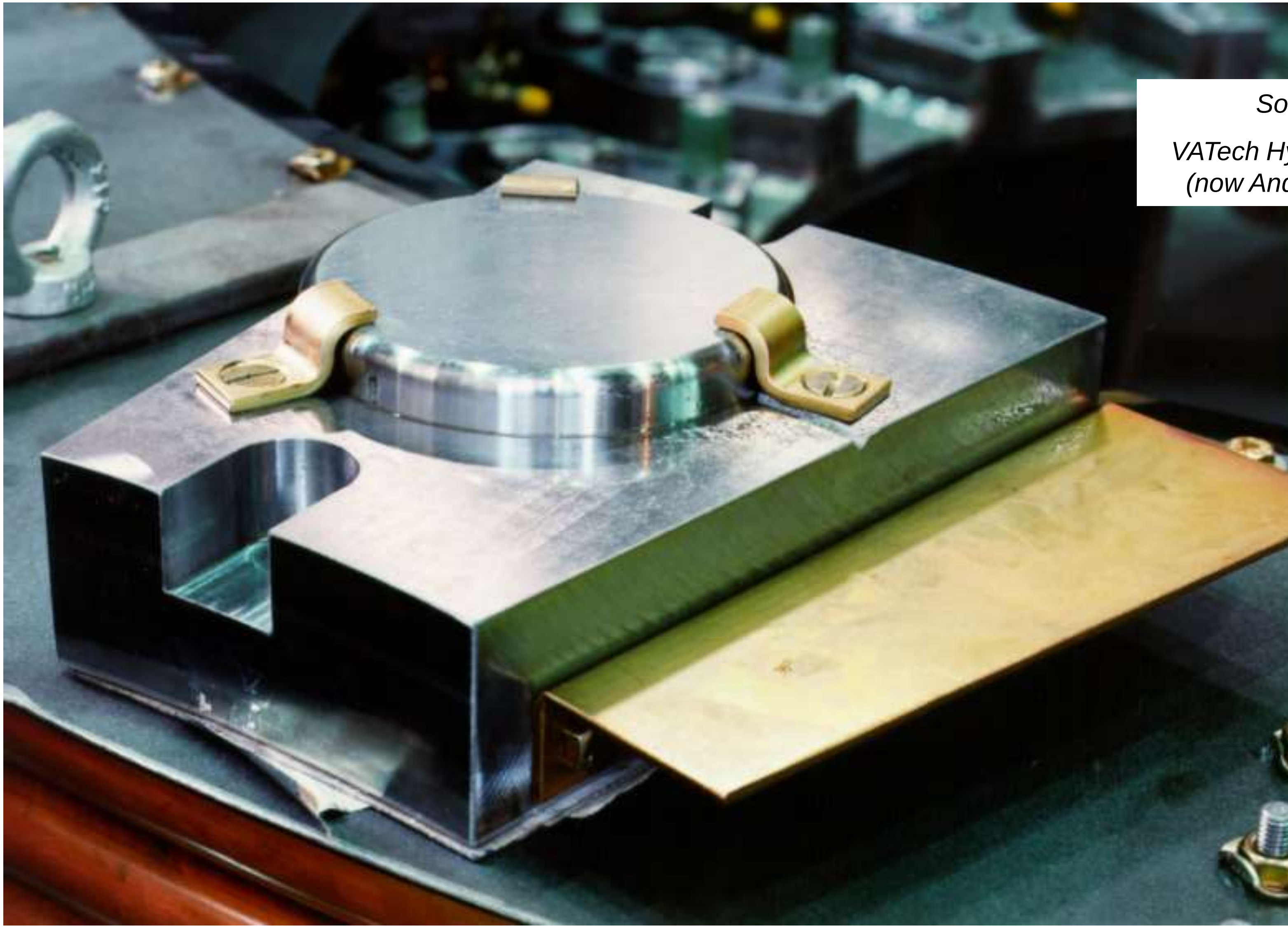


Bearing segments for vertical load

Source:

VATech Hydro, Austria (now Andritz Hydro)

Detailed view of bearing segments for vertical load



Source:

VATech Hydro, Austria (now Andritz Hydro)

Manufacturing of the salient rotor

Fixation of rotor poles for high centrifugal forces (e.g. pump storage plants)

Damper ring segment

pole press plate

pole joint bolts

three-fold hammer head fixation

Source:

VATech Hydro, Austria (now Andritz Hydro)

Manufacturing of field winding for salient pole machines

Non-insulated flat copper winding provides good heat transfer to cooling air at front sides

Inter-turn insulation

“Cooling fins” by increased copper width

Source:

VATech Hydro, Austria (now Andritz Hydro)

Completed salient pole before mounting

Pump storage
hydro power plant
Vianden/Belgium

Refurbishment

Three-fold hammer head fixation

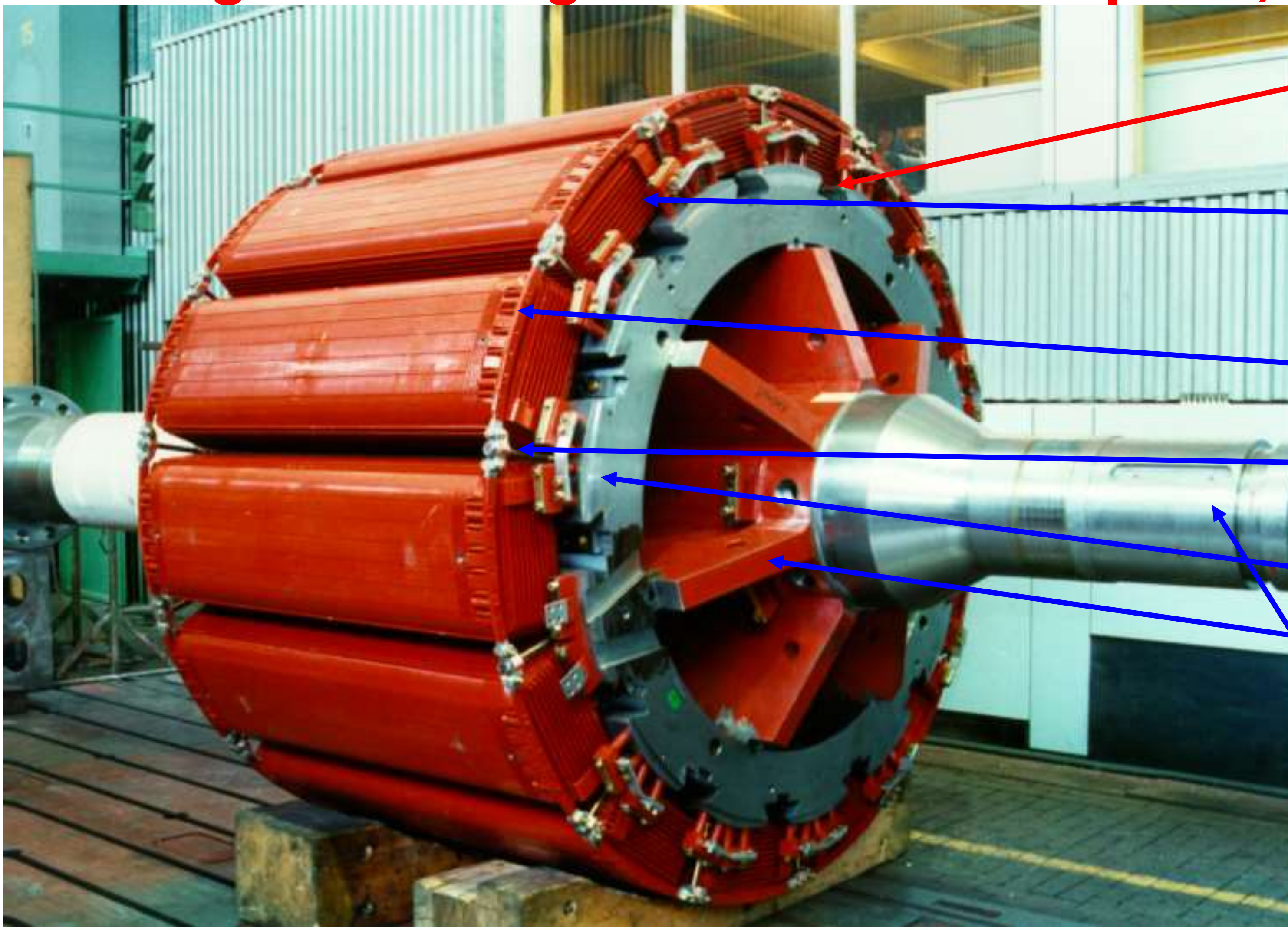
"Cooling fins" by increased copper width

Damper ring segments

Source:

VATech Hydro, Austria (now Andritz Hydro)

Completed "big hydro" salient pole synchronous rotor for high centrifugal force at over-speed, 14 poles



Source:

VATech Hydro, Austria (now Andritz Hydro)

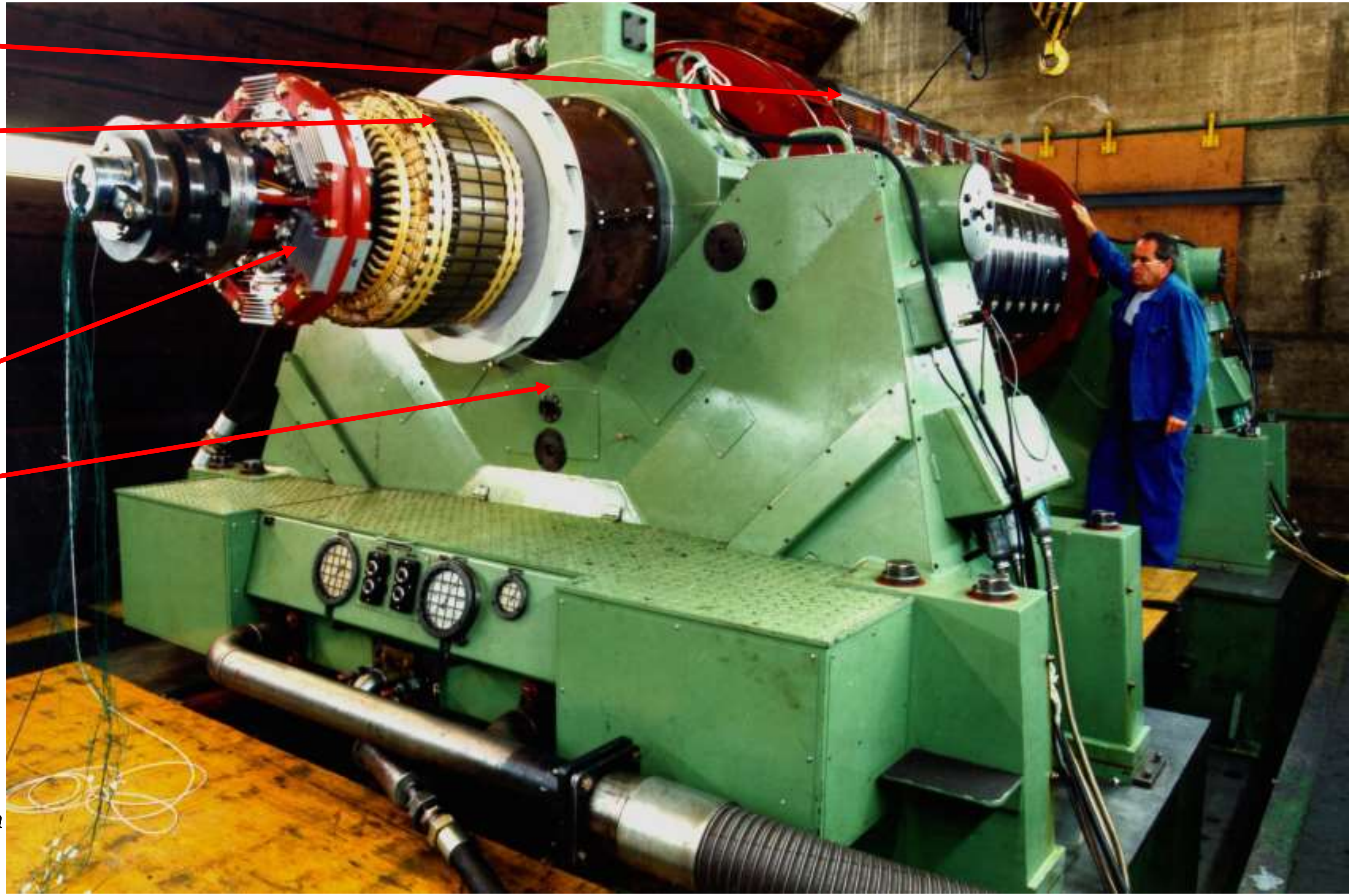
Balancing & over-speed test of salient 4 pole rotor in test tunnel

4 pole rotor

Exciter generator 3-phase winding

Rotating diode rectifier

Balancing bearing (*Schenck Company, Darmstadt*)



Source:

VATech Hydro, Austria (now Andritz Hydro)

Manufacturing of the salient rotor of bulb type generator

Ring synchronous generator with high pole count for river hydro power plant (bulb type generators)

Rotor with spider, rotor poles with field winding and damper cage

At plant site *Freudenau/Vienna, Austria*

River *Danube*

Mounting of rotor to turbine shaft

32 MVA, 50 Hz
92 poles
rotor diameter 7.45 m
rated speed 65.2/min
over-speed 219/min

circumference velocity at over-speed:
$\boldsymbol{v_{u,max}}$ **= 85 m/s**

centrifugal acceleration at over-speed: $a/g = 200$

Source:

VATech Hydro, Austria (now Andritz Hydro)

Rotor spider during milling before mounting of rotor yoke

Manufacturing of bulb type hydro generator for *Freudenau* power plant

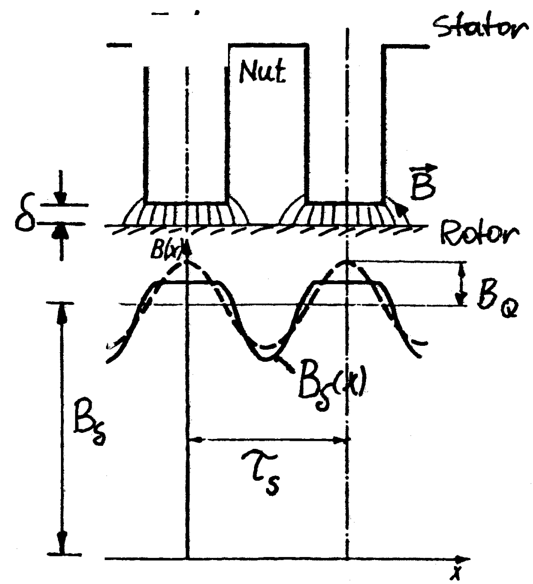
Source:

VATech Hydro, Austria (now Andritz Hydro)

Manufacturing of poles for high pole count low speed ring generator

Pole shoes, built as laminated iron stack to suppress eddy currents, which are induced by slot ripple magnetic air gap field due to stator slot openings

Slots for damper bars



Source: VATech Hydro, Austria (now Andritz Hydro)

Massive rotor pole shaft welded to laminated pole shoes

Source:

VATech Hydro, Austria (now Andritz Hydro)

Drilling holes into massive pole shaft to fix them to rotor yoke ring with screws

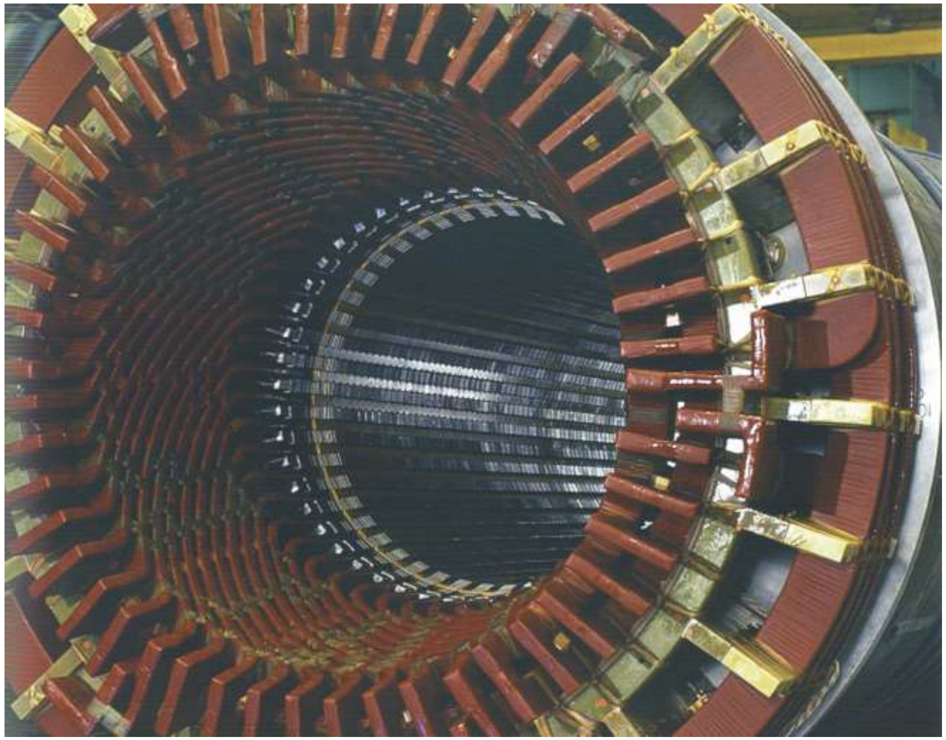
Welding machine

Welding of massive pole shaft o laminated pole shoes

Source:

VATech Hydro, Austria (now Andritz Hydro)

1.2.1 Manufacturing of big turbine generators



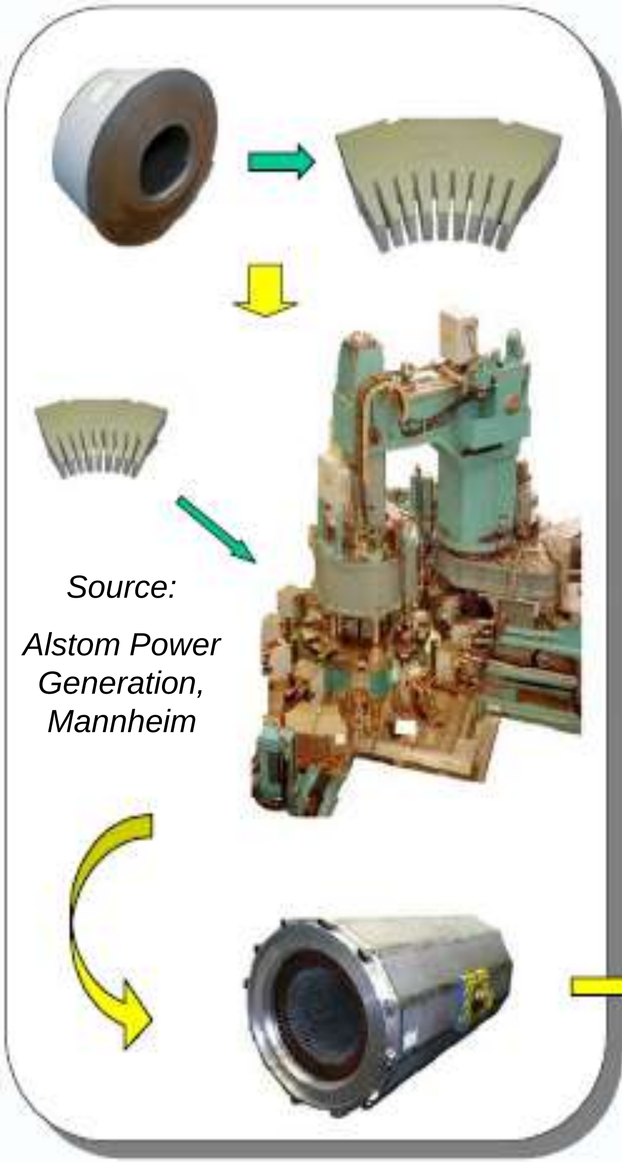
Source:

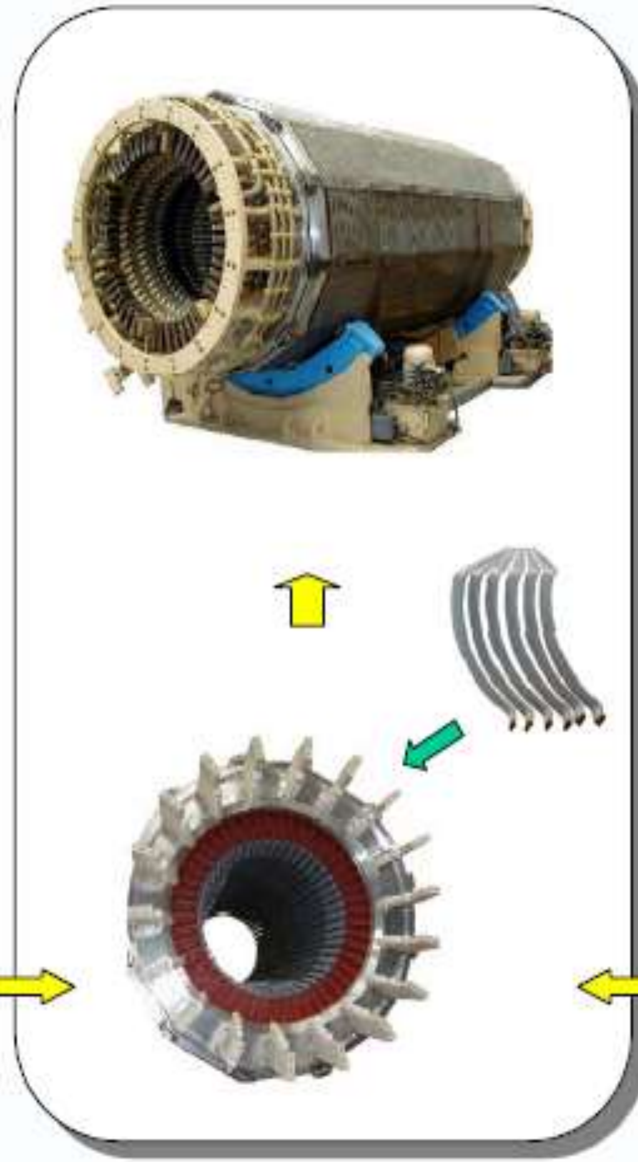
Siemens AG, Mülheim/Ruhr, Germany

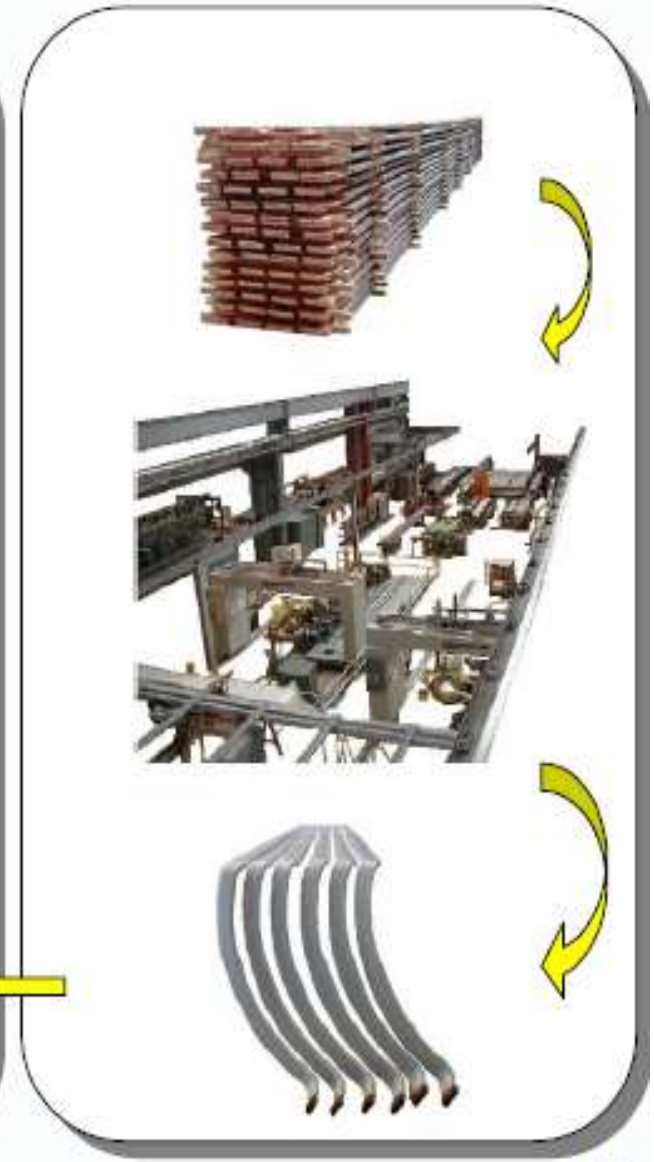
Stator iron stack

Stator winding insertion

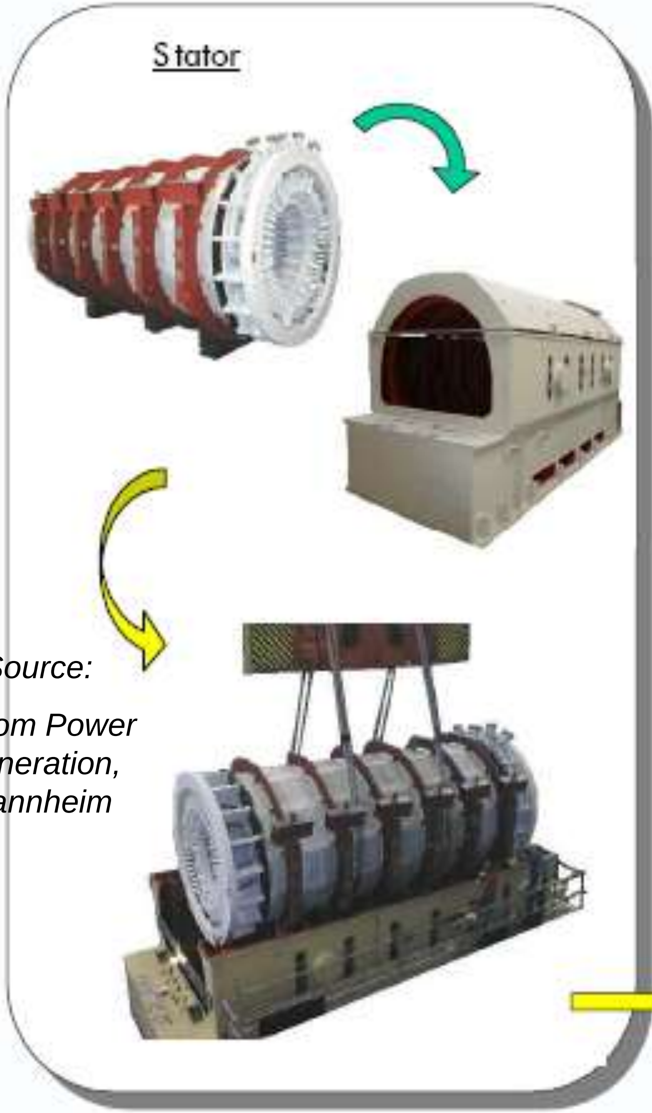
ROEBEL bar manufacturing







Stator into housing



Source:

Alstom Power Generation, Mannheim

Rotor into stator

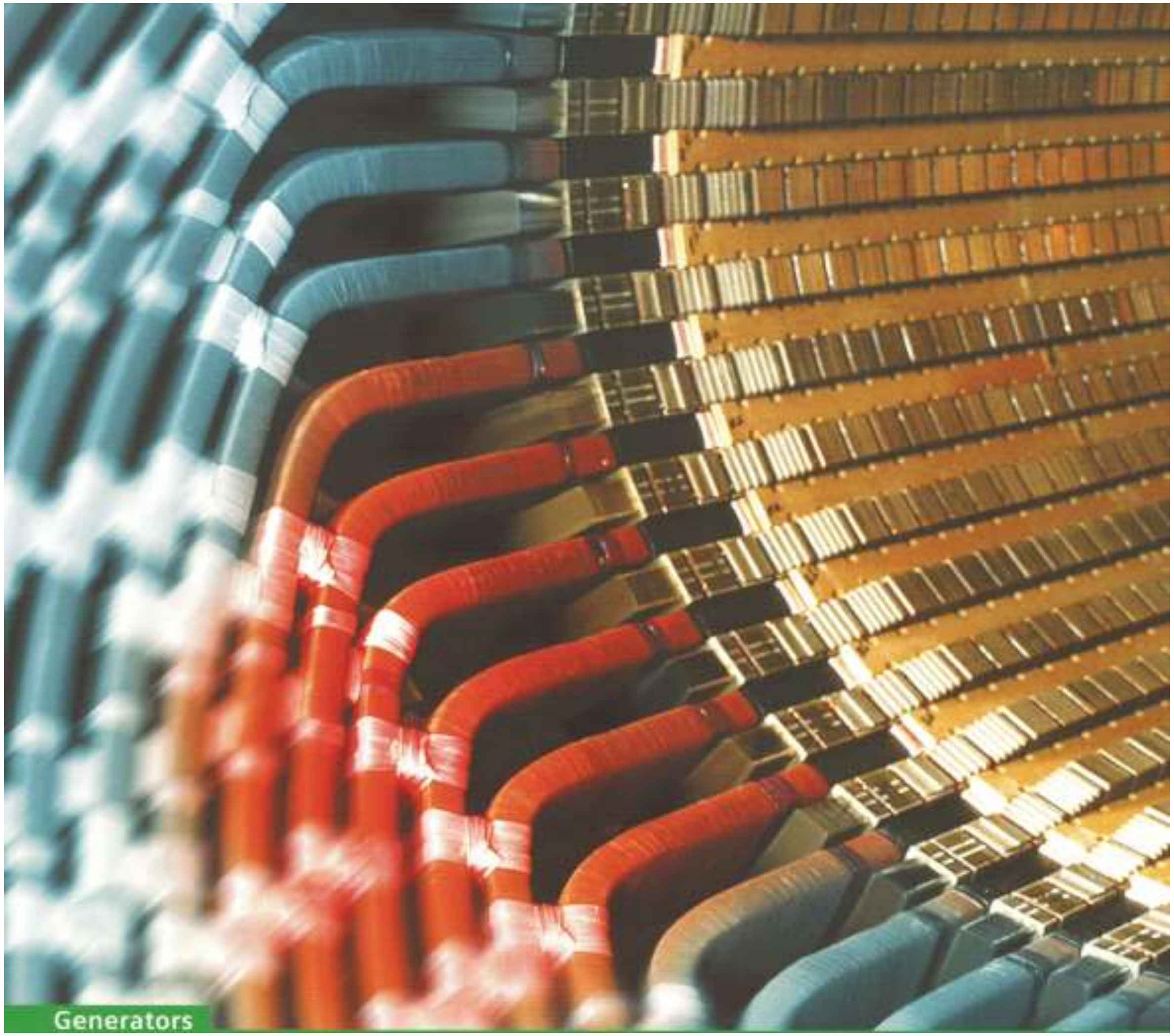
Ready for shipping

Fixation of coil overhang of stator winding

Source:

Siemens AG, Mülheim/Ruhr, Germany

Stator end zone of an air-cooled turbine generator: press plates, winding overhangs, stepped end packets

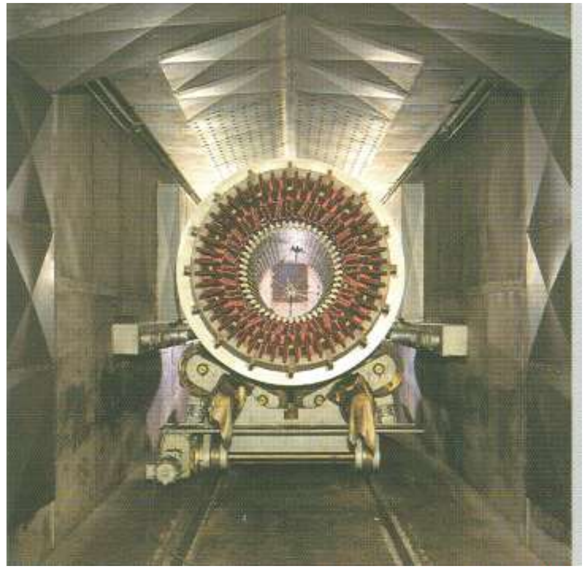


Source:

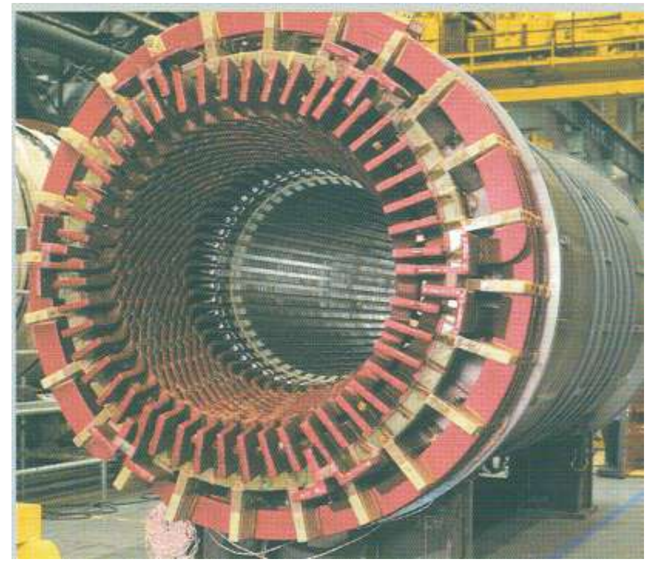
Siemens AG, Mülheim/Ruhr, Germany

Stator manufacturing

Stator core assembly with bonded stator core packs



Stator coil winding insulation system in the resin oven

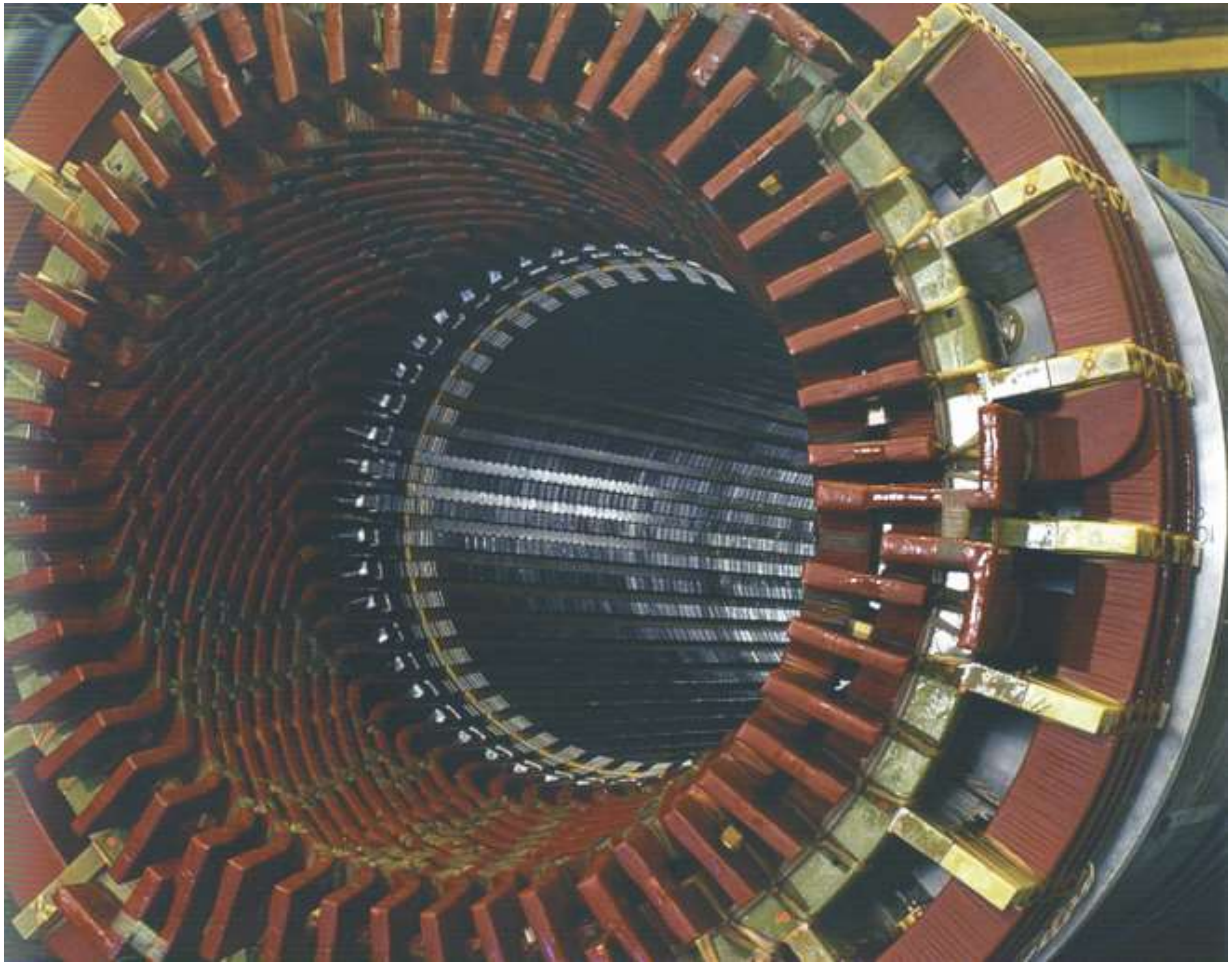


Support system of stator winding overhang

Source:

Siemens AG, Mülheim/Ruhr, Germany

Completed stator with three-phase winding and coil connections



Source:

Siemens AG, Mülheim/Ruhr, Germany

Manufacturing of air-cooled stator

Source:

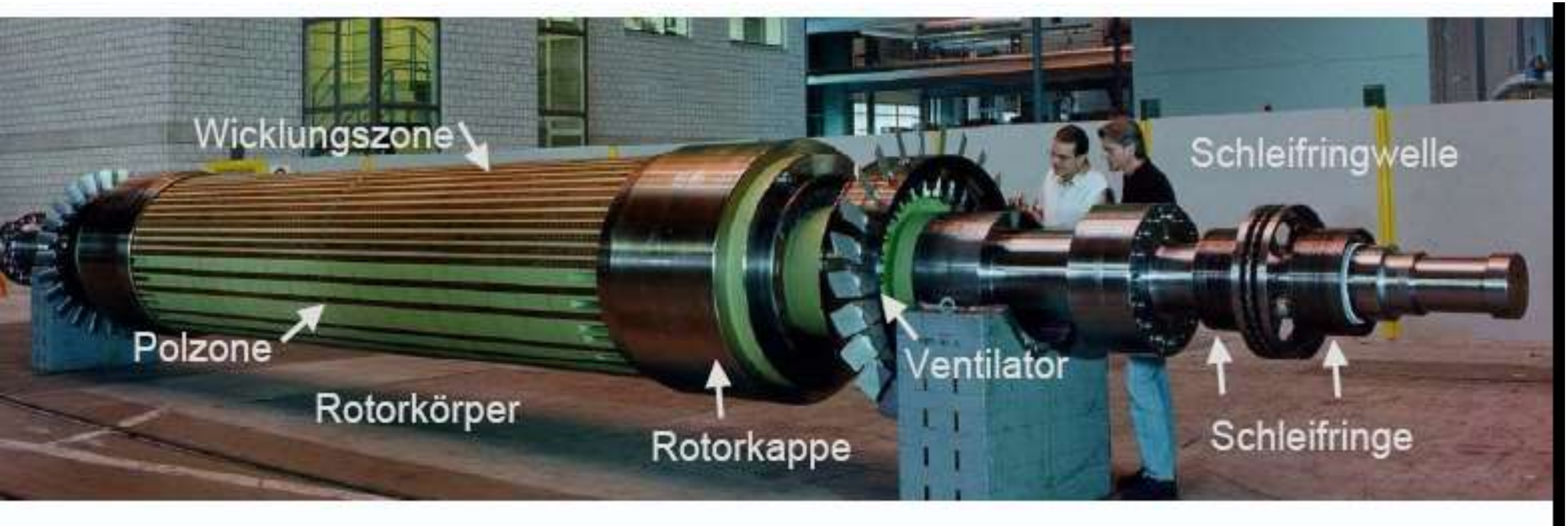
Alstom Power Generation, Mannheim

Manufacturing of stator housing

Source:

Alstom Power Generation, Mannheim

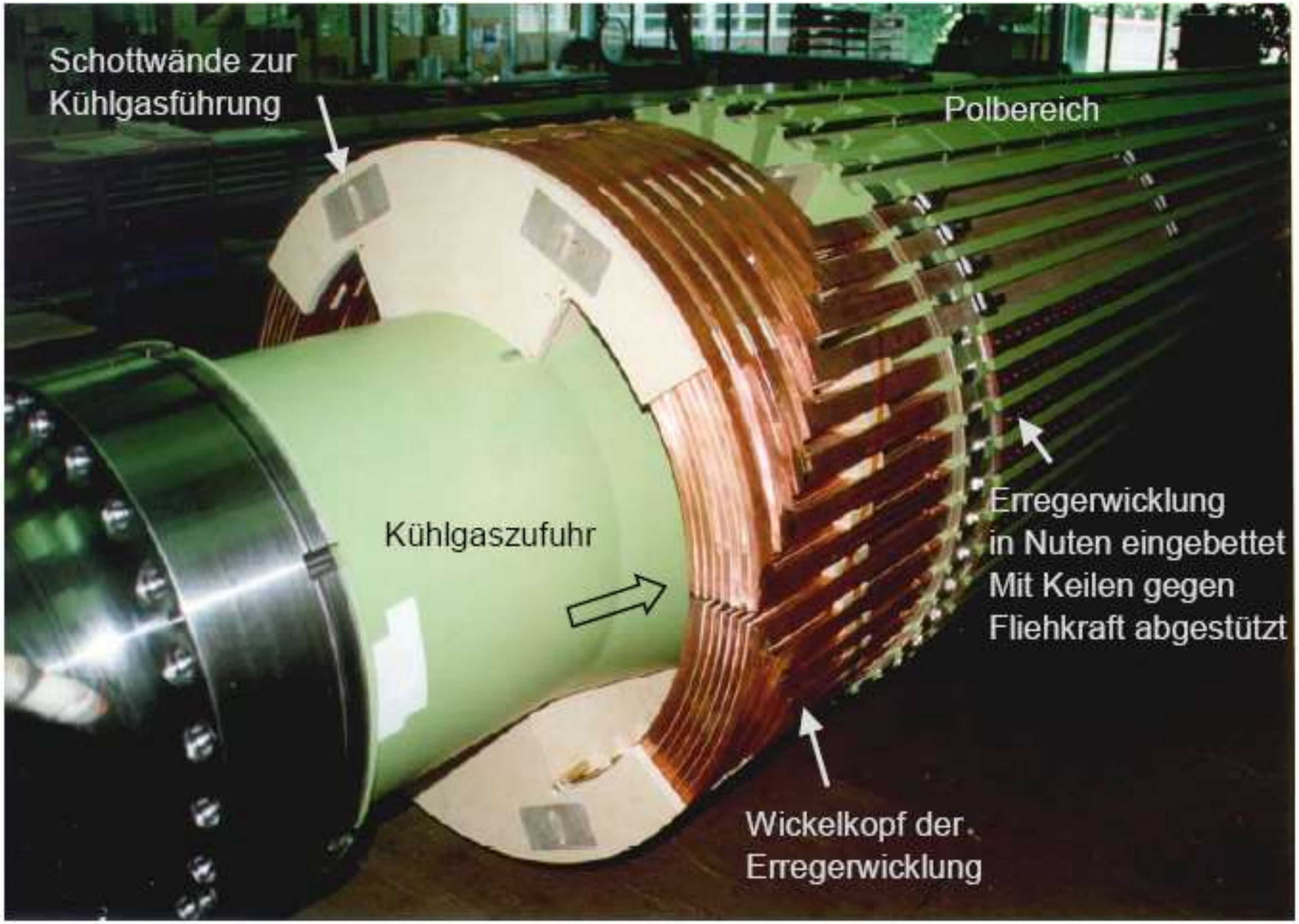
Manufacturing of Gas-cooled Two-pole Rotor



Source:

Alstom Power Generation, Mannheim

Two-pole Rotor Excitation Winding



Before the mounting of the stainless steel end caps

Source:

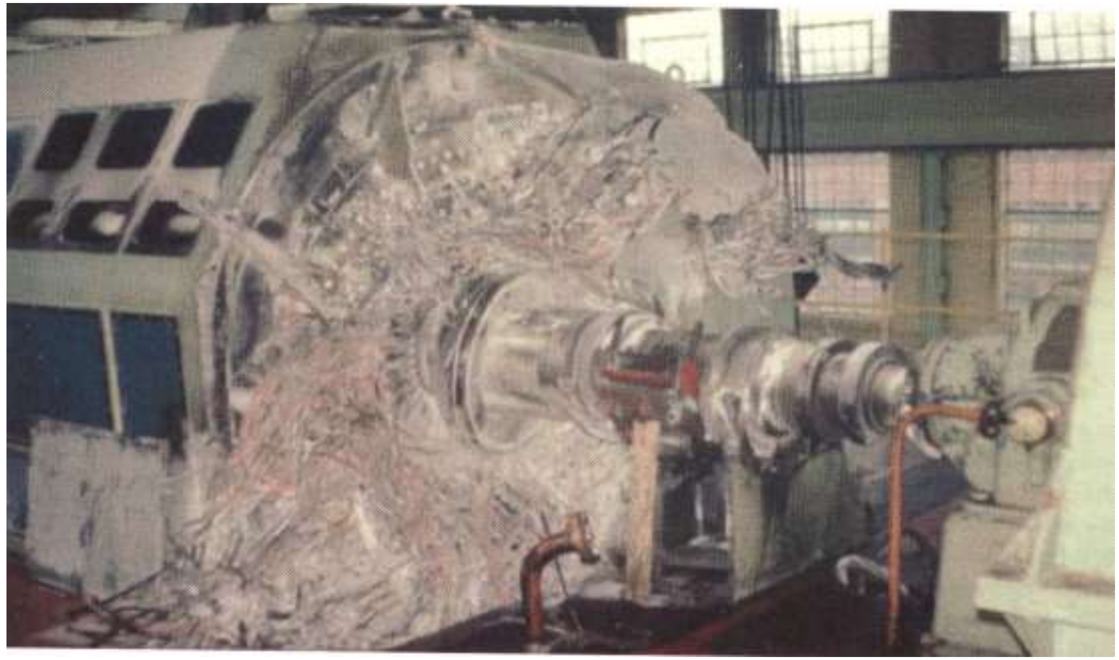
Alstom Power Generation, Mannheim

Rotor End Winding Retaining Cap

Source:

Electra, April 2012

Stainless steel end caps for retaining of the rotor end winding - Before the shrink-fit mounting on the rotor (stress: 680 MPa at n = 0, 800 MPa at operation for e. g. 600 MW generator)



Air Cooled Two Pole Turbine Generator: End cap failure due to stress corrosion cracking during the 1970s

Material:

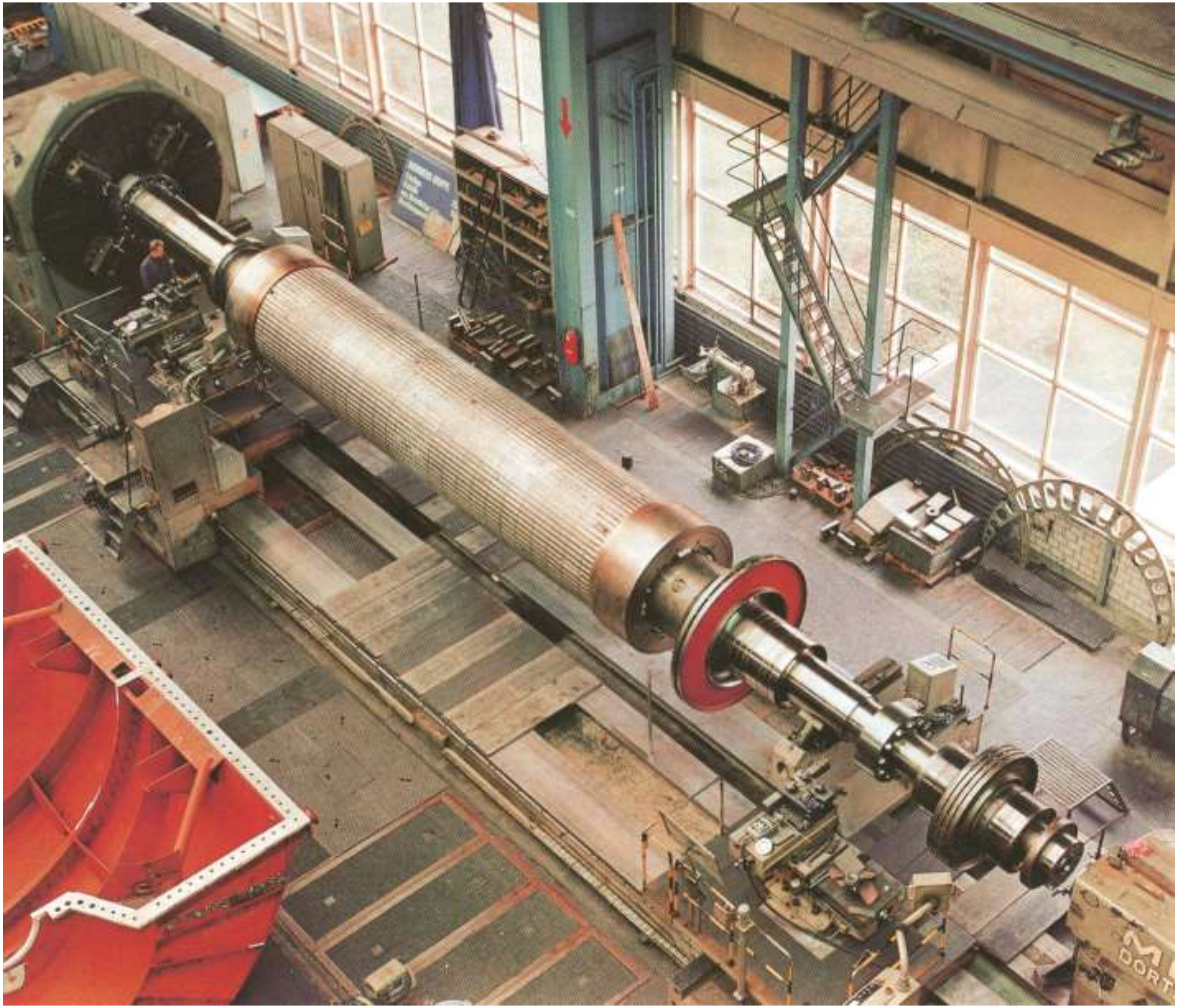
Older types: Cold worked nonmagnetic austenitic manganese steel, sensible to stress corrosion cracking in moisture or aggressive halogen atmosphere

New types: Fe-18Mn-18Cr-0. 05C-07N steel ("18:18 steel"), more resistant to stress corrosion cracking due to Cr content

Fitting of the Two-pole rotor into the stator of an air-cooled generator for a gas turbine power plant

Source:

Alstom Power Generation, Mannheim

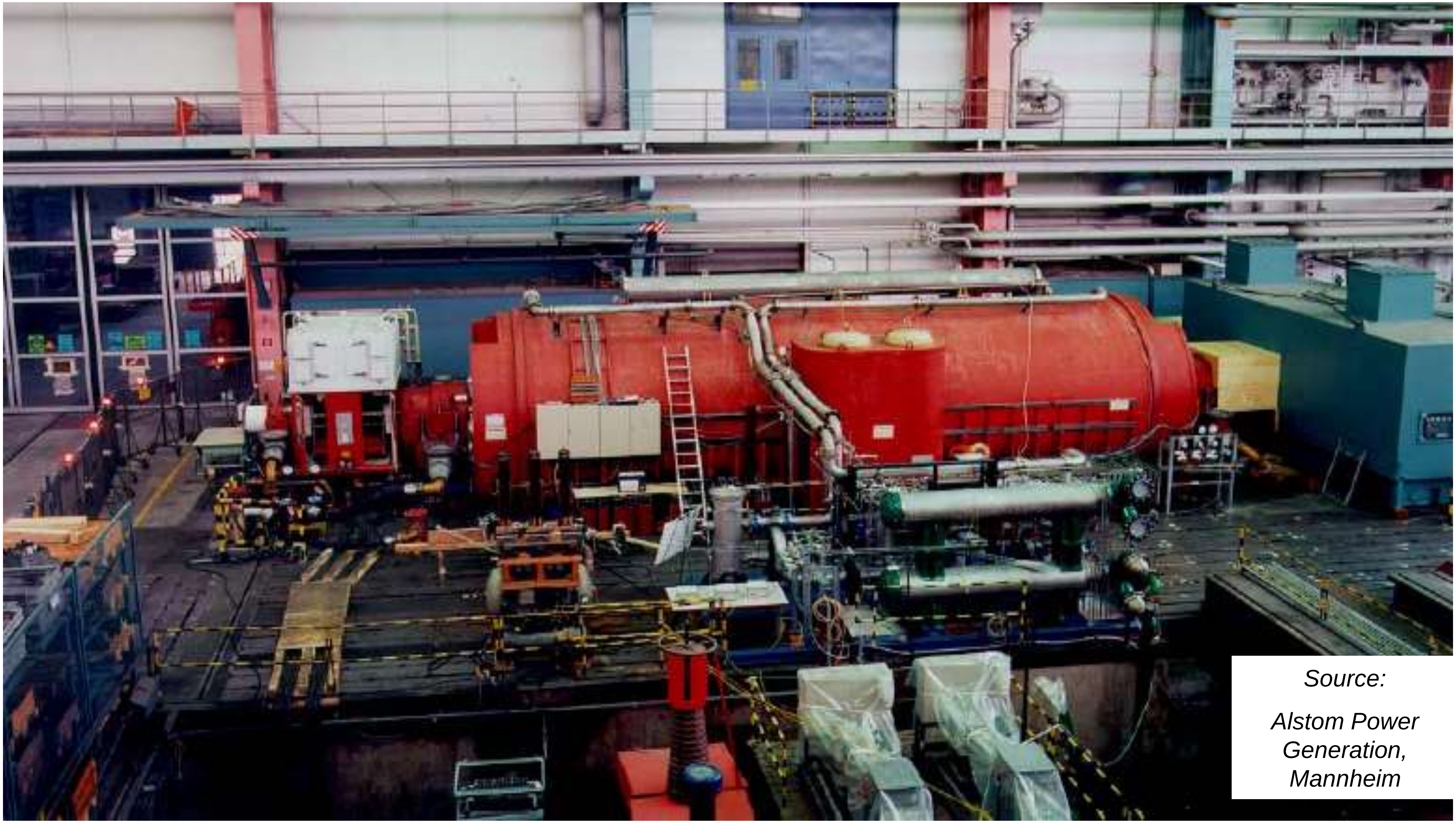


Four-pole rotor of a big turbine generator, 1500 MVA, 60 Hz, 1800/min, for a nuclear power plant

Source:

Alstom Power Generation, Birr, Switzerland (former BBC)

Testing of a turbine generator in the manufacturers test rig



Source:

Alstom Power Generation, Mannheim

Transportation of a turbine generator stator via the road

Source:

Siemens AG, Mülheim/Ruhr, Germany

Fully assembled turbine generator for easy installation on-site

Railway transportation

Car transportation

Source:

Siemens AG, Mülheim/Ruhr, Germany

Completed steam-turbine and two-pole generator group in the nuclear power plant *Leibstadt, Switzerland*, 1230 MVA, 3000/min, 50 Hz

Steam turbine

Generator

Source: Alstom, Switzerland

(former BBC)

Large Generators and High Power Drives

Summary:

State-of-the art of medium and high power machines

- Largest E-machines in the world are synchronous generators
- Maximum power of 2-pole turbine generators surpasses 1 GW
- Biggest power per generator 2 GW for four-pole turbine generators
- Salient-pole generators with up to 900 MW built
- Expensive direct water or hydrogen cooling systems needed
- Cheap air-cooling possible up to 400 MW rated power
- Each generator project has unique data = special design and manufacturing

1. Manufacturing of Large Electrical Machines

1.1 History and significance of electric machinery

1.2 State-of-the art of medium and high power machines

1.3 Trends in large generators and high power drives

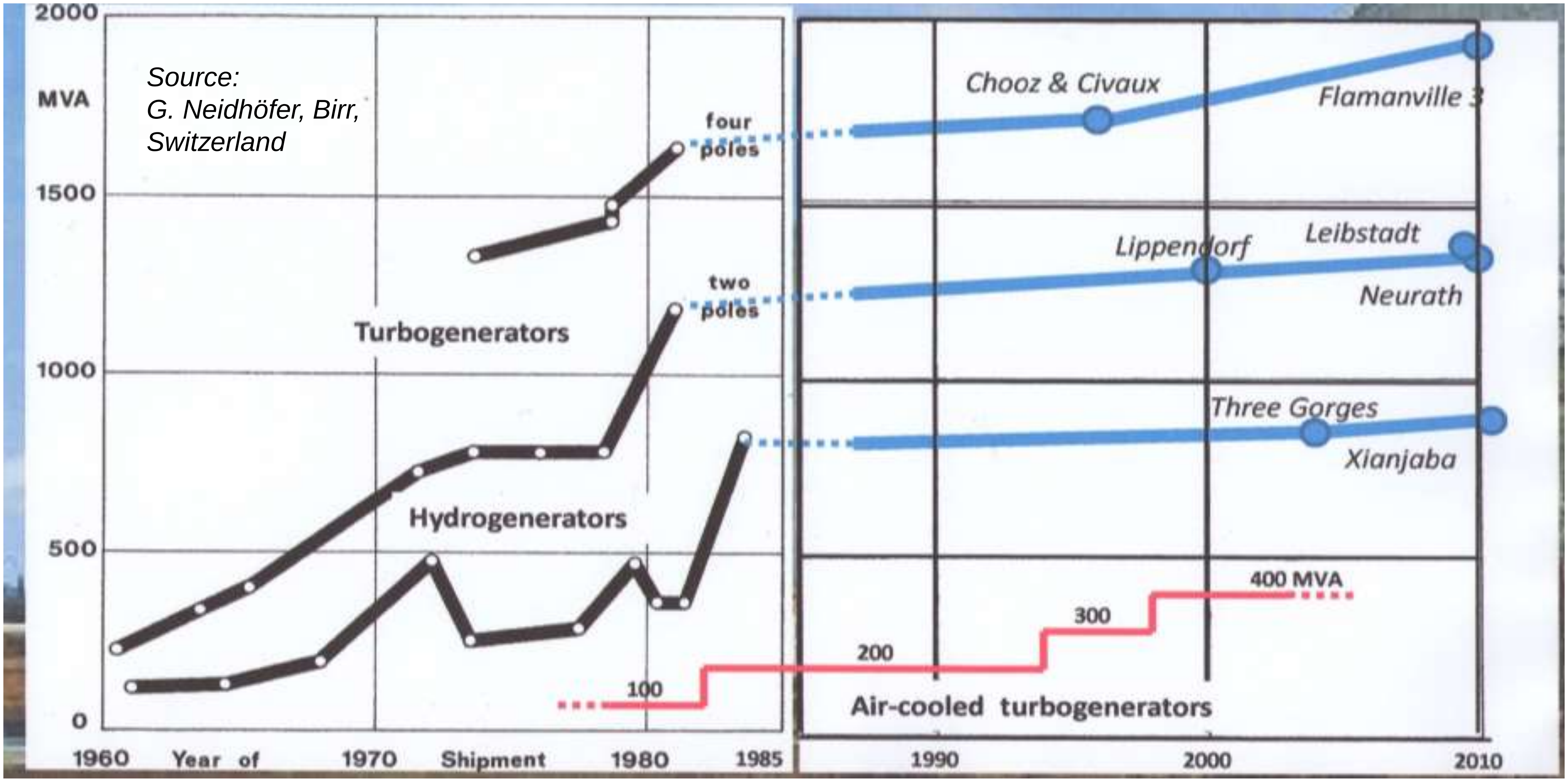
Source: Andritz Hydro, Austria

1.3 Trends in large generators and high power drives

- Increasing the size of hydro and turbine generators

1960 – 2010: Peak power ratings

2000 MVA for turbine generators - 850 MVA for hydro generators



Trends in manufacturing turbine generators

Raising power limit by improved cooling

Year		1950	1995…2000	Increase
Air gap flux density	B_δ / T	0.85	1.1	**130 %**
Current loading	*A* / A/cm	700	3200	**460 %**
Esson´s number	*C* / kVAmin/m^3	7.5	45	**600 %**

Raising power limit of air-cooled turbine generators

Year		1960	2000	Increase to
Rated apparent power	S_N / MVA	50	450 TOP AIR	**900 %**

One of the world´s largest 4-pole turbine generator

„Marriage“:

Insertion of the rotor into the stator

- Four-pole turbine-generator for ca. 2000 MVA, 50 Hz, 1500/min

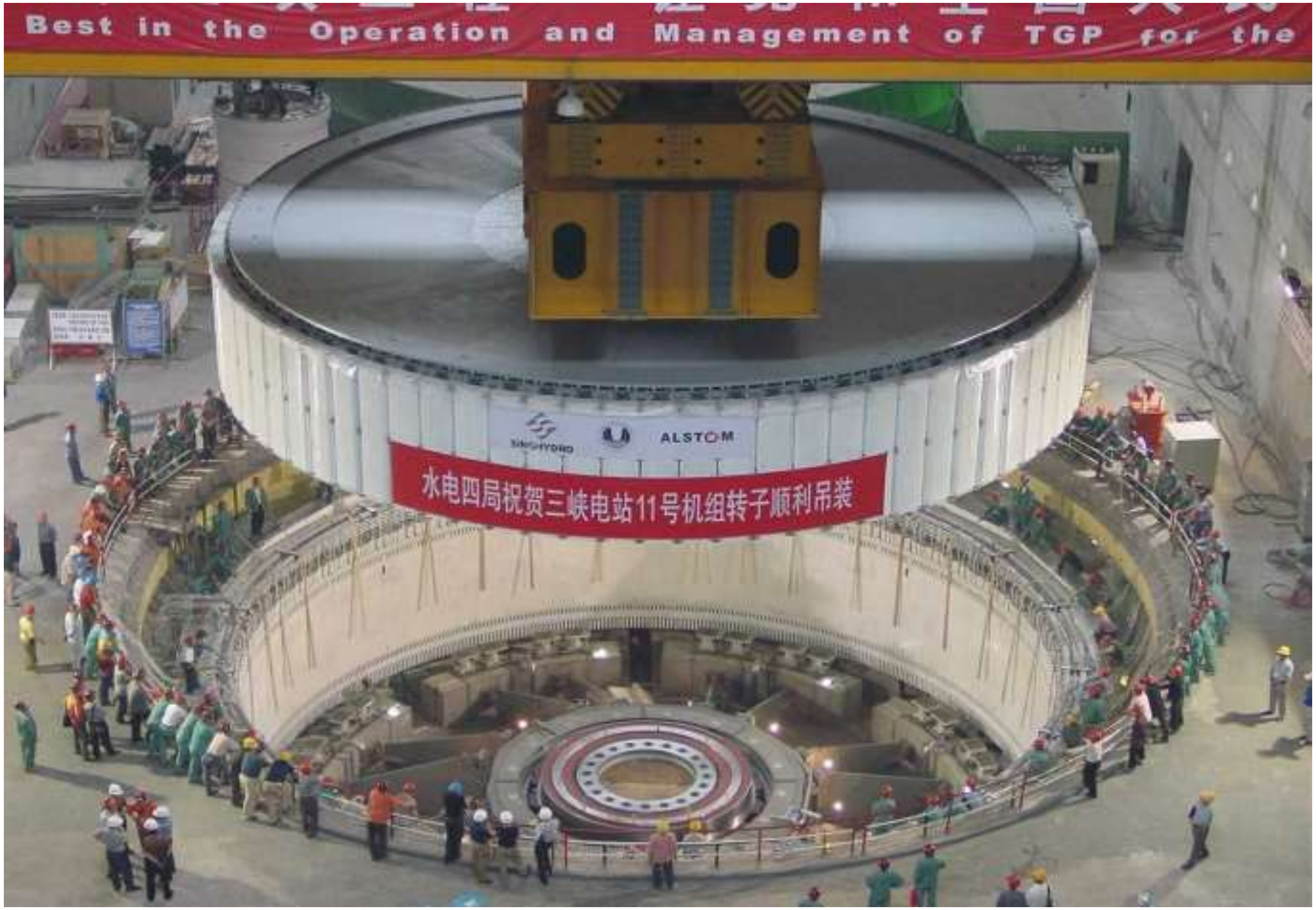
Source:

Alstom Power, Birr, Switzerland

1.3 Trends in large generators and high power drives

One of the world´s largest hydro generator

Three-gorges* hydro power plant at the river *Yangtsekiang*, *China



Vertical shaft salient pole synchronous generators 40 MVA, 700 MW, 50 HZ, 80-polig

26 generators: 18.2 GW

World´s largest hydro power plant

Source:

Alstom Power, Birr, Switzerland

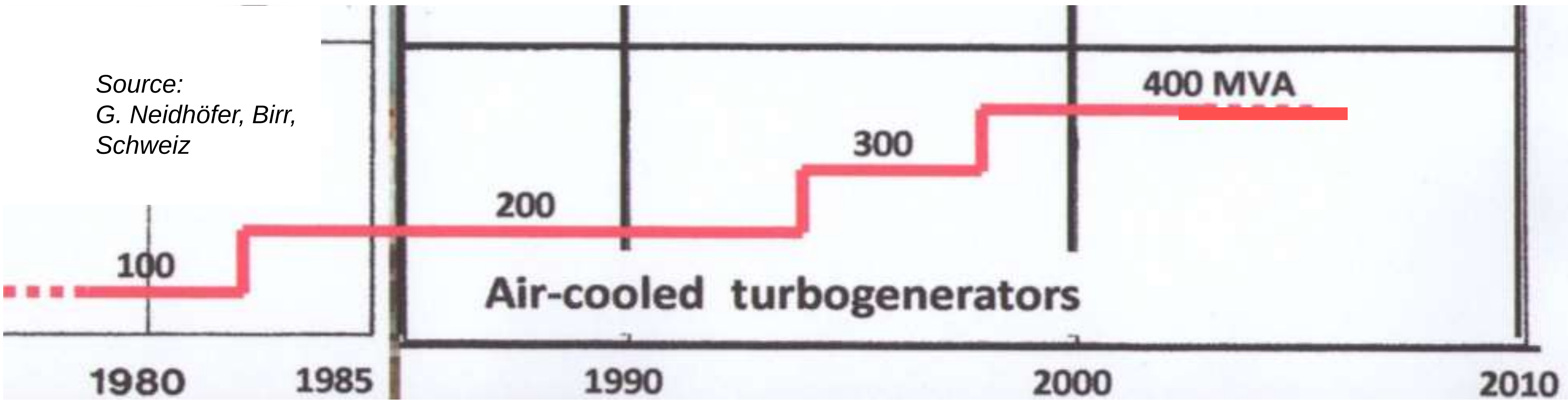
Increase of power ratings for air-cooled 2-pole turbine generators

- Power ratings fits to the rising power rating of the gas turbines

- Cheap and robust cooling system = air !

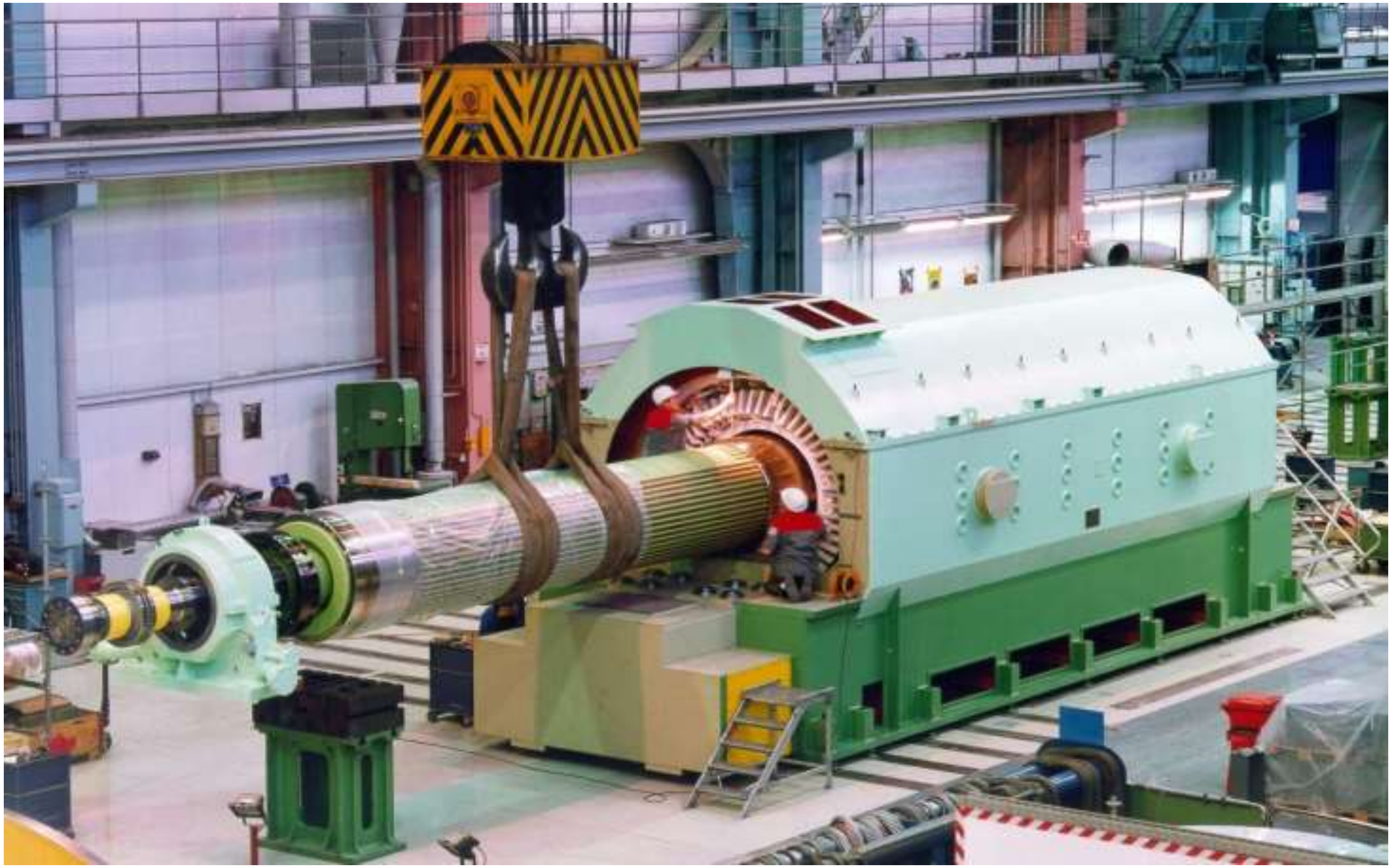
- Cooling capability increased by segmented chamber cooling

Source:
G. Neidhöfer, Birr,
Schweiz



1.3 Trends in large generators and high power drives

One of the world´s largest air-cooled 2-pole turbine generators (“TOPAIR”)



400 MVA

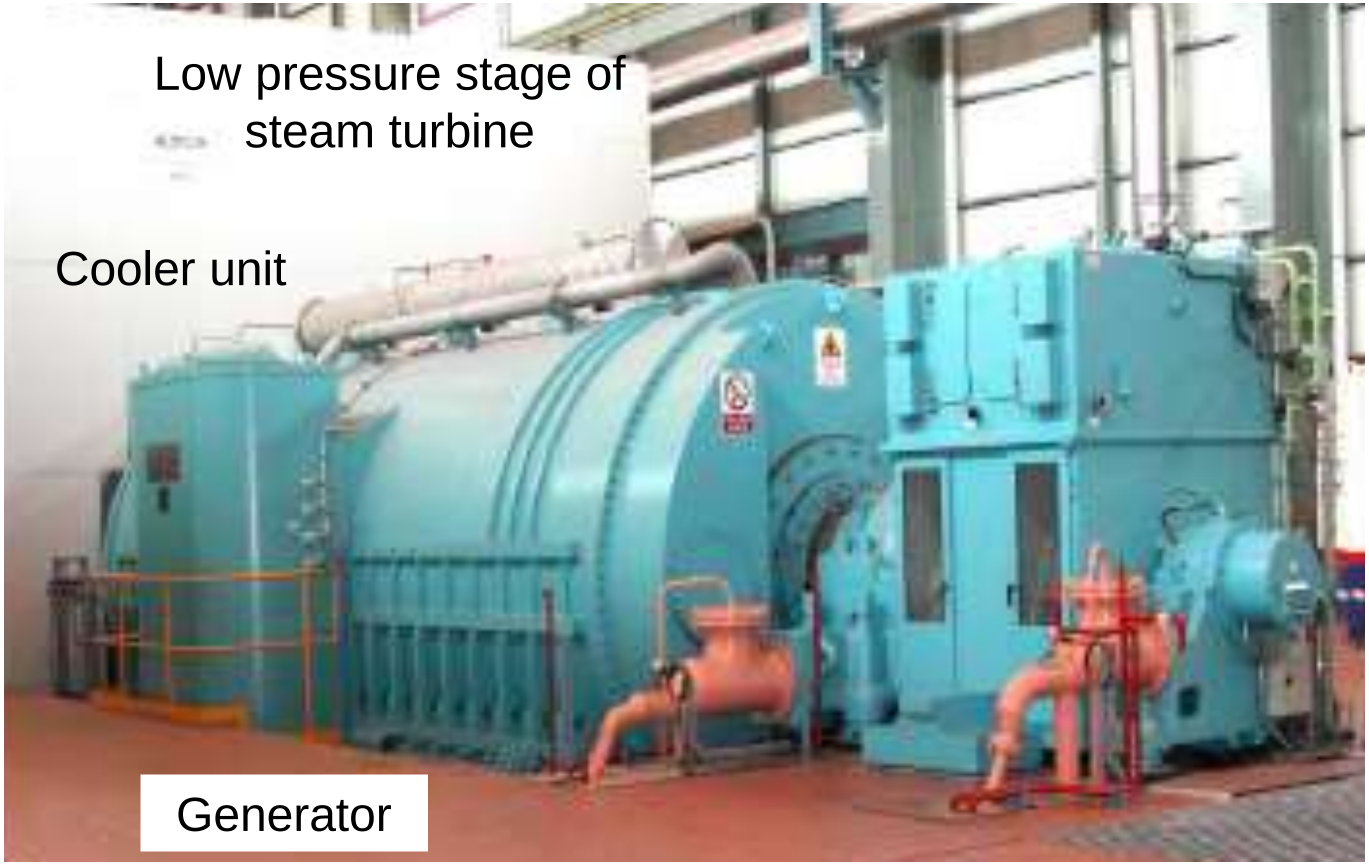
3000/min

50 Hz

Source: ABB (now Alstom Power) , Birr, Switzerland

1.3 Trends in large generators and high power drives

Above 400 MVA: Big 2-pole water/hydrogen cooled turbine generators



Exciter slip ring housing

Source: Alstom, Switzerland

Rated data: S_N = 950 MVA, Thermal Class F (155°C), utilized acc. to Class B (130°C), 700 MW, 50 Hz, 30000/min, coal power plant *Manjung*

1.3 Trends in large generators and high power drives

Big four-pole turbine generator for nuclear power plant

Exciter slip ring housing

Low pressure stage of steam turbine

Source: Alstom, Belfort

Combined hydrogen and water cooling

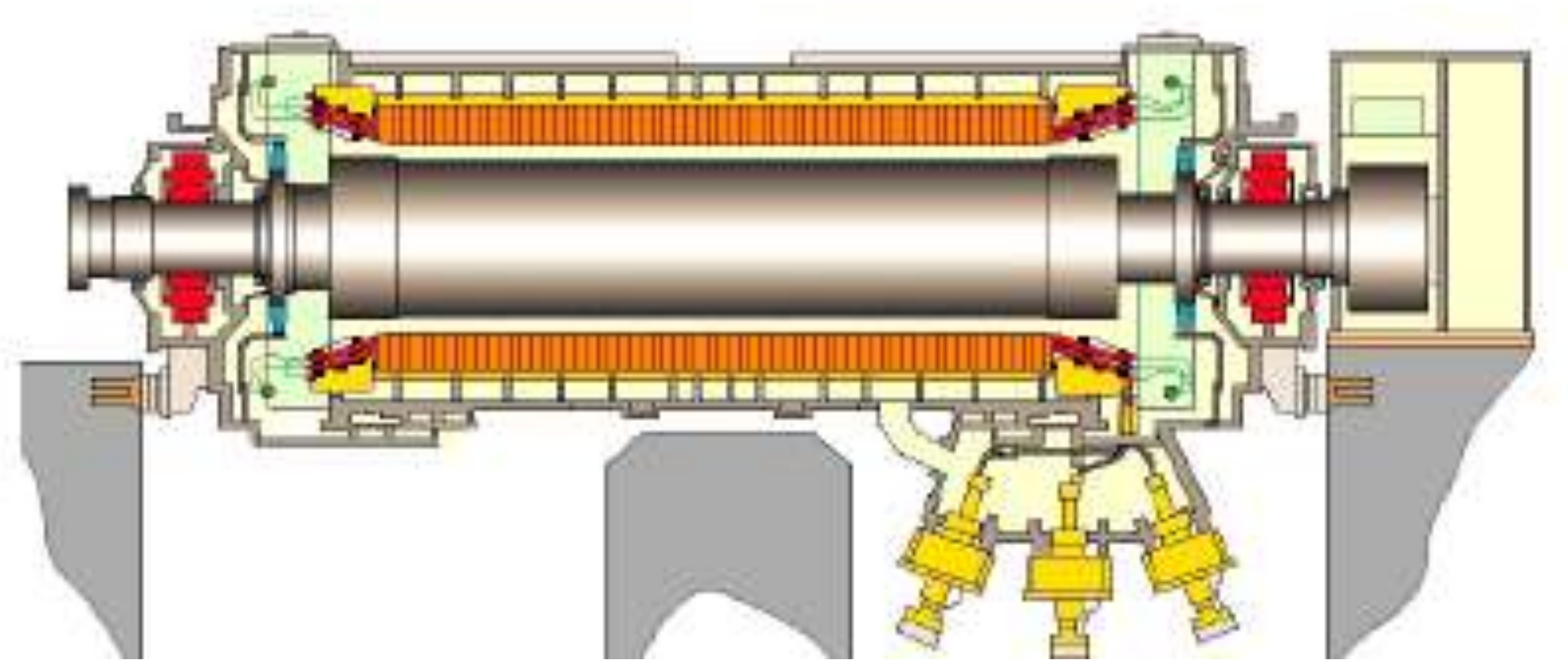
Rated data: S_N = 1722 MVA, 1500 MW, nuclear power plant *Oskarshamn*, *Sweden*

1.3 Trends in large generators and high power drives

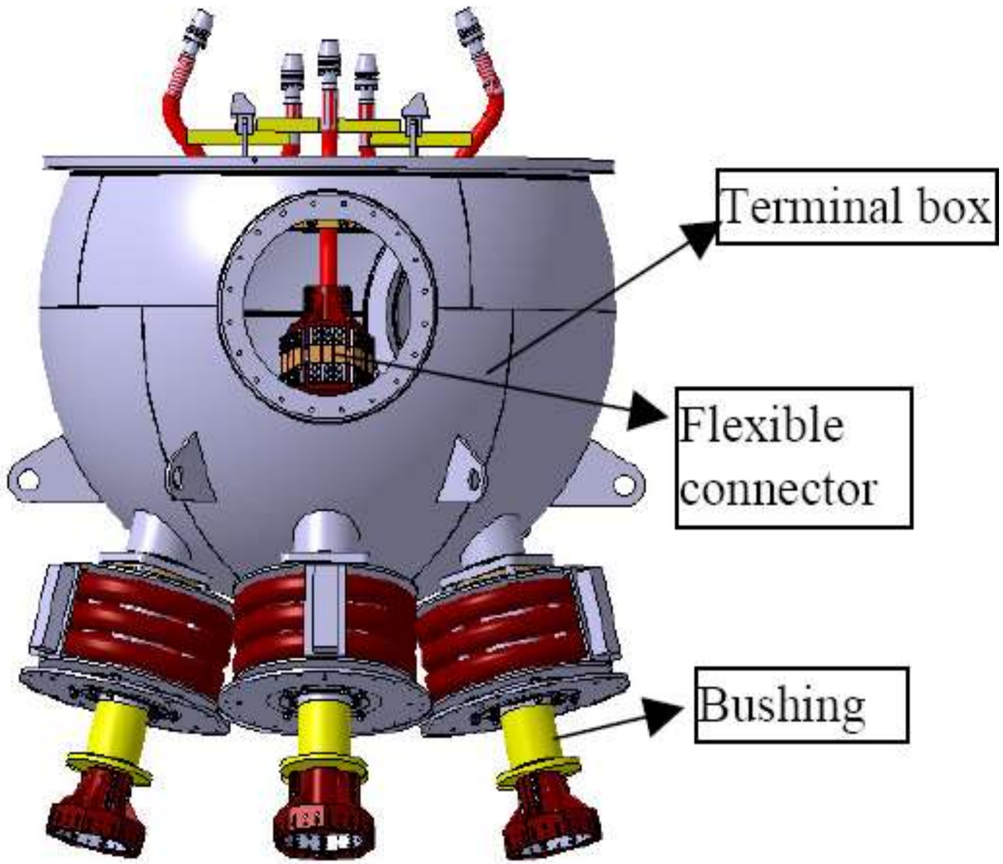
Big four-pole turbine generators for nuclear power plant

Stator: water, Rotor: hydrogen gas cooling

Source: Alstom, Switzerland



HV terminal box with bushings and winding main leads

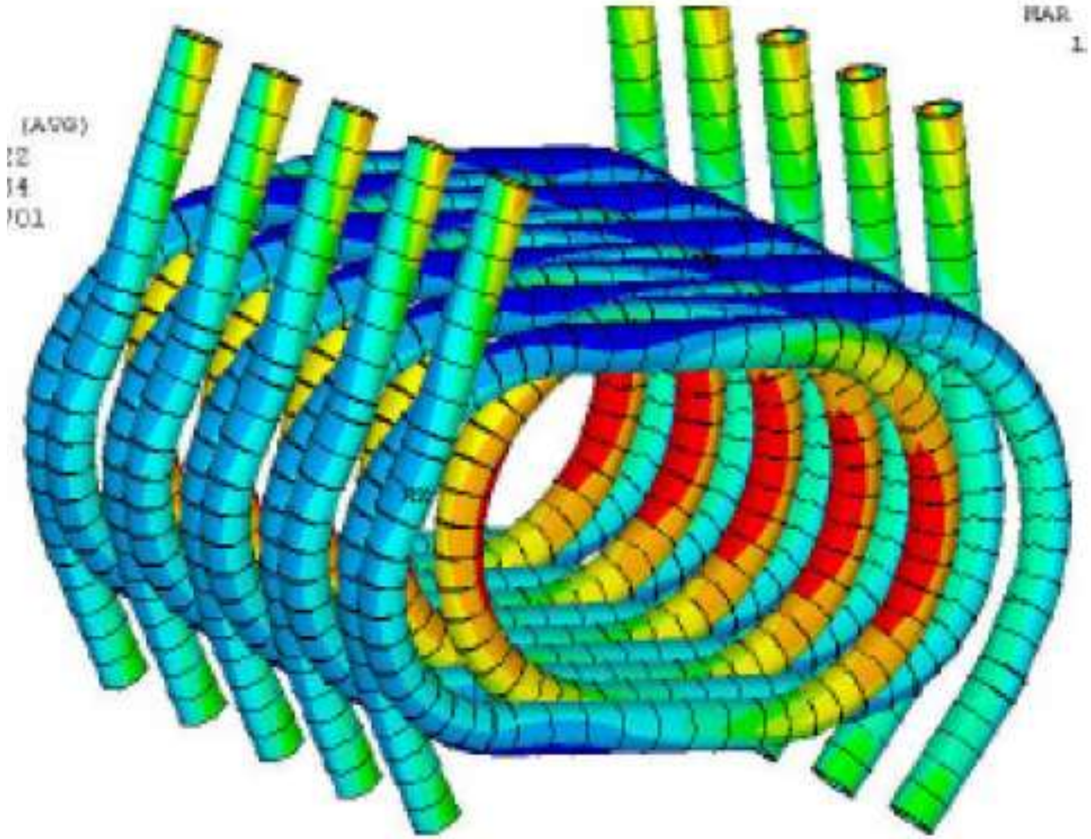


Source: Alstom, Switzerland

Wedges tightened to the flexible connection

Source: Alstom, Switzerland

Calculated displacements of the flexible connections due to thermal load



Source: Alstom, Switzerland

World´s largest electrical machine is an AC generator

- World´s biggest turbine generator 2000 MW for nuclear power plant
- Recent developments in large turbine generators

Source:

Siemens, Germany

Olkiluoto 3 2 GW turbo generator with brushless exciter at the conclusion of the type test

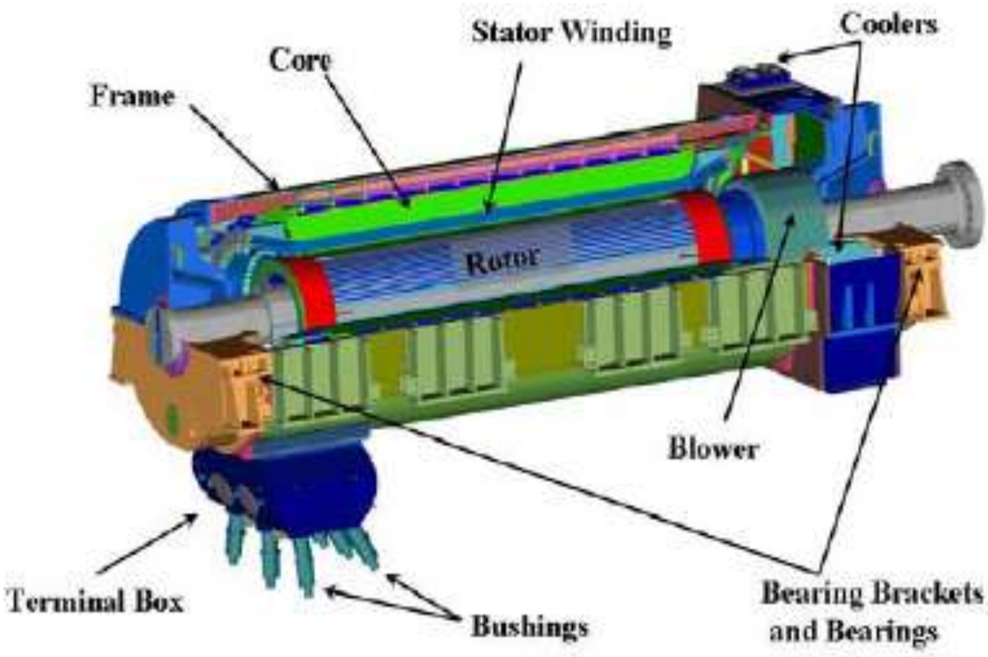
1.3 Trends in large generators and high power drives

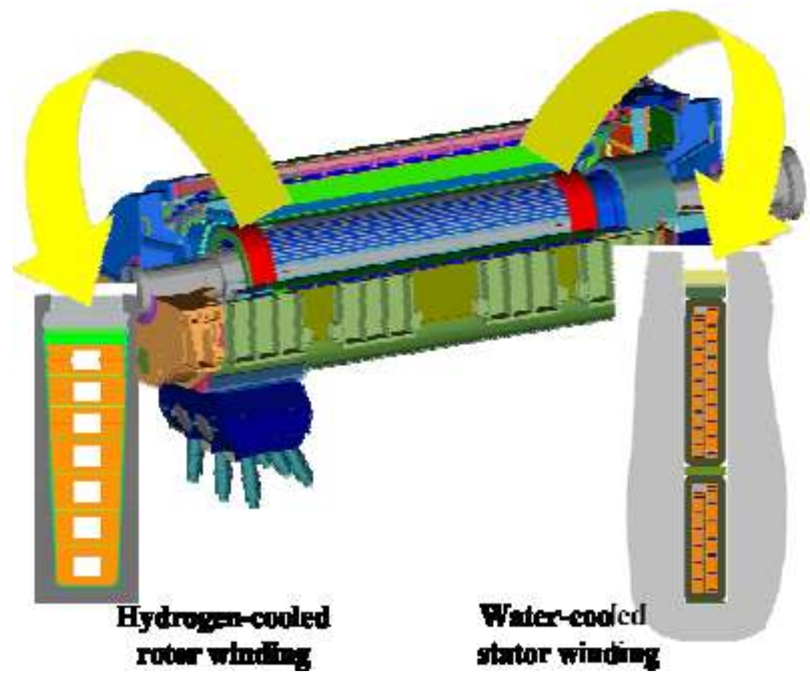
World´s biggest turbine generators 2000 MW

Rated data: S_N = 2222 MVA, Thermal Class F (155°C), utilized acc. To Class B (130°C)

$\cos\varphi_N$ = 0.9 over-excited, 27 kV, Y, 50 Hz, 1500/min, four-pole machine

I_{sN} = 47.5 kA (!), and 50 kA at 95% reduced voltage



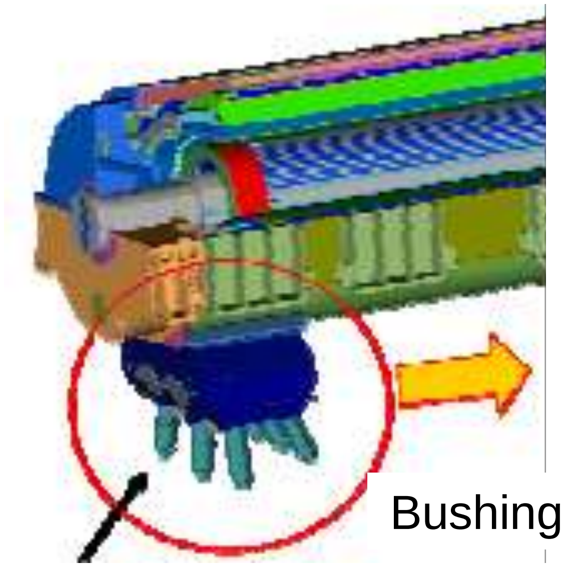


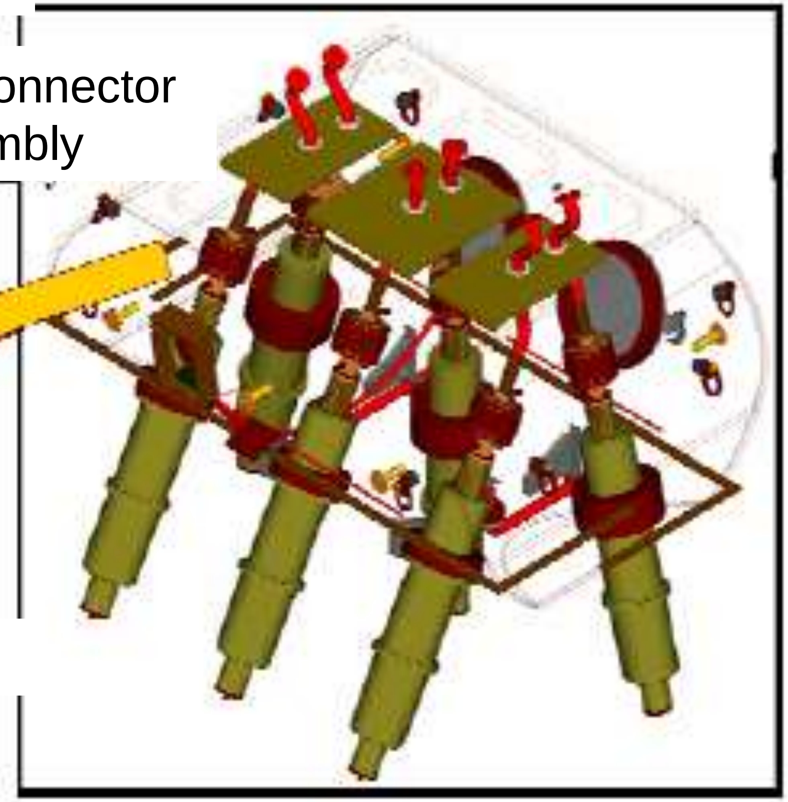
Olkiluoto 3 2 GW turbo generator

Source: Siemens, Germany

50 kA, 27 kV: 12 flexible connections per phase from main lead to the HV bushing: Current sharing only +/- 5% deviation!

12 flexible connectors per phase between main leads and bushings





Source: Siemens, Germany

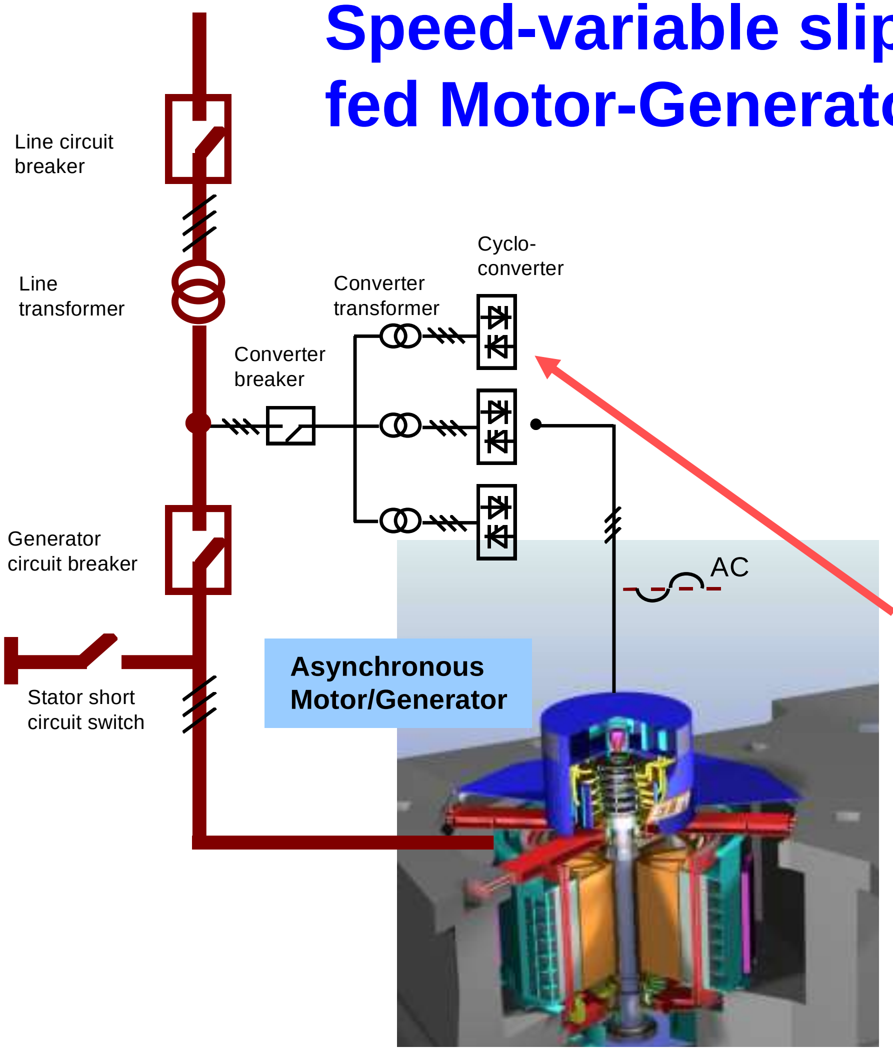
Maintenance work at generator stand still: Inspection of the winding wedges in the stator bore with a robot

Camera air-gap inspection in an air-cooled turbine generator. Due to the rather small air gap the camera robot is entering the air gap only from one side

Camera air-gap inspection in a hydrogen cooled turbine generator

Source: Alstom Power GmbH, Mannheim, Germany

Speed-variable slip-ring induction machine as doubly-fed Motor-Generator for pump storage



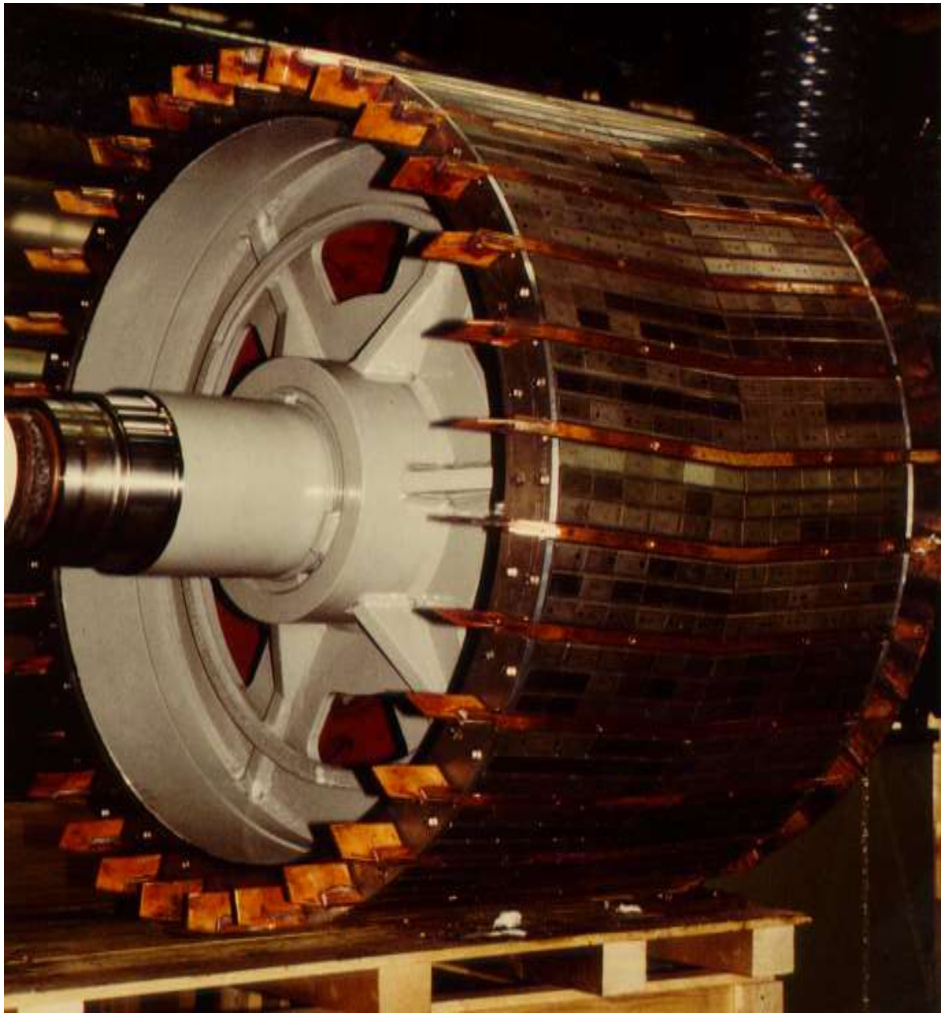
Example: *Goldisthal, Germany*
2 doubly-fed induction Motor-Generators:
340 MVA, 300 ... 346/min, 18-polig, 50 Hz

A Thyristor-controlled cyclo-converter feeds the rotor six-phase winding with 0 … 5 Hz & ca. 35 MVA power at the slip rings

Advantage: Much better fitting of the storable energy to the fluctuating grid excess power!

Source: VA Tech Hydro (now Andritz Hydro), Austria

1.3 Trends in large generators and high power drives



Use of high energy rare-earth permanent magnets (NdFeB) in speed-variable synchronous machines with MW-rating

Prototype of a 32-pole PM rotor for a synchronous motor as a propeller drive for ship propulsion

Source: Siemens AG, Nuremberg, Germany

Use of High-temperature Superconductors (HTSC) for the DC rotor winding of large synchronous machines

Prototype testing

2-pole synchronous generator for large ships

4 MW, 3600/min, 60 Hz

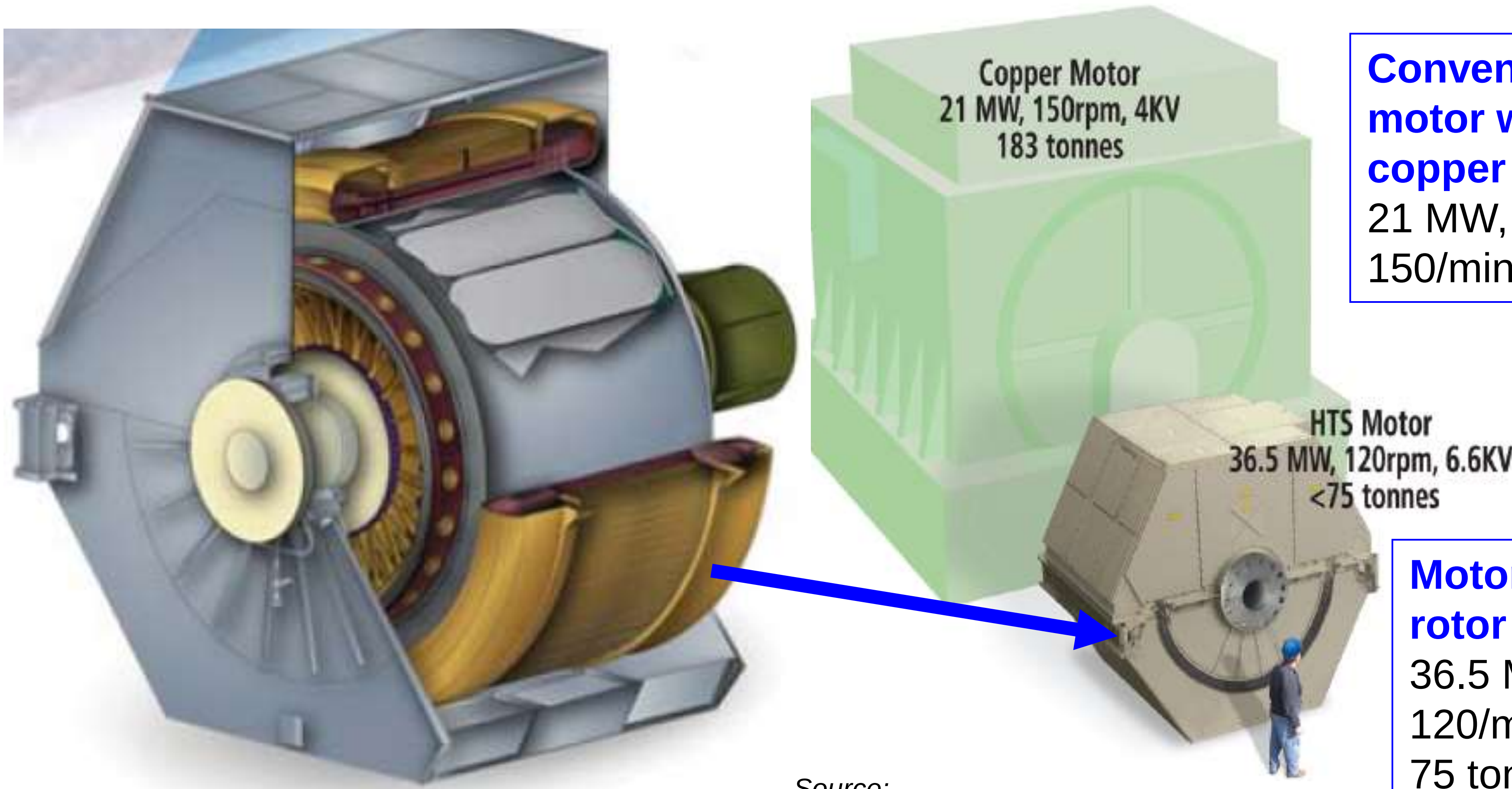
HTSC-rotor winding operated at ca. -245°C

Overall generator efficiency (incl. cooling power): ca. 98.5%

Source: Siemens AG, Nuremberg, Germany

1.3 Trends in large generators and high power drives

Downscaling of motor size: HTSC-Synchronous motor for ship propulsion



Conventional motor with rotor copper winding:
21 MW, 4 kV,
150/min, 183 tons

Motor with HTSC-rotor winding:
36.5 MW, 6.6 kV,
120/min,
75 tons

Source:
American Superconductor, USA

Large Generators and High Power Drives

Summary:

Trends in large generators and high power drives

- Further increase of rated power of gas turbines gives need for bigger air-cooled generators above 400 MW
- Variable speed motor-generators for pump storage needed
- Variable speed large induction and synchronous machines needed
- Synchronous motors in the MW-range with high temperature superconductor rotor field winding (e.g. for ship propulsion)
- Increase of size PM synchronous machines for low speed (wind turbines) up to 10 MW