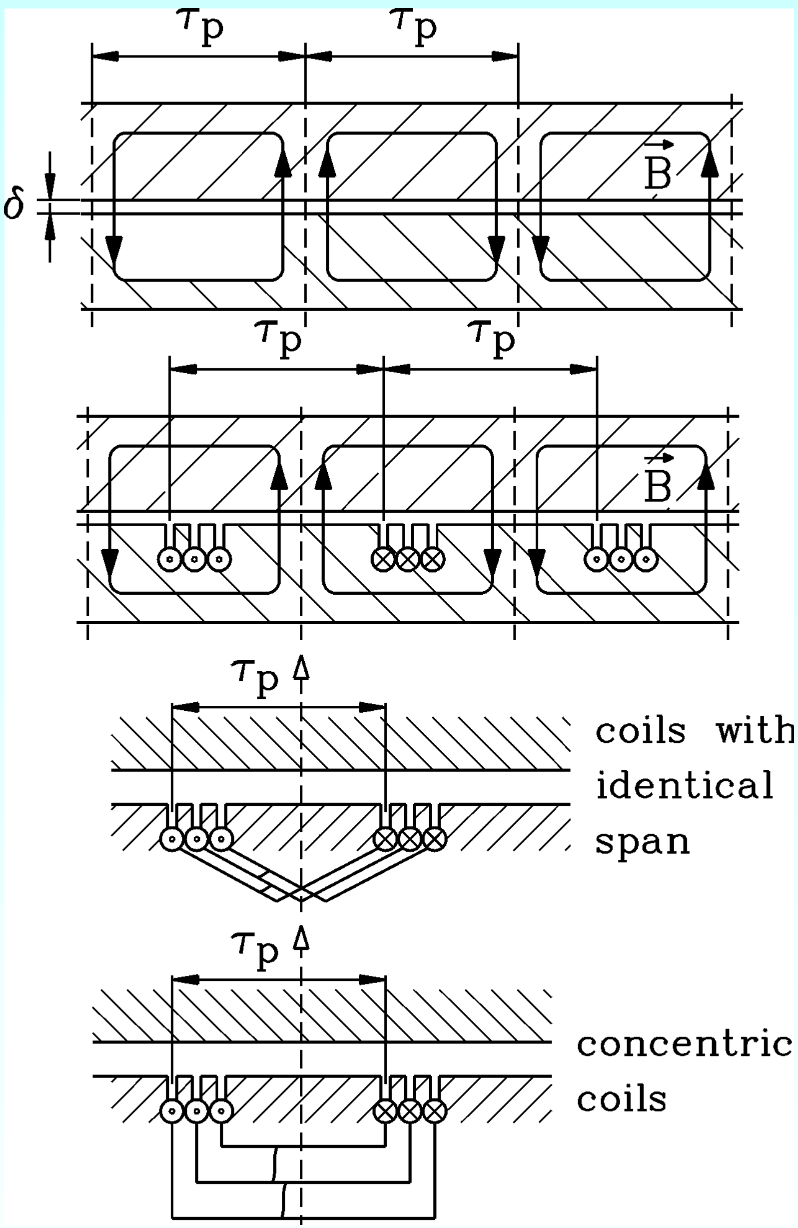
3. Three phase winding technology

Source:

VATech Hydro, Austria

Single layer winding



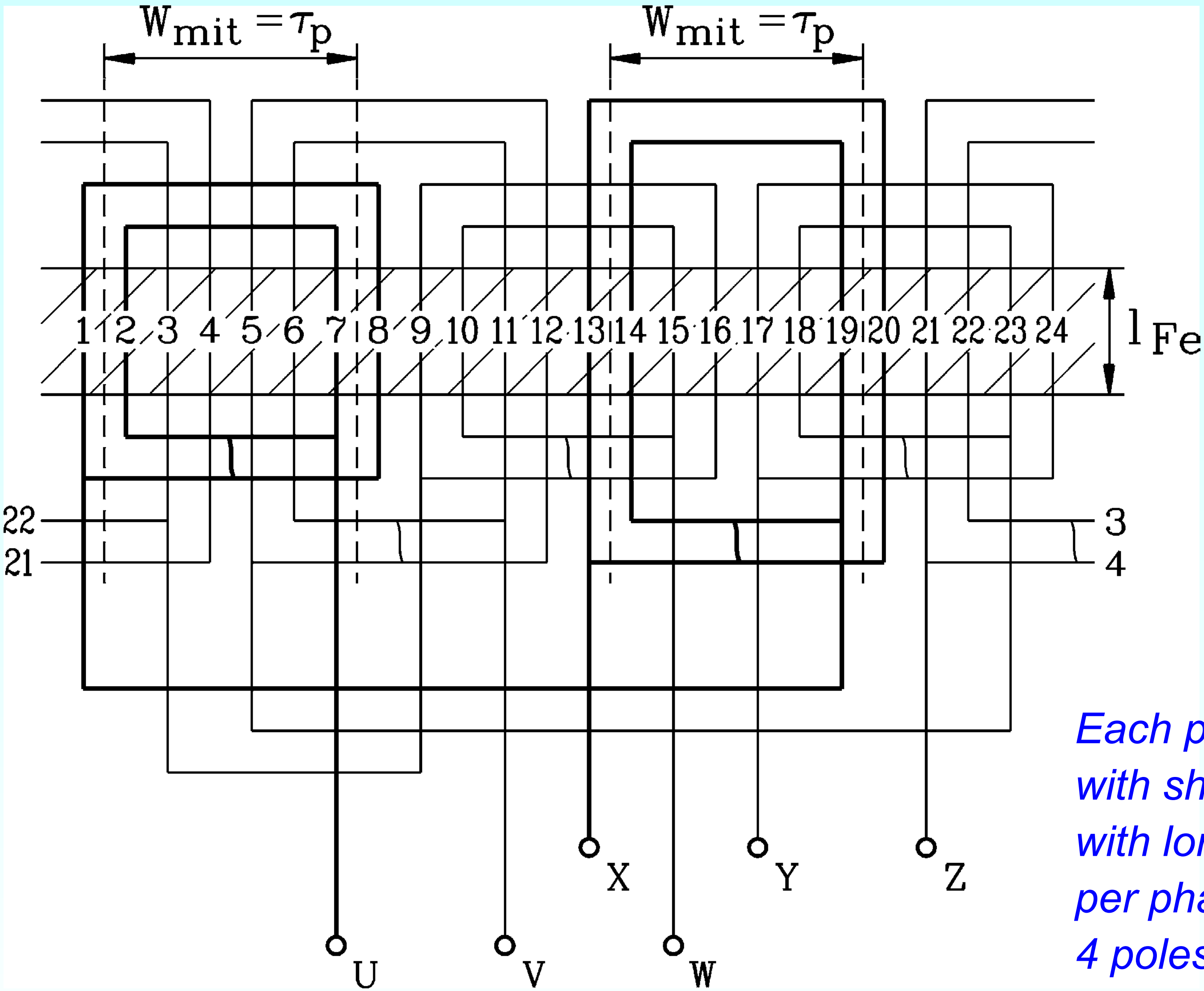
- Per slot only one coil side is placed.
- Coils manufactured as:
  - **a) Coils with identical coil span**: $W = \tau_p$
  - **b) Concentric coils**

Example:
Three-phase, 12-pole machine with $q = 3$ coils per pole and phase:
Total slot number: $Q = m \cdot 2p \cdot q = 3 \cdot 12 \cdot 3 = \underline{108}$

North- and south pole are generated by **ONE coil group per phase**.

Problem with single layer windings:
Crossing of coils in winding overhang part, as all coils are lying in the same plane. Thus some coils must be bent upward in winding overhang region **(“2nd plane”).**

Example: Single layer winding with short and long coils



Unrolled winding system gives "winding scheme" : here four-pole machine: $2p = 4$, $m = 3$, $q = 2$, $Q = \underline{24}$

Winding manufactured with concentric coils.

"Long coils" : Winding overhang part of coils is longer; so these coils may be bent upwards !

Each phase has one pole pair with short and one pole pair with long coils ! So resistance per phase is equal, but minimum of 4 poles required !

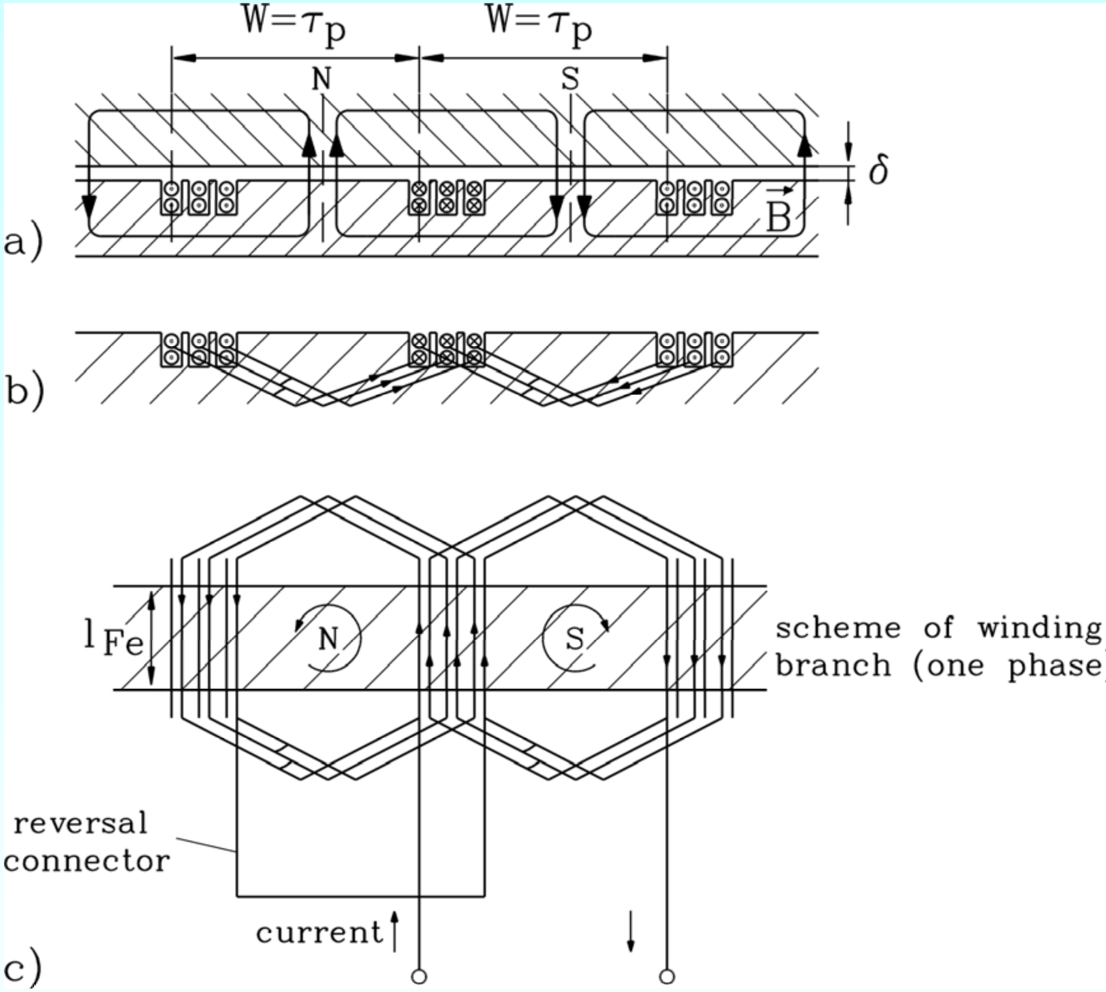
Stator three phase single-layer winding of induction machine

Round wire coils

Source:

ELIN EBG Motors, Austria

Two-layer winding

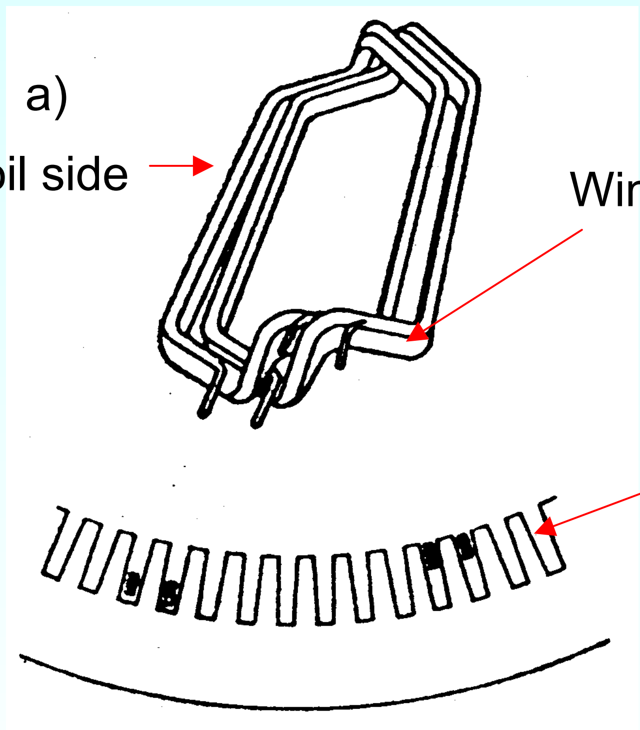


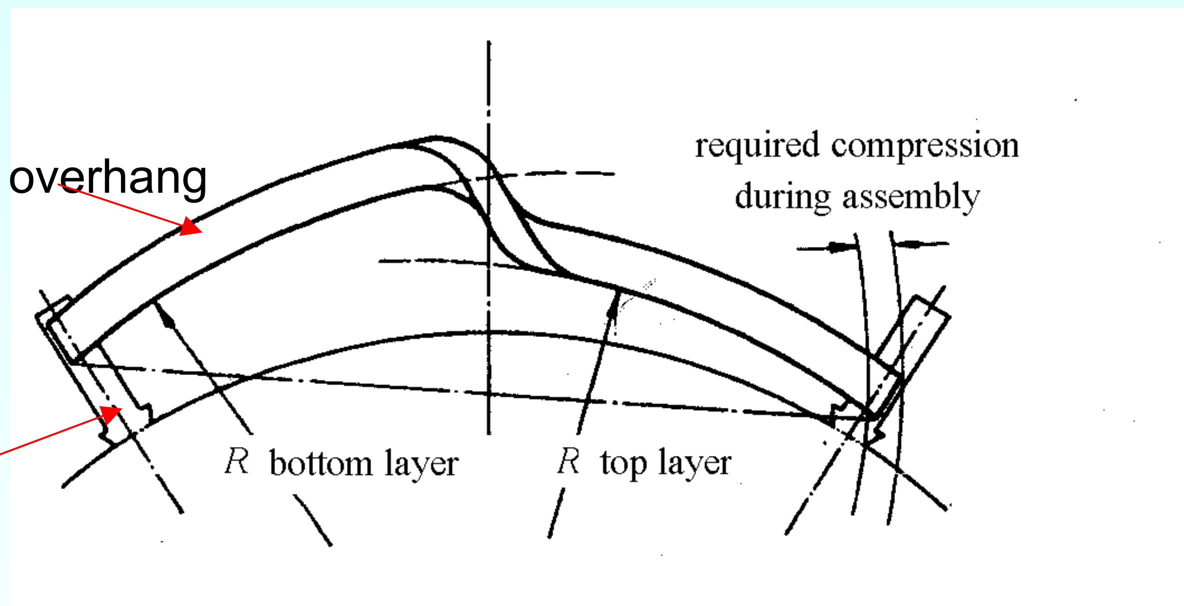
- Coils with **equal span**
- **Two-layer winding:** Per slot TWO coil sides are placed one above the other.
- North- and south pole are generated by **two** coil groups.
- Direction of current flow in N- and S-pole coils opposite !
- Changing of current flow direction by **reversal connector.**
- Bigger machine ratings typically above 500 kW: Profiled coil conductors (rectangular cross section), round wire with smaller machines !

- *Example:* For 4-pole machine we need four coil groups per phase !

Winding overhang of two-layer winding

- a) Two form wound coils before being put into the stator slots: Due to S-shape in winding overhang part of coils there are **NO** crossing points of the coils.
- b) Form wound coil with profiled conductor, placed in stator slot, with left coil side in lower and right coil side in upper layer. Manufacturing much more expensive than with round wire single-layer winding, therefore used usually only in bigger machines: e.g. **high voltage machines** up to 30 kV (“High voltage” : U > 1000 V (rms)!).





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:

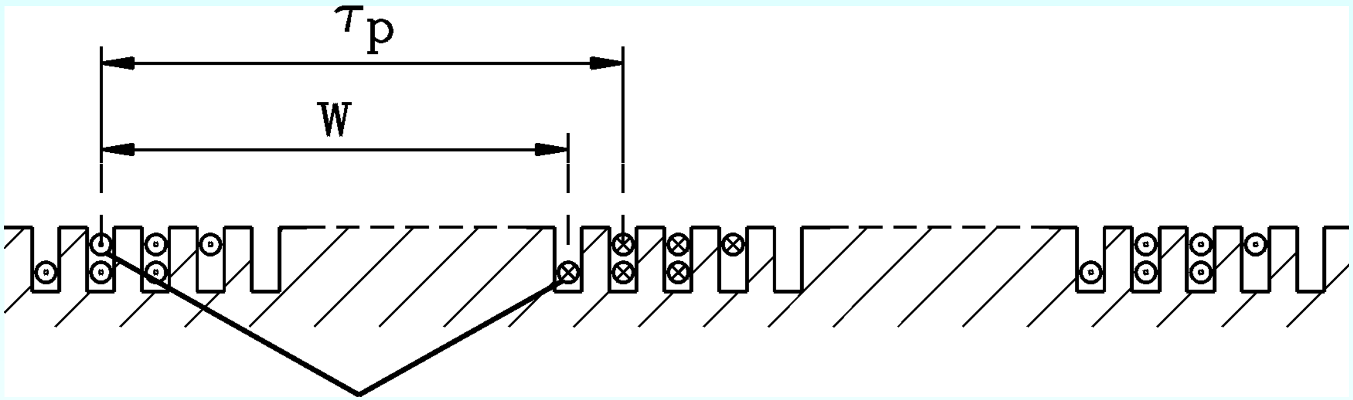
VATech Hydro, Austria

Pitching (chording) of coils $W < \tau_p$

- With **Two-layer windings: pitching of coils** is possible !
- Pitching = Shortening of coil span W , counted in number S of slot pitches

$$\boxed{W = \tau_p \cdot \frac{m \cdot q - S}{m \cdot q} = \tau_p \cdot \frac{Y_Q}{m \cdot q}}$$

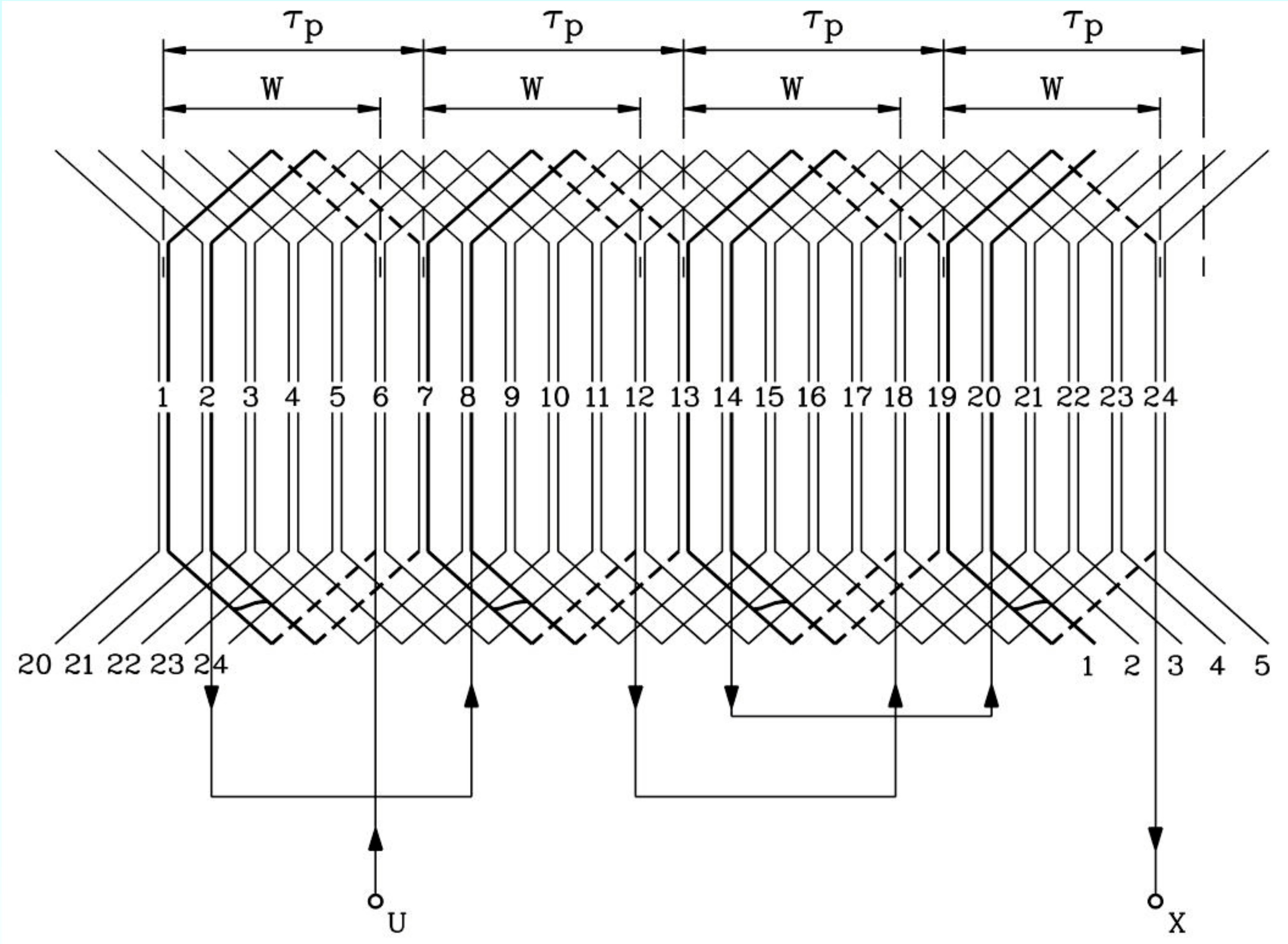
S : integer number



- Benefit of pitching: Shape of field curve fits better to ideal sinusoidal shape.
- *Example*: Four-pole machine: Data: m = 3, Q = 24, q = 2:
  Pitching is pöossible for $S < mq = 3 \cdot 2 = 6$: S = 1, 2, 3, 4, 5.
  e. g.: S = 1, hence pitching is W/τ_p = 5/6.

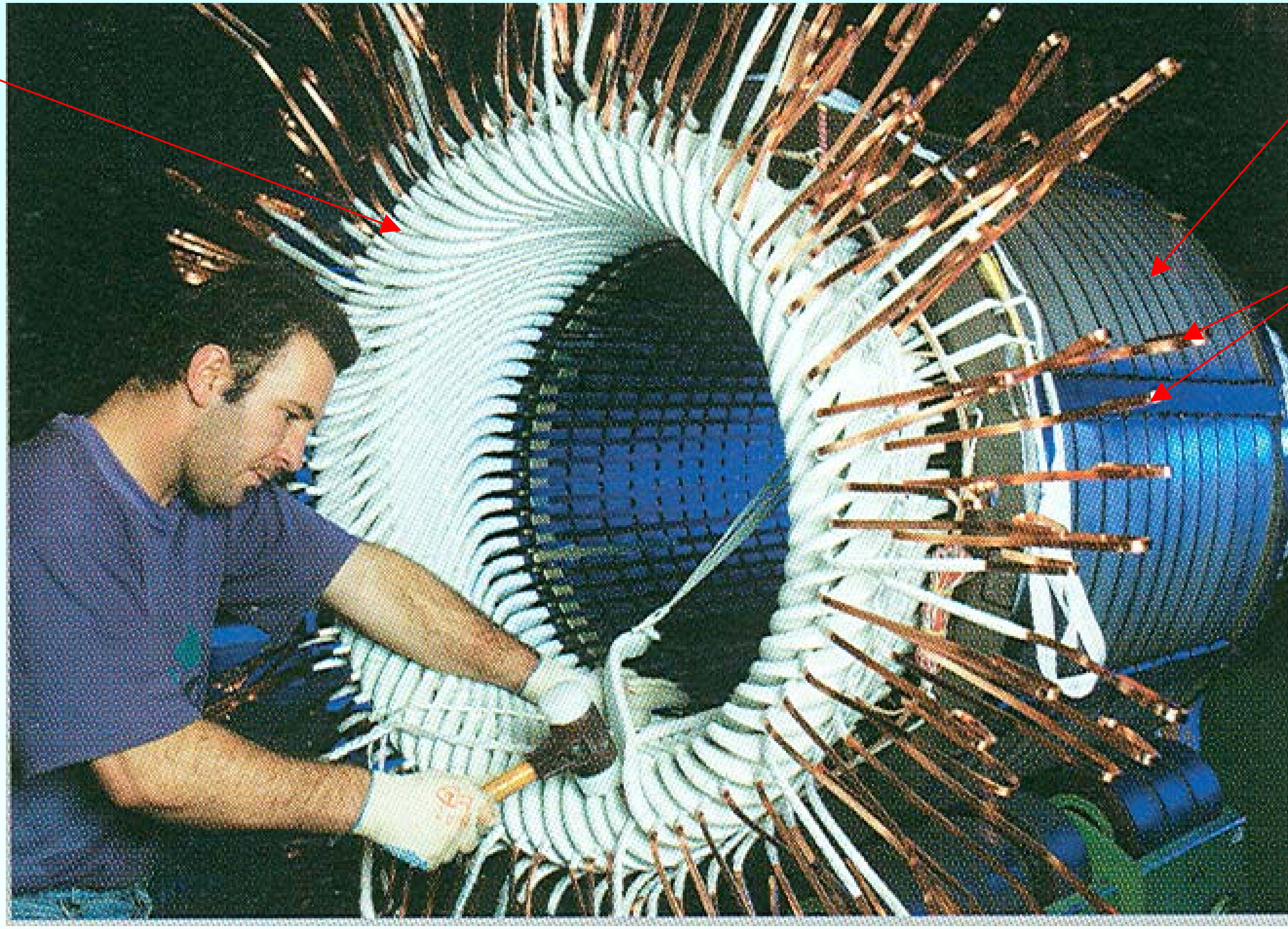
Example: Pitched Two-layer winding

- Four pole machine, m = 3, Q = 24, q = 2: Pitching W/τ_p = 5/6.



Inserting form-wound two-layer winding in induction generator stator

Winding overhang



Stator iron stack

coil ends

Source:

Winergy

Germany

Inserting form-wound two-layer winding in stator slots

Source:

ABB, Switzerland

Stator three phase two-layer winding of induction generator

Source:

Winergy

Germany

Rotor three phase two-layer winding of slip ring induction generator

Source:

Winergy

Germany

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

Ventilation duct

Tooth

Slot

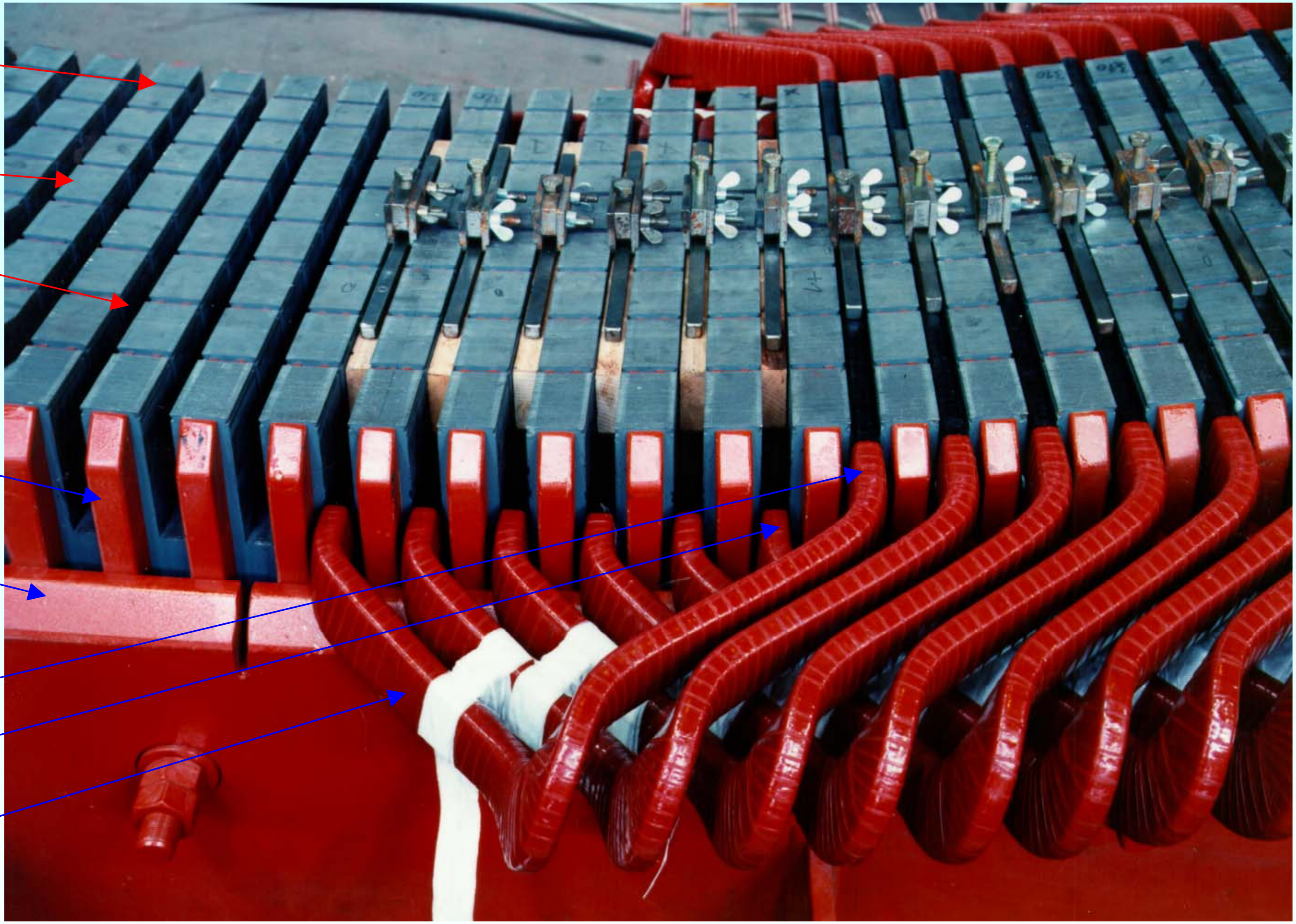
Massive iron clamping finger

Pressing plate

1st layer

2nd layer

winding overhang



Source:

VATech Hydro, Austria

Series and parallel connection of coil groups

- **Series and parallel connection** of coil groups to get one winding phase

- Example : Eight-pole machine:
  Two-layer winding: 8 coil groups, which may be connected as follows:
  - *a* = 1: Series connection of all 8 coil groups
  - *a* = 2: 4 coil groups in series, then paralleling the two series sections
  - *a* = 4: 2 coil groups in series,then paralleling the four series sections
  - *a* = 8: All 8 coil groups are connected in parallel

  Single-layer winding: 4 coil groups, which may be connected as follows:
  - *a* = 1: Series connection of all 4 coil groups
  - *a* = 2: 2 coil groups in series, then paralleling the two series sections
  - *a* = 4: All 4 coil groups are connected in parallel

- Resulting **number of turns per phase** *N:*

$$\boxed{N = \frac{pqN_c}{a}}$$ Single-layer winding

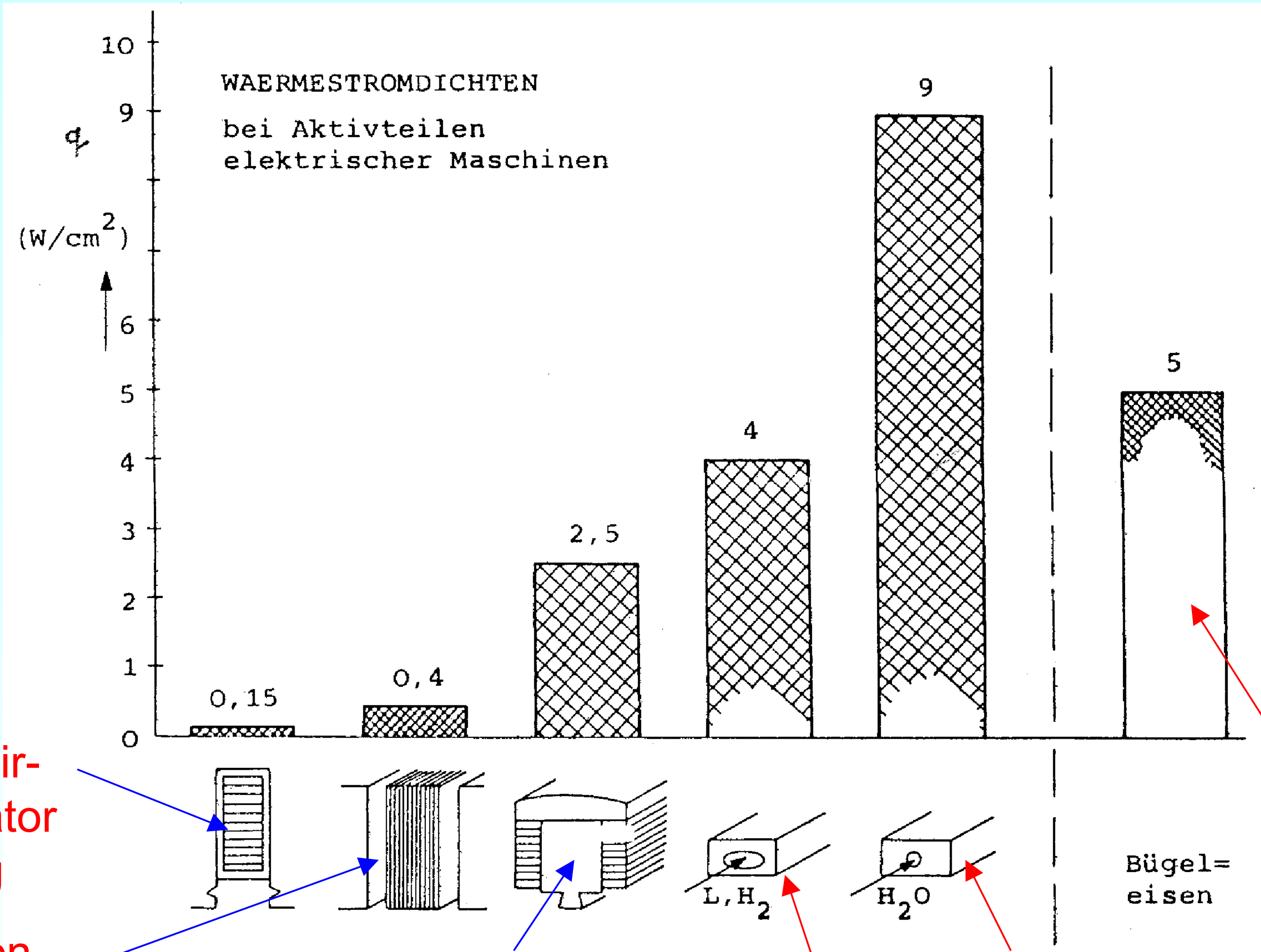
$$\boxed{N = \frac{2pqN_c}{a}}$$ Two-layer winding

- Example: $2p = 4$, $q = 2$, eleven turns per coil ($N_c = 11$), series connection of all coil groups: $a = 1$: number of turns per phase: $N = 4 \cdot 2 \cdot 11/1 = 88$

Variants of cooling of winding and iron stack

Heat flow density

(W/cm²)



Indirect air-cooled stator winding

Stator iron stack packets

Directly air-cooled rotor pole winding

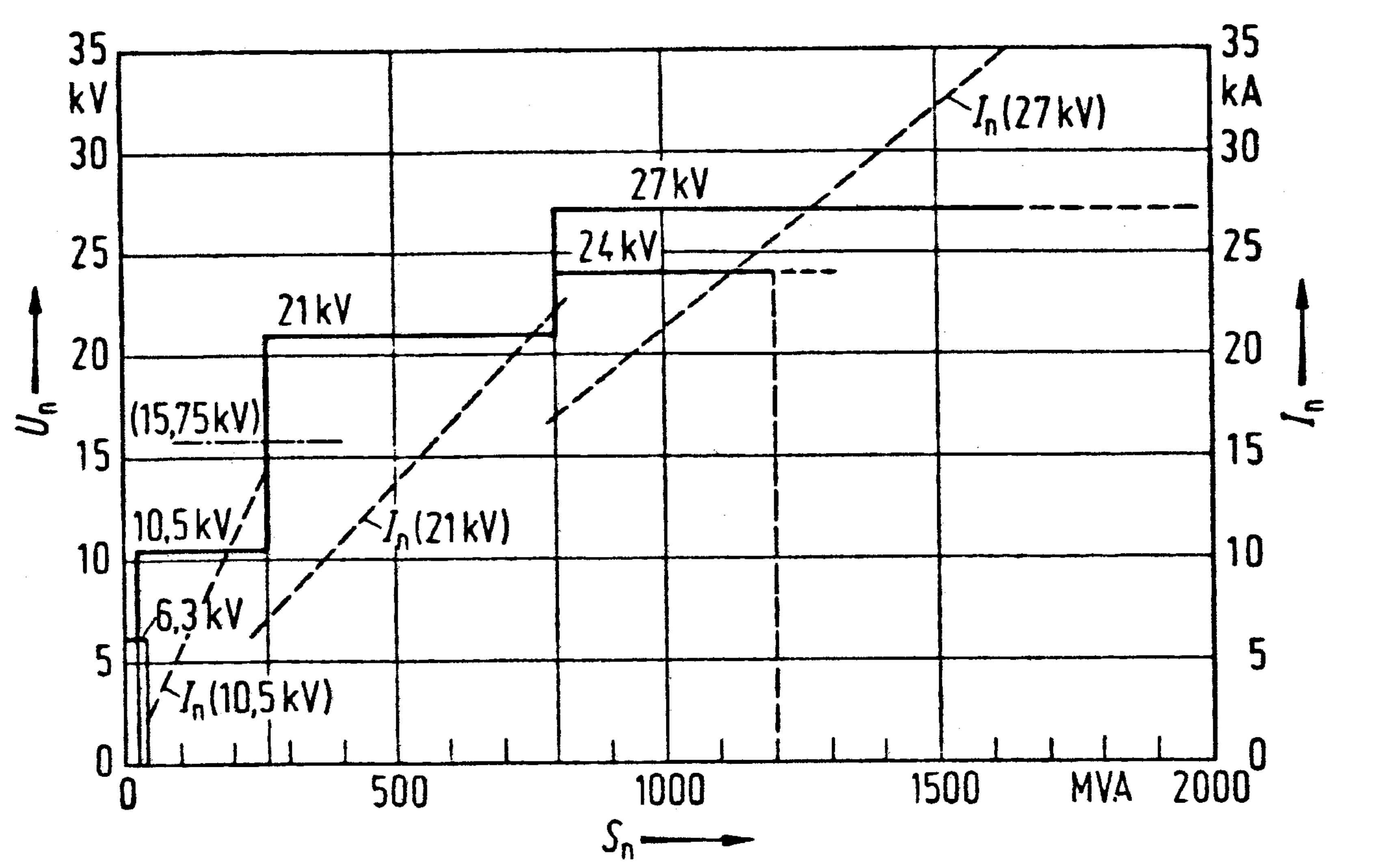
Air/hydrogen water

Directly cooled hollow conductors

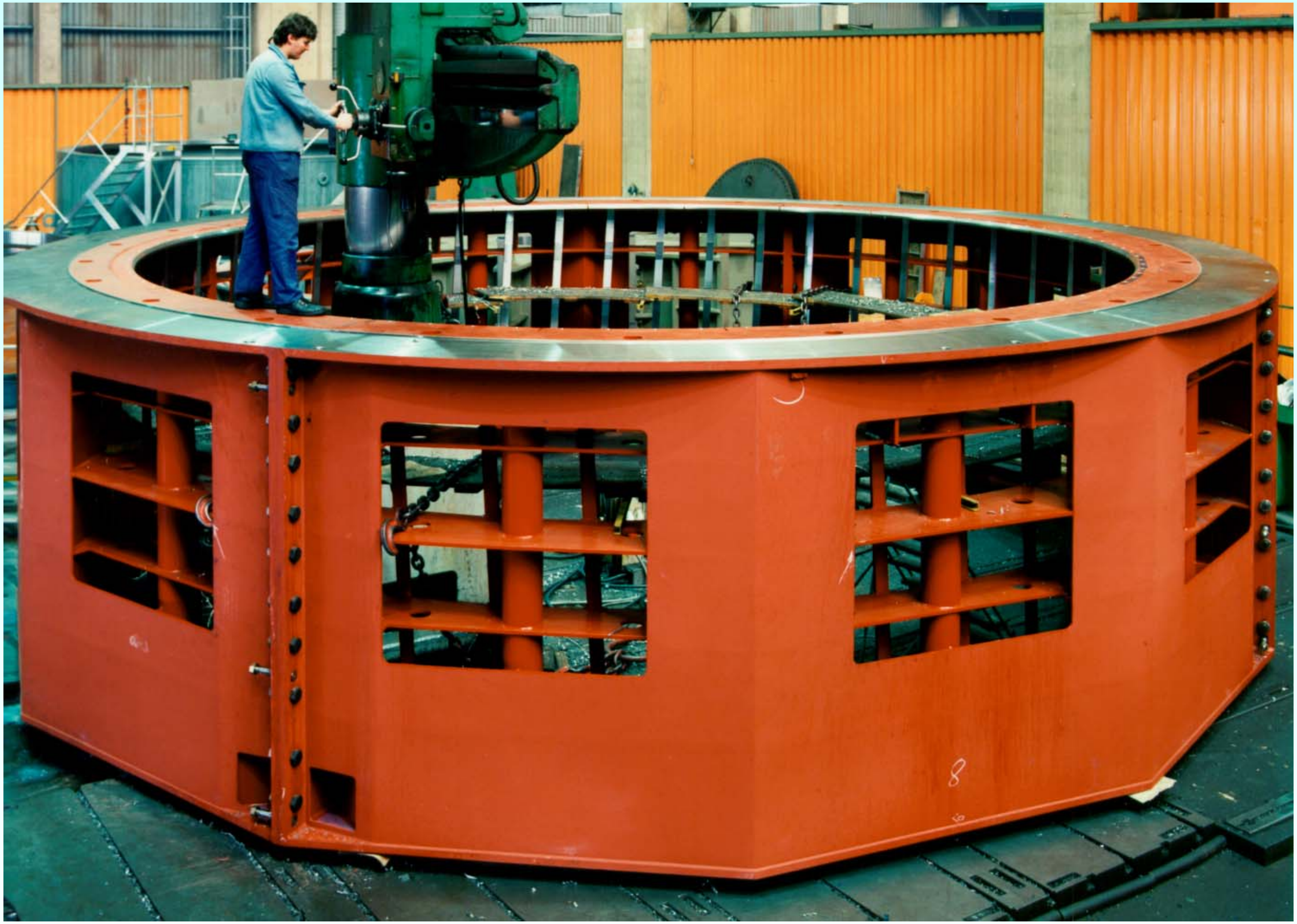
For comparison:

Heat transfer of flat -iron

Rated voltage U_n of stator winding increases with increasing apparent power S_n to limit rated current I_n



Welded stator housing of synchronous hydro generator



Source:

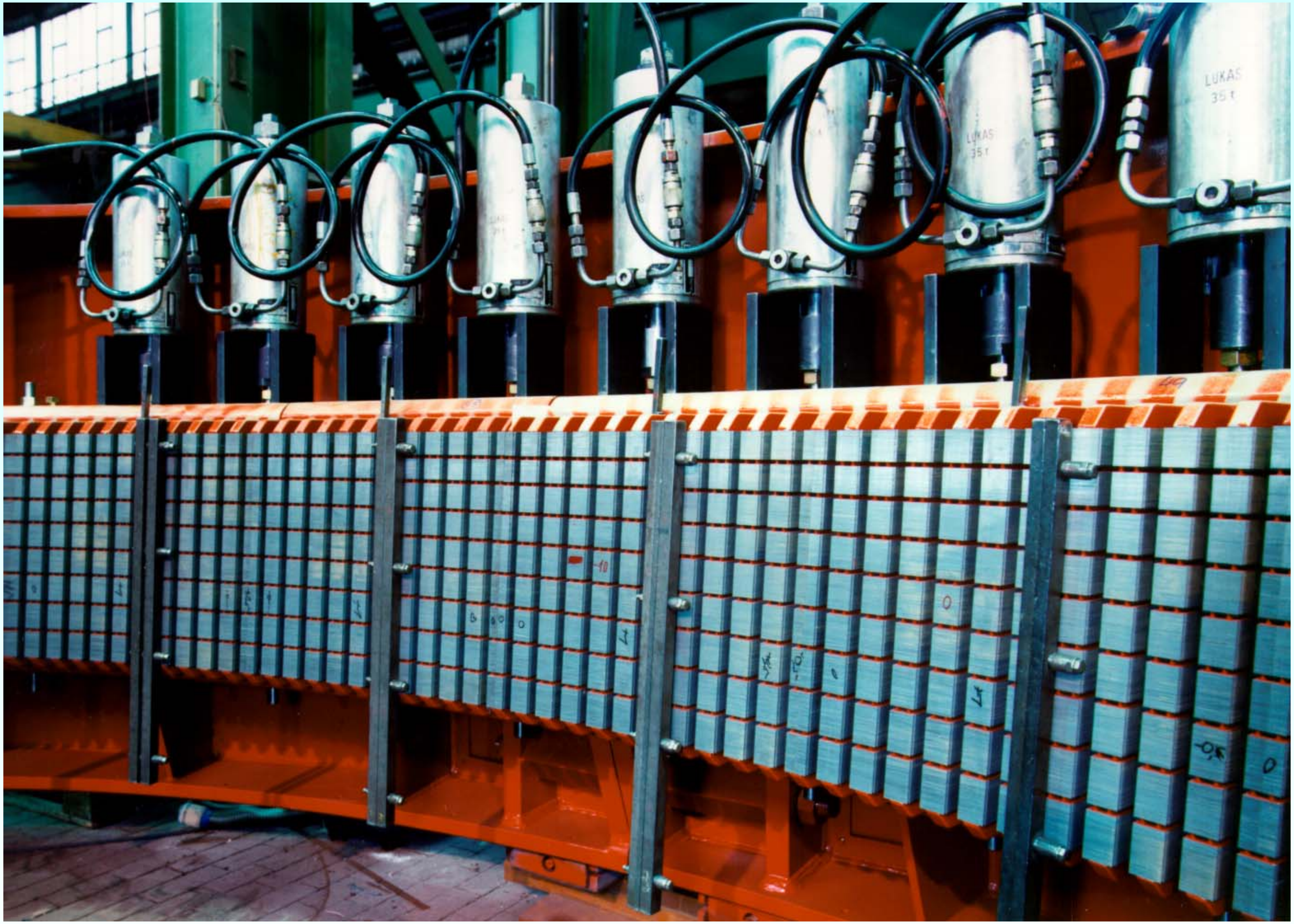
VATech Hydro, Austria

Stacking of stator iron sheets of synchronous hydro generator

Source:

VATech Hydro, Austria

Pressing of laminated stator iron core with hydraulic cylinders



Source:

VATech 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:

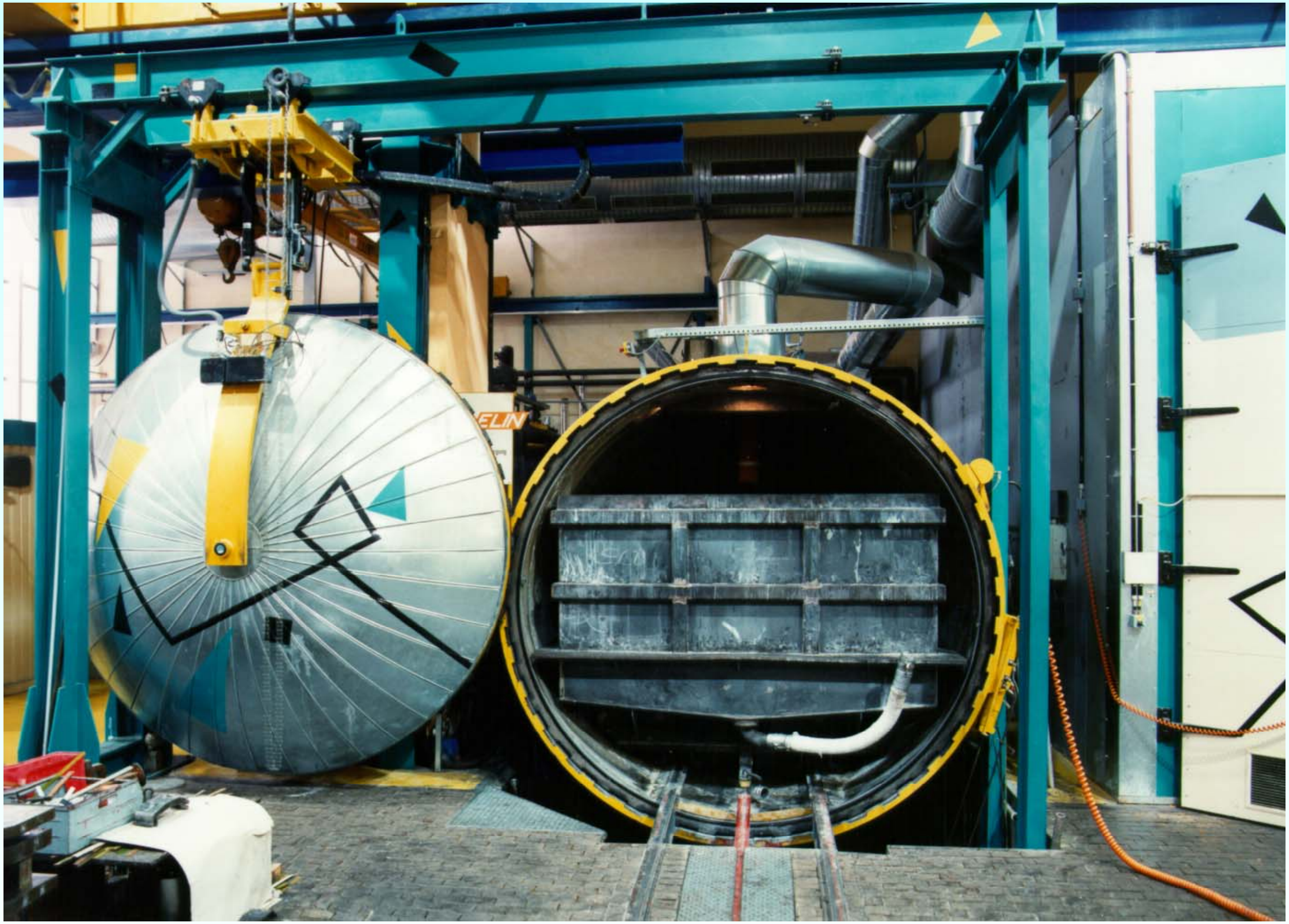
VATech Hydro, Austria

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

Source:

VATech Hydro, Austria

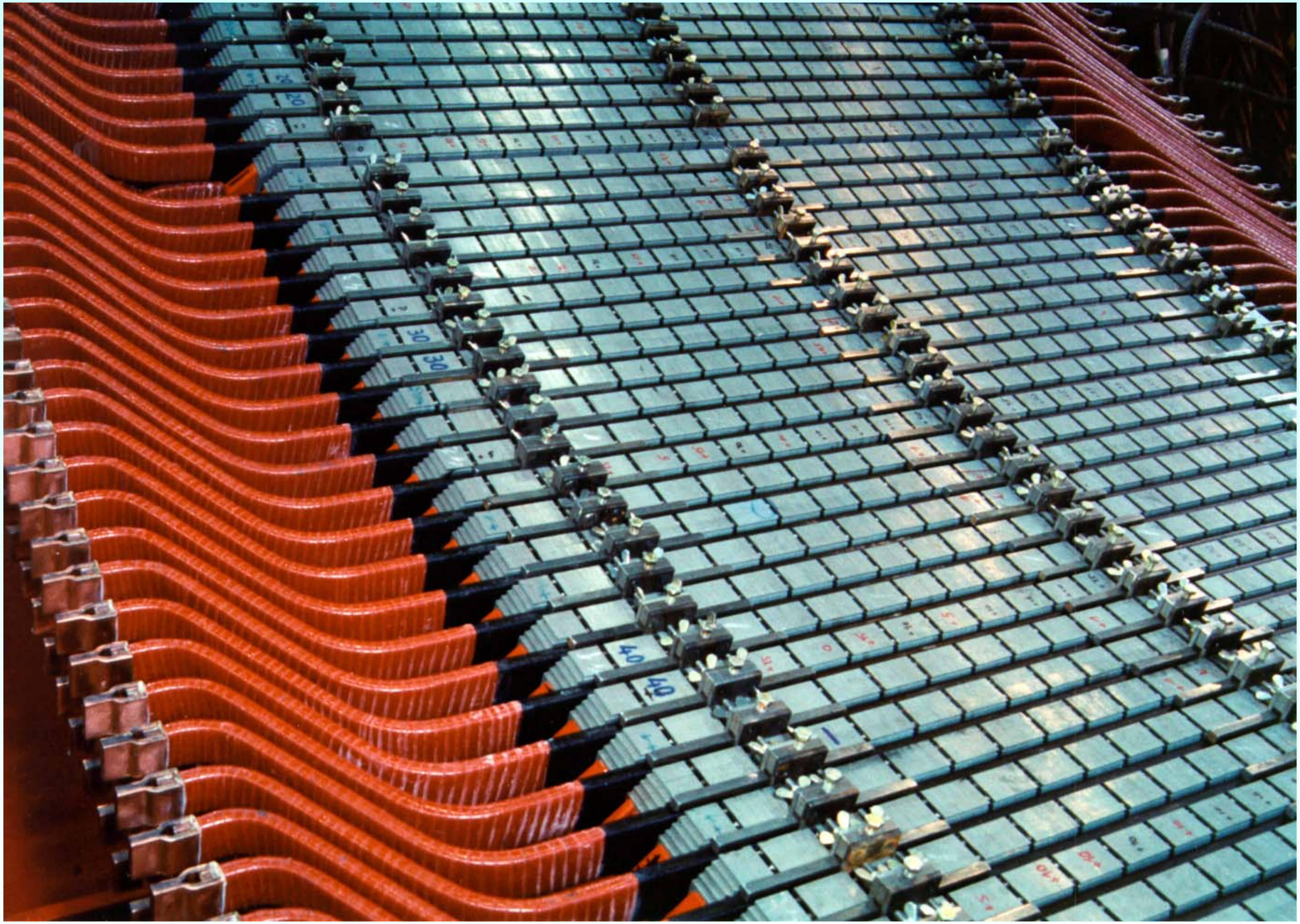
Resin impregnated coils are heated in the oven to dry and harden the insulation



Source:

VATech Hydro, Austria

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



Source:

VATech Hydro, Austria