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# Fundamentals of MV Motors

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TMEIC
We drive industry

TEXAS A&M UNIVERSITY

TURBOMACHINERY LABORATORY
TEXAS A&M ENGINEERING EXPERIMENT STATION

# Presenter Bio

Brandon Kim is a sales application engineer specializing in MV Motors at the TMEIC office in Houston, TX.

Brandon received his BSc in Mechanical Engineering at University of Warwick (UK) in 2006. He has since worked in the energy industry including several years at Hyundai Heavy Industries as an Application Engineer.

His responsibilities include power systems, MV induction and synchronous motors, and technical training. He is an active member of API-541/546 committee and IEEE.

# Overview

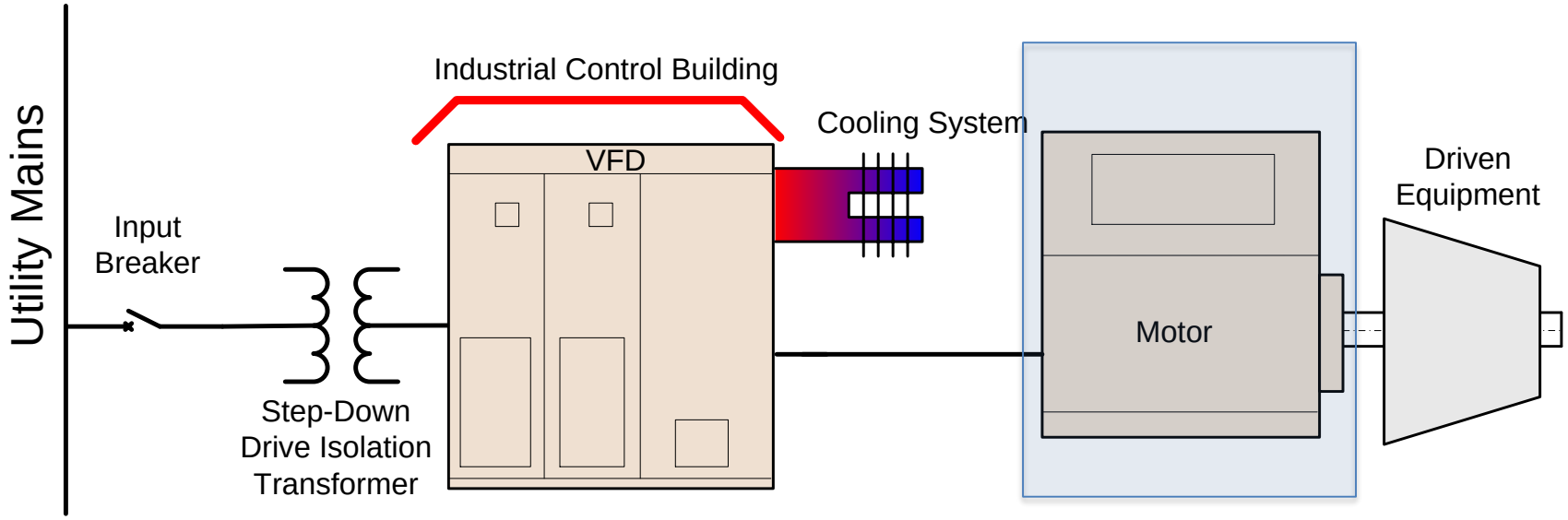
Medium voltage motors are widely applied to plant rotating machinery like compressors, pumps, fans, extruders, mills etc., ranging from a few horsepower to tens of thousands of horsepower. Safe, reliable and successful application of these motors require a system level approach.

The focus of the tutorial will be application topics that can be used right away to specify, evaluate, procure and install a successful MV motor system. The dimensions of the course will be medium voltage (>2.3kv) and motor power ranging from 500HP thru 100,000HP.

# Discussion Topics

## AC Medium Voltage Electric Motors

- MV Motor basics and terminology
- Induction Vs. Synchronous motors
- Overview of large MV motor manufacturing process
- Standards – NEMA-MG1, IEC, API
- Motor selection process
- Enclosures & Bearings
- Most Common Options / Accessories



# Definitions

What is an Induction Motor or a Synchronous motor?

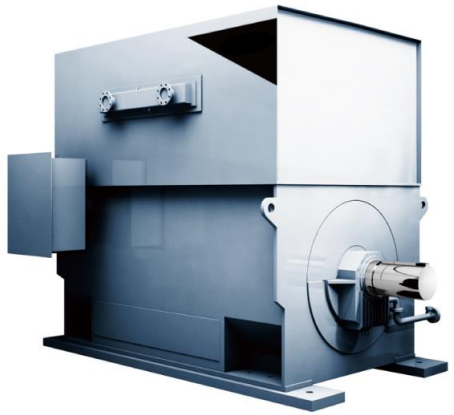
Induction motors are the “standard” industrial motors with over **+99%** being Induction.

It is an induction motor if it runs less than the “synchronous” speed. It is approx. **1785** not 1800 (% difference is “slip”).

The reason is the power is “induced” on the rotor.

Also called a **squirrel cage** motor.

# Key Differences



| Induction | Synchronous |
|---|---|
| MV = High Efficiency | +1~2% Higher Efficiency |
| Slip | No Slip |
| Good Starting Torque | No starting torque |
| Lagging Power Factor | Unity Power Factor |
| Soft Speed Control | Precision Speed Control |
| Lower CAPEX | Lower OPEX |
| Easy to Start | VSD, Pony motor or Damper bars req. |

# Example Economics

## Energy $ Difference by Motor Size and Energy Cost

| Hours / Year @ 340 days, 24 hours | 8160 |
|---|---|

| Electricity $ per KWH | $0.12 |
|---|---|

| Annual Energy Cost Difference | Motor HP Output | | | | |
|---|---|---|---|---|---|
| **Efficiency Difference** | **5,000** | **10,000** | **15,000** | **20,000** | **25,000** |
| 0.5% | $18,262 | $36,524 | $54,786 | $73,048 | $91,310 |
| 1.0% | $36,524 | $73,048 | $109,572 | $146,097 | $182,621 |
| 1.5% | $54,786 | $109,572 | $164,359 | $219,145 | $273,931 |
| 2.0% | $73,048 | $146,097 | $219,145 | $292,193 | $365,242 |

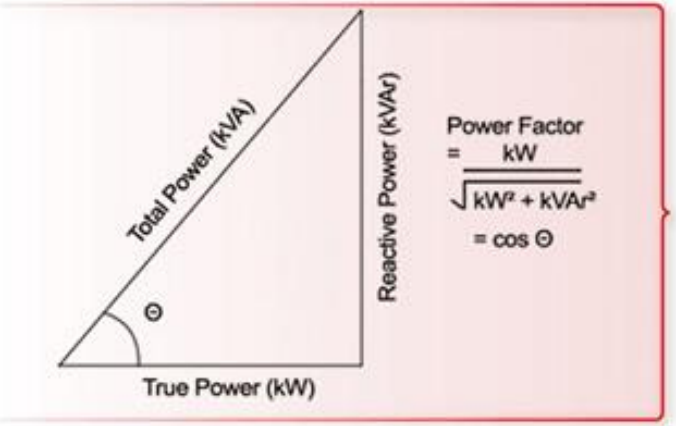
Present Quick Take favors induction motor except:

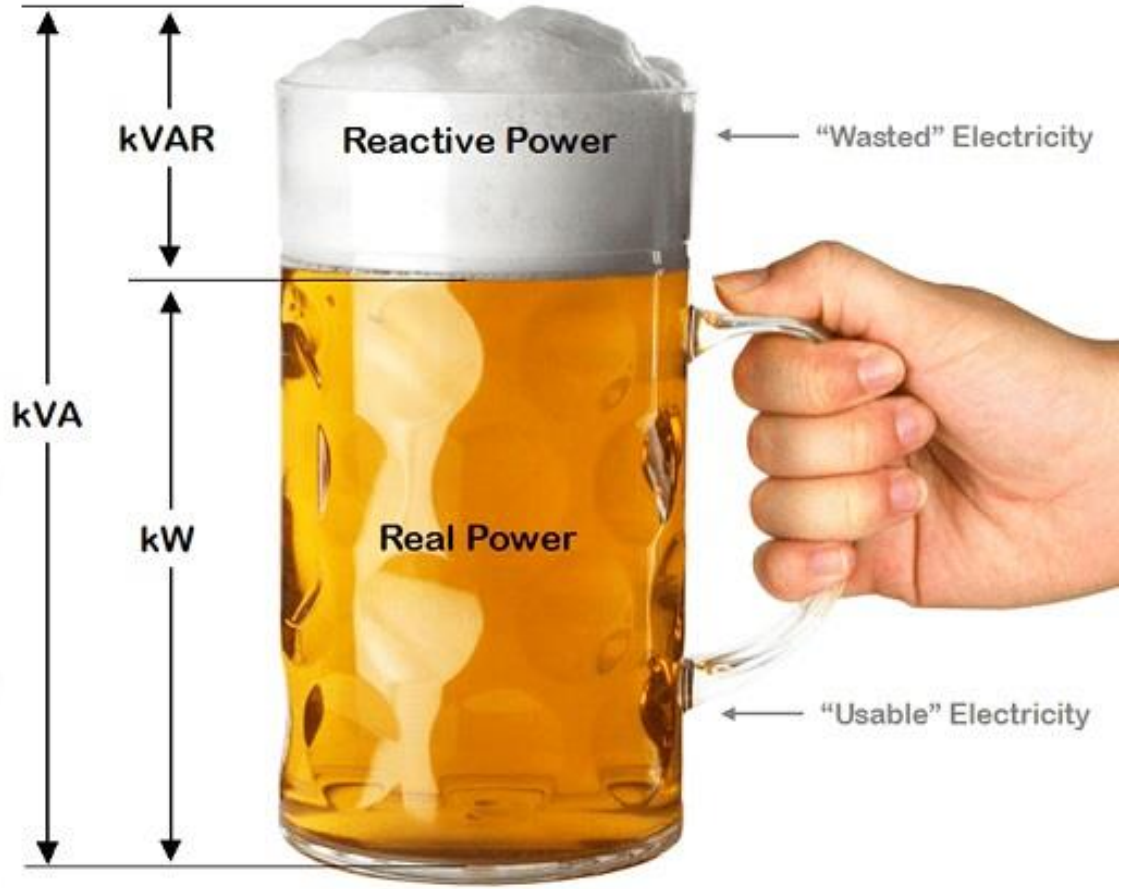
- ❑Consider sync motor for over 10 MW if slower than 12 pole
- ❑Consider sync motor for over 20 MW in 2 - 4 pole size

# Power Factor – think Beer!

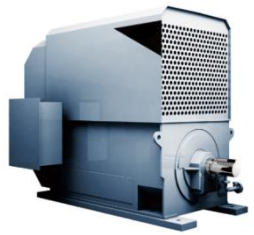
## What is Power Factor?

Power Factor is the percentage of apparent power that does real work. Understand Power Factor using Beer Mug Analogy.



# Motor Voltages



- **LV**
  - Less than 600V
- **MV**
  - 2,300V
  - 4,160V
  - 6,600V
  - 11,000V
  - 13,200V

# Poles & Speed

$$Sync.RPM = \frac{120f}{poles}$$

| Poles | 60Hz | 50hz |
|---|---|---|
| 2 | 3600 | 3000 |
| 4 | 1800 | 1500 |
| 6 | 1200 | 1000 |
| 8 | 900 | 750 |
| 10 | 720 | 600 |
| 12 | 600 | 500 |
| 14 | 514 | 429 |
| 16 | 450 | 375 |

Motor people talk about speed as “Poles”.

The number of Poles refers to the motor stator connection as to the number of North / South poles.

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Synchronous Motors run **at the Sync. RPM**

Induction Motors always run **less than Sync. RPM**

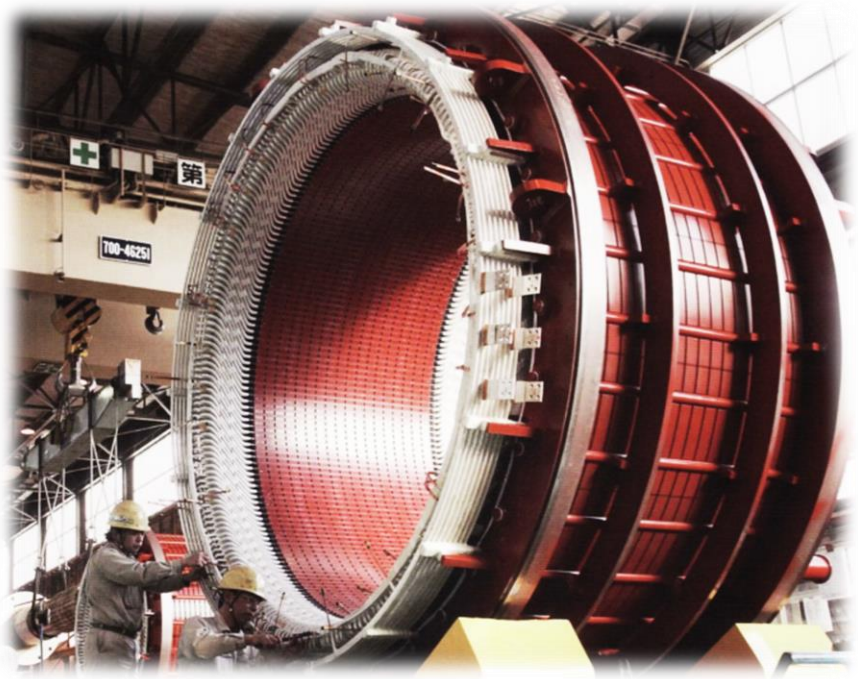
# Standards

- North America – **NEMA - MG1**
- It is the bases of **IEC** – Metric dimensions

  Most of the differences lie in testing and certifications
- API541 & API547 – Induction Machines
- API546 – Synchronous Machines

- Hazardous locations - North America
  1. NEC 501 traditional in North America
  2. NEC 505 being used now in Canada a blend of N.A. and IEC

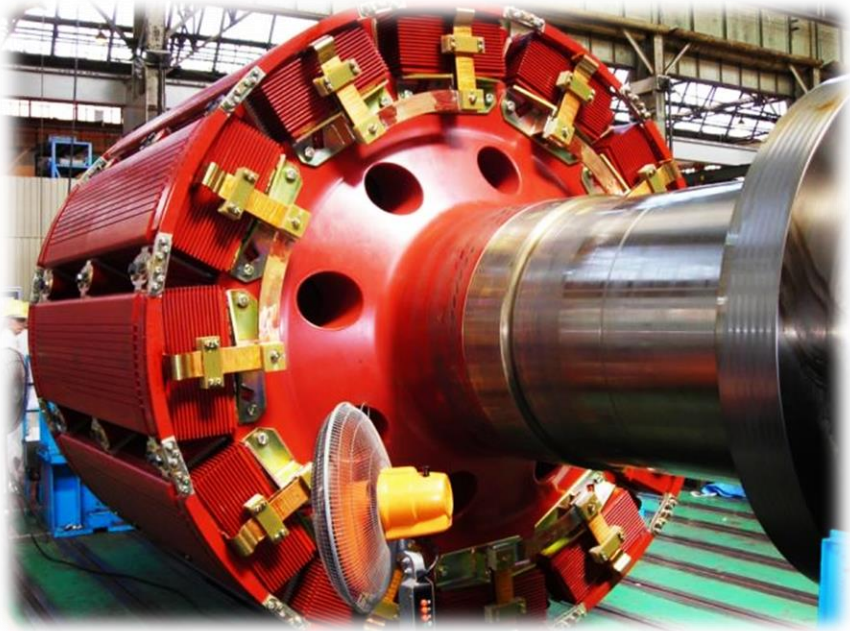
# Induction Motor



- Limited in size to about 30,000HP
- Less Efficient than Sync. Machines
- Power Factor (P.F.) is less than 1.0

No technical reason for induction motor size limit.
Efficiency 💰 is important in these power ratings.

# Synchronous Motor



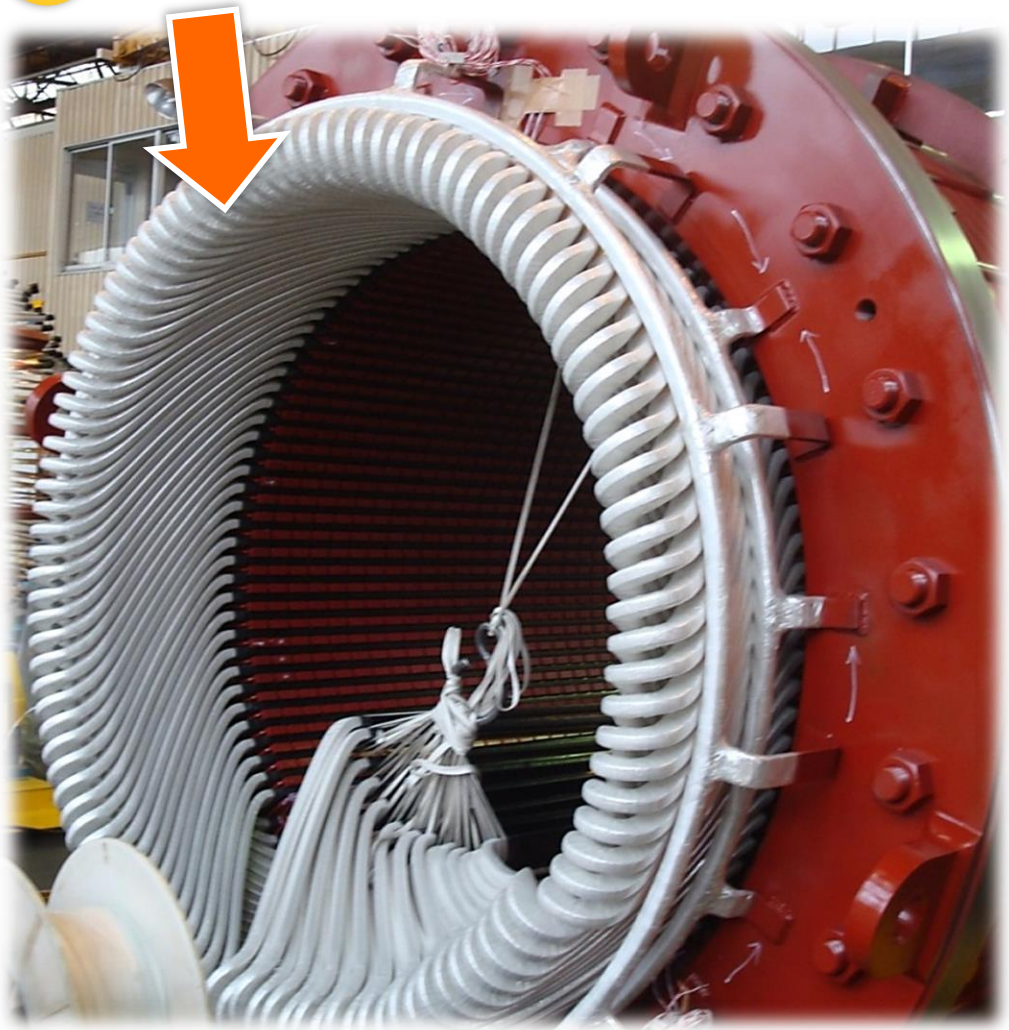
- More common for Large HP Machines
  - 30 years ago – Large Machine = 5,000HP
  - Now 30,000HP ~ 100,000HP
- 1.0 Unity Power Factor
- Rotor is magnetized to the stator
- They must have MAGNETS on the Rotor
  - *E.g. Permanent magnet motor*

# Synchronous motor - means BIG!


71,000HP - 2 Pole Synchronous Motor (Cylindrical Rotor)

# Similarities in Induction & Synchronous

Stator – is this 1) Induction or 2) Synchronous?



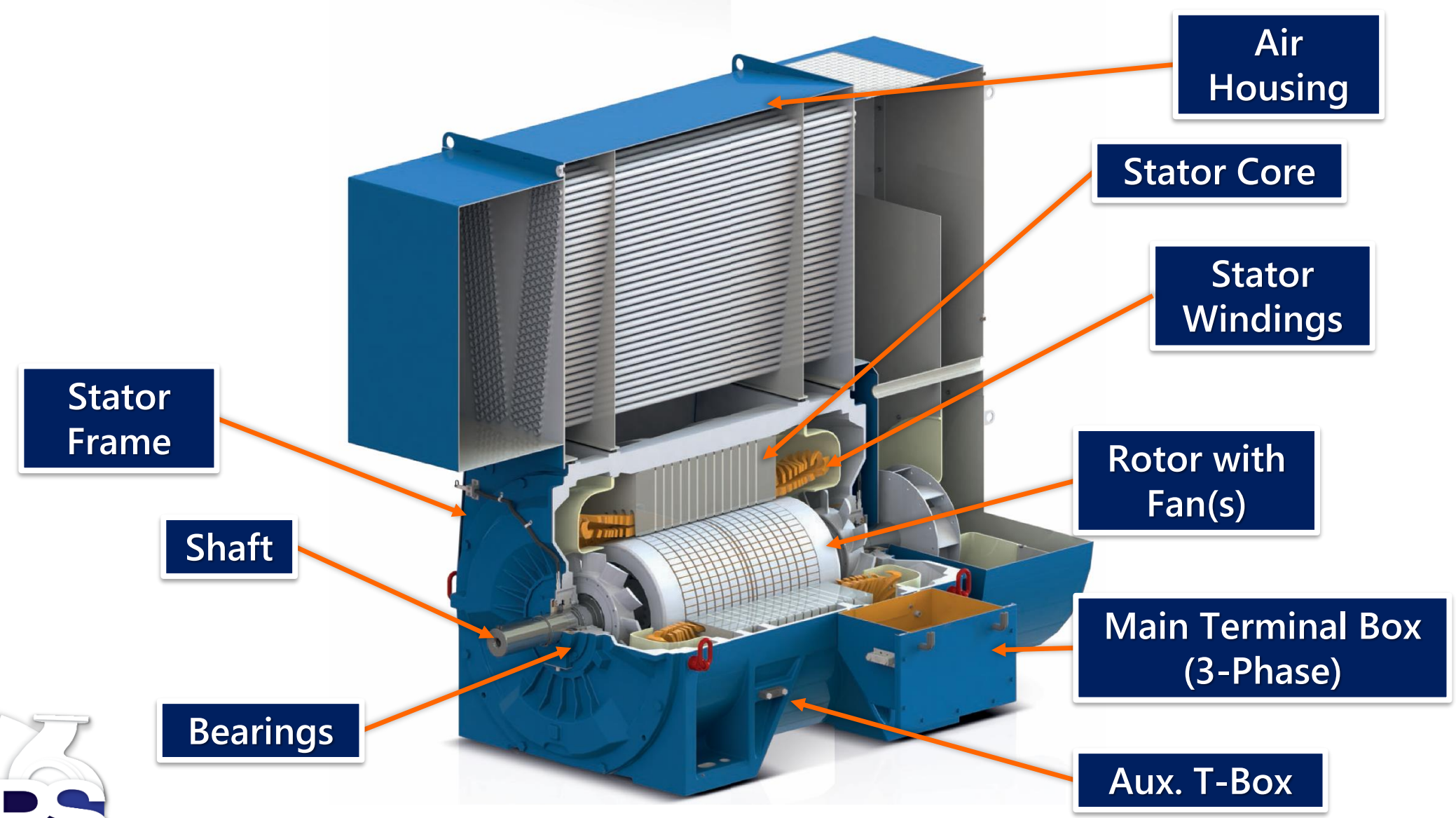
Both have:

- Near identical Stator!
- Insulations systems
- Enclosures

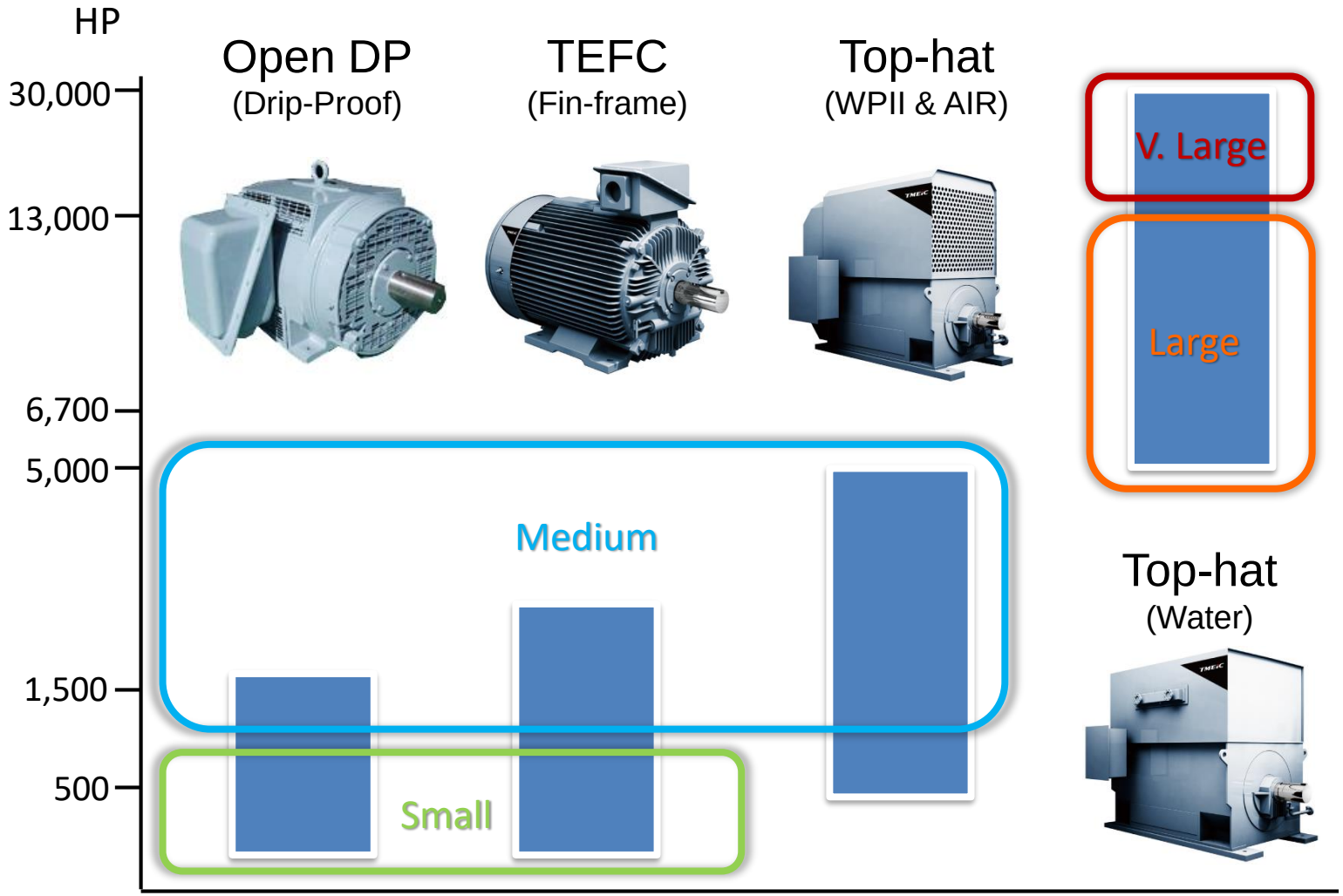
Common accessories:

- Space Heaters
- Bearing and Winding RTDs
- Differential protection

# What's inside an induction motor?



# Sizes for MV Motors



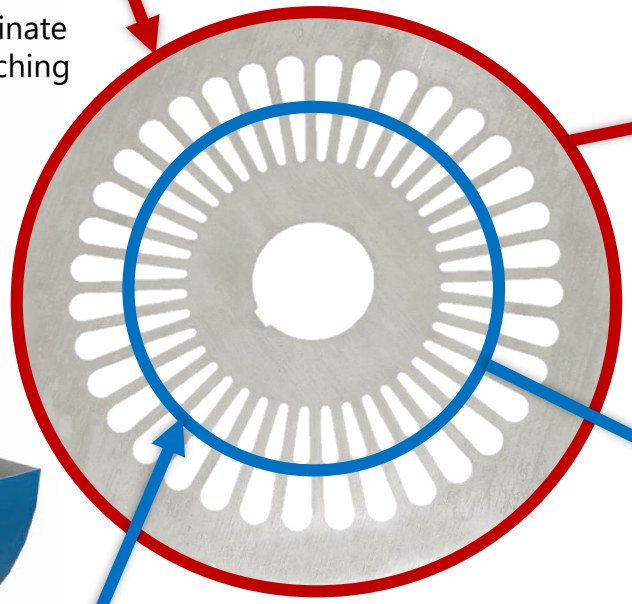
# How Induction Machines are Built and Work

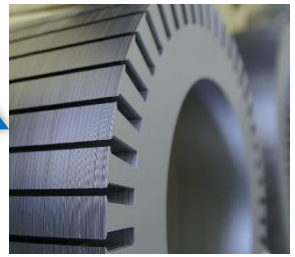
# Stator & Rotor

**Stator**

- "Stationary part"
- Connected to 3-phase AC power source
- Iron core with slots
- Creates rotating magnetic field

Laminate Punching





**Rotor**

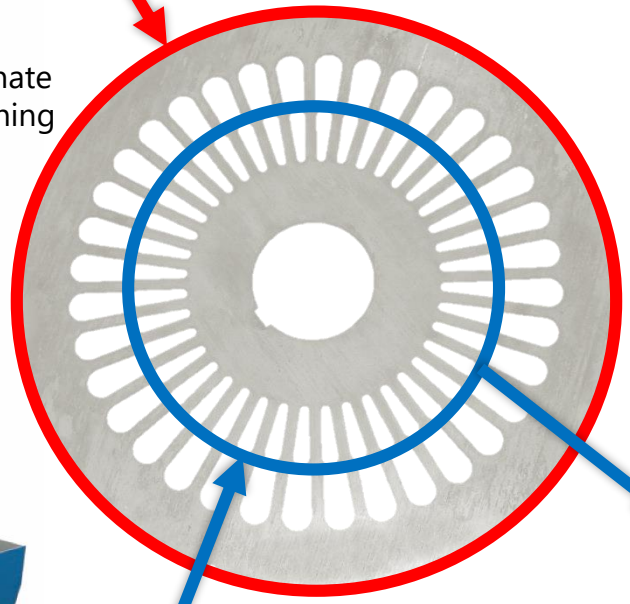
- "Go Roundy Part" (for EEs…)
- Copper bars imbedded into an iron core
- Iron core is mounted on a shaft

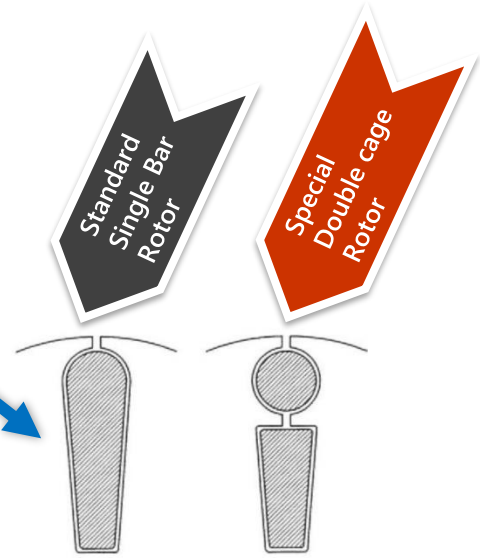
# Stator & Rotor Design

**Stator Design**

- Number of poles (Sync. speed)
- Rated line volts & frequency
- Slot wedge Material

Laminate Punching

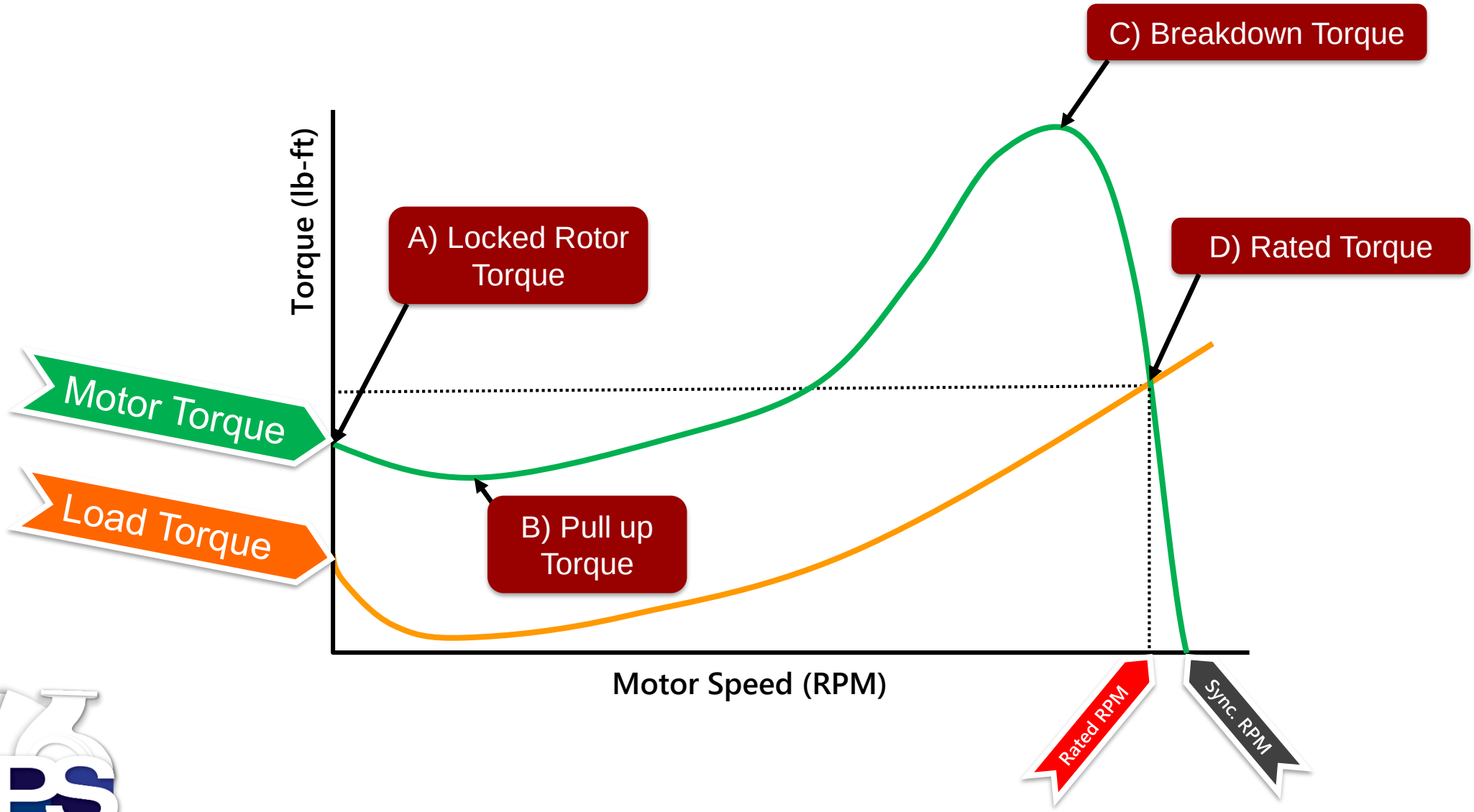





**Rotor Design**

- Number of Bars
- Bar shape & Material

# Induction motor speed vs. torque profile



# NEMA Standards & Applications

## NEMA Design B "Standard" starting torque

Fans, blowers, centrifugal pumps and compressors, etc.

*Variable Torque* Applications

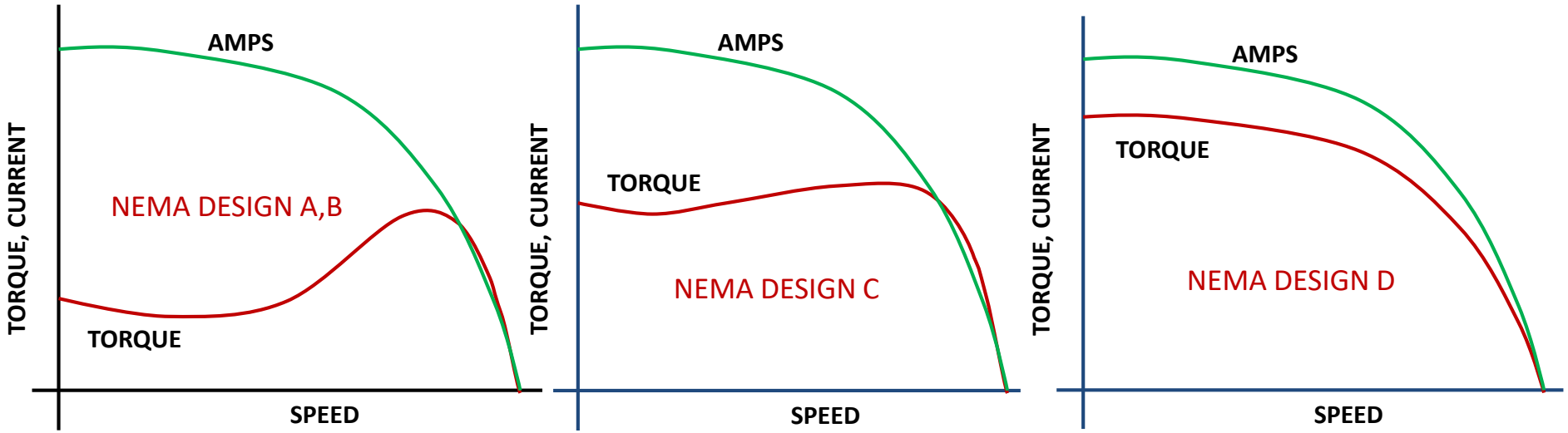
## NEMA Design C High starting torque

Reciprocating Compressors & Pumps, Positive displacement pumps, Screw Compressors

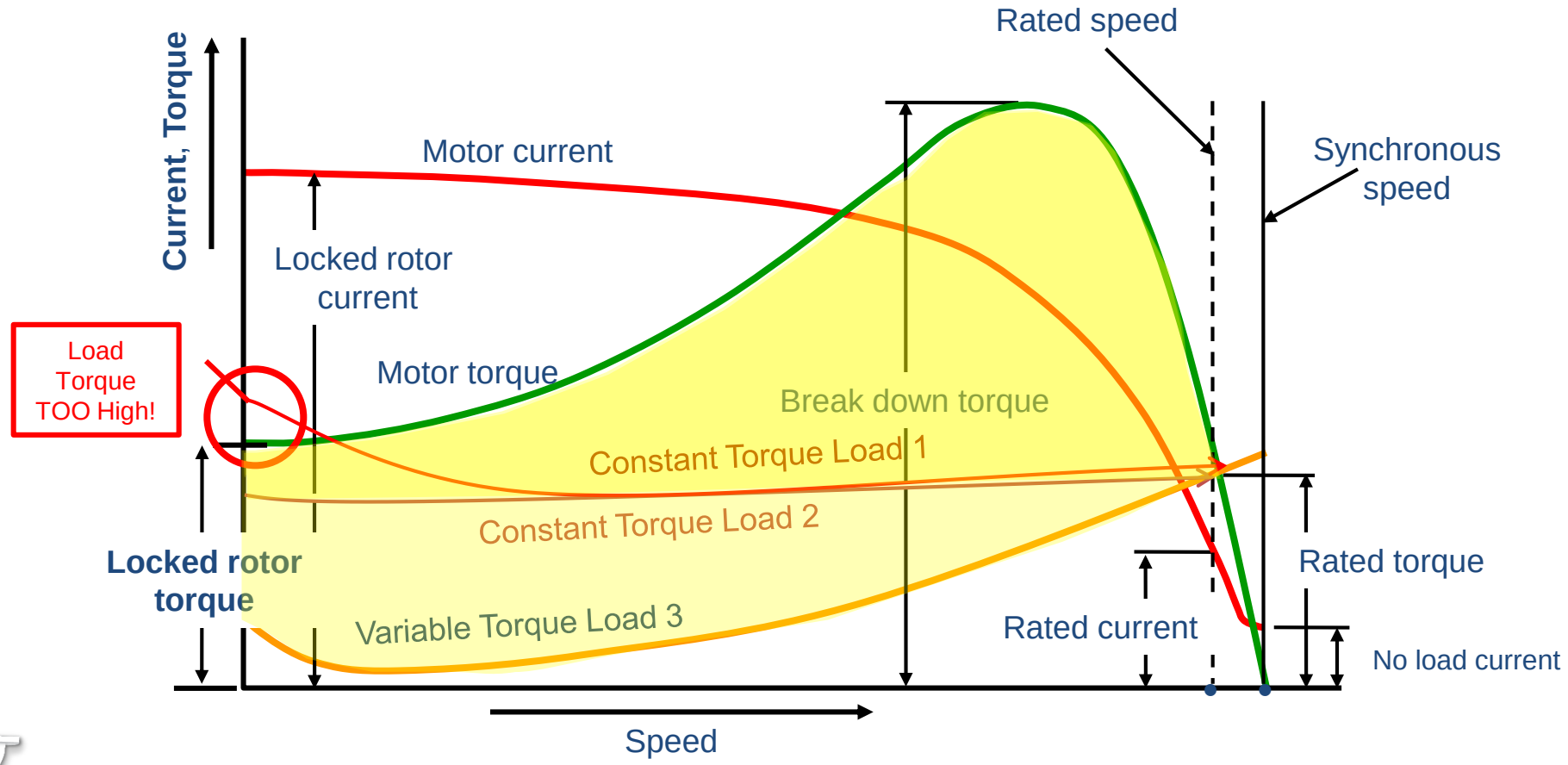
*Constant Torque Applications*

## NEMA Design D Highest starting torque, high slip

Car Shredders, Punch presses, shears, elevators, winches, hoists, oil-well pumping

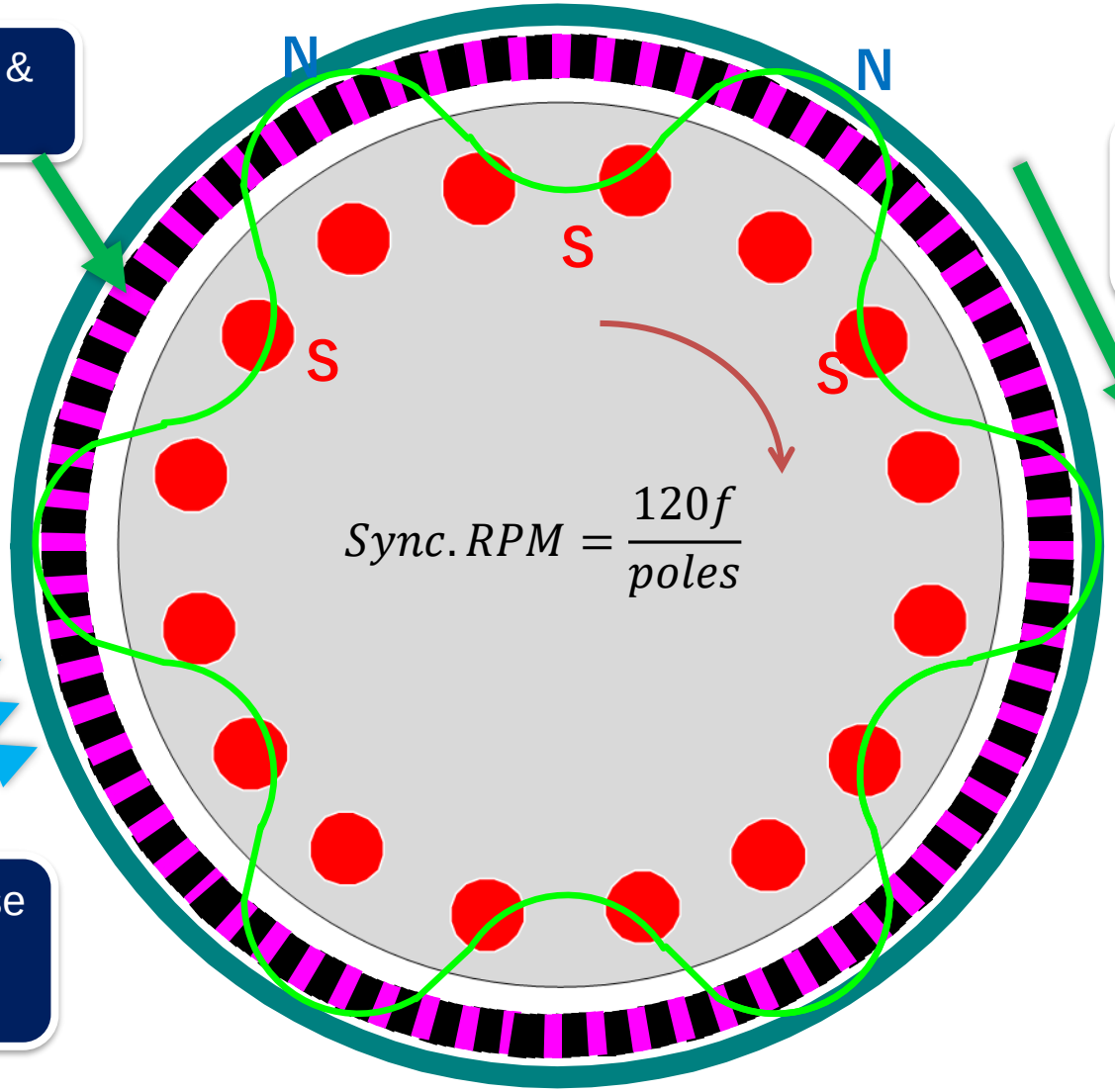


# Motor starting characteristics & starting time



# Interaction between stator & Rotor

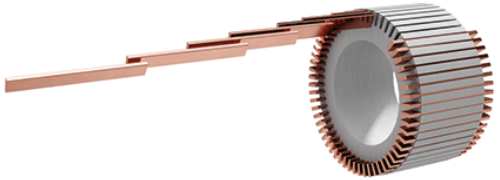
Stator Core & Windings




Stator flux wave direction

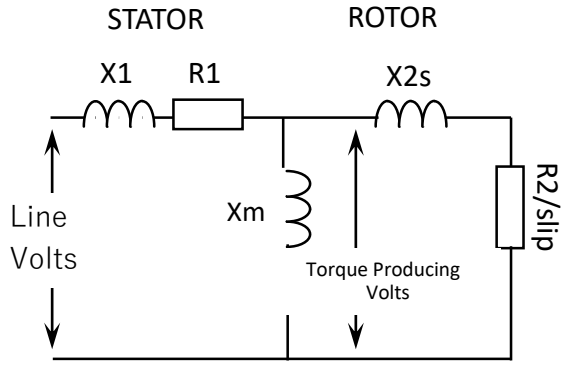
Three phase power to Stator

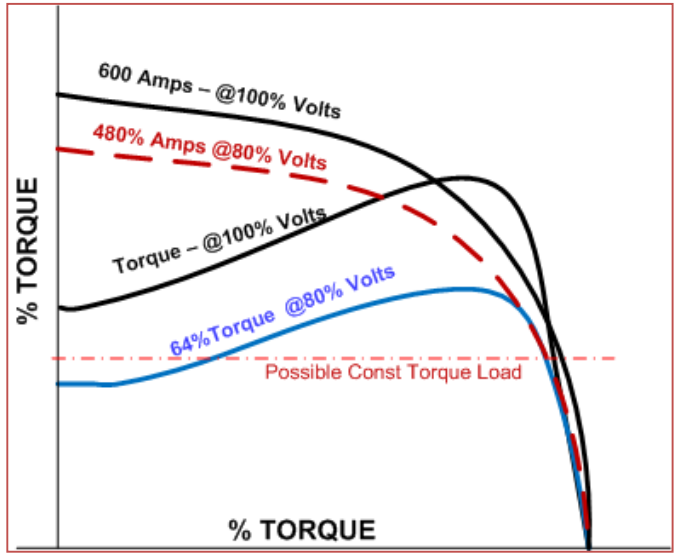
● = Rotor Bars



# Summary of electrical relationships

| | Area | Effect / Note |
|---|---|---|
| 1 | **Starting Amps** | Starting Amps falls directly with volts |
| 2 | **Torque capacity** | Rises and falls as the **SQUARE** of volts |
| 3 | **Slower Motor** | More poles = More magnetizing amps = **Low P.F.** |
| 4 | **Motor Diameter and Length effect on torque** | Torque & speed [power] increases with rotor diameter$^2$ x length |
| 5 | **Slip: % Difference of Running Speed & Sync. Speed** | NO Slip = No rotor amps, No torque! |
| 6 | **Slip and Efficiency** | High slip = high losses, low efficiency |



# Motor Selection Process

## REQUIREMENTS FOR MOTORS

### ELECTRICAL SPECIFICATIONS

- Rating (HP, Voltage, Hz, RPM)
- Load torque characteristics, Inertia
- Starting method (DOL, VFD, RVSS..)
- Power source condition
- Noise limitations

### MECHANICAL SPECIFICATIONS

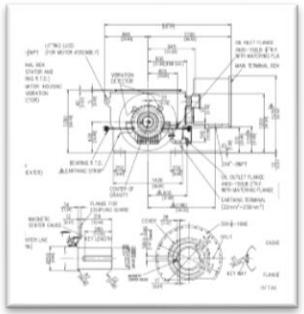
- Enclosure type (Protection and cooling)
- Bearing type, Thrust, Overspeed req.
- Speed control
- Environmental condition
  (Altitude, Ambient. Temp.,
  Explosive area class, Dust, humidity..)

## INDUSTRY / APPLICATION STANDARD (IEC, NEMA, API541 etc.)

**Electrical Design**

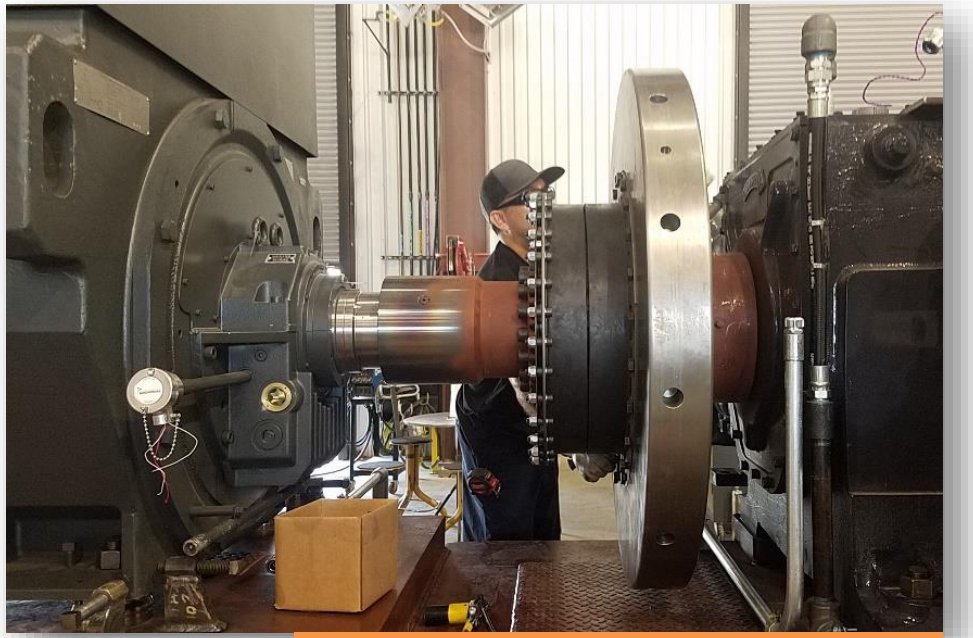
**Mechanical Design**

**Final Motor Drawing**



# Inertia

Large Axial Fan



Flywheel on Recip. Compressor

- **Starting from utility frequency**
  Rotor heats, windings stress from 650% inrush current.
- **Must limits number of starts (e.g. 2 Cold / 1 Hot)**
- **Design includes calculation of maximum allowed INERTIA**
  Bigger inertia requires Bigger motor!
- **But! No limits when starting  VFD!**

# Insulation class & temperature rise

Nearly all specifications for MV motors will state:

**Motor Insulation - Class F**

**Motor Temperature Rise not to exceed Class B**

This is a short explanation of the **most important** part of a motor construction.

# Motor insulation

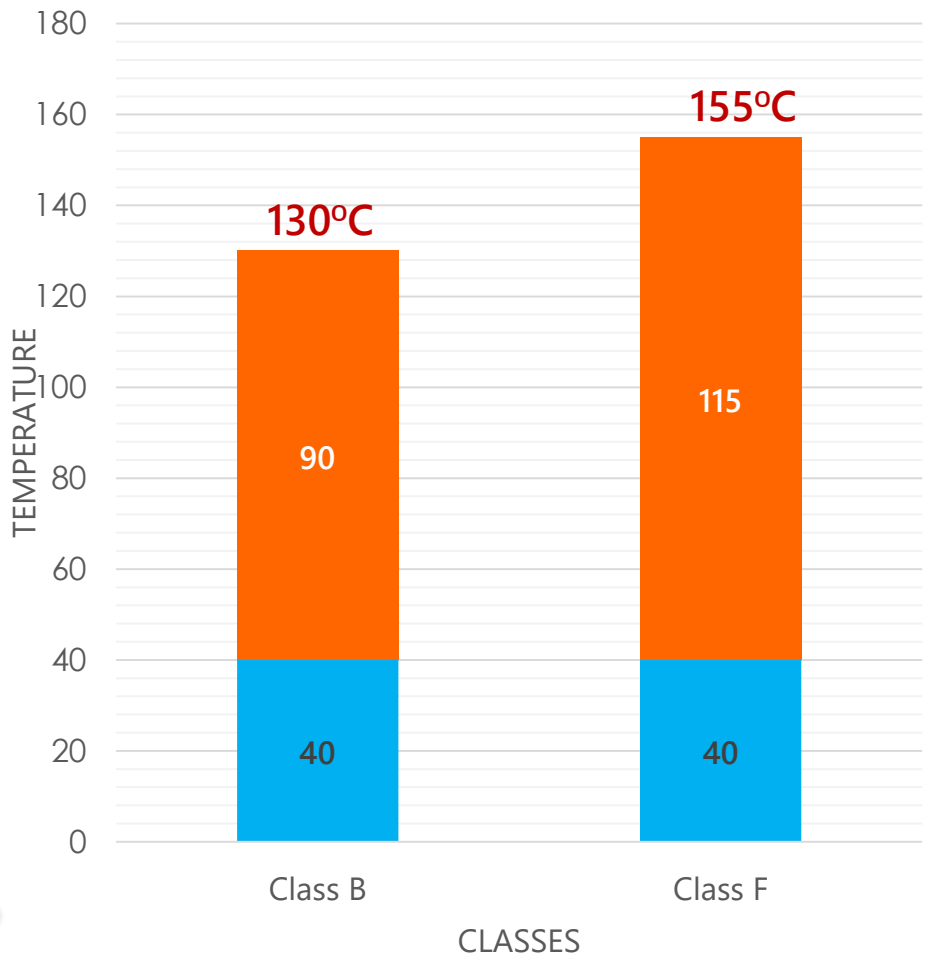
**Insulation Voltage Class:**


**Insulation Thermal Class:**

1) Maximum operating temperature
2) Allowable temperature rise at full load

| Class | Max. operation Temp. for 20,000 Hour Life, Deg. C (NEMA-MG1) | Allowable Rise over 40°C Ambient |
|---|---|---|
| A | 105° | 60° |
| B | 130° | 80° |
| F | 155° | 105° |
| H | 180° | 125° |

# Insulation & Temp. Rise Class

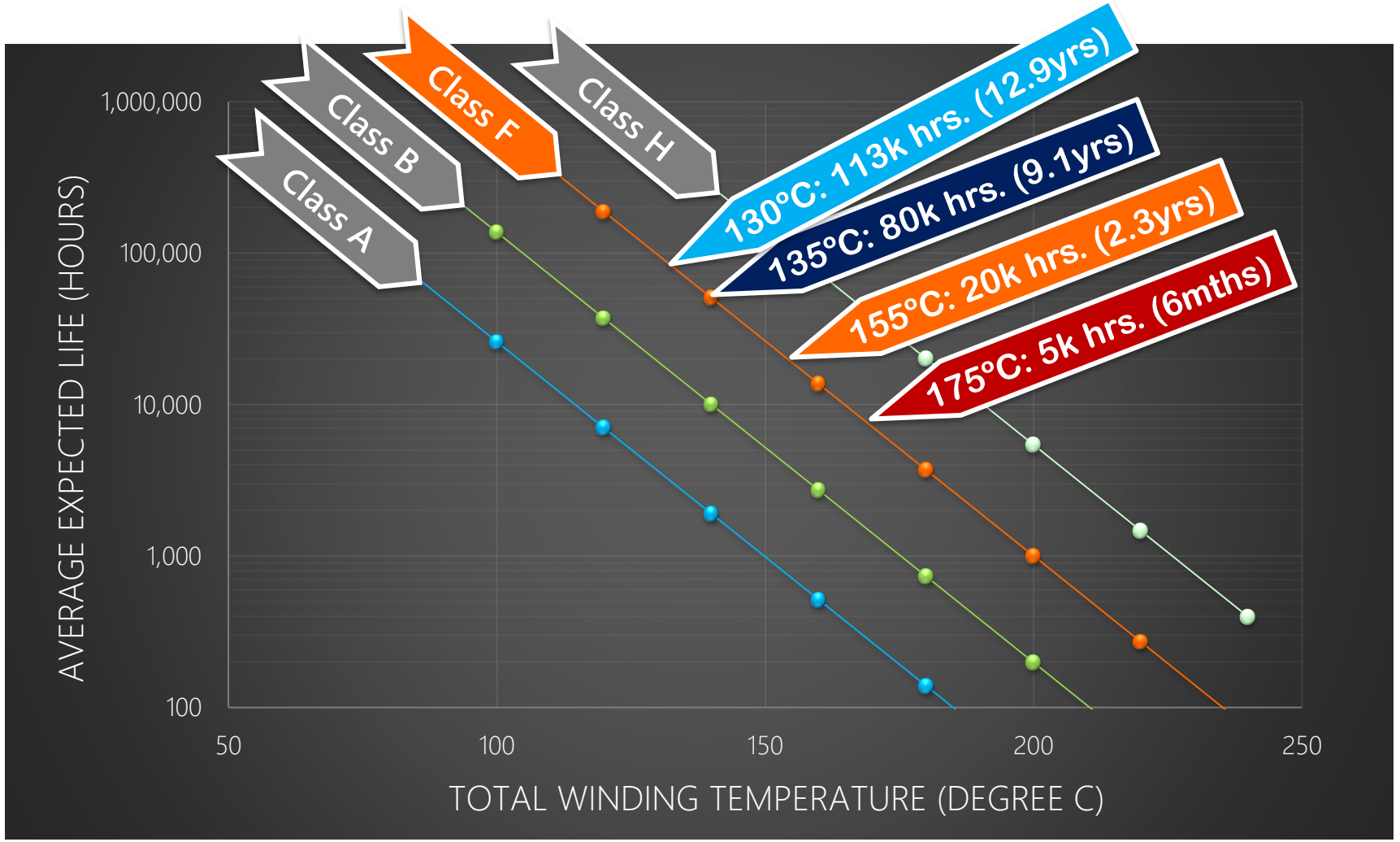



- ✓ Maximum Temperature: 155ºC
- ✓ Allowable Rise: 130ºC
- ✓ Difference: 25ºC
- ✓ 25ºC = **Thermal Margin**

**NEMA MG-1**

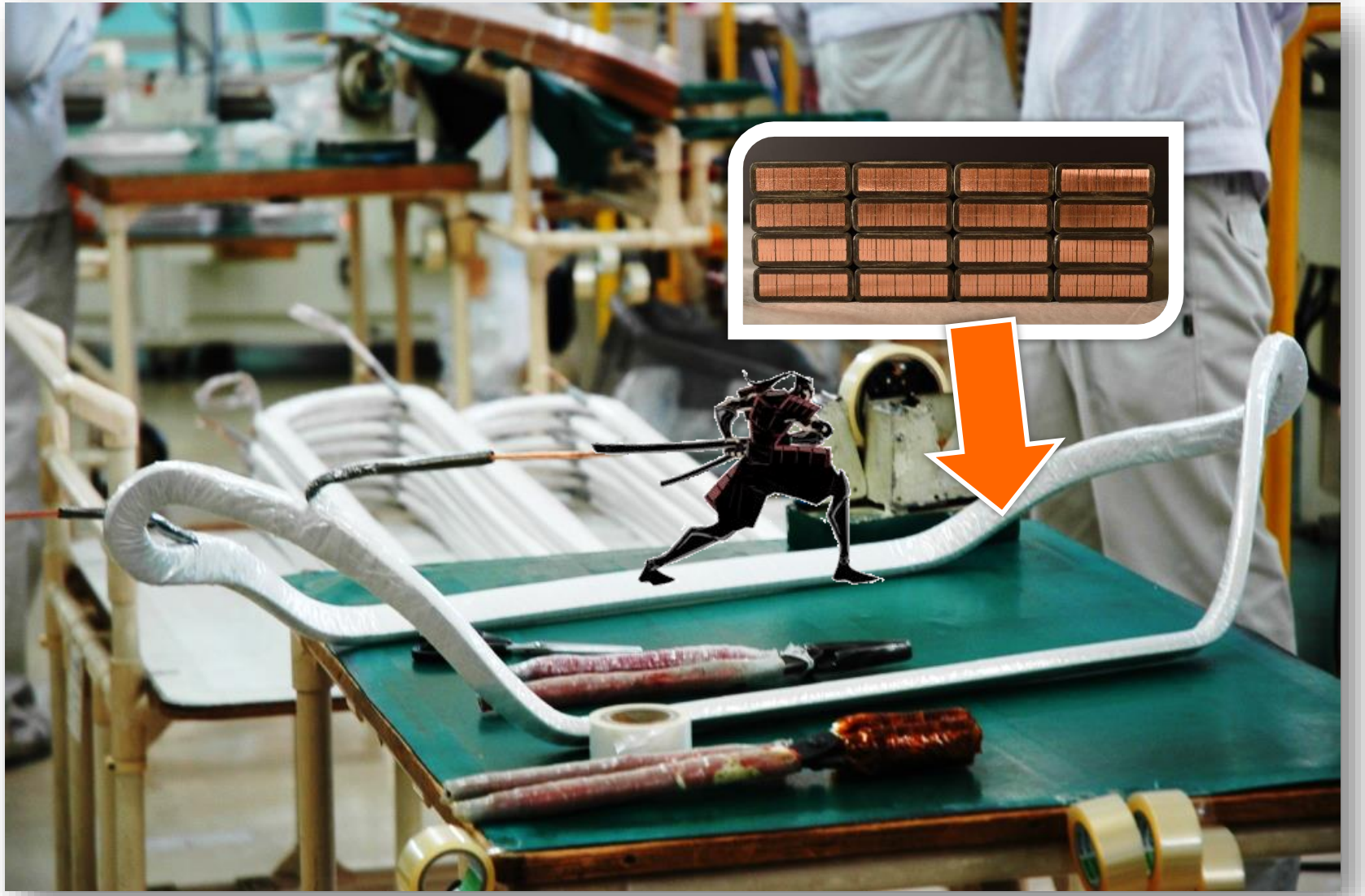
| Class | Maximum operation Temperature | Allowable Rise |
|---|---|---|
| A | 105º | 60º |
| B | 130º | 80º |
| F | 155º | 105º |
| H | 180º | 125º |

# Insulation Average Expected Life Vs. Operating Temperature




Curves and Tests show: Insulation life is DOUBLED for each 10°C reduction in operating temperature.

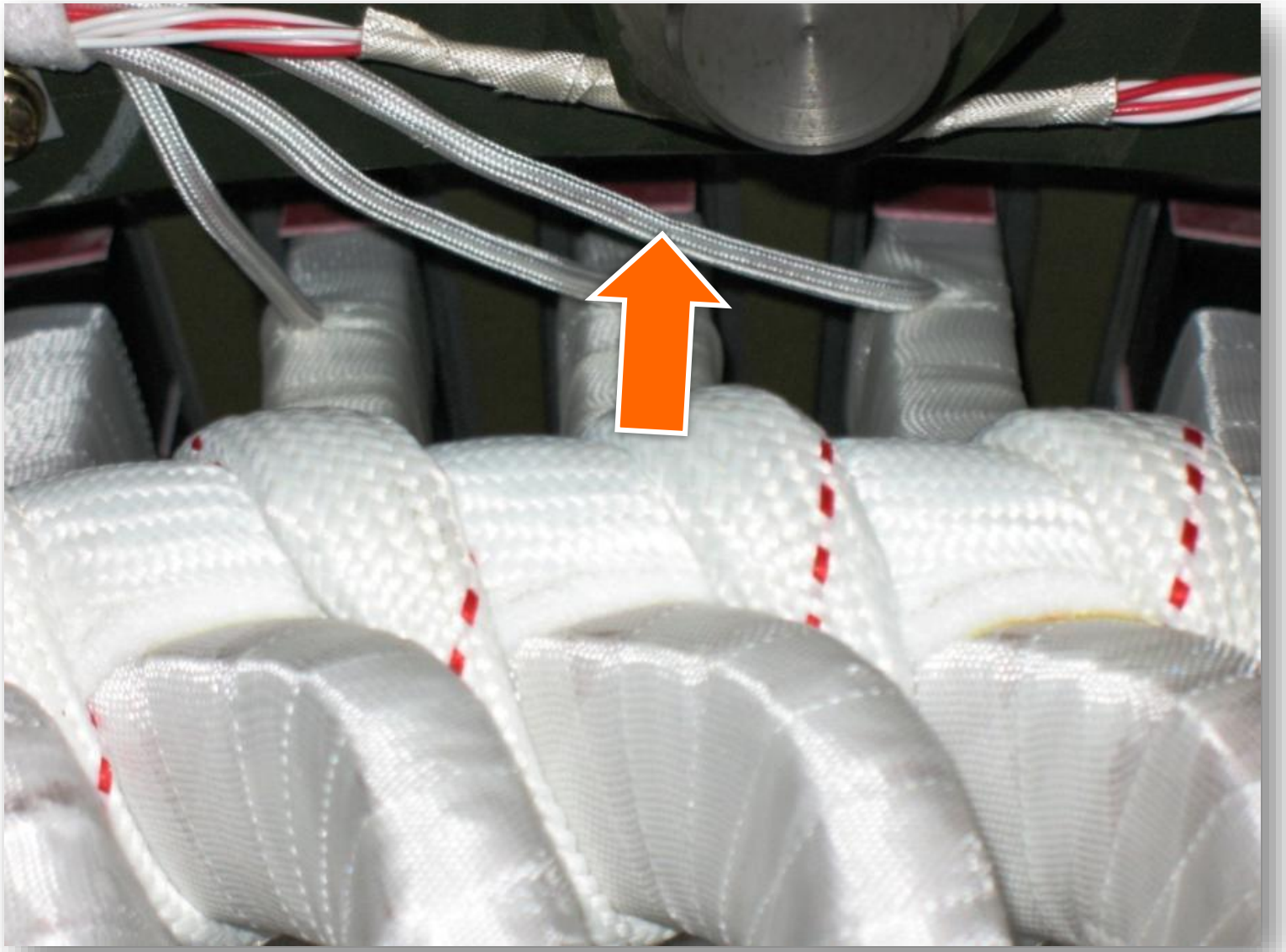
# Form wound stator coil



# Stator core with form wound coils

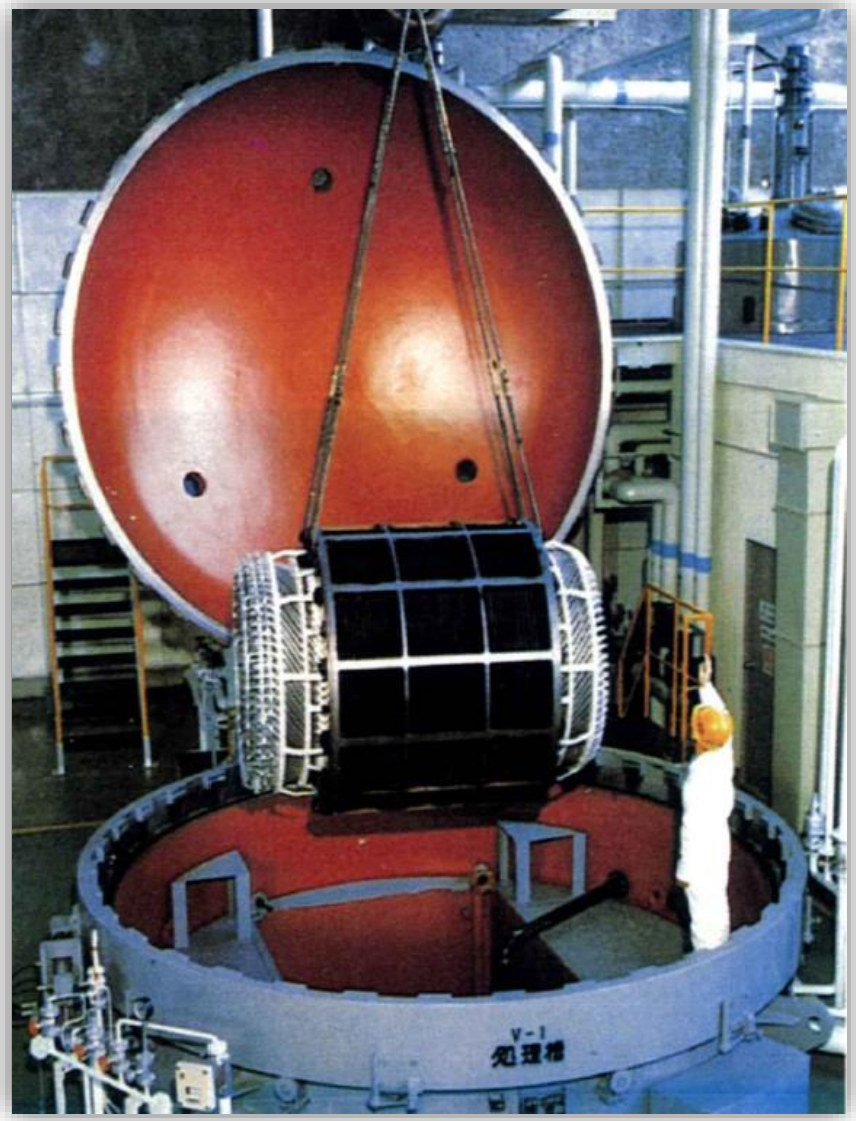
# Stator core with form wound coils

# Winding Temperature detectors & bracing



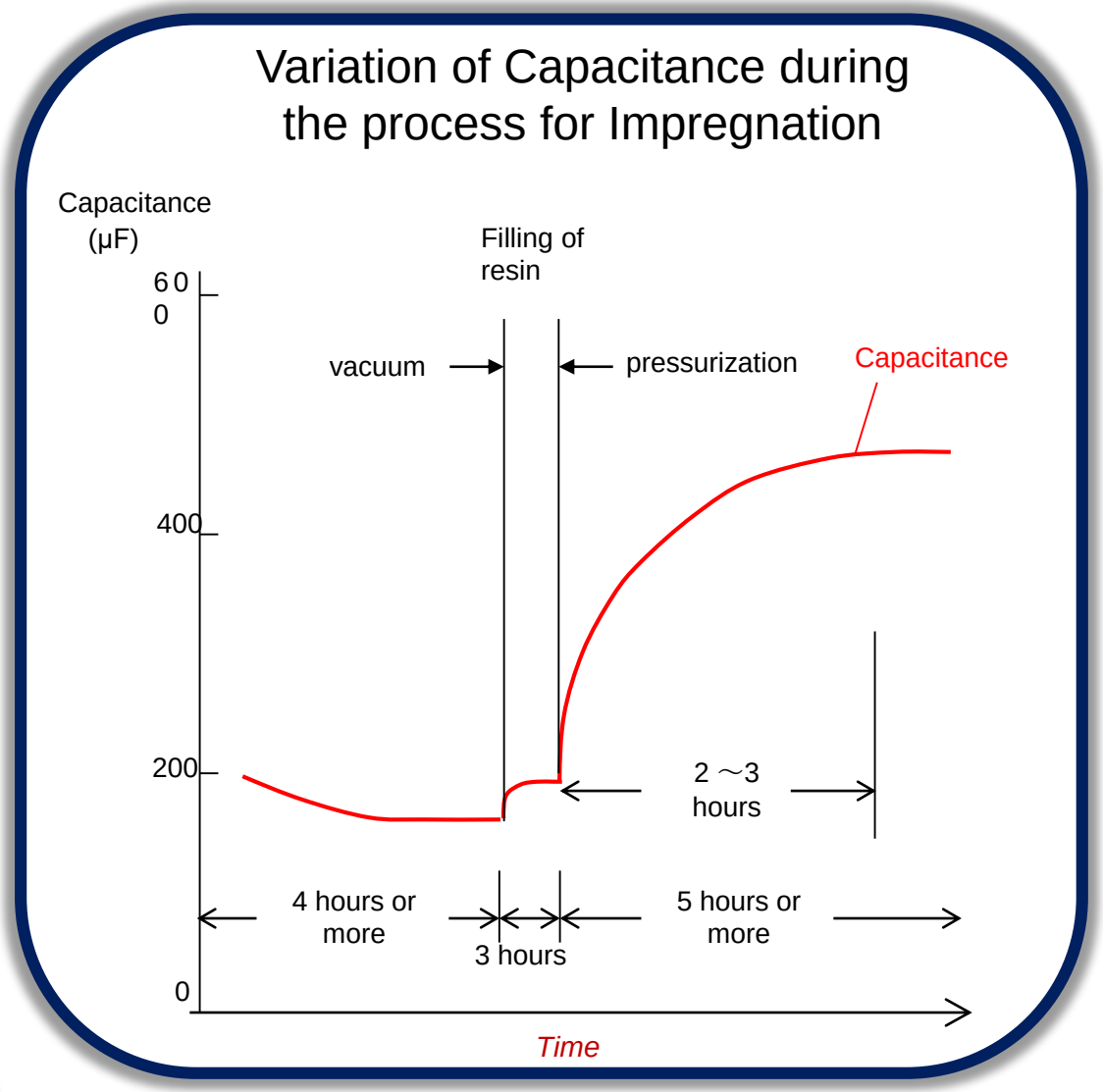
# Stator core with windings in place

# Vacuum pressure impregnation



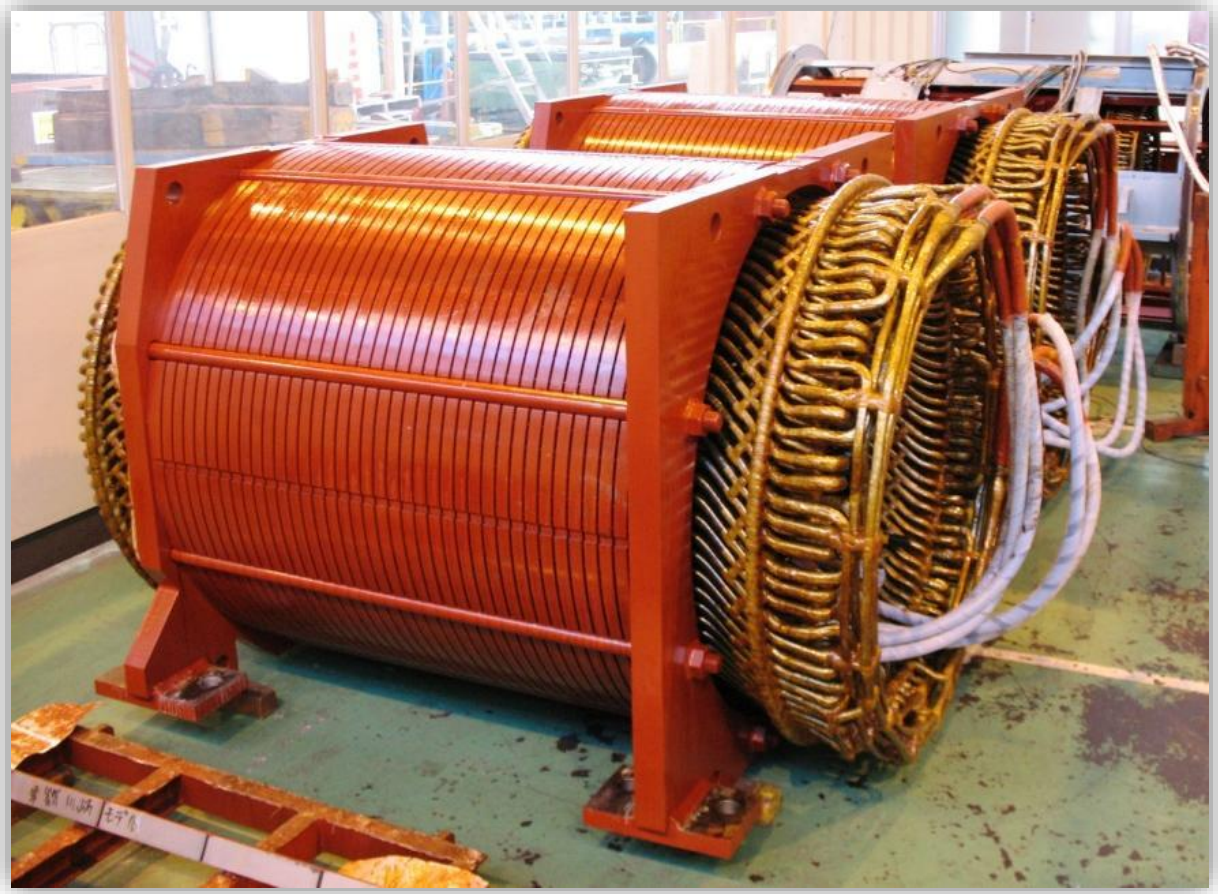
- Increases Reliability
- VPI Provides Excellent
  - ❖ Mechanical Strength
  - ❖ Thermal Rating
  - ❖ Moisture Resistance
  - ❖ Chemical Resistance

# VPI Process



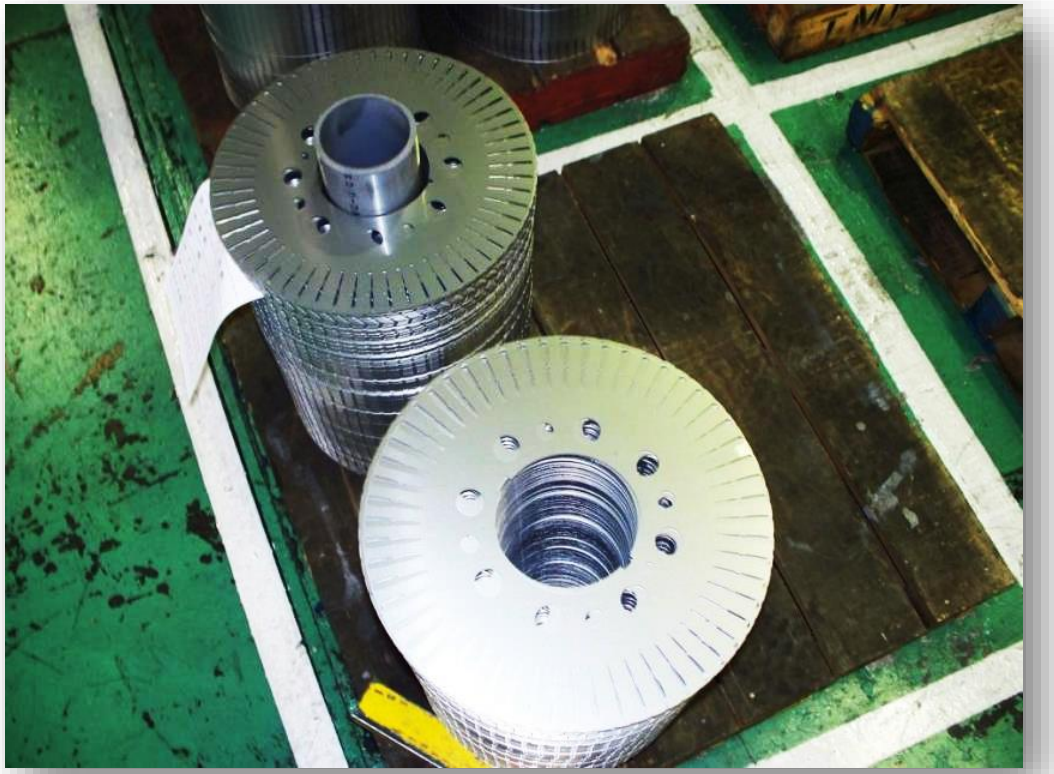

1. **Vacuum** draws out moisture from stator windings and assembly.
2. **Resin added** at atmospheric pressure.
3. **Pressurization** forces resin into all voids.
4. **Winding capacitance** increases and **levels off**, indicating end to VPI process.

# Stator core after VPI

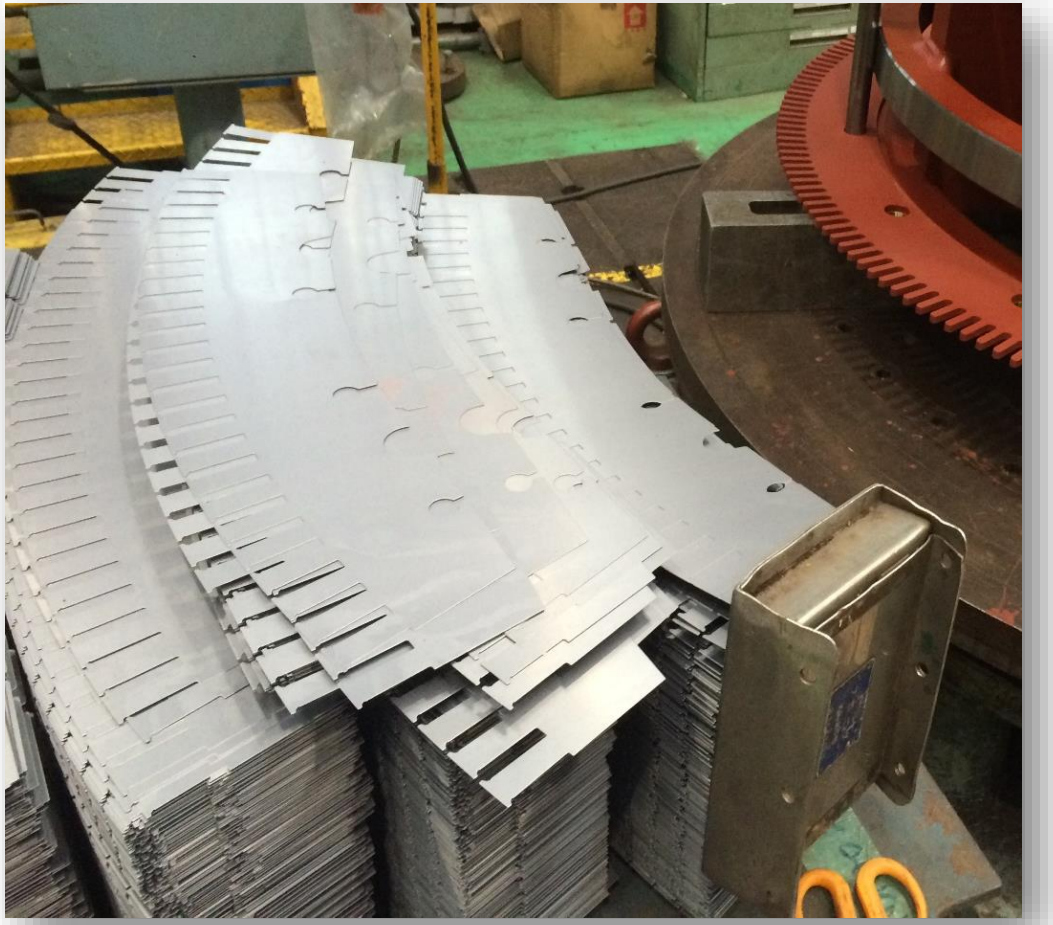


- Winding is now a solid mass, giving protection from forces during operation & starting.
- Moisture from environment is locked out.

# Rotor laminations

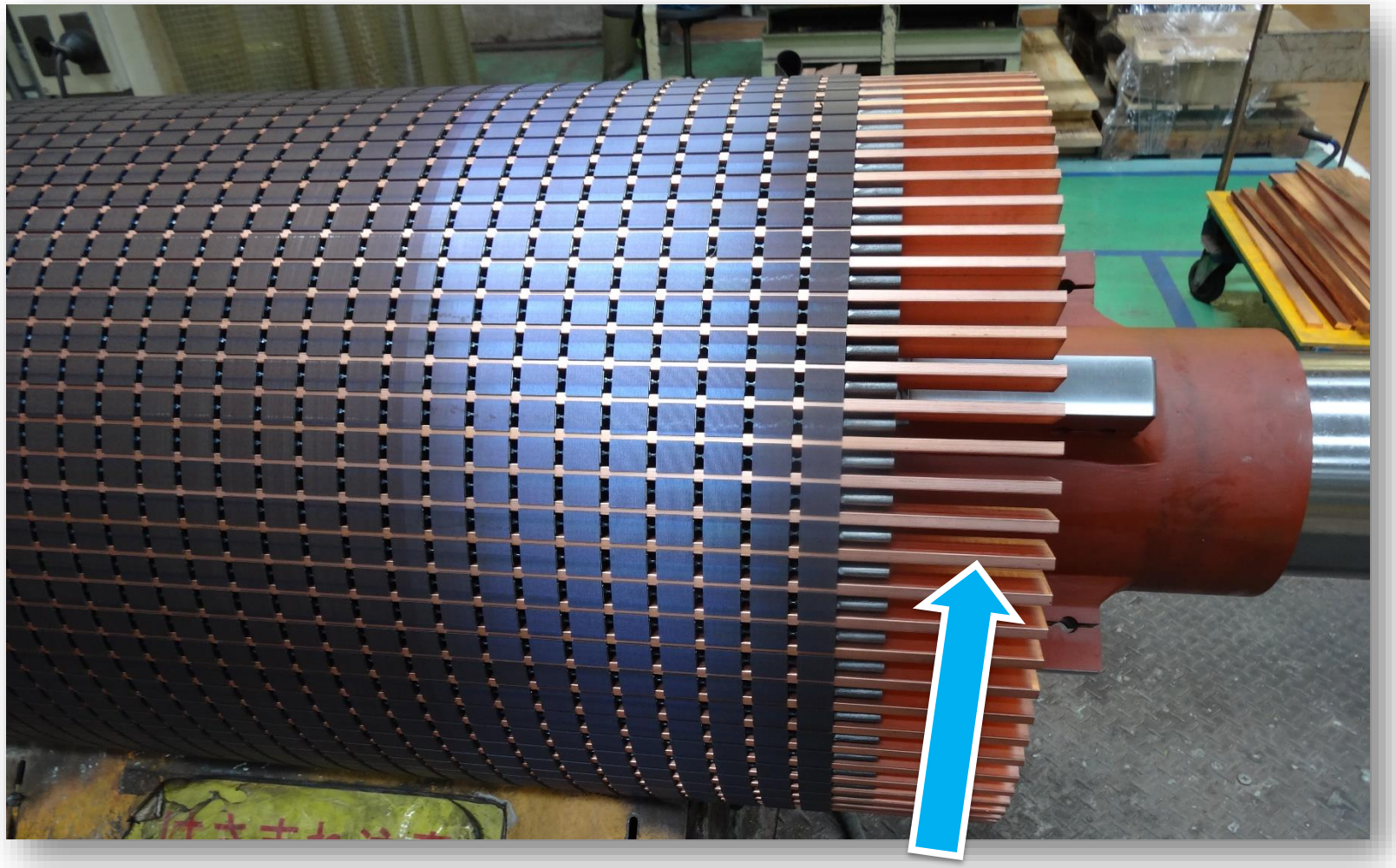


*Large / Slow machine*



# Rotor shaft & Air baffle

# Copper bar insertion

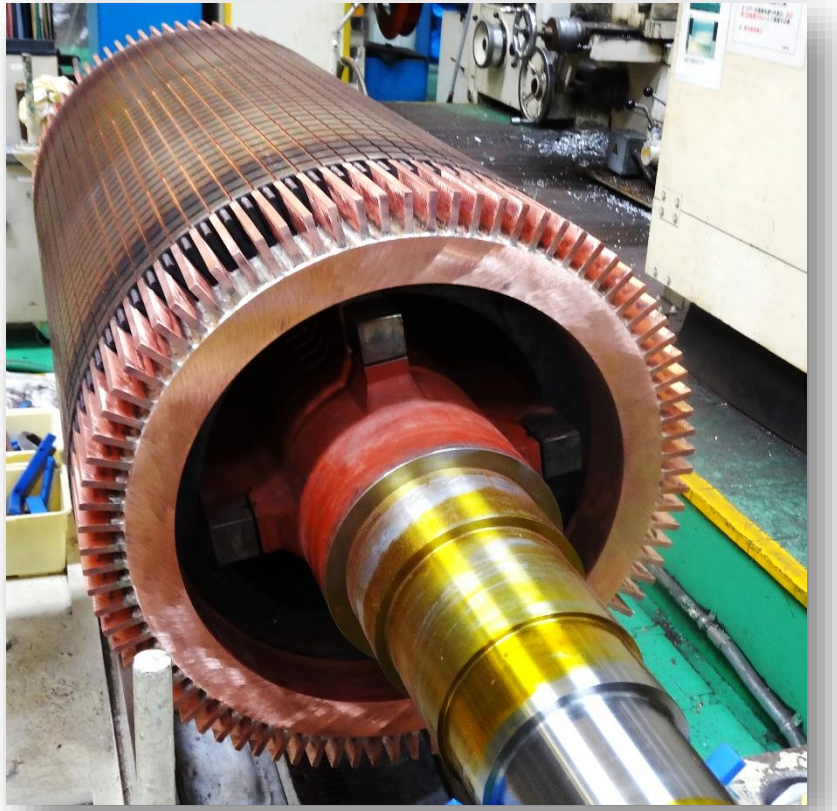


Copper bars are trimmed and finished in lathe.
End ring will be brazed to the bar ends

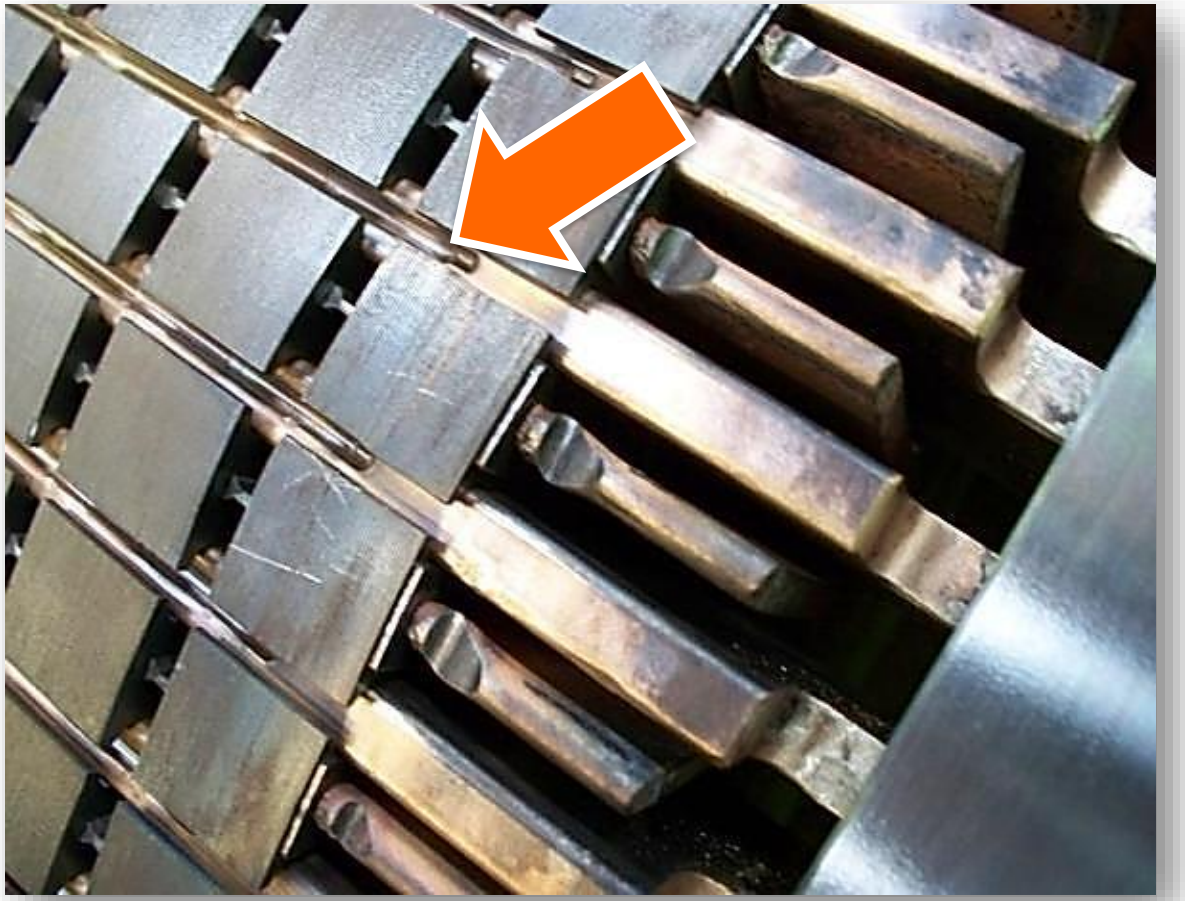
# Assembled rotors

Finished Aluminum Cast Rotor with Cooling Fins (LV Motor)

Complete Copper Bar Rotor (MV Motor)



# Swaging



- Copper bars, swaged into slot
- Swaging produces:
  - Tight bar fit
  - Avoids sparking, Vibration and
  - Reduces noise

# Completed Rotors

**High Speed (2/4P)**

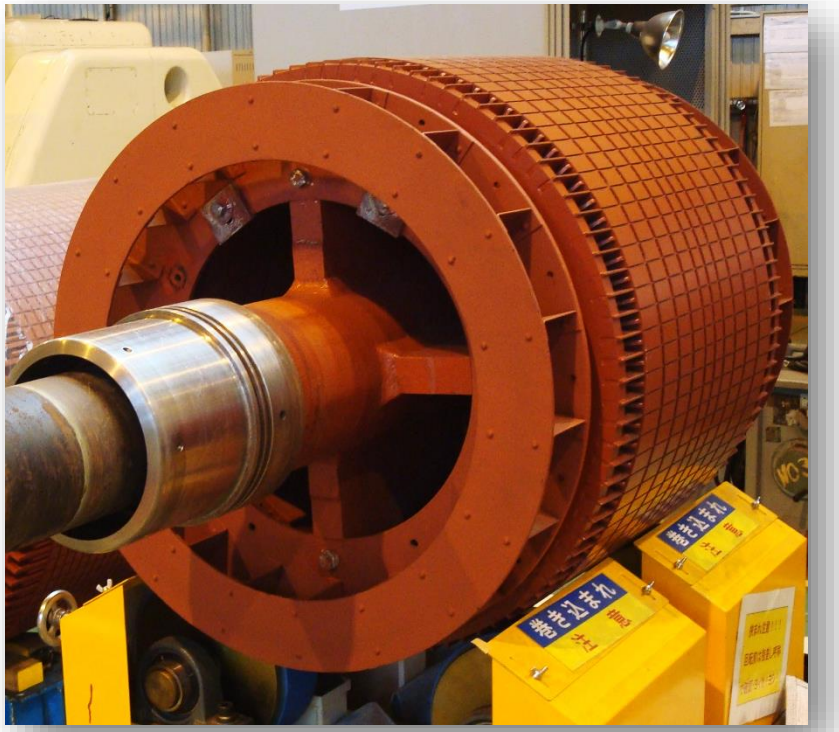
With 2x Axial Fans

Uni-directional

**Low Speed (8P+)**

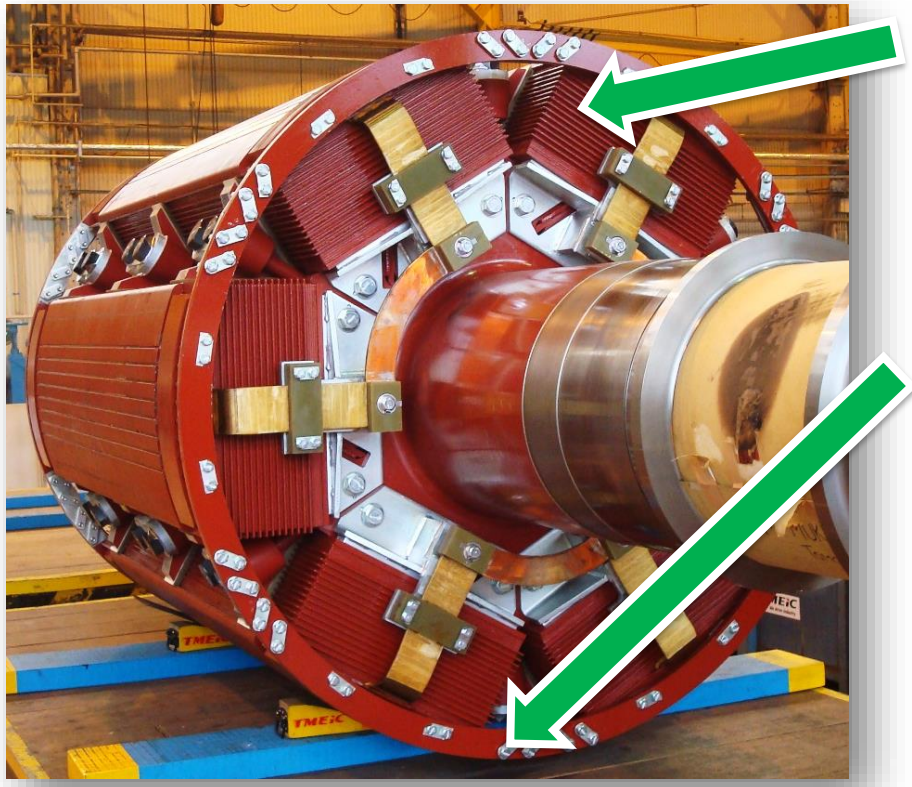
With Radial Fan

Bi-directional



# Rotor of a Synchronous motor

**Complex design with TWO flux circuits**



**DC current flux circuit**

- Field poles – alternate North & South magnetism
- Level set by external control

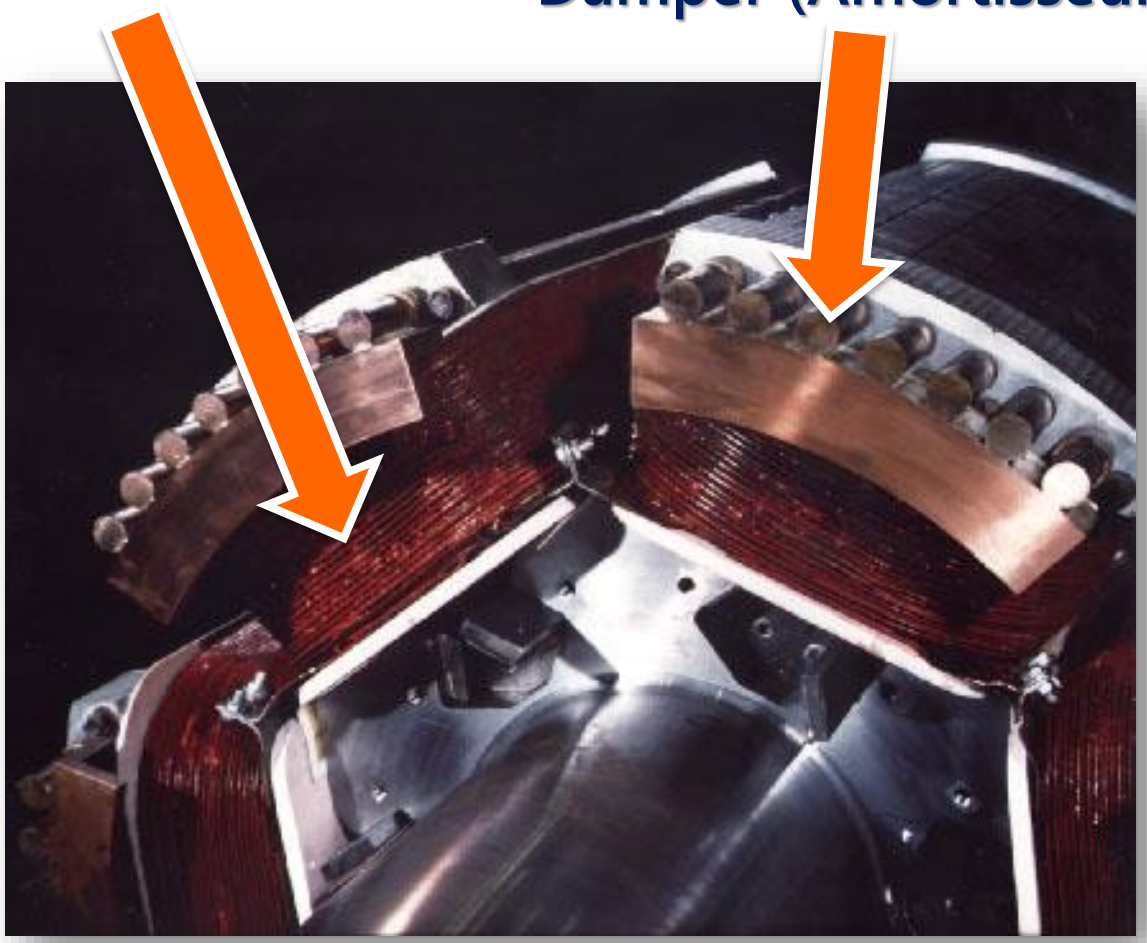
**The Induction flux circuit**

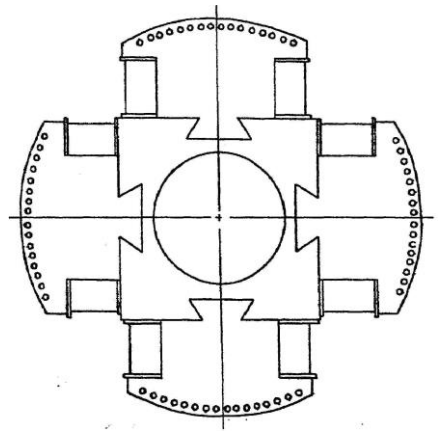
- Just like the squirrel cage induction motor design
- "Damper Bars" / "Amortisseur winding" (Typically round bars) for Starting

# Rotor of a synchronous motor

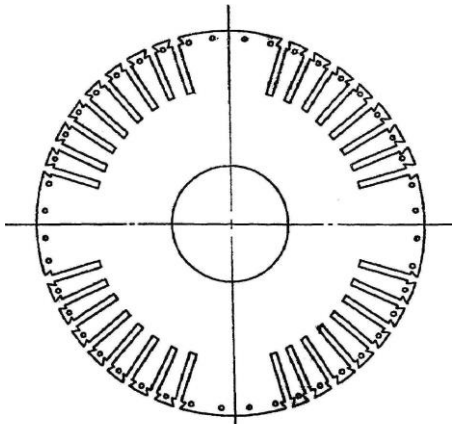
DC Field Coils

Damper (Amortisseur) Bars

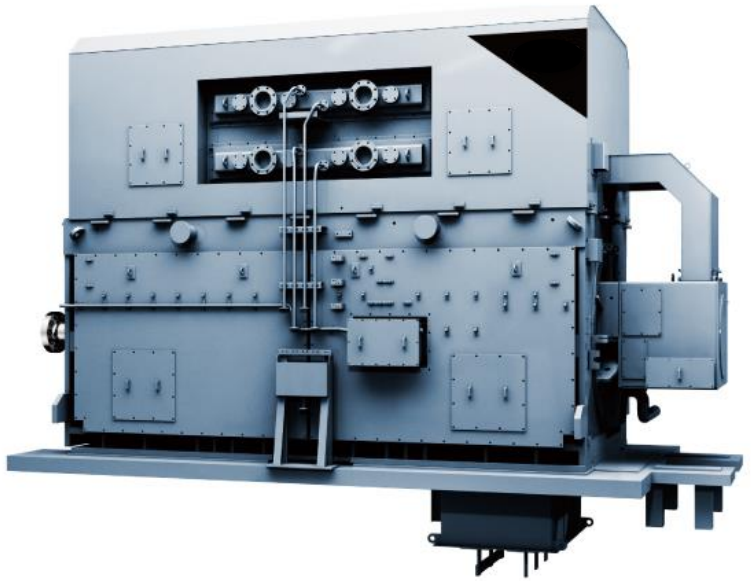




Salient-pole Type



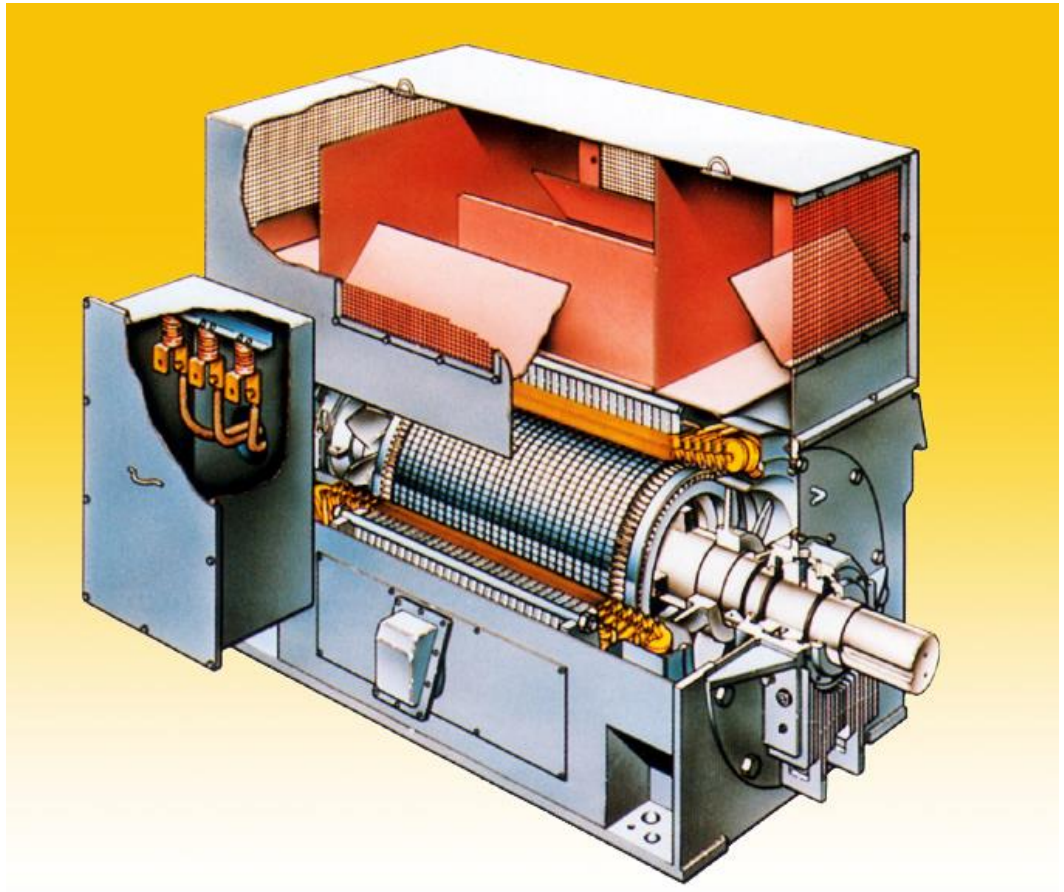
Cylindrical Type



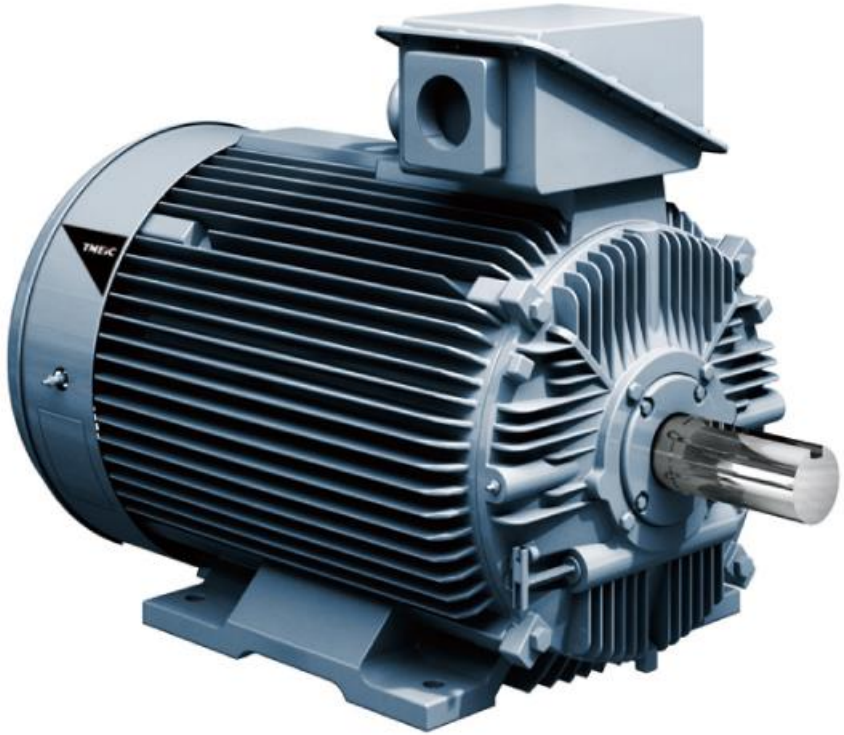
# Enclosures

# Motor enclosures

Have 2 functions – Protection and Heat Removal



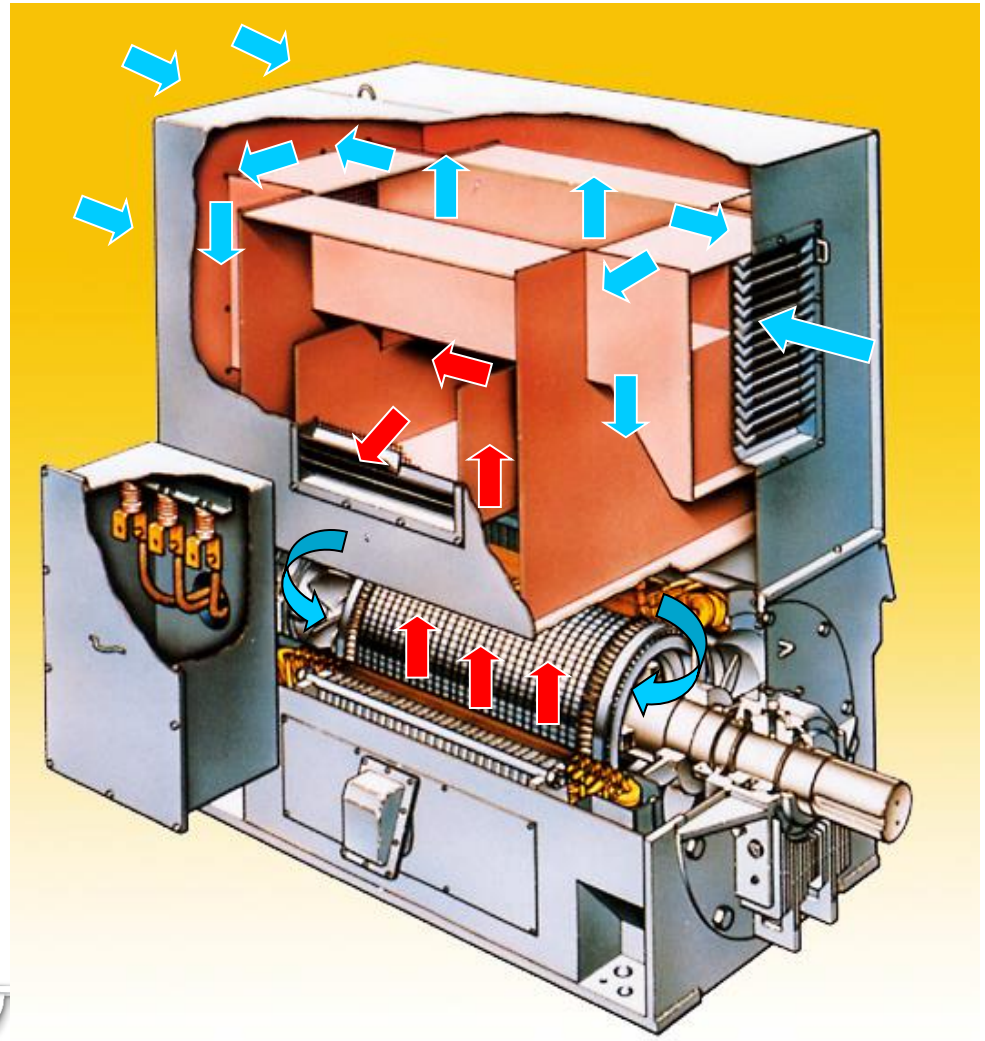
# Totally Enclosed Fan Cooled (TEFC, IP55, IC411)



- Inexpensive
- Suitable for indoor / outdoor use
- Not available for large capacity range
- Up to approx. 3000HP

# Totally Enclosed Fan Cooled (TEFC, IP55, IC411)

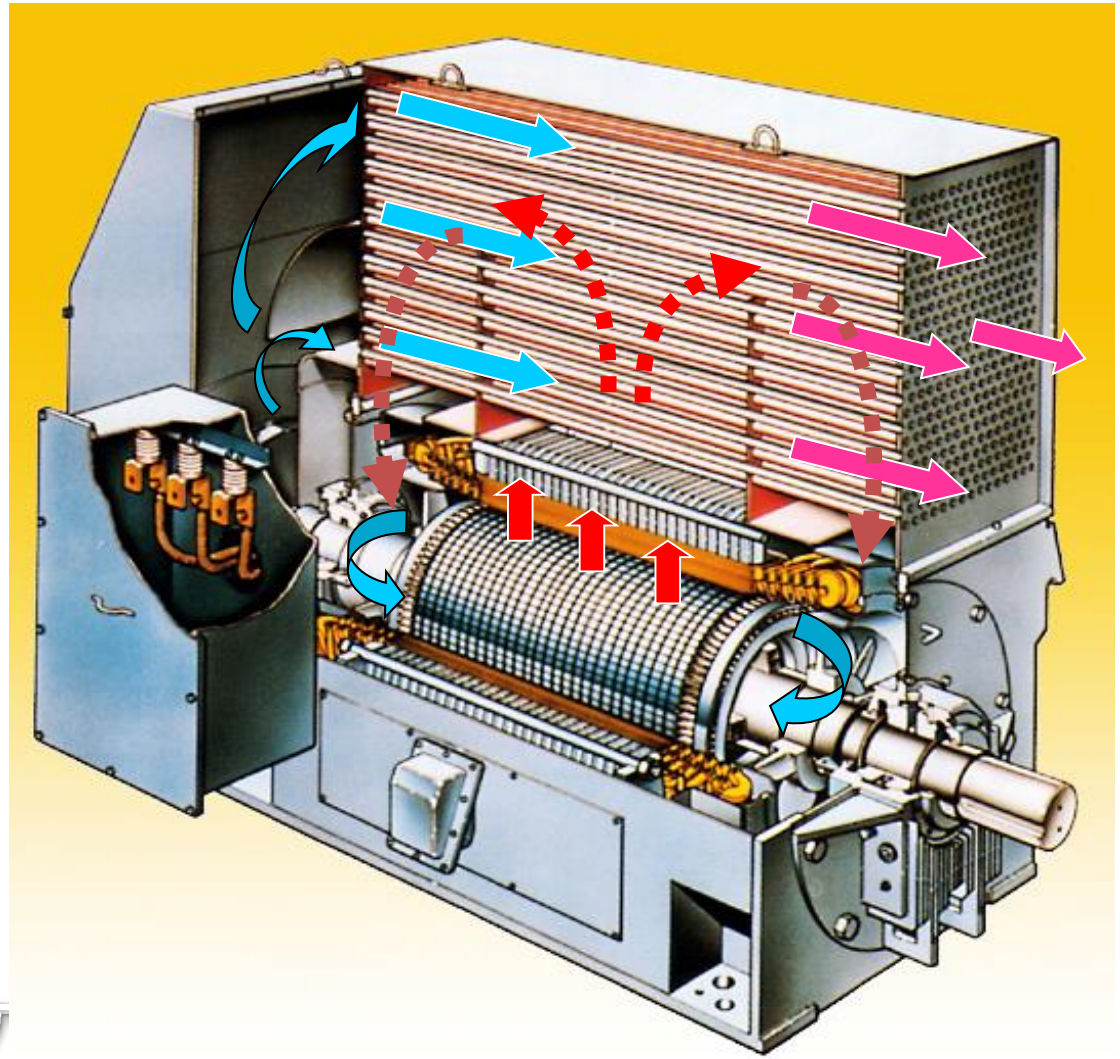
# Weather-protected type II (WPII, IP24W, IC01)



- Suitable for outdoor use, but not common outside North America
- Inexpensive
- Winding is well cooled
- Noisy

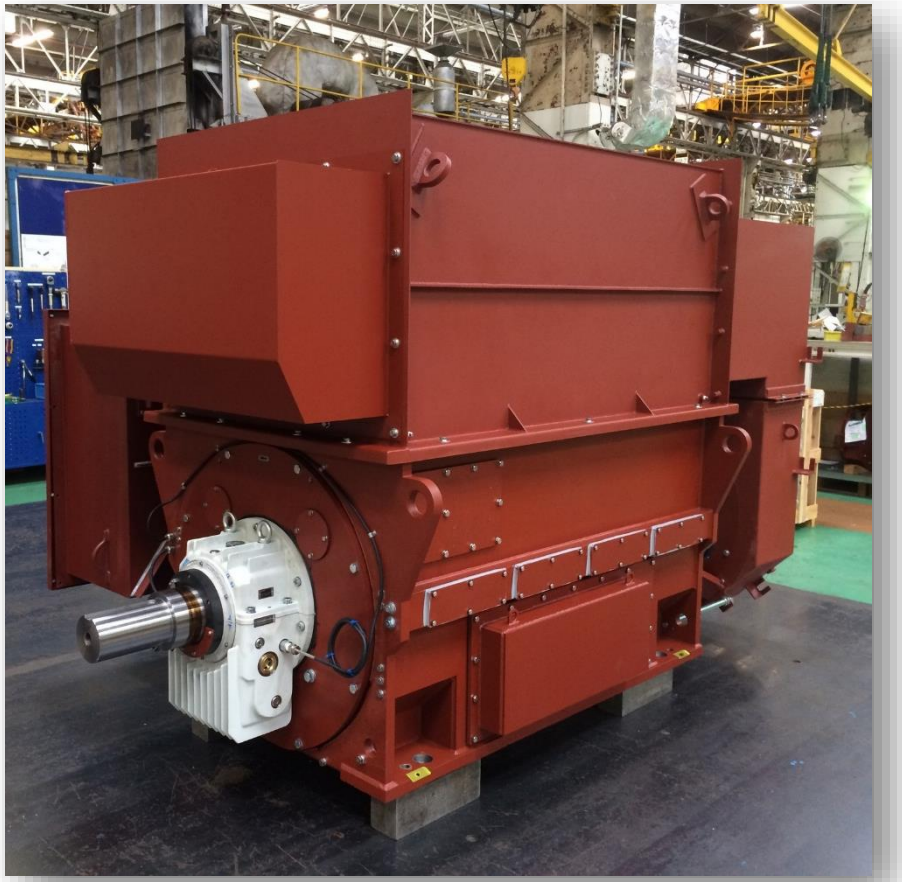
# Weather-protected type II (WPII, IP24W, IC01)

# Totally enclosed air to air cooled (TEAAC, IP55, IC611)

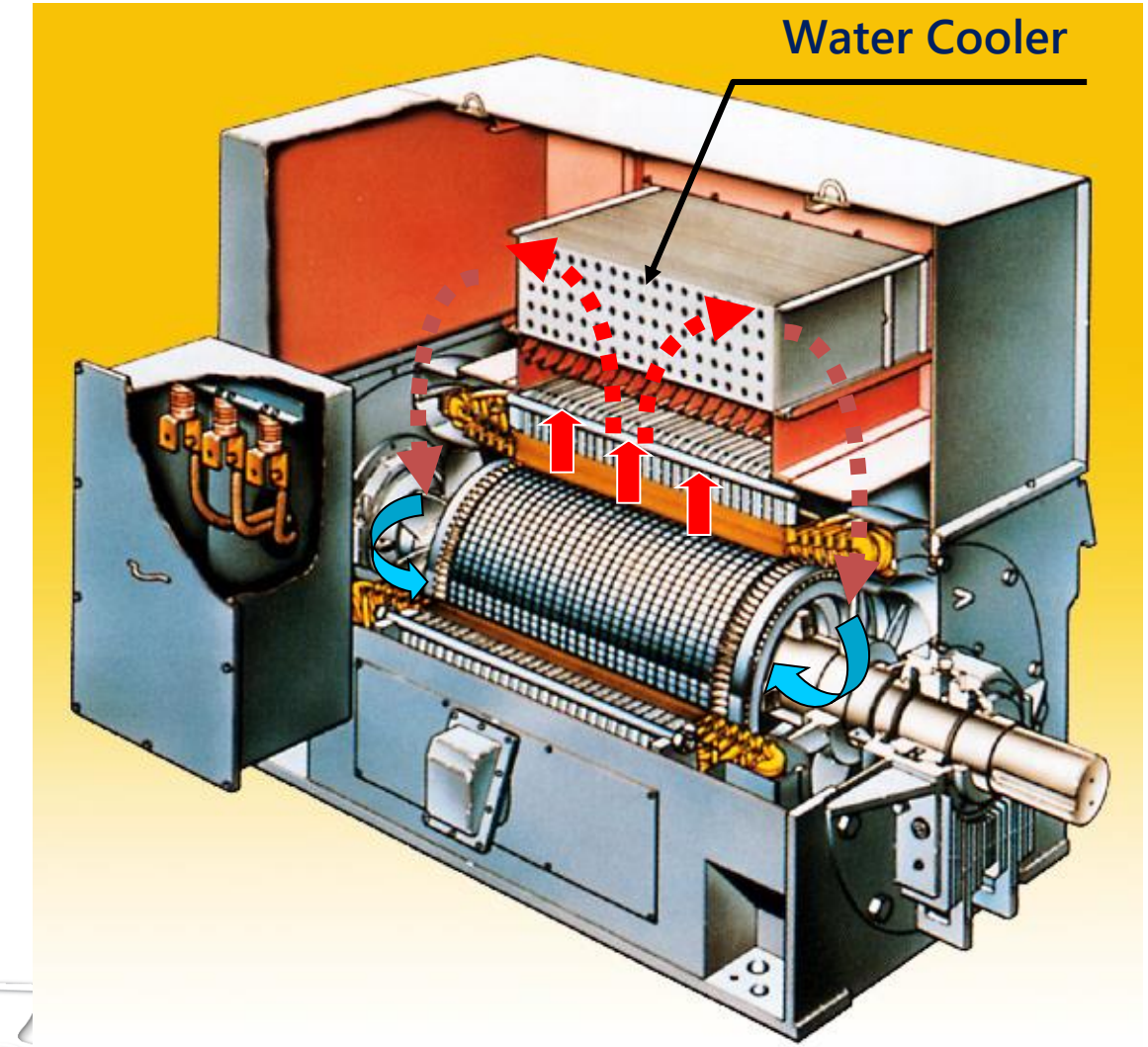


- Suitable for outdoor use, and common outside North America
- Expensive
- Winding is not well cooled (larger motor size than WPII)
- Not available for extremely large capacity motor

# Totally enclosed air to air cooled (TEAAC, IP55, IC611)



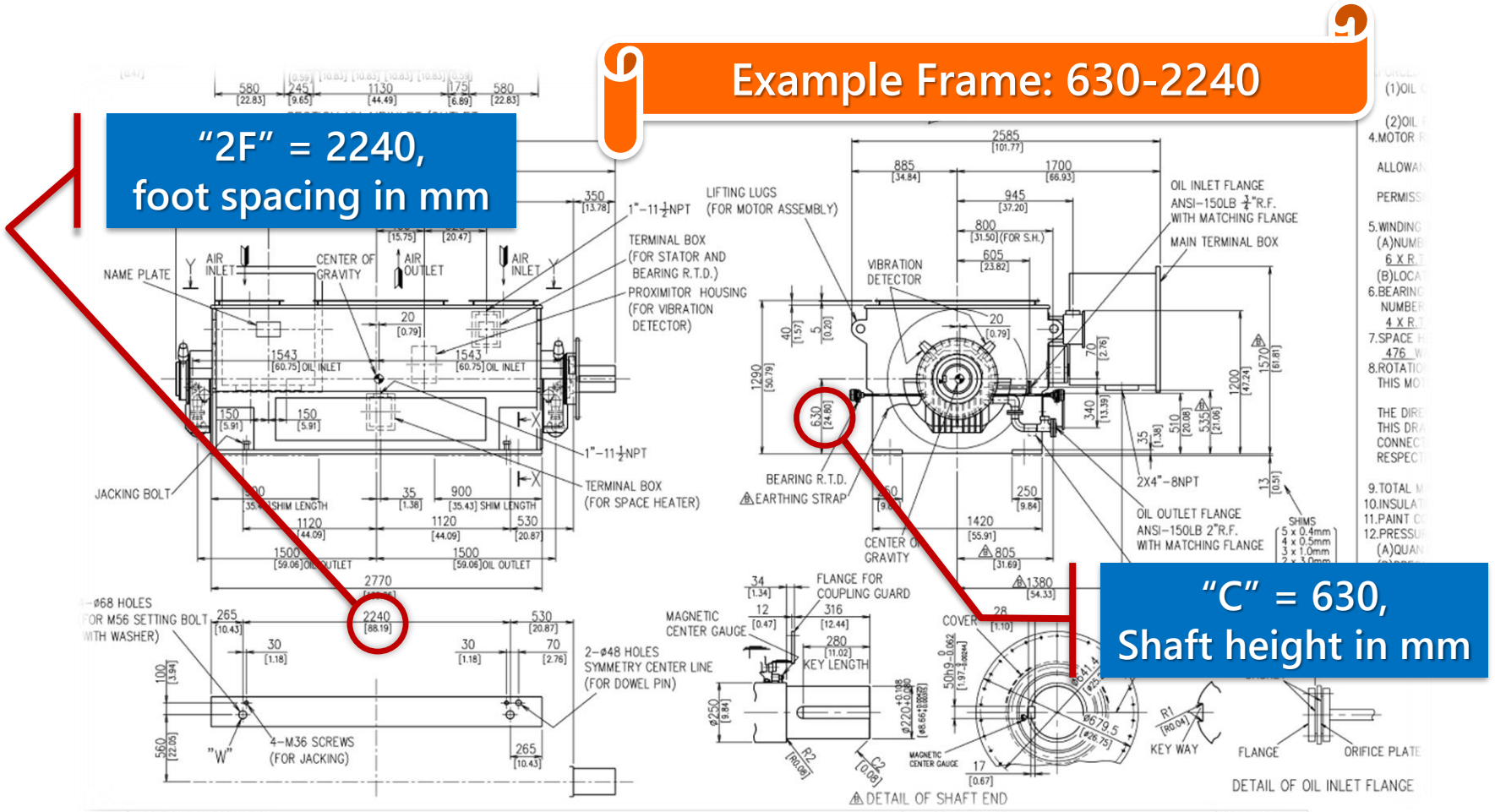
# Totally enclosed water to air cooled (TEWAC, IP55, IC81W)




- Suitable for outdoor use, but needs cooling water
- Expensive $$
- Winding is well cooled (Same motor size with WPII)
- Available for extremely large capacity motor
- Quiet

# Totally enclosed water to air cooled (TEWAC, IP55, IC81W)

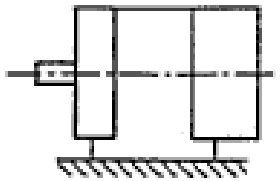
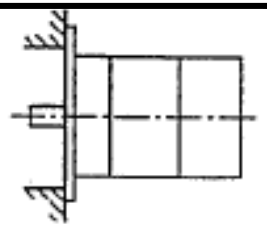
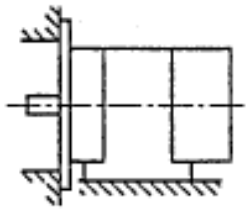
# Motor frame size – IEC conventions



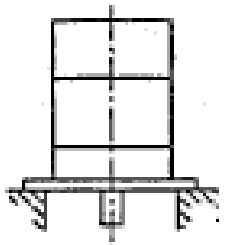
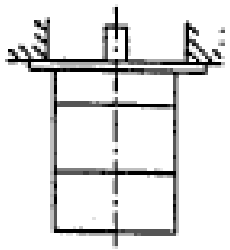
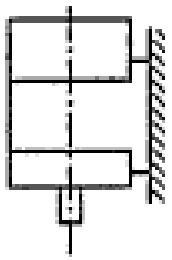
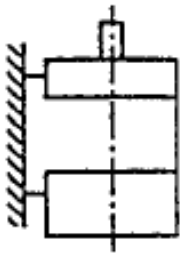

| Example C Dimension for Standard IEC frames | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 250 | 280 | 315 | 355 | 400 | 450 | 500 | 560 | **630** | 710 | 900 |

# Mounting type (per IEC60034-7)

## Designation for machines with horizontal shafts (IM B..)

| | | |
|---|---|---|
|  |  |  |
| * IM B3 | IM B5 | IM B35 |

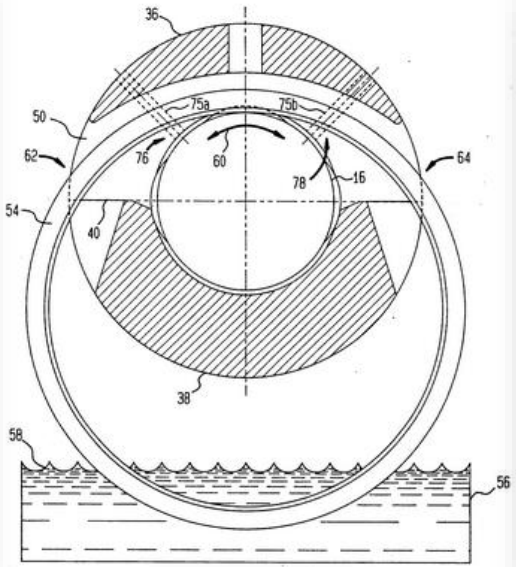
## Designation for machines with vertical shafts (IM V..)

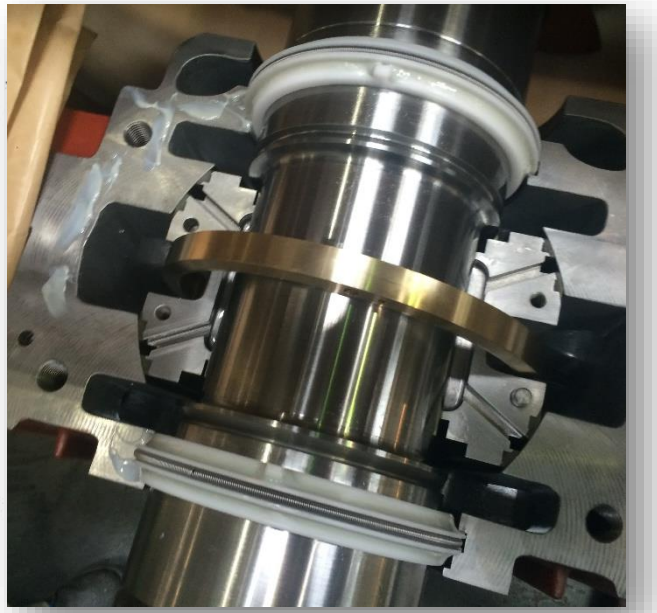
| | | | |
|---|---|---|---|
|  |  |  |  |
| * IM V1 | IM V3 | IM V5 | IM V6 |

# Anti-friction bearings


- Inexpensive compared to Sleeve bearings
- Suitable for thrust load applications
- Relatively short lubricant changing interval (months)
- Not usually suitable for very high-speed (2-pole)
- Limited bearing life (L-10 life)
  (Typical – 20k, 50k, 100k hours)

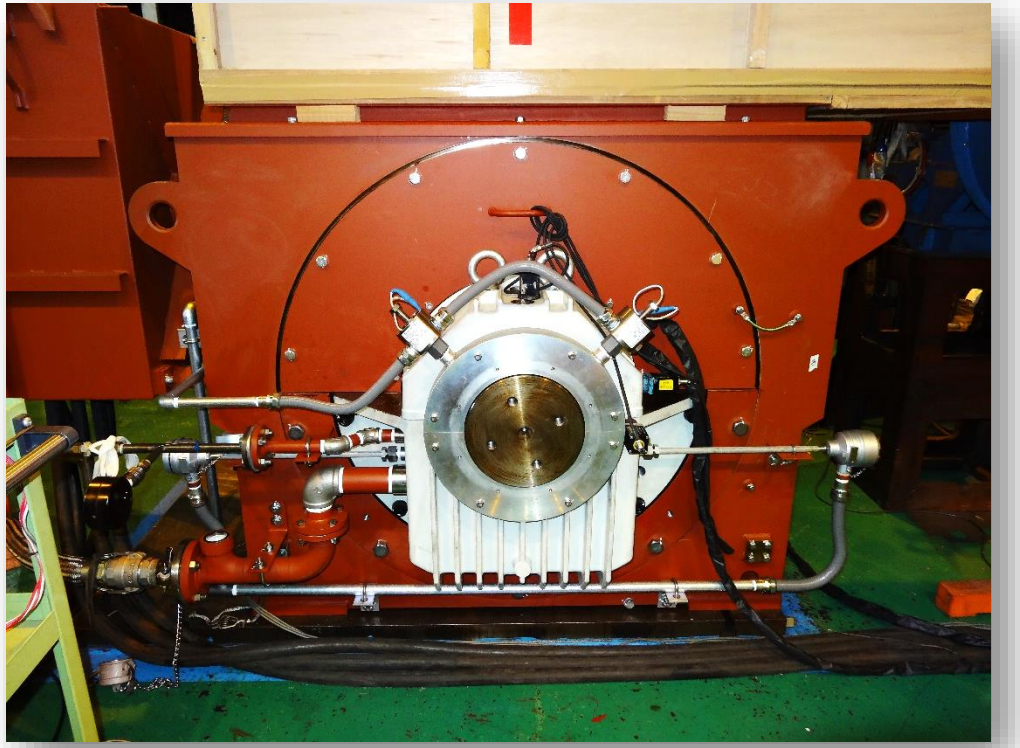
# Self-lube Sleeve bearings



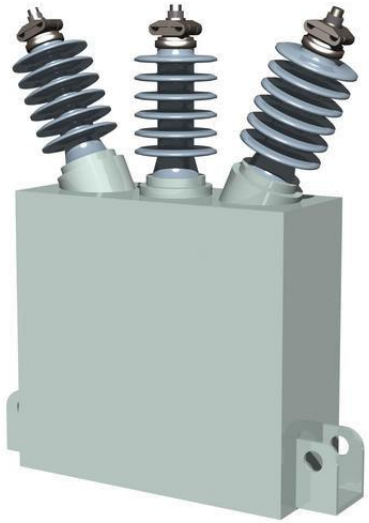



- Long bearing life
- Long lubricant changing interval (1-2 years)
- Expensive compared with A-F bearings
- Not suitable for thrust load applications
- Not suitable for extreme ambient temp. locations

# Force-lube Sleeve bearings



- Long bearing life
- Covers high-speed and highly-loaded range
- No shut-down is required for lubricant changing
- Requires oil-circulation system



# Motor Options & Accessories

# Service Factor

For MV Motors, if you specify **1.15 S.F.**
what does that mean in motor size and design?

- A  name plated 1,000HP motor must be able produce 1,150HP. (Mechanically)
- It must produce this HP and not exceed the temperature spec or maximum temperature for the location.

Note:  API driven equipment specs require an additional 10% above HP requirement.  With a 15% S.F. that makes a the motor 26% larger.

This adds cost and increase the size and weight!

# Ambient temperature & Altitude

**NEMA and IEC Motors are rated 40°C Ambient, <3300ft**

**Below -20°C** - Bearing lubrication should be reviewed

**Below -40°C** - Shaft Steel and frame should be reviewed

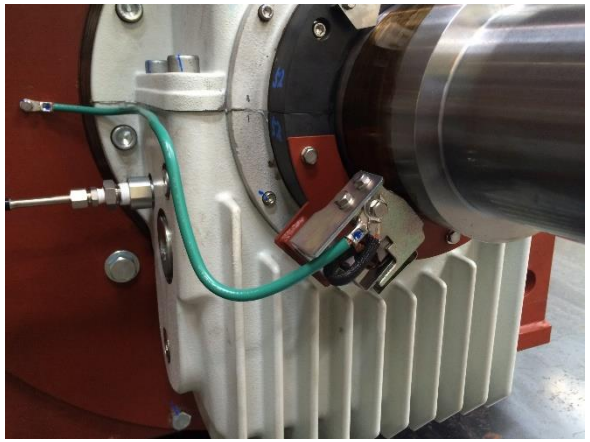
**Below -50°C** - Everything Changes

**+40°C or hotter** - Motor will increase in size (Bearing Lub+)

**Above 1000m (3300ft) altitude**
Motor will increase in size (de-rating)

# VFD Duty Motor Design

1. **Designed to NEMA-MG1 Part 31**
2. **2-Pole machines** requires **stiff shaft** to avoid critical speed
3. **Insulation reinforcement** for inverter surge voltages
4. **Specialized Cooling design** for torque load at lower speeds
   a) May require Aux. Blower for continuous cooling at any speed
5. **Shaft current protection** (bearing electric discharge erosion)
   a) Normally Non-Drive End bearing insulation plus grounding brush on drive shaft end.
   b) For hazardous area, both bearings are insulated and adoption of insulated coupling.



Shaft Grounding Brush

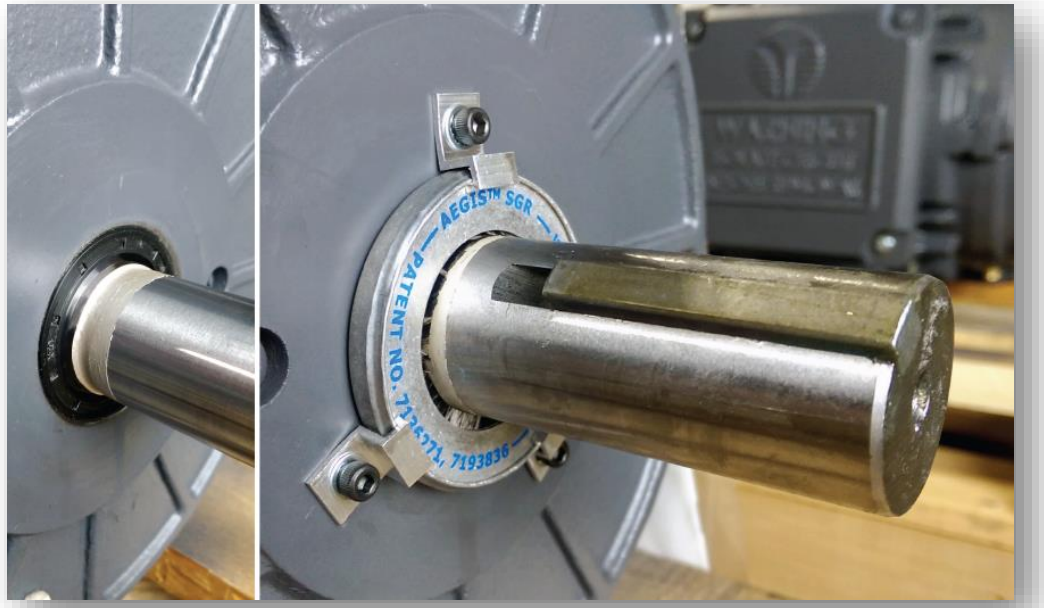
# Shaft current protection

**Standard:**
NDE Bearing insulated

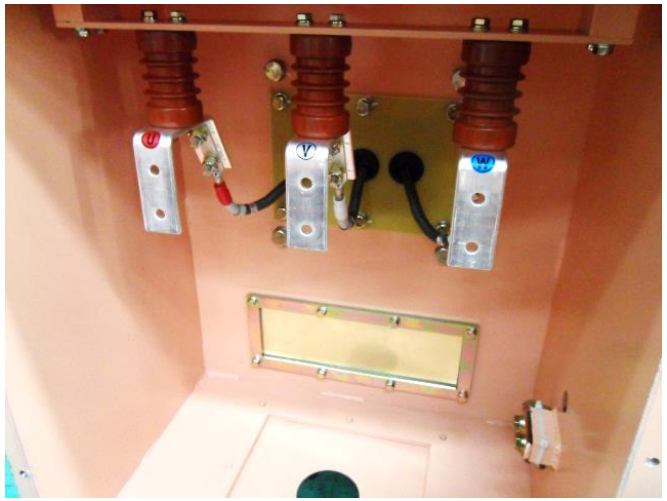
**VFD Duty Standard:**
NDE Bearing insulated
+Grounding Brush

**Hazardous Locations:**
Both Bearings insulated

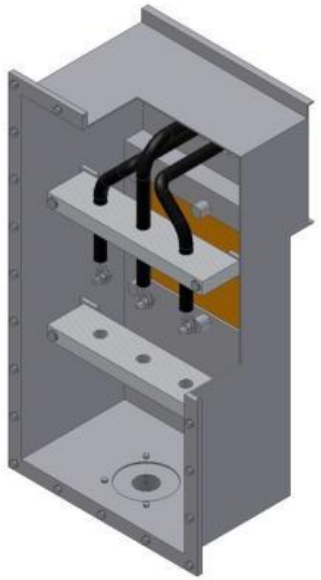
**Optional:**
- Aegis Ring
- Insulated Couplings
- Ceramic Ball bearings



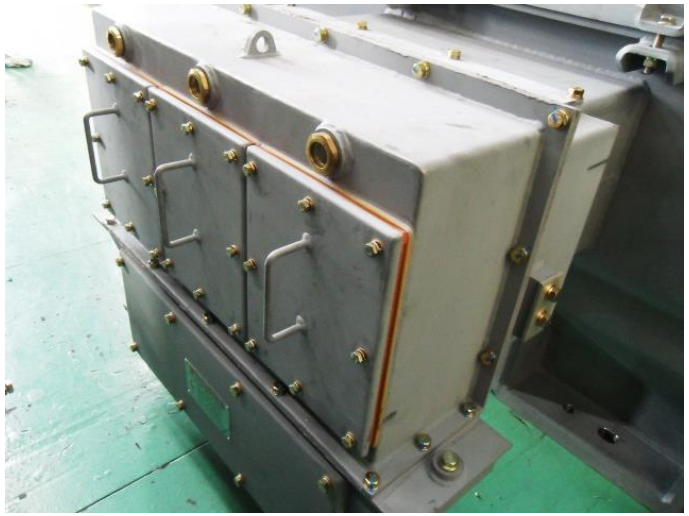
# Terminal box types



Standard type

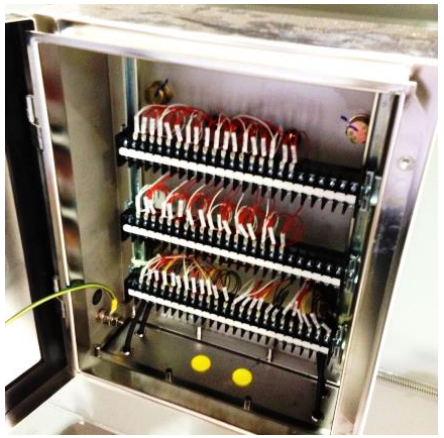


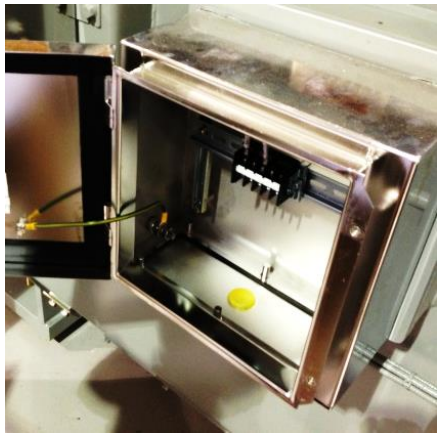
Phase insulation type



Phase segregated type

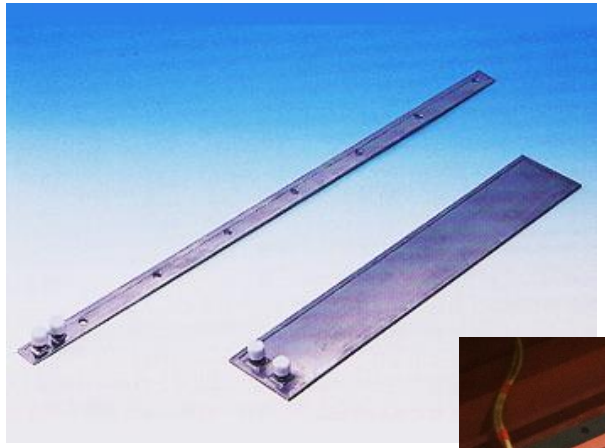
Accessories T-box



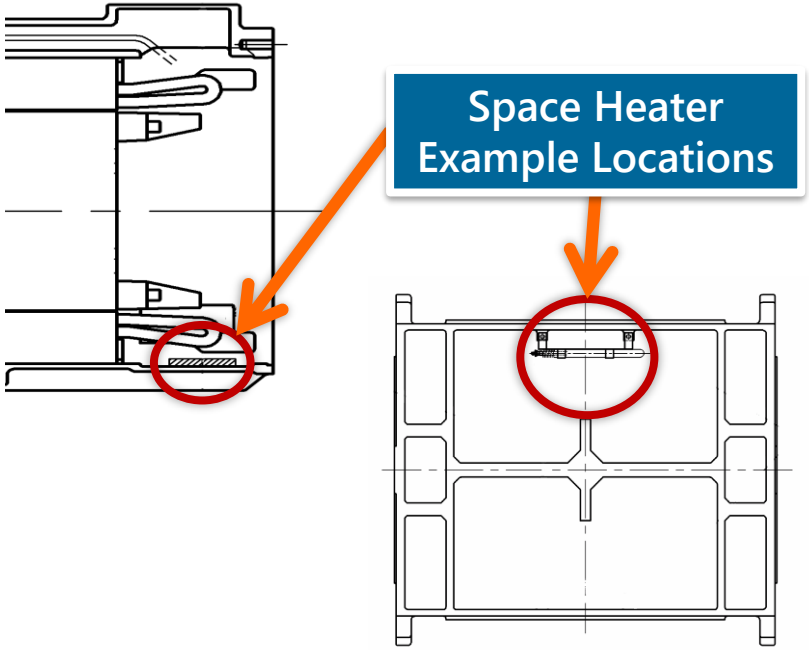


Space heater T-box

# Space Heater



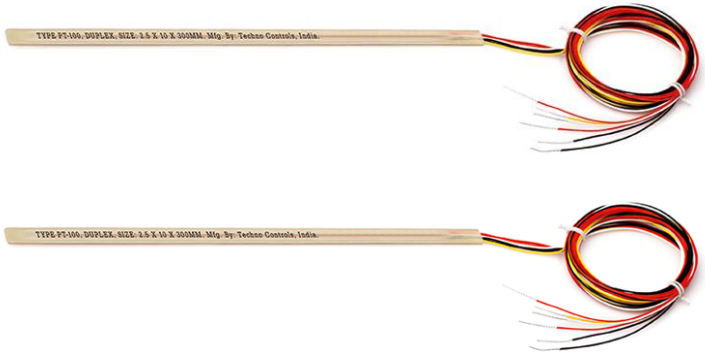
Space Heater Types




Space heater is used to avoid dew in the motor frame to protect winding insulation during the storage.

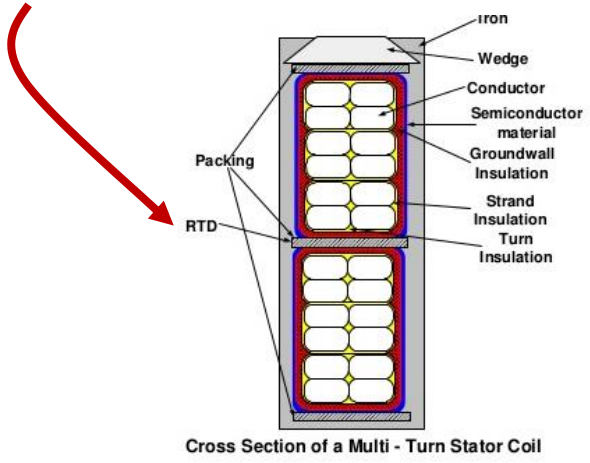
Low surface temperature is required in hazardous area.

# Temperature sensors



Stator Winding RTDs

(resistance temperature detector)

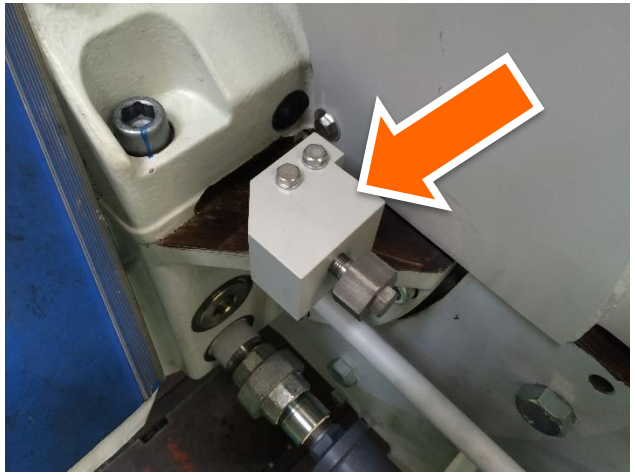



Cross Section of a Multi - Turn Stator Coil

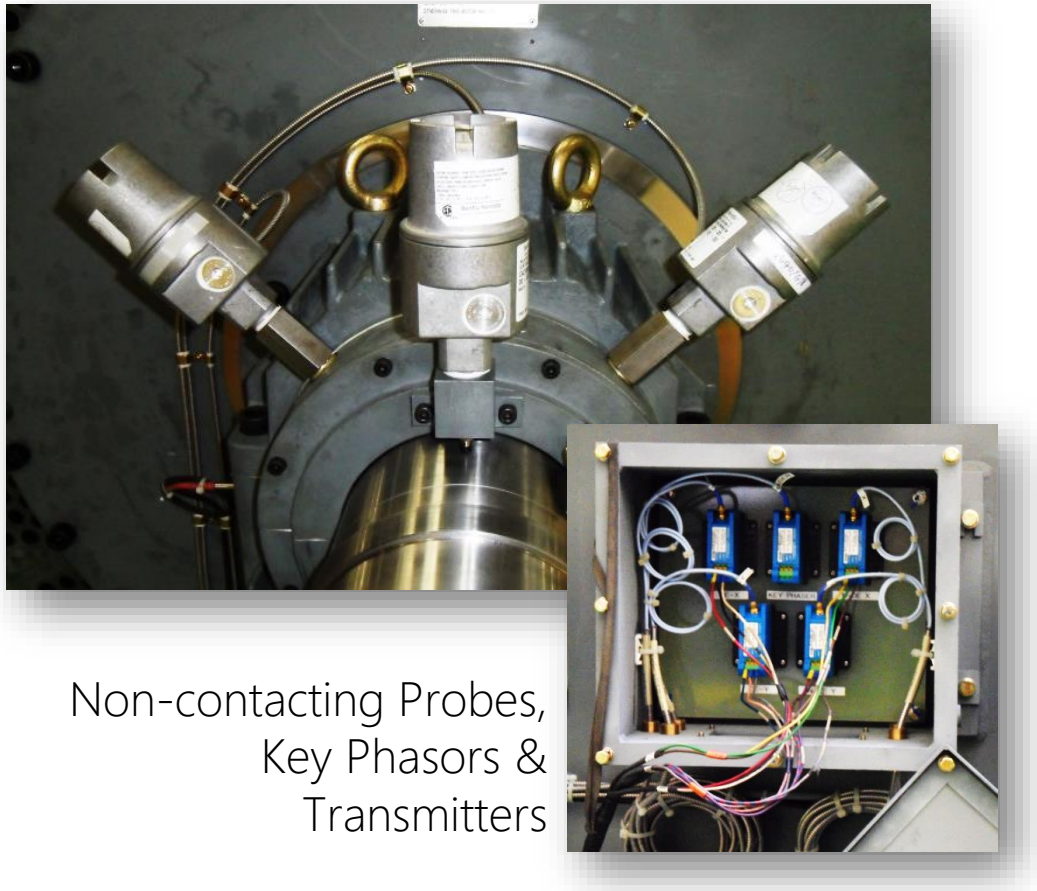
Bearing RTDs

Dial type bearing thermometer

# Vibration sensors



Bearing housing vibration sensor mounting provision



Non-contacting Probes, Key Phasors & Transmitters

# Surge protection

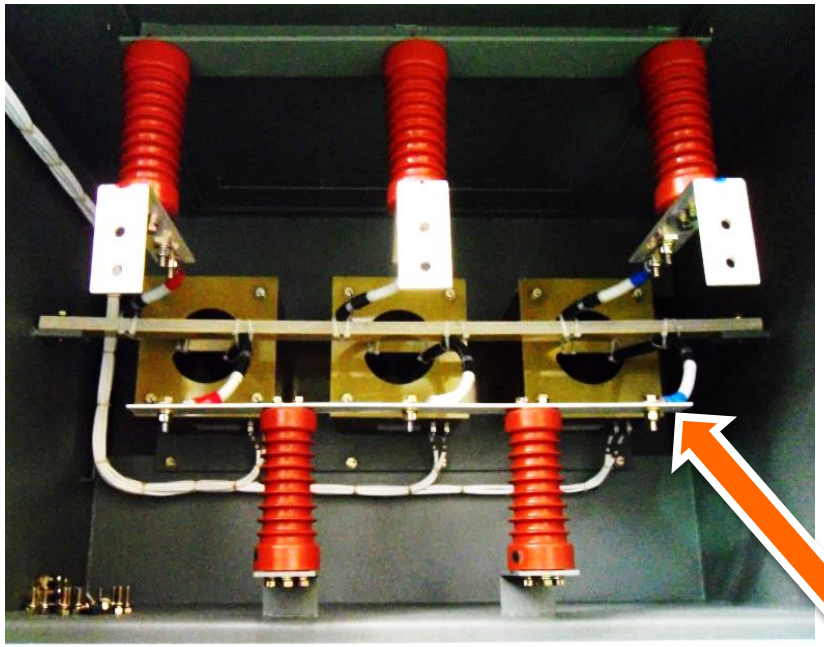
**Surge Capacitors &**

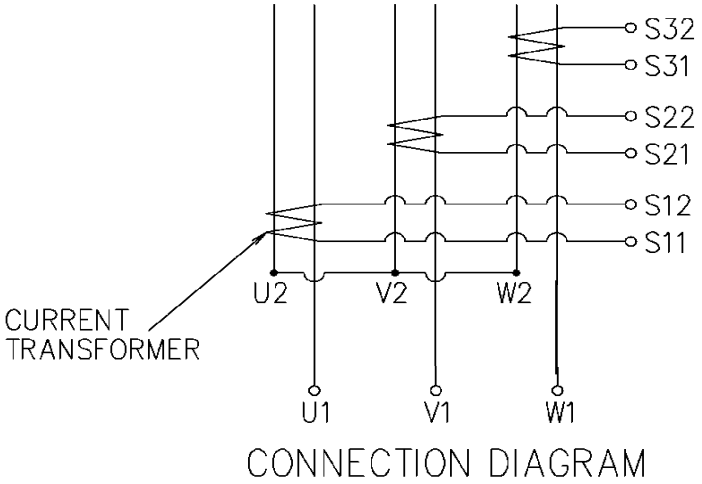
**Surge Arresters**

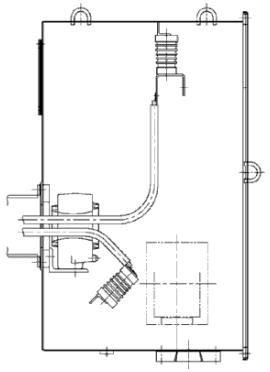
Mounted in motor Main Terminal box

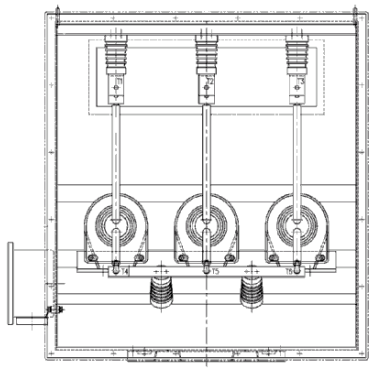
Not to be used with VFD

# Current transformer



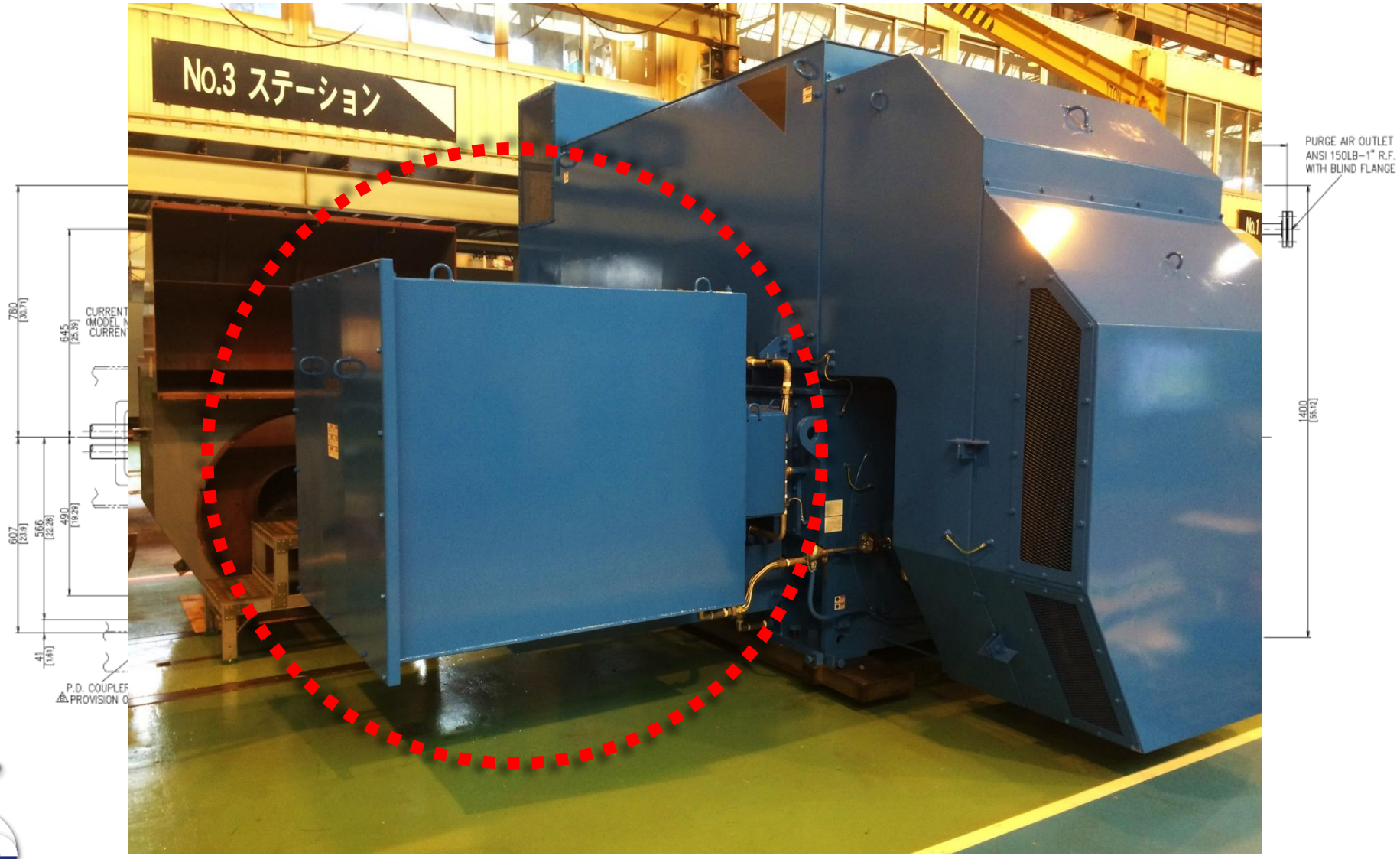




Neutral leads needs to be brought out to Main terminal box

# Terminal box… Size matters



# API541 – American Petroleum Institute Standard


Required for many motors
in use in Oil & Gas Industry

1. Max. 650% locked rotor current limitation
2. Max. 85dB(A) noise limitation
3. Sleeve Bearing
4. Very strict Vibration limits
5. 3 Cold / 2 Hot Starting
6. Minimum C-5 quality
   Stator lamination core plate
7. Feet coplanar to .005 inches,
   parallel to each other within .002 inches
8. Number of Routine Tests and Inspections: 13
9. Lots of test items

# Thanks for listening!

Questions?