Mechanical Design

Mechanical Design

- Enclosures I
  - NEMA
  - IEC
- Bearing design
- Enclosures II
  - ABS and SOLAS
  - Hazardous Location
  - Electrical Housings
- Other Design Considerations
  - Coupling and Shaft Design
  - Typical Marine Designs

Enclosures: Standards

- NEMA MG 1-2006 Section 1 Part 1
- NEMA MG 1-2006 Section 1 Part 5
- IEC 60034-5, 2000-12
- IEC 60034-6

NEMA MG 1-2006 Section 1 Part 1

- Classification according to environmental protection and methods of cooling
- Most common classifications:
  - Dripproof guarded machine (ODP)
  - Weather-protected machine: Type I & Type II WPII
  - Totally enclosed fan-cooled guarded (TEFC)
  - Totally enclosed air-to-water-cooled (TEWAC, CACW)
  - Totally enclosed air-to-air-cooled (TEAAC, CACA)

NEMA MG1-2006 Section 1 Part 5 and IEC 60034-5, 2000-12

- IP Codes
  - Protection of persons against contact with hazards
  - Protection of machine against ingress of solid objects
  - Protection of machine against harmful effects due to ingress of water

NEMA MG1-2006 Section 1 Part 5 and IEC 60034-5, 2000-12

1st digit

- 2 = protected against 12 mm objects
- 4 = protected against 1 mm objects
- 5 = dust protected
- 6 = dust tight

2nd digit

- 1 = protected against dripping water
- 2 = protected against 15 degree from vertical water spray
- 3 = protected against 60 degree from vertical water spray
- 4 = protected against splashing water
- 5 = protected against water jets
- 6 = protected against powerful water jets

Common: IP21 (ODP), IP22, IP23, IP44, IP54, IP55, IP56

Just Another Day at the Beach

True Grit

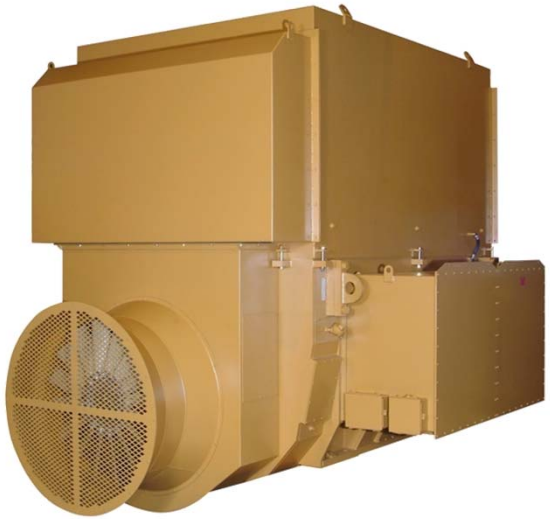
Guarded Open Drip Proof (IP22)

Totally Enclosed Fan Cooled

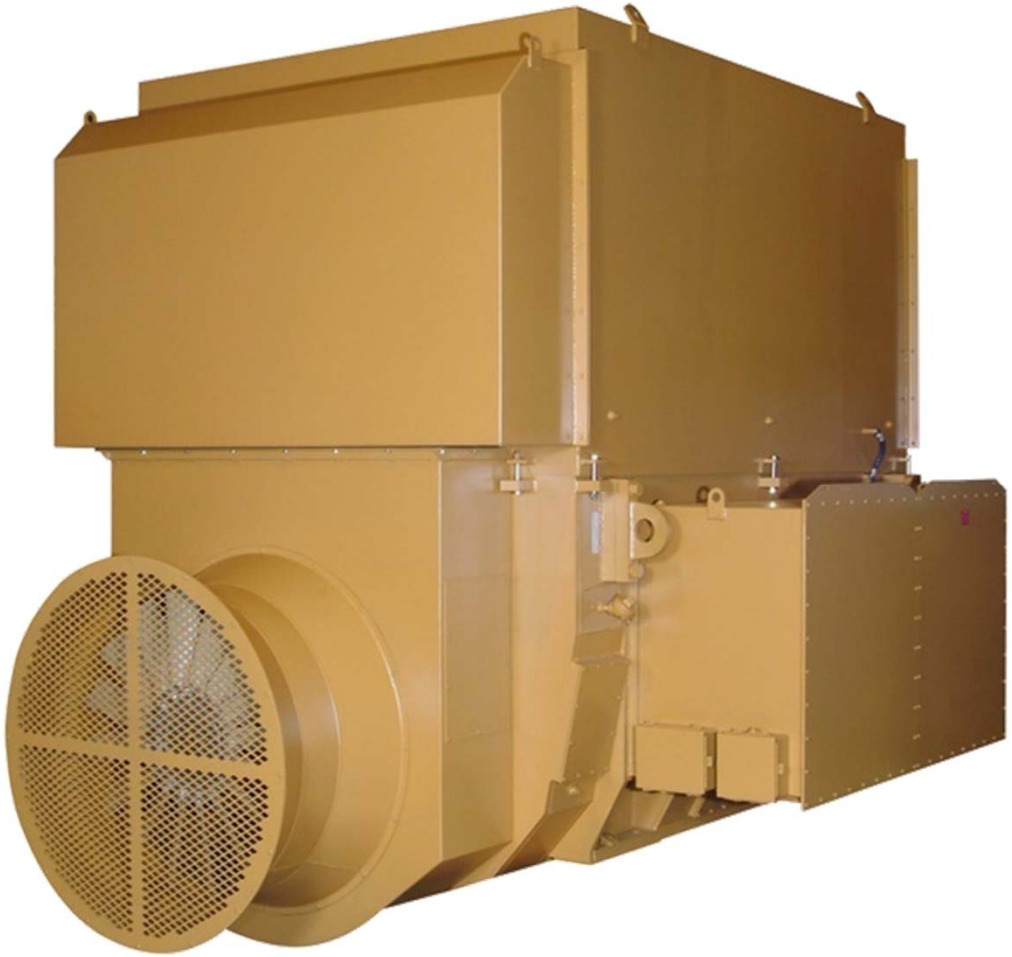
- Internal air flows over the core and windings and is circulated by a shaft-driven fan. Heat is radiated through the enclosure.
- An external shaft-driven fan pushes ambient air over the cooling fins on the outside of the machine.
- Requires a larger machine due to the added losses associated with radiant cooling.
- Meets ingress protection ratings IP44-IP56

Totally Enclosed Air-to-Air Cooled

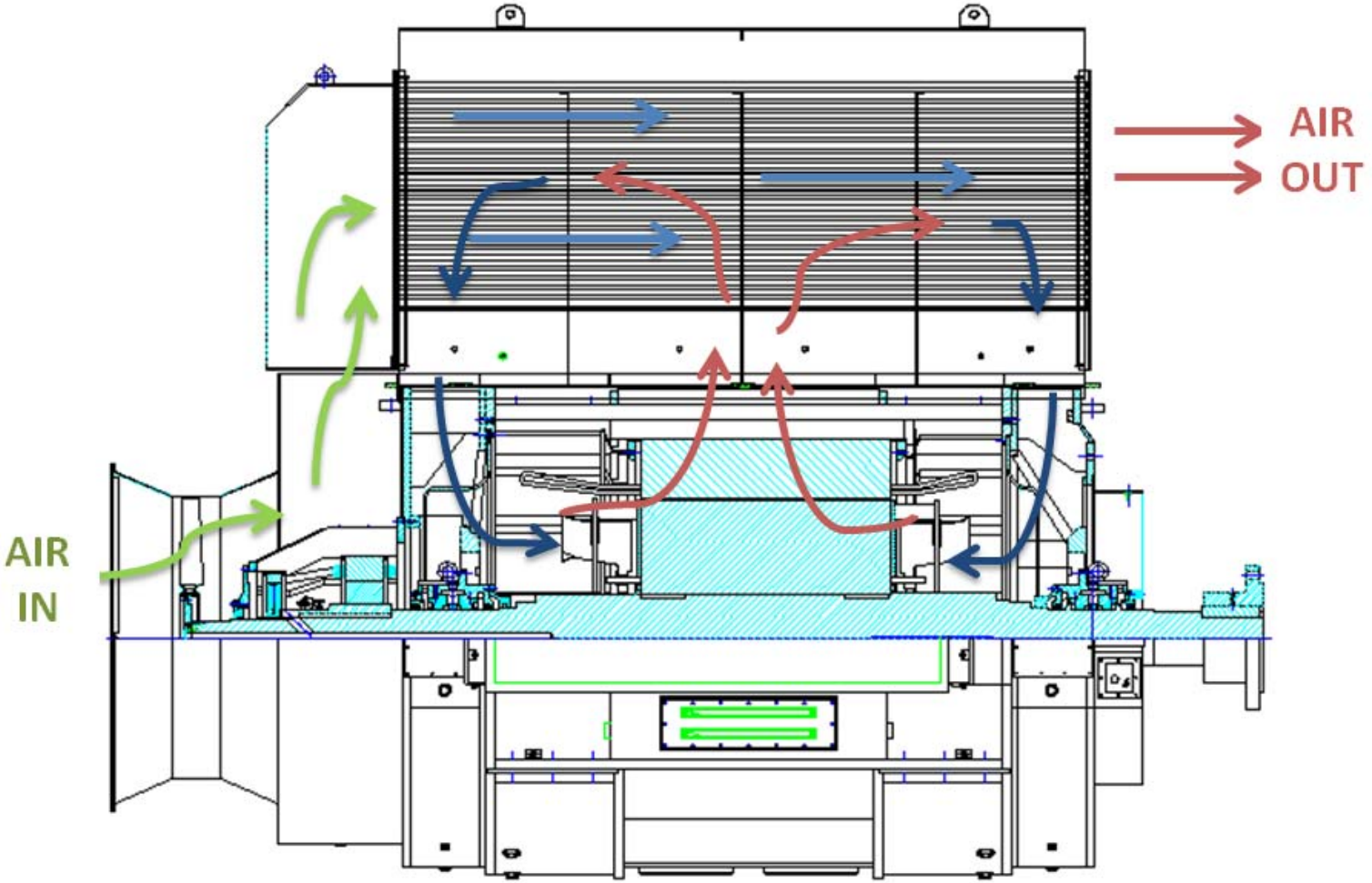
- TEAAC (CACA)
- Cooling air supplied by shaft-mounted fan or separate blowers.
- 50 to 100 CFM per kW of losses.
- Oversized for a typical 20º C rise over ambient for the internal cooling circuit. Example: 40º ambient + 30º C = 70º C internal air.
- Ambient air temp remains constant.
- Typically the internal generator inlet air temp will be ambient + 20º C so the generator needs 35 - 40% over-sizing to equal an ODP.



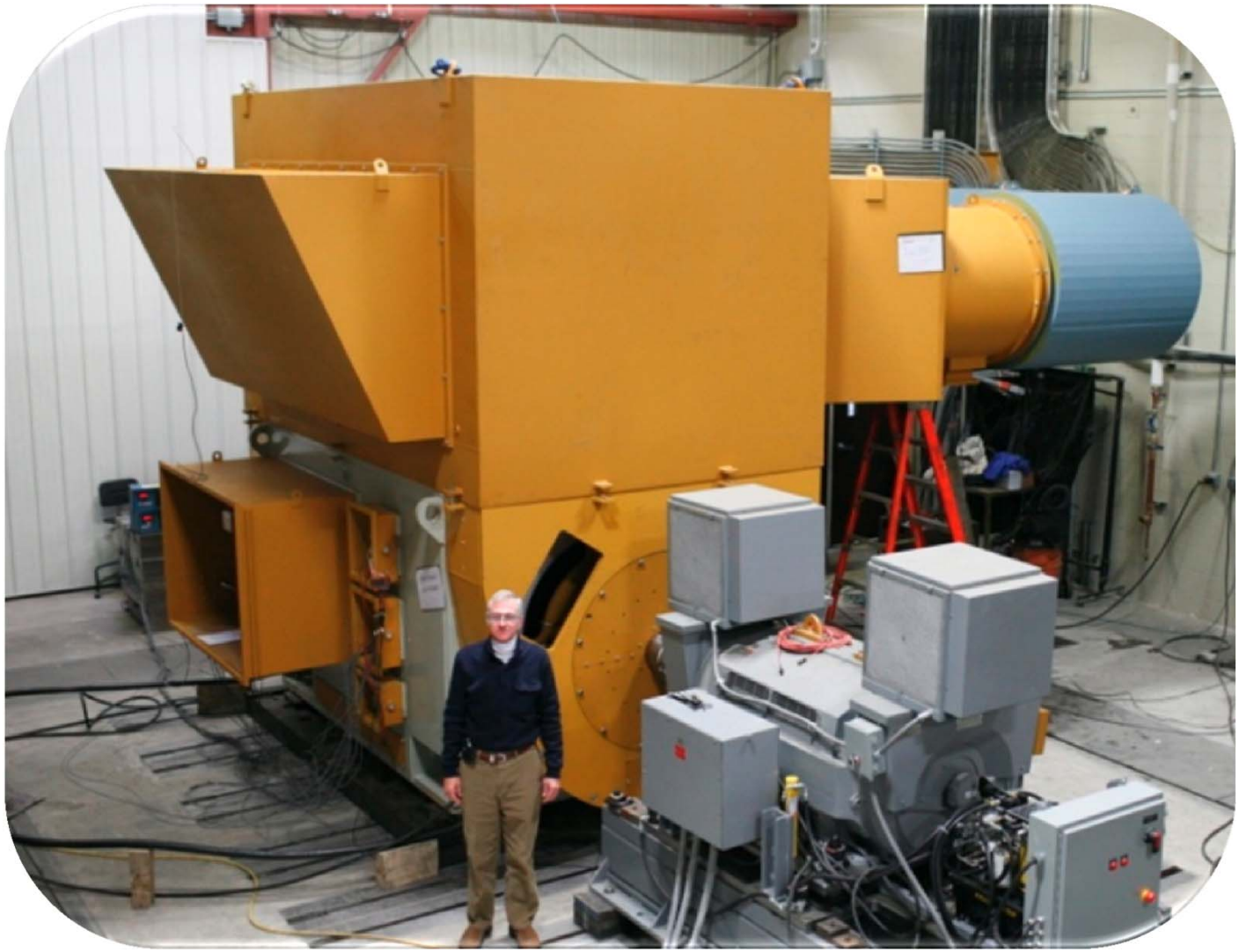
TEAAC: Shaft-Mounted Fan



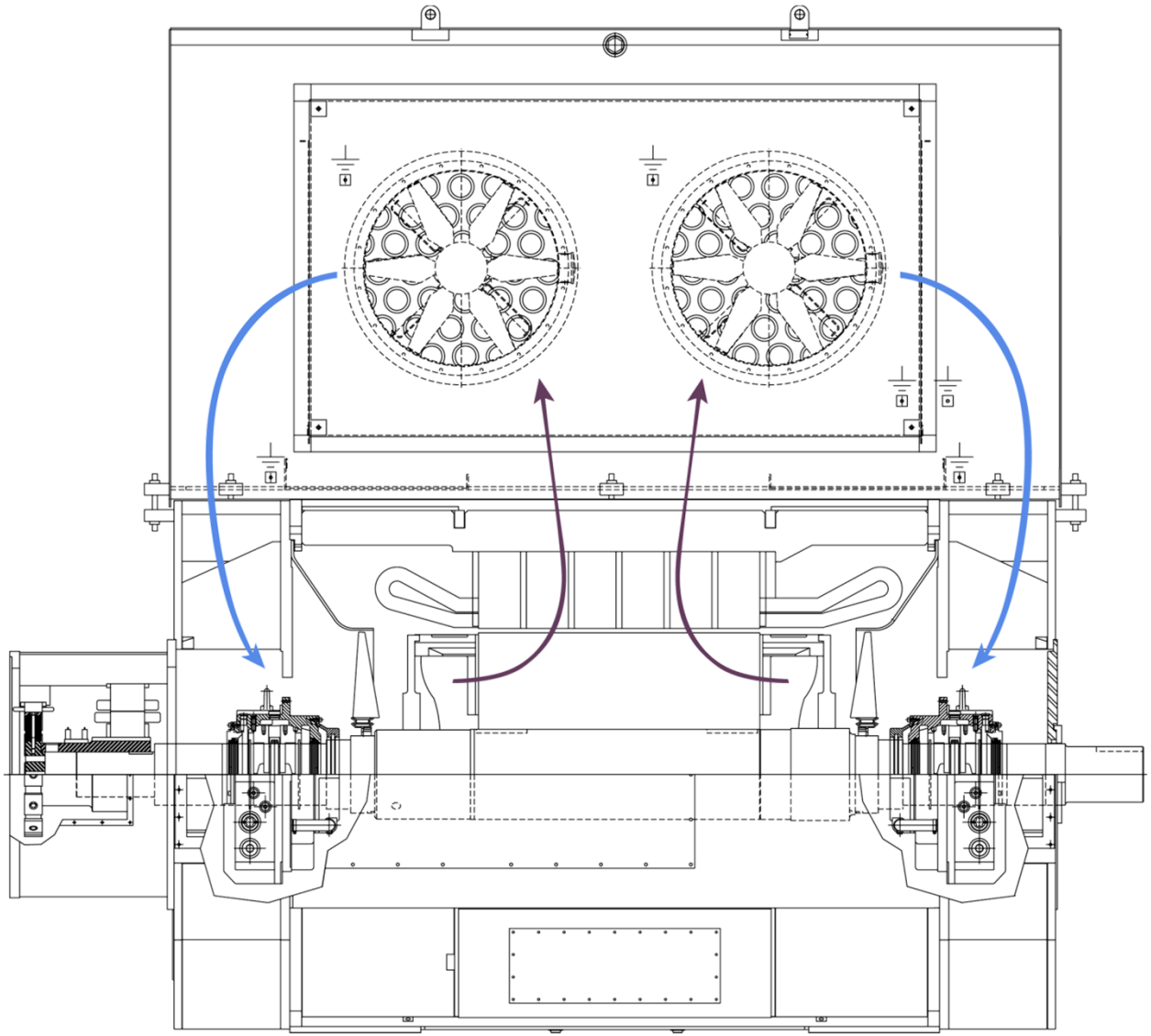
TEAAC: Shaft-Mounted Fan (cont.)



TEAAC: Separate Blowers

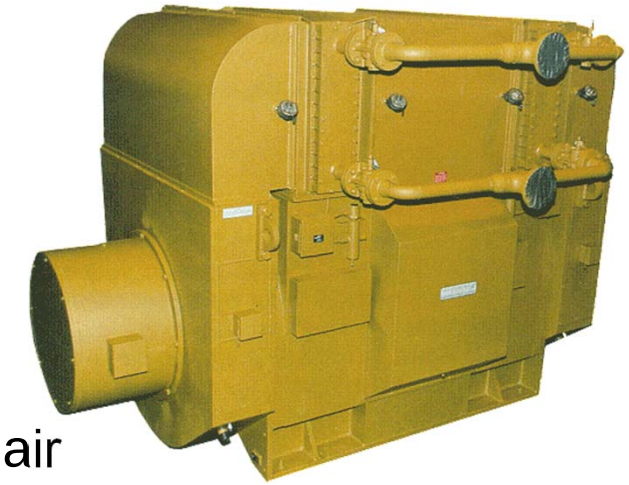


TEAAC: Separate Blowers (cont.)

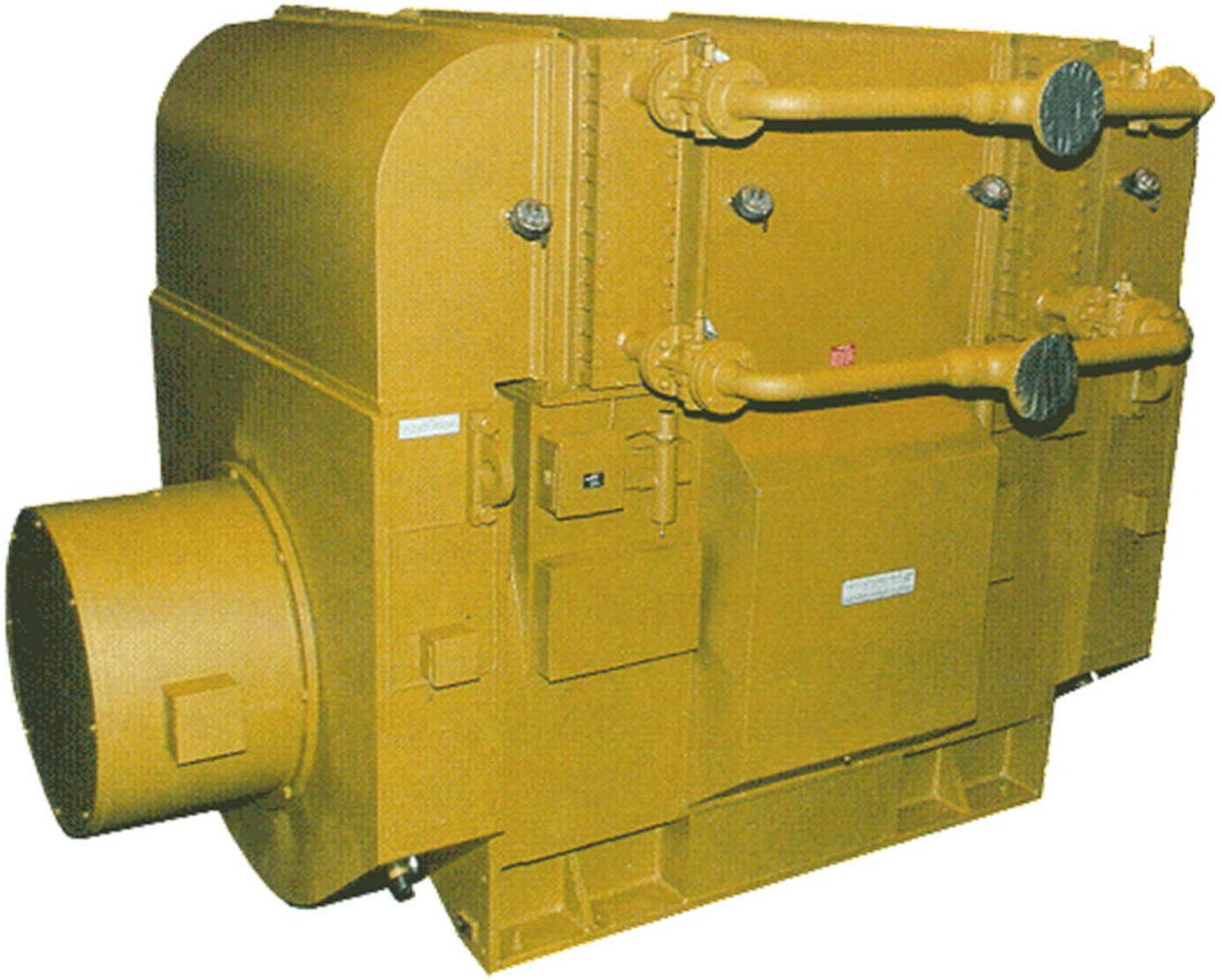


Totally Enclosed Air-to-Water Cooled

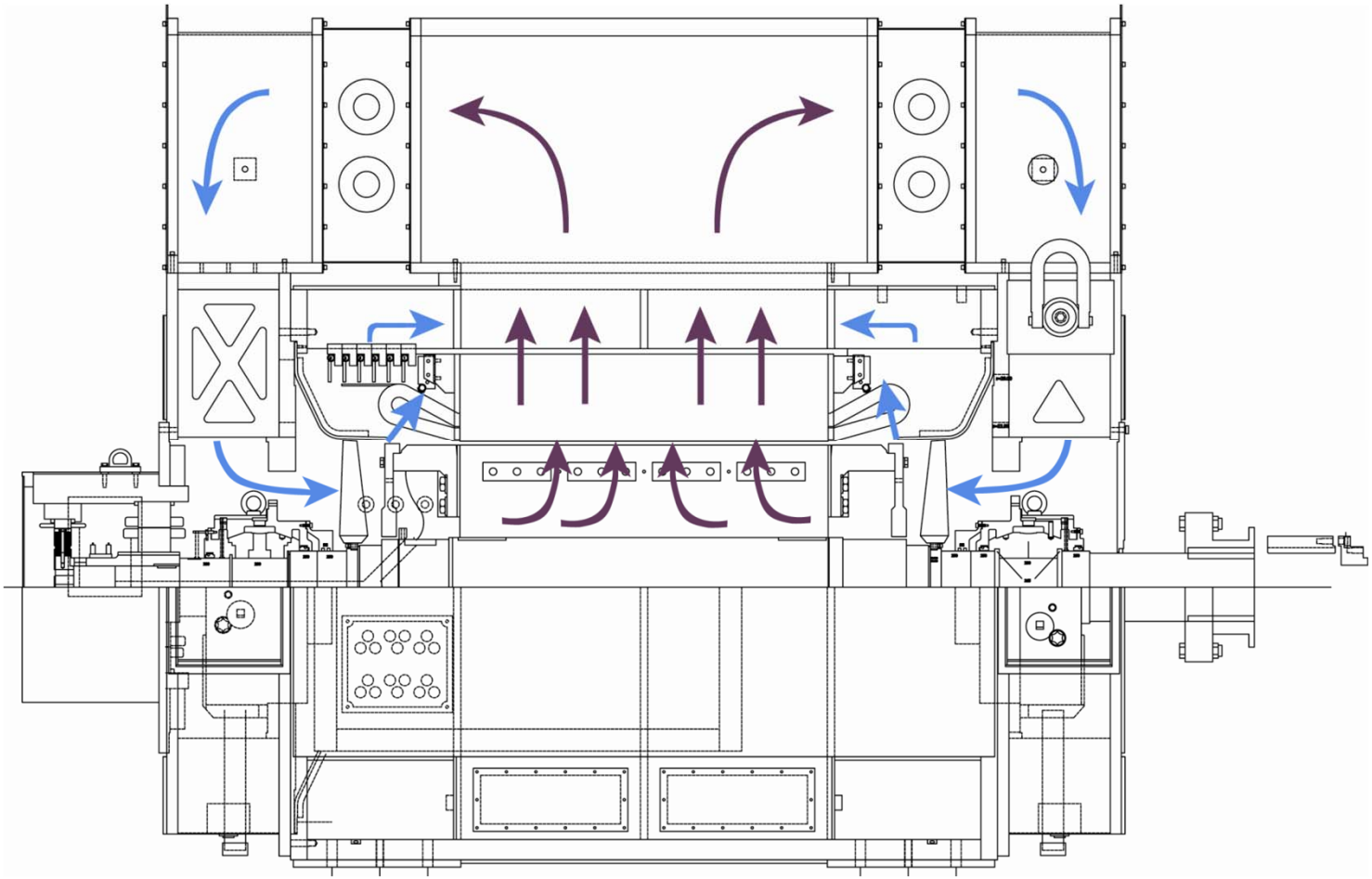
- TEAWC (CACW).
- Has cooling water inlet and outlets.
- Flow; 1 gpm / kW loss.
  - Usual water = 32º C
  - Single tube = + 8º C = 40º C internal air
  - Double tube = +18º C = 50º C internal air
- For typical 32º C water there is no de-rate for single-wall application. Ex: 32º C water + 8º C = 40º C incoming air.
- With 32º C water we typically can provide 40º C air back to the inlet side of the generator, so they are sized similarly to an ODP machine.



Totally Enclosed Air-to-Water Cooled

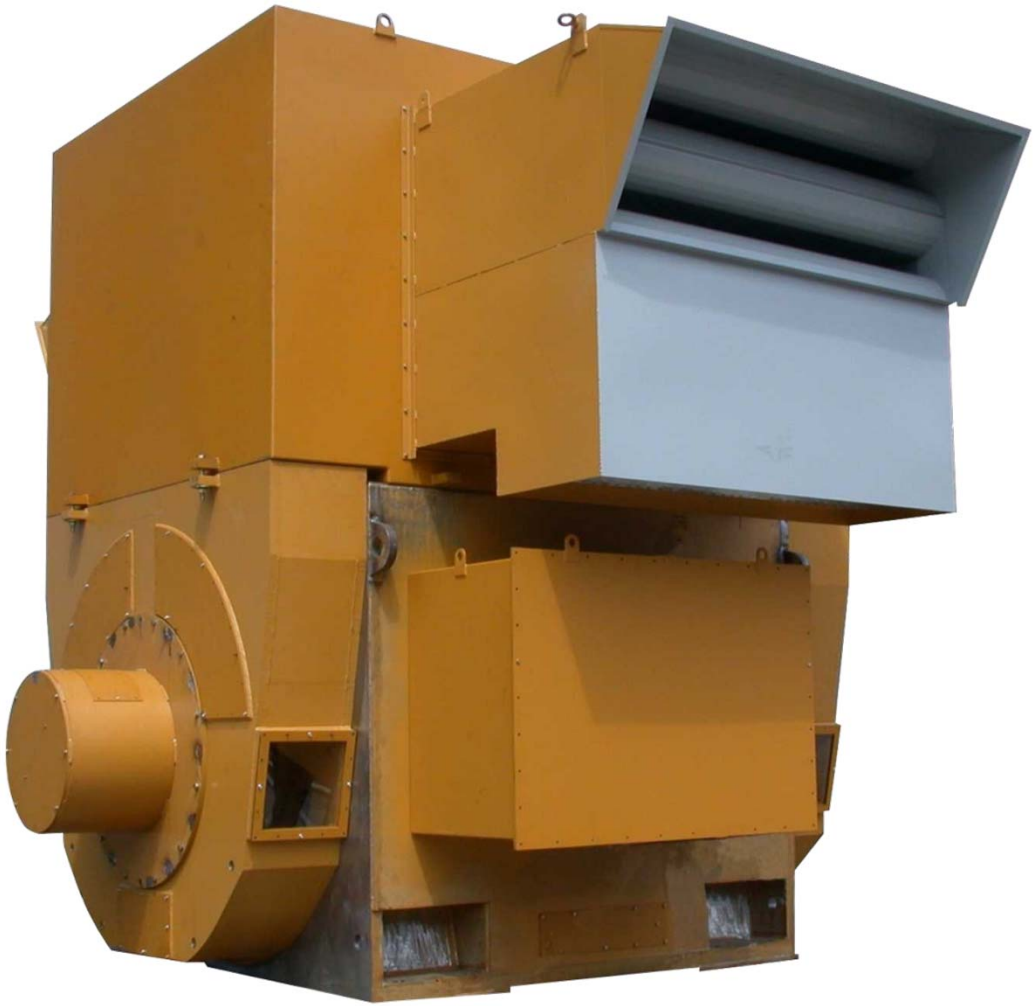


Totally Enclosed Air-to-Water Cooled (cont.)

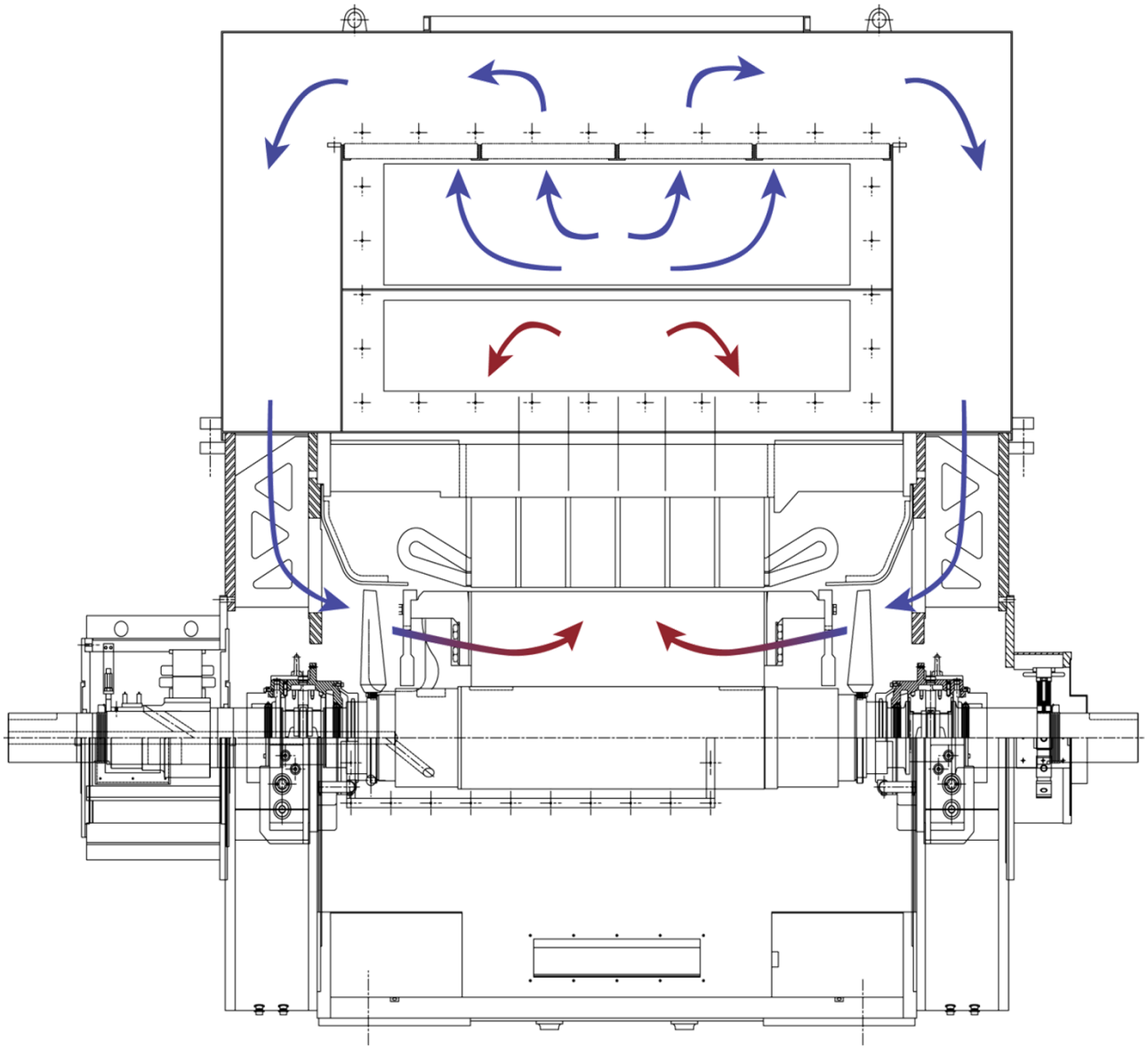


Weather Protected II

- Inlet air has three 90 degree direction changes and <600 fpm (<3 m/sec) air speed.
- Optional air filters.
- Inlet air temp remains unchanged so sizing is equal to an ODP.

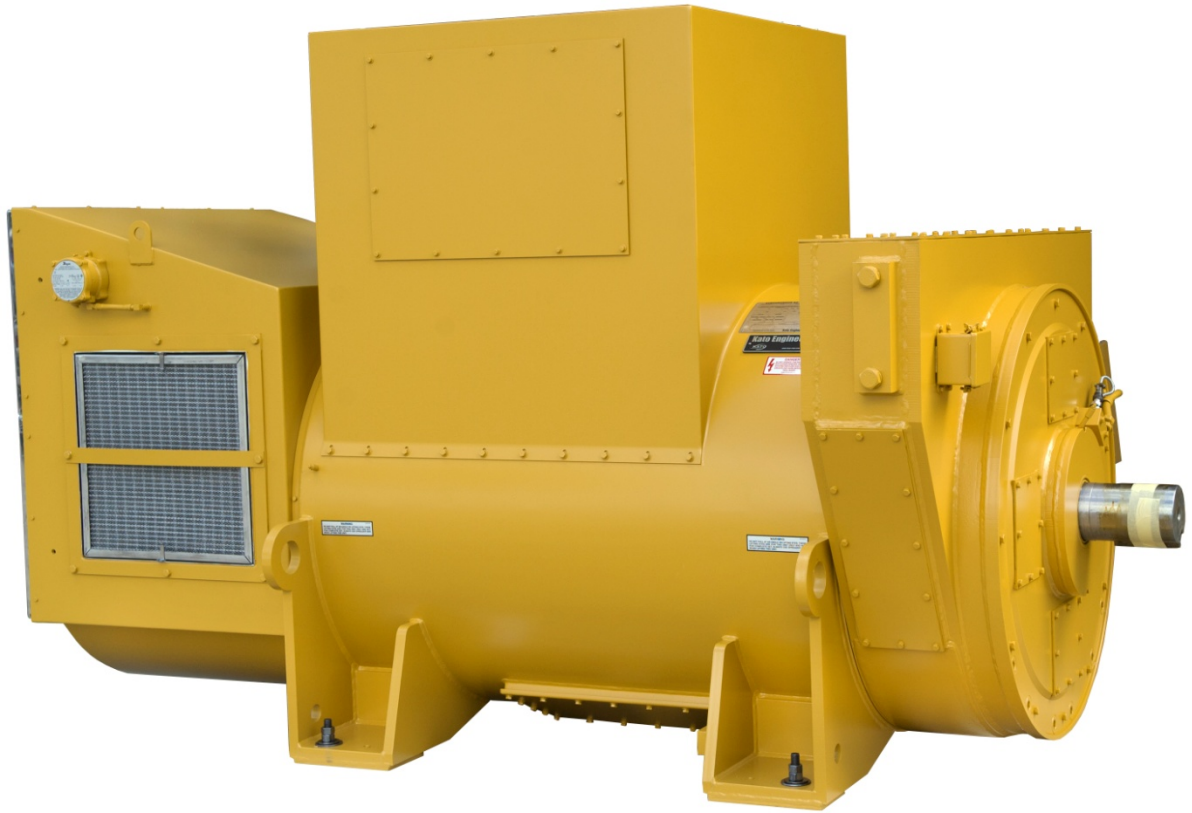


Weather Protected II (cont.)



Air Filters

- A differential pressure safety switch is included.



IEC 60034-6 Classification

- Sequence of numbers and letters to identify cooling type, (e.g., TEWAC, TEAAC) and cooling medium (e.g., air, water, hydrogen)
  - A number is placed first, indicating the cooling circuit arrangement. It is applies to both primary and secondary circuits.
  - Each circuit is designed by a letter (indicating coolant), followed by a number (indicating coolant movement method).
  - The letter and number for the primary circuit (around windings) are placed first followed by those for the secondary circuit.

Example: I C 8 A 1 W 7

IEC 60034-6 Classification (cont.)

- Circuit arrangement (machine construction and cooling medium routing)

0	Free circulation
1	Inlet pipe or outlet duct circulated
2	Outlet pipe or outlet duct circulated
3	Inlet and outlet pipe or duct circulated
4	Frame surface cooled
5	Integral heat exchanger (using surrounding medium)
6	Machine-mounted heat exchanger (using surrounding medium)
7	Integral heat exchanger (using remote medium)
8	Machine-mounted heat exchanger (using remote medium)
9	Separate heat exchanger using surrounding or remote medium)

IEC 60034-6 Classification (cont.)

- Coolant Type

A	Air
F	Freon
H	Hydrogen
N	Nitrogen
C	Carbon dioxide
W	Water
O	Oil
S	Any other
Y	Reserved

IEC 60034-6 Classification (cont.)

- Method of circulation

0	Free convection
1	Self-circulation
2-4	Reserved
5	Integral independent component (independent of machine rotational speed)
6	Machine-mounted independent component
7	Separate and independent component or coolant system pressure
8	Relative displacement
9	All other components

IEC 60034-6 Classification (cont.)

- Kato code TEWAC (CACW), IP44, IP54 = IC8A1W7
  - 8 = Machine-mounted heat exchanger with remote medium
  - A = Primary circuit cooling medium is air
  - 1 = Self circulation of medium
  - W = Secondary cooling medium is water
  - 7 = Separate circulation not mounted to machine.
- Kato code TEAAC (CACA), IP44, IP54 = IC6A1A1
  - 6 = Machine-mounted heat exchanger using surrounding medium
  - A = Primary circuit cooling medium, air
  - 1 = Self circulation of medium
  - A = Secondary cooling medium, air
  - 1 = Self circulation of medium

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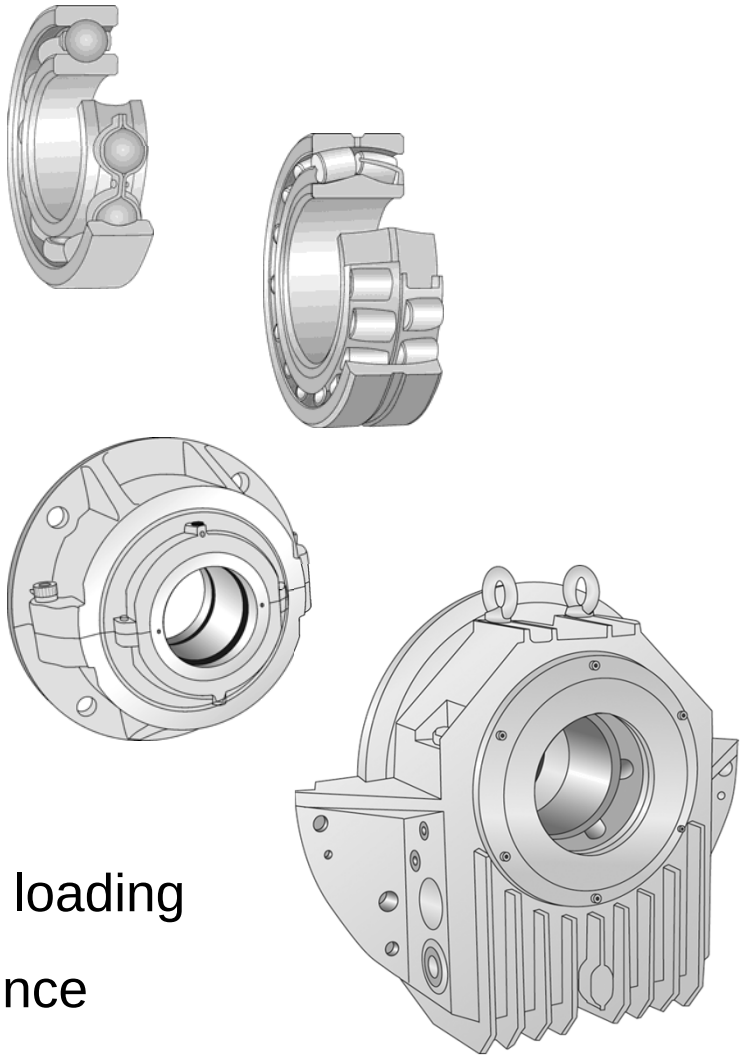
Bearing Design: Which ones and why?

- Types
  - Ball
  - Spherical roller
  - Split roller
  - Sleeve
- Considerations
  - Size
  - Initial cost
  - Life cycle cost
  - Orientation: radial and axial loading
  - Certification agency preference
  - Customer preference



Initial Cost

- Bearing type
- Oil system requirement (sleeve bearings)
  - Cooling
  - Hydrostatic jacking for slow roll
  - Redundancy of oil lube system
  - Black Start
- Grease auto lubricator (anti-friction) used for extended lubrication intervals

Size

- L_{10} calculation (anti-friction)
- Loads: axial and radial
  - Orientation
  - Generator rotor weight
  - Magnetic forces
- Torque on the bearing ID (ie. shaft size)
  - RPM
  - kW rating
  - Shaft material
- Shock loads
- Maximum speed rating (anti-friction)
- Minimum load capability (anti-friction

Life Cycle Costs

- Grease (anti-friction)
  - Interval VS sealed/shielded
  - Grease “valve”
- Oil change interval (sleeve) and cooler requirements
  - Oil operating temperature
    - Ambient temperature
    - Oil viscosity
  - Rotor weight
  - Oil type
    - Mineral
    - Synthetic

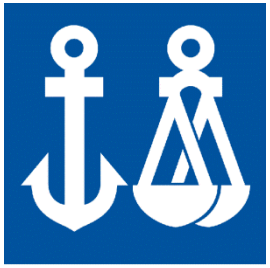
Orientation

- Land based
- Ship board
- Oil platform
- High shock

Photo: Royal Navy/MOD

Certifying Agency

- ABS
- API
- DNV
- US Navy
- Others



Ball Bearing

- Pros
  - Low cost
  - Grease lubricated
  - Thrust capable
  - Intermediate maintenance cycle (~2000 hours)
  - Good for black start as no pre-lube is required
- Cons
  - Speed limited as size increases
  - Life limited as load and speed increases
  - Maintenance
  - Replacement requires coupling removal
  - High shock

Spherical Roller Bearing

- Pros
  - Low cost
  - High load capacity
    - High thrust capacity
    - High radial load capacity
  - Grease lubricated
  - Self aligning
- Cons
  - Speed limited as size increases
  - Life limited as load and speed increases
  - Short maintenance cycle (~200 hours)
  - Requires removal of coupling for replacement
  - High shock

Split Roller Bearing

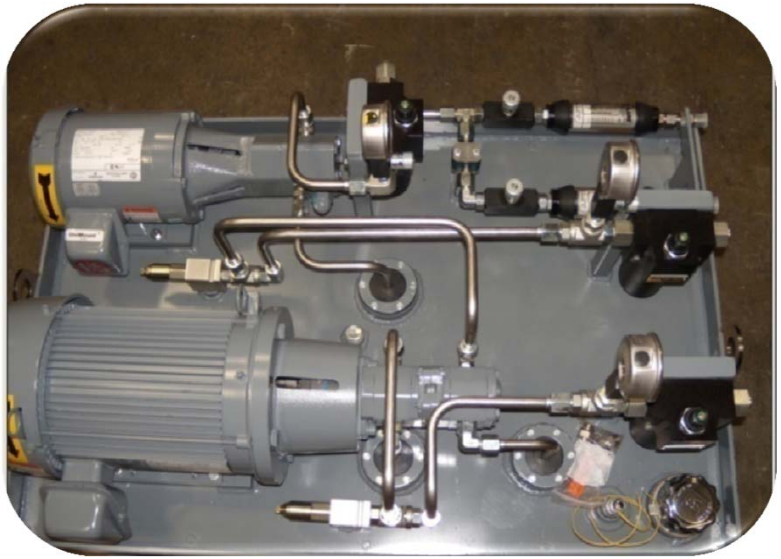
- Pros
  - Split for “easy” disassembly (no coupling removal)
  - Cost effective for medium-sized generators (5 to 6-inch diameter shafts)
  - Grease lubricated (extended cycle with “Auto-Lube”)
  - High radial load capacity
  - Labyrinth seals standard
  - Self aligning
- Cons
  - Speed limited as size increases
  - Life limited as load and speed increases
  - Short maintenance cycle (~200 hours)
  - “Low” thrust capability
  - High shock

Sleeve Bearing

- Pros
  - Long life
  - Long maintenance intervals (8000 hours or more)
  - High thrust capability
  - Cost effective for large sizes (6-inch diameter shafts and up)
  - Split for “easy” disassembly (no coupling removal)
  - Capable of high shock loading without damage
  - Self aligning
  - Available with integral insulation
  - “Self lubricating” in some applications

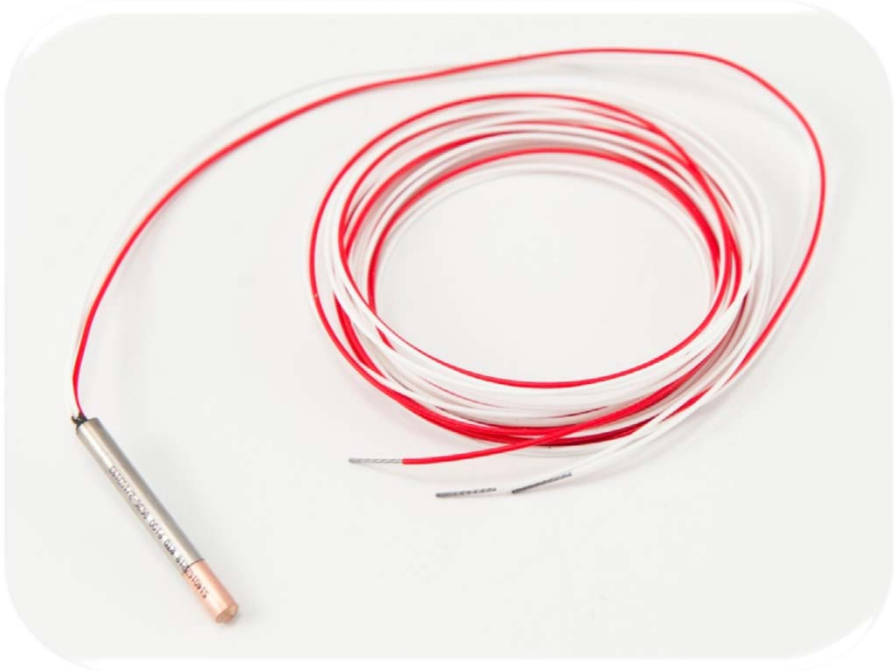
Sleeve Bearing (cont.)

- Cons
  - May require supplemental cooling method
    - High speed
    - High ambient temperature
    - High loads
  - May require forced lubrication (High thrust load or hydrostatic jacking for slow roll)
  - High cost for smaller sizes
  - Susceptible to oil leaks
  - Dependent on circulating oil system in some applications



Bearing Temperature Detectors

- Two types of RTDs available:
  - Platinum (100 ohm)
  - Copper (10 ohm) optional
- Recommended for high-hour applications.



Oil Life (in Sleeve Bearings)

- Temperature dependent
  - Applications
  - Certifying agencies
  - Shipboard
- Totally enclosed
- Life decreases by 1/2 for every 10º C above 85º C
- Mineral oil - 8000 hour oil life at ~85º C
- Synthetic oil - 16,000 hour oil life at ~95º C

Factors Affecting Temperature

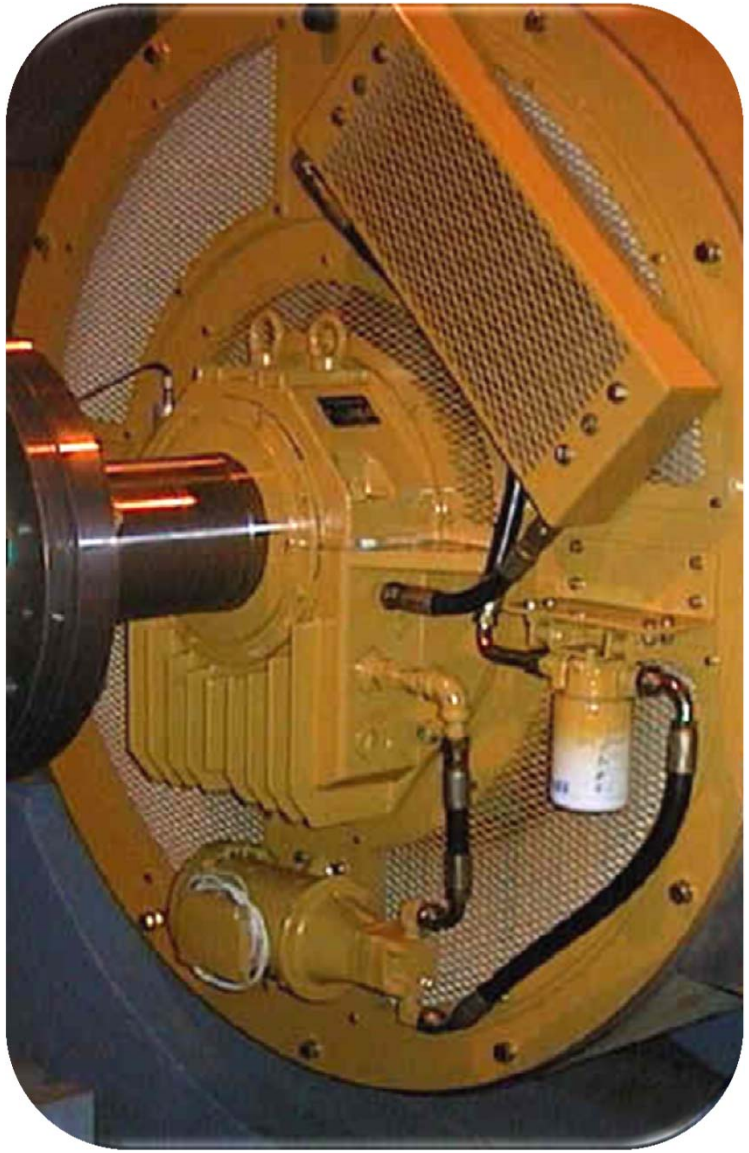
- Viscous shear of oil
  - Speed dependent
    - RPM
    - Diameter of journal
  - Width of journal
  - Viscosity of oil (ISO VG46)
  - Thrust load
  - Radial load
  - Bearing clearance

How to Keep Temperature Under 85° C

- Decrease bearing losses
  - Reduce oil viscosity
  - Decrease journal diameter
  - Decrease thrust load
  - Decrease radial load
- Increase heat dissipation
  - Use larger bearing housing
  - Increase air velocity across bearing housing
  - Use mid-mount housing (EM); increases surface area
  - Minimize insulating materials in heat conduction path
- Use an oil cooler

Oil Cooler

- Oil cooler
- Filter
- Pump
- Motor
- Hoses and fittings



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Enclosures: ABS and SOLAS

- ABS Rules for Classing and Building Steel Vessels 2014, Part 4, Chapter 8, Section 3, Para 1.11.2

  Equipment in areas affected by a local fixed pressure water-spraying or a local water-mist fire extinguishing system in machinery spaces (2014):

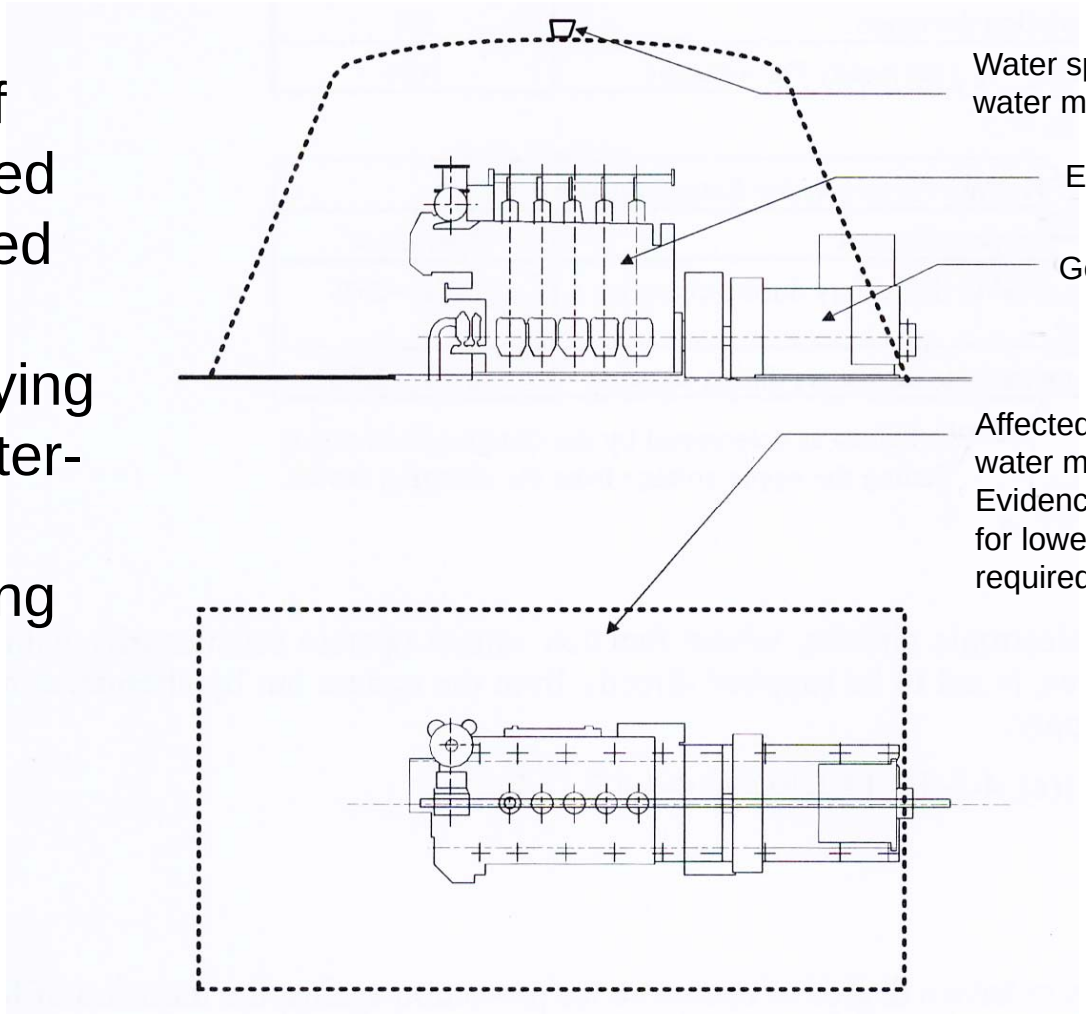
  Electrical and electronic equipment within areas affected by local fixed pressure water-spraying or local water-mist fire extinguishing systems are to be suitable for use in the affected area. See 4-8-3/Figure1. Where enclosures have a degree of protection lower than IP44, evidence of suitability for use in these areas is to be submitted to ABS, taking into account:

  1) The actual (water spraying or fire extinguishing) system being used and its installation arrangement and,

  2) The equipment design and layout (inlets, filters, baffles vents, etc. to prevent or restricted water ingress. The cooling airflow must be maintained).

Enclosures: ABS and SOLAS (cont.)

- Figure 1. Example of area affected by local fixed pressure water spraying or local water-mist fire extinguishing system in machinery spaces. (2014)



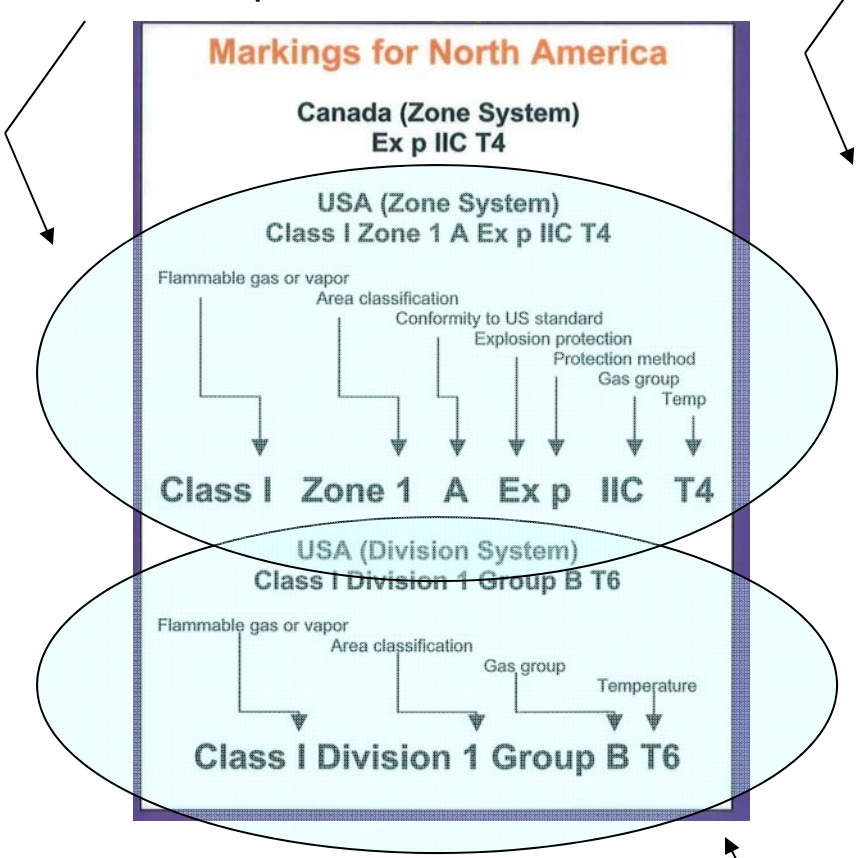
Hazardous Location

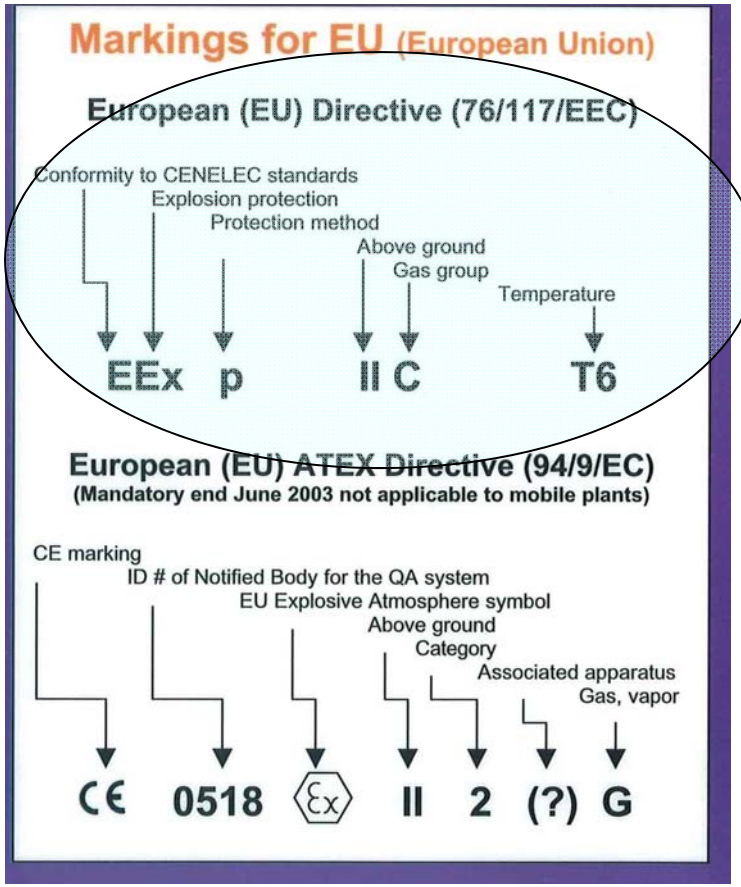
- Hazardous Location Class I Div or Zone II / EEx nA
  - NEC 500 and 505 plus UL 1836 (USA)
  - CEC and CSA applicable standard (Canada)
  - EN 50021 and 50014 (European Union) Kato has generator range certified by BASEEFA, UK
  - IEC 60079-15, 60079-00
- Hazardous Location EEx P II T3
- Applications must be submitted to our Engineering Dept. for quotation!

Hazardous Location Markings

Kato product:
Class 1 Zone 2 A Ex n IIA&B T3 Class 1 Zone 2 A Ex p IIA&B T3

Kato Product:
EEx n IIA&B T3
EEx p IIA&B T3

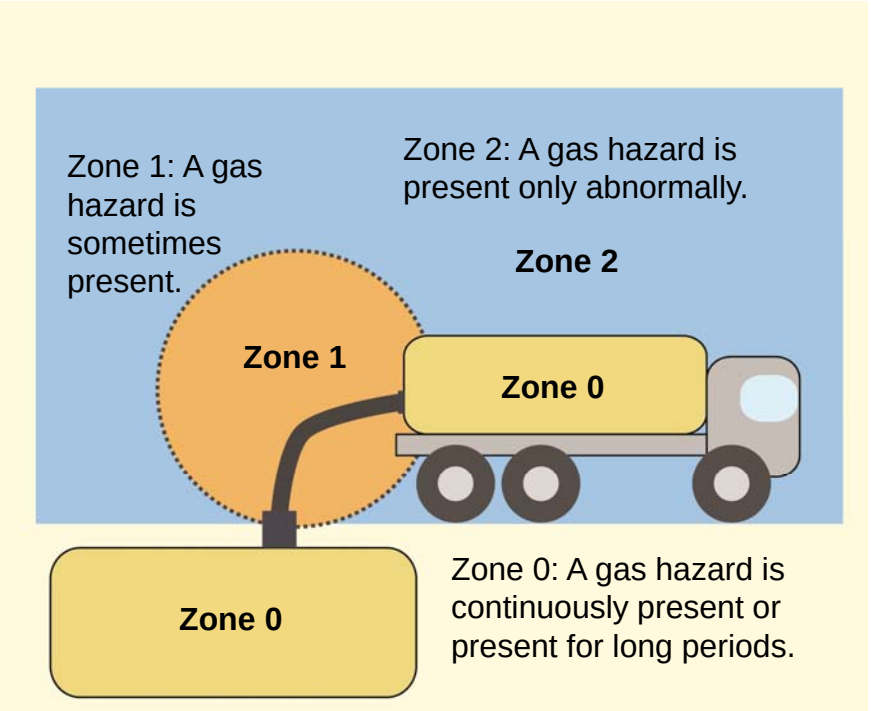




Kato product: Class 1 Div 2 Groups C&D T3

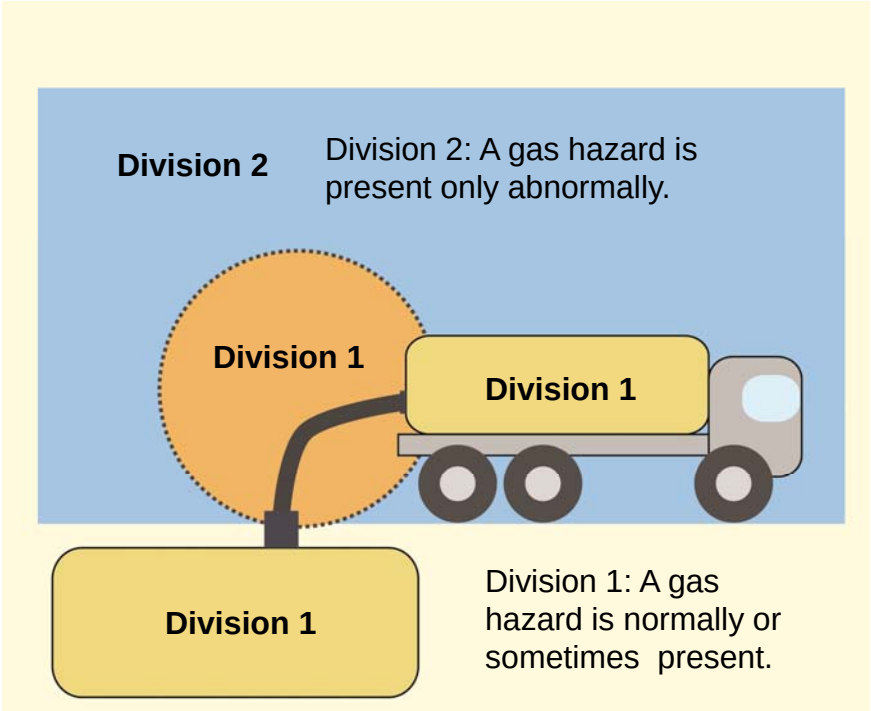
Hazardous Location: Zones

- Zones
  - Zone 0: Gaseous hazard continuously present.
  - Zone 1: Gaseous hazard intermittently present.
  - Zone 2: Gaseous hazard abnormally present.
  - Zone 20: Dust hazard continuously present.
  - Zone 21: Dust hazard intermittently present.
  - Zone 22: Dust hazard abnormally present.



Hazardous Location: Divisions

- Divisions (For USA and existing Canadian sites)
  - Division 1: Explosive atmosphere is normally or intermittently present.
  - Division 2: Explosive atmosphere is present abnormally only.



Hazardous Location: Gas Grouping

HazLoc Hand Chart

Gas Groupings

www.expoworldwide.com

IEC Canada (CEC)	USA (NEC 505)	EU (Europe)	Canada (CEC) USA (NEC 500)	Gas, Dust, Fiber
Group IIC	Class I, Group IIC	Group IIC	Class I, Group A	Acetylene
			Class I, Group B	Hydrogen
Group IIB	Class I, Group IIB	Group IIB	Class I, Group C	Ethylene
Group IIA	Class I, Group IIA	Group IIA	Class I, Group D	Propane
			Not within CEC /NEC	Methane
			Class II, Group E (Div 1 Only)	Metal Dust
			Class II, Group F	Coal Dust
			Class II, Group G	Grain
			Class III	Fibers

Temperature Class

Surface (°C) Temp	IEC, EU (Europe) USA (NEC 505)	USA (NEC 500) Canada
450 (842 F)	T1	T1
300 (572 F)	T2	T2
280 (536 F)		T2A
260 (500 F)		T2B
230 (446 F)		T2C
215 (419 F)		T2D
200 (392 F)	T3	T3
180 (356 F)		T3A
165 (329 F)		T3B
160 (320 F)		T3C
135 (275 F)	T4	T4
120 (248 F)		T4A
100 (212 F)	T5	T5
85 (185 F)	T6	T6

Hazardous Location: Protection

Protection Concepts [North America]

Type of Protection	Permitted Use						Basic Concept of Protection
	USA			*Canada*			
	NEC® 500	*NEC® 505*		*Existing*	*New*		
	Division	*Zone*	*Code*	*Division*	*Zone*	*Code*	
Increased Safety	NA	Zone 1, 2	AEx e	NA	Zone 1, 2	Ex e	No arcs, sparks, or
Non-Incentive	Div 2	Zone 2	AEx n	Div 2	Zone 2	Ex n	hot surfaces
Flameproof Explosionproof Powder Filled	NA Div 1, 2 NA	Zone 1, 2 NA Zone 1, 2	AEx d NA AEx q	NA Div 1, 2 NA	Zone 1, 2 NA Zone 1, 2	Ex d NA Ex q	Contain the explosion, prevent flame propagation
Intrinsic Safety	Div 1, 2 NA	Zone 0, 1, 2 Zone 1, 2	AEx ia AEx ib	Div 1, 2 NA	Zone 0, 1, 2 Zone 1, 2	Ex ia Ex ib	Limit the spark energy and temperatures
Pressurized (Purged)	Div 1, 2	Zone 1, 2	AEx p	Div 1, 2	Zone 1, 2	Ex p	Exclude gas from
Encapsulation Oil Immersion	NA Div 2	Zone 1, 2 Zone 1, 2	AEx m AEx o	NA Div 2	Zone 1, 2 Zone 1, 2	Ex m Ex o	ignition sources

Note: NEC® Article 501.1 permits the use of zone-rated equipment in Class I Division 2 locations.

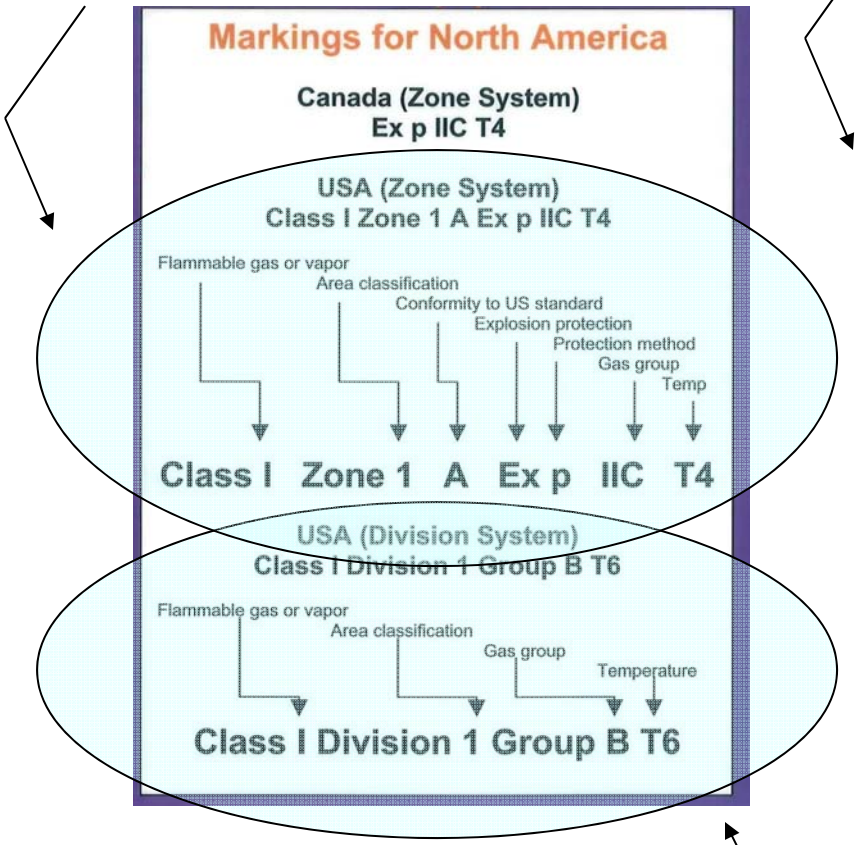
Kato can comply with this AEx p or Ex P Pressurized system

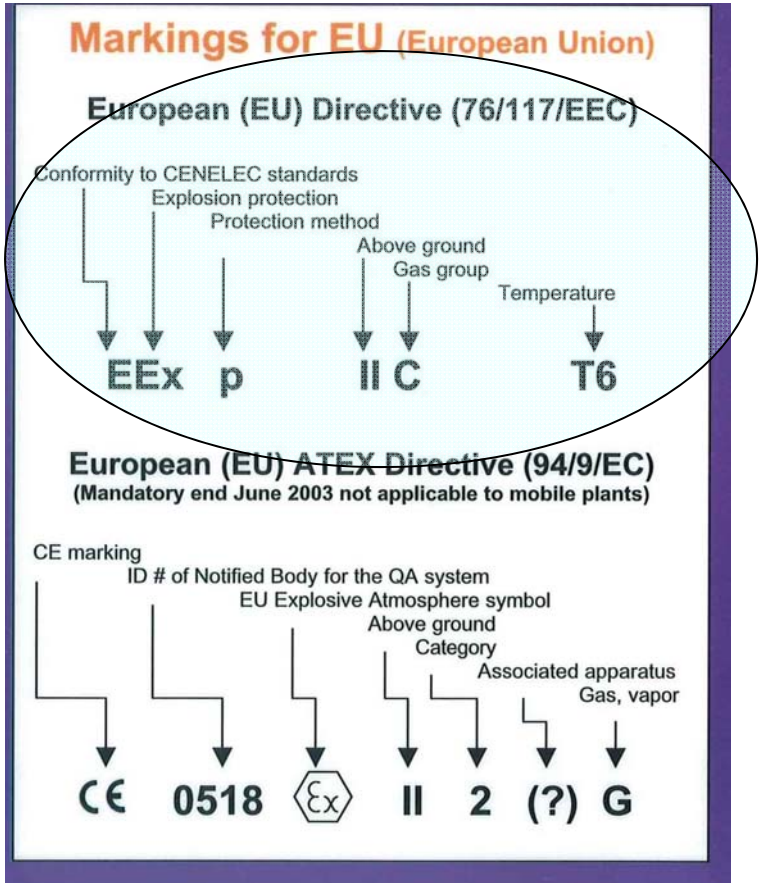
Kato can comply with this Div 2 or AEx n code (non-sparking)

Hazardous Locations: Markings

Kato product:
Class 1 Zone 2 A Ex n IIA&B T3
Class 1 Zone 2 A Ex p IIA&B T3

Kato Product:
EEx n IIA&B T3
EEx p IIA&B T3





Kato product: Class 1 Div 2 Groups C&D T3

Hazardous Locations: Future Marking

Classification	Class 1, Zone 2				Class 1, Division 2
Geographic location	Europe (mandatory per European directive)		Worldwide per IEC EX	North America, NFPA 70 (NEC code) chapter	North America, NEC code chapter
Standards	EN/IEC 60079-15 (2005)		IEC 60079-00 IEC 60079-15	CAN/CSA-C22.2 no. 100-04 CAN/CSA-C22.1-06 CAN/CSA-C22.2 no. 145-M1986 CAN/CSA-C22.2 no. 213-M1987 NFPA 90 (NEC) + CAN/CSA E60079-15:03	+ UL SU 1836 (Guide)
Kato selected certifying body	Self compliance	BASEEFA	CSA or BASEEFA	CSA	CSA
Main marking on main nameplate	ExII 3G Ex nA IIB T3 + CE marking	+ BASEEFA 04 ATEX 0361 X CE marking	Ex nA IIB + IEC certificate # given by notified agency	AEx nA II A & II B, T3 CSA 1881034	Class I, Div. 2, Groups B C D, T3 CSA 1881034
Certification to customer	Self declaration	BASEEFA 04 ATEX 0361 X	IEC certificate	CE certificate #1881034	

Electrical Housings

- NEMA 250-2003 Enclosures up to 1000V
- IEC 60529:2001-02 (IP Codes)

NEMA 250-2003

Table 1
COMPARISON OF SPECIFIC APPLICATIONS OF ENCLOSURES FOR INDOOR NONHAZARDOUS LOCATIONS

Provides a Degree of Protection Against the Following Conditions	Type of Enclosure									
	1 *	2 *	4	4X	5	6	6P	12	12K	13
Access to hazardous parts	X	X	X	X	X	X	X	X	X	X
Ingress of solid foreign objects (falling dirt)	X	X	X	X	X	X	X	X	X	X
Ingress of water (Dripping and light splashing)	...	X	X	X	X	X	X	X	X	X
Ingress of solid foreign objects (Circulating dust, lint, fibers, and flyings **)	...	...	X	X	...	X	X	X	X	X
Ingress of solid foreign objects (Settling airborne dust, lint, fibers, and flyings **)	...	...	X	X	X	X	X	X	X	X
Ingress of water (Hosedown and splashing water)	...	...	X	X	...	X	X	...	...	...
Oil and coolant seepage	...	...	...	..	...	...	...	X	X	X
Oil or coolant spraying and splashing	...	...	...	...	...	...	...	...	...	X
Corrosive agents	...	...	...	X	...	...	X	...	...	...
Ingress of water (Occasional temporary submersion)	...	...	...	...	...	X	X	...	...	...
Ingress of water (Occasional prolonged submersion)	...	...	...	...	...	...	X	...	...	...

* These enclosures may be ventilated.

** These fibers and flyings are nonhazardous materials and are not considered Class III type ignitable fibers or combustible flyings. For Class III type ignitable fibers or combustible flyings see the *National Electrical Code*, Article 500.

NEMA 250-2003 (cont.)

Table 2
COMPARISON OF SPECIFIC APPLICATIONS OF ENCLOSURES FOR OUTDOOR NONHAZARDOUS LOCATIONS

Provides a Degree of Protection Against the Following Conditions	Type of Enclosure									
	3	3X	3R*	3RX*	3S	3SX	4	4X	6	6P
Access to hazardous parts	X	X	X	X	X	X	X	X	X	X
Ingress of water (Rain, snow, and sleet **)	X	X	X	X	X	X	X	X	X	X
Sleet ***	...	...	...	...	X	X	...	...	...	...
Ingress of solid foreign objects (Windblown dust, lint, fibers, and flyings)	X	X	...	...	X	X	X	X	X	X
Ingress of water (Hosedown)	...	...	...	...	...	...	X	X	X	X
Corrosive agents	...	X	...	X	...	X	...	X	...	X
Ingress of water (Occasional temporary submersion)	...	...	...	...	...	...	...	...	X	X
Ingress of water (Occasional prolonged submersion)	...	...	...	...	...	...	...	...	...	X

* These enclosures may be ventilated.

** External operating mechanisms are not required to be operable when the enclosure is ice covered.

*** External operating mechanisms are operable when the enclosure is ice covered. See 5.6.

IEC 60529:2001-02

- IP codes (same as NEMA MG-1)
  - Protection of persons against contact with hazards
  - Protection of machine against ingress of solid objects
  - Protection of machine against harmful effects due to ingress of water

IEC 60529:2001-02 IP Codes

1st digit

- 2 = protected against 12 mm objects
- 4 = protected against 1 mm objects
- 5 = dust protected
- 6 = dust tight

2nd digit

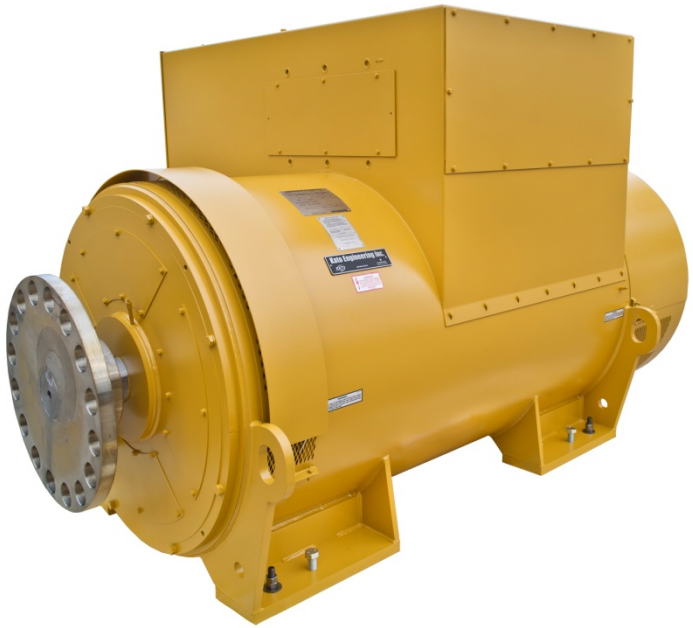
- 1 = protected against dripping water
- 2 = protected against 15 degree from vertical water spray
- 3 = protected against 60 degree from vertical water spray
- 4 = protected against splashing water
- 5 = protected against water jets
- 6 = protected against powerful water jets

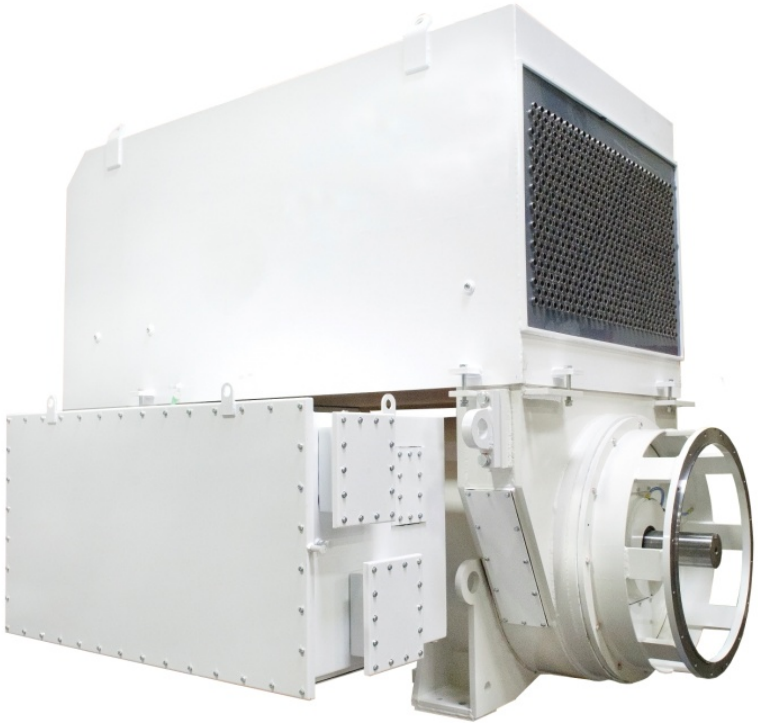
Common: IP21 (ODP), IP22, IP23, IP44, IP54, IP55, IP56

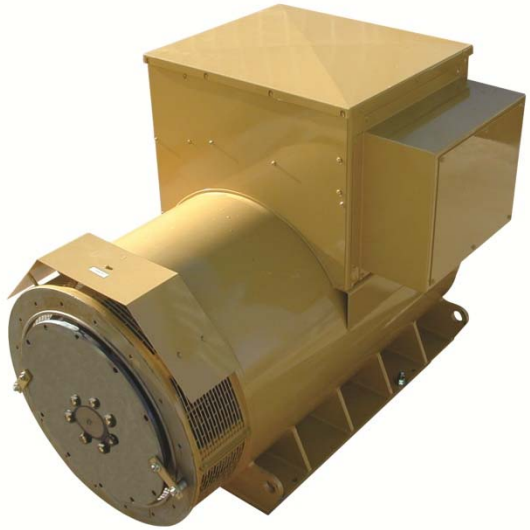
Mechanical Design

- Enclosures I
  - NEMA
  - IEC
- Bearing design
- Enclosures II
  - ABS and SOLAS
  - Hazardous Location
  - Electrical Housings
- Other Design Considerations
  - Coupling and Shaft Design
  - Typical Marine Designs

Coupling Examples







ABS Requirements and Certification

- American Bureau of Shipping
- Typical temperature rating; 90° C rise over 50° C ambient.
- Certified shaft and coupling material required.
- Overspeed test required on all units.
- IP23 terminal box (minimum; IP44 terminal box when above 1000 V).
- Black start / emergency power units preferred to be rolling element bearings to avoid external pre-lube system.
- Generally frames larger than 9.6 require sleeve bearings with external pre-lube system.

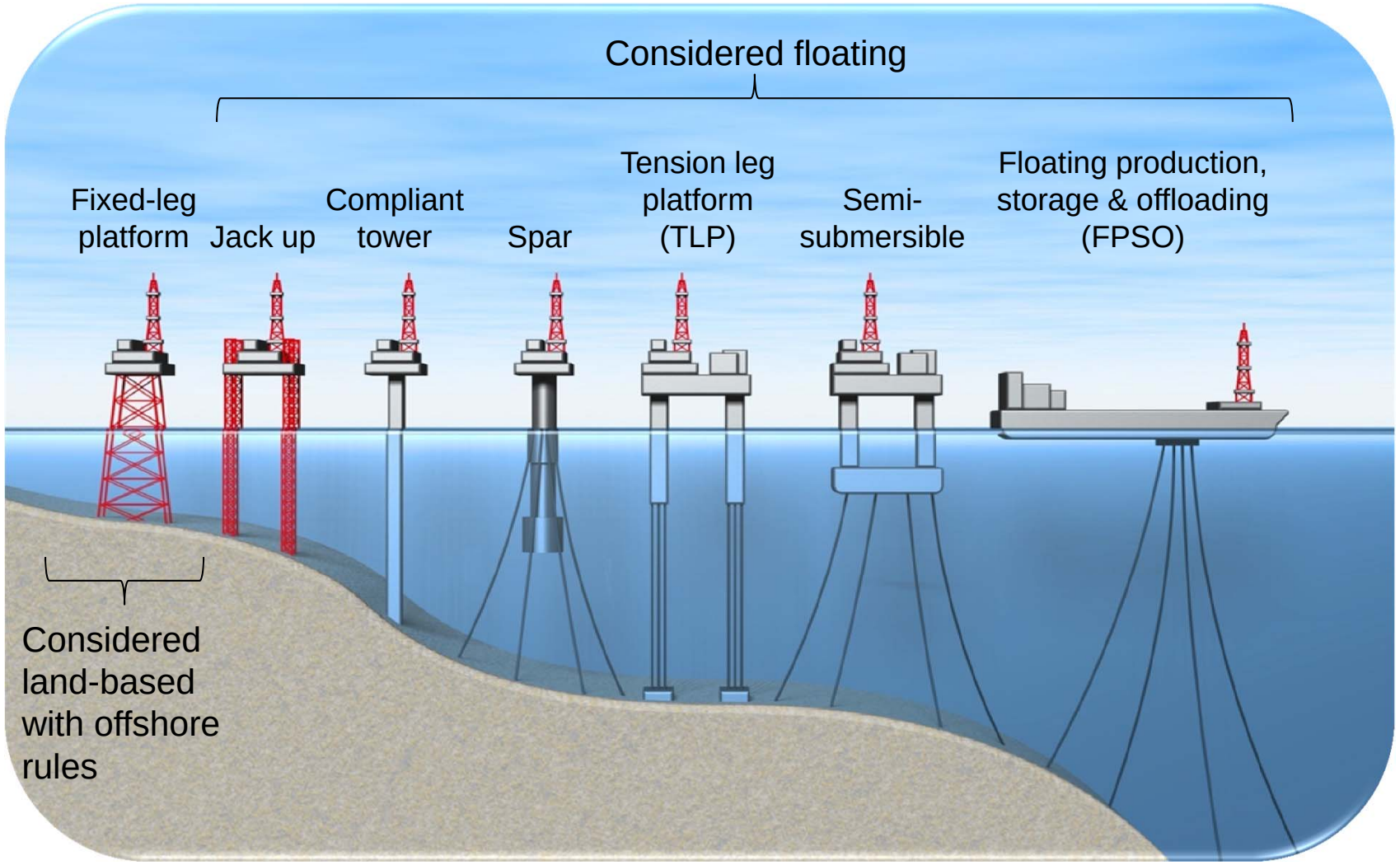
ABS Requirements and Certification (cont.)

- Pitch (fore-and-aft/trim) and roll (athwartship/list) requirements - mobile offshore drilling units (MODU)

Condition	Static	Dynamic
Column-stabilized units	15º in any direction	22.5º in any direction
Self-elevating units	10º in any direction	15º in any direction
Surface units	15º list and 5º trim simultaneously	7.5º pitching simultaneously

	Angle of Inclination			
	Athwartship		Fore-and-Aft	
Installations, components	Static	Dynamic	Static	Dynamic
Propulsion and auxiliary machinery	15	22.5	5	7.5
Emergency power installation	22.5	22.5	10	10
Emergency fire pumps and their drives	22.5	22.5	10	10
Electrical and electronic appliances and control systems	22.5	22.5	10	10

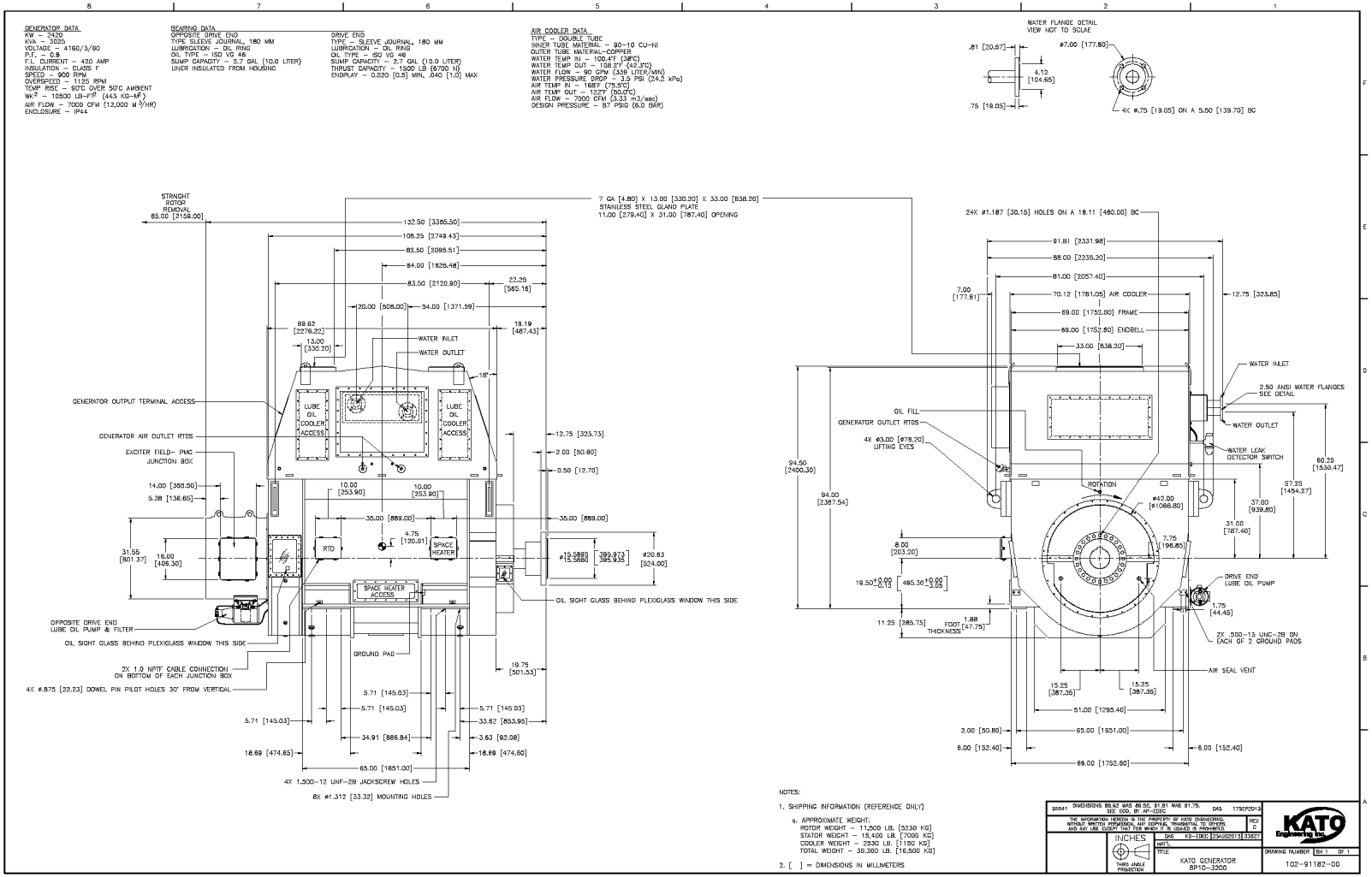
Platform/Floater Recognition Chart



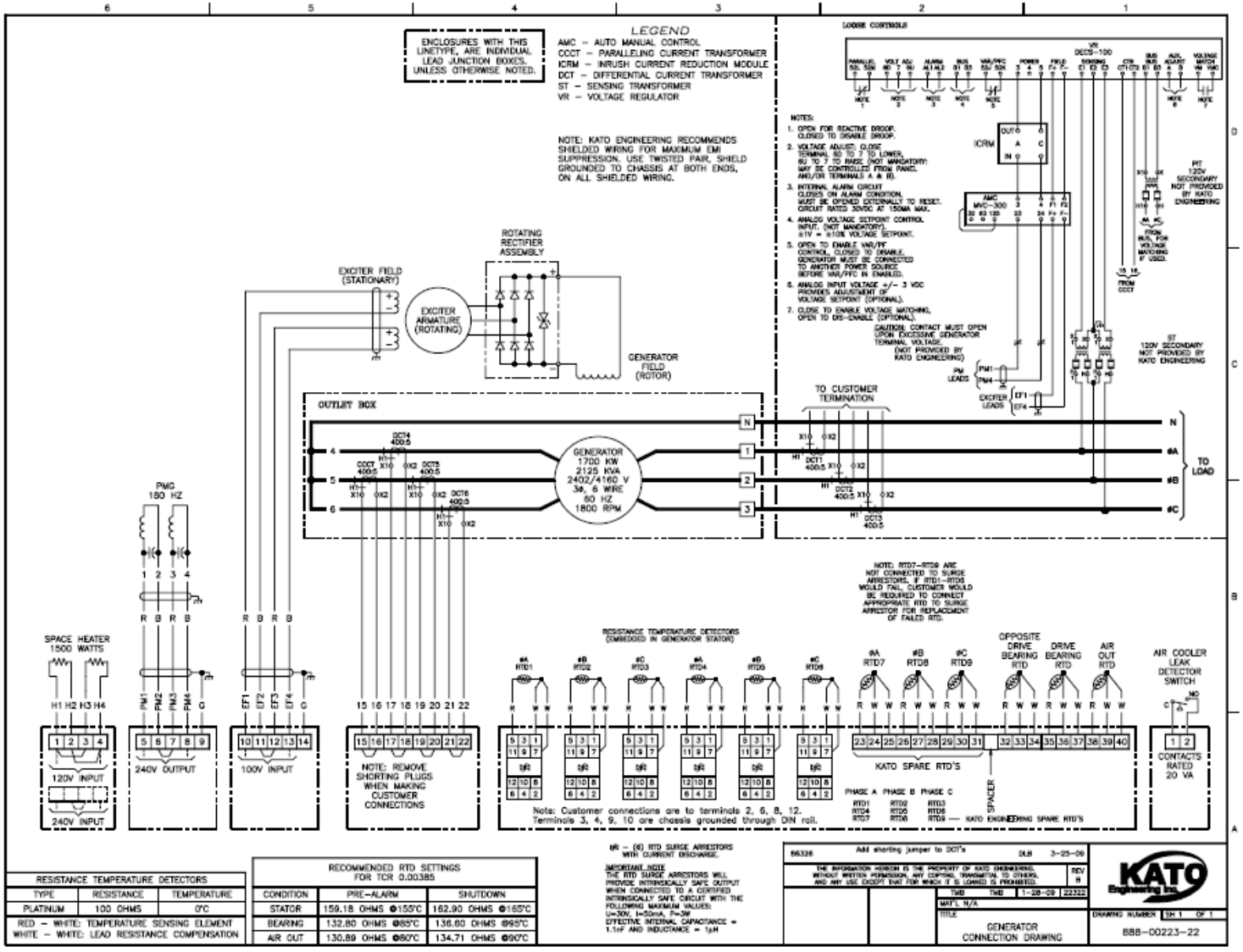
API Requirements

- American Petroleum Institute
  - Bus bar lead construction for sealing lead connections
  - 6 kV and up to be TEEAC or TEWAC unless otherwise specified.
  - Space heater max temp 200° C
  - Forged rotor shaft with proximity probe surfaces for sleeve bearings
  - Specific balancing procedure
  - Additional machining requirements for mounting holes, parallel mounting surfaces
  - Insulated bearings on both ends
  - IP55 shaft seals on sleeve bearings
  - NEMA 4 (IP55) terminal boxes
  - Stainless steel plumbing, air screens, and external hardware
  - Water immersion testing

Customer Interface Drawings: 102



Customer Interface Drawings: 888



Customer Interface Drawings: 107