SCOPE

- INDUSTRIAL /UTILITY MOTORS OVER 250 HP
- INDUCTION AND SYNCHRONOUS
- WHAT DO WE WANT FROM A MOTOR?
- WHAT DO WE ORDER?
- APPLICATION QUESTIONS
- TESTING
- INSTALLATION AND STARTUP
- KEEPING IT RUNNING
MOTOR RATINGS/TYPES

• ‘LARGE’
  ➢ HIGHER POWERS (OVER 250 HP TYPICAL)
  ➢ HIGHER VOLTAGES
  ➢ FORM WOUND
  ➢ INDUCTION OR SYNCHRONOUS, 3 PHASE
## Synchronous and Induction Motor Comparison

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SYNCHRONOUS

- MOST ARE BRUSHLESS
- SLOW SPEED AND LARGE 4/6 POLES
- FIXED SPEED STARTS AS INDUCTION, RUNS AS SYNCHRONOUS
- STARTING WINDING SQUIRREL CAGE OR SOLID POLE
- DC FOR MAIN FIELD COMES FROM ROTATING RECTIFIER AND FIELD APPLICATION SYSTEM
- MAY HAVE FIELD DISCHARGE RESISTOR
EXCITATION SCHEMATIC
WHAT DO WE WANT FROM AN ELECTRIC MOTOR?

- MUST START AND DRIVE THE LOAD
- MUST BE DURABLE
- MINIMUM LIFE CYCLE COST
  - PURCHASE COST
  - REPAIRS
  - COST OF OUTAGES
  - INPUT ENERGY COSTS
START AND DRIVE THE LOAD

- Generate more torque than load draws through the speed range.
- Don’t overheat on high inertia/long starts.
- Run cool at full load.
- When required, operate OK on a drive.
STARTING TORQUE

- MOTOR MUST GENERATE A MARGIN (10% MINIMUM) OF TORQUE OVER THE LOAD TORQUE THROUGH THE SPEED RANGE.
- MUST PROVIDE FOR REDUCED VOLTAGE DUE TO HIGH STARTING CURRENTS
- CURRENT PROPORTIONAL TO VOLTS (1.1 TO 1.3)
- TORQUE PROPORTIONAL TO VOLTS (2.2 TO 2.6)
STARTING

- TIME REQUIRED INCREASES WITH TOTAL INERTIA
- AT ZERO SPEED 100% OF POWER ACROSS AIR GAP (INTO ROTOR) GOES INTO HEAT
- PROPORTION OF HEAT DECREASES LINEARLY WITH SLIP
- 50% SPEED – 50% POWER GOES TO HEAT
- 90% SPEED – 10% POWER GOES TO HEAT
- UP TO 50° C PER SECOND
- LONG STARTS GIVE HOT ROTOR
- 350° C TYPICAL CAGE LIMIT (METALLURGY, DIFFERENTIAL EXPANSION)
ROTOR TEMPERATURE

- TEMPERATURE GRADIENT DURING START
- MOST LOCKED ROTOR LOSSES NEAR OUTER EDGE OF BARS
- AVERAGE RATE OF RISE = $P_{ag} \times \text{SLIP}/(M \times SH)$
  - $P_{ag}$ = POWER ACROSS AIR GAP (INPUT POWER – STATOR LOSSES) (watts)
  - $M$ = MASS OF CAGE (gm)
  - $SH$ = CONDUCTOR SPECIFIC HEAT (copper 0.389 J/g.K)
ROTOR BAR DESIGN

- SHAPE
  - SINGLE, DOUBLE
  - DEEP BAR
  - COFFIN
  - INVERTED T
  - FABRICATED/CAST?
  - ETC

- MATERIAL
  - COPPER, ALLOY
  - ALUMINUM, ALLOY
  - CONDUCTIVITY
  - STRENGTH
  - DENSITY
  - SPECIFIC HEAT
  - THERMAL EXPANSION
  - BRAZE/WELD?
SOLID POLE

- SYNCHRONOUS
- MOSTLY 4 AND 6 POLE
- STARTING HEATS STEEL POLE FACE
- RELIES ON CURRENTS IN STEEL FOR TORQUE
LOADED RUNNING

- **INSULATION:**
  - Run Cool
  - Thermal Ratings
  - Voltage Spikes

- **BEARINGS:**
  - Fatigue
  - Temperature
  - Vibration
  - Lubrication

- **ROTOR:**
  - Unbalanced Supply
  - Broken Bars
  - Rubs

- **EXCITATION**

- **OTHER PARTS:**
  - Fans
  - Frame
  - Shaft
INSULATION

- STRAND/TURN/GROUND WALL
- VARIOUS MATERIALS:
  - ENAMEL
  - MICA
  - MYLAR
  - GLASS FIBER
  - DACRON
  - EPOXY OR POLYESTER TO HOLD IT TOGETHER
Cross section of slot section of 13.8 kV, multi strand turn, multi turn stator coil.
INSULATION TEMPERATURE

- KEEP IT COOL
- CLASS F – 20000 HOURS AT 155 C
- ARRHENIUS – DOUBLE LIFE APPROXIMATELY EVERY 10 C COOLER
- 135 C – 80000 HOURS; 125 C -- 160000 HOURS
- CLASS B RISE – GIVES 120 C TO 130 C HOT SPOT IN 40 C
VOLTAGE/INSULATION

- STRESS ON GROUNDWALL
  - Power frequency
  - Impulse

- STRESS ON TURN/STRAND INSULATION
  - Power Frequency
  - Impulse

- PARTIAL DISCHARGE
VOLTAGE ENDURANCE

Fig 1
AC Voltage Endurance of Rotating Machine Insulation on Coils
INTERTURN STRESSES

- POWER FREQUENCY -- LOW STRESSES
- VOLTAGE IMPULSES
  - HIGH STRESSES TURN TO TURN ON LINE END COILS
  - FAST RISE TIMES ARE WORSE
- IEEE 522
- SURGE PROTECTION – ARRESTERS AND CAPACITORS (Arresters limit the volts, Capacitors reduce the dV/dt)
- ANSI C62.21 GIVES GUIDANCE
POSSIBLE STRESSES
IEEE 522

**Impulse Voltage Per Unit**

- $V_L$ = MACHINE VOLTAGE, kV
- $V_1$ = $(\sqrt{2} / \sqrt{3}) \cdot V_L$ at 0.0 $\mu$s
- $V_2$ = 3.5 $V_1$ at 0.1 $\mu$s
- $V_3$ = 5 $V_1$ at $\geq 1.2$ $\mu$s

**Front Rise Time, $\mu$s**

0 1 2 3 4 5 6 7 8
PARTIAL DISCHARGE

- LOW ENERGY BREAKDOWN IN INSULATION
- HIGH STRESSES, SHARP CORNERS AND VOIDS
- EVENTUALLY ERODES INSULATION
- USEFUL PREDICTOR OF INSULATION FAILURE
- AVOID PROBLEMS BY:
  - SMOOTH CONDUCTOR SURFACES
  - STRESS CONTROL COIL TREATMENT
  - MINIMISE VOIDS IN INSULATION
  - PD RESISTANT INSULATION
BEARINGS

- ANTI FRICTION
  - BALL, ROLLER, RADIAL, THRUST
  - $L_{10}$ LIFE EXPECTANCY, LOAD $^{1/3}$ DEPENDENT

- HYDRODYNAMIC
  - SLEEVE, TILT PAD, THRUST (VERTICALS)
  - BABBIT METAL (TIN, LEAD ETC)
  - WEDGE OF OIL PREVENTS METAL TO METAL CONTACT
  - VIRTUALLY INFINITE LIFE
BEARING FAILURE

- LOSS OF LUBRICATION
- DIRT
- VIBRATION
- FATIGUE (ANTI FRICTION)
- TEMPERATURE
- ELECTRIC CURRENT
LUBRICATION

- OIL (HYDRO_DYNAMIC AND SOME HIGH SPEED ANTI FRICTION)
  - CORRECT VISCOSITY IMPORTANT (HIGHER VISCOSITY INCREASES LOSSES BUT MAINTAINS THE OIL FILM)
  - OIL RING (SLEEVE) OR PUMPED SYSTEM FOR NON SLEEVE, AND HIGHER LOSSES

- GREASE (OIL PLUS THICKENER)
  - REPLACEMENT INTERVAL TEMPERATURE DEPENDENT
  - SOME ARE SEALED TO KEEP GREASE IN AND DIRT OUT
TEMPERATURE

- HIGH LUBRICANT TEMPERATURE REDUCES STIFFNESS OF OIL FILM
- FASTER CHEMICAL BREAKDOWN
- MAX. TEMPERATURE DEPENDS ON COMPOSITION (SYNTHETICS VERSUS MINERAL BASE)
- CAN AFFECT BEARING METAL STRENGTH AND STABILITY
VIBRATION

- CAUSES FATIGUE OF ANTI FRICTION BEARINGS
- AFFECTS OIL FILM THICKNESS (ANTI FRICTION AND HYDRODYNAMIC)
- MAY GIVE METAL TO METAL CONTACT, SMEARING
- CAUSES OTHER NON BEARING PROBLEMS
- SEISMIC VERSUS PROXIMITORS?
CAUSES OF VIBRATION

- UNBALANCE (4W/N)
- THERMAL VECTOR SHIFT
- MISALIGNMENT
- BENT SHAFT
- ELECTROMAGNETIC (2 x SUPPLY FREQUENCY)
- RESONANCE [SIMPLE SQRT (K/M)]
VECTOR SHIFT

50 micro m pp FULL SCALE

CCW ROTATION
BEARING CURRENTS

- STATOR/ROTOR SLOT COMBINATIONS *(ADDRESS BY MOTOR DESIGN)*
- WELDING *(DON’T WELD)*
- ASD NEUTRAL DISPLACEMENT *(APPLICATION)*
- ASD dV/dt *(APPLICATION)*
- ELECTROSTATIC FROM DRIVEN EQUIPMENT
- BEARING INSULATION, GROUNDING BRUSHES
ROTOR DAMAGE

- UNBALANCE SUPPLY
- BROKEN BARS
- STARTING DUTY
- RUBS
UNBALANCED SUPPLY

- Stator negative sequence currents cause 120 Hz rotor currents
- High rotor currents cause heating and retarding torque
- Overheat rotor squirrel cage
- Should derate motor
UNBALANCE SUPPLY
BROKEN BARS

- TORSIONAL OSCILLATIONS (RECIP. COMPRESSORS)
- OVERHEATING
- POOR BRAZING
- POROUS CASTINGS
- OVERHEATING
- BAR LOOSENESS
STARTING DUTY

- EXCESSIVE OR LONG DURATION STARTS
- LOCKED ROTOR
- OVERHEAT ROTOR
- DAMAGE CAGE AND LAMINATIONS
STATOR/ROTOR RUBS

- CAUSED BY:
  - BEARING FAILURE
  - “ROTOR PULLOVER”
- DAMAGES LAMINATIONS AND INTERLAMINAR INSULATION
- CAUSES EXCESSIVE LOSSES AND LOCAL OVERHEATING
- SCRAP, RESTACK OR OTHER REPAIR
EXCITATION (SYNCH)

- LOSS OF EXCITATION CAUSES PULLOUT AND OVERHEATING
- AVOID BY:
  - SECURE POWER SUPPLY (CVT, UPS)
  - COMPONENT REDUNDANCY WHERE PRACTICAL
  - BURN IN COMPONENTS
  - API 546 CLAUSE 2.5
OTHER DAMAGE

- SHAFT
  - BREAKAGE
  - BENDS
  - JOURNAL RUB
- FANS
  - BREAKING
- FRAME
  - BREAKING WELDS, CASTINGS
DURABILITY

- BUY THE RIGHT MOTOR
- TEST IT
- INSTALL AND START IT UP CORRECTLY
- MAINTAIN IT
BUY THE RIGHT MOTOR

- ACCEPTABLE BIDDERS
- EVERGREEN CONTRACT?
- DECIDE WHAT YOU NEED
- SPECIFY IT
- EVALUATE PROPOSALS
- ORDER MOTOR
- MAINTAIN DISCUSSIONS
ACCEPTABLE BIDDERS

- TRACK RECORD WITH US?
- TRACK RECORD WITH OTHERS?
- HAVE THEY DONE IT BEFORE?
- **DO WE WANT TO SET UP A PERMANENT DEAL?**
WHAT DO YOU NEED?

- Output Power
- Starting Torque
- Start Current
- Start Frequency
- Losses
- Voltage
- Mounting
- Hostile Environment?

- Enclosure
- Surge Protection
- Fixed or Adjustable Speed
- Bearings
- Oscillatory Torques
- Spared/Unspared?
- Talk to Operators
SPECIFY

- SAY WHAT YOU WANT
- USE INDUSTRY STANDARD (PLUS EXCEPTIONS)
- API 541 – LARGE, CRITICAL INDUCTION
- API 547 – REGULAR INDUCTION
- API 546 – SYNCHRONOUS
- USE THE DATA SHEETS!
Form-wound Squirrel-Cage Induction Motors – 500 Horsepower and Larger

Downstream Segment

ANSI/API STANDARD 541-2003
FOURTH EDITION, JUNE 2004
General-purpose Form-wound Squirrel Cage Induction Motors—250 Horsepower and Larger

API STANDARD 547
FIRST EDITION, JANUARY 2005

American Petroleum Institute
Brushless Synchronous Machines—500 kVA and Larger

Downstream Segment

API STANDARD 548
THIRD EDITION, SEPTEMBER 2008
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2. (3) WP-II - The WP-II (Weather Protected Type II as defined by NEMA) is a common enclosure. Air from outside the motor is drawn into and passed through the interior for cooling. The WP-II enclosure is intended for outdoor applications. It is constructed so that high-velocity airflow is generated by the motor and is discharged without entering the internal passages to the electric parts of the motor. It may be an appropriate enclosure when exhaust dust is present or if the area does not have free air exchange. The motor discharged from the motor can cause a closed-door to become excessively hot. WP-II machines with a rated voltage over 4000 Volts may have a shorter insulation life due to tracking.

2. (3) WP-I - The WP-I enclosure (Weather Protected Type I as defined by NEMA) is not commonly used in chemical applications. Air from outside the motor is drawn in and passed through the interior for cooling. The WP-I enclosure should be limited to outdoor or indoor walls where the motor may be exposed to a slight weather condition or air movement. It may not be an appropriate choice where air exchange is present or if the area does not have free air exchange. The motor discharged from the motor can cause a closed-door to become excessively hot. WP-I machines with a rated voltage over 4000 Volts may have a shorter insulation life due to tracking.

2. (3) DPG - The DPG or ODG enclosure (Drip Proof Guard or Open Drip Proof as defined by NEMA) offers the least amount of protection from the local environment. It should only be applied in an indoor environment with clean air. It is not recommended for outdoor use as it probably gives reduced reliability in all applications.

2. (3) Air Filters - Air filters are required for WP-I or WP-II machines by the Standard. They may also be specified for WP-II or DPG machines. In lieu of filters, provisions for filters can be specified also. It is highly recommended that all motor air filters be of the air-cooled type. Air filters are required. If the motor is to be used in a location where dust or moisture is present, a filter must be installed. When filters are specified, it is wise to do the selection so that the filters can be exchanged from the motor and cleaned.

2. (3) Air Filter Capability - The default requirement of the Standard is for filters that capture 90% of 10 micron dust particles. If a different capacity is required, or if the Purchaser wishes to specify what type of air filters are required, the contract section on line 19.

2. (3) Purchaser Specified Filters - If the Purchaser wants to specify a particular type of air filter, provide all the details on line 19.

2. (3) Differential Pressure Device - This device is recommended for any machine with air filters. The differential pressure device is installed to monitor the pressure difference across the air filters when it increases as they become clogged with dust and need cleaning. Air flow into the motor will then be limited due to the clogging of the filters. Provision may also be made to be selective for WP-I and DPG machines. The practice at the Supplier usually dictates the gauge of switch or both are supplied. Note that if the motor is to be used in a Division 1 area, an Optical Device that is supplied has a control type switch, the data must be enclosed in a certified enclosure. If the Purchaser wishes to specify a particular type of DP device, then supply the details requested on line 22.

2. (3) Enclosure for 6KV and above - The standard now requires the use of a Totally-Enclosed type of motor enclosure when the motor voltage rating is 6000 volts or greater. However, there may be applications where the Purchaser has successfully used WP-II or WP-I enclosures and desires it again. To clarify this for the Supplier, select this bullet for this choice if applicable.

2. (3) TEFC - The TEFC enclosure (Totally-Enclosed Fan-Cooled as defined by NEMA) is a construction where free exchange of air is prevented between the inside and outside of the motor. The motor is therefore designed to provide cooling only through fans or other means of air circulation.
EVALUATE PROPOSALS

- DO WE TRUST THE BIDDER?
- DOES IT MEET THE REQUIREMENTS?
- DISCREPANCIES, COMMENTS, EXCEPTIONS?
- NET PRESENT VALUE?
  - FIRST COST (PURCHASE, TESTING, SHIPPING)
  - STARTUP
  - LOSSES
  - AUXILIARIES
  - MAINTENANCE
DISCUSS/ORDER

- SORT OUT QUESTIONS BEFORE ORDERING
- IS IT STILL A GOOD DEAL?
- ORDER
- MAINTAIN COMMUNICATIONS DURING CONTRACT
TEST THE MOTOR

- CRITICAL
  - IN PROCESS QC CHECKS?
  - “COMPLETE” TEST
  - WITNESS?
  - VIBRATION?
  - HEAT RUN
  - STARTING PERFORMANCE?
  - OTHER?

- NON CRITICAL
  - “ROUTINE” TESTS?
INSTALL IT CORRECTLY

- CORRECT ALIGNMENT
- THERMAL GROWTH?
- FOOT COPLANARITY
- SOLID BASE?
START IT UP CORRECTLY

- ELECTRICAL CHECKS
- MECHANICAL CHECKS
- LUBRICANT?
- PROTECTION
- UNCOUPLED RUN
MAINTAIN IT

- KEEP IT DRY
- KEEP IT CLEAN
- KEEP IT COOL
- KEEP IT FRICTION FREE (Lubrication)
- MONITOR PERFORMANCE (Vibration, Temperatures, PD)
- CHECK/MAINTAIN IT AT TURNAROUND
REPAIRS

- SELECT THE REPAIRER AHEAD OF TIME
- IEEE 1068
- MAINTAIN CONTACT DURING REPAIRS
- GET PHOTOGRAPHS

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SPARKING

- MOSTLY DURING STARTS
  - High Currents
- AIR GAP
  - Keep Bars Tight, not broken
  - Cast better than Fabricated
  - Higher speed worse
- FABRICATED FRAME
  - Bonding Jumpers
- HIGH VOLTAGE WINDINGS
  - Tracking, Contamination
OPERATION ON DRIVES

- **ROTOR VOLTAGE BUILDUP**
  - $1/2CV^2$
  - Seldom if Ever an Issue? (MIE 15 TO 400 microjoule)

- **“HIGH TORQUE/LOW SPEED”**
  - Shaft Mounted Fan Cannot Remove Heat

- **ROTOR TEMPERATURES**
  - What Data There is –probably not an issue

- **TORSIONAL OSCILLATIONS**
  - Seldom an Issue with Modern Drives
THANK YOU
QUESTIONS?