MOTORS 101

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BILL LOCKLEY

lockleyb@telusplanet.net

SCOPE

- INDUSTRIAL MOTORS DRIVING PUMPS
- 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

7000 HP, 3600 rpm, 6600 Volts for a Liquids Pipeline. 10000 kg 900 mm Shaft Height, 2300 mm length

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

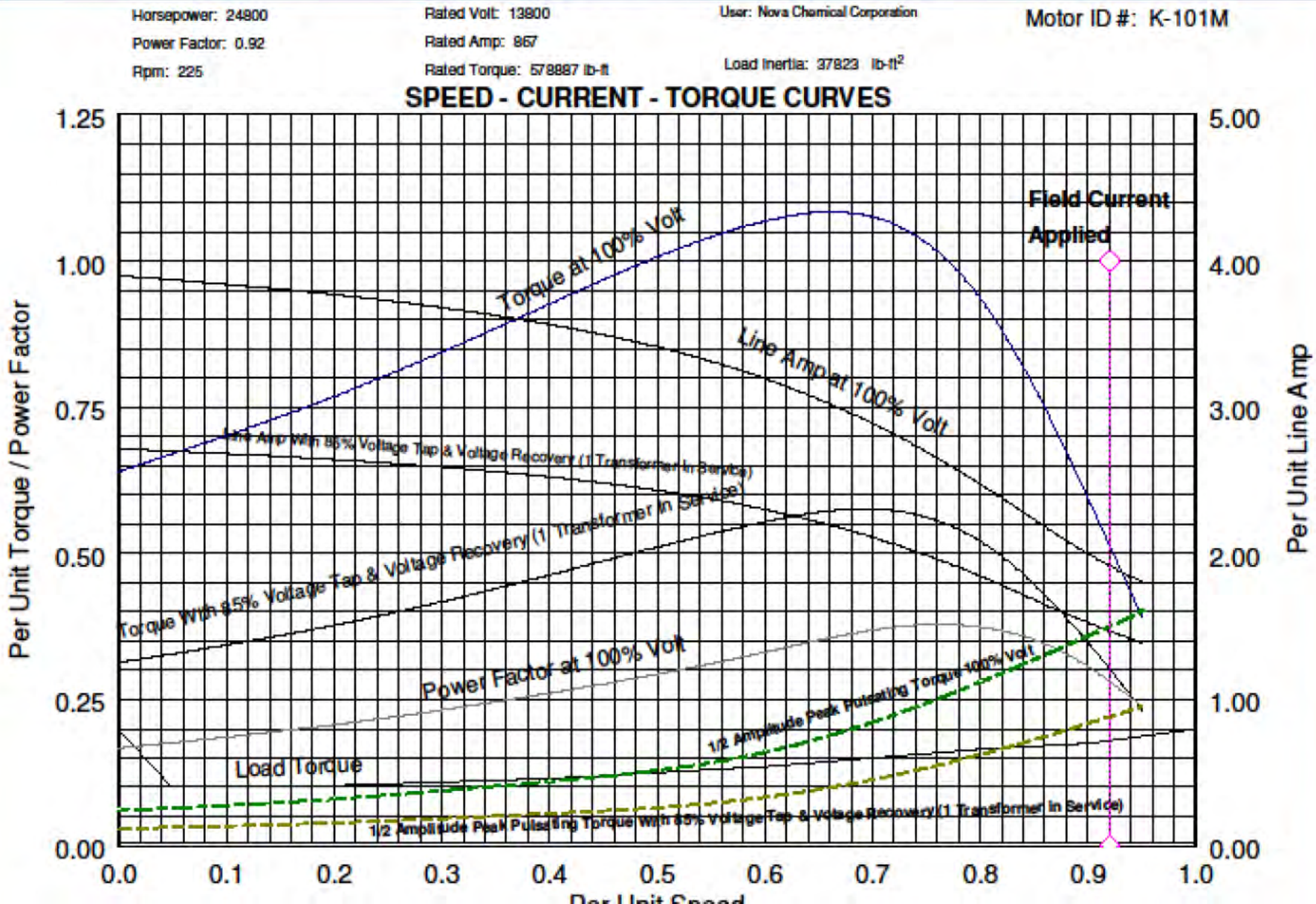
START AND DRIVE THE LOAD

- 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 TO1.3)
- TORQUE PROPORTIONAL TO VOLTS (2.2 TO 2.6)

STARTING


Horsepower: 24800
Power Factor: 0.92
Rpm: 225
Rated Volt: 13800
Rated Amp: 867
Rated Torque: 578887 lb-ft
User: Nova Chemical Corporation
Load Inertia: 37823 lb-ft²
Motor ID #: K-101M
SPEED - CURRENT - TORQUE CURVES
Field Current Applied
Torque at 100% Volt
Line Amp at 100% Volt
Line Amp With 85% Voltage Tap & Voltage Recovery (1 Transformer In Service)
Torque With 85% Voltage Tap & Voltage Recovery (1 Transformer In Service)
Power Factor at 100% Volt
1/2 Amplitude Peak Pulsating Torque 100% Volt
Load Torque
1/2 Amplitude Peak Pulsating Torque With 85% Voltage Tap & Voltage Recovery (1 Transformer In Service)
Per Unit Torque / Power Factor
Per Unit Line Amp
Per Unit Speed
1.25
1.00
0.75
0.50
0.25
0.00
5.00
4.00
3.00
2.00
1.00
0.00
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0

LOADED RUNNING

- INSULATION:
  - Run Cool
  - Thermal Ratings
  - Voltage Spikes
- BEARINGS:
  - Fatigue
  - Temperature
  - Vibration
  - Lubrication
- ROTOR:
  - Unbalanced Supply
  - Broken Bars
  - Rubs
- OTHER PARTS:
  - Fans
  - Frame
  - Shaft

INSULATION TEMPERATURE

- KEEP IT COOL (Low Losses, Good Cooling)
- 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

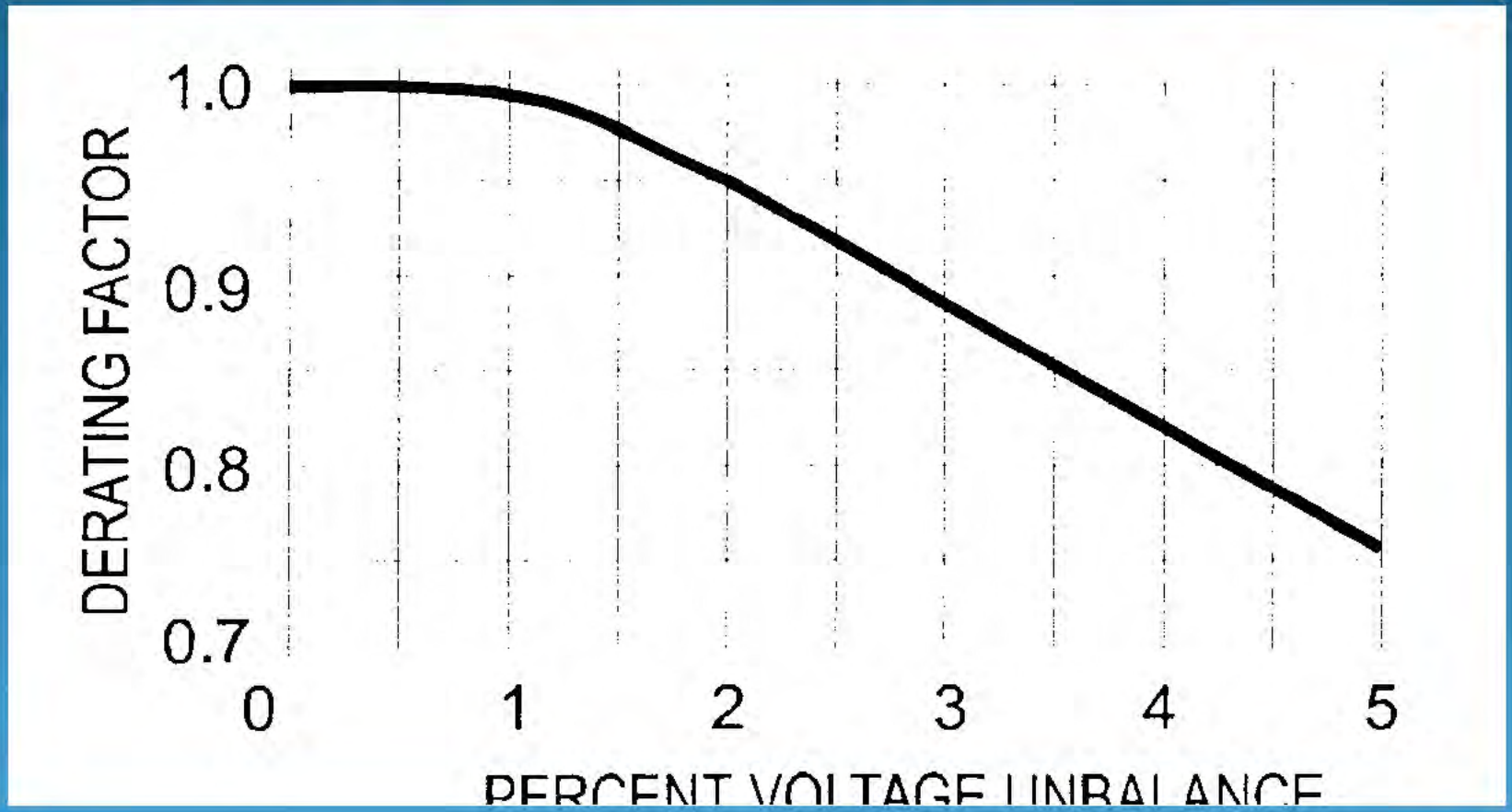
BEARINGS

- 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

UNBALANCE SUPPLY



DURABILITY

- BUY THE RIGHT MOTOR BUILT FOR THE DUTY (ENCLOSURE, INSULATION, LOW VIBRATION RUNS COOL)
- TEST IT
- INSTALL AND START IT UP CORRECTLY
- MAINTAIN IT

LIFE CYCLE COSTS

- INITIAL PURCHASE COST
- INSTALL AND STARTUP COSTS
- CAPITALISE:
  - MAINTENANCE COSTS (PRESENT VALUE)
  - COST OF LOSSES (PRESENT VALUE CALCULATION)

CAPITALISED LOSSES ARE USUALLY LARGEST NUMBER. REQUIRE EFFICIENCY DATA, INTEREST RATES ETC.

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?

PUMP

- OUTPUT POWER
- STARTING TORQUE
- START CURRENT
- START FREQUENCY
- LOSSES
- VOLTAGE
- MOUNTING
- HOSTILE ENVIRONMENT?

ELECTRICS

- 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
- IEEE 841 – BELOW 500 HP
- 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

American
Petroleum
Institute

Helping You Get The Job Done Right.℠

General-purpose Form-wound Squirrel Cage Induction Motors—250 Horsepower and Larger

API STANDARD 547
FIRST EDITION, JANUARY 2005

API
American Petroleum Institute

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

IEEE

IEEE Standard for the Repair and Rewinding of AC Electric Motors in the Petroleum, Chemical, and Process Industries

IEEE Industry Applications Society

Sponsored by the
Petroleum and Chemical Industry Committee

IEEE
3 Park Avenue
New York, NY 10016-5997, USA

27 March 2013

IEEE Std 1068™-2009
(Revision of
IEEE Std 1068-1996)

STARTING

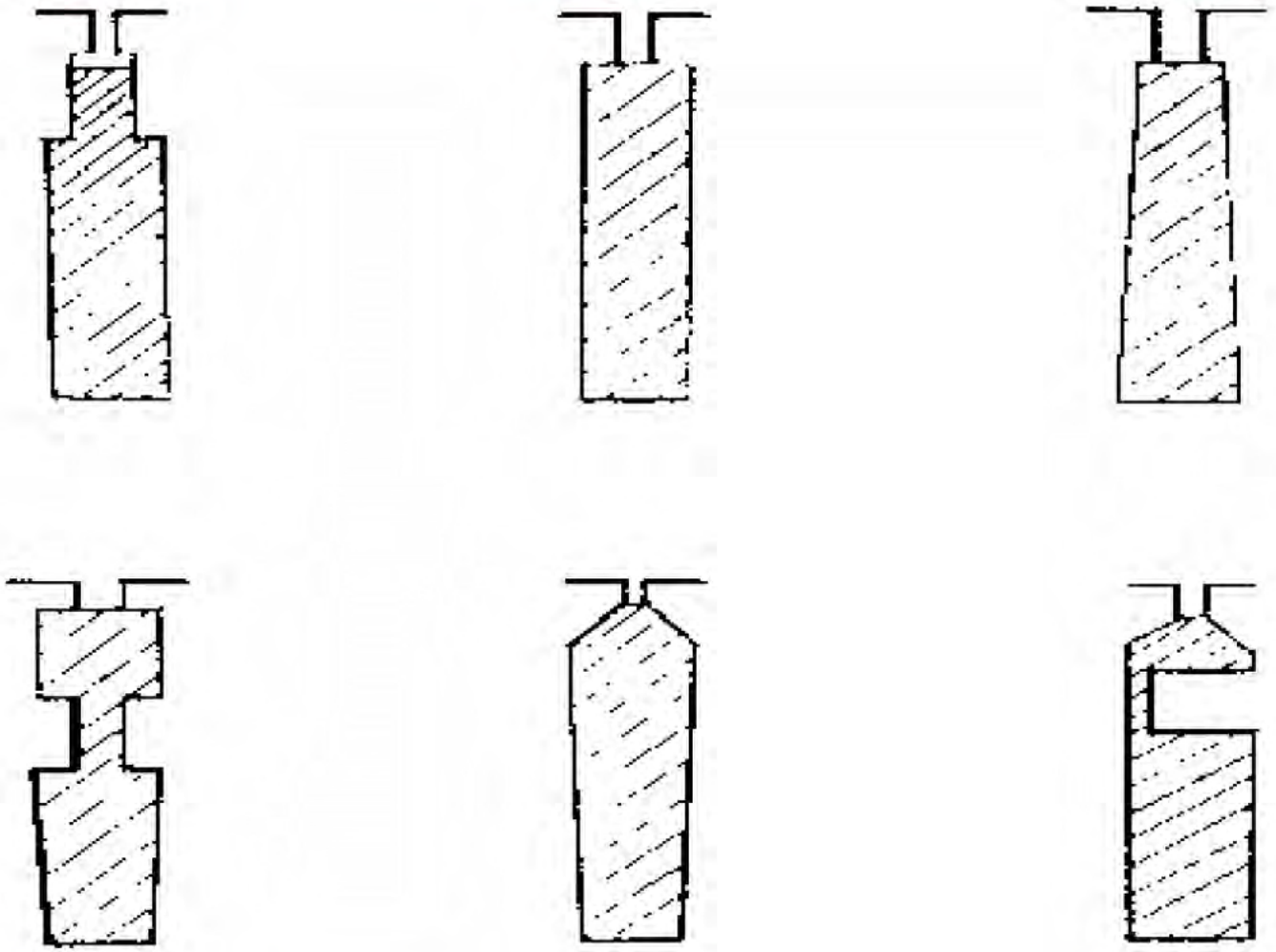
- TIME REQUIRED INCREASES WITH TOTAL INERTIA
- AT ZERO SPEED 100% OF POWER ACROSS AIR GAP (INTO ROTOR) GOES INTO HEAT
- PROPORTION OF HEAT DECREASES LINEARLY WITH SLIP
- 50% SPEED – 50% POWER GOES TO HEAT
- 90% SPEED – 10% POWER GOES TO HEAT
- UP TO 50° C PER SECOND (IN COPPER)
- LONG STARTS GIVE HOT 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} x SLIP/(M x 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

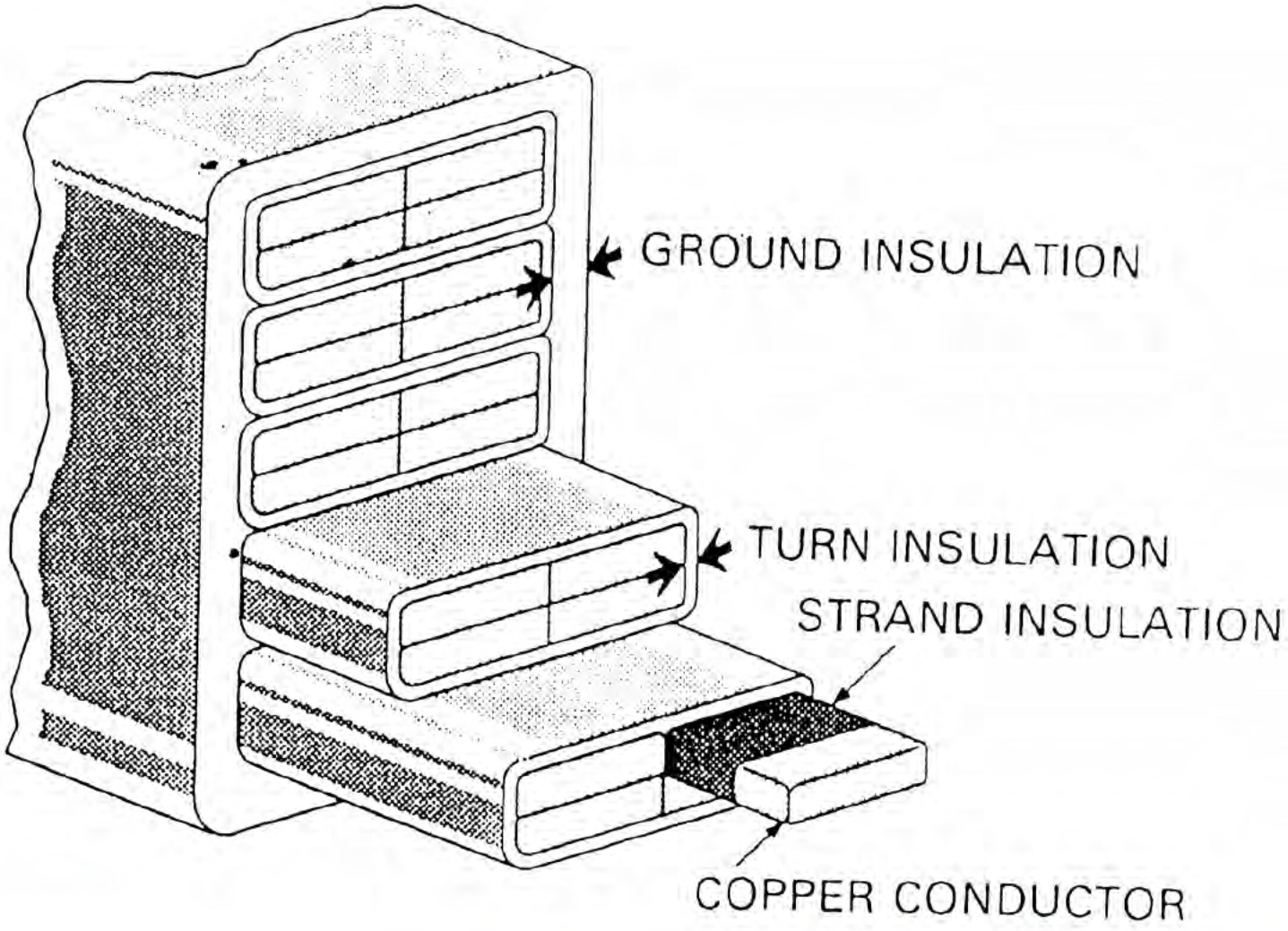
- SHAPE
  - SINGLE, DOUBLE
  - DEEP BAR
  - COFFIN
  - INVERTED T
  - FABRICATED/CAST?
  - ETC
- MATERIAL
  - COPPER, ALLOY
  - ALUMINUM, ALLOY
  - CONDUCTIVITY
  - STRENGTH
  - DENSITY
  - SPECIFIC HEAT
  - THERMAL EXPANSION
  - BRAZE/WELD?



INSULATION

- STRAND/TURN/ GROUND WALL
- VARIOUS MATERIALS:
  - ENAMEL
  - MICA
  - MYLAR
  - GLASS FIBER
  - DACRON
  - EPOXY OR POLYESTER TO HOLD IT TOGETHER

COIL INSULATION



VOLTAGE ENDURANCE

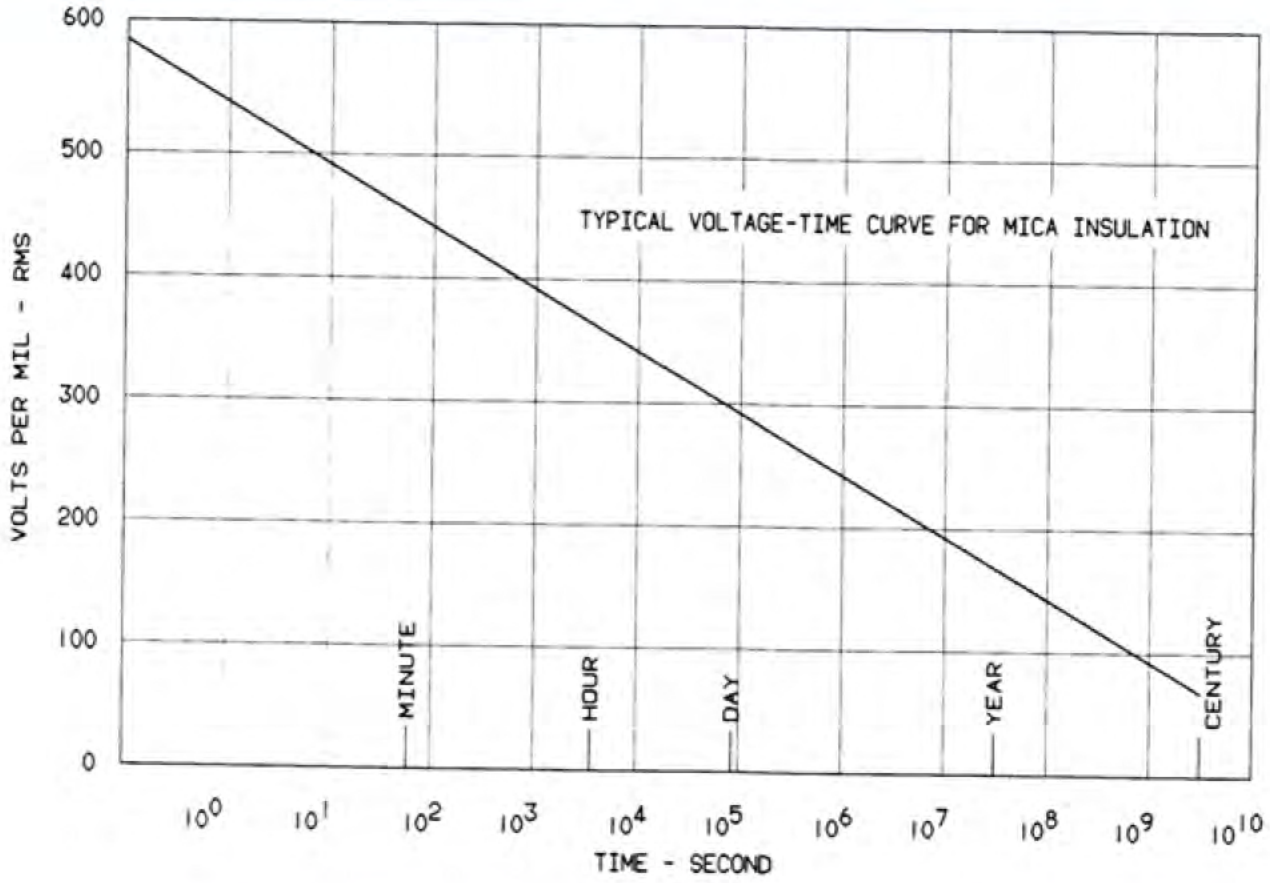
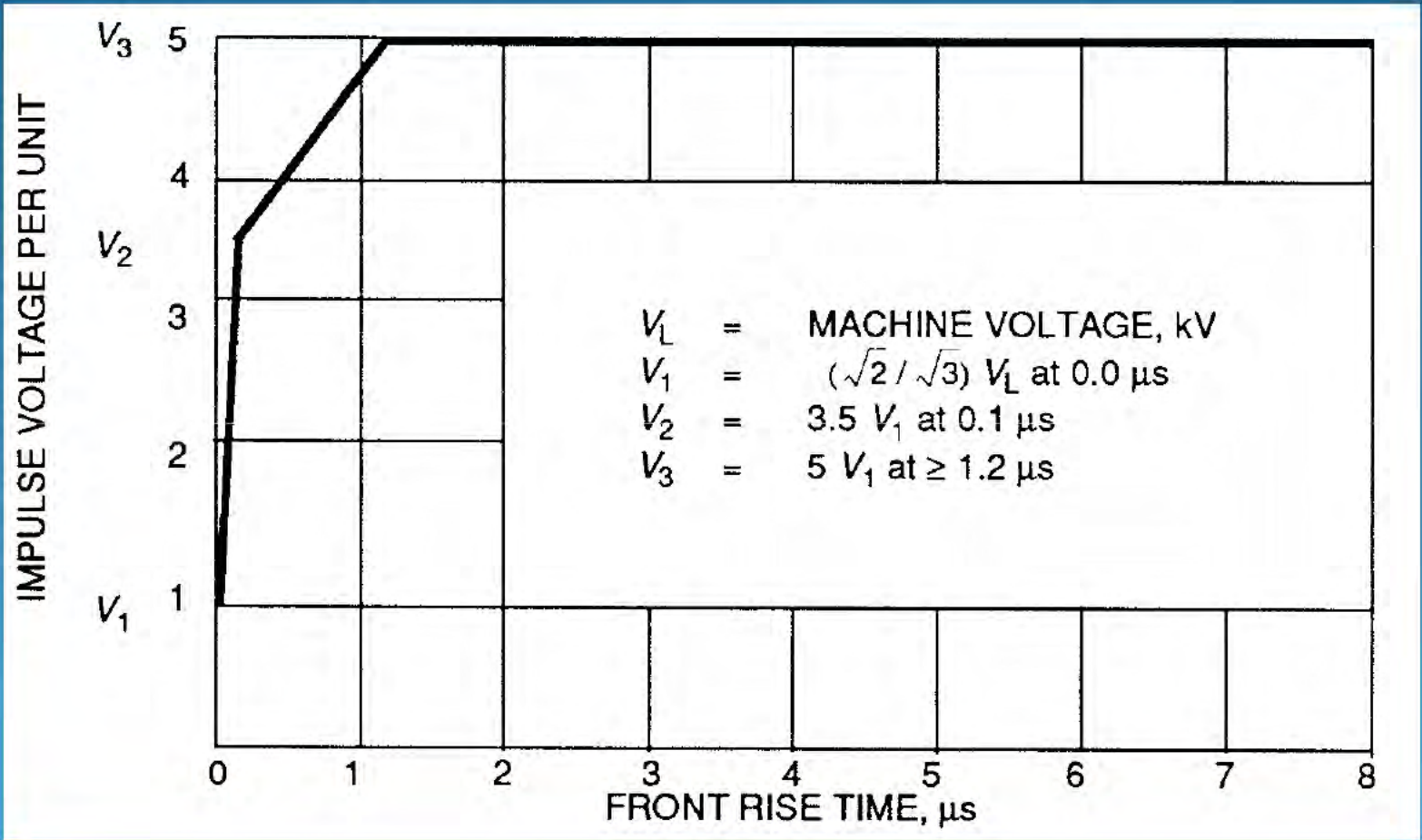


Fig 1
AC Voltage Endurance of Rotating Machine Insulation on Coils

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



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

LUBRICATION

- OIL (HYDRODYNAMIC AND SOME HIGH SPEED ANTI FRICTION i.e. large and high speed)
  - 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; smaller and low speed)
  - REPLACEMENT INTERVAL TEMPERATURE DEPENDENT
  - SOME ARE SEALED TO KEEP GREASE IN AND DIRT OUT

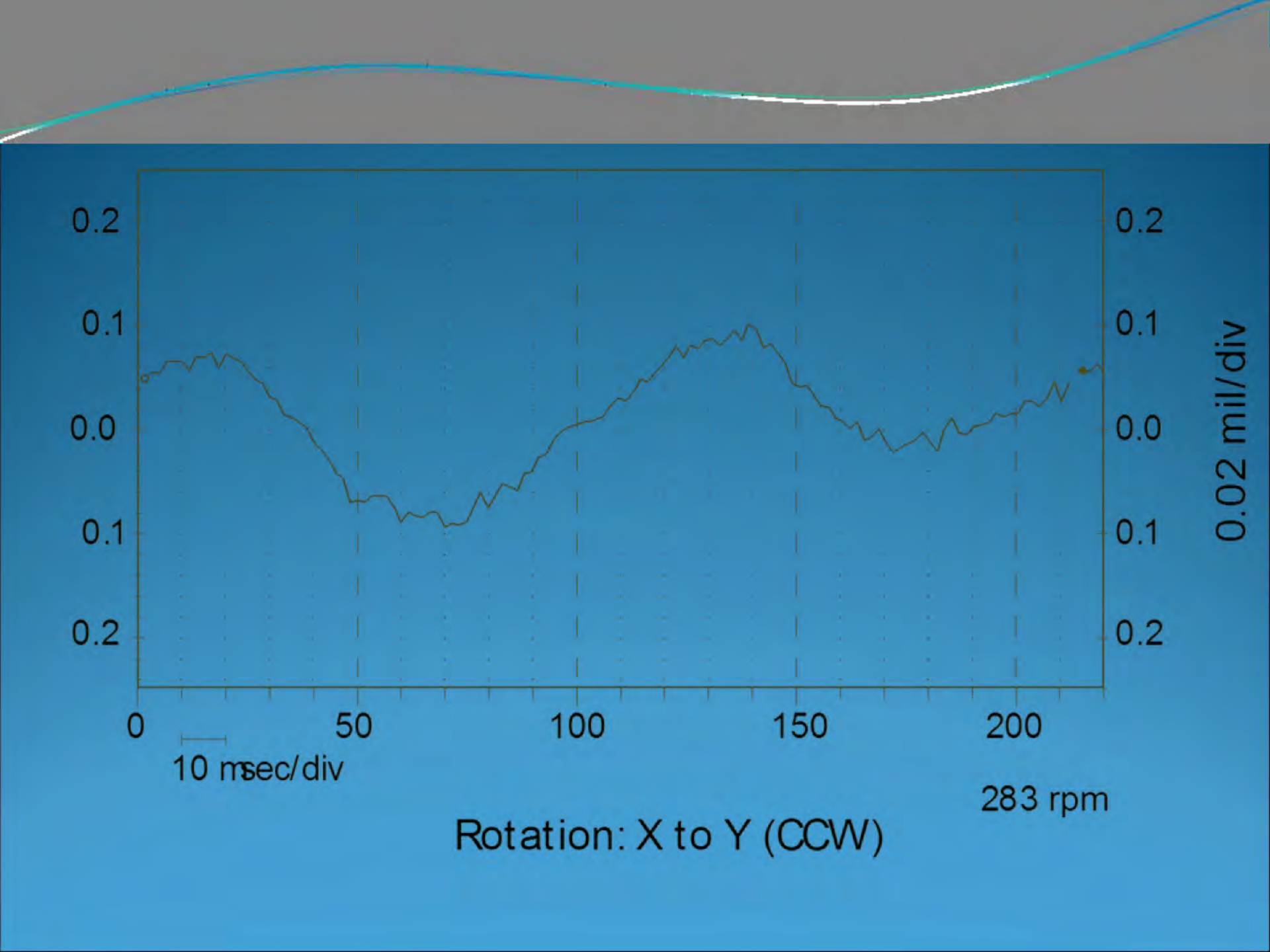
TEMPERATURE

- 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

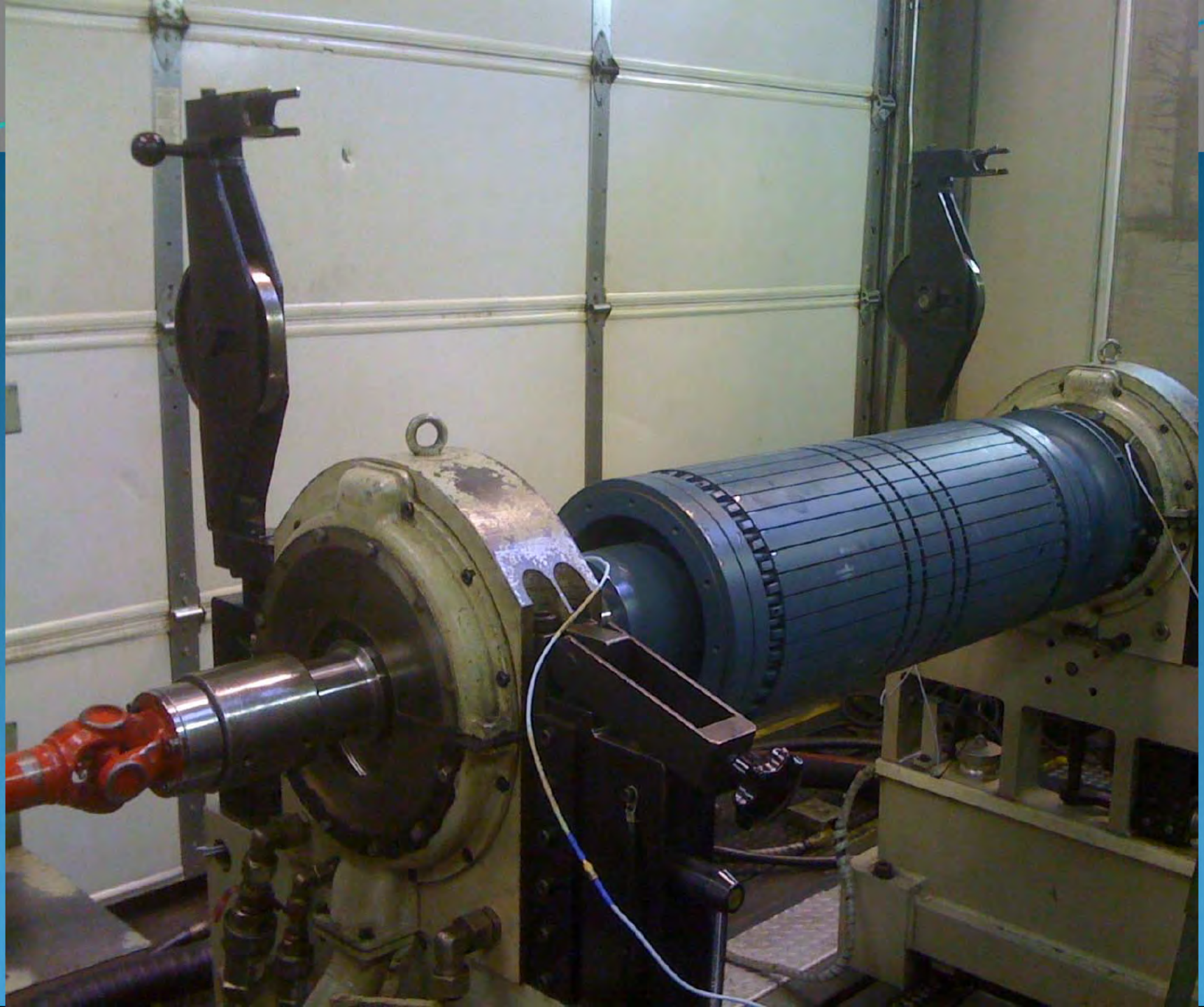
- CAUSES FATIGUE OF ANTI FRICTION BEARINGS
- AFFECTS OIL FILM THICKNESS (ANTI FRICTION AND HYDRODYNAMIC)
- MAY GIVE METAL TO METAL CONTACT, SMEARING
- CAUSES OTHER NON BEARING PROBLEMS
- SEISMIC VERSUS PROXIMITORS?

PROXPAC ®
PROXIMITY TRANSDUCER SYSTEM


0.2
0.1
0.0
0.1
0.2
0.2
0.1
0.0
0.1
0.2
0.02 mil/div
0
50
100
150
200
10 msec/div
283 rpm
Rotation: X to Y (CCW)

CAUSES OF VIBRATION

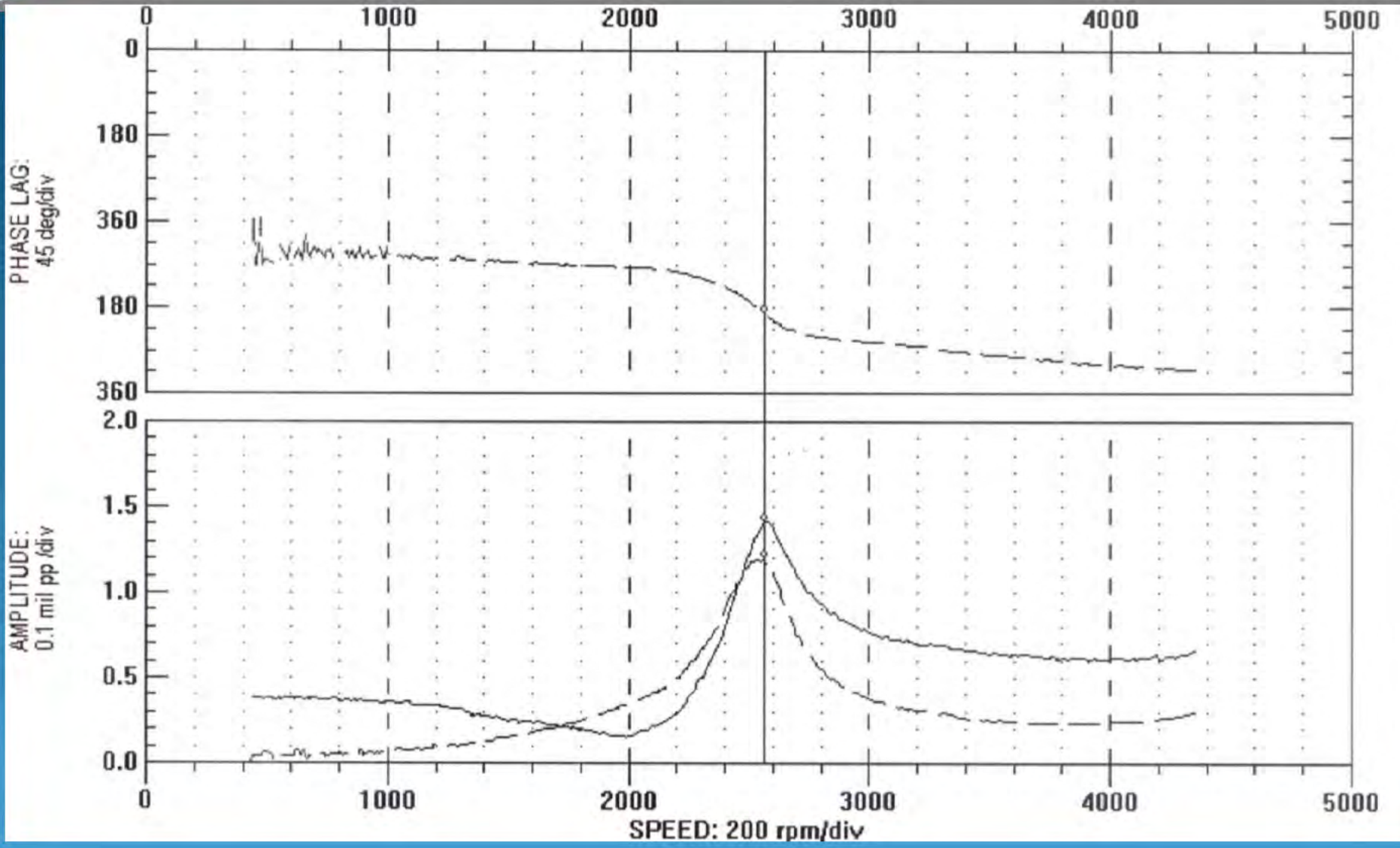
- UNBALANCE (4W/N)
- THERMAL VECTOR SHIFT
- MISALIGNMENT
- BENT SHAFT
- ELECTROMAGNETIC (2 x SUPPLY FREQUENCY)
- RESONANCE [SIMPLE SQRT (K/M)]



VECTOR SHIFT

50 micro m pp FULL SCALE

CCW ROTATION


0
1000
2000
3000
4000
5000
PHASE LAG:
45 deg/div
0
180
360
180
360
AMPLITUDE:
0.1 mil pp /div
2.0
1.5
1.0
0.5
0.0
SPEED: 200 rpm/div

BEARING CURRENTS

- STATOR/ROTOR SLOT COMBINATIONS *(ADDRESS BY MOTOR DESIGN)*
- WELDING *(DON'T WELD ON ROTOR)*
- 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

BROKEN BARS

- TORSIONAL OSCILLATIONS
- OVERHEATING
- POOR BRAZING
- POROUS CASTINGS
- OVERHEATING
- BAR LOOSENESS

STARTING DUTY

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

NUMBER OF STARTS

- SHORT TERM 3 COLD, 2 HOT IS TYPICAL DEFAULT. MORE FOR “EASY” SHORT STARTS, LESS FOR LONG STARTS.
  - DEPENDS ON SQUIRREL CAGE TEMPERATURE, 300 TO 350 C.
- LONG TERM DEFAULT IS 5000 STARTS IN LIFETIME.
  - FATIGUE OF WINDINGS, BRACING, AND ROTOR BARS.

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

OTHER DAMAGE

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

SPARKING (Larger machines)

- 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?