SKF®

Static & Dynamic Motor Testing

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VIBRATION INSTITUTE

Piedmont Chapter #14

2009 Annual Seminar

Baker

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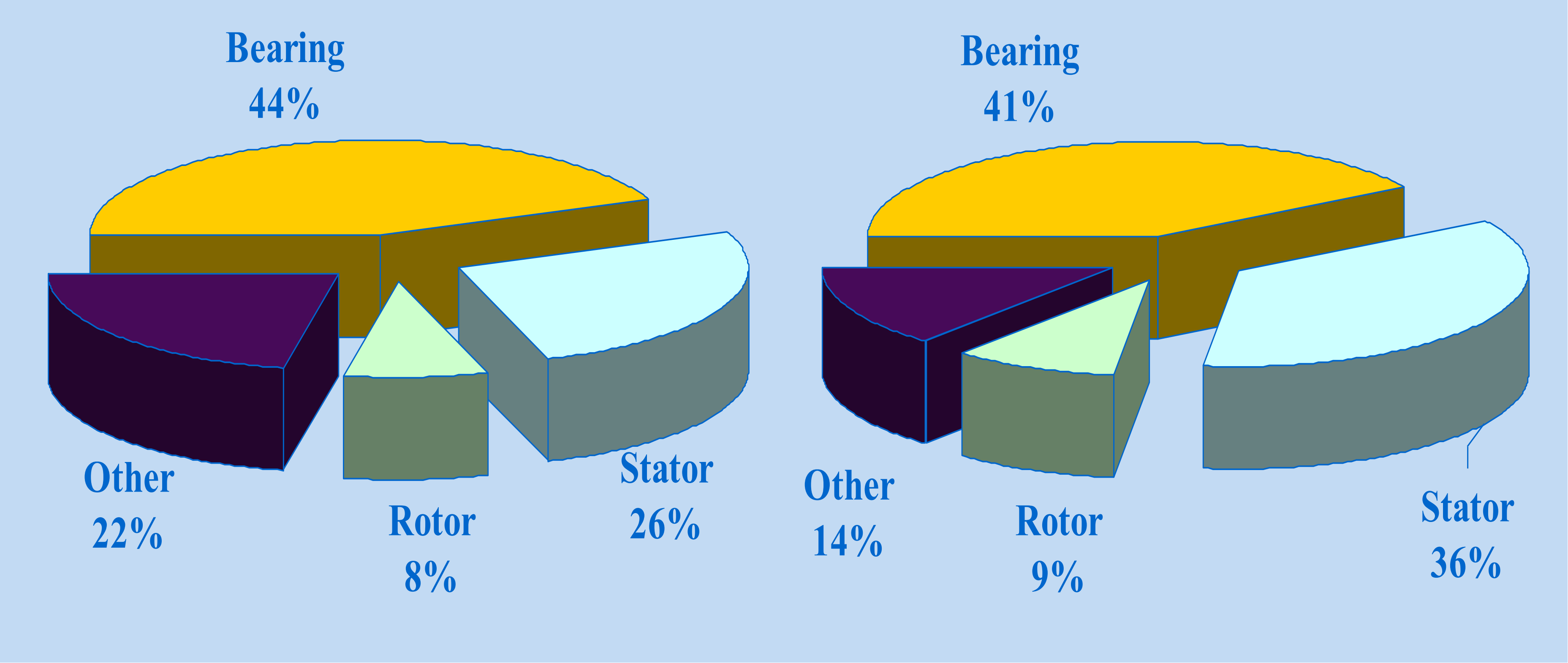
Motor Failure Areas

IEEE Study (Early 1990's)

EPRI Study (Mid 1990's)



Static Motor Testing

Intro to Static Motor Monitoring

Defining Static (Off-Line) Electric Motor Testing

WHAT IS IT: Measuring and tracking electrical properties of the winding circuit in an effort to determine its health and reliability while the motor is deenergized.

HOW:

<u>Low Voltage Testing</u>

Measuring specific electrical parameters at or below nameplate voltages to determine a change in the electrical circuit properties.

<u>High Voltage Testing</u>

Testing motor insulation at voltage levels similar to those the motor encounters in it's normal environment.

Winding Design

Random Winding

(Mush Winding)

Form Coil

Testing Insulation Systems

- Multimeters
- Meg-Ohm-Meter
- Resistance Meters (DLRO, Bridges)
- Low voltage circuit evaluation (i.e. Capacitance, Inductance)
- High Potential Test – AC-DC
- Surge Testing
- Corona Testing
- Partial Discharge Detection
- Infrared, Ultrasonic, Vibration

Topics of Discussion

Insulation Strength

Failure Mechanisms

Testing Theory

- Test Parameters
- Pass/ Fail Criteria

Methods of Testing

Predictive Indicators in Electrical Motor Testing

Dielectric Strength of Good Insulation

Properties of the Dielectrics

Dielectric Strength

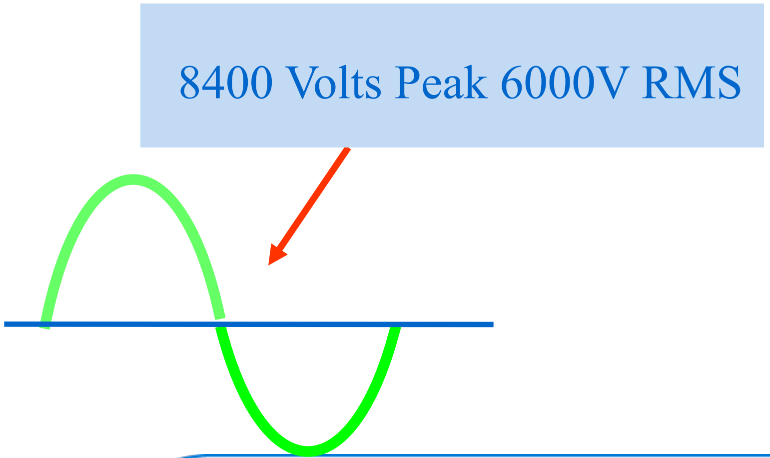
Puncture/Breakdown

Wire for a 460V AC motor has

6000VAC insulation capability (NEMA MG-1)

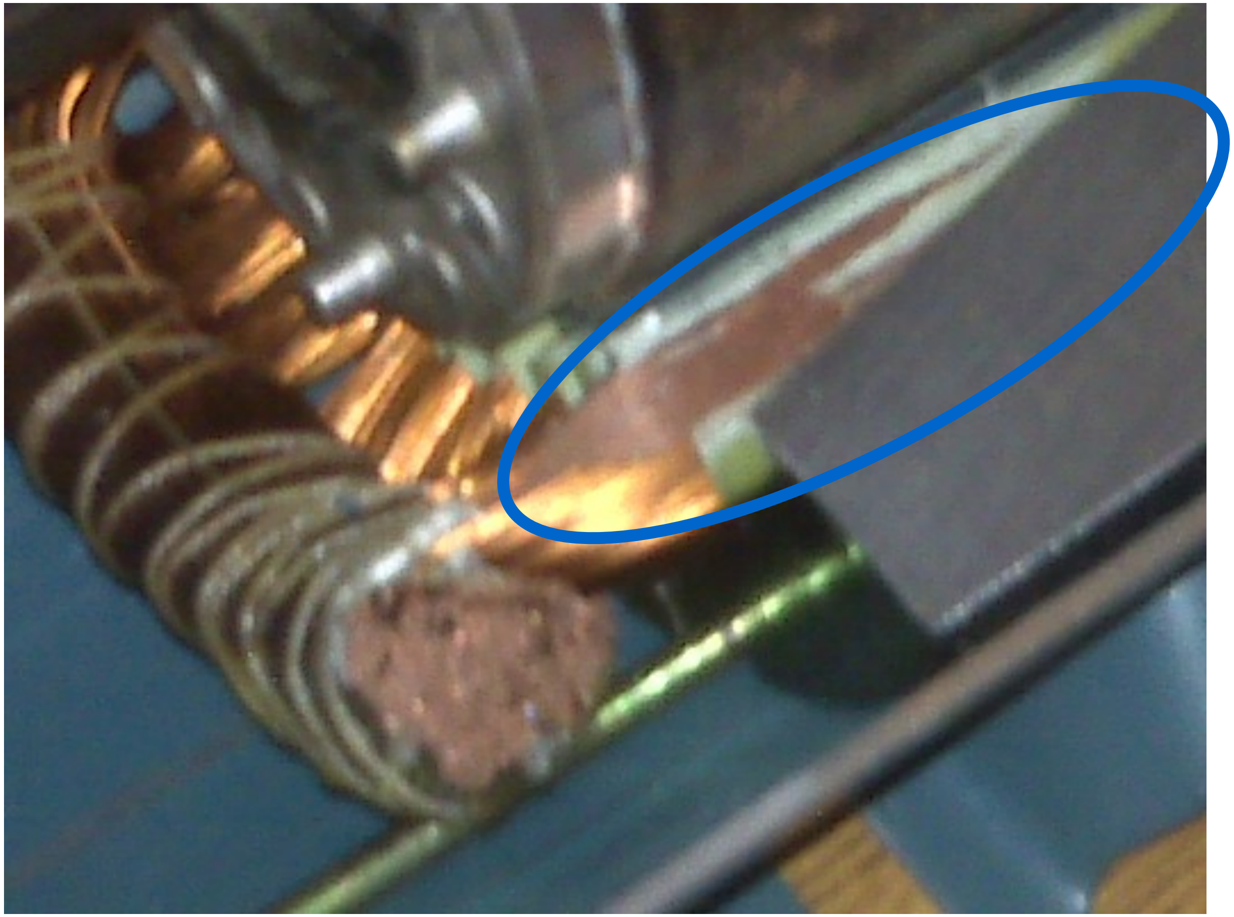
Or:

$$6000\,AC\sqrt{2} = 8400\,VDC$$

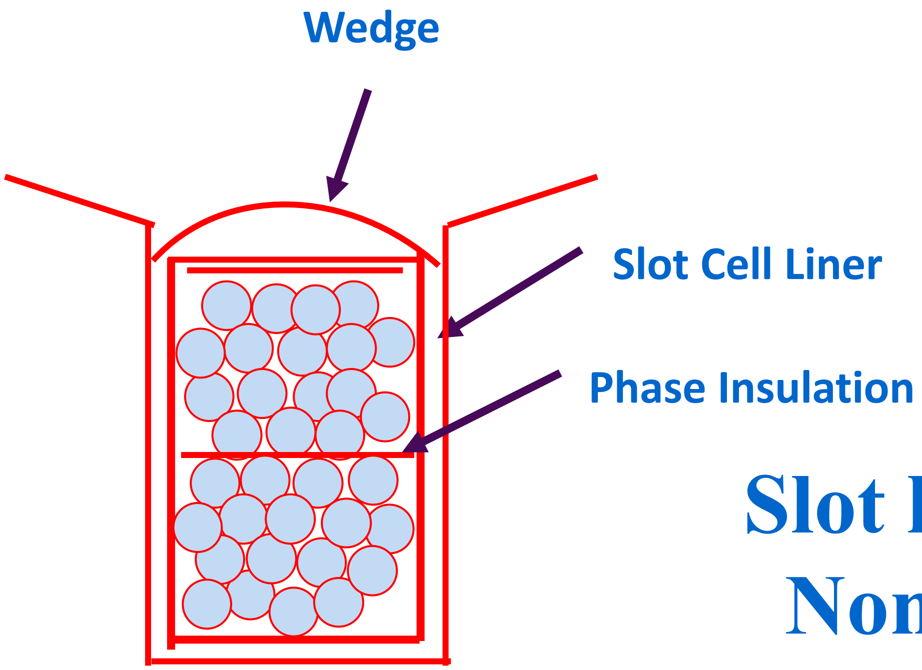


Demonstrate the Dielectric Strength of the Magnet Wire

One Slot of a 460 volt Motor



Properties of the Dielectrics



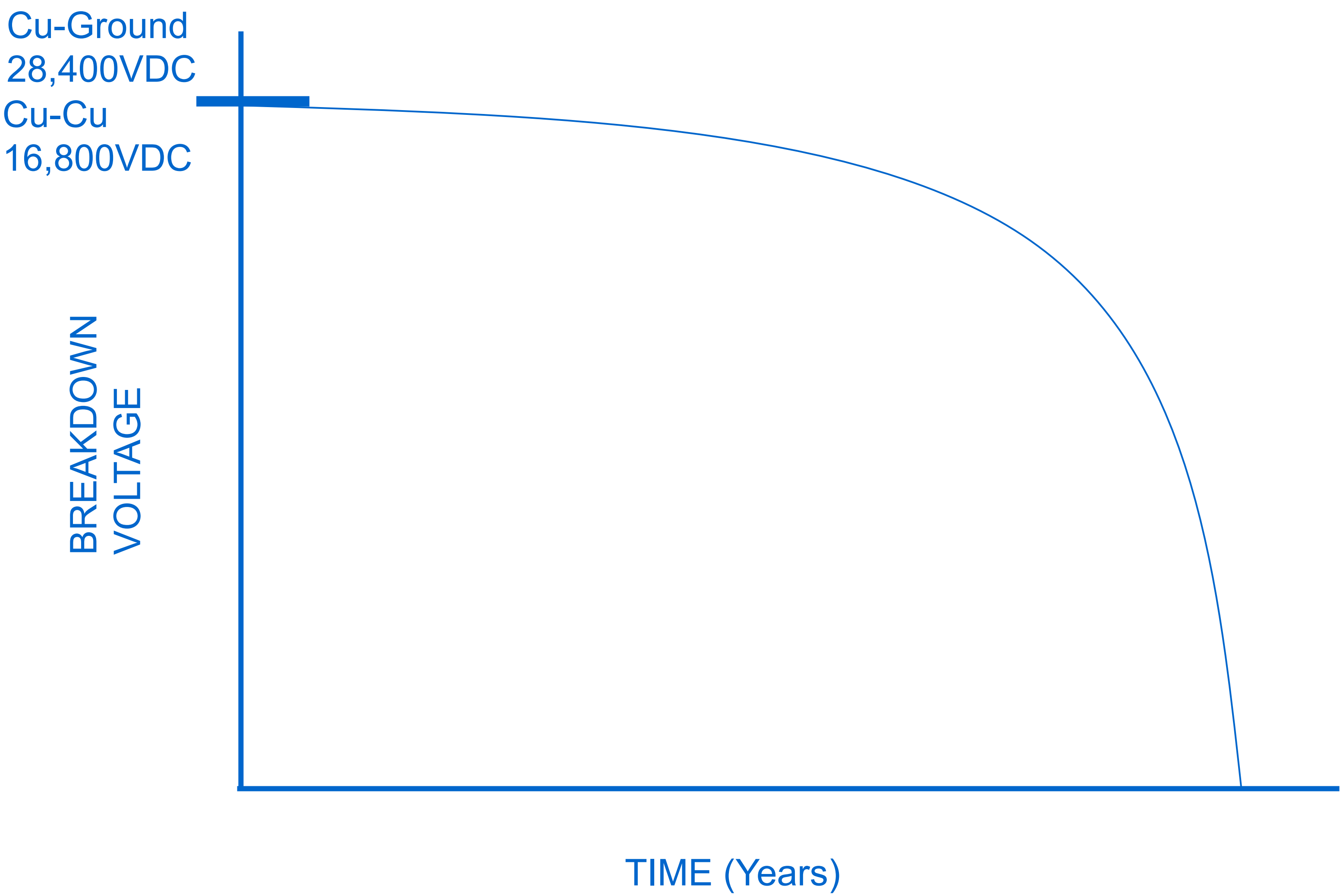
Single slot in a random wound 3 Φ Motor

Slot liner is 20,000 VDC
Nomex-Mylar-Nomex

- **Combined Insulation to Ground is**

8400 VDC + 20,000 VDC = 28,400 VDC

Insulation Life Curve

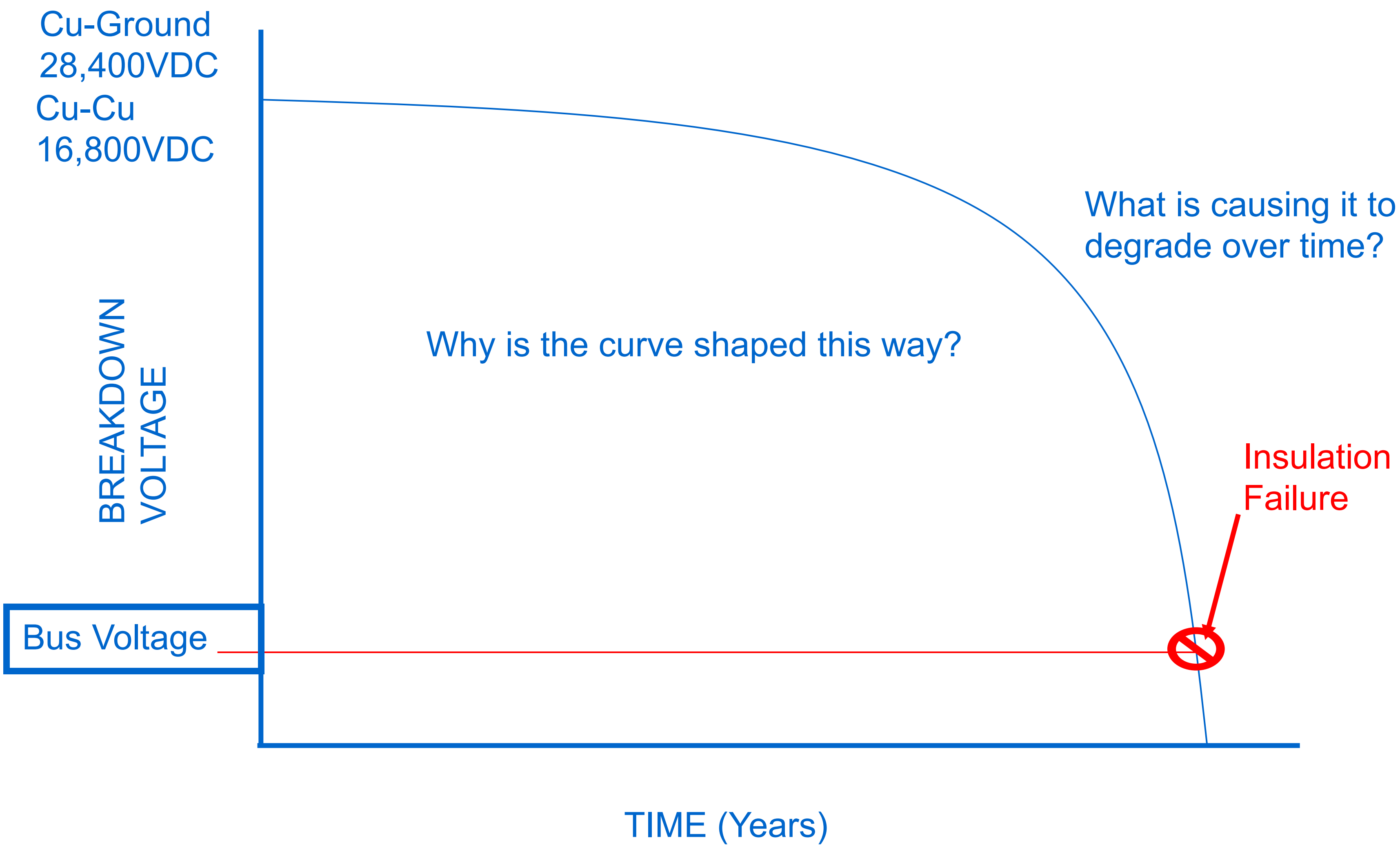


Important Point

The Dielectric Strength of Good Insulation is Very High!

MUCH HIGHER THAN THE NAMEPLATE RATING!

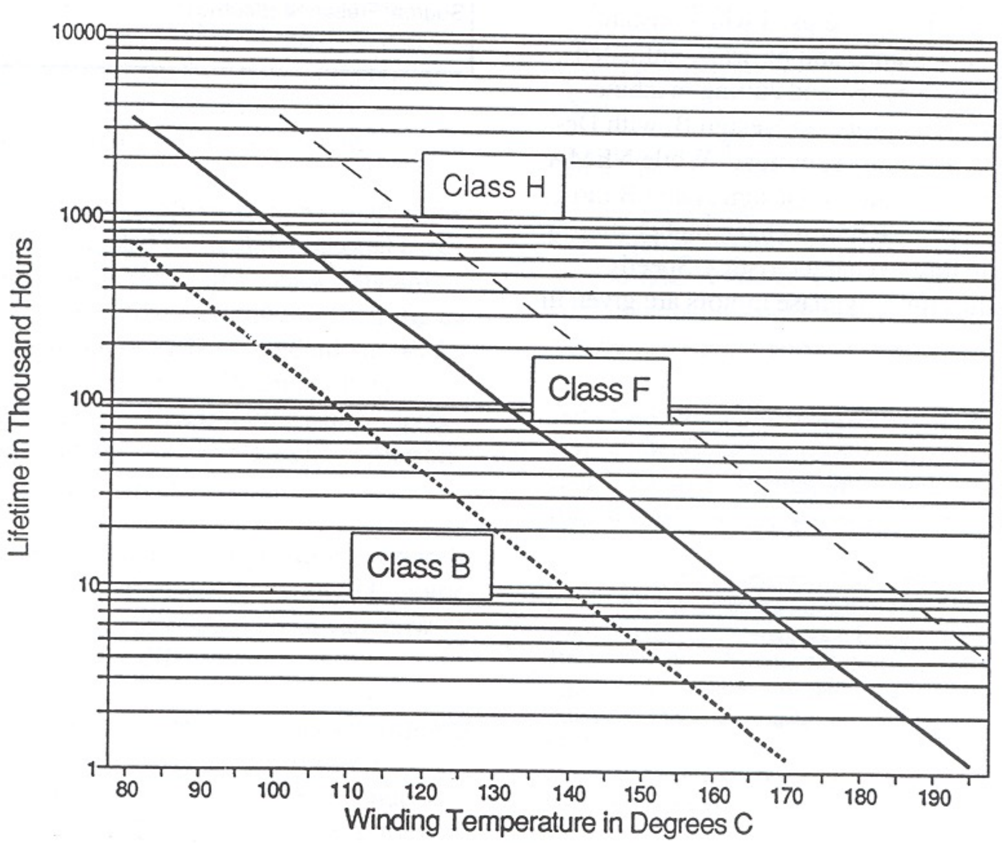
Insulation Life Curve



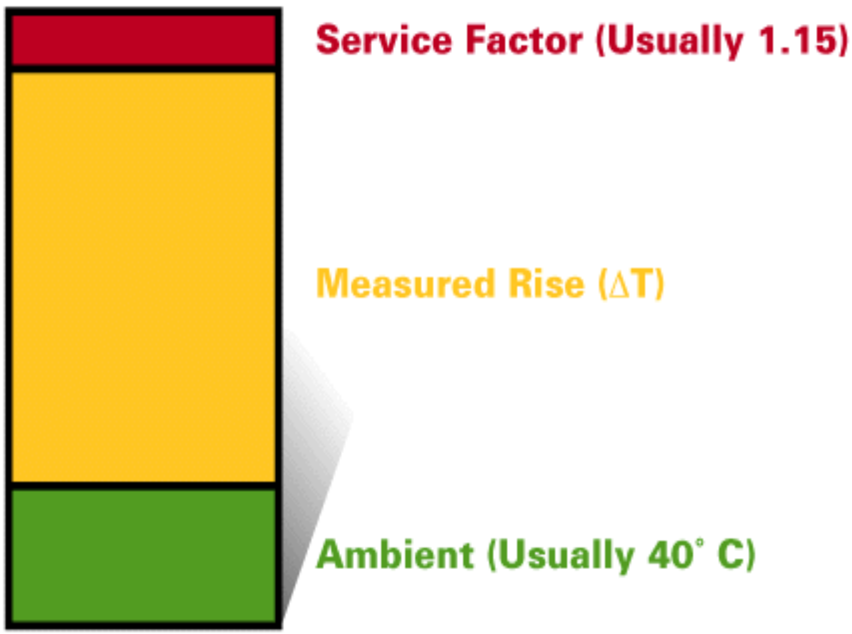
Causes of Insulation Failure

Thermal Aging (IEEE 101)

- For every 10C increase in temperature of the insulation, the rate of insulation degradation is doubled.



Insulation Systems

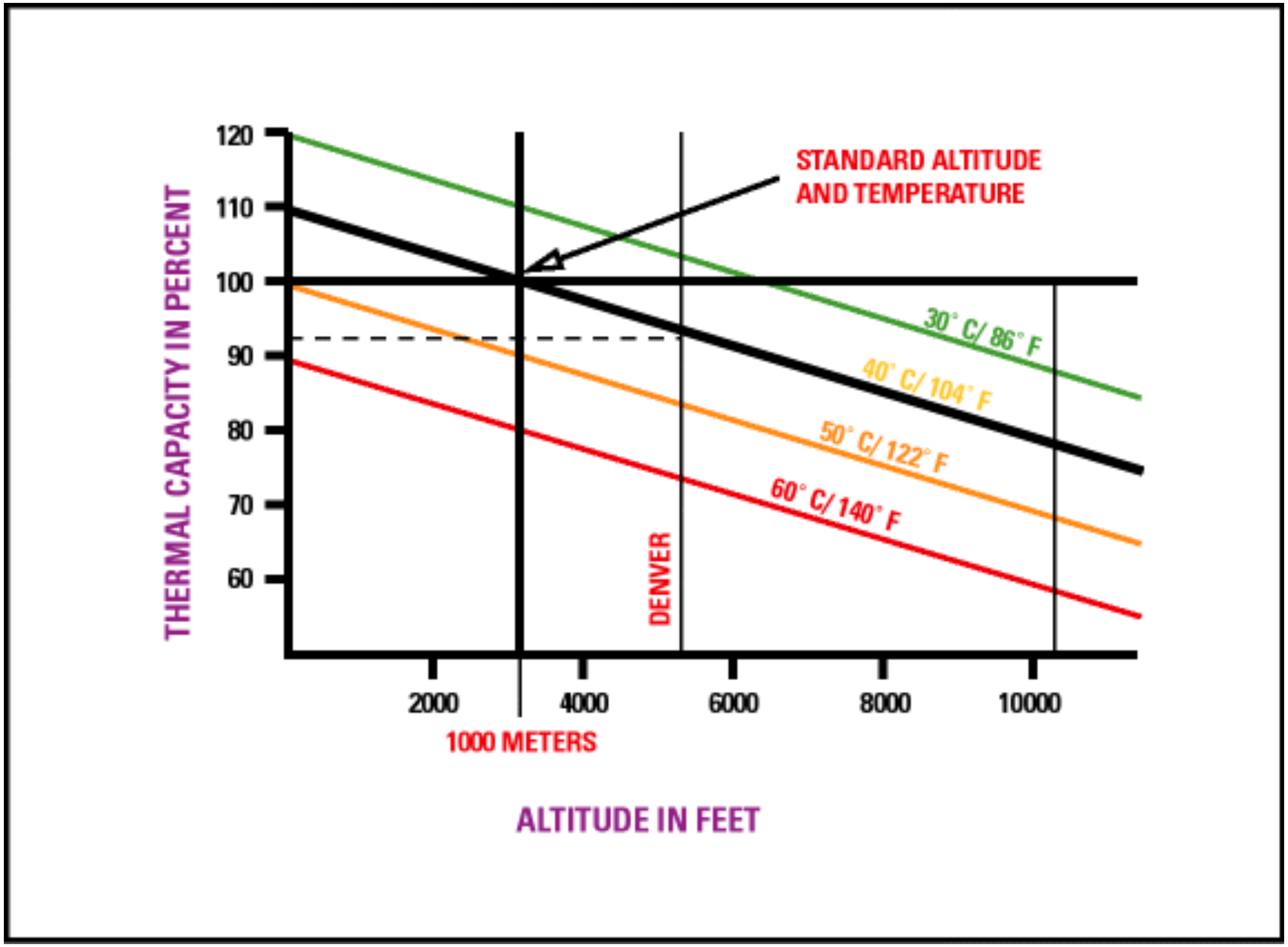


CLASS	TOTAL TEMPERATURE
A	105° C
B	130° C
F	155° C
H	180° C
H+	220° C
C	

Thermal Contributors

- Load (Increased current creates heat by I^2R)
- Ambient Conditions
  - Temperature
  - Altitude
- Starting Current & Initial Temperature Rise (Restarts)
- Thermal Insulation from Contamination
- Power Quality
  - Harmonic Voltage Factor
  - Under and Over Voltage
  - Voltage Imbalance

Thermal Capacity/ Altitude



Causes of Insulation Failure

Thermal Aging (IEEE 101)

- For every 10C increase in temperature of the insulation, the rate of insulation degradation is doubled.

Contamination

- Chemical, deposit on the winding actively attack the insulation
  - (i.e. Acids, Caustics, EP-2 Grease)
- Some contamination can also lead to thermal insulation
- Abrasive wear of insulation due to impact from air flow

Mechanical

- Movement within the winding at start up
- Thermal growth of materials

Over Voltage Spikes

- High Voltage surges caused by Switching, Lightning, VFD’s

How Long Should a Motor's Insulation Last?

100,000 hours

11.4 years – All Day, Every Day, Every Year

$$\frac{100{,}000\ hours}{24\ hours} = 4166\ days = 11.4\ years$$

33 years – 8 hours a Day, Every Day

1

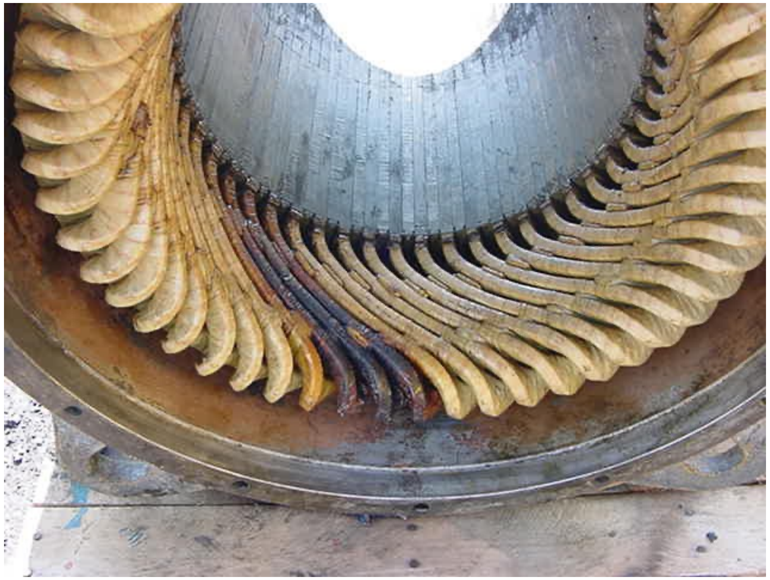
Failure Mechanisms

Turn to Turn Failure

80% of electrical stator failures start as turn-to-turn fault

Most will fail to ground in the slot and some phase to phase, but the root cause will be turn to turn failure

General Electric Paper



Reasons why most failures begin as "turn to turn" failures

- Turn insulation is the weakest insulation in the motor.

  Both Mechanically and Dielectrically

- All Contributors to Insulation Degradation are acting evenly on the winding, however this winding is more exposed to outside influence.

  (i.e. Contamination, Movement, Abrasion, Thermal Insulation)

- Movement from start up rubs the turns together causing wear.

  (D.E. Crawford\General Electric)

- Damage caused by winding and handling process.

- Starting, Stopping, Lighting, and VFD's cause voltage spikes which in turn produce high turn to turn voltages.

D.E. Crawford, "A Mechanism of Motor Failures." General Electric Company, 75CH1014-0-EI-19.

"…Looseness, motion and wear develop as the result of certain stresses applied to the motor windings by the service it sees. Careful analysis revealed the following conditions:

- **Differential thermal stresses**
- **Different coefficients of expansion**
- **Varnish weakening at higher temperatures**
- **Magnetic force due to winding currents"**

"…Wear between the moving components is a natural consequence of motion and it was found when the likely points were located…"

D.E. Crawford Movie

B.K. Gupta, B.A. Lloyd, G.C. Stone, D.K. Sharma, N.E. Nilsson, and J.P. Fitzgerald, "Turn Insulation Capability of Large AC Motors. Part 3 – Insulation Coordination.", IEEE Transactions on Energy Conversion, Vol. EC-2, No. 4, December 1987.

"…. In 1982, a working group of the IEEE Rotating Machinery Insulation Subcommittee published criteria which set a minimum capability for large motors of any age to withstand voltage surges. ….Figure 2 shows the highest surges from all the motors monitored in this study (which had no surge protection), compared to IEEE curve. More than 50% of the motors monitored experienced surges which exceed the IEEE recommended withstand level…"

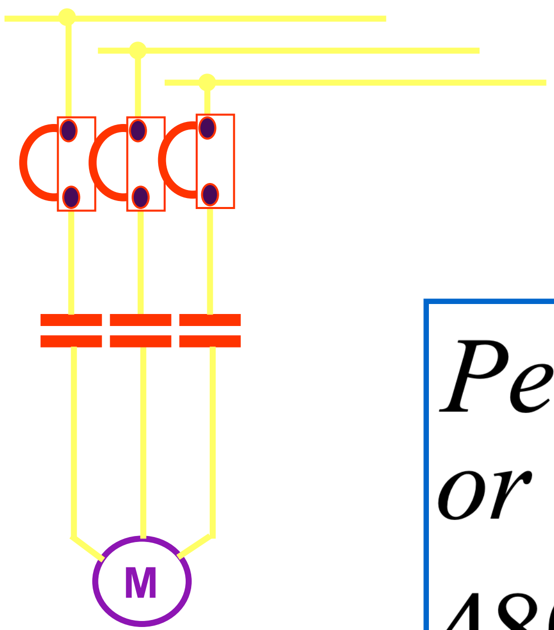
"…The most common deterioration process, especially in a motor with a long service record, involves the gradual loosening of the insulated turns due to shrinkage and loss of mechanical strength in the insulation as a result of operation at high temperatures. Under the influence of magnetic forces caused by either starting currents or the normal 60hz current, the turns rub against one another, abrading away the turn insulation. Eventually enough insulation is removed that a mild surge, or even the normal 60Hz interturn voltage will short circuit the turn."

Voltage and Insulation Breakdown

Motors do not fail at operating voltage where they see 20 to 30 volts turn to turn

Every time the motor starts it sees voltage spikes of up to 5 pu (per unit) (~2000V for a 460v Motor)

Insulation Failure on Start-up



Voltage spikes on Start-up

EPRI Study:

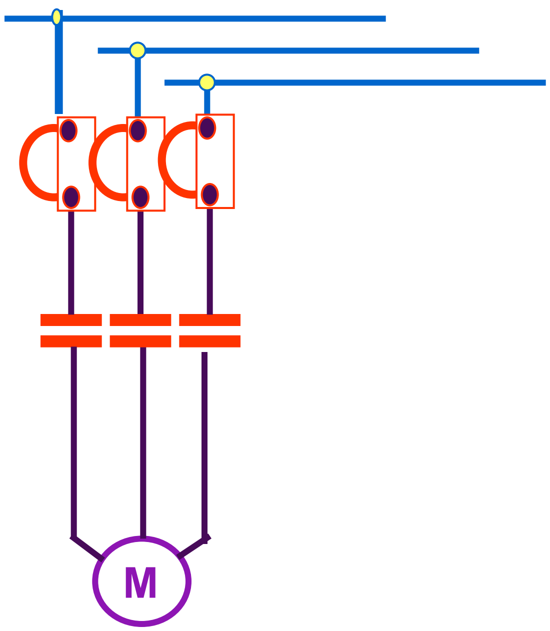
$$PerUnitVolts = E_L \div \sqrt{3} \times \sqrt{2}$$

or

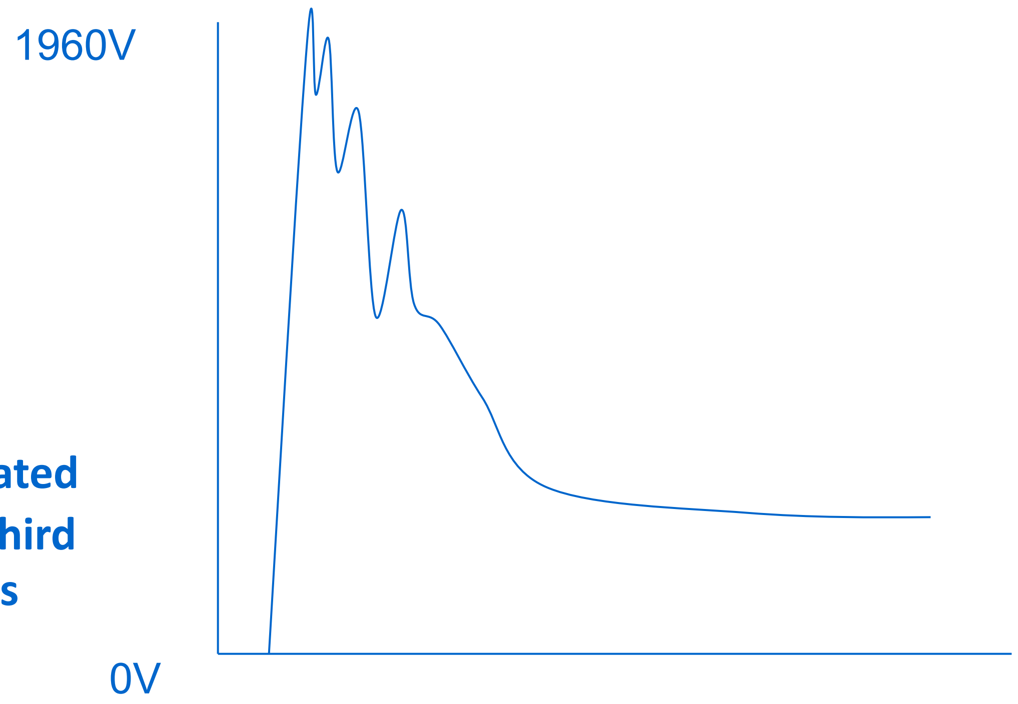
$$480V \div \sqrt{3} \times \sqrt{2} = 392Volts$$

Worst Cast Spike = 5 Per Unit (392V) = 1960 Volts Spikes on Starting

Voltage Spikes on Start-up

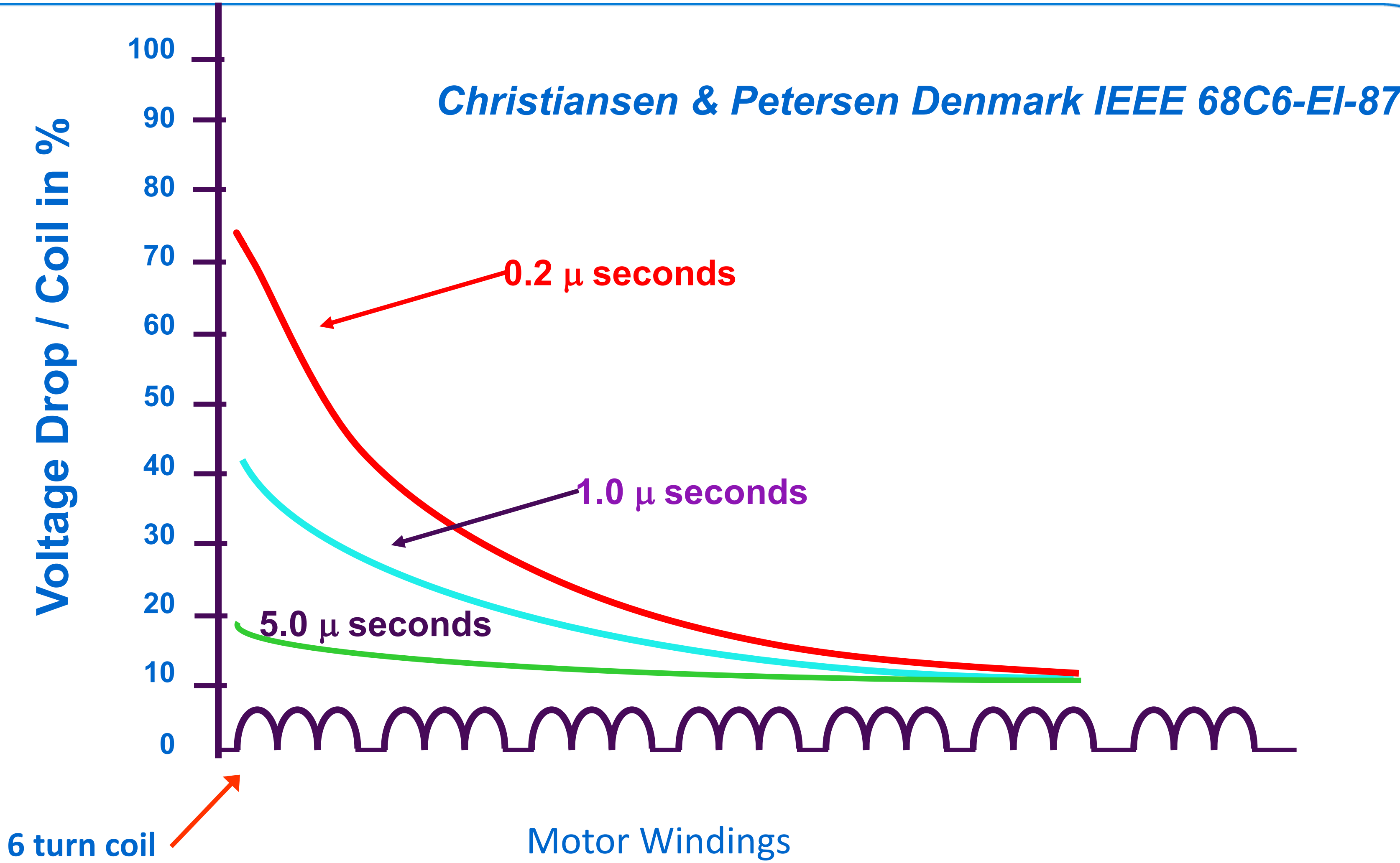


Rise time of Voltage spike is .2 to .5 micro seconds



Spikes are generated as the second & third contacts closes

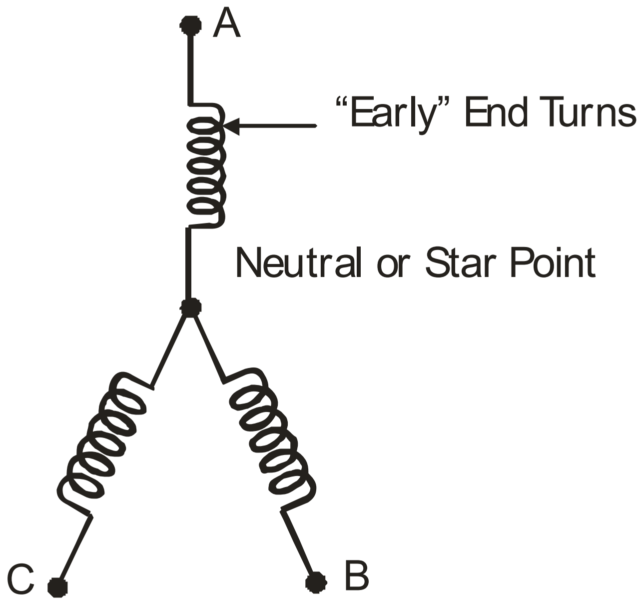
Voltage Distribution Across Motor Coils



Motor Windings
Two pole Wye - Six turns per coil - ~ 1000 hp

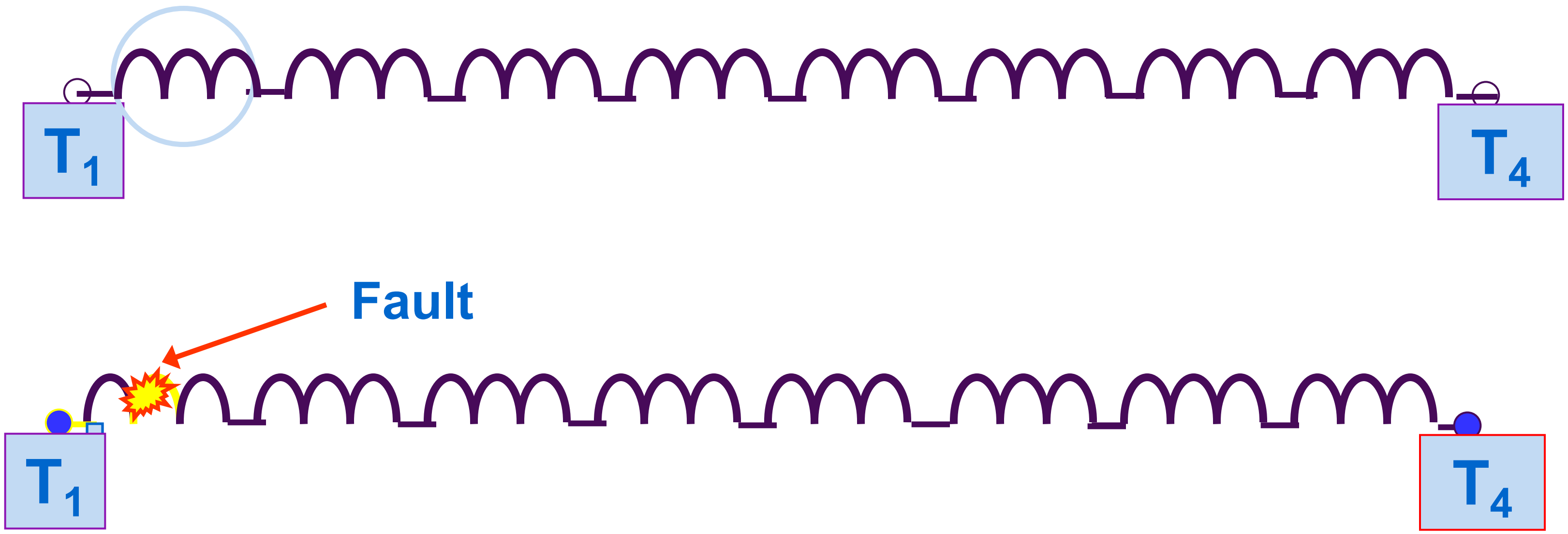
Early Turn Failure

- Majority of Turn to Turn failures start at the early turns
- Most early turn failures are a result of high voltage spikes



Turn to Turn Failure

Area most likely to have a copper to copper failure.



Lightening caused failure may happen further into the weakened winding, a result of the slower voltage rise time.

E.P. Dick, B.K. Gupta, P.Pillai, A. Narang, "Practical Calculation of Switching Surges at Motor Terminals." IEEE/PES 1988 Winter Meeting, Jan 31, 1988.

"….Given a maximum prestrike voltage on third pole closing of 2.82 per unit, the steep-fronted motor terminal surge can vary between 2 and 5 per unit depending on the configuration."

Peter Zotos, "Motor Failures due to Steep Fronted Switching Surges: The Need for Surge Protection – User's Experience." IEEE Transactions on Industry Applications, Vol. 30, No. 6, November/December 1994.

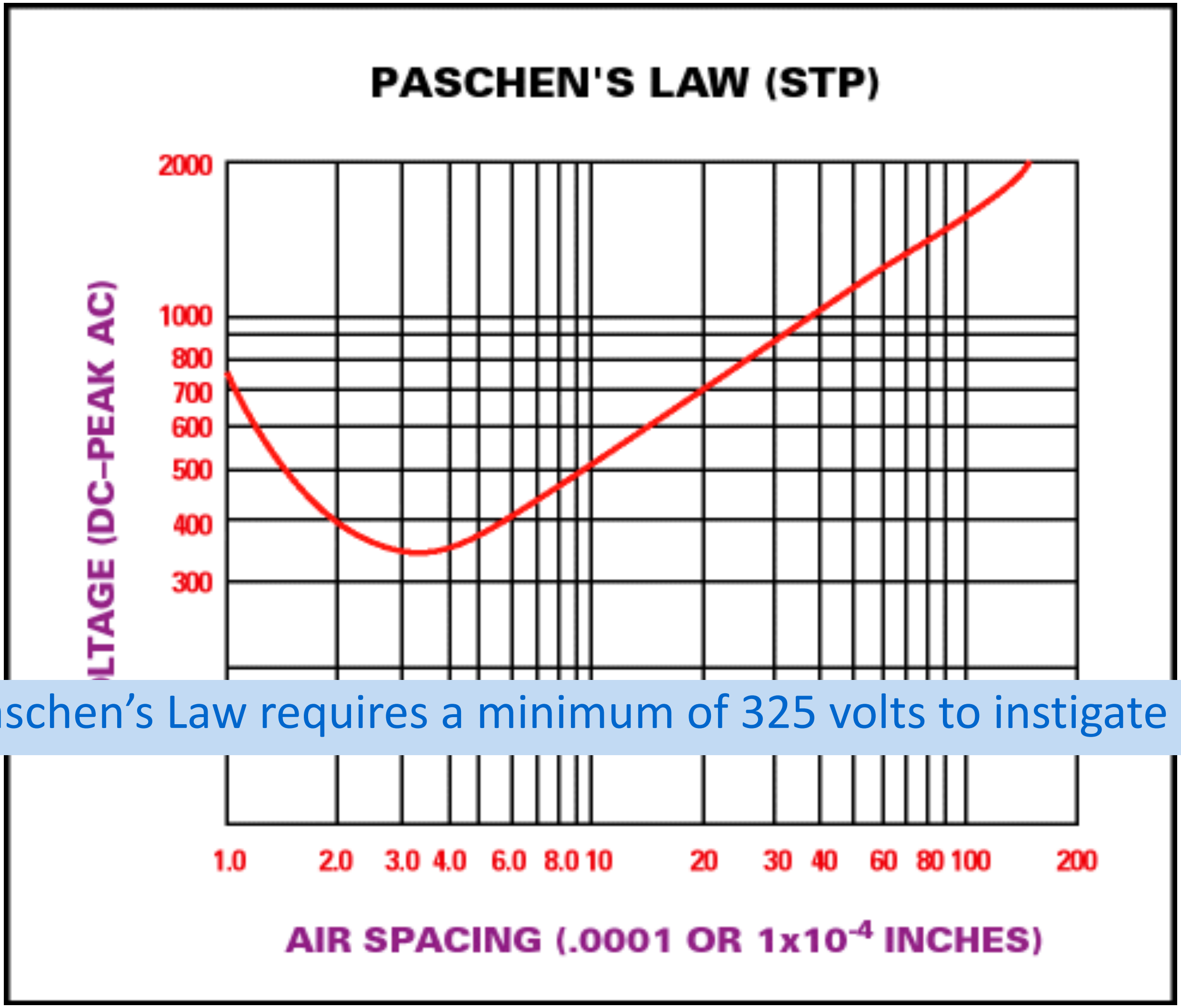
"…The prime purpose of the paper is to establish that motor winding insulation provided with "dedicated interturn insulation" can withstand stress generated by switching surges with amplitude as high as 5 p.u. and with a rise time range of 1-0.1us without the use of shunt capacitors."

"…Studies show that significant surges are present only during breaker closing operations while energizing the motor. Most surges have 1-3 p.u. magnitudes and 0.2 – 0.6us rise times……The highest recorded surge was 4.6p.u. with 0.57us rise time in normal operations."

"…Independent tests, conducted on air blast (station-type) circuit breaker, show that the highest recorded surge was 3.44 p.u. with a rise time of 3us for normal and abortive starts."

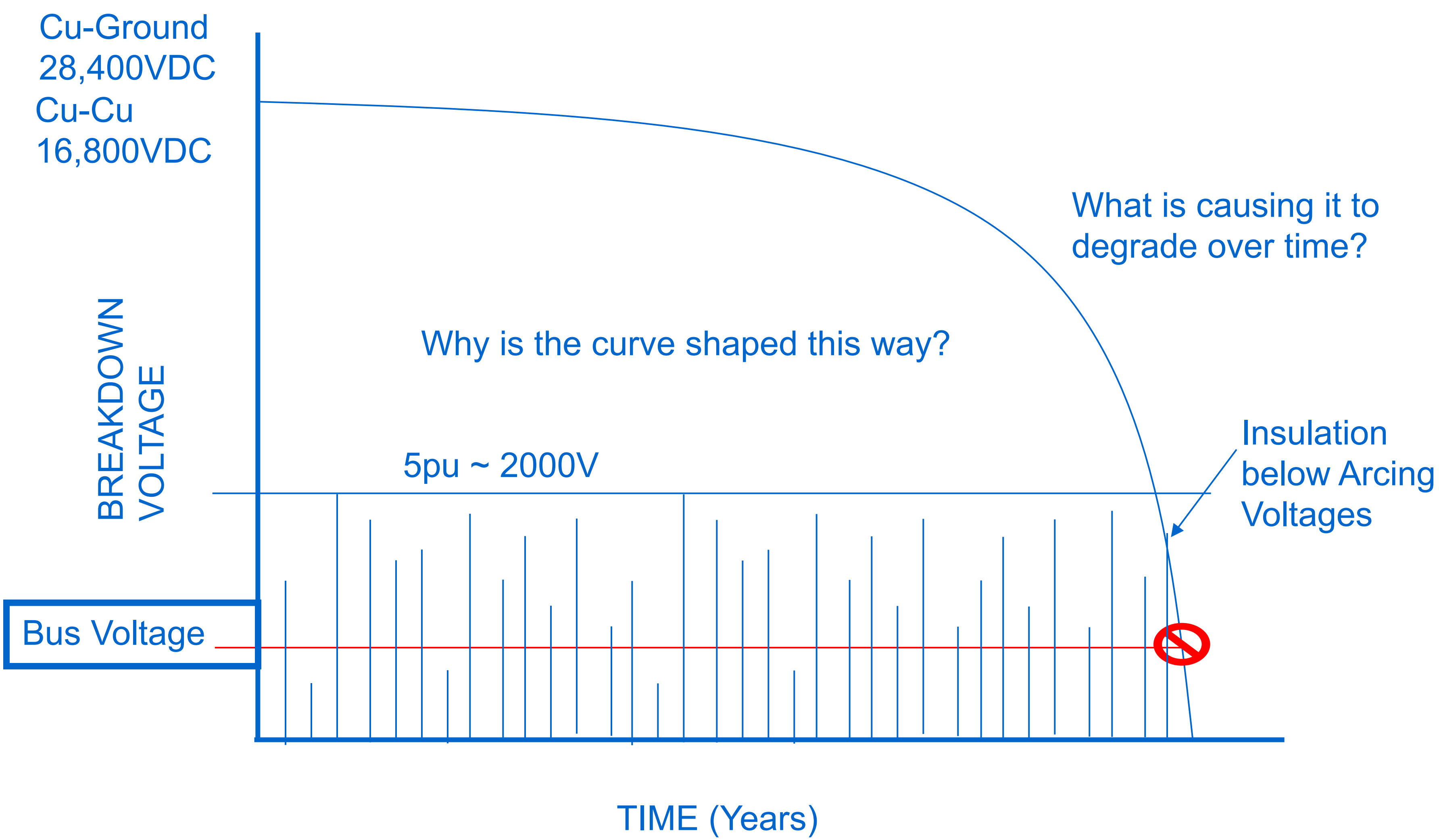
"…. Tests conducted by national organizations show that the worst surges have a magnitude of as high as 4.6 p.u. and a rise time of 0.1us; however, most motors experience surges on the order of 3 p.u. magnitude with a rise time of 0.2-0.6us. Surge tests conducted on motors show that the stator winding insulation has a surge strength in excess of 5 p.u. to 0.1us rise time."

Paschen’s Law



Paschen’s Law requires a minimum of 325 volts to instigate an arc.

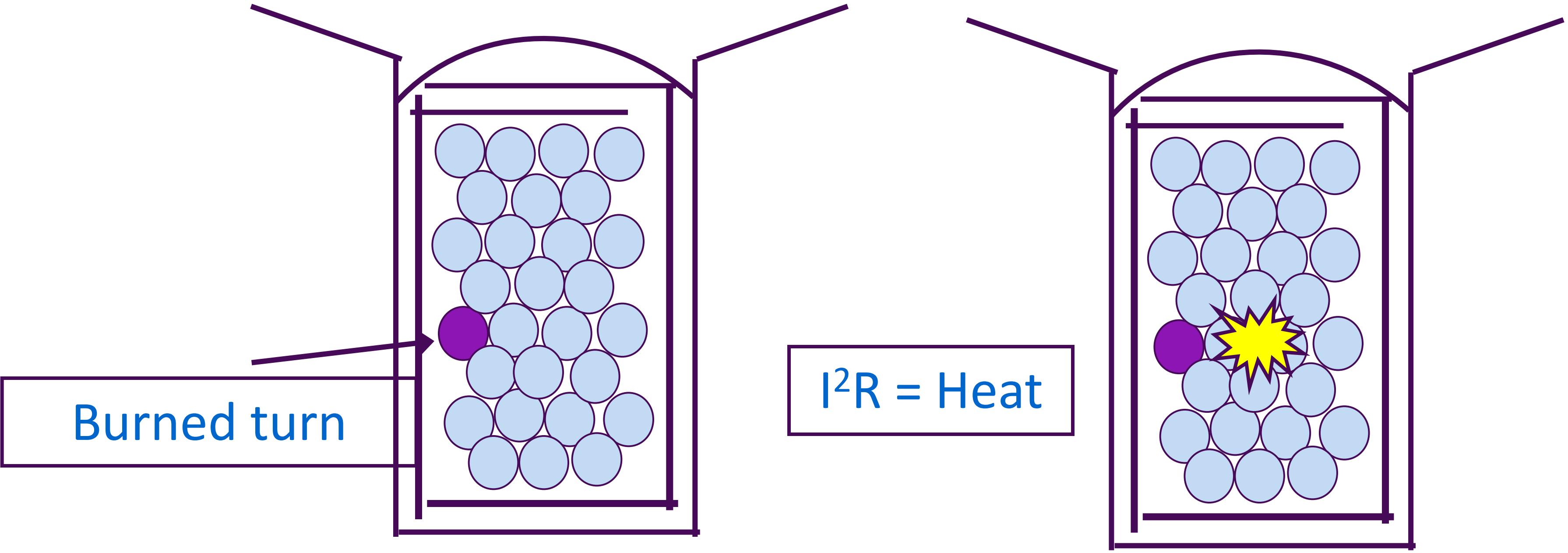
Insulation Life Curve



Fused Shorted Turns

Once the dielectric strength falls below the operating voltage the turns will fuse together!

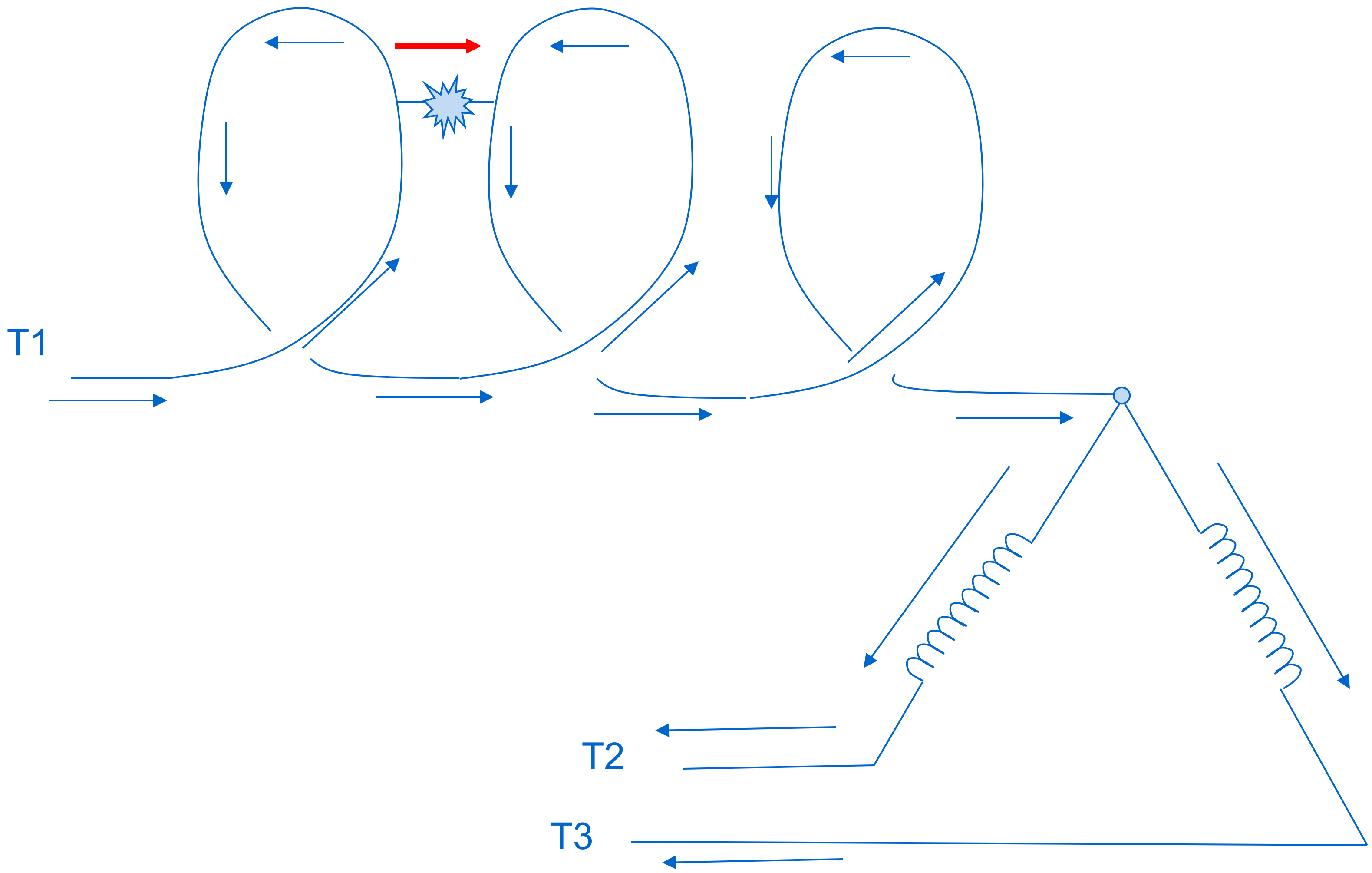
Auto Transformer Action of Welded Fault



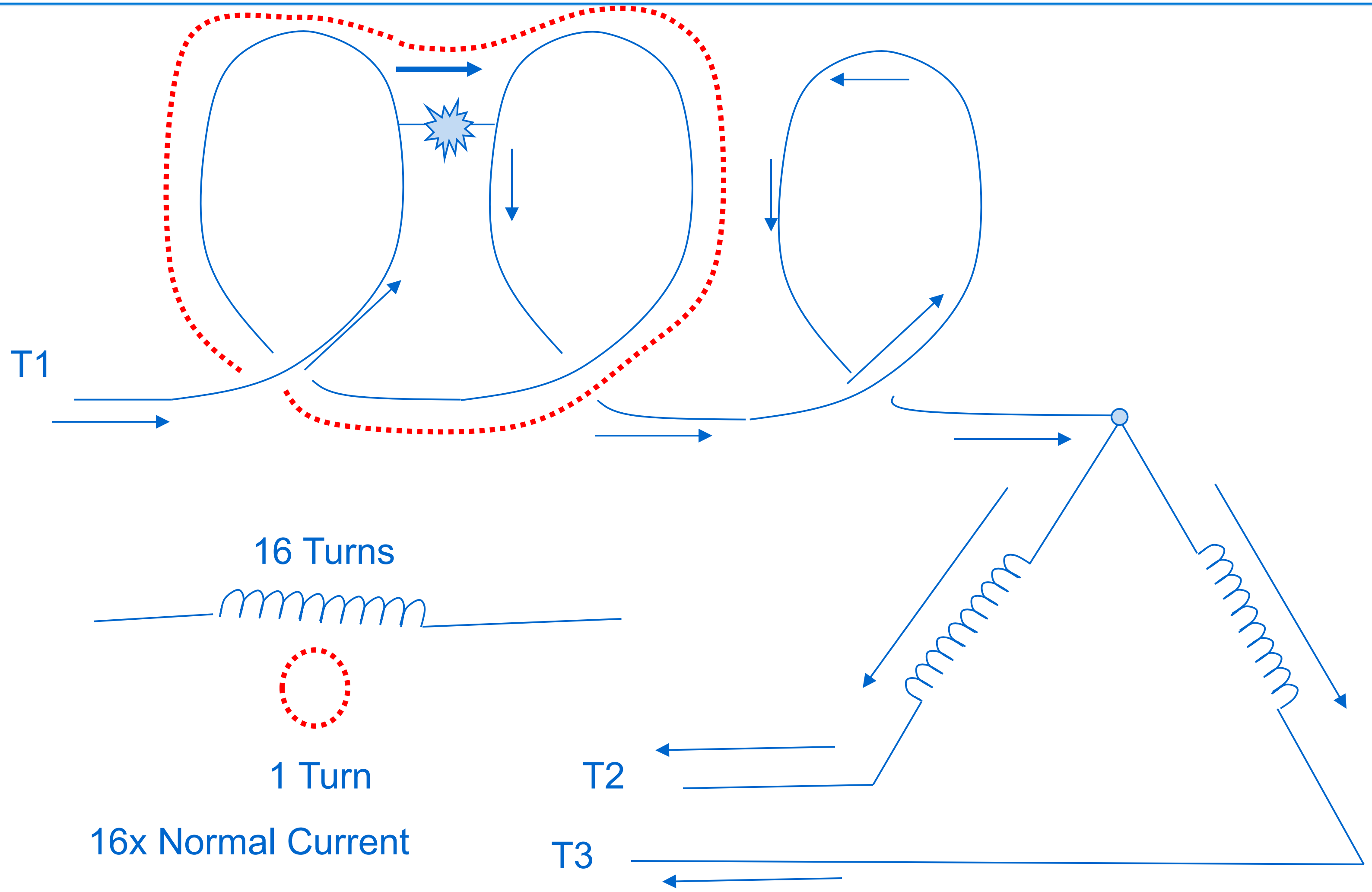
•Initial shorting of the turns is often in the extension, however, the failure to ground will be in the slots.

According to IEEE the welded faulted turns will burn through the slot cell liner to ground within 15 minutes.

Auto Transformer Action of Welded Fault



Auto Transformer Action of Welded Fault



16x Normal Current

» 32x Normal Heat (I^2R)

Turn to Turn Movie

Real-Life
Turn-to-Turn
Fault

R.M. Tallam, T.G. Habetler, R.G. Harley, "Transient Model for Induction Machines with Stator Winding Turn Faults." IEEE Transactions on Industry Applications, Vol. 38, No. 3, May/June 2002.

"….A turn fault in the stator winding of an induction machine causes a large circulating current to flow in the shorted turns, of the order of twice the blocked rotor current. **If left undetected, turn faults can propagate, leading to phase-ground or phase-phase faults. Ground current flow results in irreversible damage to the core and the machine might have to be removed from service. Incipient detection of turn faults is essential to avoid hazardous operating conditions and reduce down time."**

Important Point # 6

Once the turns fuse the motor fails almost immediately, leaving no time for other forms of testing.

Steps of Typical Motor Failure

1) Dielectric Strength of a new motor is very high
2) Motor will see normal aging

- Thermal
- Chemical
- Mechanical

3) Dielectric Strength falls below level of switching surges

- Arcing occurs when motor starts up

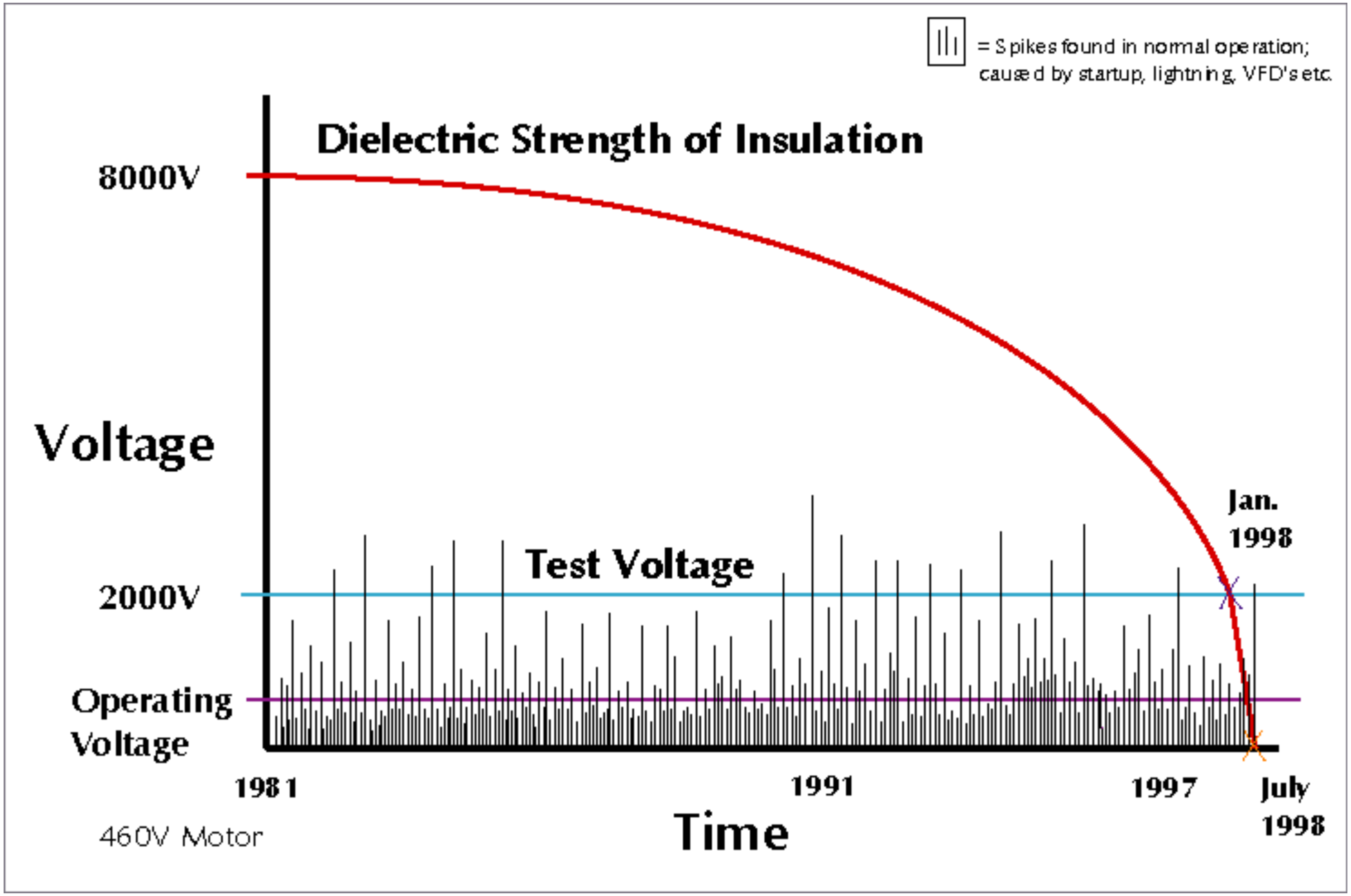
Steps of Typical Motor Failure

4) Insulation begins to deteriorate much faster
5) Dielectric Strength drops below operating voltage

- The short fuses

6) Transformer action causes high induced current - high heat
7) Rapid Failure

Dielectric Strength and Voltage Spikes



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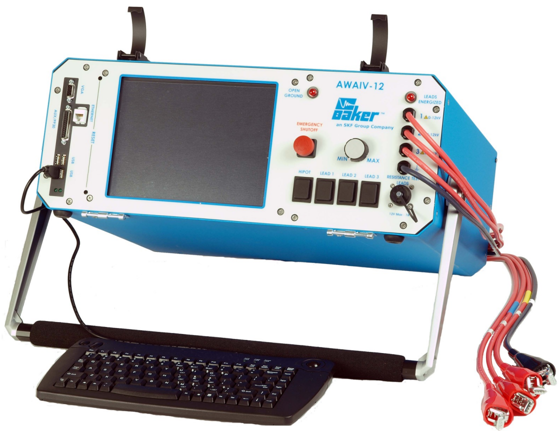
Motor Testing

Baker Off-Line Equipment

Trouble Shooting (TS)

Quality Assurance (QA)

Predictive / Preventive Maintenance (PPM)



Off-Line Motor Testing

- Coil Resistance (PPM, QA, TS)
- Meg-ohm Test (PPM, TS)
- PI (polarization test) (PPM, QA)
- Hipot Test (PPM, QA, TS)
- Surge Test (PPM, QA, TS)

Delta Resistance

The picture can't be displayed.

$$\frac{0.90 - 0.80}{0.85} = 11.76\%$$

Example: 1-2=0.80 ohms; 2-3=0.85 ohms; 1-3=0.90 ohms

$$\frac{R\max - R\min}{Raverage} \times 100\%$$

Or

$$\frac{Max\ deviation\ \ from\ \ Avg}{Avg} = \frac{0.05}{0.85} = 5.9\%$$

Resistance Testing Issues

Balance between phases

- # of Turns per phase
- Diameter copper
- High resistance connections
- Turn-To-Turn shorts
- Turn-To-Turn Opens

Meg-Ohm Testing

Apply test potential for 1 minute

Correct to 40° C.

Rule of thumb:

Resistance halves for each 10° C temperature increase

$$R_{40^\circ C} = R_{TEMP} \bullet 2^{\frac{T-40}{10}}$$

Rule of thumb:

Minimum value acceptable

1 meg ohm + 1 meg ohm / KV

(Corrected to 40° C)

Meg-Ohm Test

Meg-Ohm-Meter

- It Can:
  - Determine if the motor has failed to ground.
  - Dirty motor (Surface leakage)
  - Perform a Polarization Index and Dielectric Absorption Test.

Meg-Ohm Test

- It Cannot:
  - Determine if a motor is good
  - Find a Turn-to-Turn Fault
  - Find an Open Phase
  - Find a Phase-to-Phase Fault

Megohm Test Voltage

IEEE 43-2000 Table 1:

V line (AC)	V test (DC)
< - 2500	500 - 1000
2500 - 5000	1000 - 2500
5000 -12000	2500 - 5000
> 12000	5000 -10000

Polarization Index, Dielectric Absorption Test

PI Test 10min/1min

DA Test 3min/30sec

Polarization Index Test

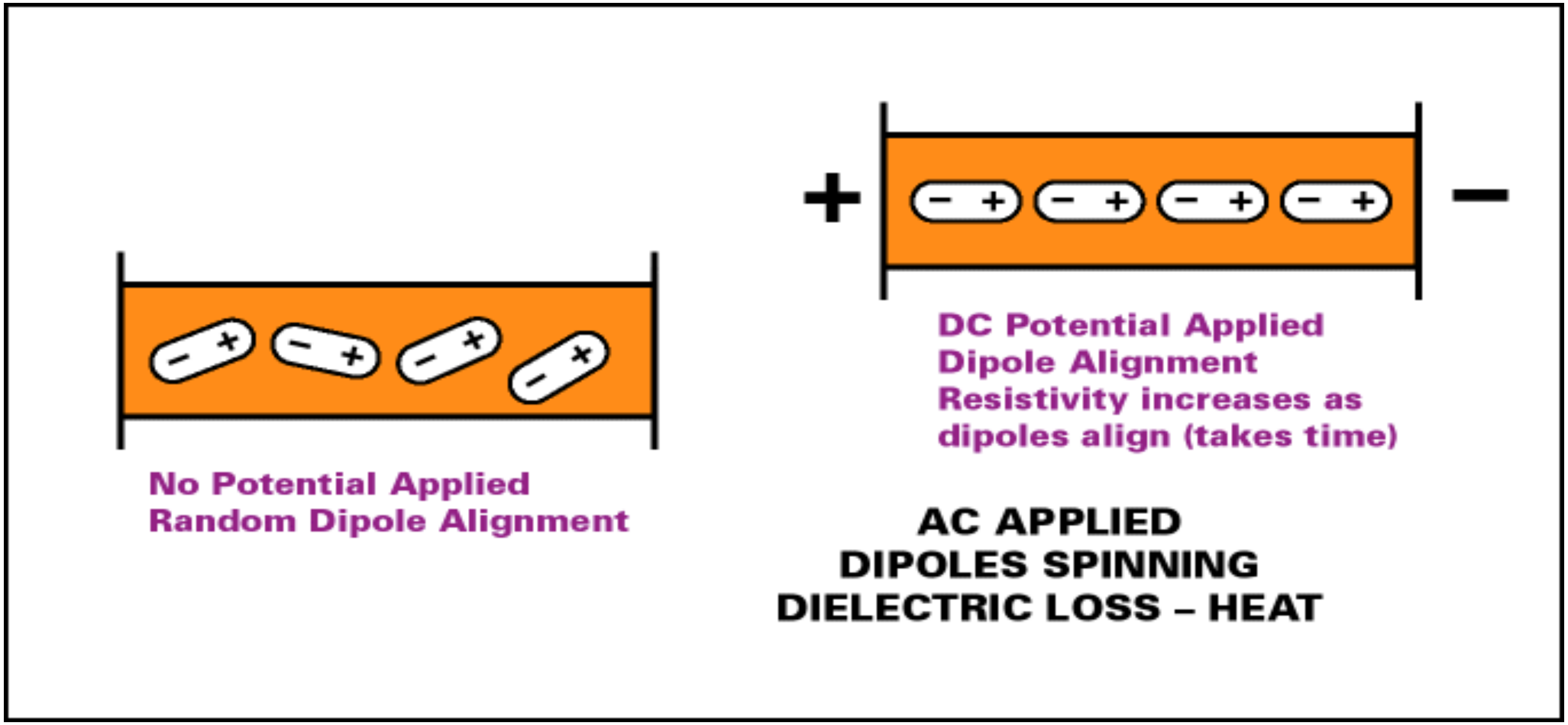
The ratio of insulation resistance after ten (10) minutes of minute. continuously applied DC, divided by the insulation resistance at one (1)

An indication of age and/or wet insulation

A fresh dry motor will easily exceed 20000 meg-ohms at 10 minutes.

PI Tip 1: Test instrument must be capable of measuring at least 20,000 meg ohms. It is preferred to have 50,000 meg ohm measuring capability.

PI and DA Test



Polarization Index, Dielectric Absorption Test

Can find-

- Deteriorated ground wall insulation
- Dry-rotted, hard, brittle ground wall insulation, contamination

PI & DA Pass Fail Levels

- Greater than 1 let it run (Common Field Rule)
- IEEE 2 or greater
- No accepted standard for DA
- DA value should closely resemble PI Ratio (>2)

Polarization Index Test

PI Tip 3: Insulation reading at one (1) minute should easily exceed 20000 meg- ohms.

This is recommended when trending. A simple P I > 1.0 is good enough to run.

PI Tip 4: Winding temperature should be less than 40C , but greater than ambient.

This will reduce the chance of condensation increasing the surface leakage.

(Test motor soon after shutdown, about 30 minutes. RTDs can be a useful indicator).

Surface leakage is a usually a result of moisture in the connection box

Polarization Index Test

PI Tip 5: It is recommended (Industry Standard) that the PI test voltage equal or exceed the numerical value of line voltage

Example: 460VAC - test at 500vdc

2300VAC - test at 2500vdc

4160VAC - test at 5000vdc

PI Tip 6: Small motors and generators can become polarized in much less than 10 minutes.

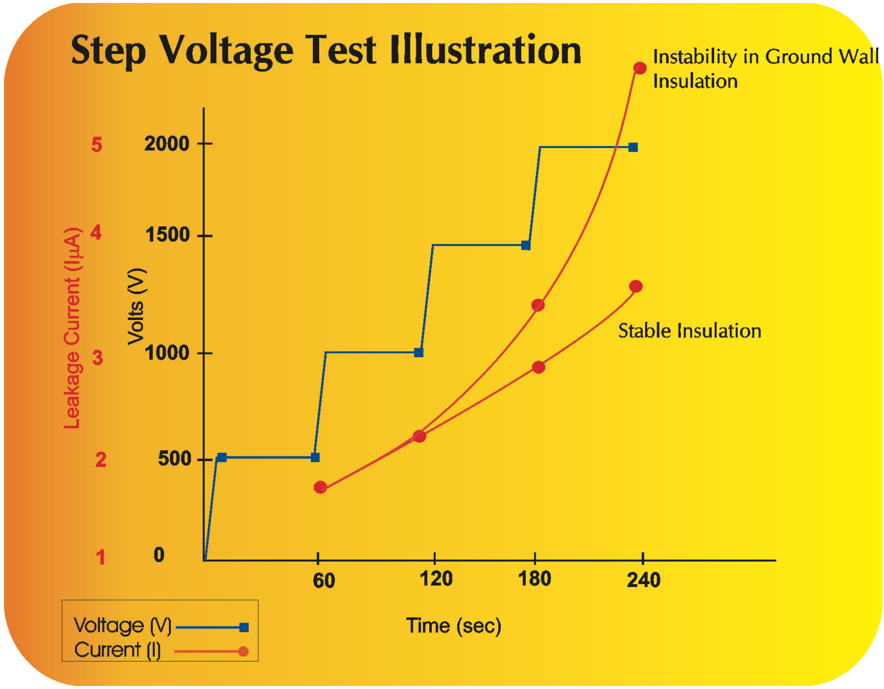
It is suggested that motors/generators 100hp or greater be PI tested.

Apparatus smaller then 100hp often can be tested using the “DA” test.

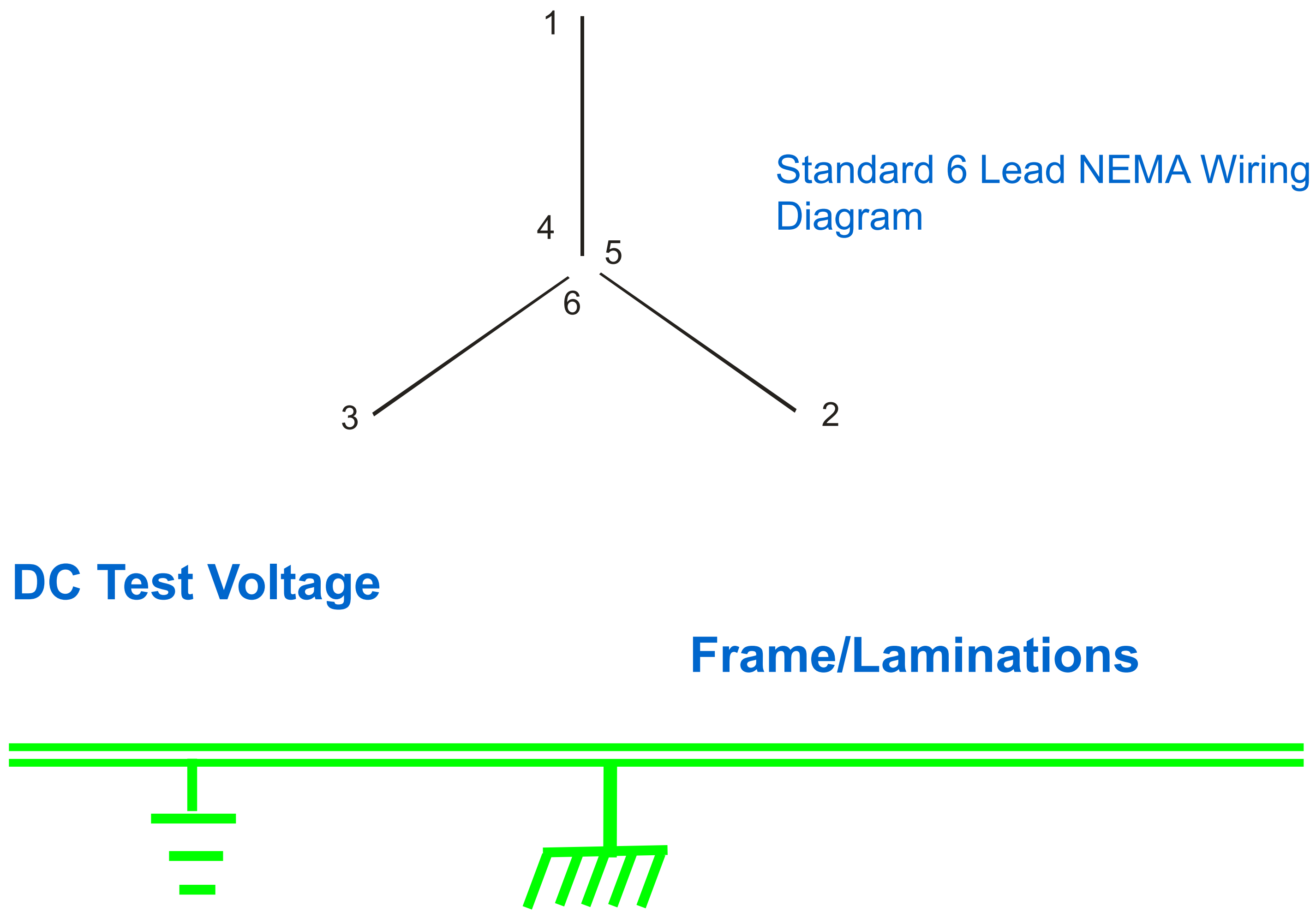
The parameters of time can vary, but 3 minutes divided by ½ minute seems to work well.

High Potential Testing

- Conventional HiPot,
- Ramped HiPot,
- Step Voltage HiPot



Hipot Testing



Hipot Testing

Can find-

- Weak Ground wall insulation
- Cable insulation

DC High Potential Testing
ANSI / IEEE Std 95-1977

Apply test potential for 1 minute Correct to 40 C.

Rule of thumb: Resistance halves for each 10 C temperature increase

ANSI/IEEE 95-1977

Insulation Testing of Large AC Rotating Machinery with High Direct Voltage

5.1 DC Test Voltage = 1.7 X AC Test Voltage

5.2 Maintenance Proof Testing

AC 125% to 150% of Terminal Voltage

Example:

4160 VAC

(1.25) (4160) (1.7) = 8800 VDC

(1.50) (4160) (1.7) = 10,600 VDC

Baker Instrument suggests:

Twice Voltage + 1000 Volts

or (4160) (2) + 1000 = 9320 VDC

Hi-Pot testing

NEMA MG-1

3.01.6 - Apply for 1 minute

12.03 - 1000 VAC + 2 X rated volts — 1920 VAC

3.01.12 - 75% Installation Test Volt — 1440 VAC

20.48.2 - DC Test = 1.7 X AC Test (DC insulation test) — 3264 VDC

Baker recommends Twice Voltage + 1000 — <u>1920VDC</u>

For motors in service

Example: 460 Volt Machine

HiPot Test Voltages IEEE 95-1977
Para 5.2 for Maintenance Proof Testing

Vline	Per Unit	Min Test V Vline*1.25X1.7	Max Test V Vline*1.5*1.7
480	392	1020	1224
575	469	1222	1466
600	490	1275	1530
2300	1878	4888	5865
4160	3397	8840	10608
6900	5634	14663	17595
13800	11268	29325	35190

EASA DC HiPot (Table 4.2)

Vline	New 1.7(2V+1000)	In Service 65% of New
480	3332	2165.8
575	3655	2375.75
600	3740	2431
2300	9520	6188
4160	15844	10298.6
6900	25160	16354
13800	48620	31603

Gupta, Stone, and Stein, "Use of Machine HIPOT testing in Electric Utilities." 0-7803-7180-1 IEEE, 2001 (IEEE Dielectrics and Eletrical Insulation Society)

Survey of utilites doing HIPOT testing.

"Does Hipot Testing damage a good winding? This question is raised many times, most often by managers, who have to approve the tests. The answer is a resounding NO. Hipot tests do not introduce any significant degradations in a machine with a good insulation system. Machines that have failed a hipot test have always revealed poor insulation systems upon later examination. Chances are that they would have failed in service, especially if an over voltage from surges or a power system fault were to occur. Hence, only machines with poor or marginal insulation systems are likely to fail during the hipot test."

Gupta, Stone, and Stein, “Use of Machine HIPOT testing in Electric Utilities.” 0-7803-7180-1 IEEE, 2001 (continued)

“…All coils and bars used in modern machines have the capability to pass a voltage endurance test.”

“…..13.8kV winding should survive for 250 hours at 35kV at about 100degC….. If a 400 hour test represents 25 years of line in-service, then a one minute 29kV over potential test at 100degC ages the insulation by 9 hours. If the temperature effect is taken into account using, say a 10-degree rule, the *reduction in life caused by the hipot test at room temperature (30degC) is about 1/16 of an hour only.”*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Fort Collins, CO 80525
(970) 282-1200
(970) 282-1010 FAX
(800) 752-8272
www.bakerinst.com

Step Voltage Test

vs

Continuous Ramp HiPoT

vs

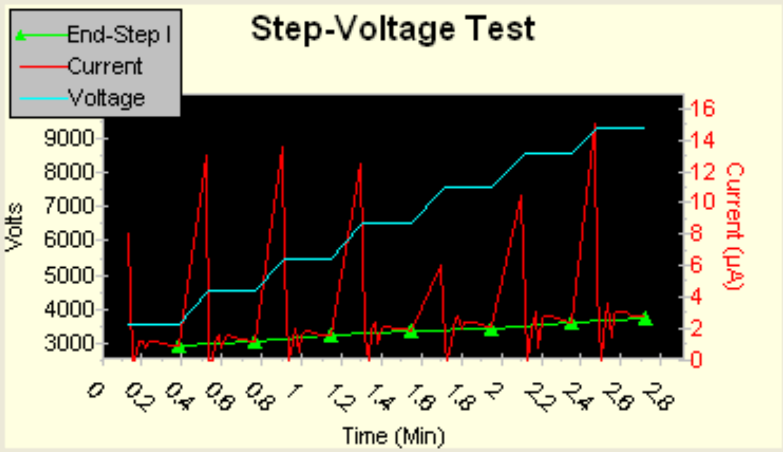
Conventional HiPot

Step Voltage Test

- Raises test voltage in steps, holding at preset levels for a preset time.
- Allows “charging” current influence to be mitigated.
- Divides the two currents for analysis
- Holds final target voltage for one minute as defined by IEEE 95-1977 and NEMA MG-1.

Benefits and Uses

- Is less stressful to windings.
- Useful when the condition of the motor is unknown or suspect.
- Useful when more frequent testing is required.
- Useful when the motor has moisture contamination.



Current vs Voltage

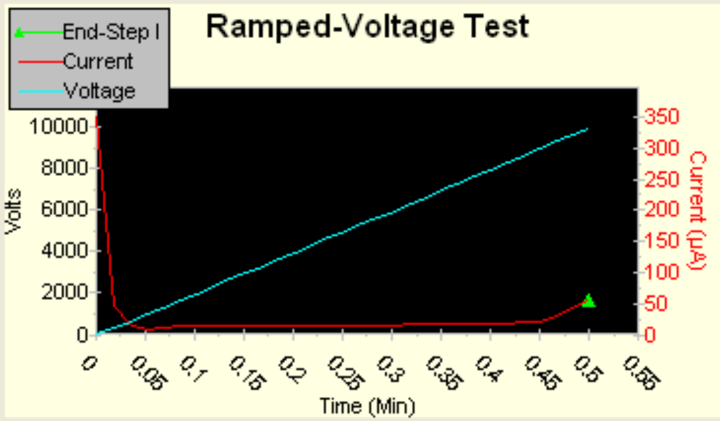
Current/Voltage vs Time

Time (Sec)	Volts	Current(µA)	Megohms
15	3510	0.90	3900
15	4520	1.20	3767
15	5500	1.50	3667
15	6540	1.80	3633
15	7560	2.00	3780
15	8560	2.40	3567
15	9360	2.60	3600

Continuous Ramp HiPot

- Ramp to target voltage using a preset voltage rate but does not pause until target voltage is reached.
- Shows instability in the “charging” current.
- Does not hold final target voltage for one minute as defined by IEEE 95-1977 and NEMA MG-1.

Time	Test ID	Temp	Re...	Mohm	PI	Hipot	Srg
08/05/05 14:04:23	Ramped ...					FAIL	
08/05/05 14:02:40	Ramped ...					PASS	
08/05/05 13:59:16	Ramped ...					PASS	



Current vs Voltage

Current/Voltage vs Time

Time (Sec)	Volts	Current(µA)	Megohms
30	10000	55.00	182

Conventional HiPot Test

Quickly “ramps” to target voltage and holds for one minute.

- Creates a more normal start up environment.
- Is the fastest of all the dc high voltage tests.

Hold final target voltage for one minute as defined by IEEE 95-1977 and NEMA MG-1.

Surge Testing

- Not a new concept. First recorded in 1936.
- Initially developed by General Electric & Westinghouse.

Surge Test

Field Testing Can Find-

- -Weak insulation (PPM, QA, TS)
  - Turn-To-Turn
  - Phase-To-Phase
  - Coil-To-Coil

Surge Testing

- Can find-
  - Weak insulation turn to turn, phase to phase, coil to coil (QA, TS, PPM)
  - Reversed coils (QA)
  - Turn-To-Turn shorts (QA,)
  - Unbalanced turn count (QA)
  - Different size copper wire (QA)
  - Shorted laminations (QA)

Motor Shop Testing vs. Field Testing

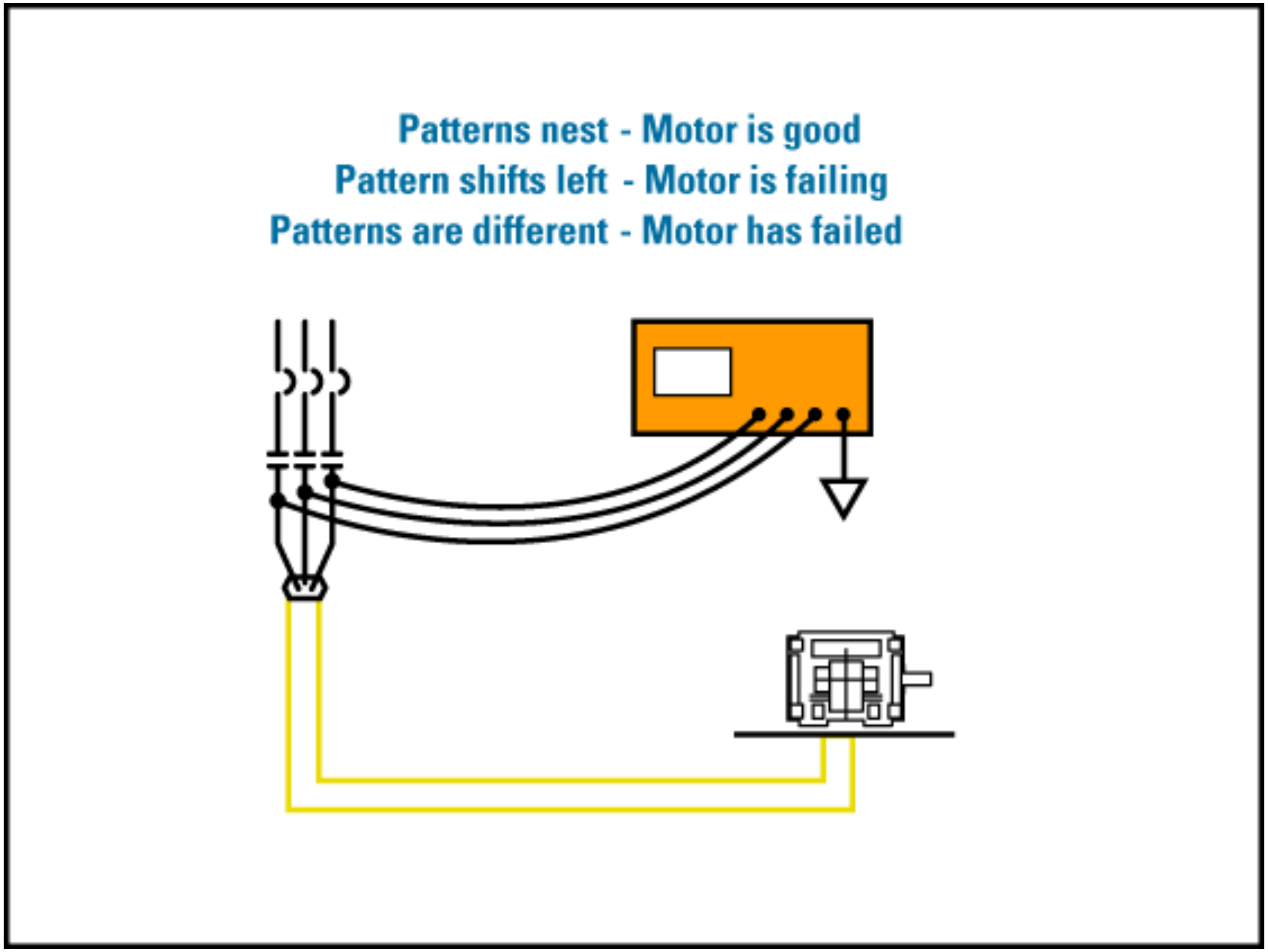
Field Testing

- Do not compare the wave forms
- Pulse - Pulse EAR

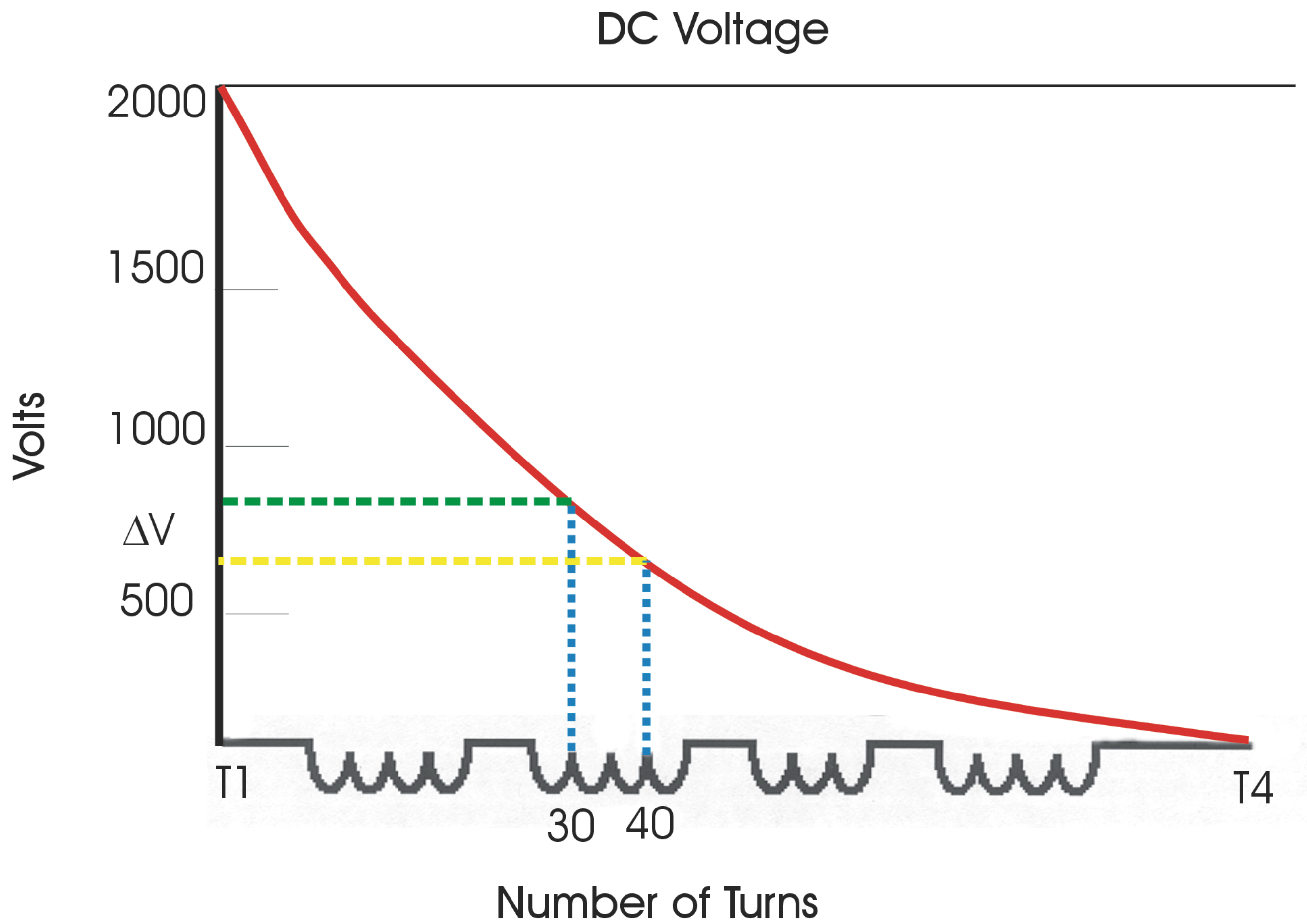
Motor Shop testing

- Must compare wave forms
- Line - Line EAR

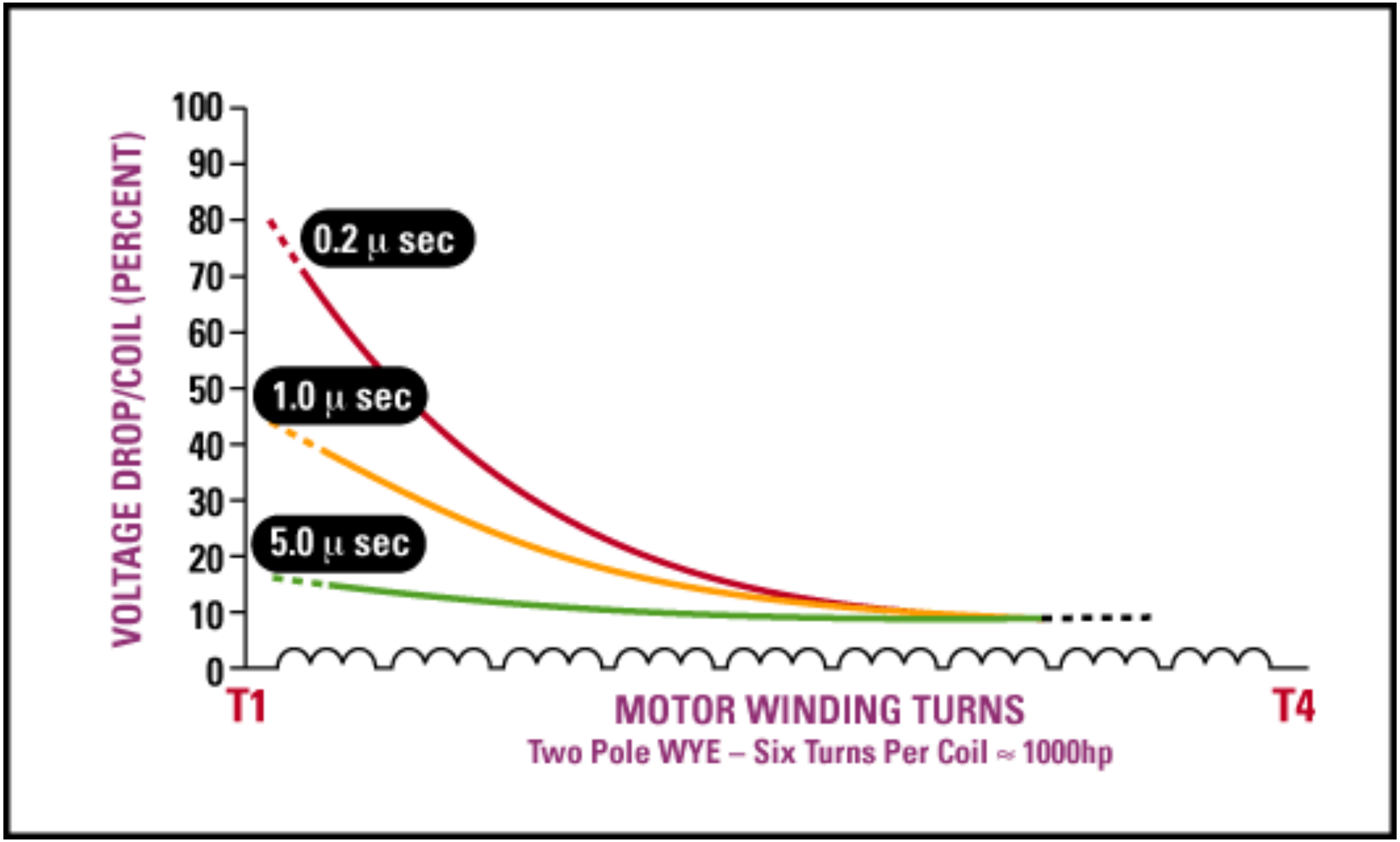
Surge Testing



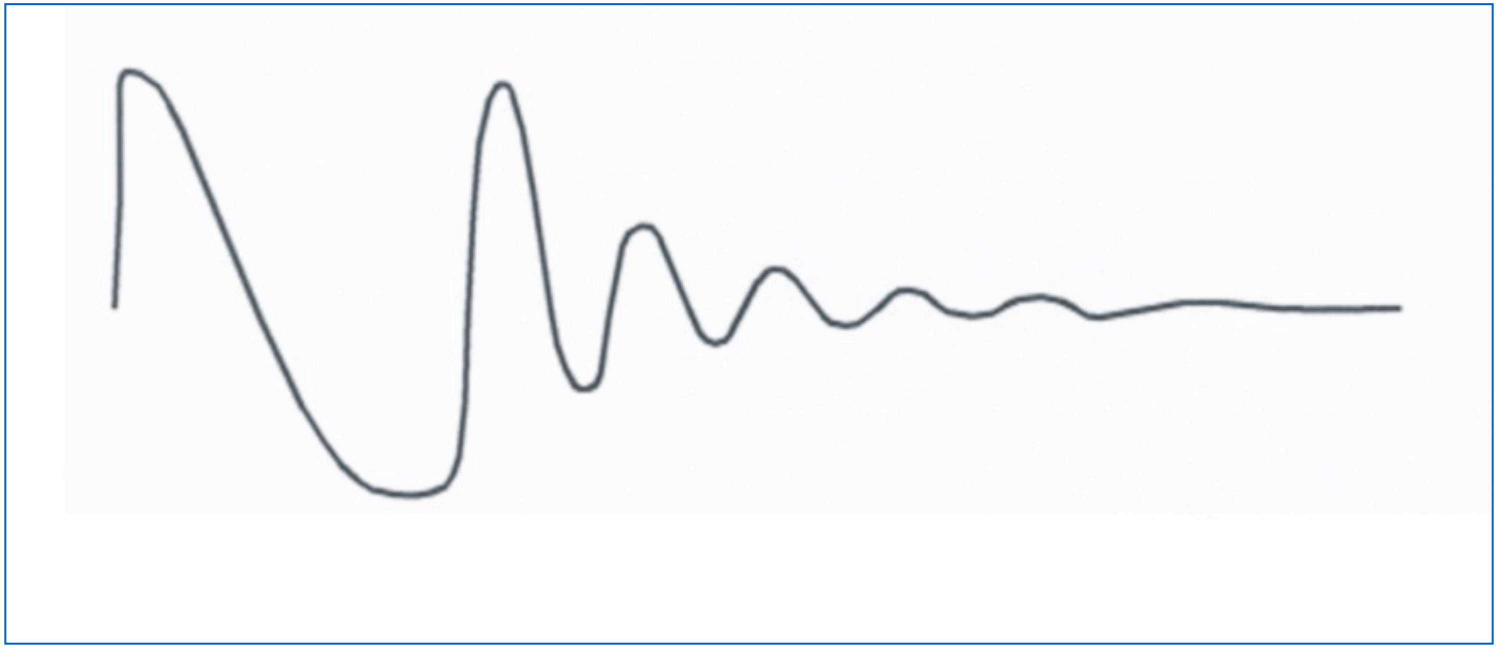
Voltage Drop over the Turns



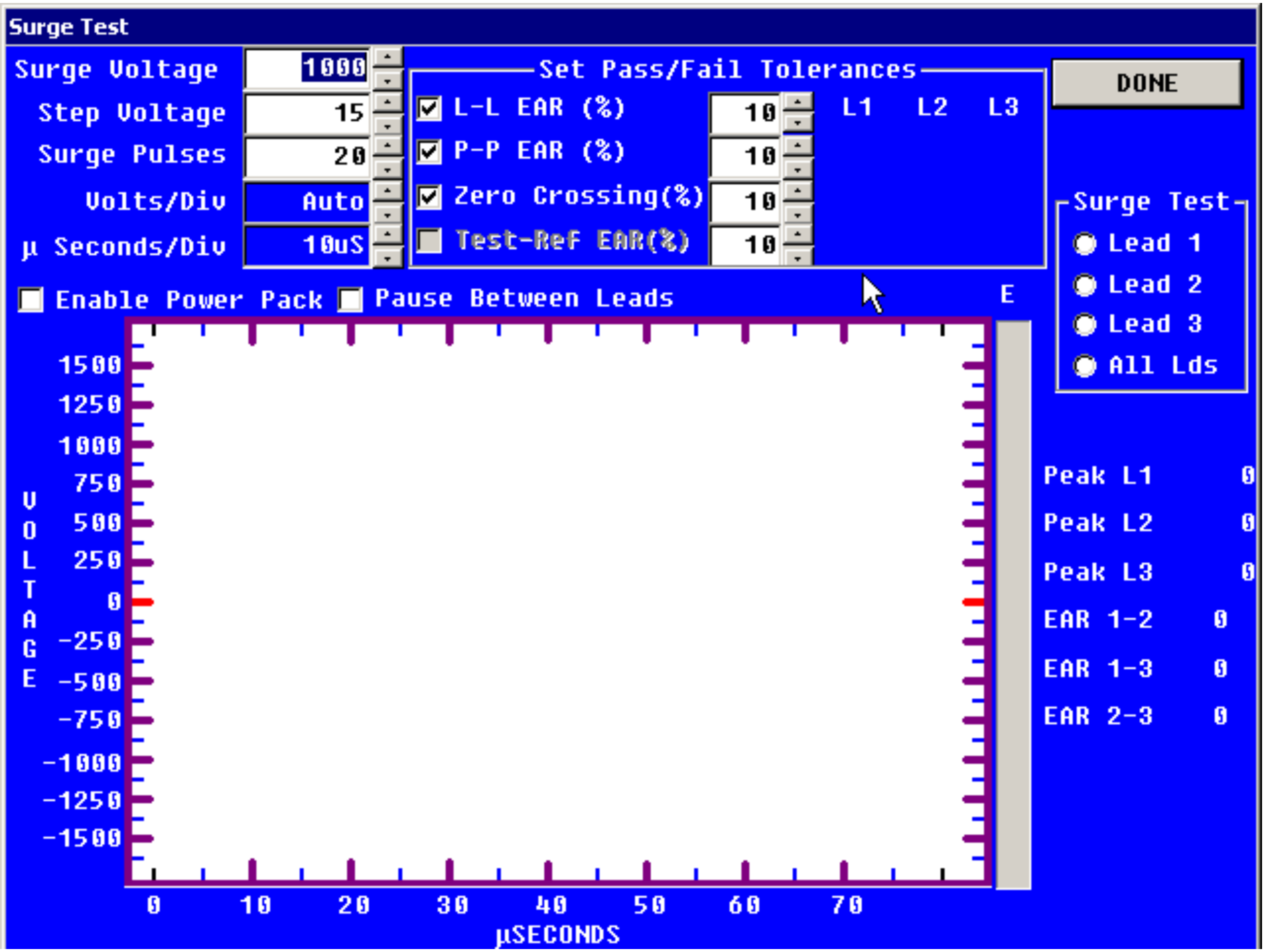
Voltage Distribution Across Coils as a Function of Surge Pulse Rise Time



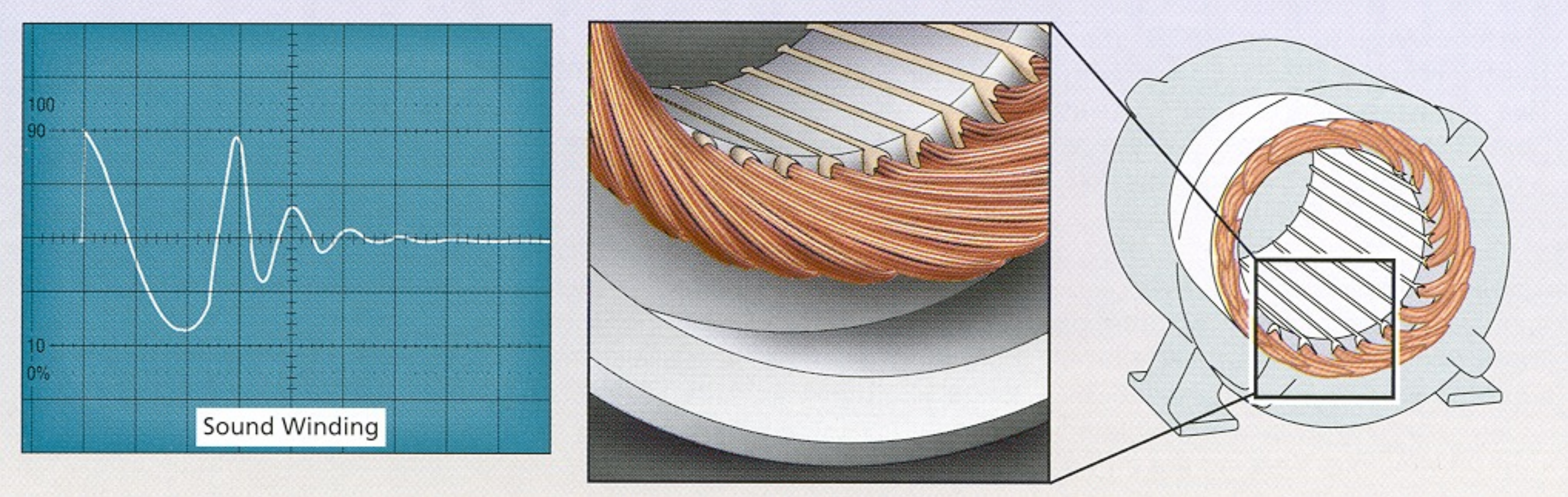
Surge Ring



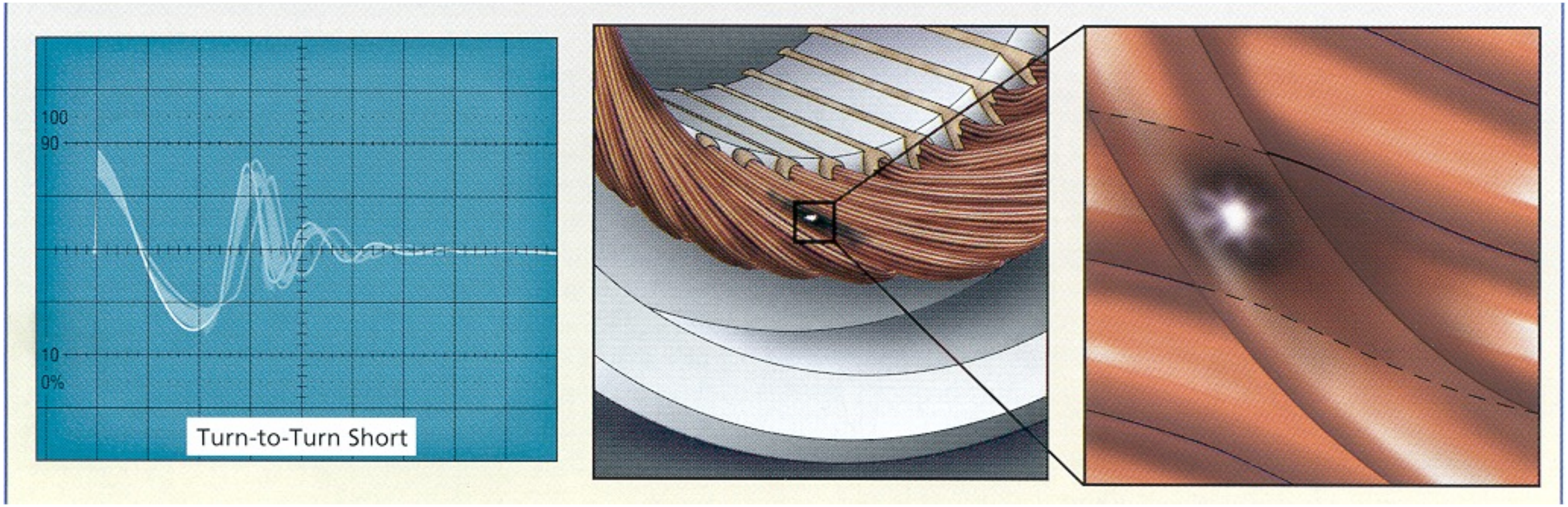
How does the surge test work?


Surge Test
Surge Voltage 1000
Step Voltage 15
Surge Pulses 20
Volts/Div Auto
µ Seconds/Div 10uS
Set Pass/Fail Tolerances
L-L EAR (%) 10
P-P EAR (%) 10
Zero Crossing(%) 10
Test-Ref EAR(%) 10
L1 L2 L3
DONE
Surge Test
Lead 1
Lead 2
Lead 3
All Lds
Enable Power Pack
Pause Between Leads
E
1500
1250
1000
750
500
250
0
-250
-500
-750
-1000
-1250
-1500
VOLTAGE
0 10 20 30 40 50 60 70
µSECONDS
Peak L1 0
Peak L2 0
Peak L3 0
EAR 1-2 0
EAR 1-3 0
EAR 2-3 0

Good Windings



Weak Turn to Turn Insulation



IEEE 522 Surge

Vline	New 3.5*pu	In Service 75% of New
480	1372	1029
575	1643	1232
600	1715	1286
2300	6573	4930
4160	11888	8916
6900	19718	14789
13800	39437	29578

IEC 34-15 Surge Test

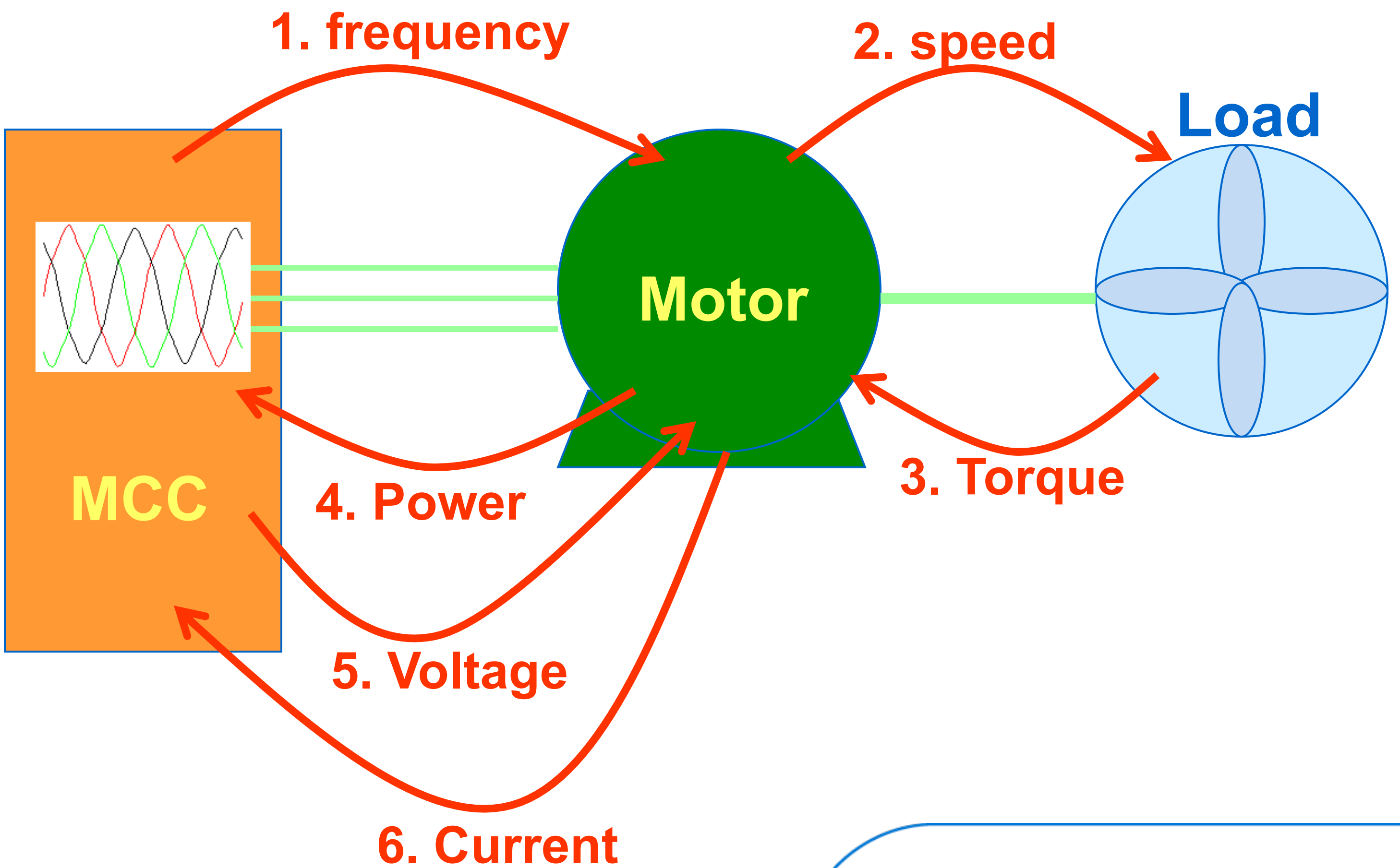
Vline	New 4E+5000	In Service 65% of New
480	6920	4498
575	7300	4745
600	7400	4810
2300	14200	9230
4160	21640	14066
6900	32600	21190
13800	60200	39130

Questions and Comments?

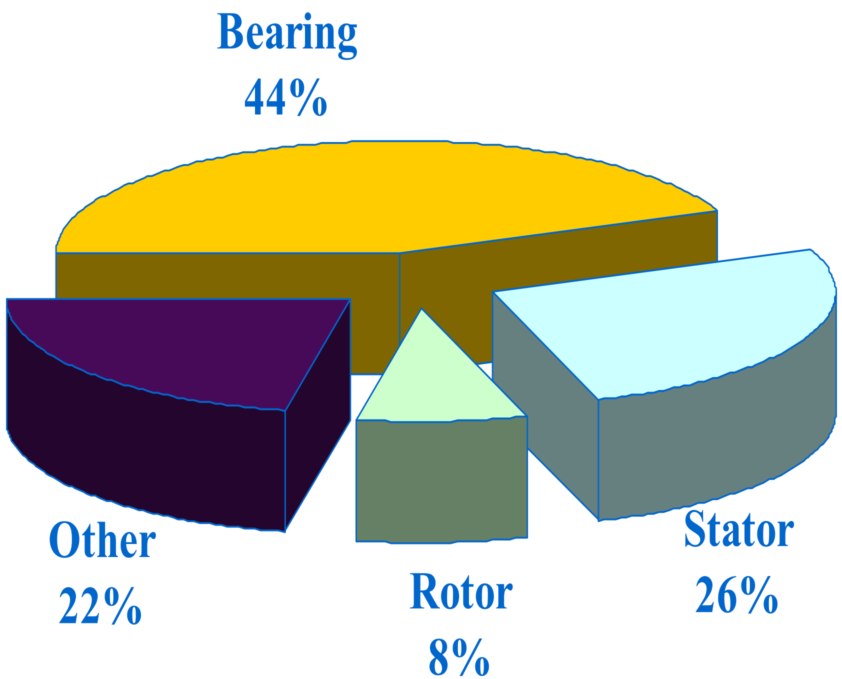
Dynamic Motor Monitoring

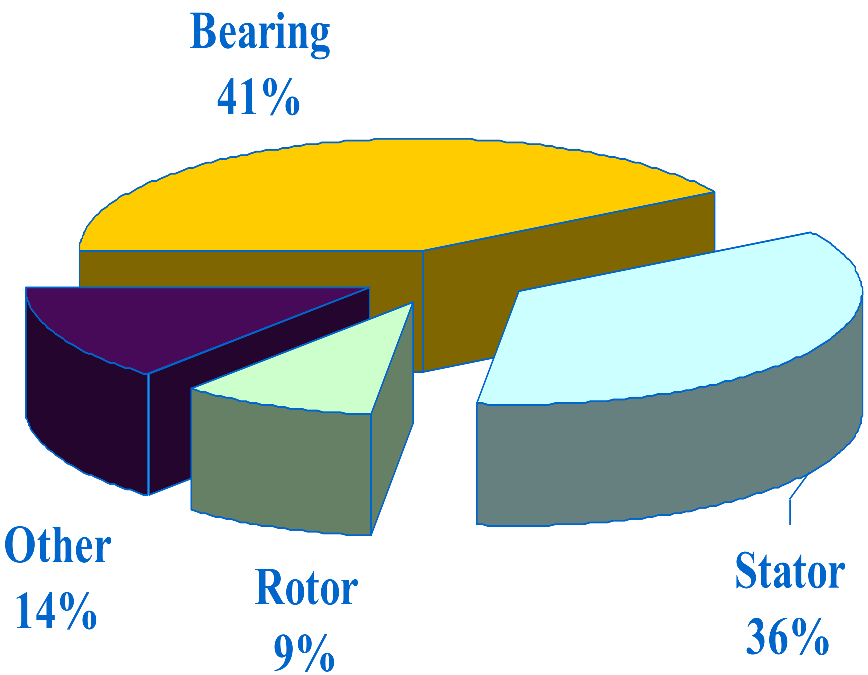
Intro to dynamic motor monitoring

Chain of events:
Cause and effect

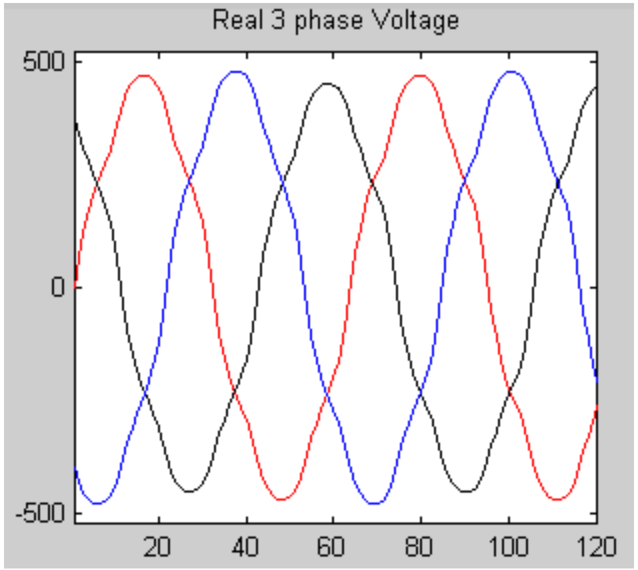


Motor Failure Areas:
IEEE Study / EPRI Study





Power Condition:



- Voltage level
- Voltage balance
- Voltage distortion

- Voltage issues come from up-stream
- Voltage problems affect whole bus

Incoming Power

Low Voltage → Over Currents (Over Heat)

High Voltage → Low Power Factor

→ Iron Saturation

→ Ultimately Higher Losses

Over/Under Voltage

Voltage deviations usually caused by

- Poorly performing or improperly adjusted transformers
- Undersized conductors
- Poor connections
- Low power factor sources in the distribution system

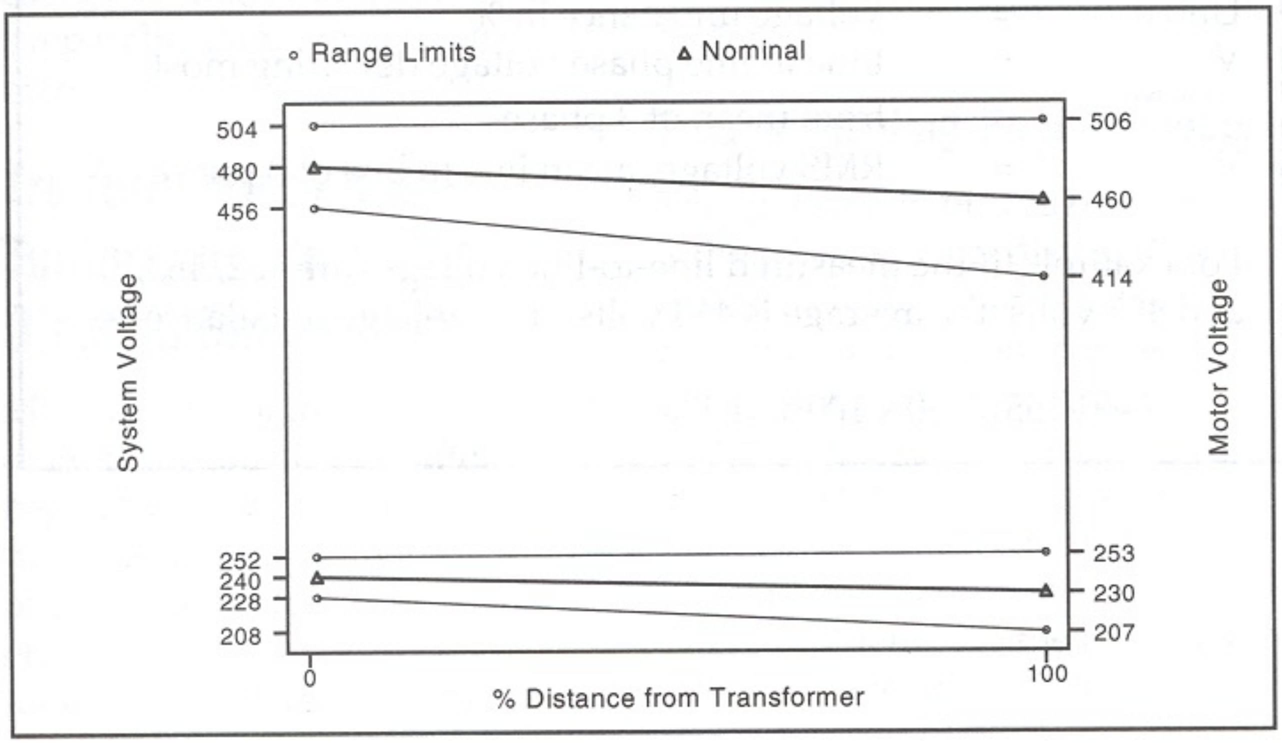
Over/Under Voltage

Motors are designed to operate with +/- 10% of rated voltage

Ideally, voltage supply deviation should be less than +/- 2%

When operating over/under voltage a motors performance, efficiency, and power factor change

Acceptable Voltage Range on Motors & Systems



Comparison of voltage level

-Average winding temp

-Motor efficiency*

Voltage	-10% (414V)		Normal (460V)		+10% (506V)	
HP Full Load	Temp	Eff	Temp	Eff	Temp	Eff
10	66	90.0	56	91.4	55	91.5
20	84	90.4	70	91.8	67	92.1
50	84	91.9	69	93.1	62	93.6
100	82	94.2	72	94.8	69	94.9
200	90	94.9	77	95.5	74	95.7

*US Motors

Typical Values for TEFC 4-pole Energy Efficient Motors

Incoming Power

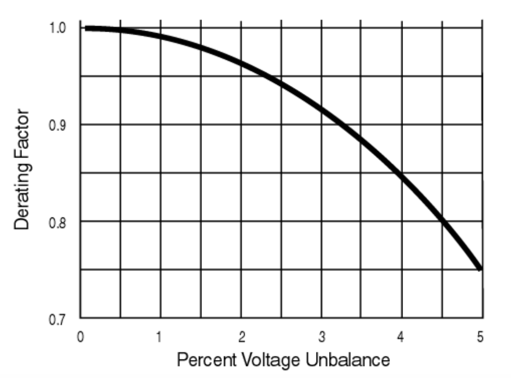
Voltage Balance

Unbalanced Voltages → Negative Sequence currents & Voltages

→ Low Power Factor

→ Iron Saturation

Faster Degradation



NEMA Derating for Unbalance

Unbalances

When a voltage unbalance reaches 5 %, the phase currents can differ by as much as 40 %.

$$Unbal = 100 \times \frac{|V_{maxdev} - V|}{V}$$

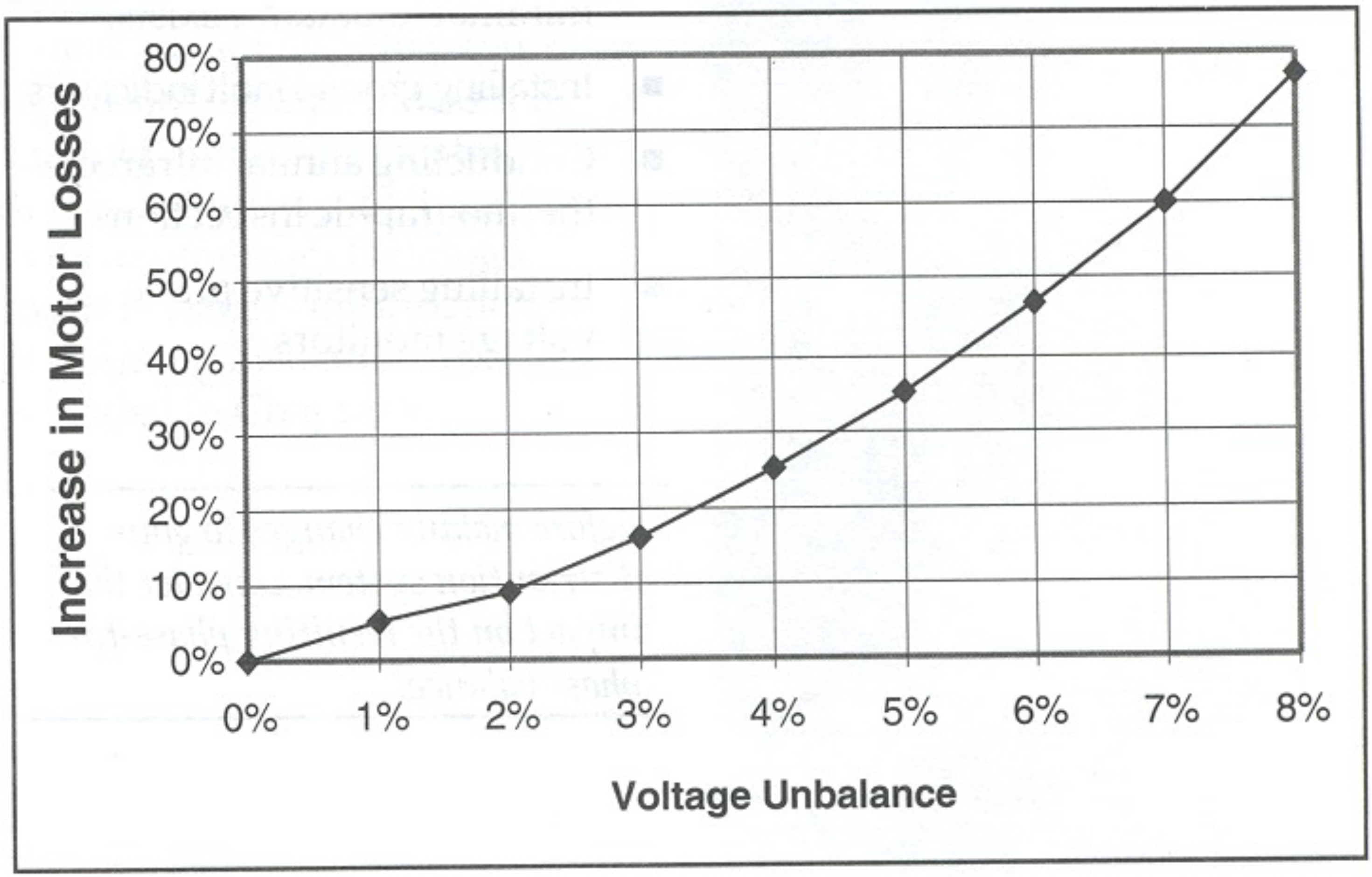
Where:

Unbalance = Voltage unbalance in %

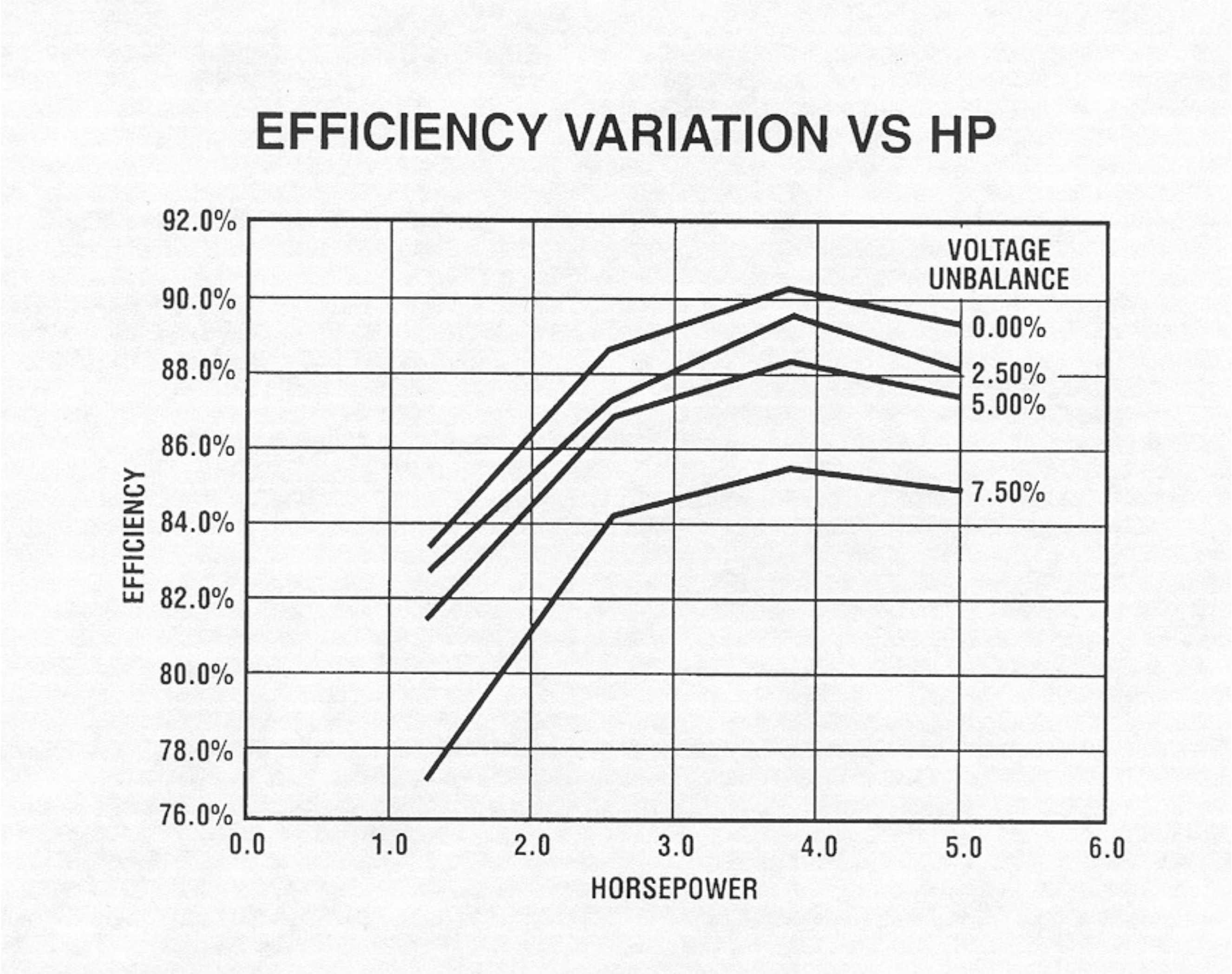
V_{maxdev} = Line to line phase voltage deviating most from mean of 3 phases

V = RMS voltage, mean line to line of 3 phases

Effects of Voltage Unbalance on Motor Losses



Efficiency Variation vs HP



Investigate Unbalances:

Voltage unbalanced

Find (and fix) V unbalance reason.

Odd case / Bad Signals

R unbalance possible.
Only assessment:
% I unbalance test log.

Current balanced

Current unbalanced

Everything ok.

Significant load?

(N): No assessment.

(Y): Investigate R unbalance down-line.

Voltage balanced

Incoming Power

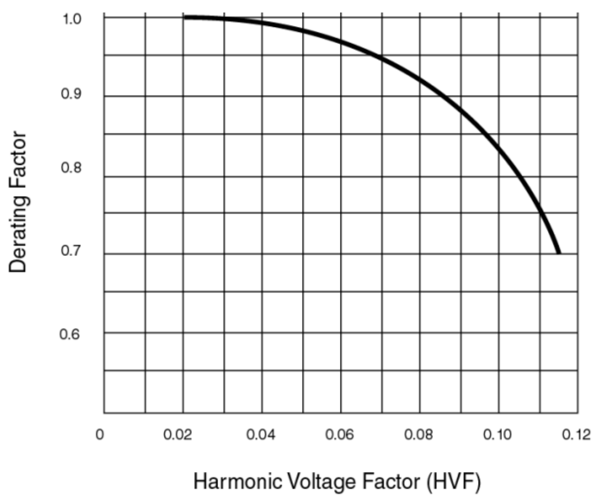
Voltage Distortion

Non Sinusoidal Voltages → Create Non-Sinusoidal Currents

→ Create Additional Heat

→ Causes Lower Efficiencies

Faster Degradation



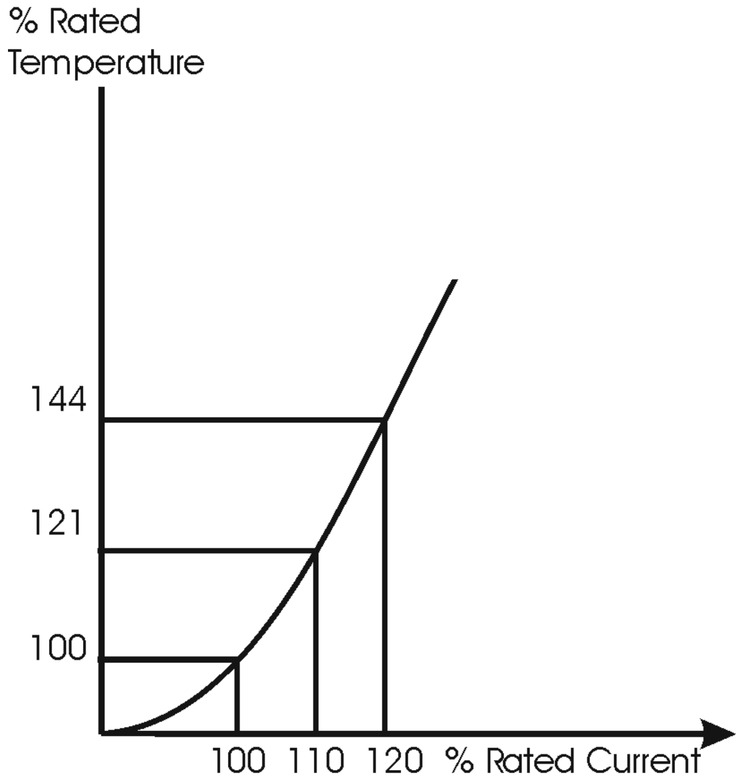
NEMA Derating for Harmonics

Motor Overheating

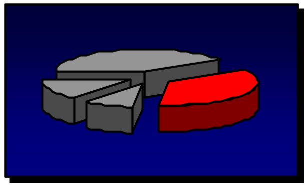
I^2R Losses → Motor Currents

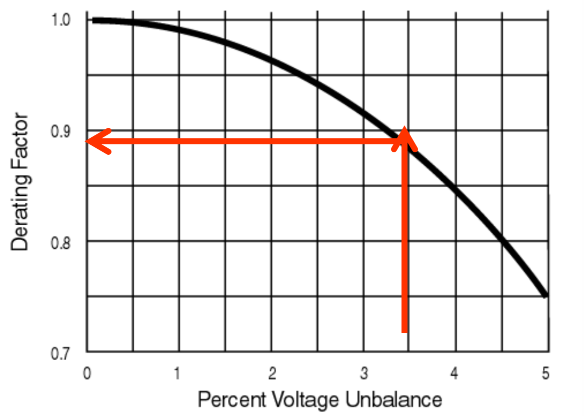
100% rated Current → 100% rated temperature

110% rated Current → 121% rated temperature

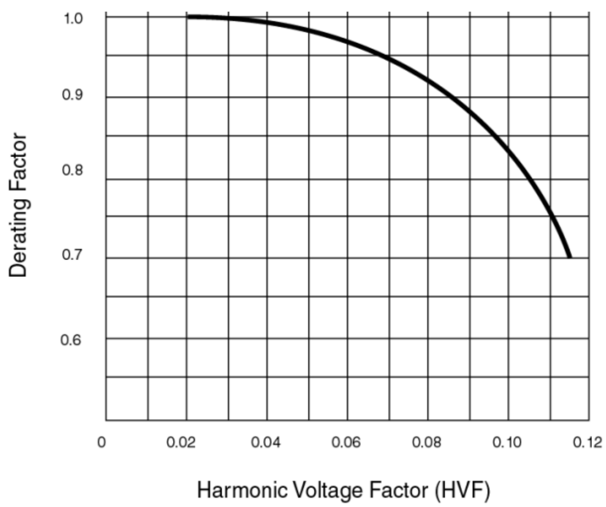


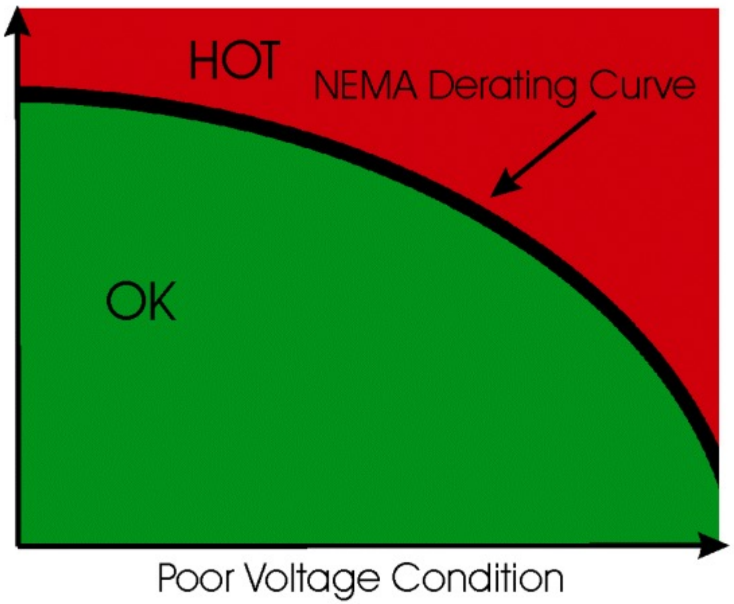
Stator



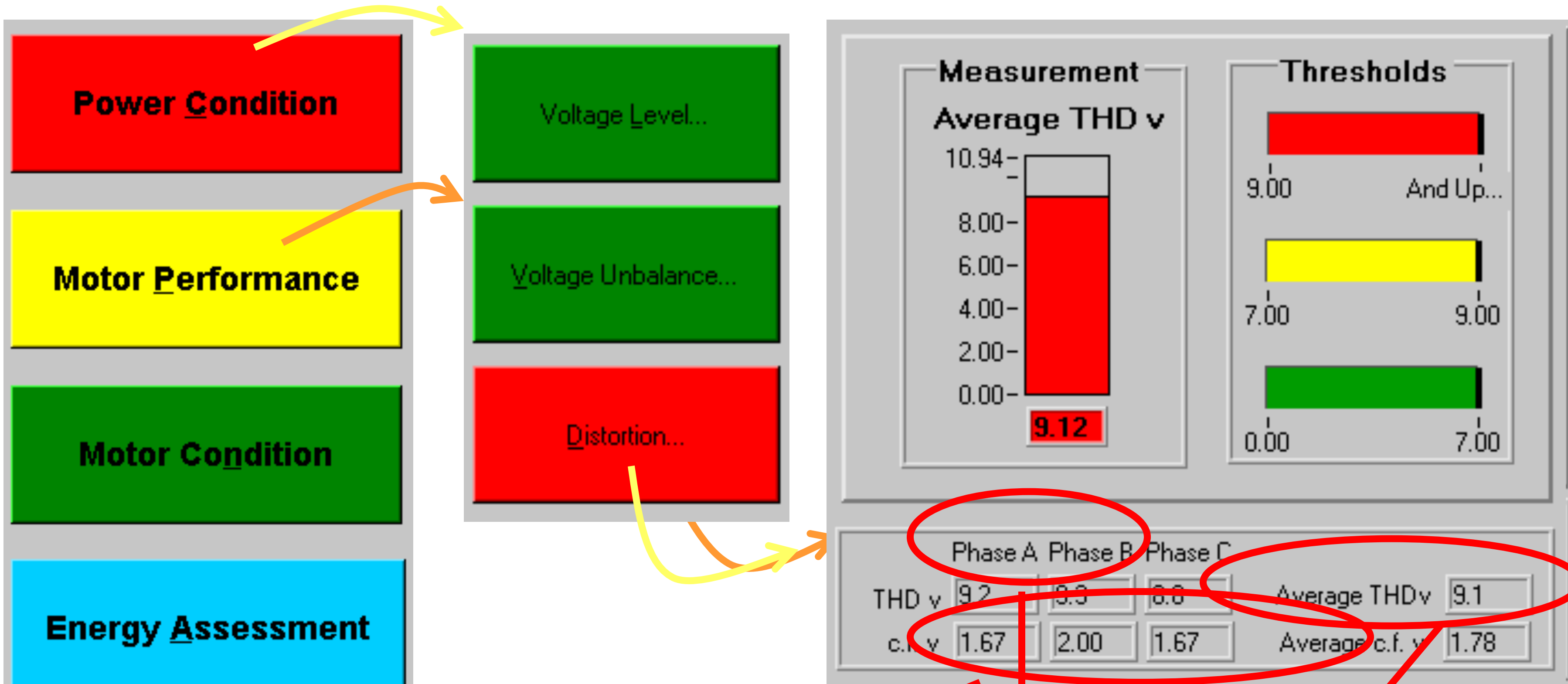


- Voltage quality
- NEMA derating





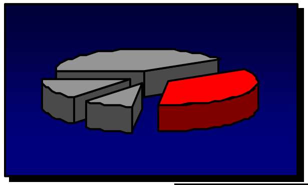
Effective s.f.



$$\text{Eff. s.f.} = \frac{\%\ \text{Load}}{\%\ \text{NEMA derating}}$$

Test station 300 hp   3570 rpm

Motor Performance: Service Factor and Temperature



	Temperature (C)		
Horsepower	Full Load	1.15 SF	1.25 SF
10	49	64	77
20	56	75	91
50	75	102	128
100	64	80	94
200	69	89	106

* Courtesy U S Motors

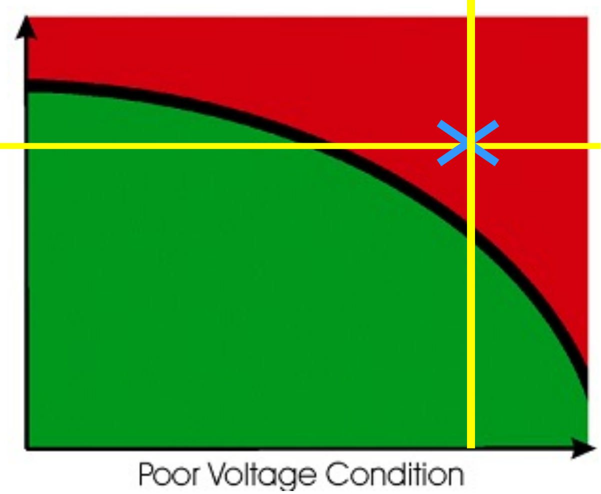
Effective s.f.

Pulp & Paper Industry:

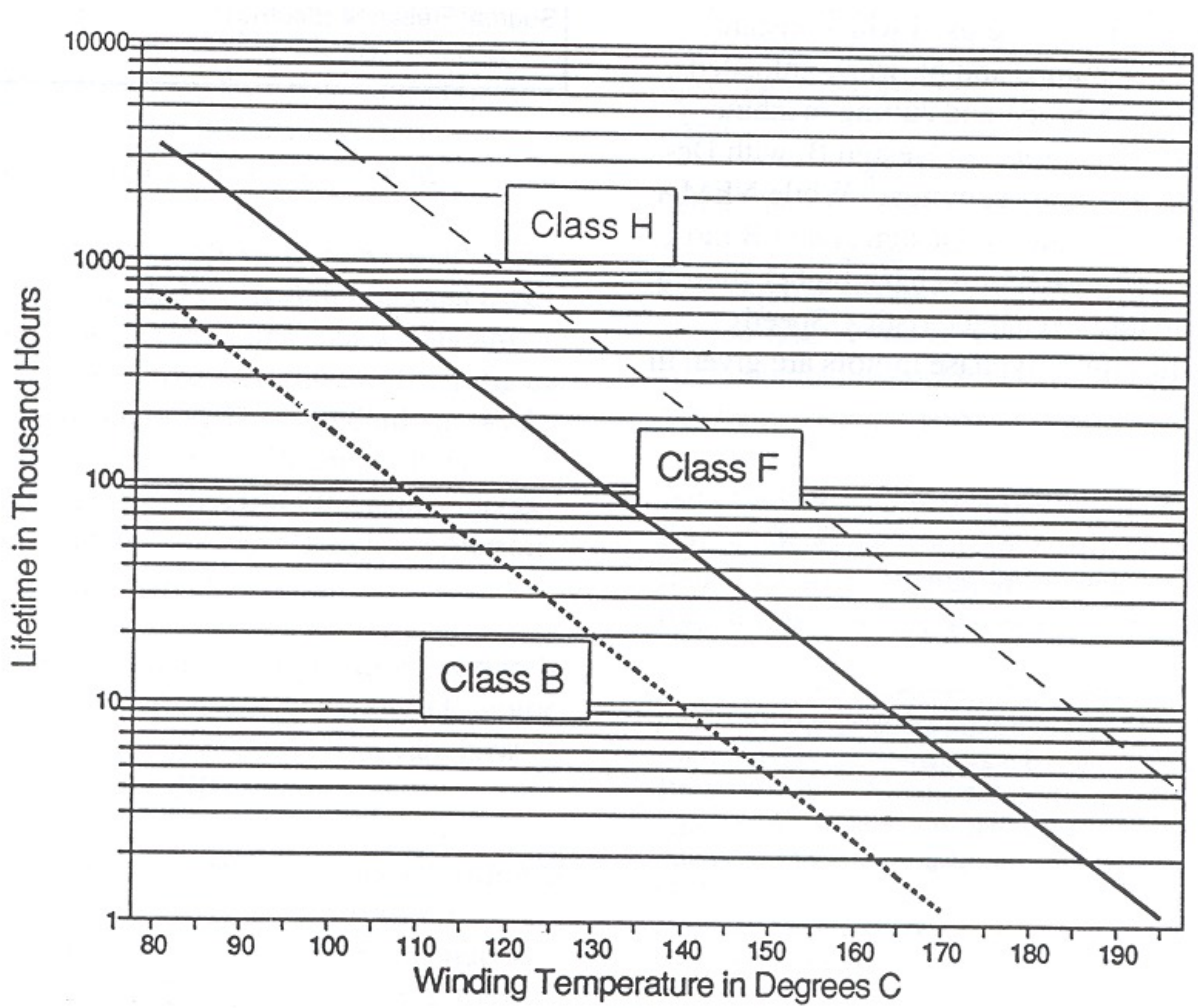
NP Speed	1482	Volts	660
kW	400.00	Amps	418.00

Operating RMS values		
Voltage Level	658.2 V	99.7%
Current Level	378.4 A	91.4%
Load Level	312.6 kW	78.1%

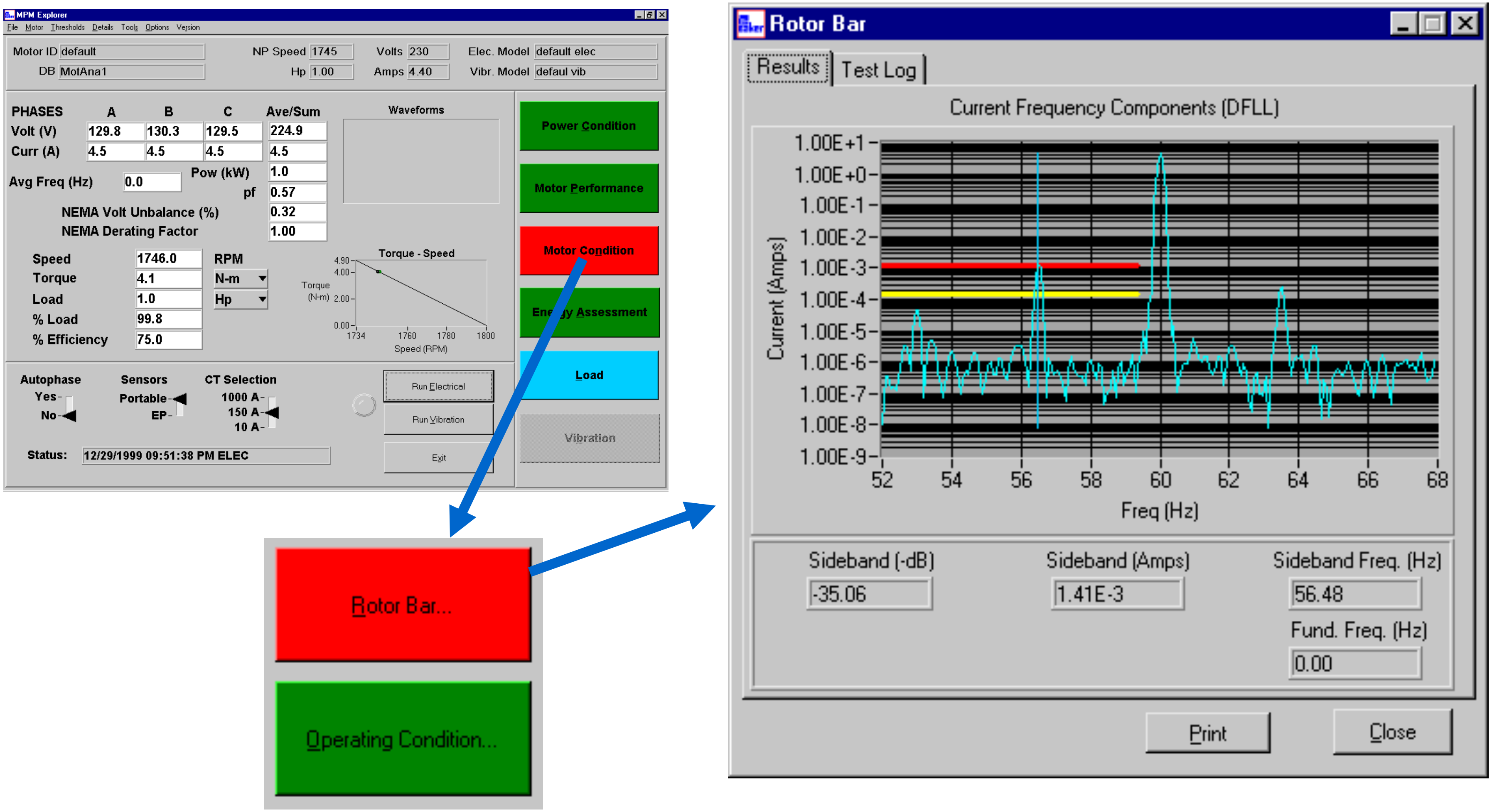
Voltage Unbalance	3.66%
Voltage Distortion	9.80%
NEMA derating %	0.6
Eff. s.f.	1.28



Service Life vs Operating Temperature for Insulation



Motor condition: Broken rotorbar



Fan 1 hp 1740 rpm

Motor Condition: Broken rotor bar issues

Requires constant torque level

Torque ripple

Next one breaks sooner

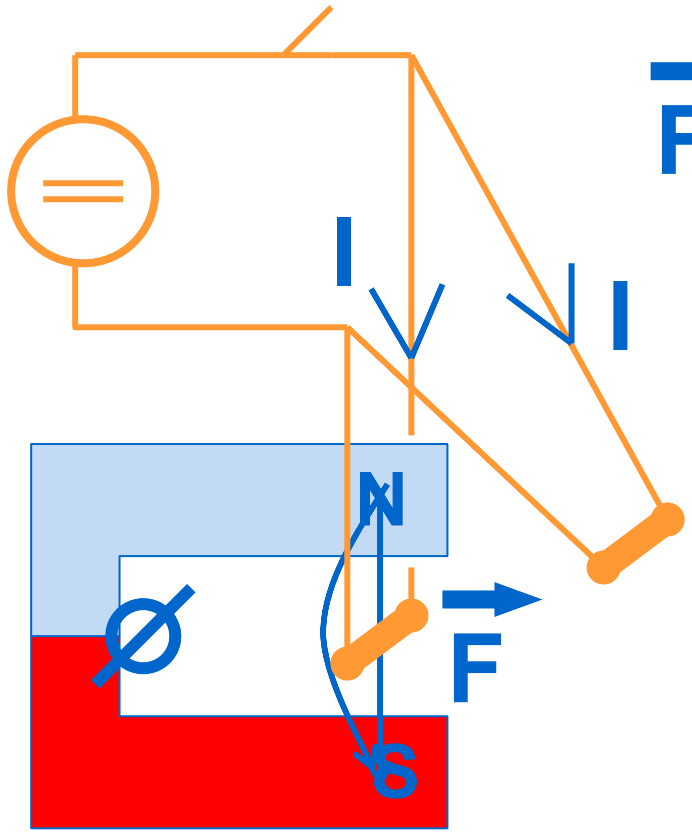
Current increases

Temperature increases

Insulation life shortens

Typically non-immediate death

Torque Calculation:



$$\vec{F} = \vec{I} \otimes \vec{\varnothing}$$

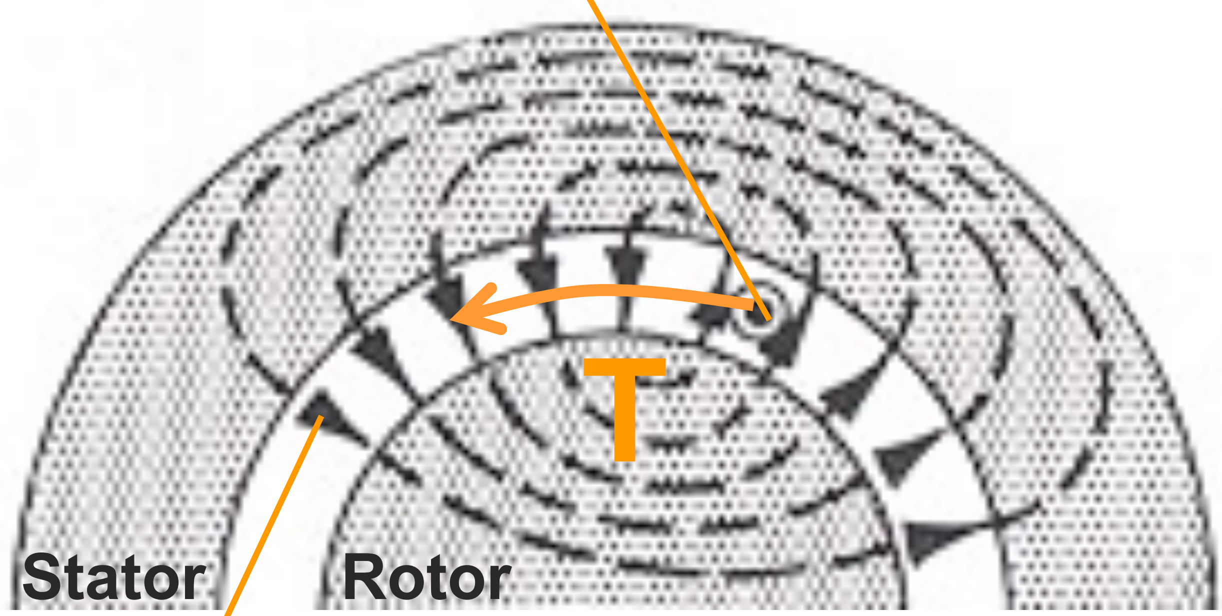
$\vec{F}$: Force

$\vec{I}$: Current

$\vec{\varnothing}$: Flux

Calculating Torque:

Rotor Current: Monitored with Stator Current



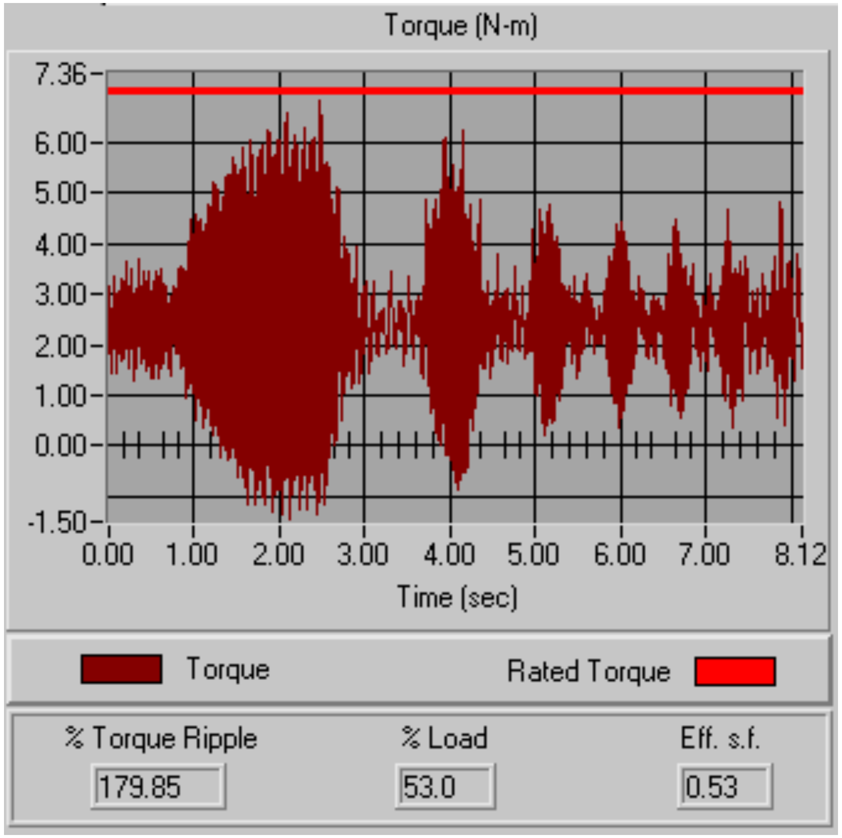
Flux: Generated by stator Voltage

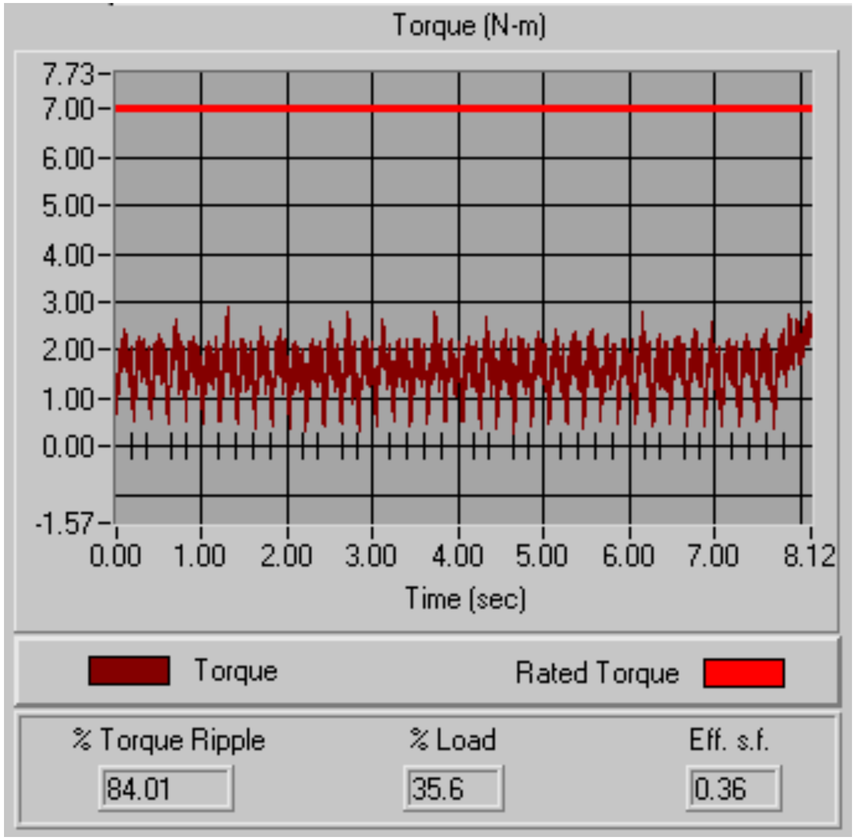
$$T(t) = f(\ V(t), I(t)\ )$$

According to Park's theory, 1920.

Cavitation Torque signature:

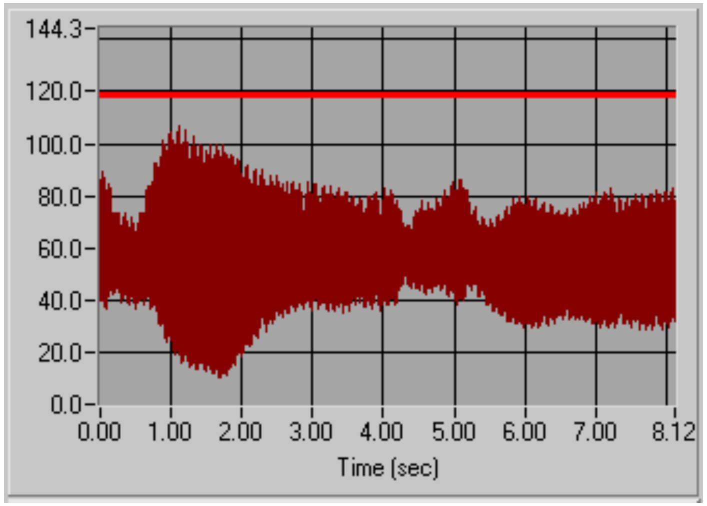
GM Body shop

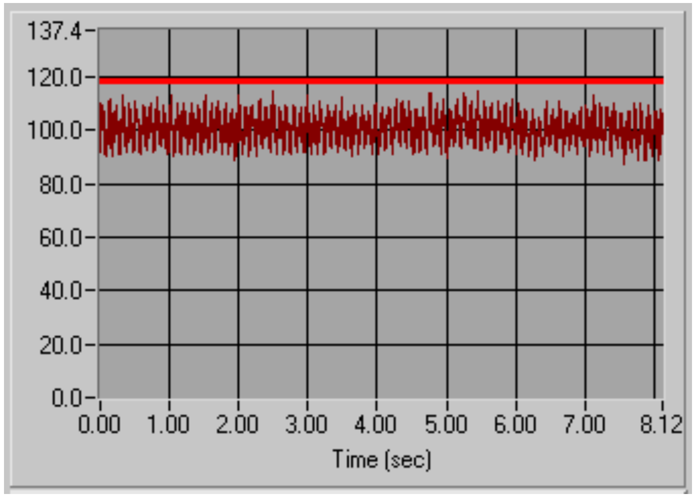




Torque Signature:

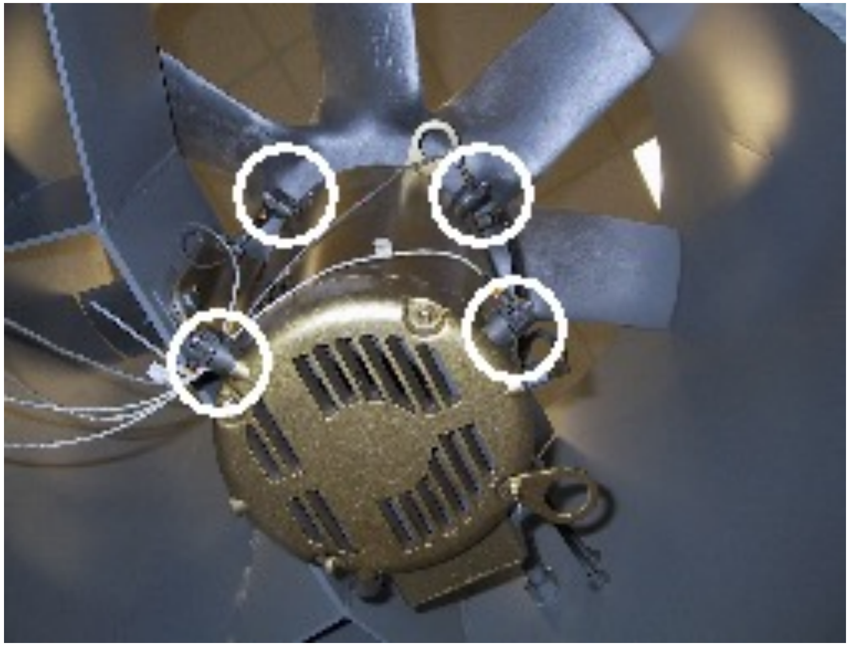
4160V sunken pump

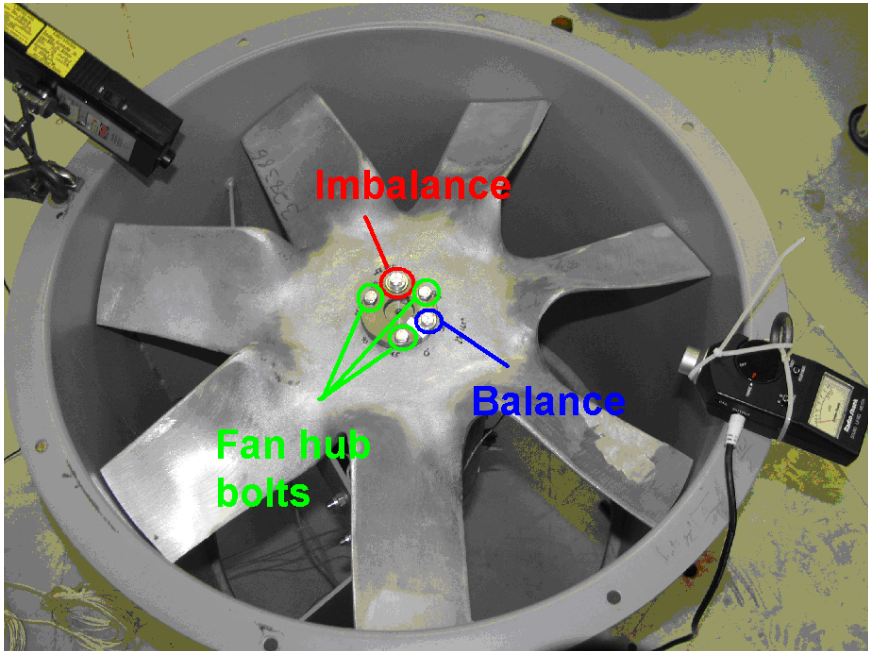




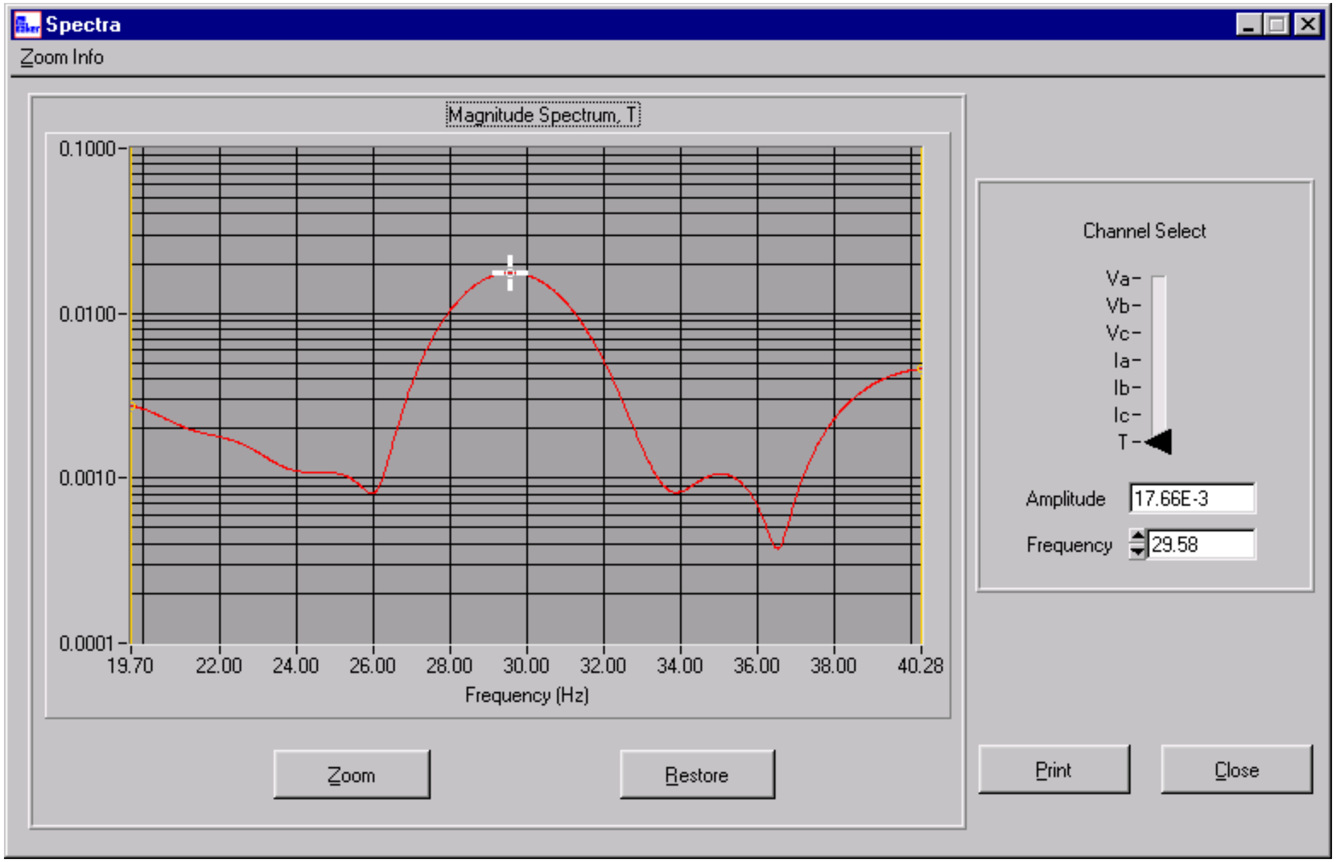
Torque vs. Frequency:Mechanical Imbalance

Investigating vibration and torque for inaccessible loads:

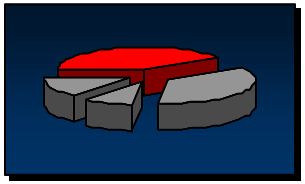


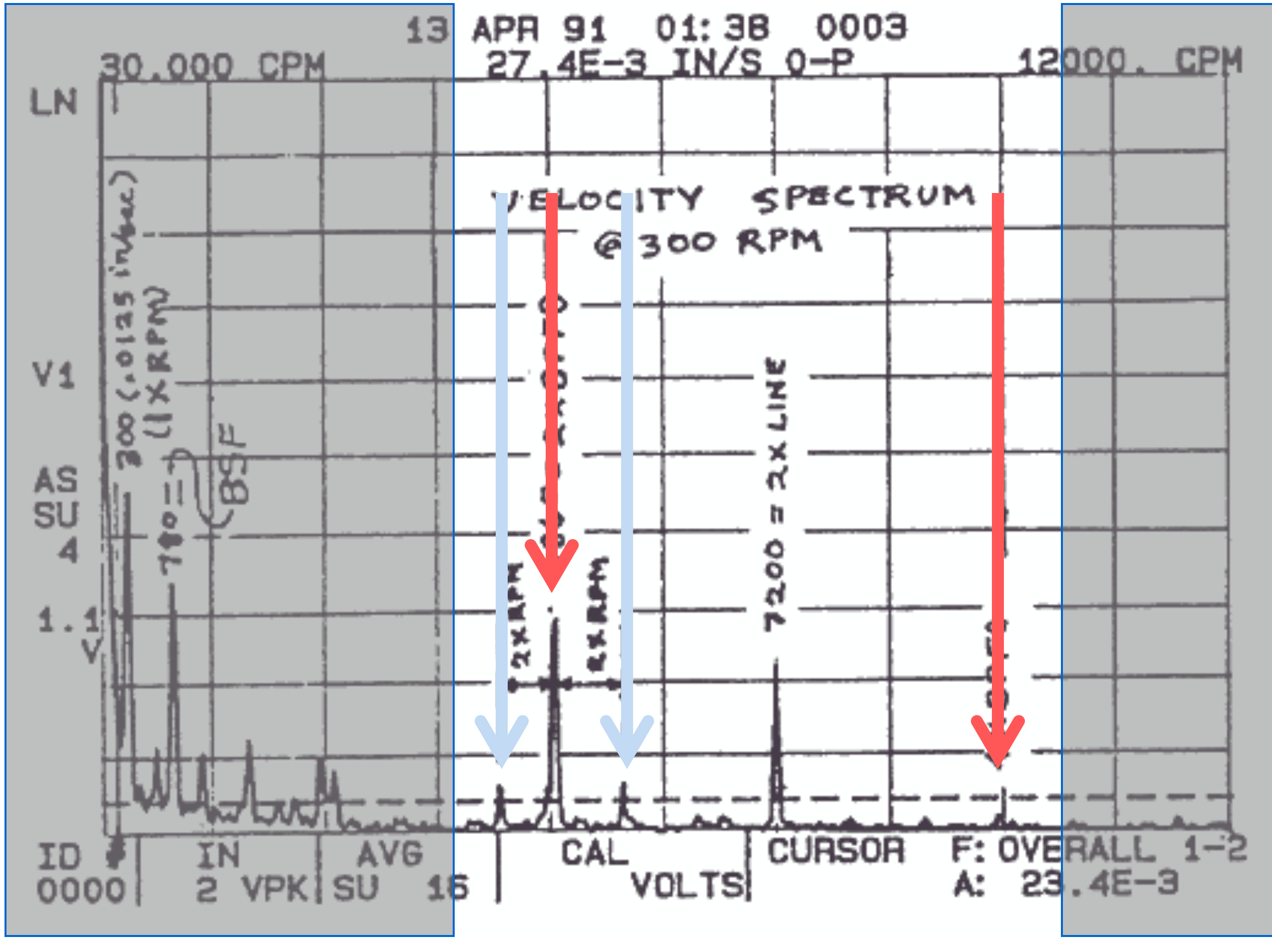


Torque vs. Frequency: Mechanical imbalance



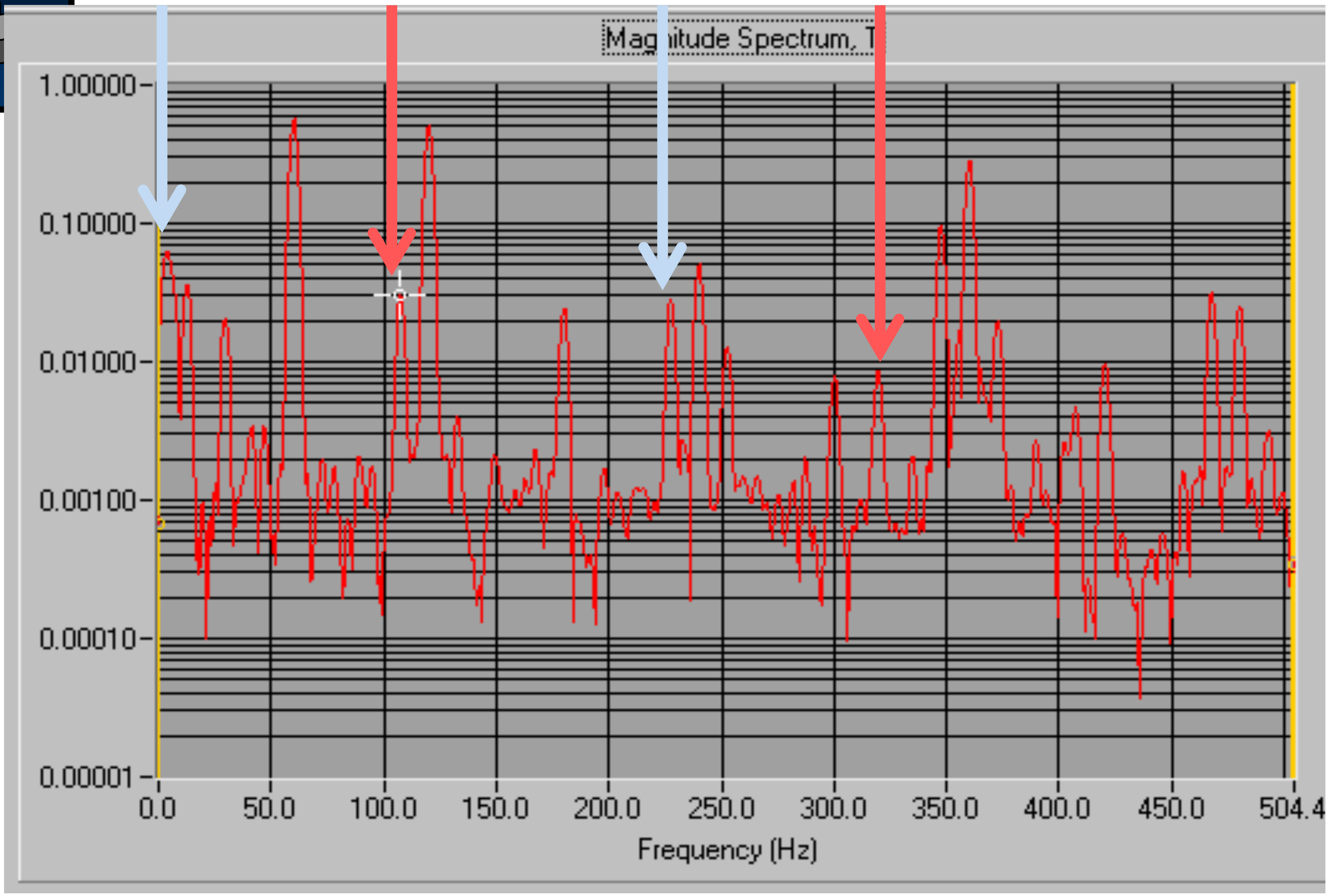
Motor failure areas: Bearings





harm. * BPFO ± 2 * RPM

Motor Failure Areas: Bearings

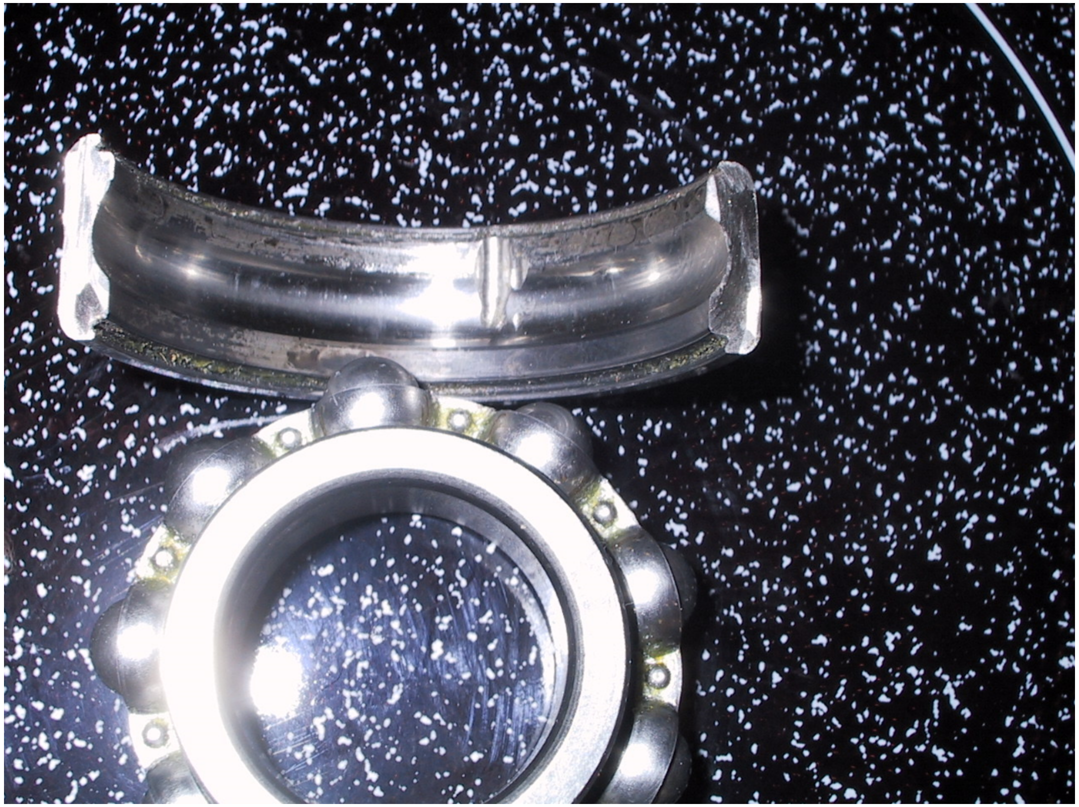


5hp 4 pole

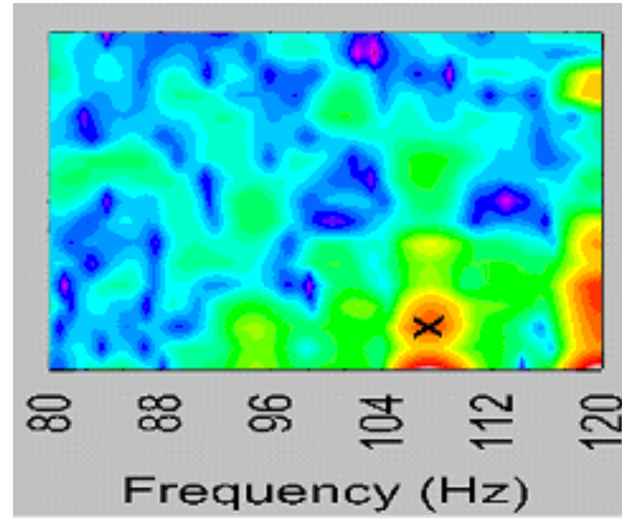
harm. * BPFO

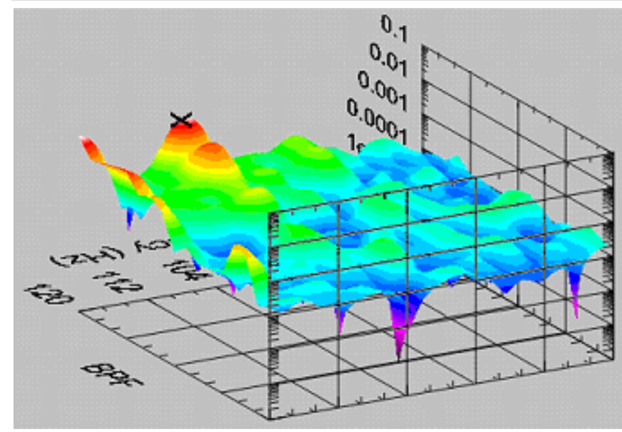
± 2 * Fund Freq

3D Demodulation:



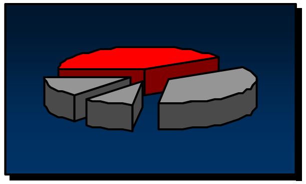
$$Outer\ \ Race\ (BPFO) = \frac{n}{2} f (1 - \frac{Bd}{Pd} Cos \beta)$$

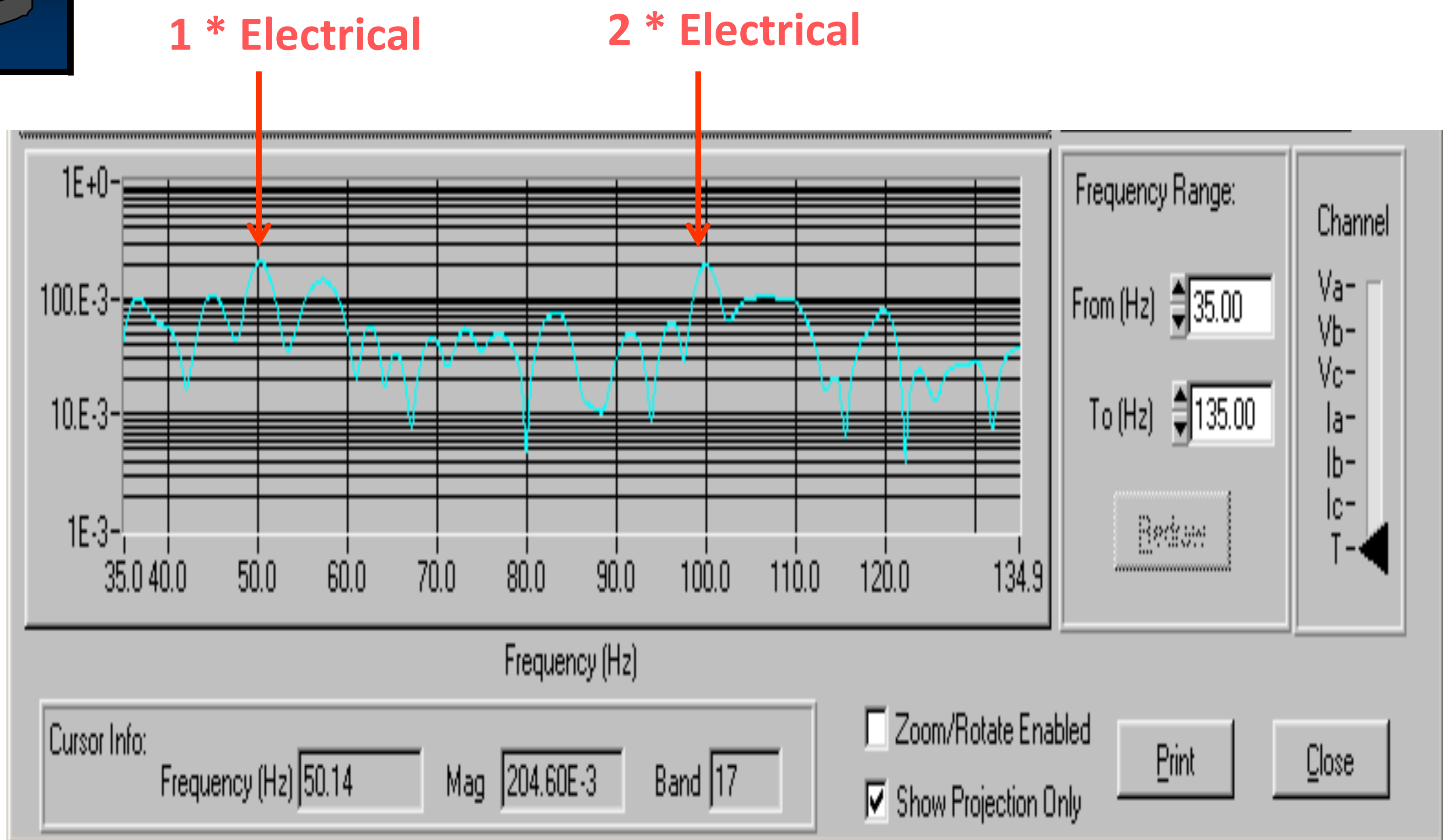




BPOF: 107Hz

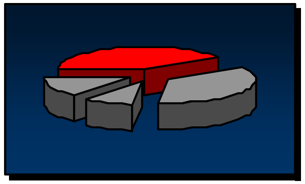
Eccentricity: Demodulated Torque





50Hz 2 pole 300hp

Demodulated signals: Torque vs. Current

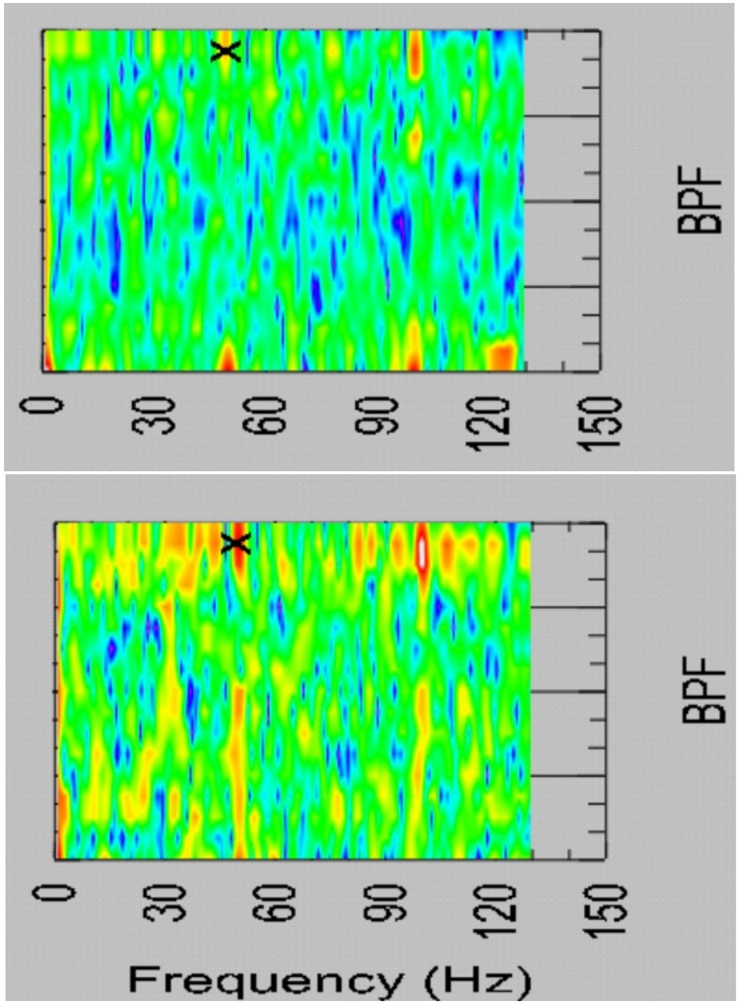


	Demodulated Torque		Demodulated Current	
	1* RPM	2* RPM	1* RPM	2* RPM
Bad Motor #1	3.47E-05	7.94E-05	0.00324	0.03150
Bad Motor #2	4.26E-05	7.96E-05	0.00398	0.03091
Good Motor #1	2.96E-05	1.35E-05	0.00245	0.03109
Good Motor #2	3.46E-05	1.42E-05	0.00308	0.03057
Factor	1.20	5.90	1.31	1.01

Conclusions:

- Demodulated Current method does not agree with vibration's methods.
- Demodulated Torque reacts like vibration's methods.
- This method is independent of Motor design.
- This method does not disagree with IEEE motor scientist's research.

3D Demodulation: Eccentricity in motor



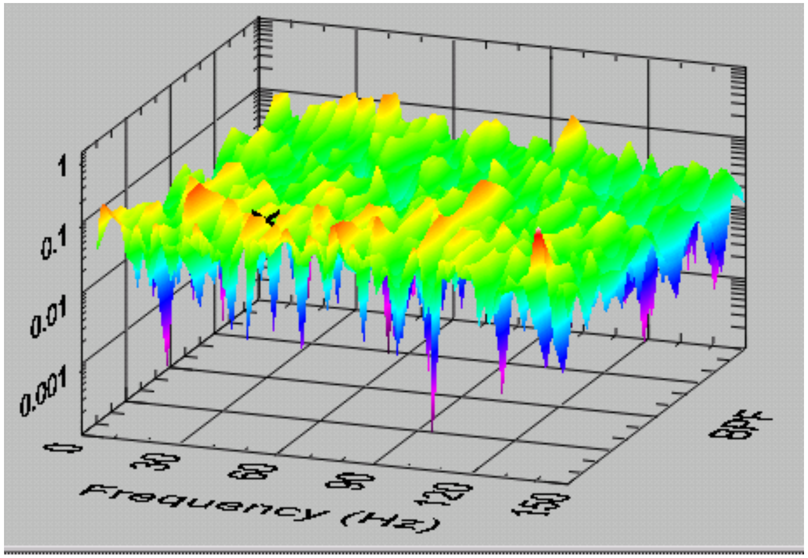
2 ‘identical’ 50Hz 4 pole

Eccentricity typical @:

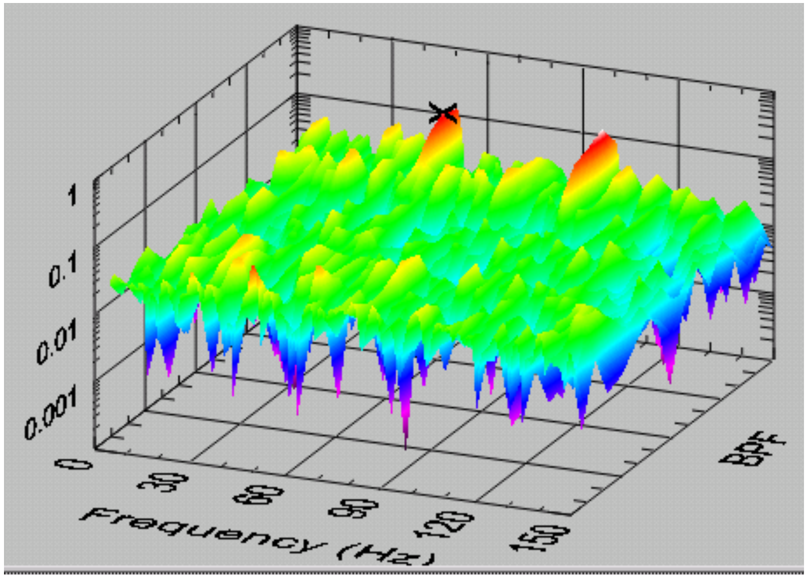
- 1x, 2x (25Hz, 50Hz)

One ‘good’, one ‘bad’

3D Demodulation: Eccentricity in motor



'Good'

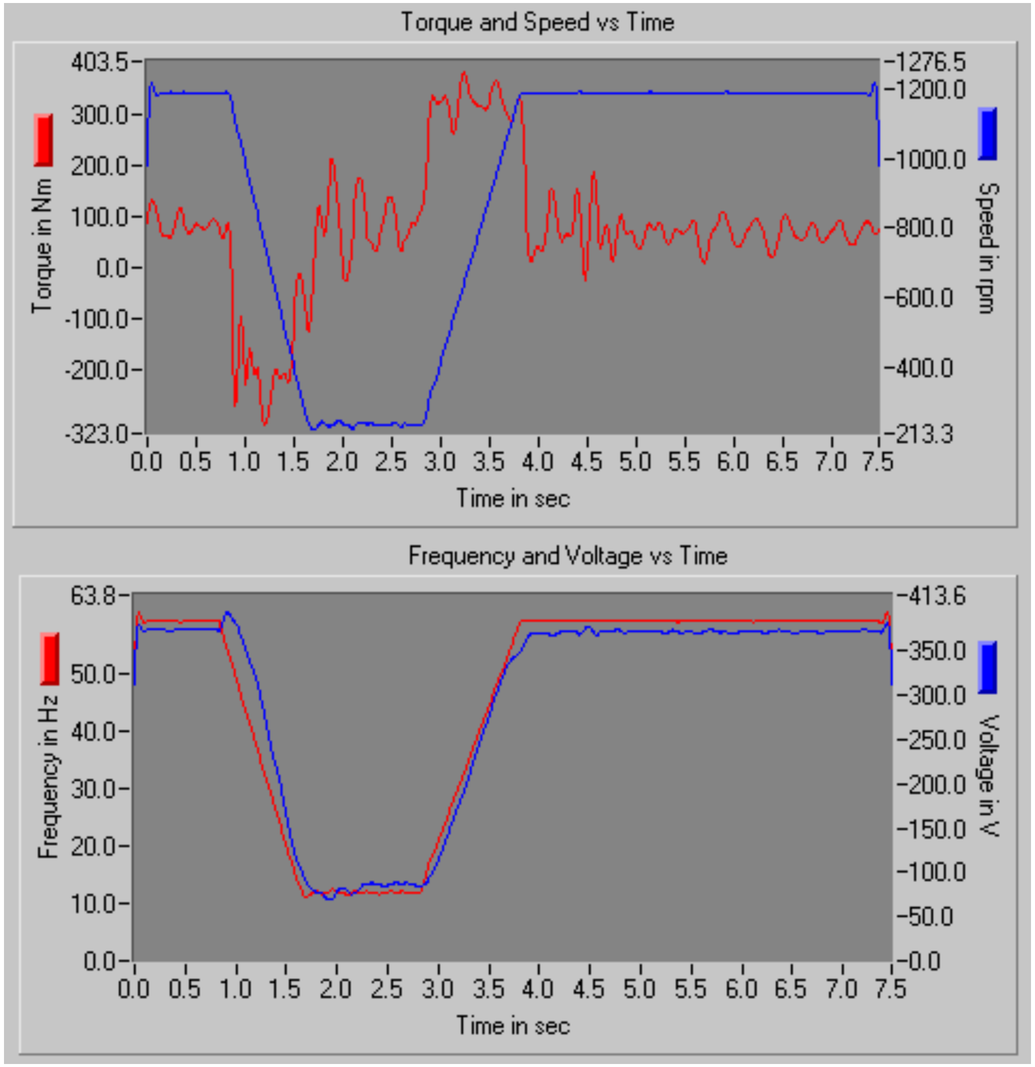


'Bad'

VFD: Variable Frequency

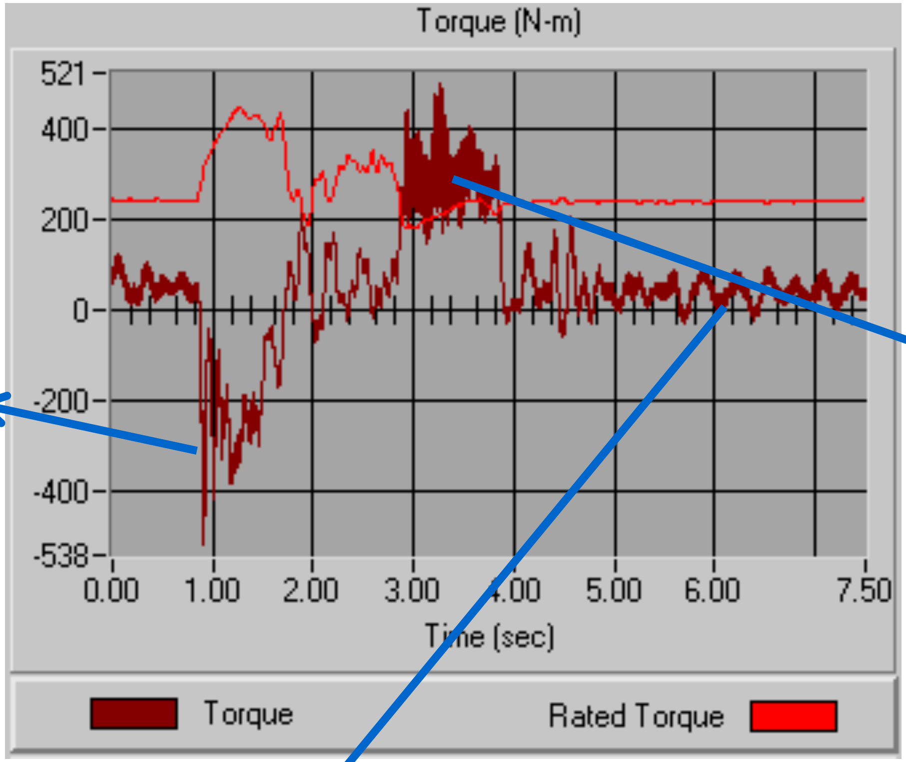
Conveyor drive
60 hp 1200 rpm

- **Frequency control**
- **Speed control**
- **Torque control**
- **Vector drive**
- **V over f**
- **Feedback loop**



VFD: What is going on?
Conveyor Drive. 60 hp 1200 rpm

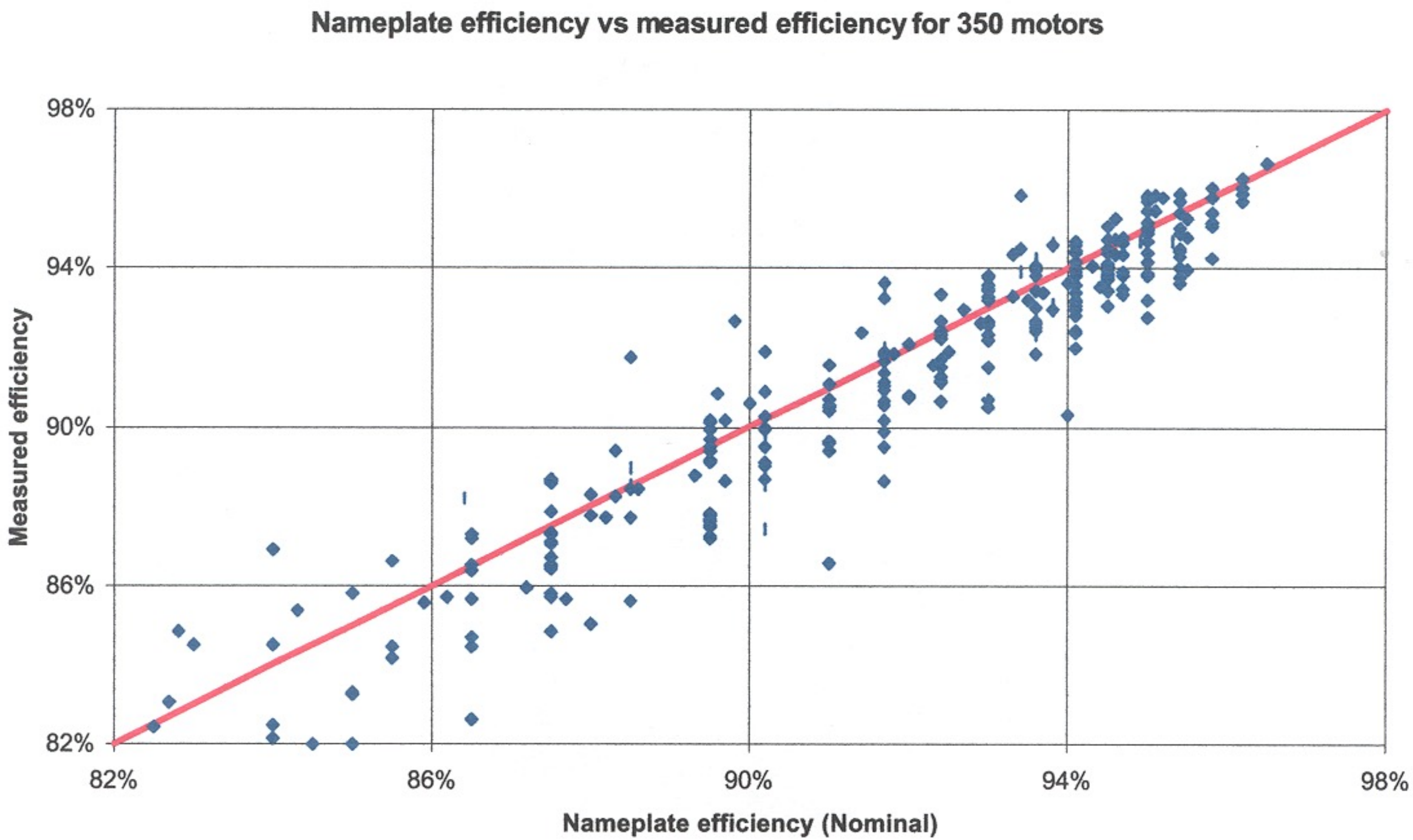
- Breaking
- Generator



- Over rated

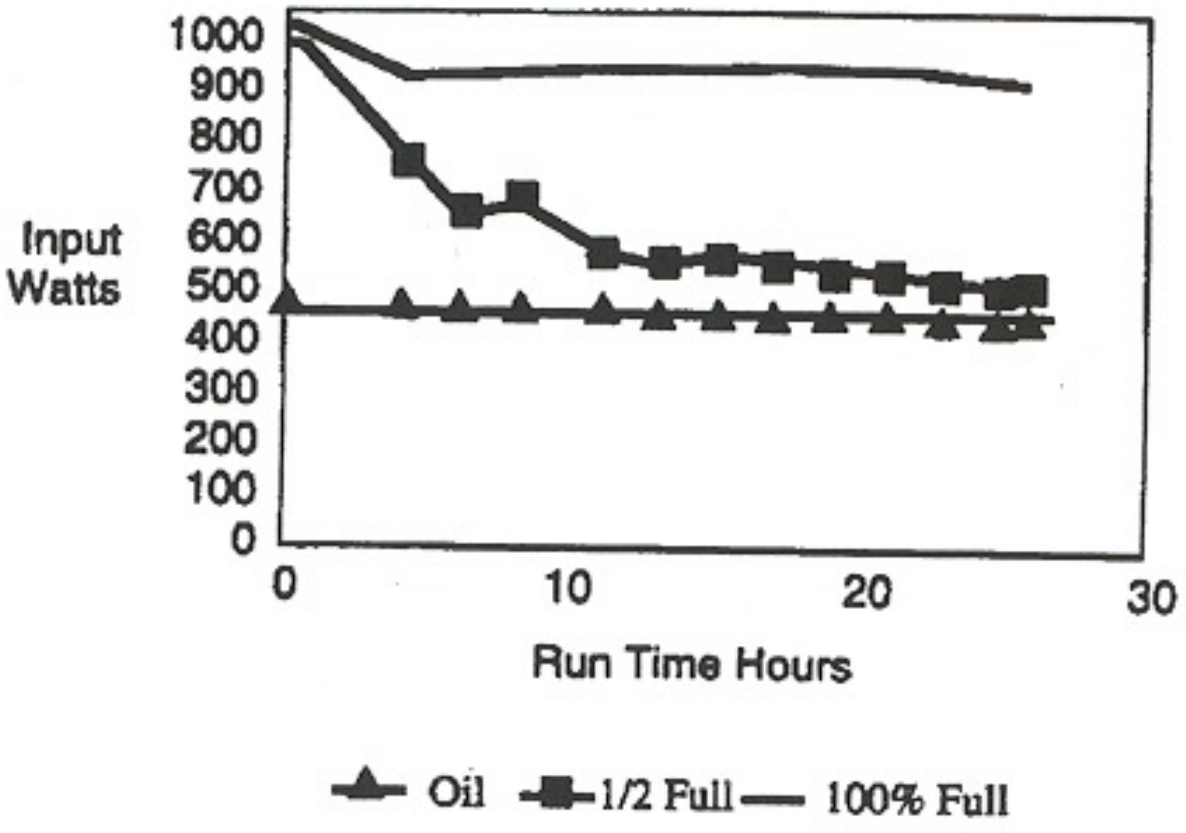
- Oscillating
- Flawed control loop design

Testing Motors*



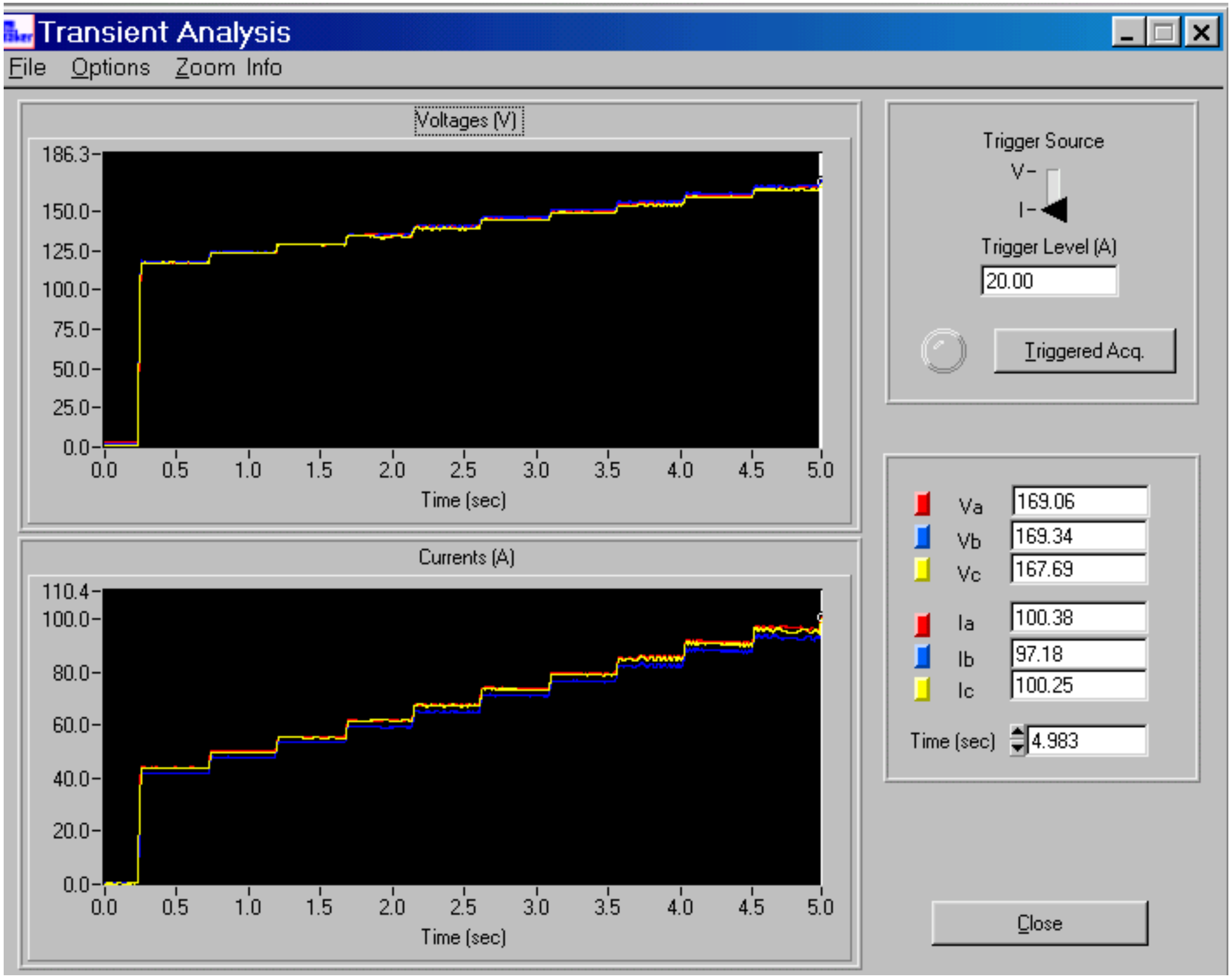
*LTEE

Effect of Grease on No Load Losses 60 Hp, 4 Pole*

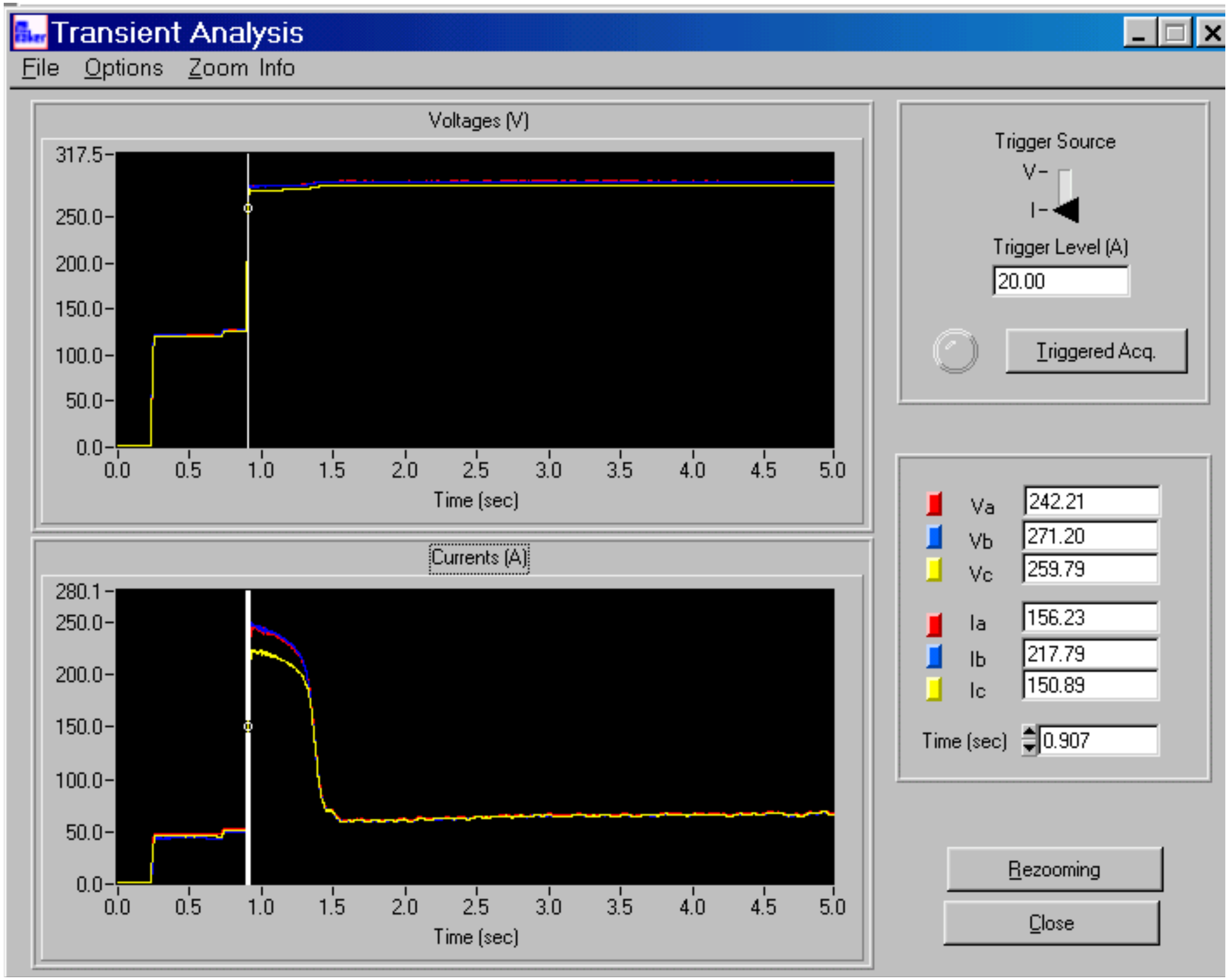


*GE

Transient Analysis



Transient Analysis



VFD: Typical issues: Common problems in the field

Over voltage spikes

Shaft voltages

Bearing failures

Voltage distortion on input

Voltage distortion on output

Vary output voltages with freq.

Thank You