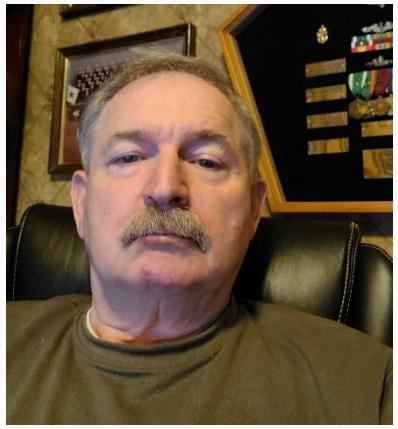
FLUKE® Reliability

How today's advanced electric motor testing technologies expose motor failure

Don Donofrio

Accelix™
Webinar Series

Speaker Bio



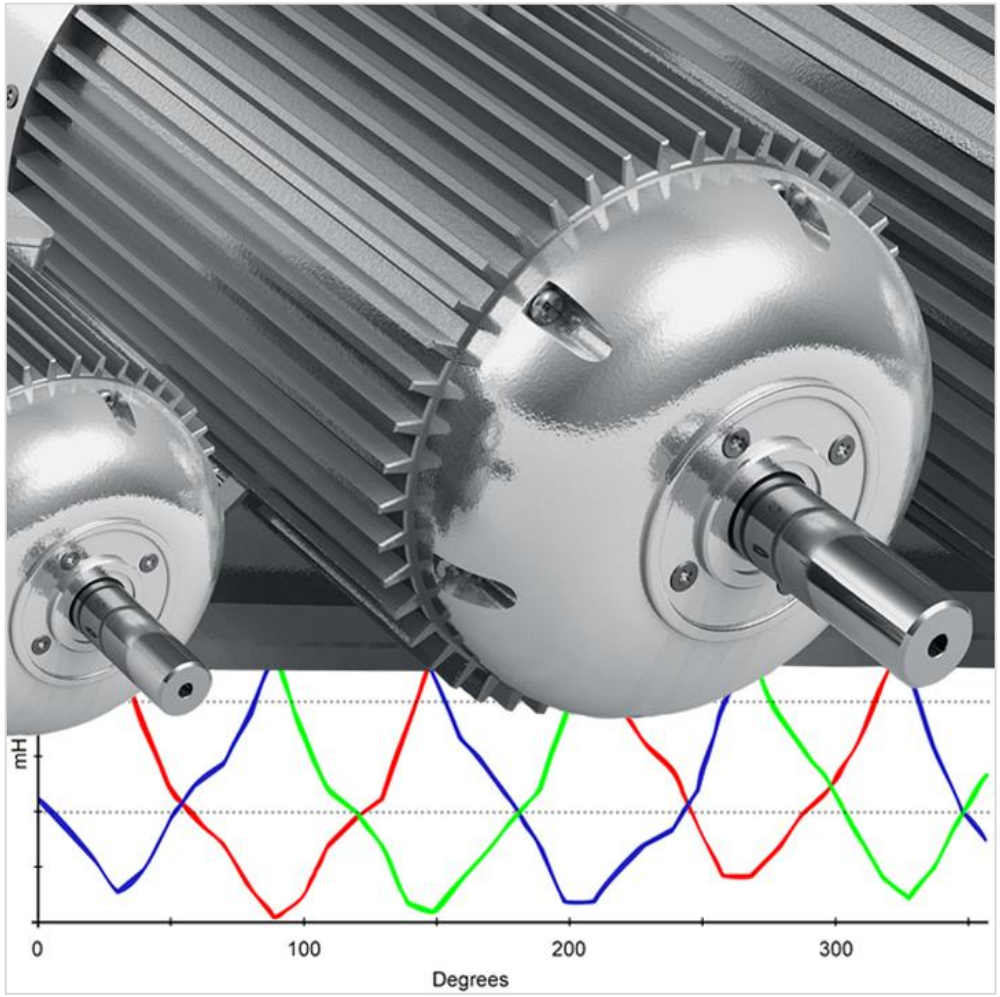
Don Donofrio

- Technology Lead at The Snell Group – Electric Motor Testing and Power Quality
- Worked for PdMA, Rockwell Automation / Reliance Electric, IVC
- With The Snell Group since 2002
- Retired from U.S. Navy, 20 years in Nuclear Submarine Service
- More than 45 years experience with electrical, electronic systems and electric motors

Electric Motor Testing Technologies

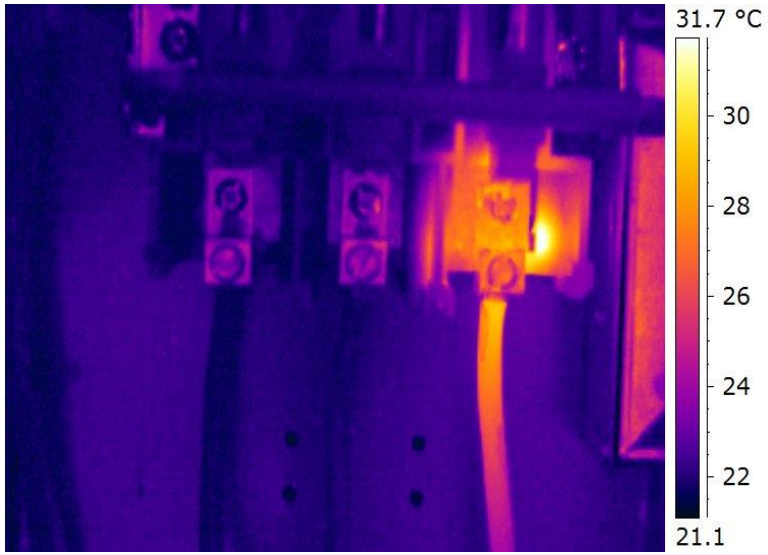
Motor Solutions®

Don Donofrio
The Snell Group



Who is The Snell Group?

The world's leading experts on using
Infrared Thermography and Electrical Motor Testing

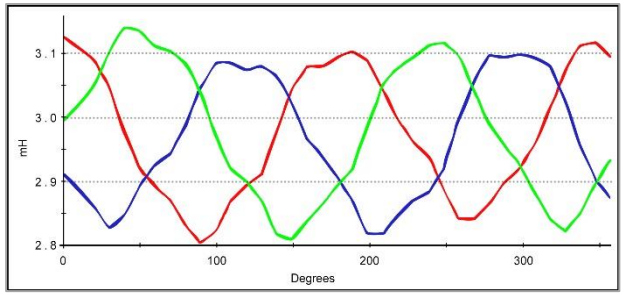


- Established in 1986
- Offices in Vermont and Missouri
- We are a knowledge-base company
- Two major condition-based technologies and three service platforms

Who is The Snell Group?

Two Technologies

Infrared Thermography



Electric Motor Testing

Three Services

Training

Consulting

Inspection

POLL QUESTION No. 1

How much experience does your company have conducting motor tests?

(Click only one answer)

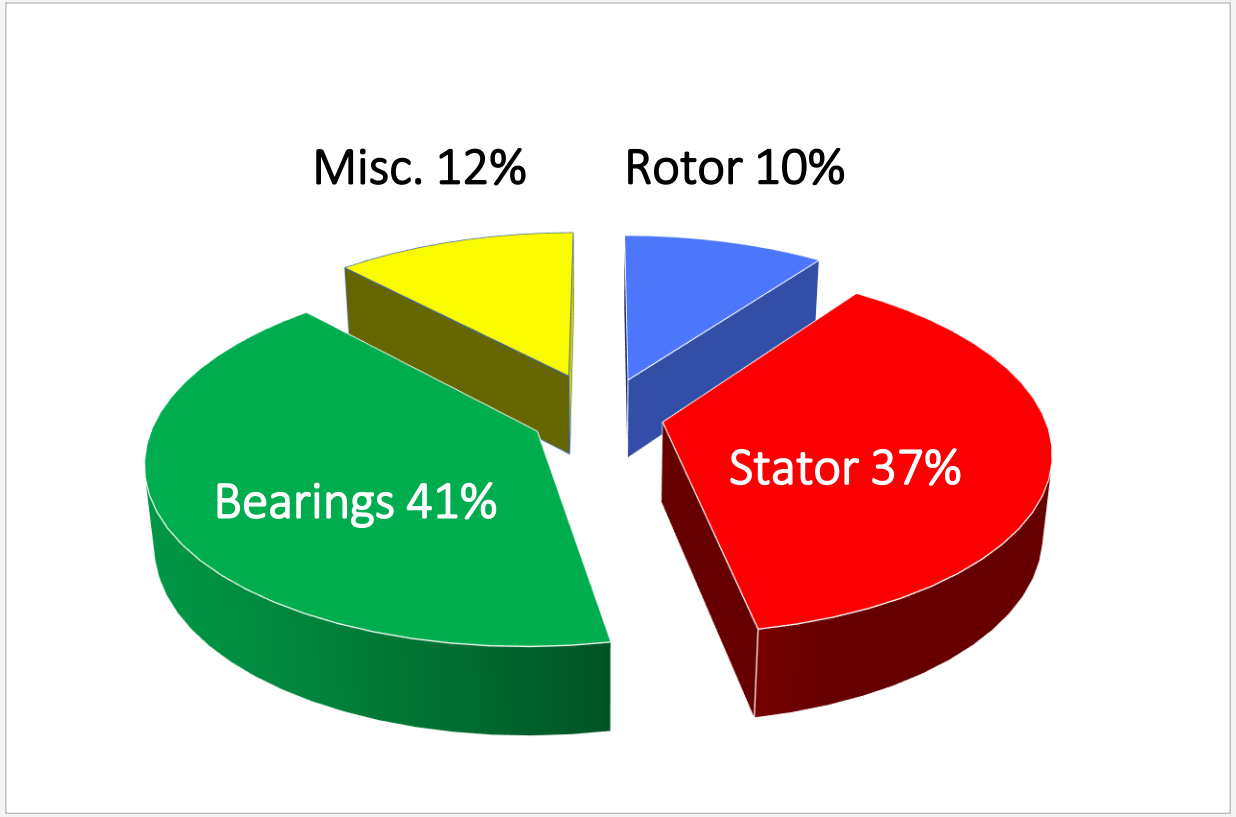
- Advanced
- Intermediate
- Beginner
- Never tried it
- Not sure

Why Test Electric Motors

- In the United States electric motors consume close to 25% of the electricity
- Depending upon industrial process they can consume 60% to 90% of the electricity.
- Motor's cost 5 to 12 times their initial purchase cost in energy the first year
  - 25hp motor, running continuously: about $15,000 per year to operate
  - 100hp motor, running continuously: about $56,000 per year to operate
- Motor Energy Consumption should be a concern for everyone
- Motors are like roofs; we don’t think about them until…..
- All mechanisms that lead to motor failure cause increased operating temperature, which leads to insulation failure
- Motor testing identifies those failure mechanisms.

Motor Circuit Data Analysis

1986 EPRI / GE Motor Failure Study



More Interesting Facts

- Each year, more motors are repaired than are sold new
  - For every new motor sold, approximately 2.5 motors are repaired.
- It is estimated that motors are repaired on average every 5 to 7 years.
- Motors are frequently operating for 20 to 30 years
- The U.S. Department of Energy says greater attention to motor system management can reduce motor energy costs by as much as 18 percent, while helping to boost motor productivity and reliability.
- According to EPRI, “The efficiencies of mechanical equipment in general can be increased typically 10 to 15 percent by proper maintenance.”

Types of Electric Motor Testing

De-Energized:

- Motor is shut down
- Provides the safest means of testing
- Provides the least opportunity for testing
- Enables assessment of insulation

Energized:

- Most common means of testing
- Power Quality snapshot
- Current and Electrical Signature
- Torque Analysis
- Requires specialized equipage for insulation testing. (Limited)

De-energized Motor Testing

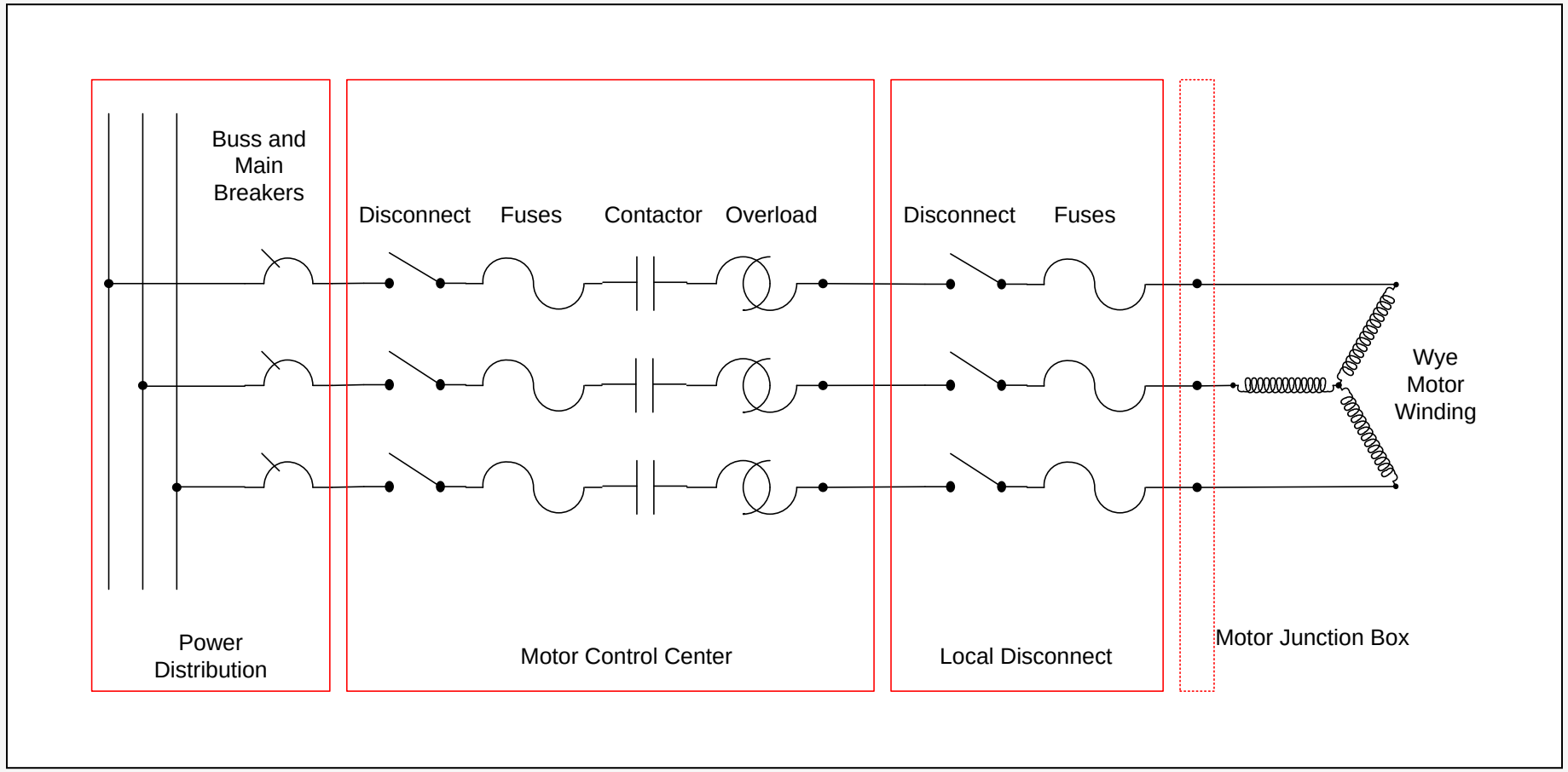
Excellent Testing Method for identifying:

- Circuit Connection Faults
- Cable Faults
- Motor Winding Issues
- Rotor Anomalies
- Protective and Auxiliary Circuitry
  - Surge Protection
  - Power Factor Correction

Excellent Tool for:

- Motor Acceptance (into inventory)
- Equipment Troubleshooting
- Equipment Commissioning
- Condition Monitoring

Sample Circuit



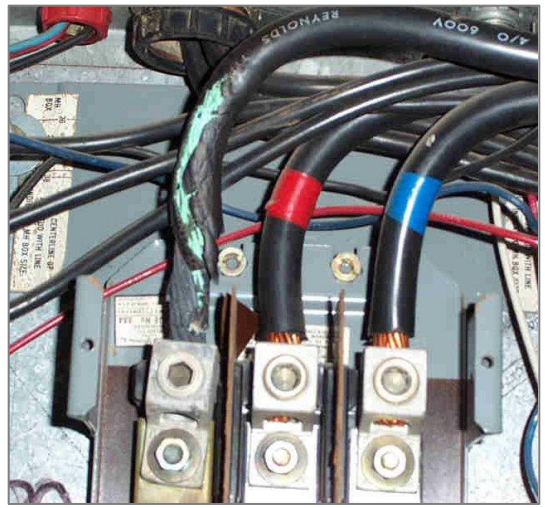
Measurement Capabilities

- Resistance
- Inductance
- Impedance
- Phase Angle
- Fault Localization
- Current Frequency Response I/F
- Rotor Influence Check
- Capacitance to Ground
- Resistance to Ground(RTG)
- Surge Testing
- Hi Potential Testing
- Step Voltage
- Timed Resistance Testing
  - Polarization Index
  - Dielectric Absorption

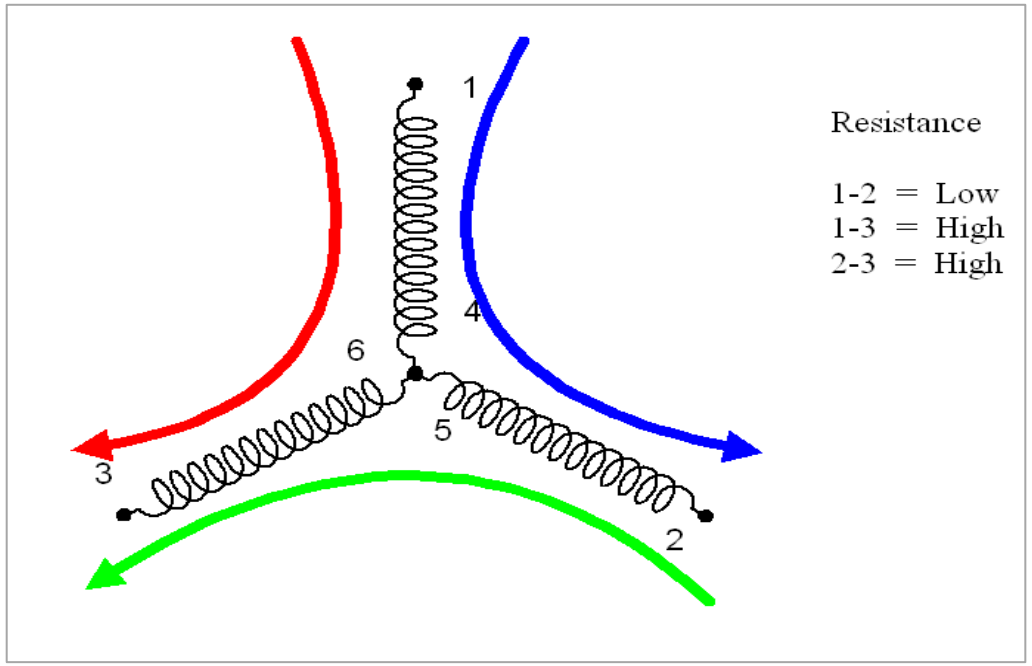
Resistance Analysis

Motor Data Analysis

- High Resistance Connections
  - Loose/Overtightened Connection
  - Poor Crimps
  - Frayed Conductor Strands
  - Improper wire size/lug
  - Corrosion
  - Multiple conductors under one lug.



Resistance Case Study

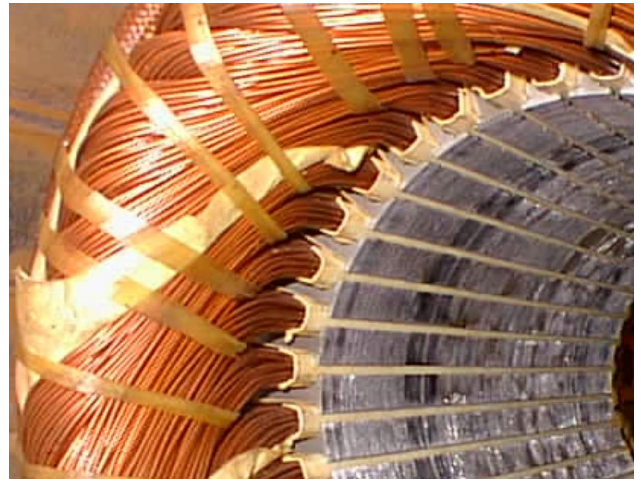


Test Date	07/05/2001	04/01/2003
Test Time	05:25:24 PM	07:30:14 PM
	Baseline	
Frequency	1200	1200
Mohm Ph 1 to Gnd		
Charge Time	15	15
Voltage	500	500
Motor Temp	35	35
Measured Mohm	119.0	2299.0
Corrected Mohm	84.1	1600.0
pF Ph 1 to Gnd	14000	12500
ohm Ph 1 to 2	9.55000	*8.93000*
ohm Ph 1 to 3	9.55000	9.83000
ohm Ph 2 to 3	9.57000	9.84500
mH Ph 1 to 2	77.450	76.600
mH Ph 1 to 3	82.350	81.400
mH Ph 2 to 3	85.000	83.700
Avg. Inductance	~~81.600~~	~~80.567~~
% Res. Imbalance	0.14	**6.35**
% Ind. Imbalance	~~5.09~~	~~4.92~~
$ Power Loss	0.26	11.90
Test Location	T-Leads	T-Leads
MCE #	030522	030602HV
User		
Notes	No	No

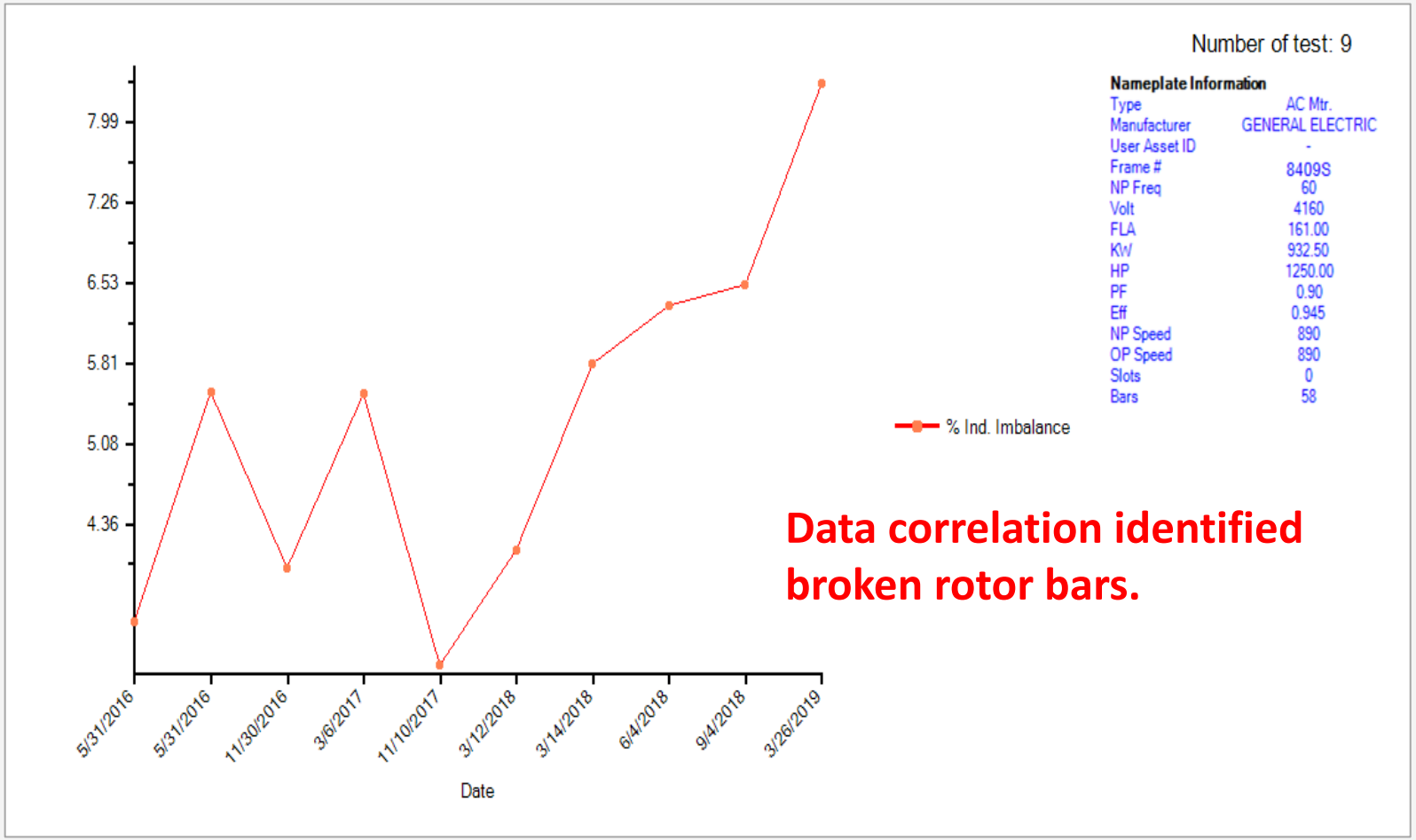
Inductance

Inductance (milli-henrys)

- Opposition to changes in circuit current
- Affected by virtually everything in the motor
- Power Factor Capacitors



Trending Inductance Case Study



Data correlation identified broken rotor bars.

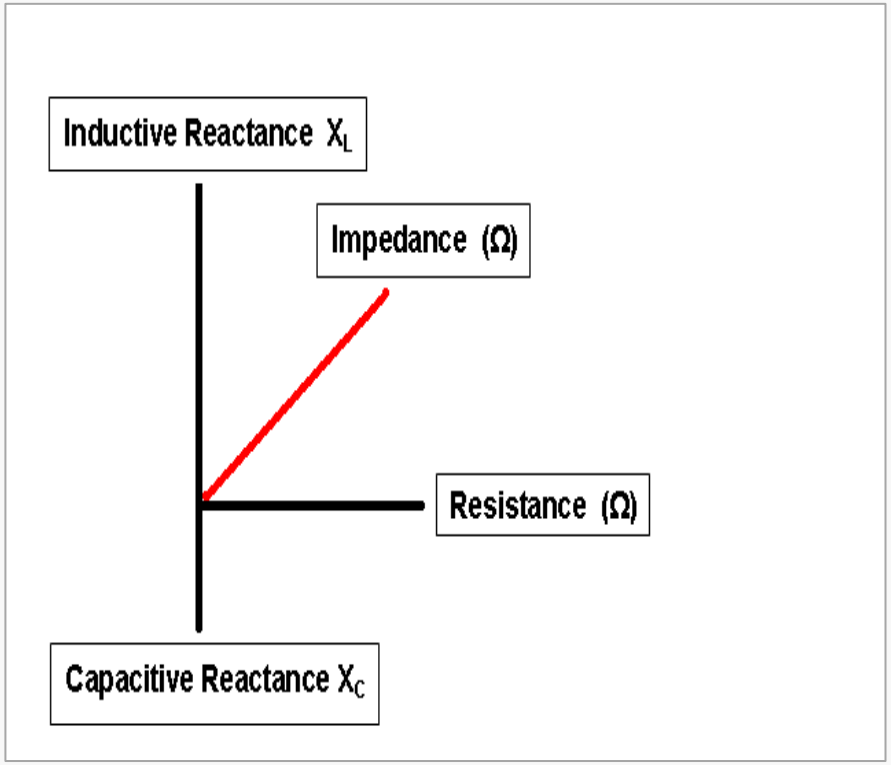
Impedance and Phase Angle

Impedance

- Vectoral Sum of Resistance, Inductive and Capacitive Reactance
- Total Opposition to AC Current

Phase Angle

- Angular displacement of the Impedance vector from the Resistance
- Represents the angular displacement of Voltage and Current on an energized circuit



Phase angle correlates to voltage and current phase angle.

Current Frequency Response

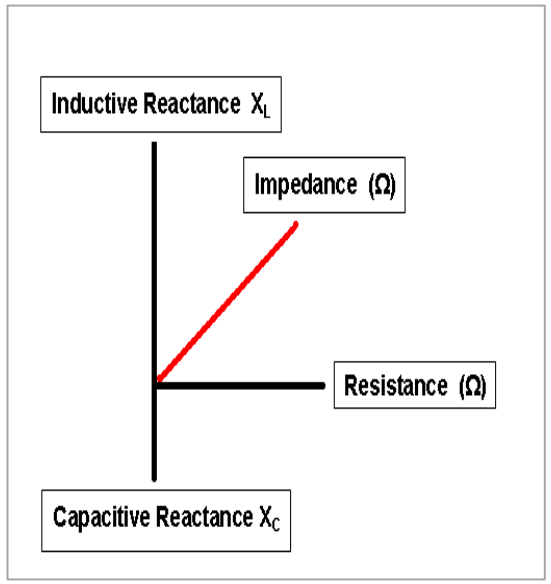
Motor circuit Reactance measurement requires an AC test signal

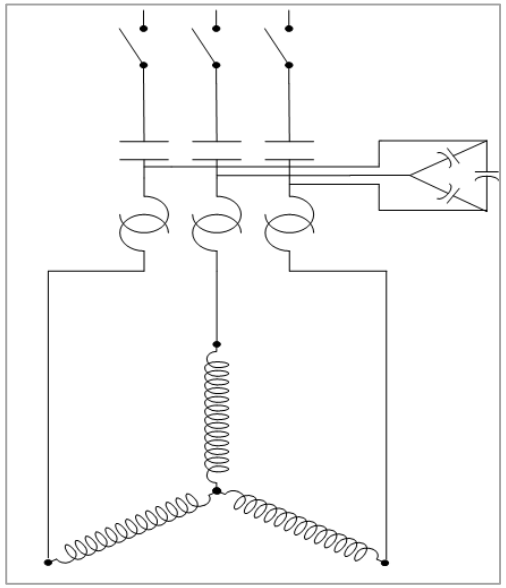
- Virtually no capacitance between phases
- Doubling test frequency can double X_L
- Doubling X_L will almost half I_{X_L}
- Measurement of Reactance Current ideally would be 50%
- Core material magnetic properties will have affect
- Ultimately looking for balanced current response

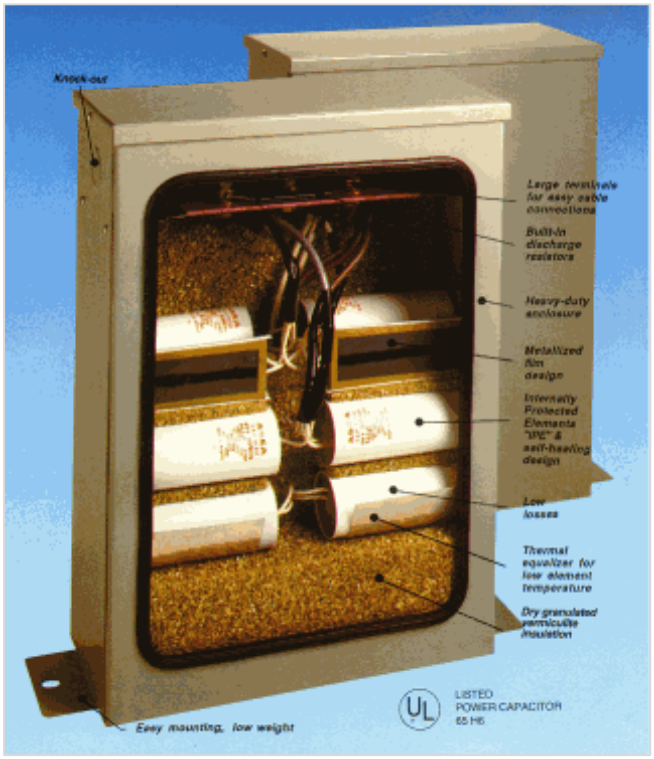
Capacitance

Power Factor Correction Capacitor

- High Unbalanced Inductance
  - Bulk Correction*
  - External Box
  - Internal Motor Connection Box







*** Will see affects on Power Quality**

Motor Fault Localization

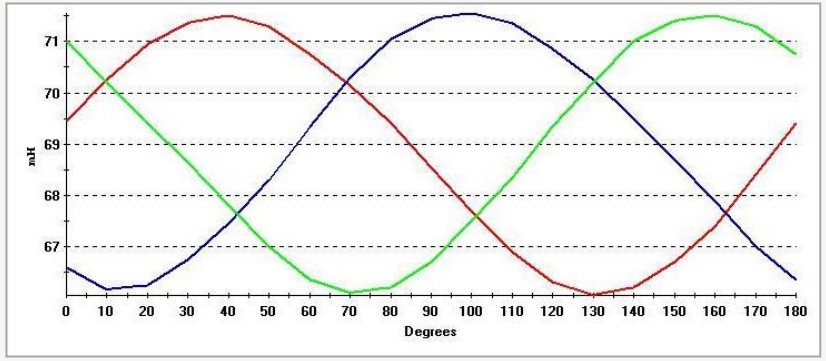
Resistance Unbalance	Inductance Unbalance	Impedance Unbalance	Analysis
Low	Low	Low	Normal
Low	Moderate	Moderate	Rotor Anomaly
Moderate	Moderate	Moderate	Stator Fault
Low	High	High	Defective PF Capacitor

Note: If you exhibit an inductance unbalance and balanced resistance with the rotor removed; look for incorrect wiring, such as a reversed coil.

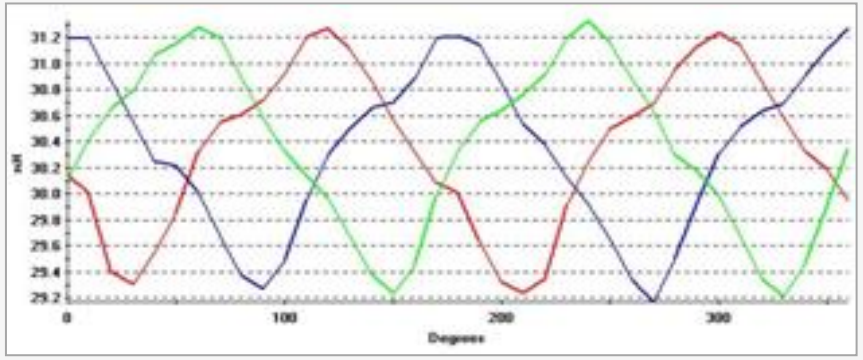
Rotor Influence Testing

- Rotor Influence Check (RIC)
- Inductance is plotted over arc of Pole Group
  - Perform before any other testing
  - Start at “keyway” up
  - Perform Initial test plus 18 additional tests
  - Best results are obtained when motor was run at load, prior to testing

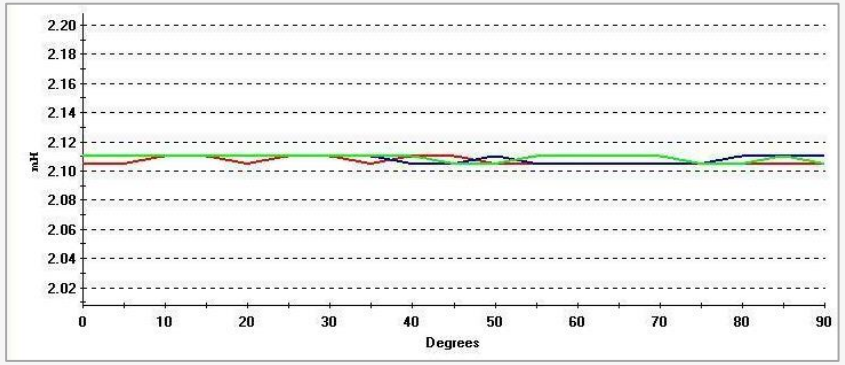
Rotor Influence Check



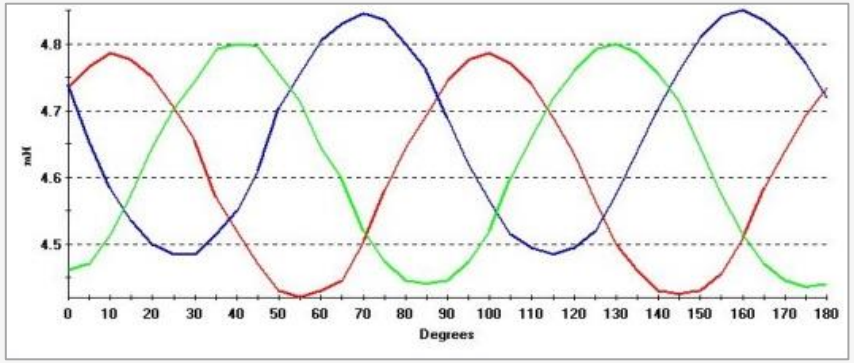
Normal



Rotor Anomaly

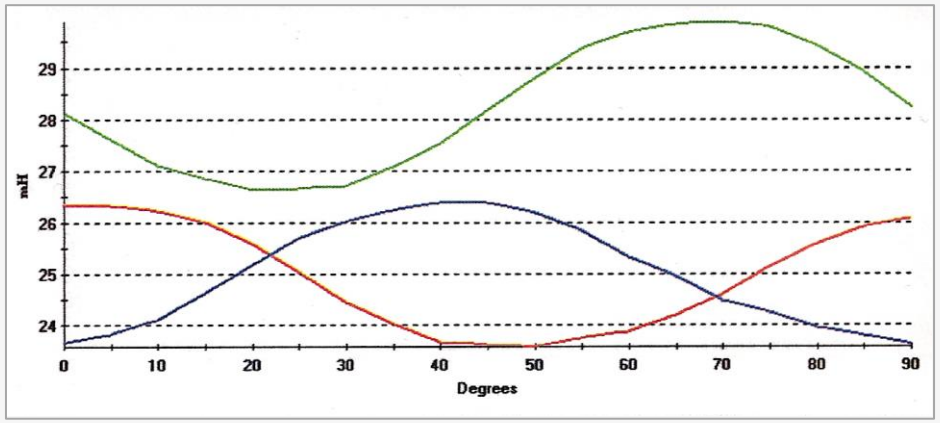


Low Influence Rotor

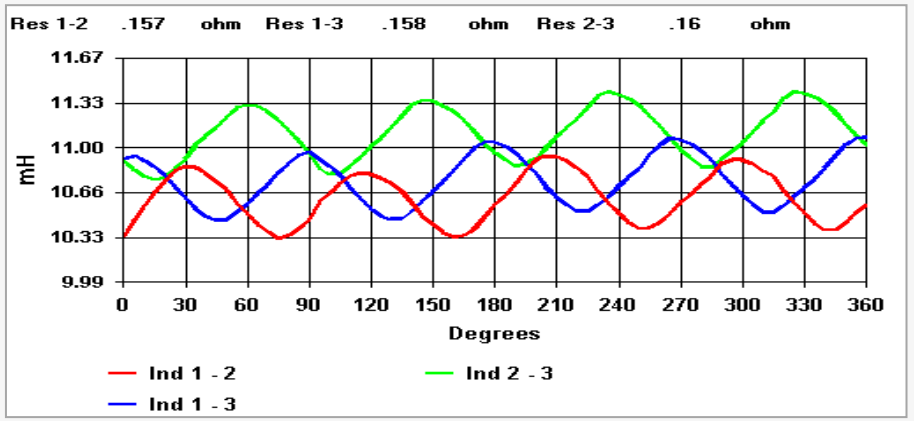


Concentric Wound

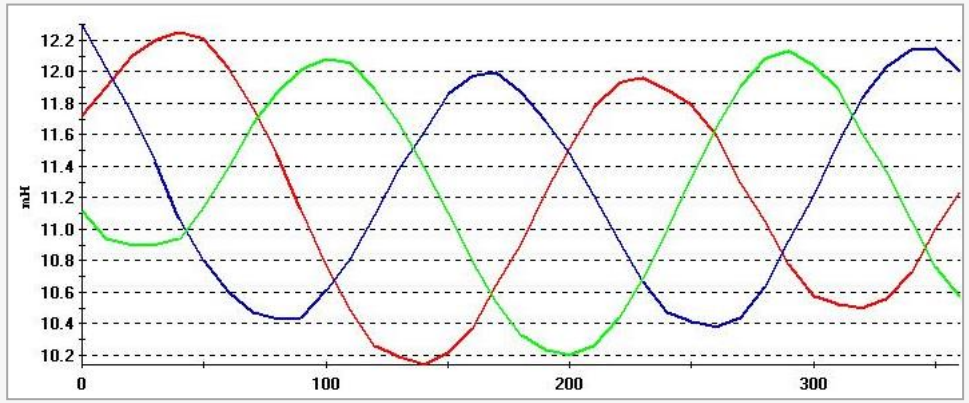
Rotor Influence Rotor



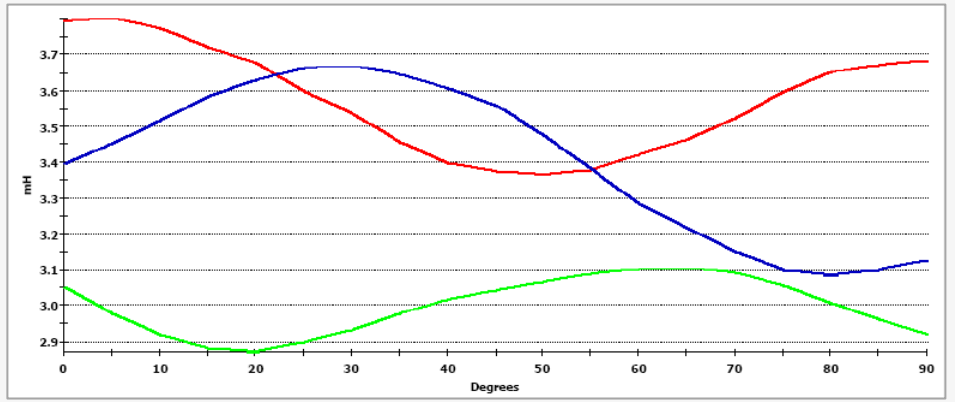
Turn or Coil Fault in one phase



Turn or Coil Fault in one phase



Eccentricity

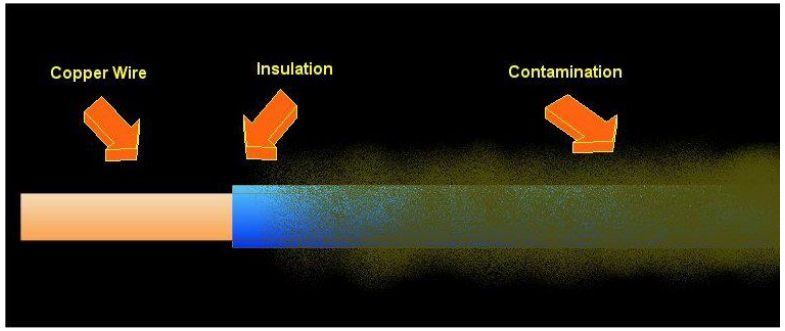


Phase to Phase Short 2-3

Capacitance

Capacitance (pico-farads)

- Primarily occurs between conductors and Stator Slots
- When measured to ground
- Increases as contamination accumulates on windings
- Early Waring System for Insulation



Insulation Testing

Insulation Testing

- RTG
- Hi-Pot AC and DC
- Surge Tester
- Timed Resistance Testing
  - Polarization Index
  - Dielectric Absorption

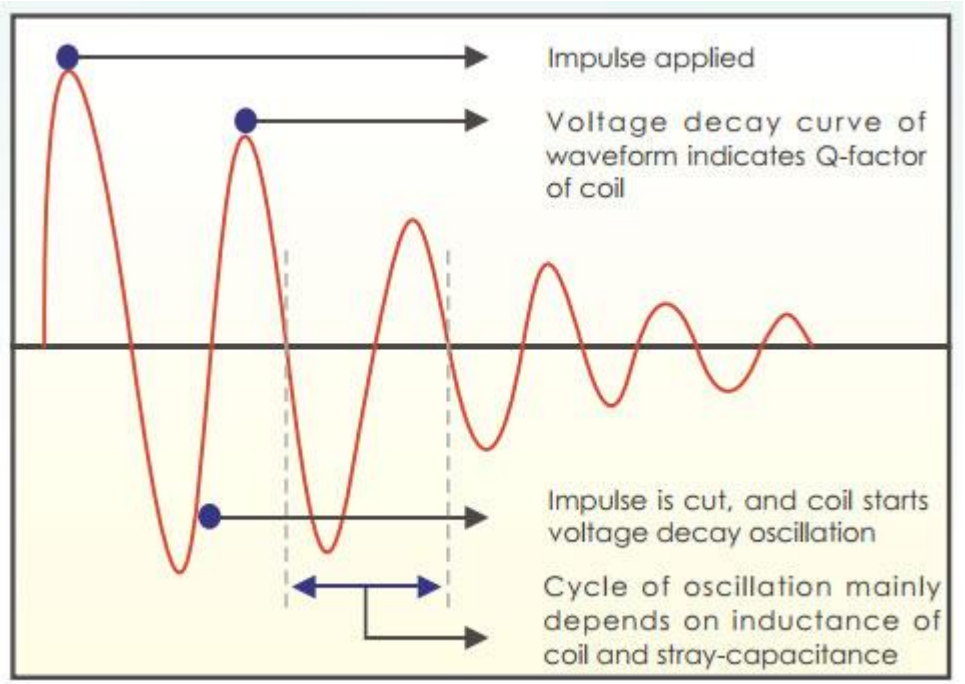
Surge Testing

Application of Surge Test Signal

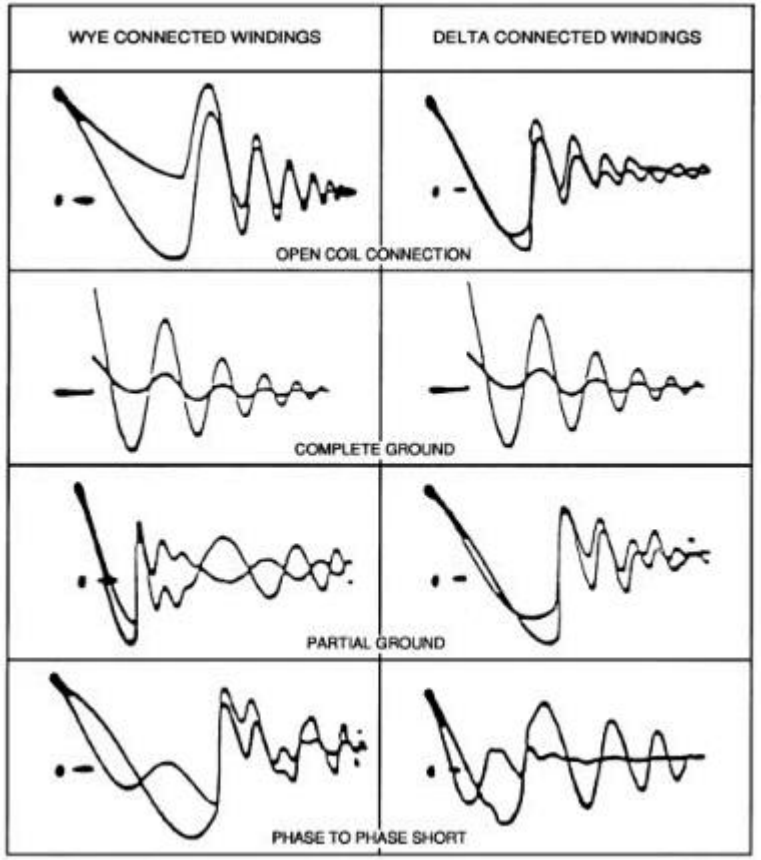
- Pass/Fail (potentially destructive test)
- Produces a waveform
- Analyzed by comparison of phase to phase
- Subject to interpretation
- Manual operation

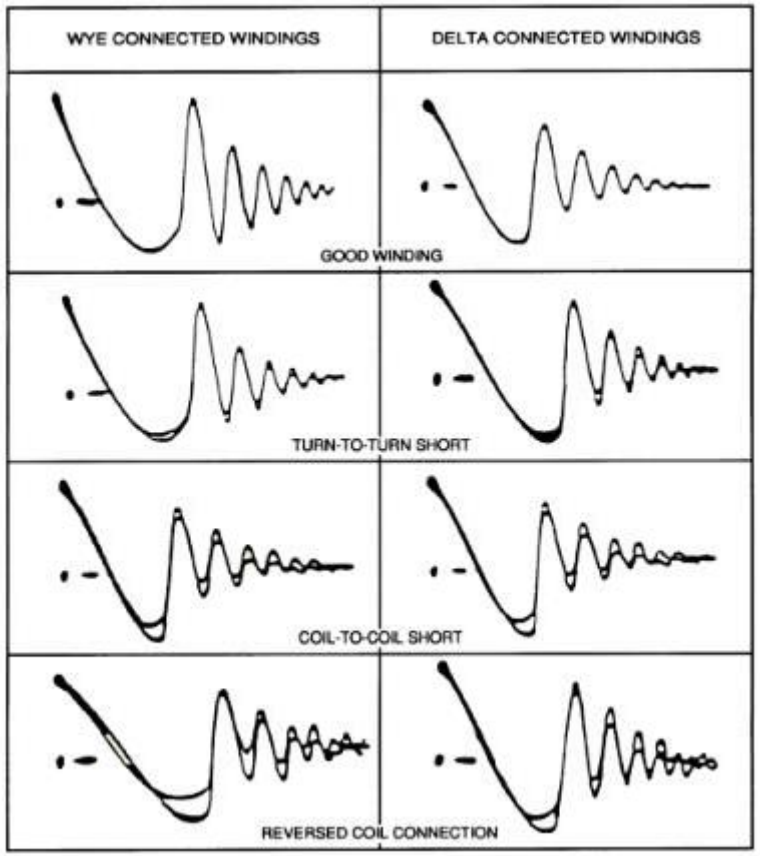
Mid 90's provided computer control

- Real time analysis
- Sensitive triggering (not destructive)
- Automated analysis
- Provided a platform for RCM



Surge Waveforms





Surge Testing

Pulse to Pulse Error Area Ratio (ppEAR)

- Successive pulses of increasing potential
- Difference between each pulse is determined
- A change in EAR indicates possible early stage of breakdown.
- Rotor can be installed for this testing

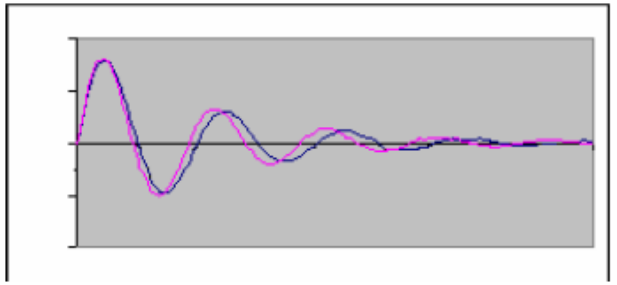


Figure 1 Two Waveforms To Be Compared

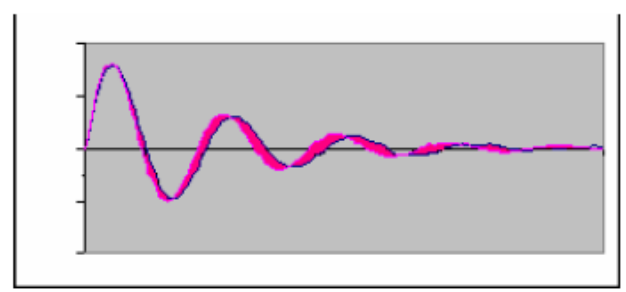


Figure 2 “Difference” Area Between Waveforms

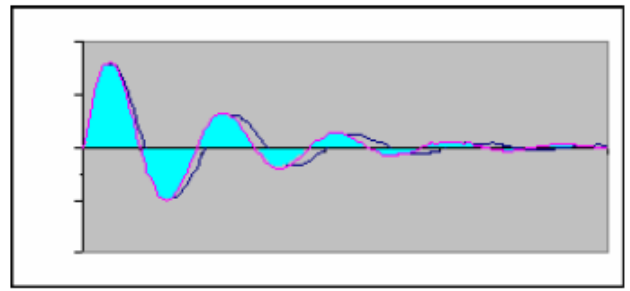
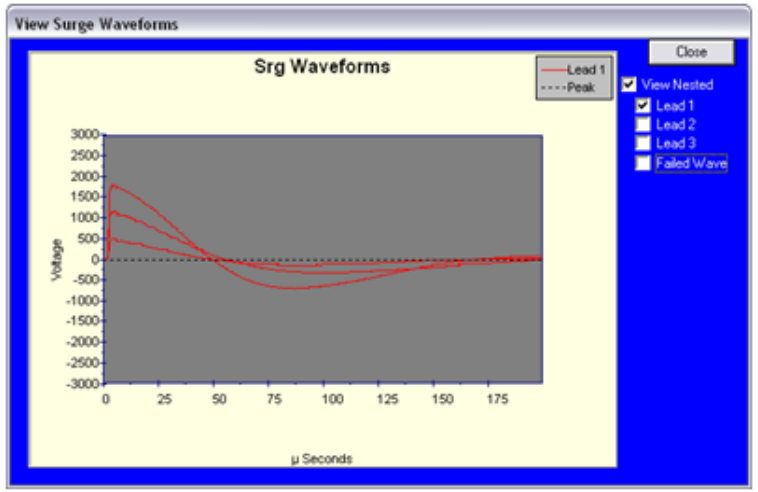
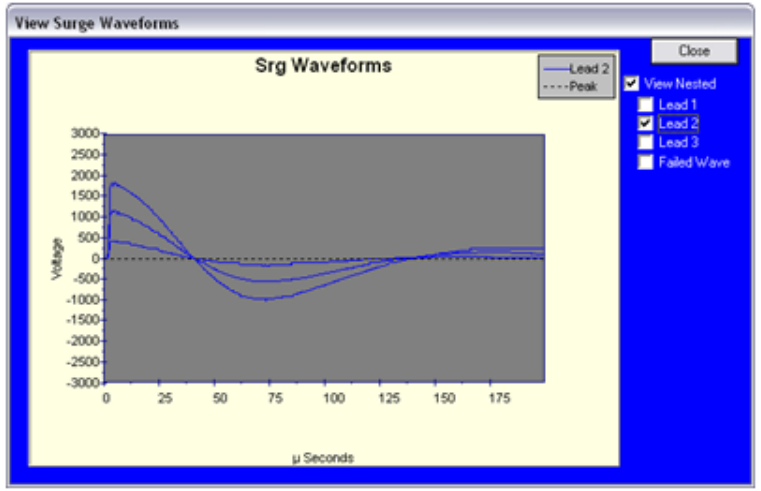
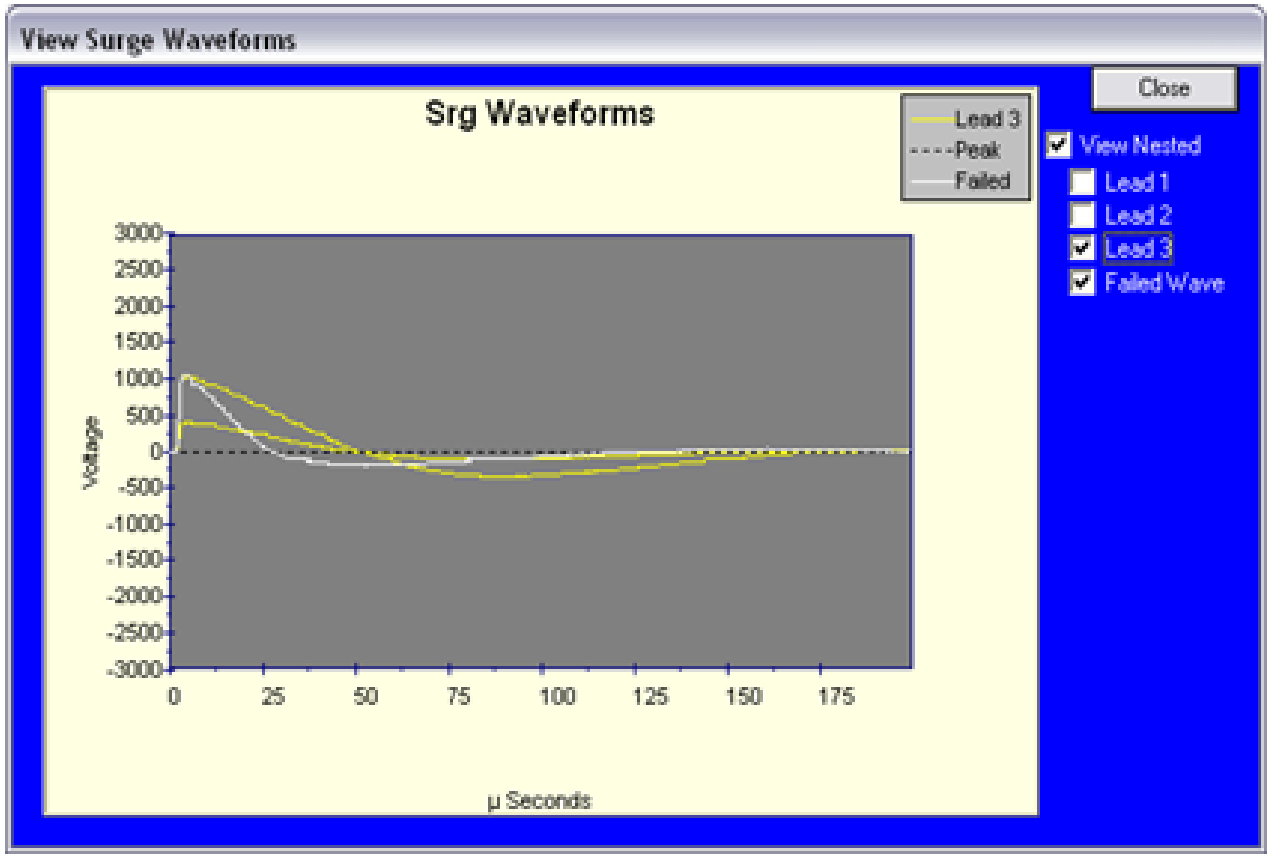


Figure 3 Area Under One Waveform

Weak Insulation Turn to Turn







High Potential Testing

High Voltage Test (HiPot)

- Tests insulation to a maximum limit
- Computer controlled
  - Non-destructive
  - Used for RCM
- Both AC and DC
  - AC – High Voltage distribution
  - DC – Motor and Motor Circuits

Vline	New 3.4*Vline+1700	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

Timed Resistance Testing

Polarization Index Profile

- Graphing Timed Resistance Test Results will provide unique patterns or profiles
- The resultant pattern is indicative of differing anomalies
- Profiles can be separated into five basic patterns

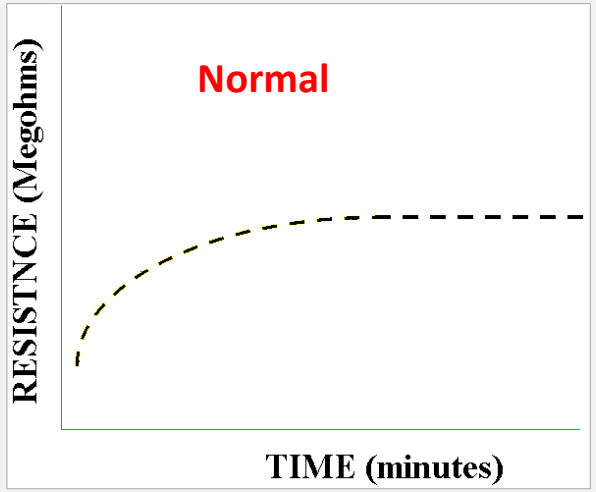
POLL QUESTION No. 2

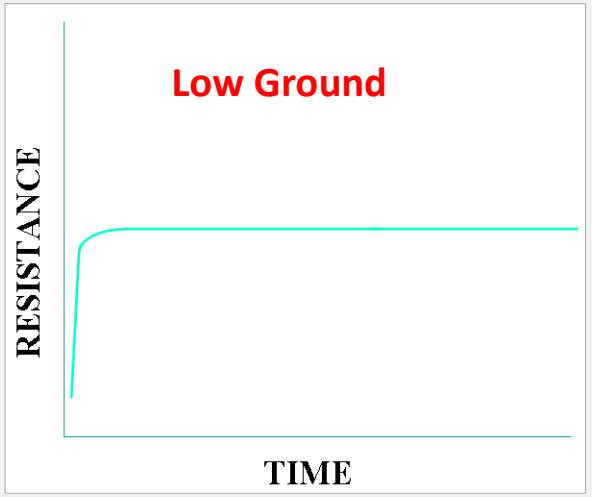
How applicable is motor testing to your plant or facility?

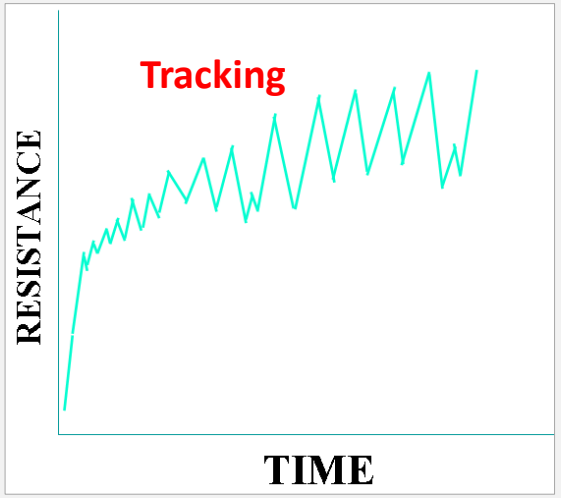
(Click only one answer)

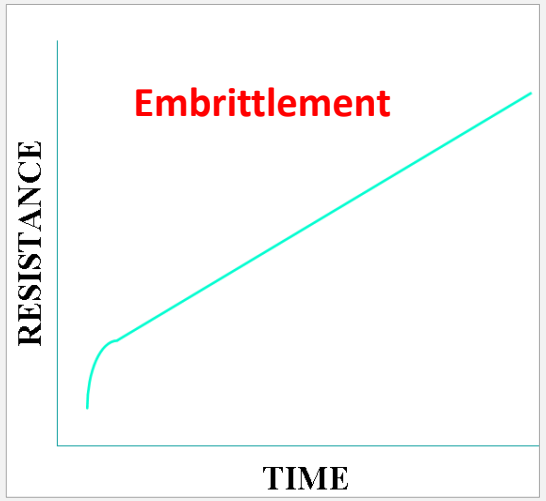
- Highly applicable
- Somewhat applicable
- Not very applicable
- Not sure

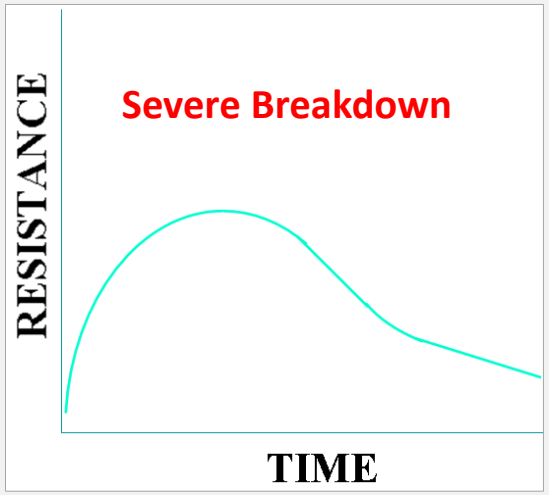
PI Profile





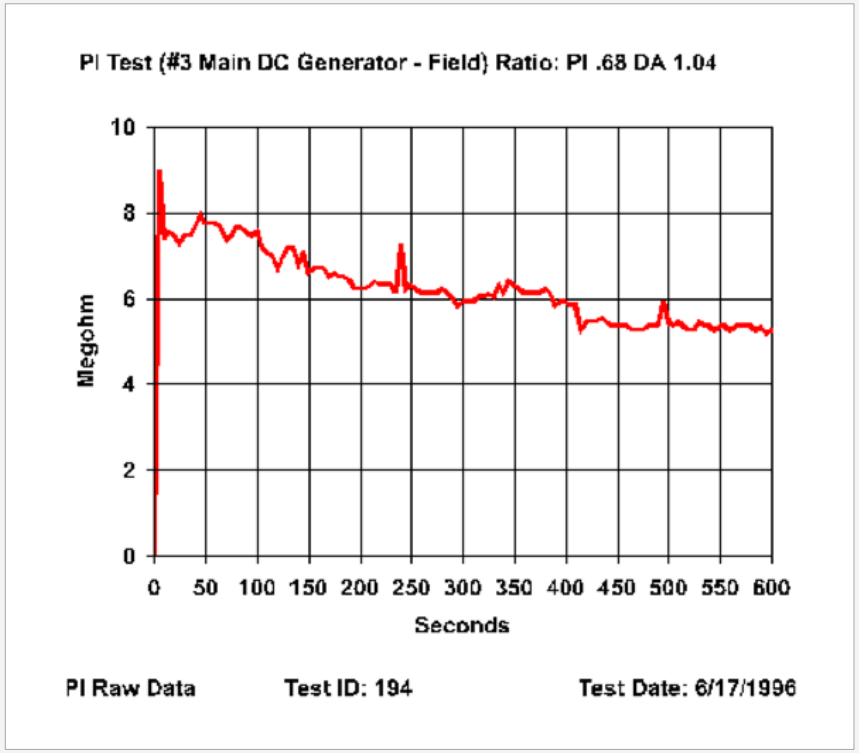


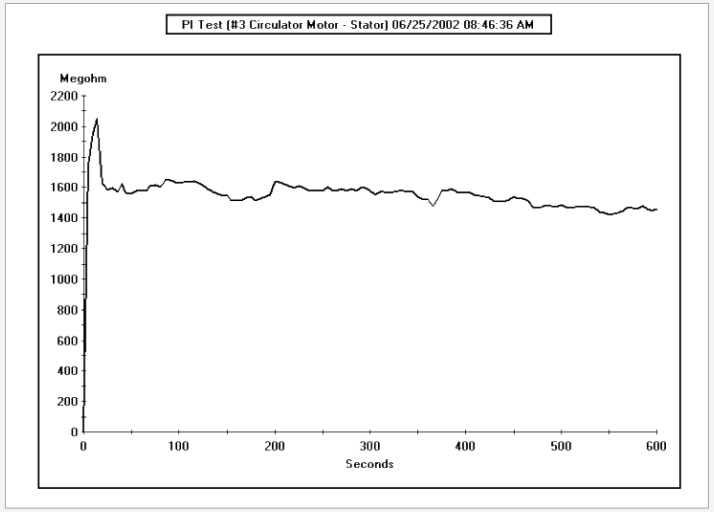


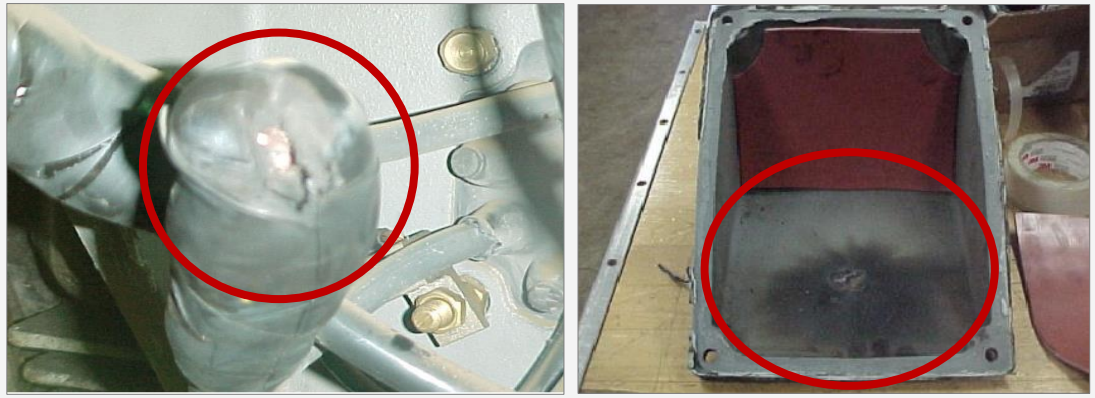


PI Case Studies

DC Generator - unit failed within 1 day after start.





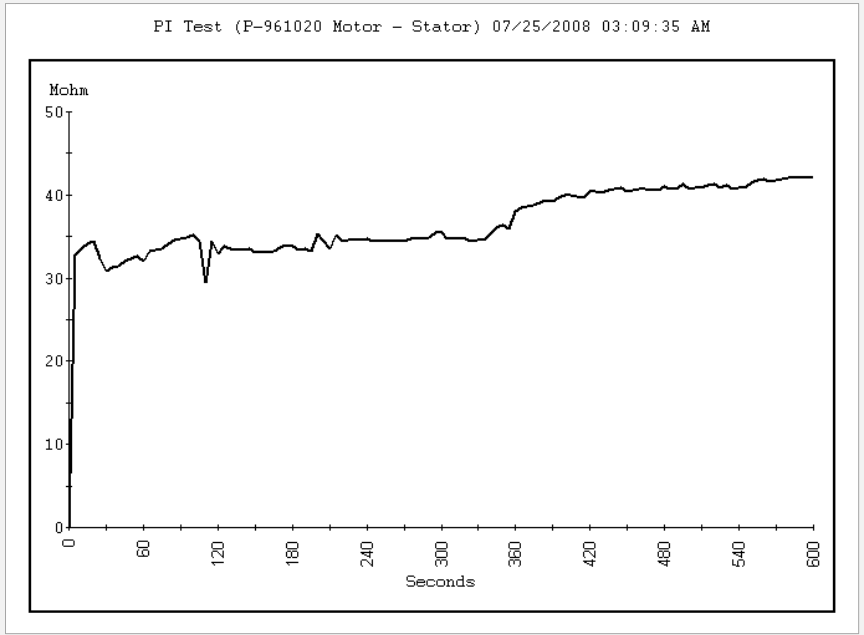


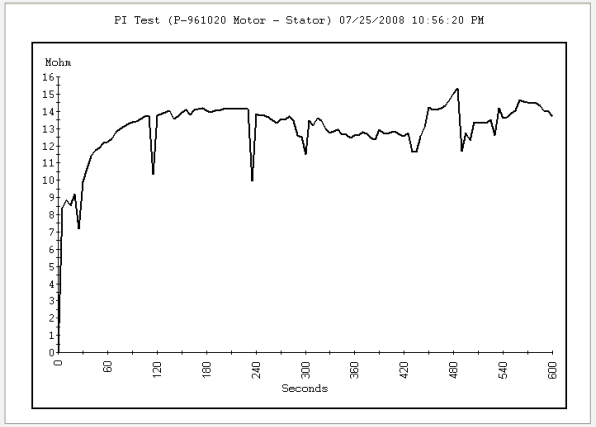
Indoor pump motor.

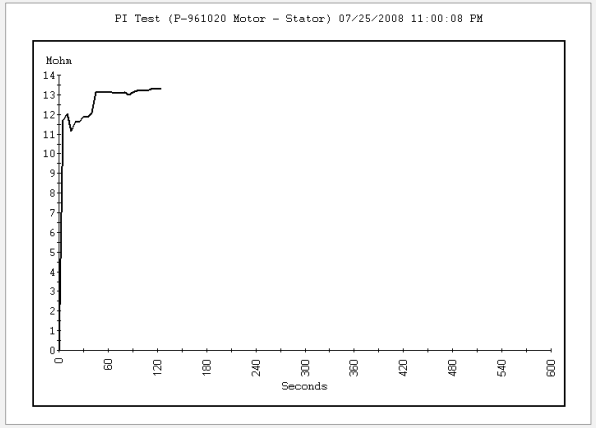
PI Case Study

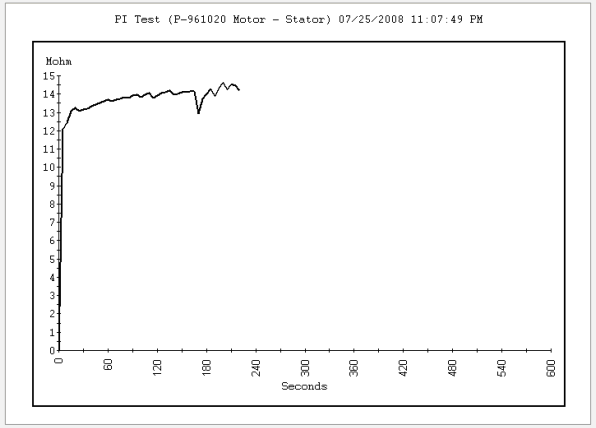
Acceptance Testing

- Installed 4160V 250 HP
- 100Meg Minimum Spec
- Tested From Starter





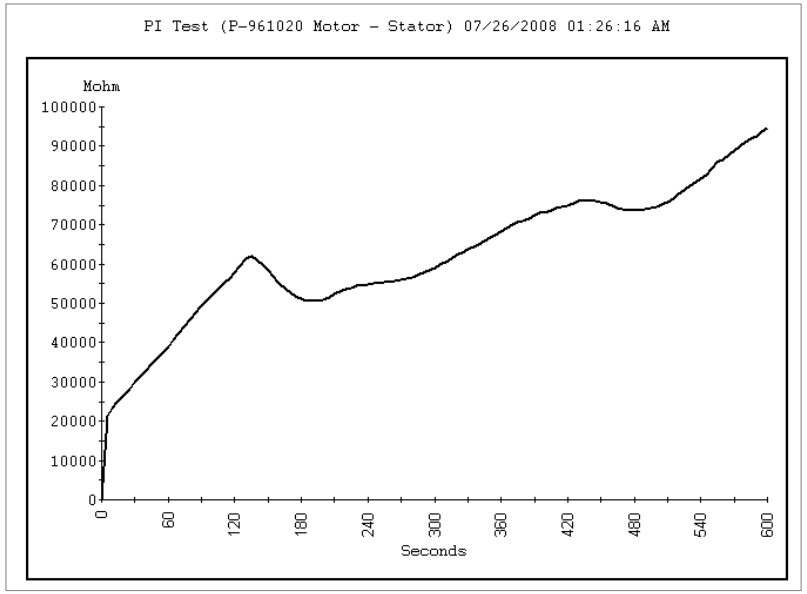




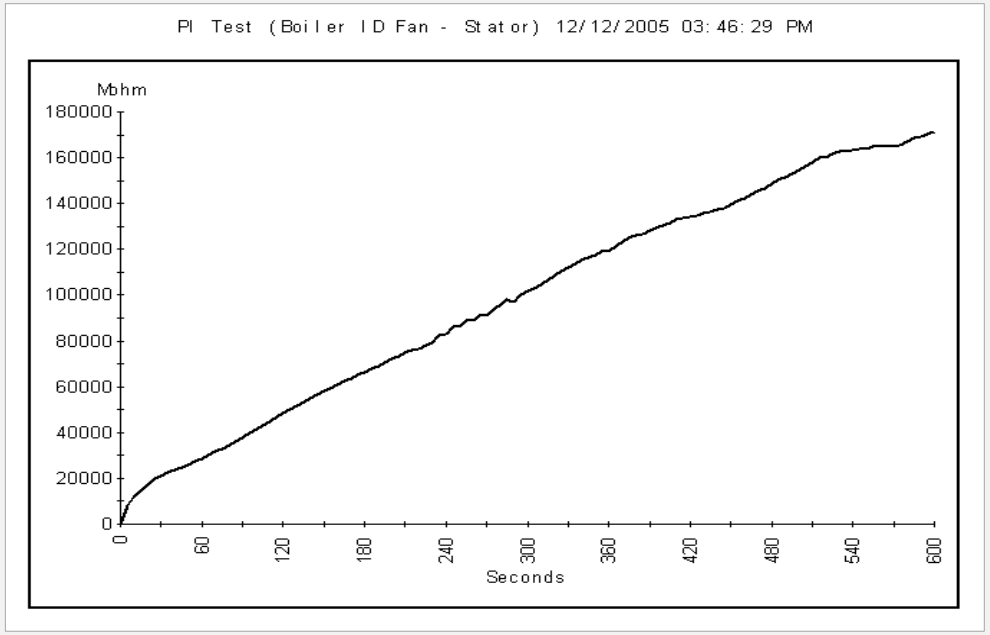
Tested the next day, all phases read the same.

PI Case Study

- One phase lead was removed from the insulator terminal in the starter cabinet
- Resistance to ground immediately went to 21,200 Meg in 5 seconds
- 94,649 Meg 2.43 PI



PI Case Studies



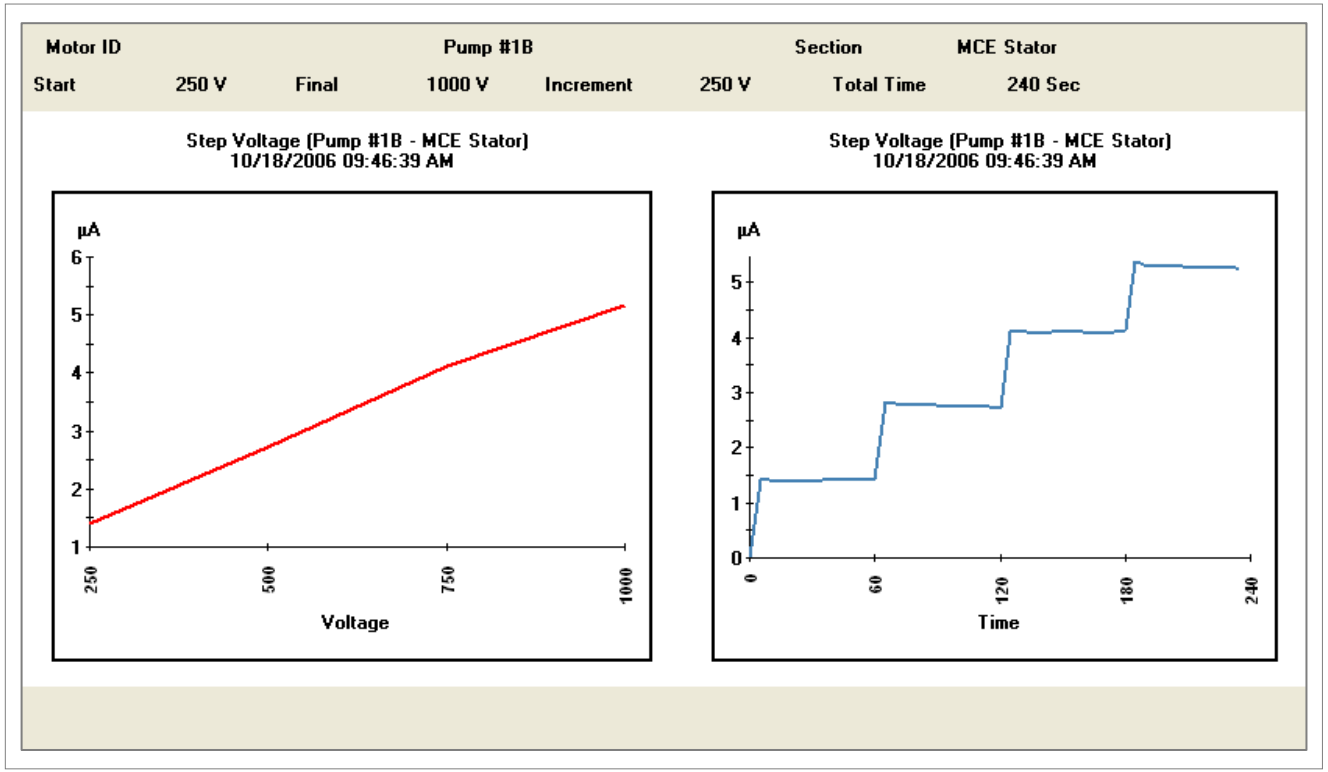
Boiler ID Fan Embrittled Cabling

Rejected Cabling

Step Voltage Testing

Timed Resistance Test

- Displays:
  - Voltage
  - Current
- Step's voltage incrementally at user defined duration
- Monitor current at each step
- Observe for a jump in current
- Perform at baseline and when PI is unstable



Energized Electric Motor Testing

- Entails connection of voltage leads and amp probes to the motor leads or secondary circuits (CTs, PTs) on medium and high voltage motors
- Provides a means of assessing Power Quality, current, and electrical signature analysis (MCSA, ESA)
- Provides a means of identifying many mechanisms that lead to motor failure.
- Most OEM instruments cannot assess insulation integrity.
- More opportunity to conduct energized testing
- Can be incident-free, if safe practices and procedures are followed

Energized Electric Motor Testing

Expedient Testing Method for identifying:

- Power Quality Problems
- Motor and Motor Circuit Electrical Issues
- Motor and Drive Train Mechanical Issues
- Most Failure Mechanisms that lead to motor insulation breakdown

Excellent Tool for:

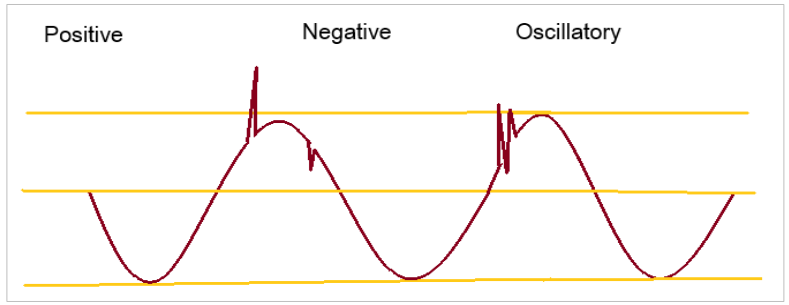
- Equipment Troubleshooting
- Equipment Commissioning
- Condition Monitoring
- Power Quality Fault Isolation / Localization

Power Quality Problems

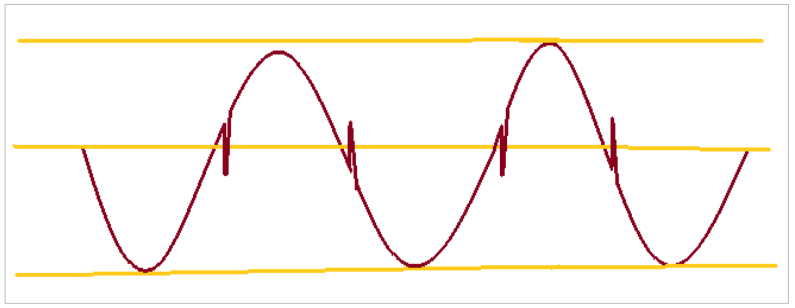
- High Frequency Event
  - Unidirectional
  - Oscillatory Impulse
- Voltage Fluctuation (Flicker)
- Voltage Sag
- Voltage Swells
- Notching – Zero Voltage Crossing
- Transient Over Voltages
- Unbalanced Voltage
- Unbalanced Current
- Reactive Current Unbalance
- Power Factor
- Harmonics
  - Even Harmonics
  - Odd Harmonics
  - Zero Harmonics
  - Mechanical Harmonics
  - Sequence currents
- Frequency Deviation
- Ground Anomalies

Power Quality Problems

- High Frequency Event
  - Unidirectional - Impulsive
  - Oscillatory Impulse

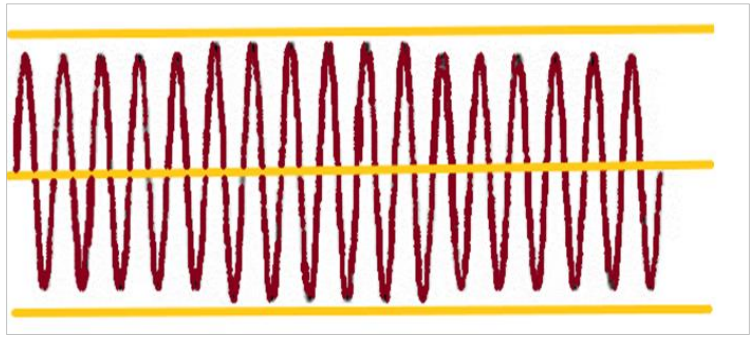


Transients

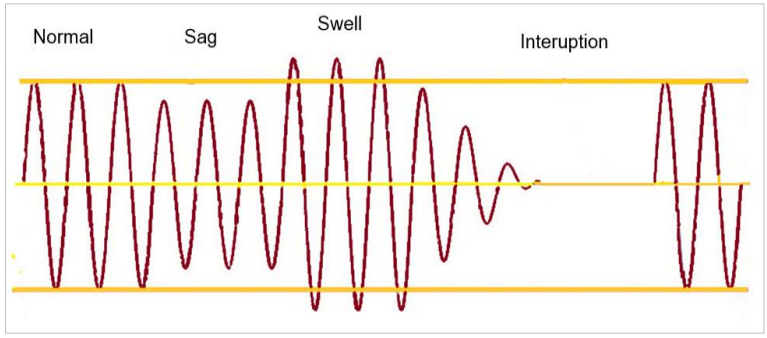


Zero Crossing Transients

- Voltage Fluctuation (Flicker)
- Voltage Sags, Swells



Voltage Fluctuation-Flicker

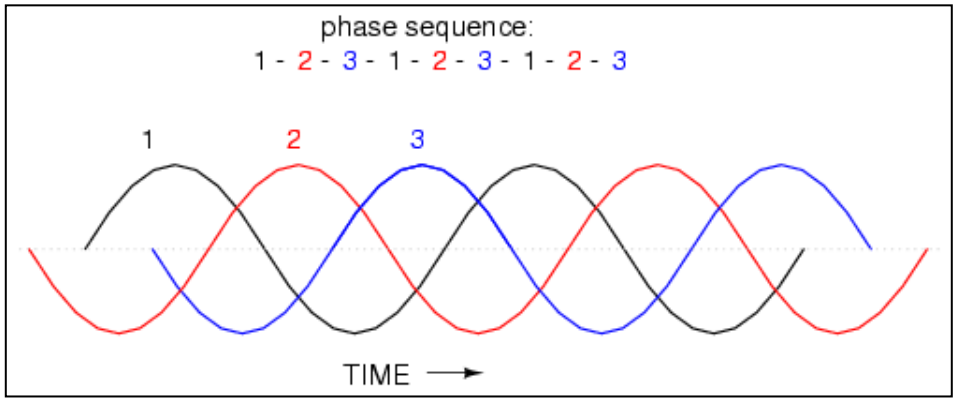


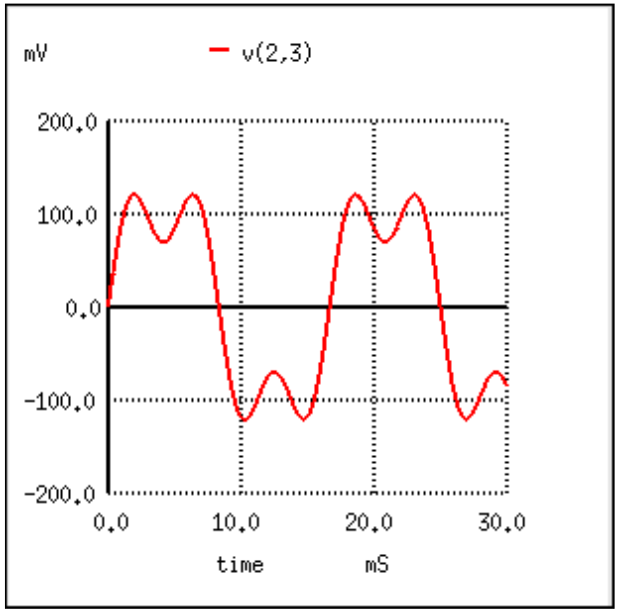
Voltage Anomalies

Power Quality Problems

Harmonics

- Multiples of the fundamental frequency
  - US 60Hz
  - Europe 50Hz
- Differing schools of thought:
  - Harmful
  - Not Harmful
  - It’s prudent to believe they are and monitor accordingly.
  - Produce heat at the square of the number given equal value of the first





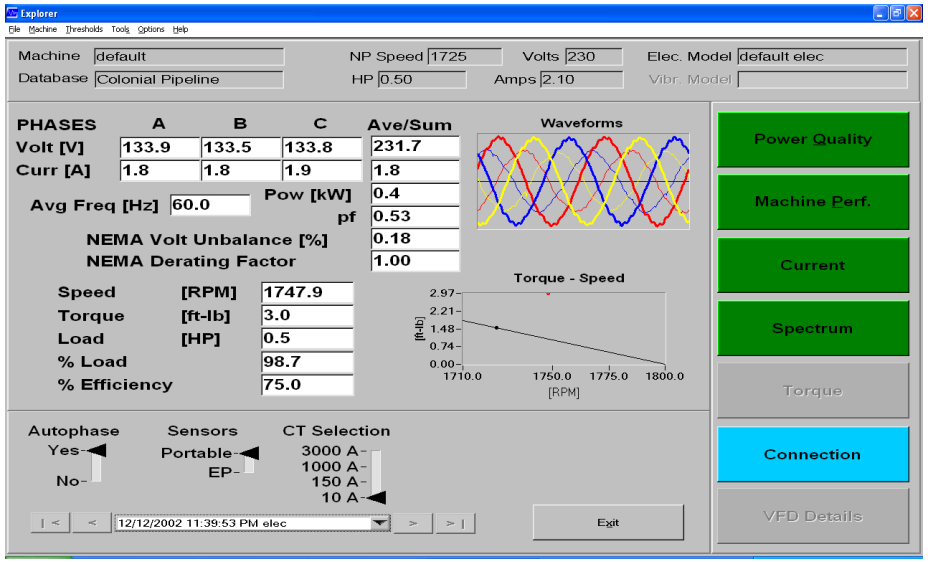
Harmonic Sequence

1	60	Pos	9	540	Zero Triplen	17	1020	Neg
2	120	Neg	10	600	Pos	18	1080	Zero
3	180	Zero Triplen	11	660	Neg	19	1140	Pos
4	240	Pos	12	720	Zero	20	1200	Neg
5	300	Neg	13	780	Pos	21	1260	Zero Triplen
6	360	Zero	14	840	Neg	22	1320	Pos
7	420	Pos	15	900	Zero Triplen	23	1380	Neg
8	480	Neg	16	960	Pos	24	1440	Zero

Power Quality Analysis

- **Voltage Analysis**
  - Check Balance:
    - Phase to Phase
    - Phase to Neutral
  - Harmonic Distortion

- **NEMA Derating**
  - Voltage Balance
  - Harmonic Voltage Factor



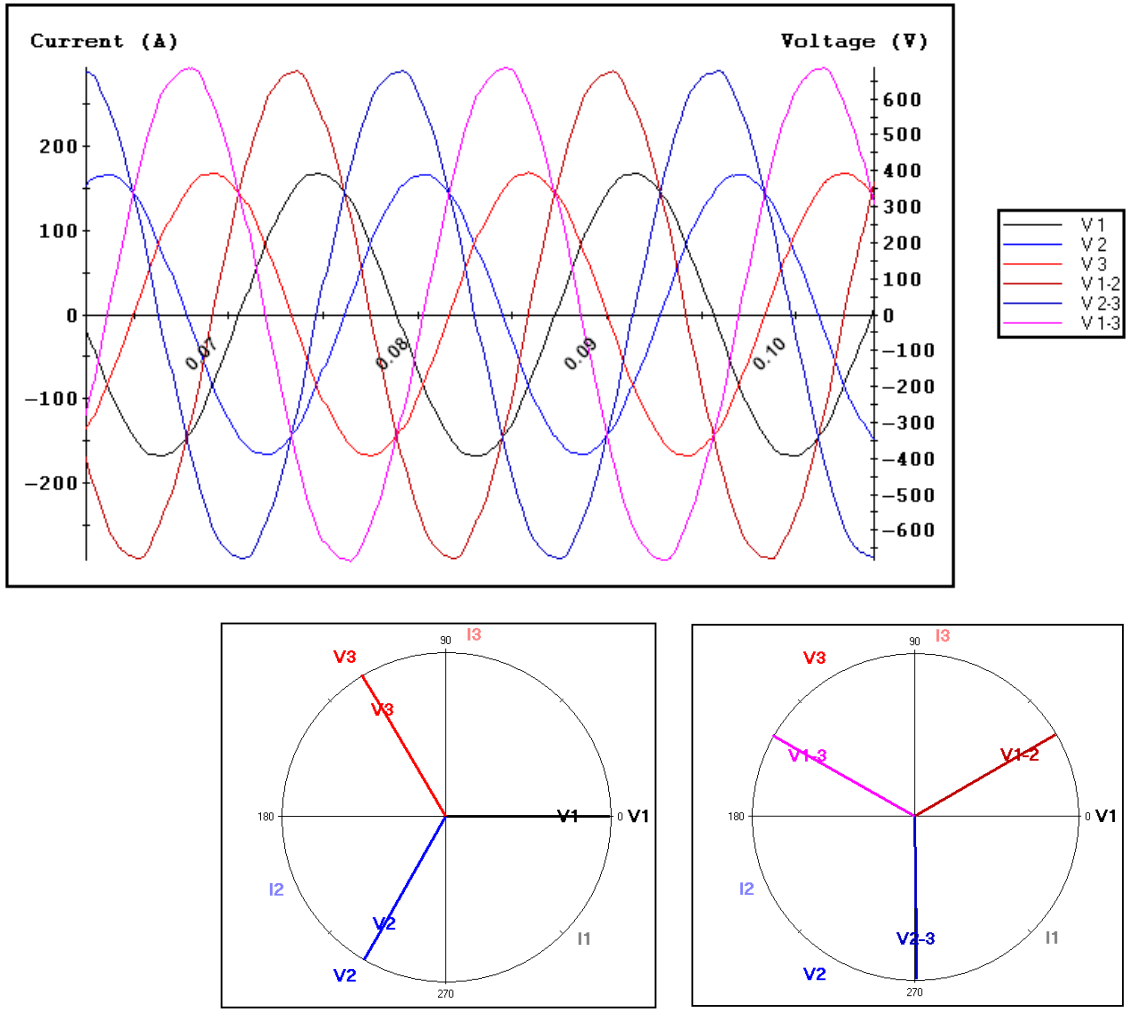
	Phs-1	Phs-2	Phs-3	Total	Units
Power factor	0.875	0.020	0.883	0.597	
Real Pwr.	25.2	0.6	25.8	51.6	HP
Reactive Pwr.	14.0	28.3	13.7	56.0	HP
Apparent Pwr.	28.9	28.3	29.2	86.3	HP
Running Cnt.	77.05	76.20	78.51	77.25	Amp
Line Voltage	482	480	481	481	Volt

	Fund RMS	Tot RMS	C.F	THD
Voltage 1-2	478.65	479.07	1.42	0.87
Voltage 2-3	483.86	484.28	1.43	0.77
Voltage 1-3	487.66	488.08	1.43	0.91
Average	483.39	483.81		
% Imbalance	0.98	0.98	HVF	0.00
%NEMA Derating	99.52	%NEMA	Derating	100.00
Voltage 1	279.13	279.39	1.39	1.30
Voltage 2	276.75	277.00	1.40	1.20
Voltage 3	281.38	281.64	1.40	1.26
Average	279.09	279.34		
% Imbalance	0.84	0.84		

Power Quality Analysis

Voltage Analysis

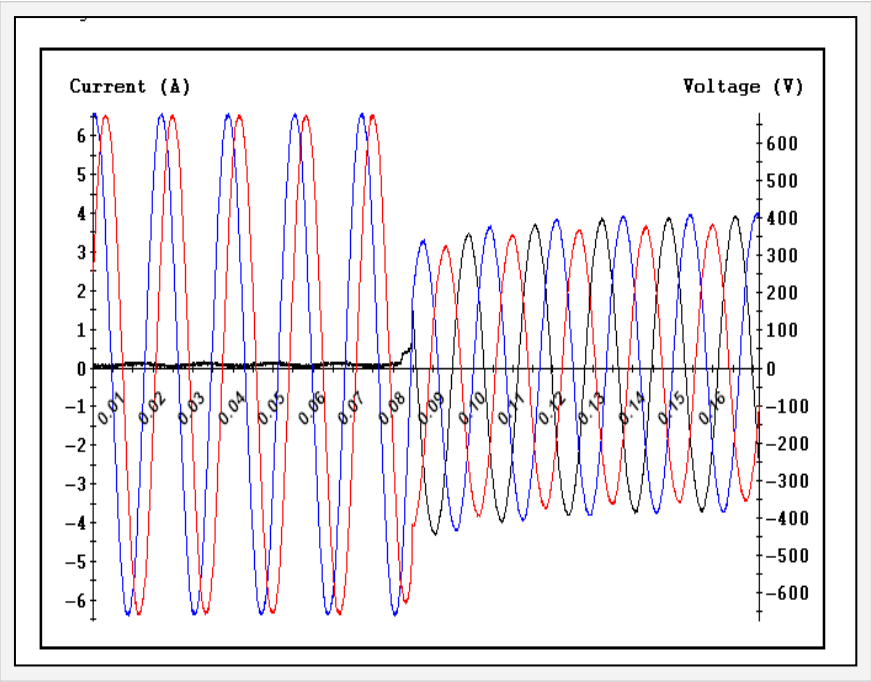
- Should be reviewed first
- Most important parameter
  - Must be balanced
  - Proper phasing
  - Will affect all other PQ values
  - Can have deleterious affects
- A 3%-5% Phase to Phase voltage unbalance will half motor life

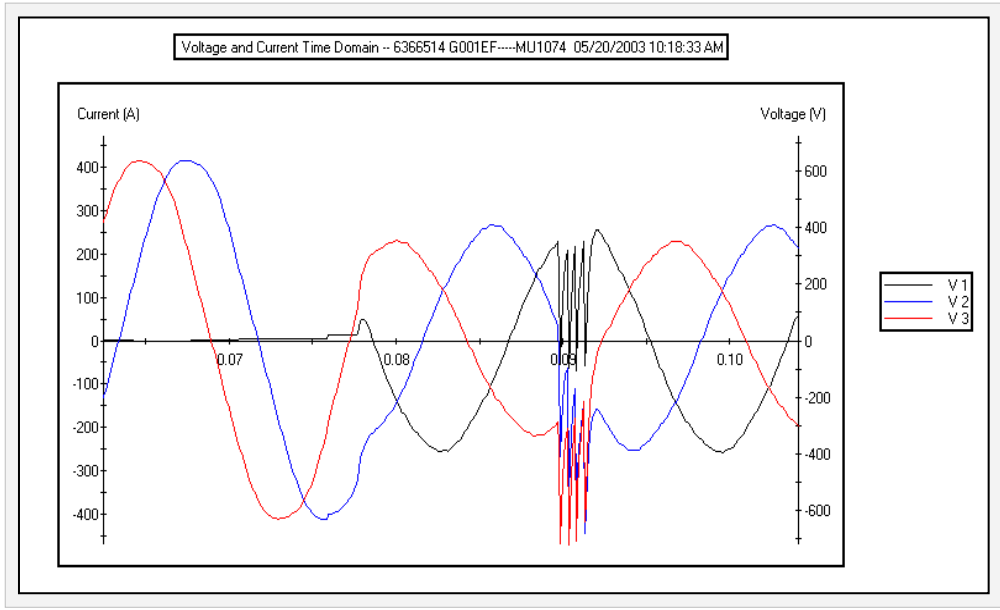


Ground Fault

Voltage to Neutral

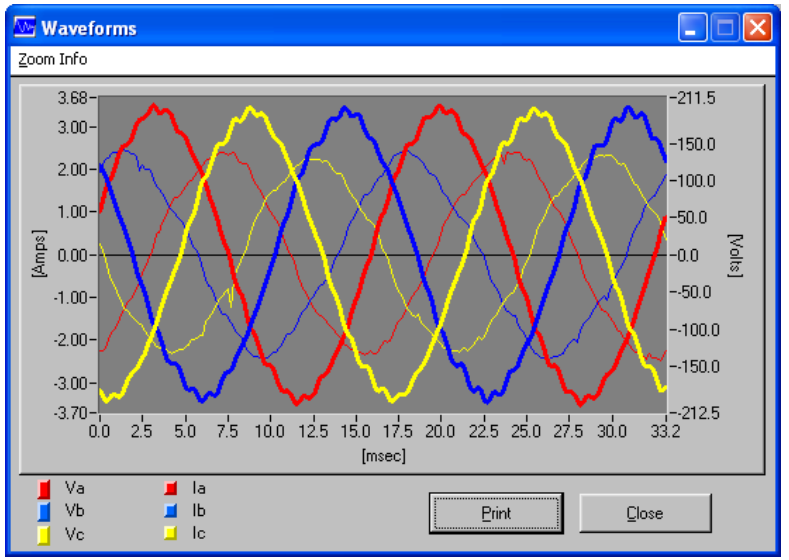
- Useful for identifying grounds on un-grounded systems
- Phase with the low voltage is the affected phase
- Unaffected phase voltage increases

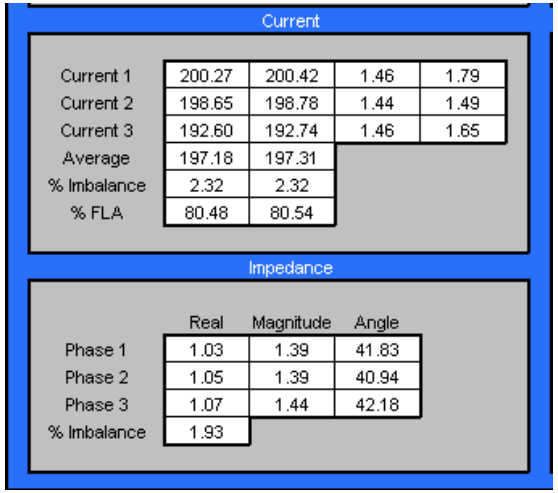




Power Quality Analysis

- Current Analysis
- Balanced Voltage does not mean you will have balanced current
- Current should be:
  - Balanced with loading
  - Should exhibit proper phasing
  - Should be free of distortion

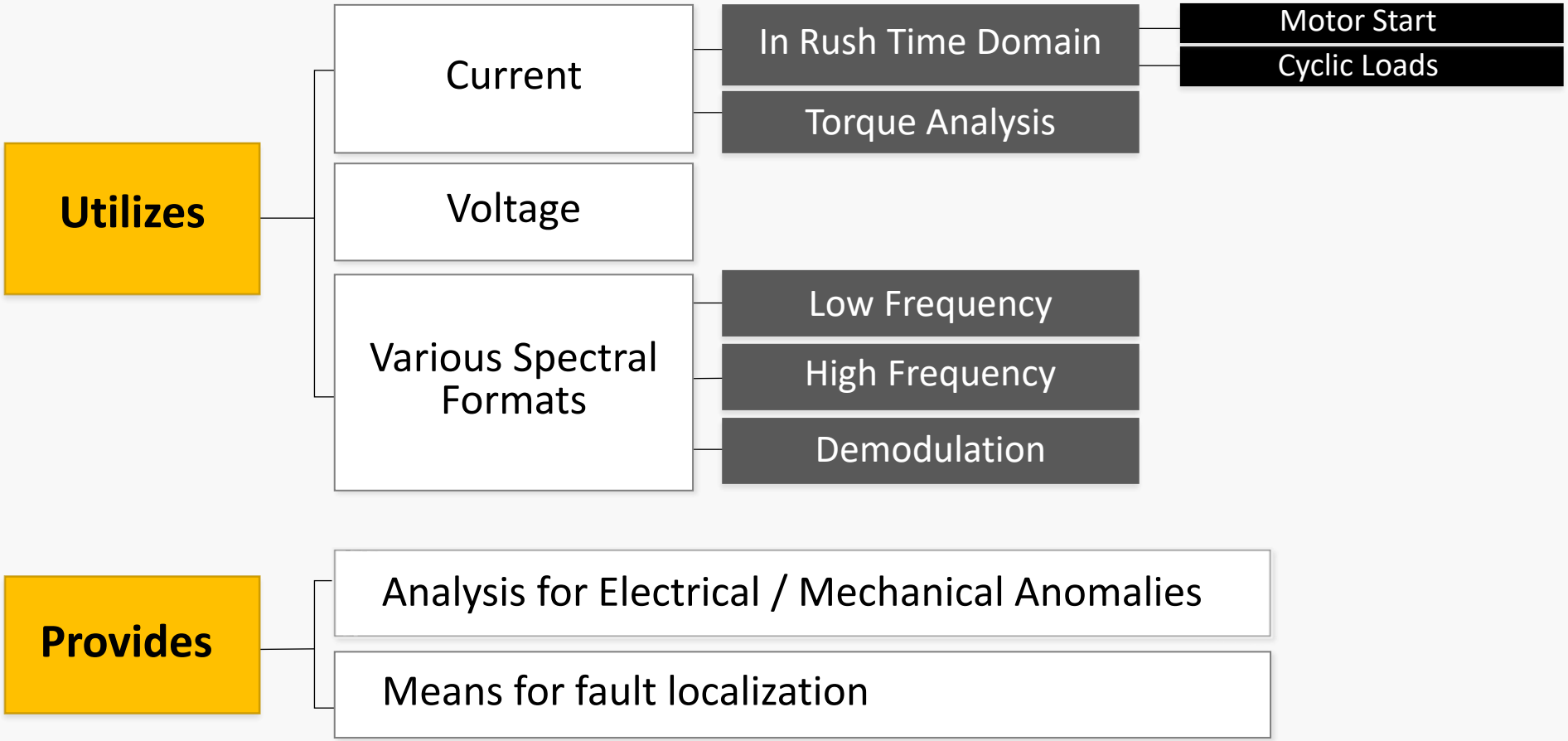




Data Correlation

Current Unbalance	Impedance Unbalance	Analysis
Low >3-5%	Low >3-5%	Normal
Moderate (Example 8%)	Comparable (Example 8 – 15%)	High Resistance Connection
Moderate (Example 8%)	2x Current % or > (Example 18 –30%)	Stator Fault (Shorted Turns, Coils)
Moderate (Example 8%)	High (Example 50 –80%)	Defective PF Capacitor

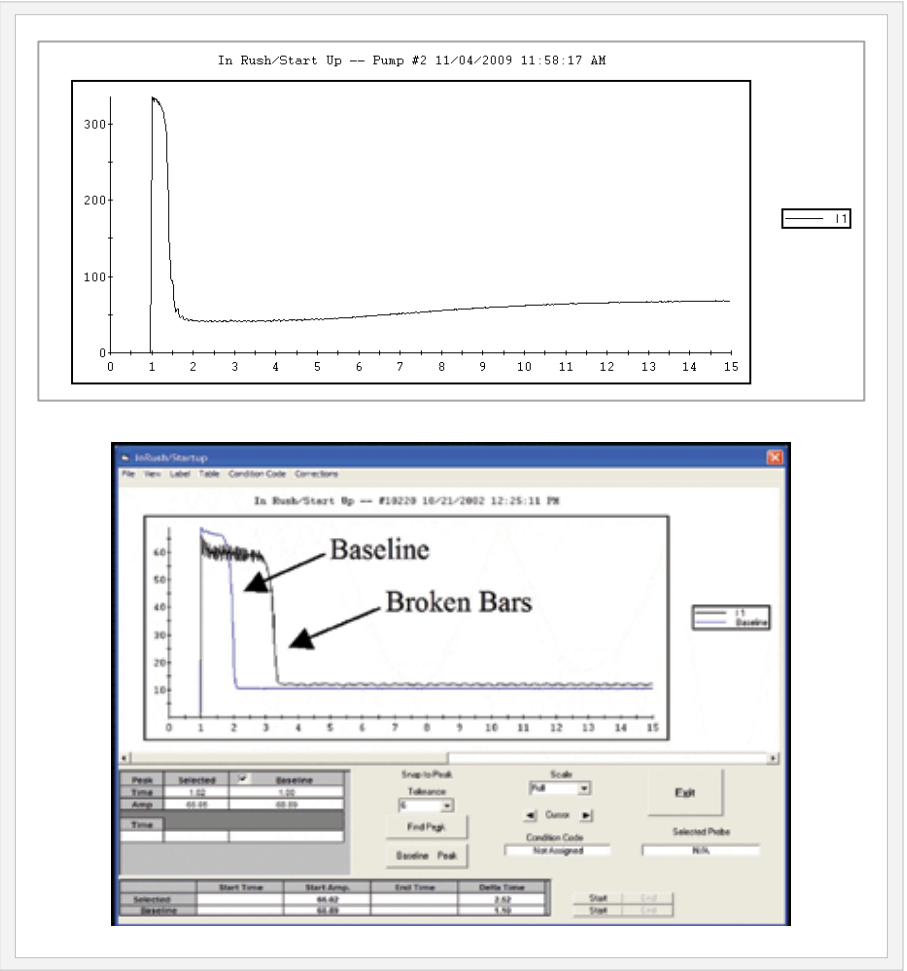
Electrical Signal Analysis



Monitoring Motor Starts

Importance of Monitoring Motor Starts Provides:

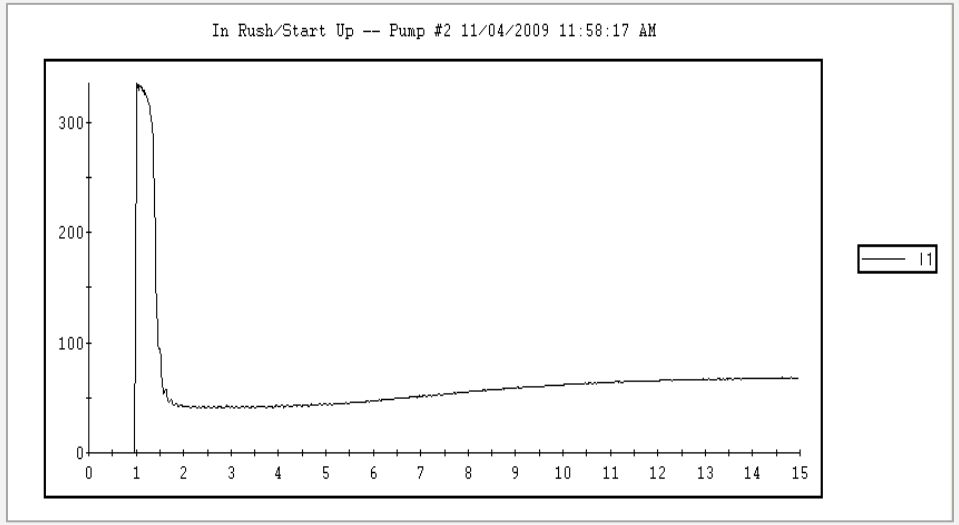
- Monitoring of In-Rush
- Transition Timing
- Rotor Bar Correlation
- Load Evaluation
- Timing Circuit Verification
- Start Circuit Evaluation
- Trending



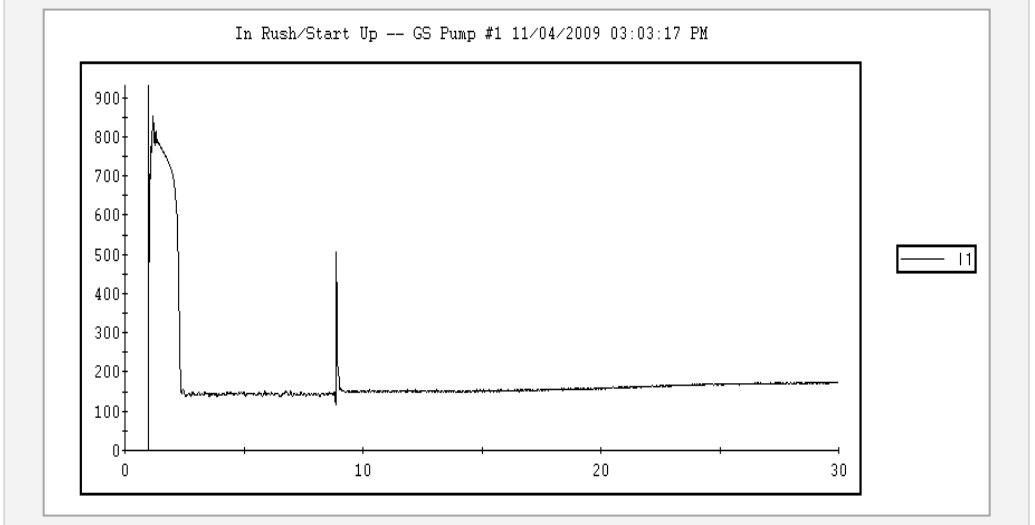
Starting Profile Analysis

Current Peak Trend	Transition to Run Time	Analysis
Normal	Normal	Normal
Lower in one channel	Longer	High Resistance Connection
Higher in all channels	Longer	Mechanical Load Problem
Lower in one or more channels	Longer	Rotor Fault (May also have ripple)

Starting Circuits

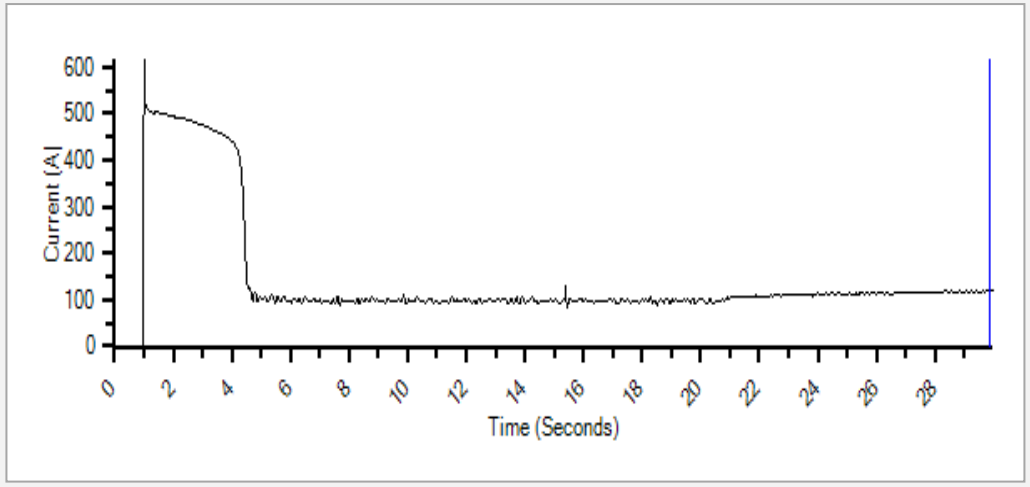


75 Horsepower
Across Line

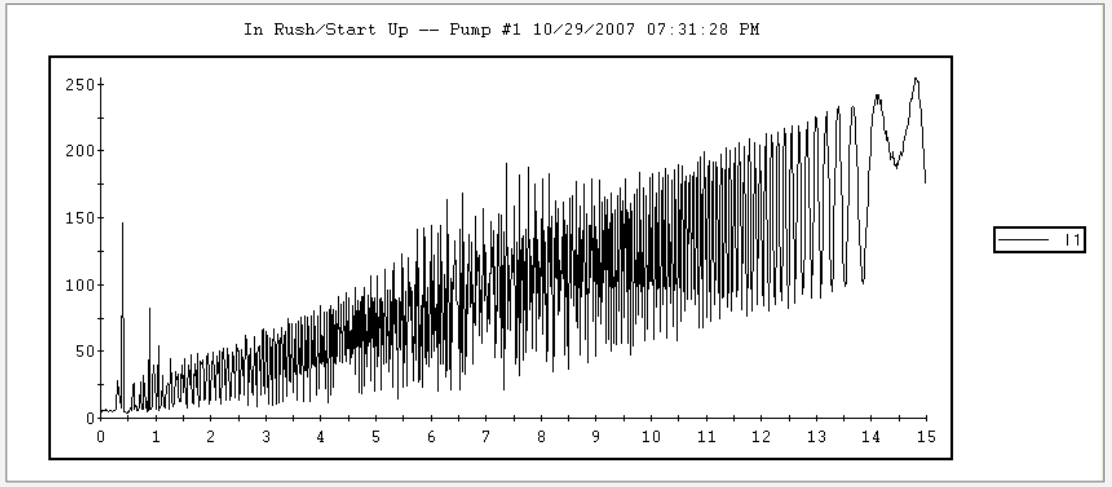


400 Horsepower
Soft Start

Starting Circuits

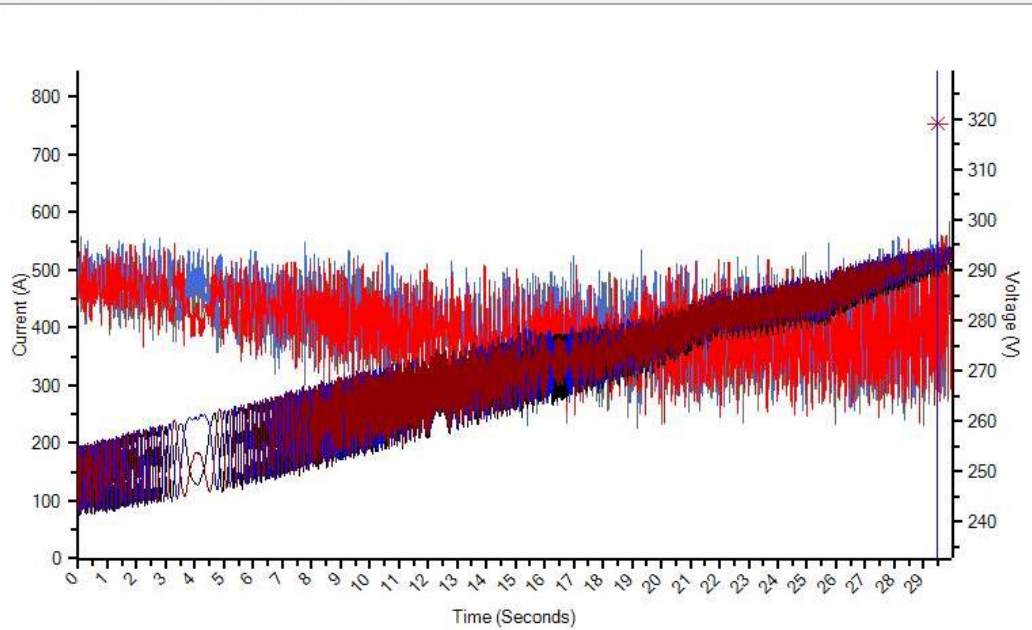


4000 HP Start Reactor
(Variable Transformer Taps)



VFD Start

Starting Circuit Case Study



Nameplate Information

Type	AC Mtr.
Manufacturer	U.S. ELECTRIC
User Asset ID	-
Frame #	6808PZ
NP Freq	60
Volt	480
FLA	507.00
KW	298.40
HP	400.00
PF	0.88
Eff	0.920
NP Speed	715
OP Speed	715
Slots	0
Bars	0

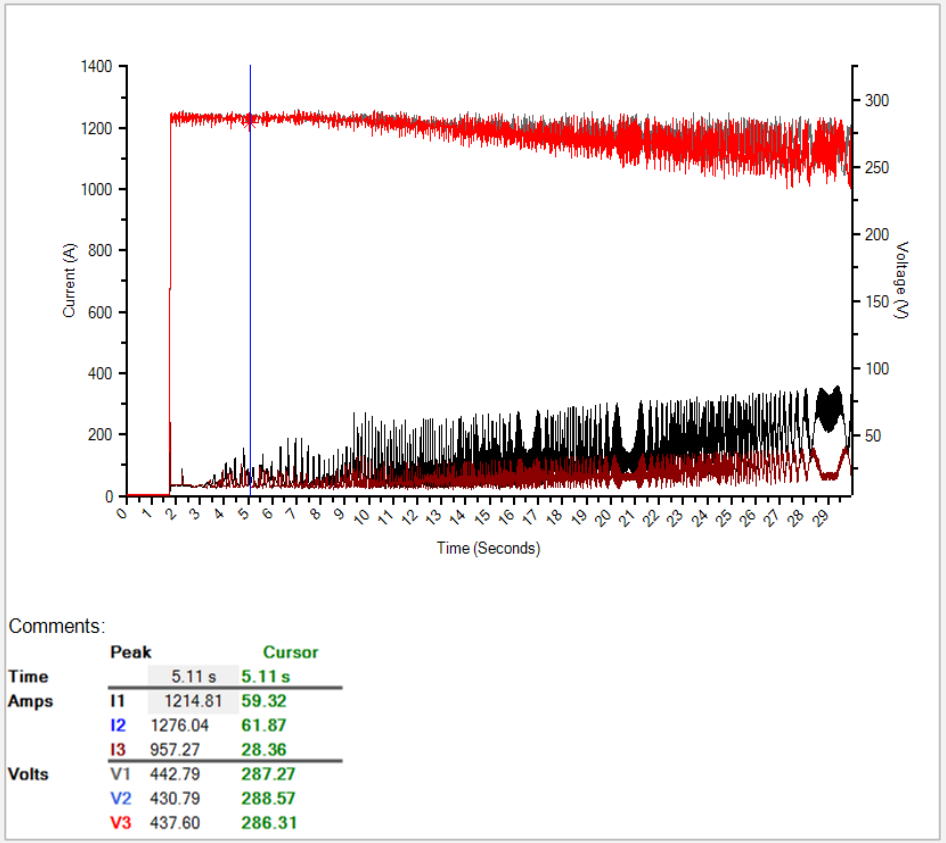
Start Time	0
Start Amp.	1
End Time	1
Delta Time	1

Comments:

		Peak	Cursor
Time		29.52 s	29.52 s
Amps	I1	751.71	490.14
	I2	767.64	534.76
	I3	765.37	526.74
Volts	V1	456.28	287.59
	V2	451.81	295.93
	V3	453.41	293.92

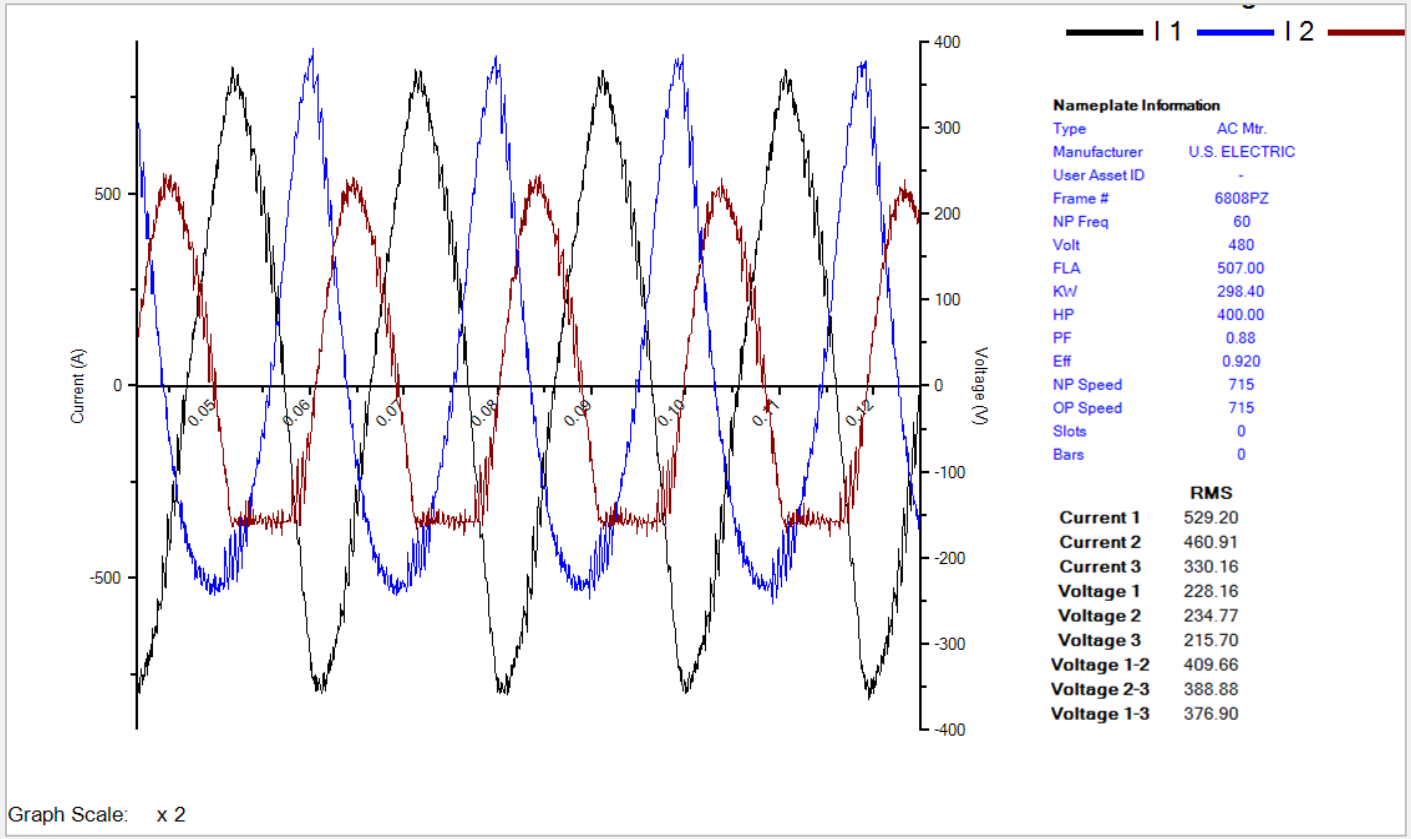
Normal VFD Start

In Rush on a Defective VFD



Comments:

		Peak	Cursor
Time		5.11 s	5.11 s
Amps	I1	1214.81	59.32
	I2	1276.04	61.87
	I3	957.27	28.36
Volts	V1	442.79	287.27
	V2	430.79	288.57
	V3	437.60	286.31



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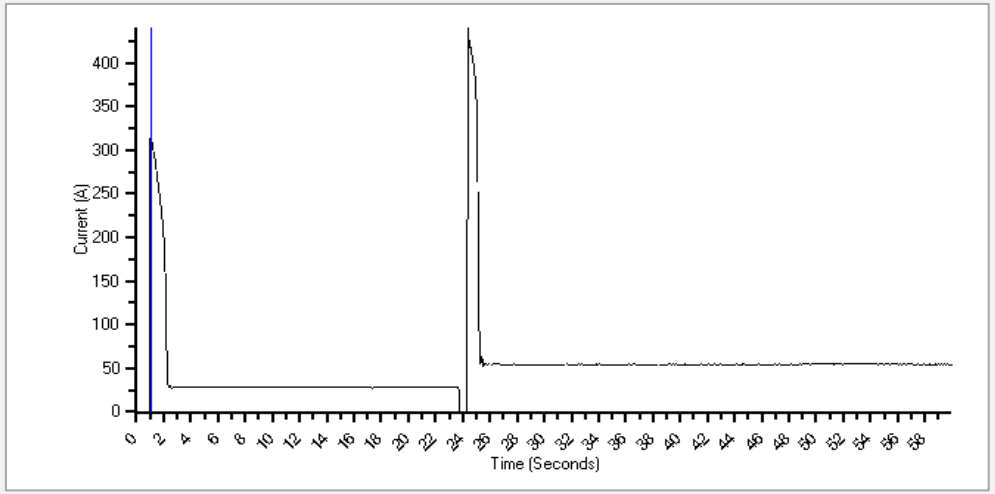
FLA	507.00
KW	298.40
HP	400.00
PF	0.88
Eff	0.920
NP Speed	715
OP Speed	715
Slots	0
Bars	0

RMS	
Current 1	529.20
Current 2	460.91
Current 3	330.16
Voltage 1	228.16
Voltage 2	234.77
Voltage 3	215.70
Voltage 1-2	409.66
Voltage 2-3	388.88
Voltage 1-3	376.90

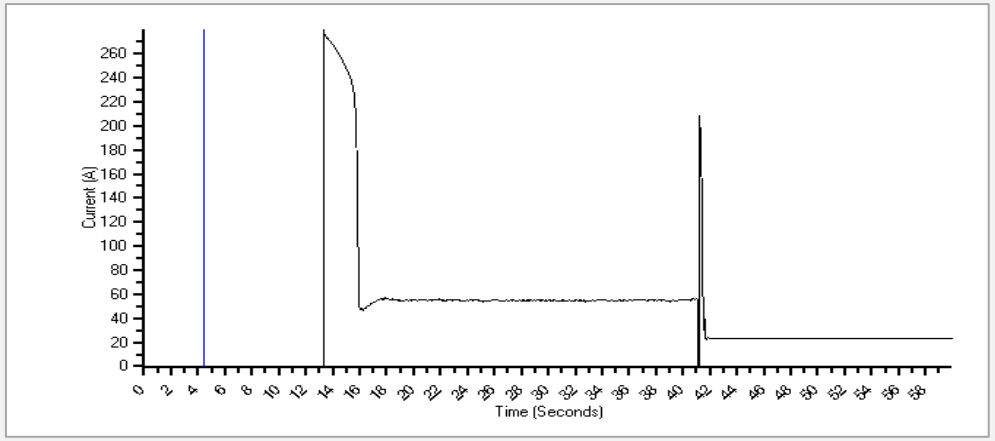
Graph Scale: x 2

Starting Circuits Case Studies

- **50HP 2 Speed Fan**
  - Normal Start
  - Start in Slow
  - Shift to Fast



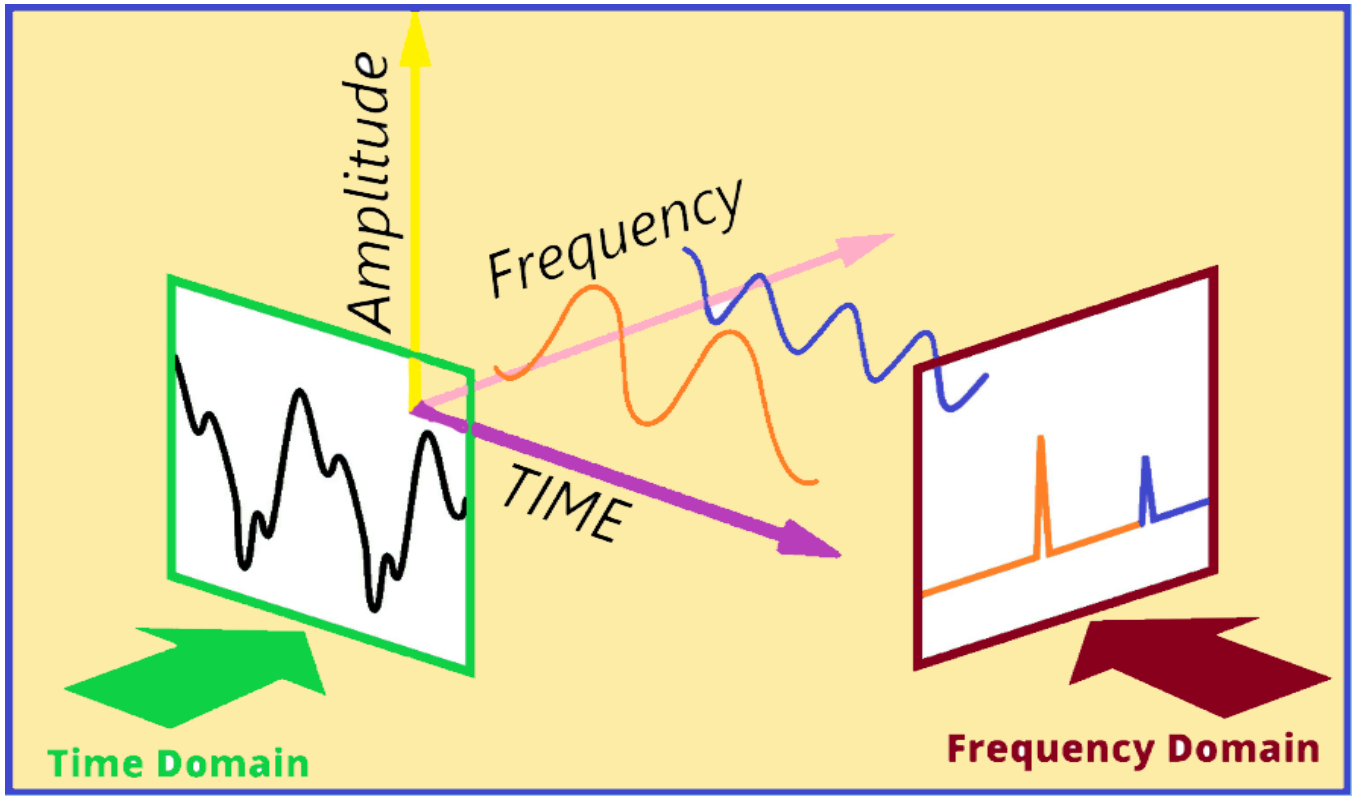
- **50HP 2 Speed Fan**
  - Contactors wired backwards
  - Started in Fast, Shifted to Slow



ESA, MCSA - FFT

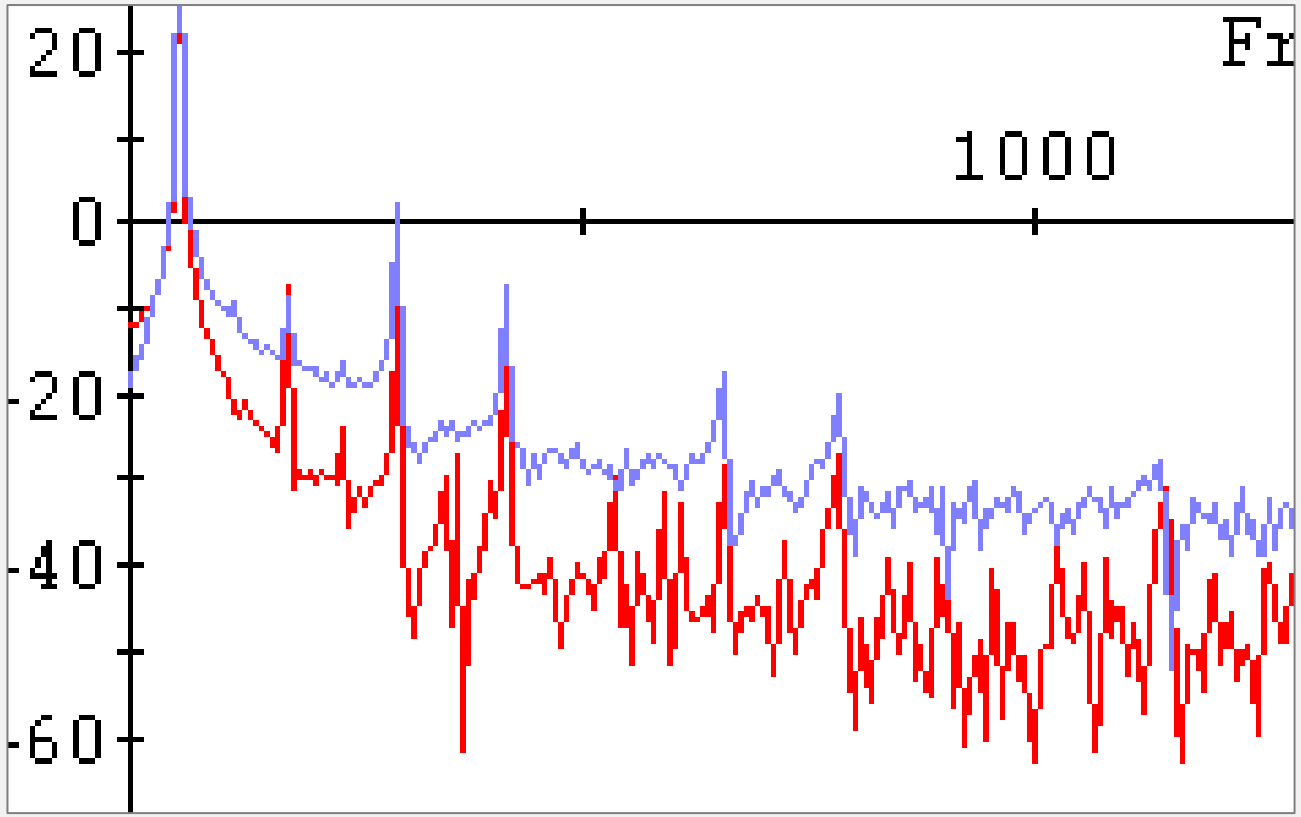
Fourier Transform- Time Domain to Frequency

- Signal Processing
- Prolonged Calculations
- All Frequencies present are caused by something



Fault Localization

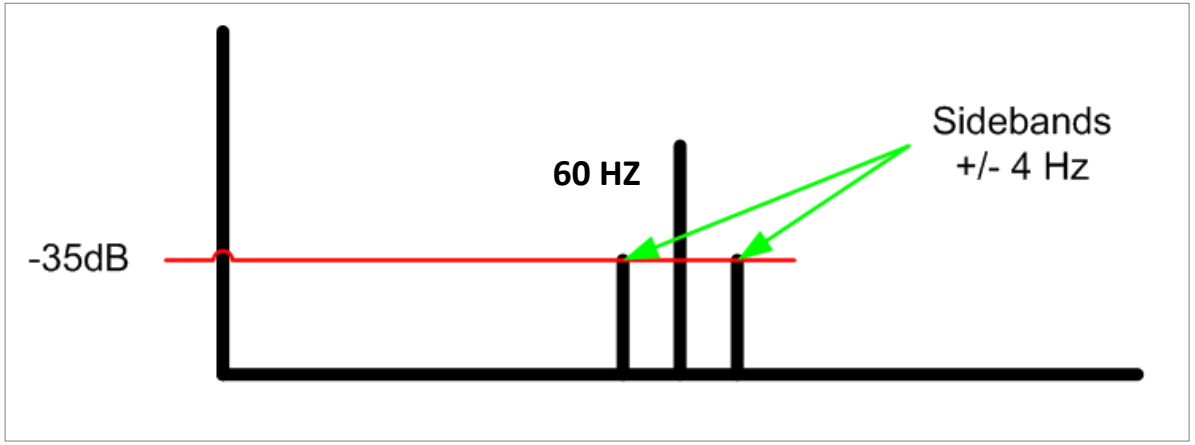
Overlay of Voltage and Current FFTs



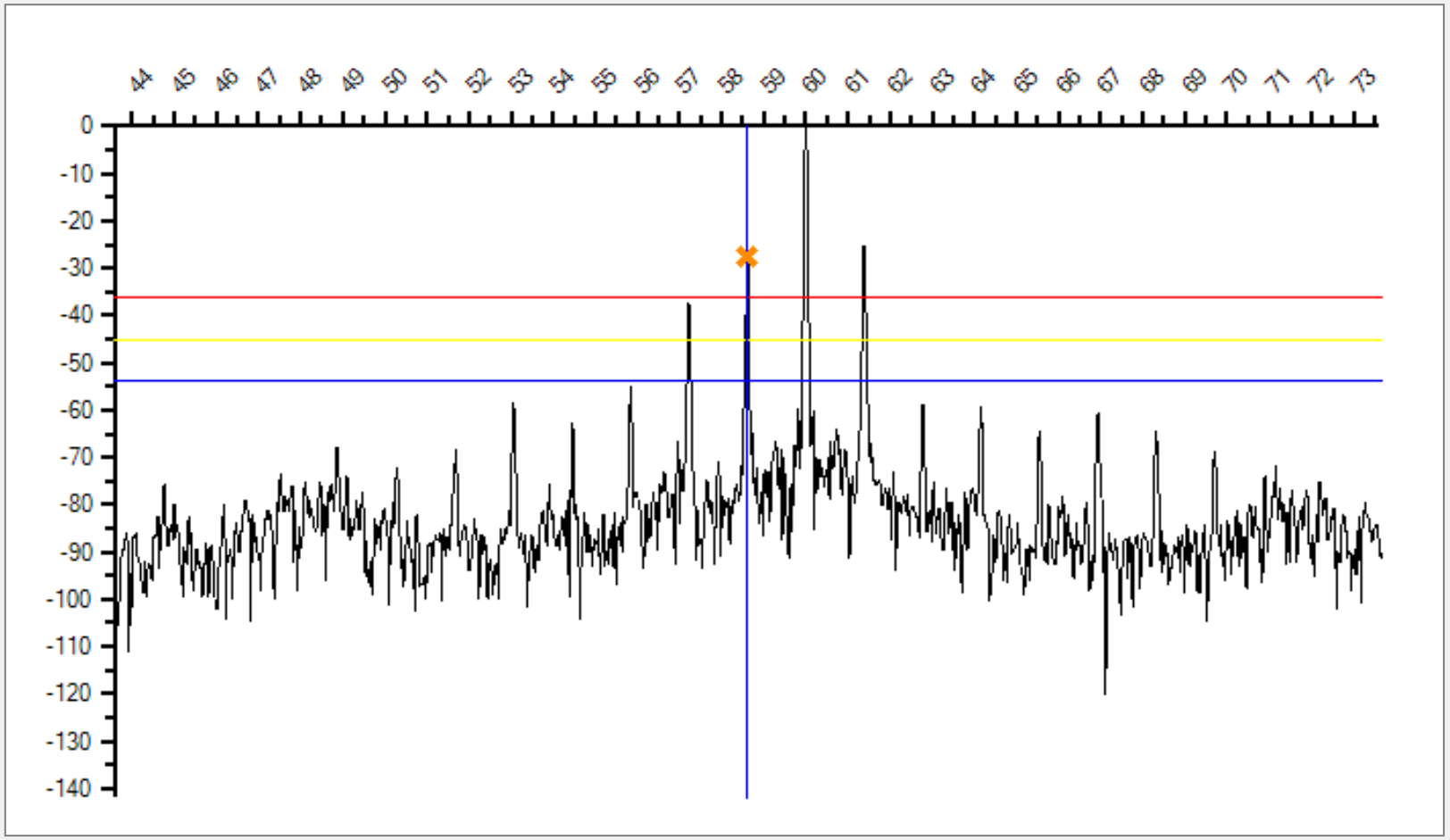
Rotor and Stator Analysis

- Identifying broken Rotor Bars

dB Level	Rotor Condition	Recommended Action
54-60	Good	Normal Monitoring
45-54	Observe	Increase Monitoring
36-45	Caution	Correlate Data
<36	Severe	Secure and Repair



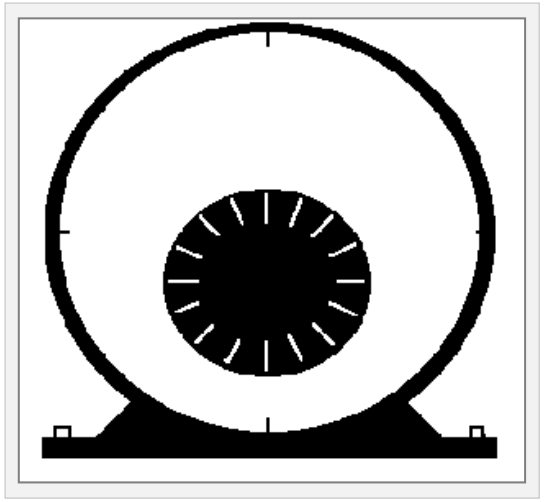
Broken Rotor Bars

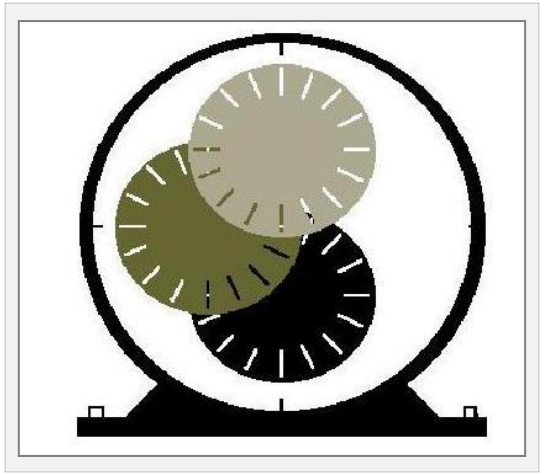


Rotor and Stator Analysis

Eccentricity

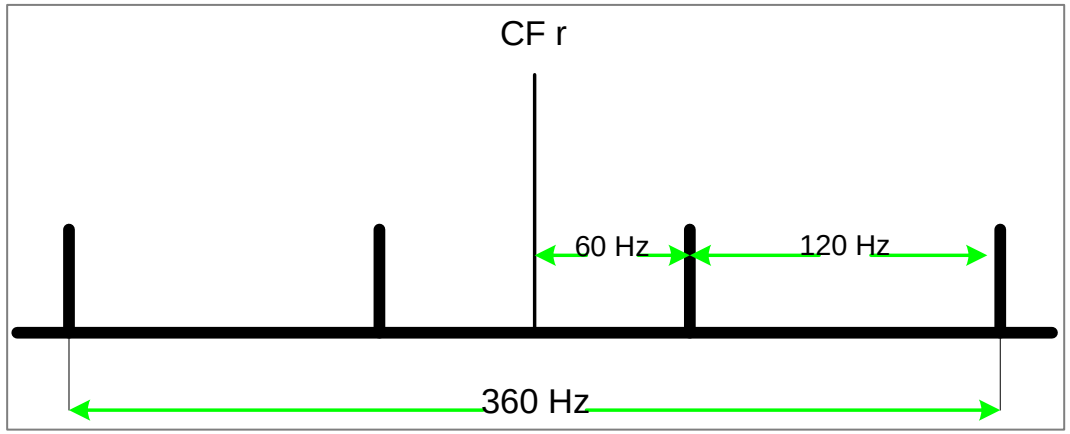
- Rotor is not running in magnetic center
  - Radially
  - Axially
  - Combination of both
- Types
  - Static – Constant offset from centerline
  - Dynamic – Variable off set from centerline



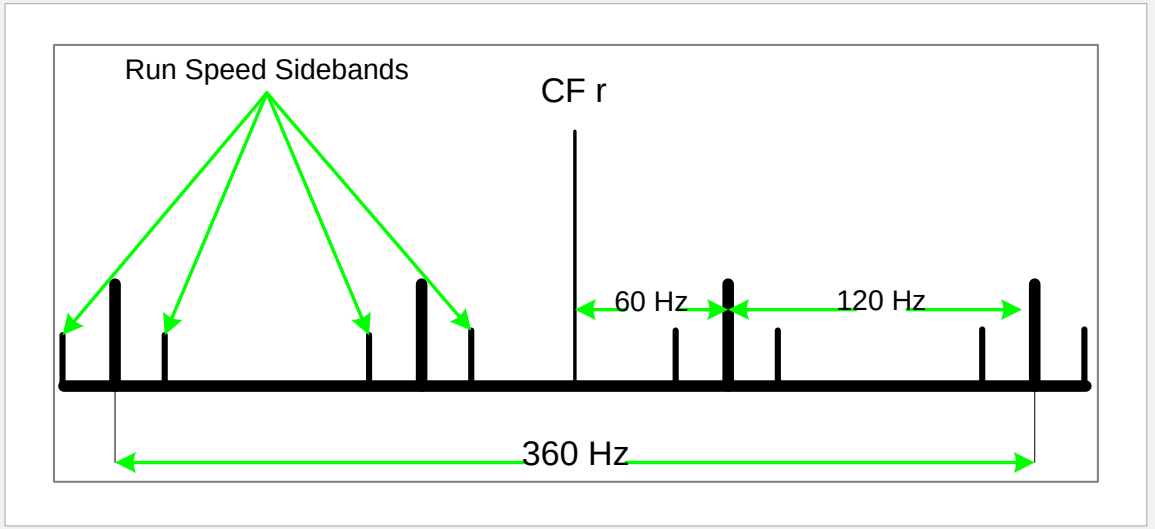


Rotor and Stator Analysis

- **Eccentricity causes <u>non-harmonic</u> peaks**
  - Based on (Rotor Speed) x (# of Rotor Bars) / 60



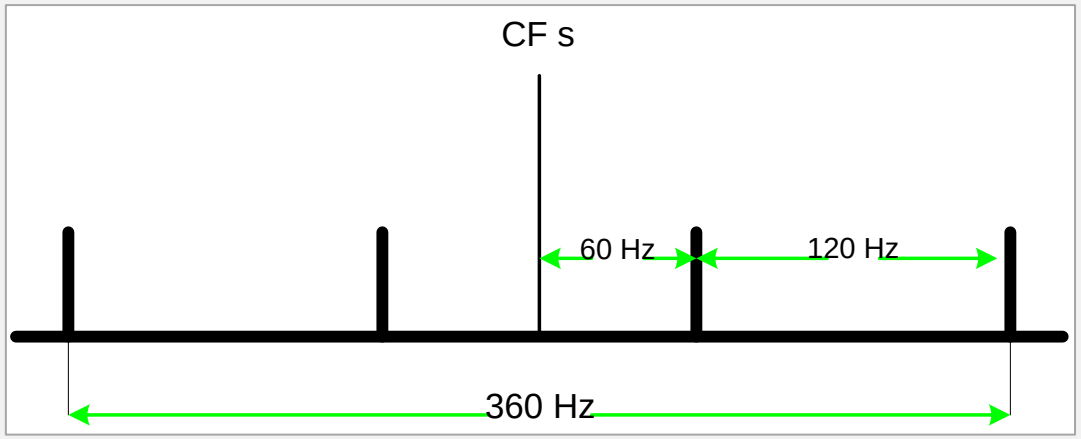
- **Dynamic Eccentricity**
  - Pole Pass sidebands are present



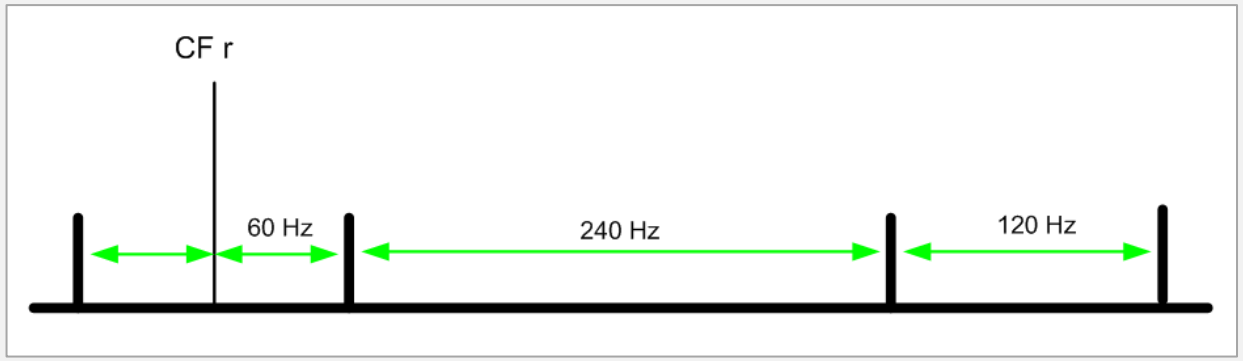
Rotor and Stator Analysis

Stator Mechanical Fault

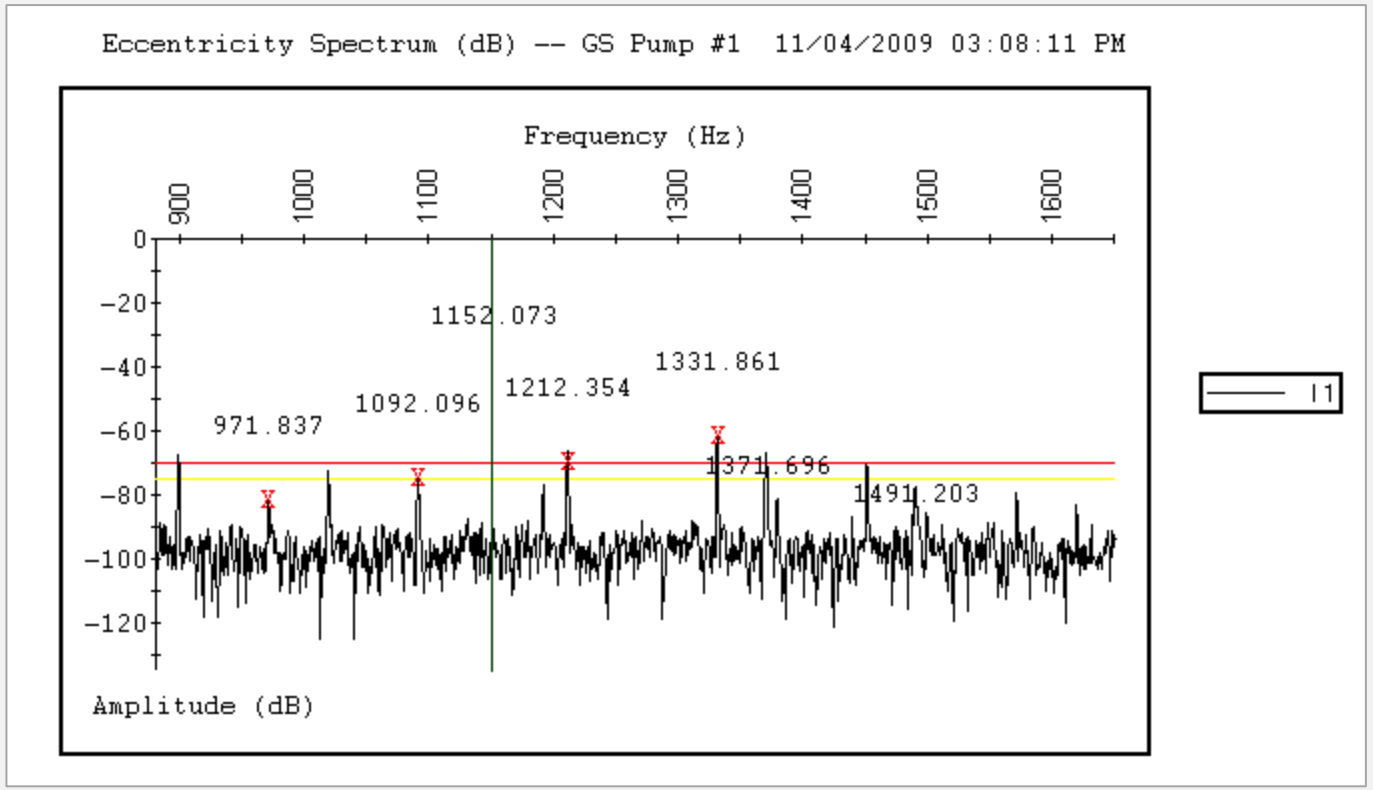
- Core movement
- Loose coils

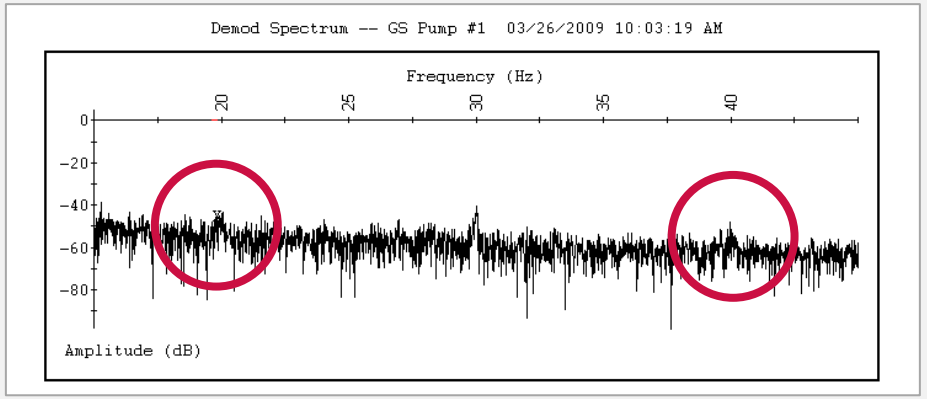


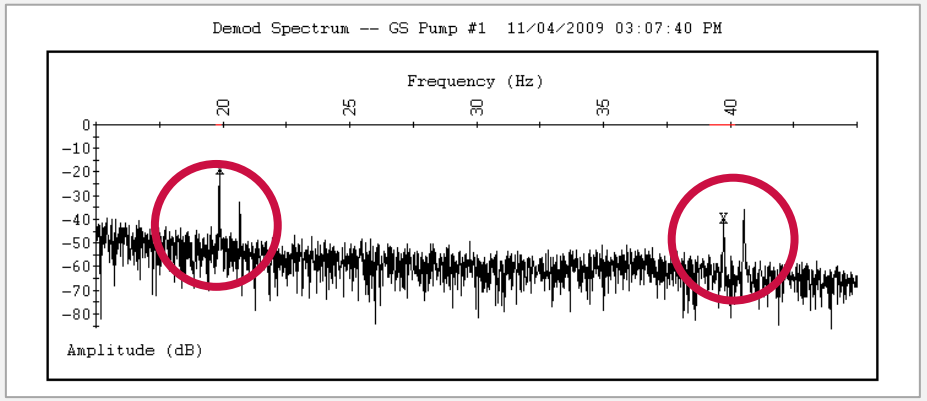
Mechanical Unbalance / Misalignment



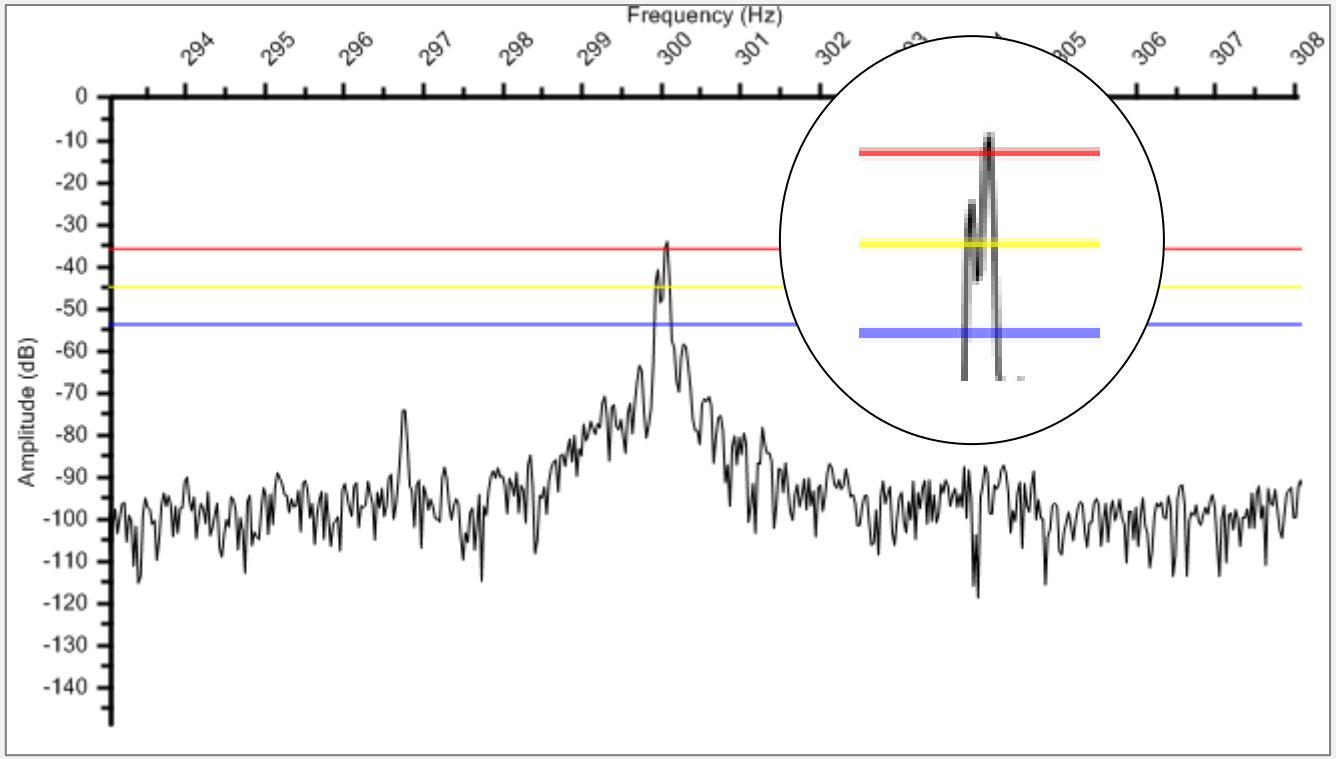
Mechanical Unbalance / Misalignment



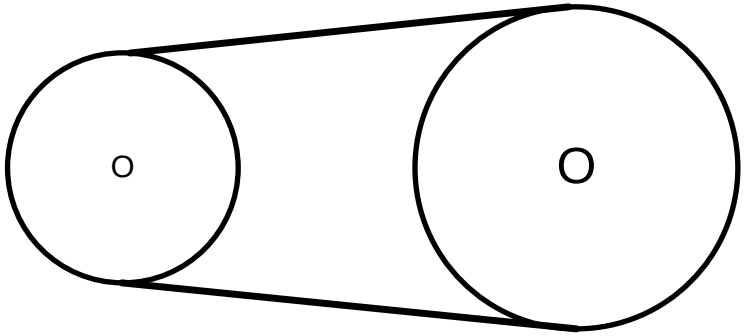


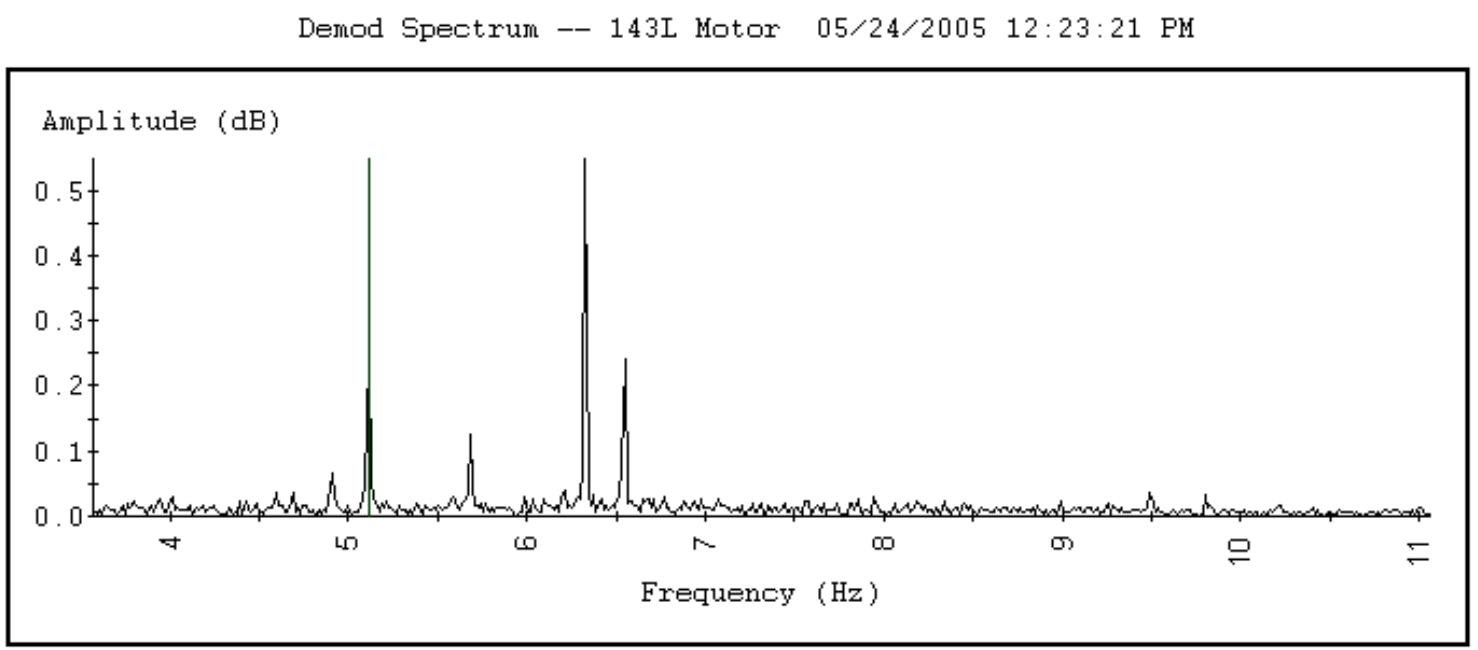


Rotor Axial Movement



Belt Frequencies



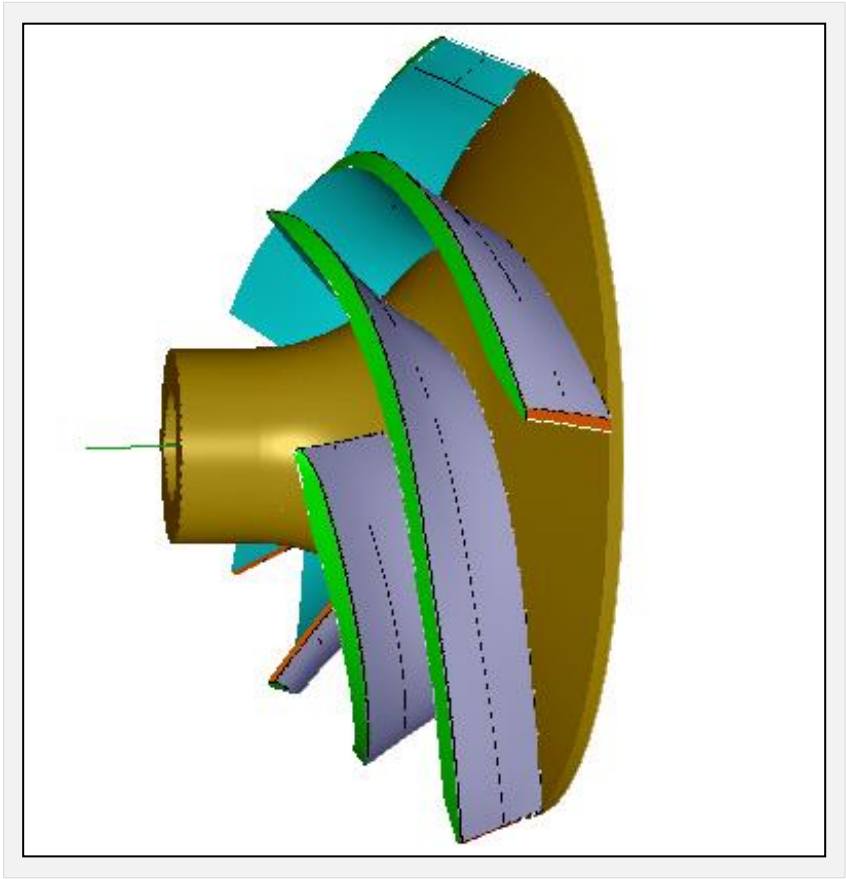


NP Speed	1180
Num Poles	6
NP Current	115
% FLA	80.26
% Load Var	1.185
% Max Var	4.767
Speed	1183.59
H Cursor Amp	
V Cursor Hz	5.112
Amp at V Cursor	0.244
V Cursor Speeds:	
Pole Pass	1148.88
Mechanical	306.72
Reflected	3906.72

Mechanical Fault Analysis

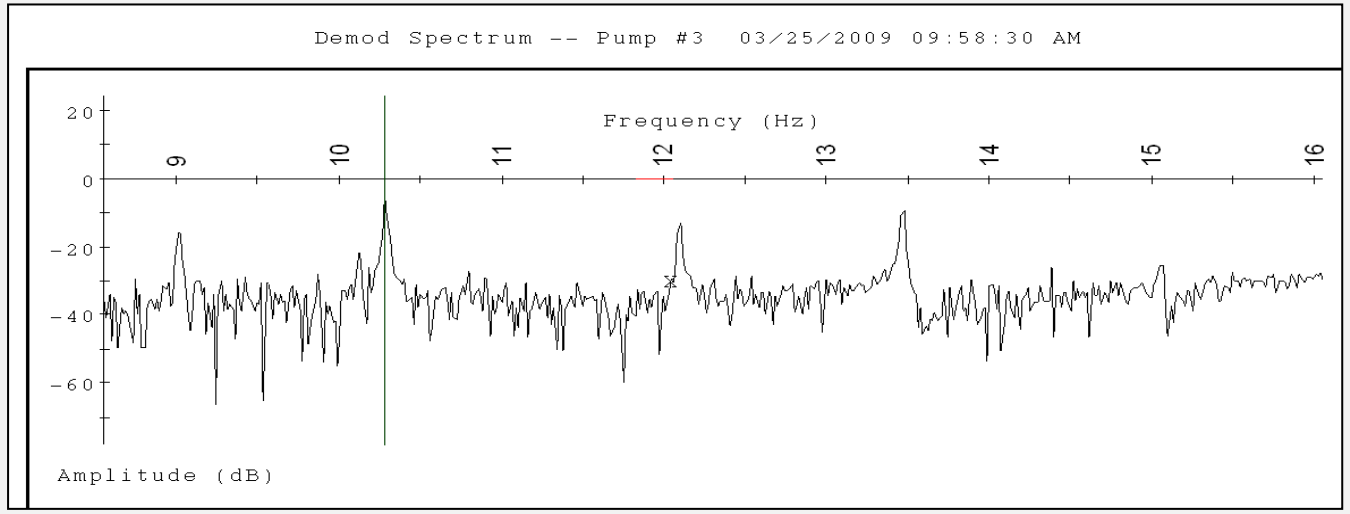
Blade Pass Frequencies

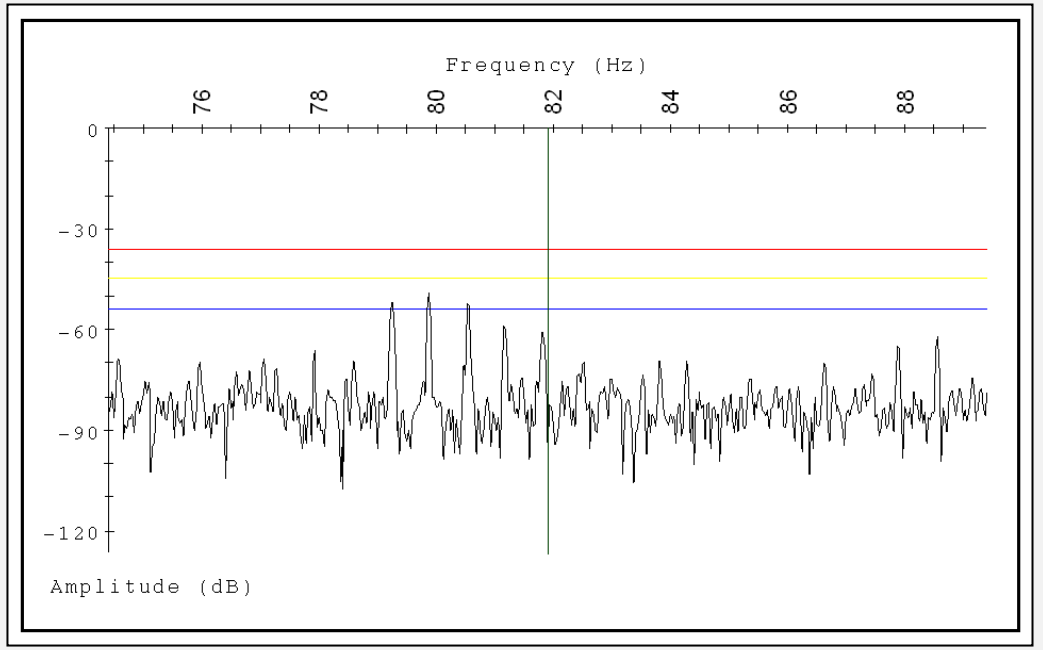
- Multiply the number of blades times the pole pass frequency. (electrical)
- Multiply the RPM of the pump shaft times the number of blades on the impeller (mechanical)
- For belt driven fans multiply the RPM of the driven sheave, times the number of fan blades



Mechanical Fault Analysis

Bearings in final stages display non-integer peak pairs at lower frequencies





Motor Testing Overview

Electric Motor Testing provides a considerable number of tests to evaluate and trend critical motor parameters

- This presentation was meant to be a brief introduction into these capabilities
- Additional, more involved and detailed presentations are available for this venue, that break down many of the individual evaluation methods discussed

info@thesnellgroup.com

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Additional Resources

Free White Papers

Electrical [click to collapse/expand]

Mechanical [click to collapse/expand]

Buildings [click to collapse/expand]

Equipment [click to collapse/expand]

Standards & Procedures [click to collapse/expand]

IR Theory [click to collapse/expand]

NDT [click to collapse/expand]

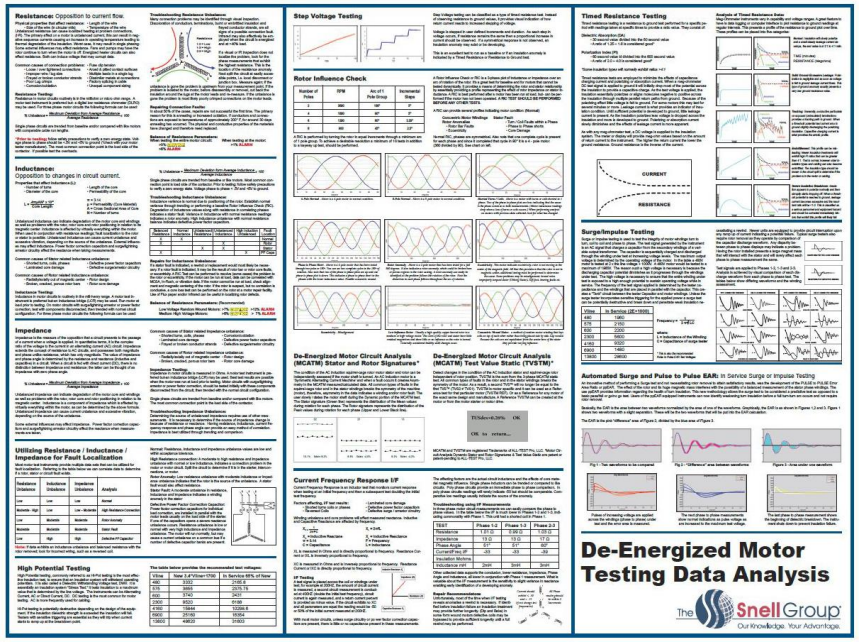
Electric Motor Testing [click to collapse/expand]

Free E-Newsletter

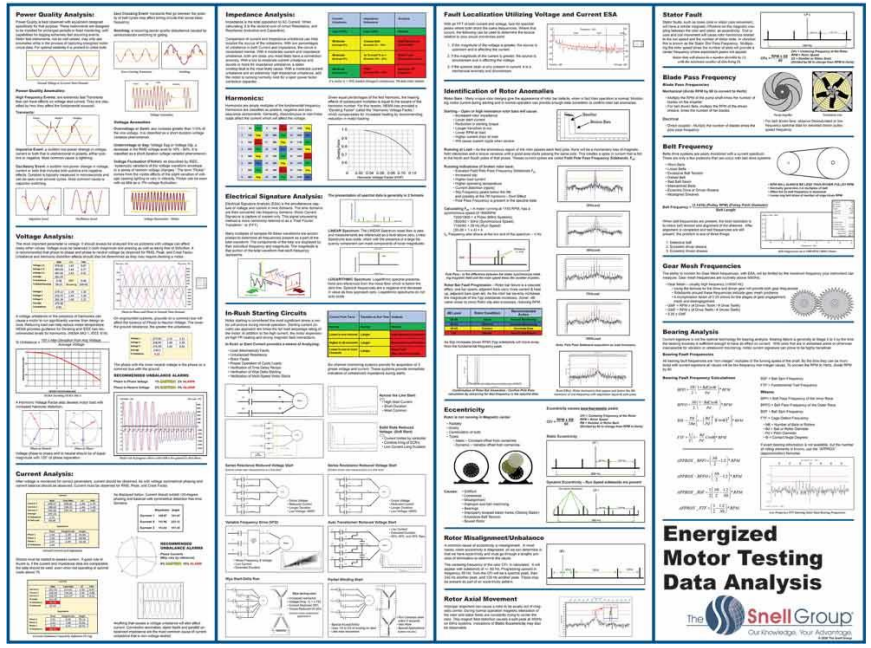
Additional Resources

Motor Testing Wall Charts

Laminated 36” x 48”



De-Energized Data Analysis



Energized Data Analysis

info@thesnellgroup.com

Questions

QUESTIONS?

Thank you!

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Power Quality and Electric Motor Testing
The Snell Group

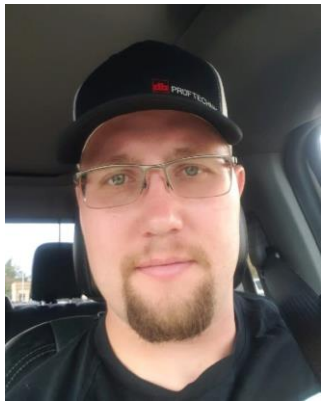
Next Webinar:

BEST PRACTICE WEBINAR | Wednesday, Feb. 17, 11 a.m. ET

Industrial machine alignment: Tips for getting precise measurements in demanding conditions

Mines, sawmills, and pulp and paper plants represent some of the toughest environments to maintain machine alignment. **Matt Joinson**, the owner and operator of Jaffray Millwright and Welding, located in Jaffray, British Columbia, knows this well. He's got many stories to tell as well as advice for alignment professionals across sectors.

Joining him in this webinar is **Payam Assadi**, Fluke Reliability sales manager for Pruftechnik Canada, as they discuss how to get precise measurements in challenging conditions, how to avoid downtime and high maintenance costs, and the best alignment tools for the job.



Matt Joinson

Payam Assadi

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