Bearings and Drives

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presented at

Vibration Institute

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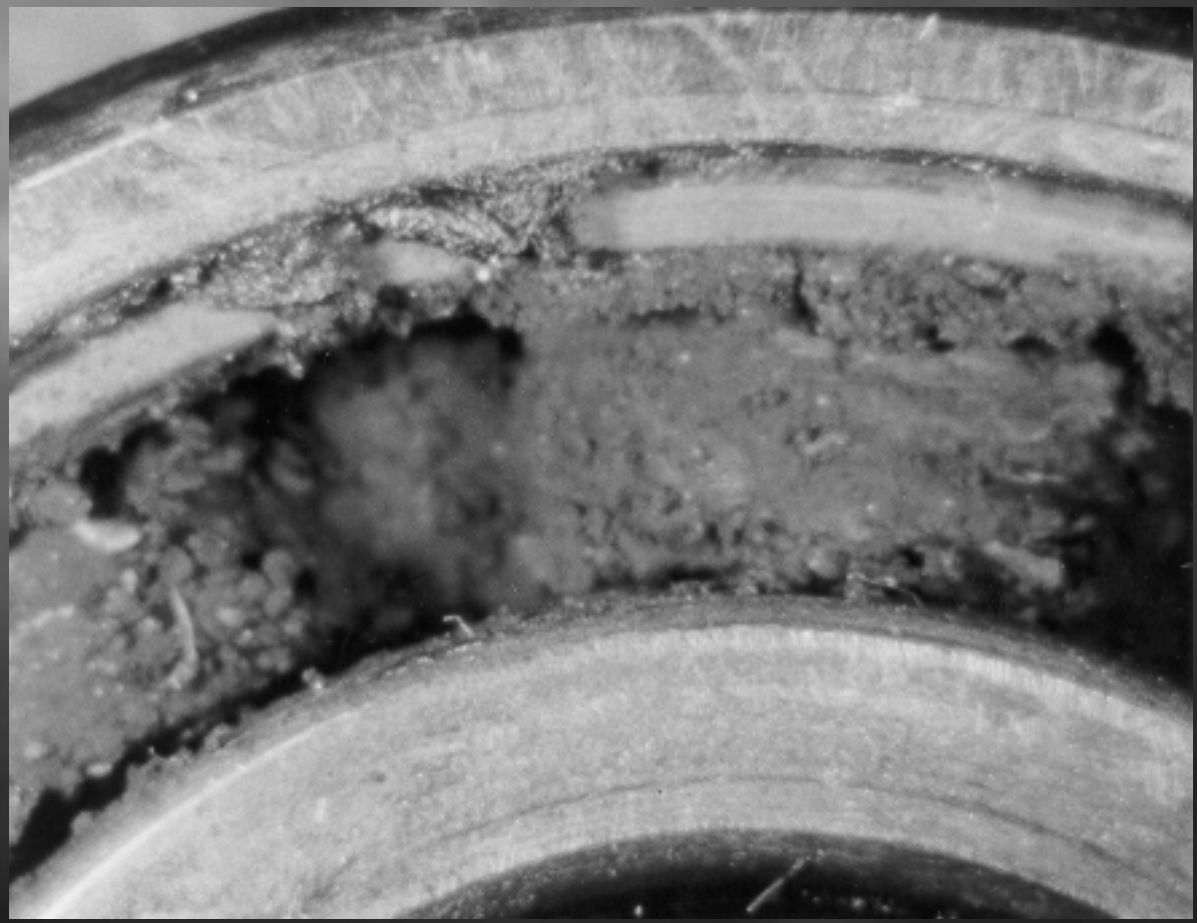
Rockwell Automation

PreServ PLANT SITE SERVICES

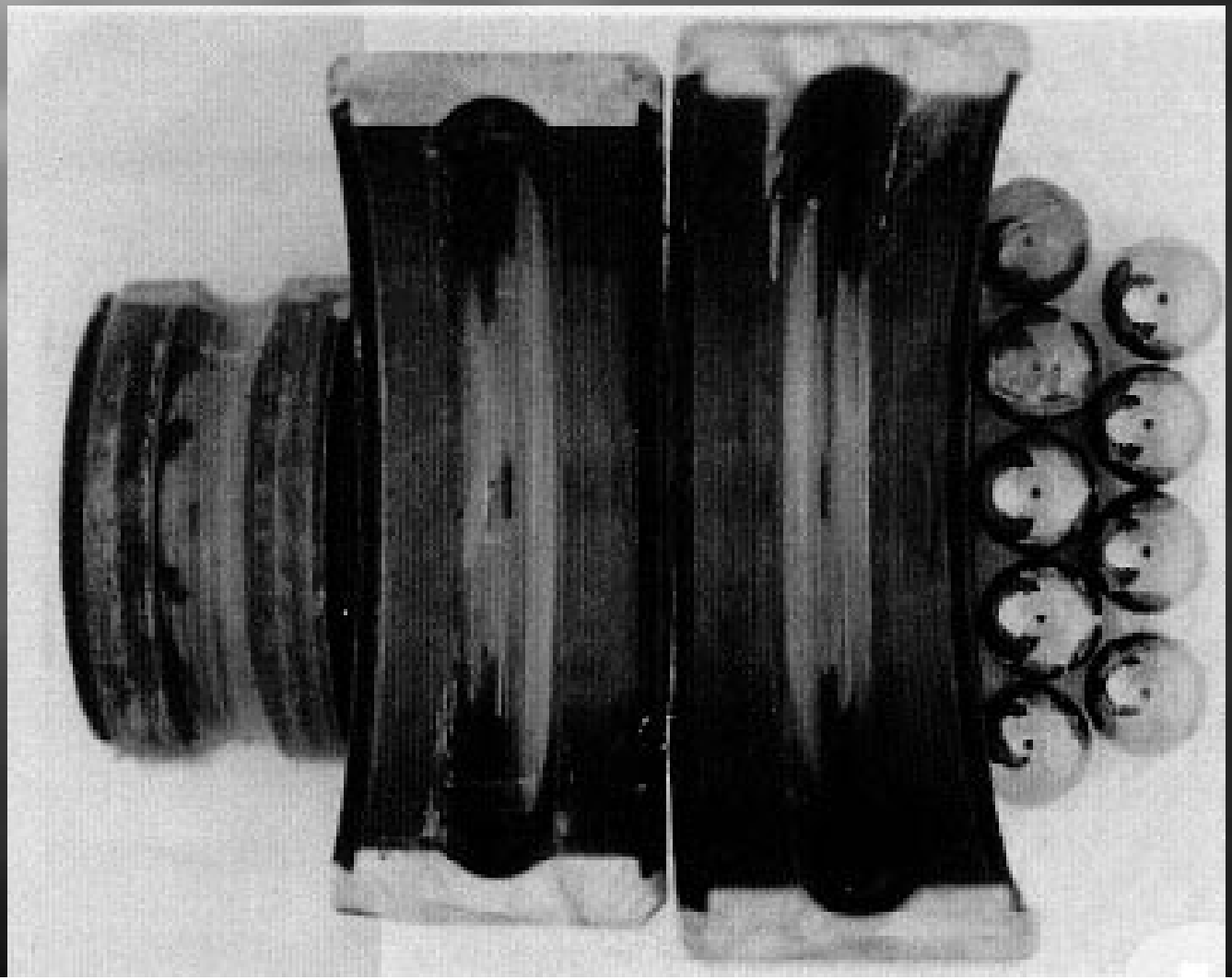
The Problem

- Historical Damage (Utility Power)
- PWM (Pulse Width Modulation)
- IGBT (Insulated Gate Bi-Polar Transistor)
- What Can You Do ?

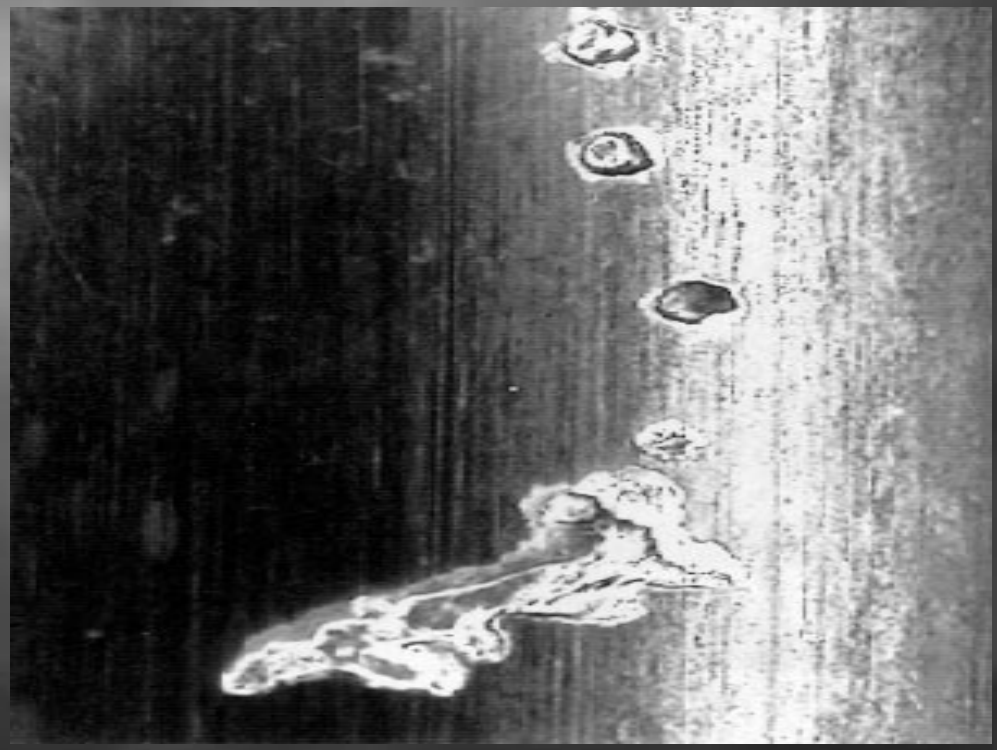
Lubrication Decomposition



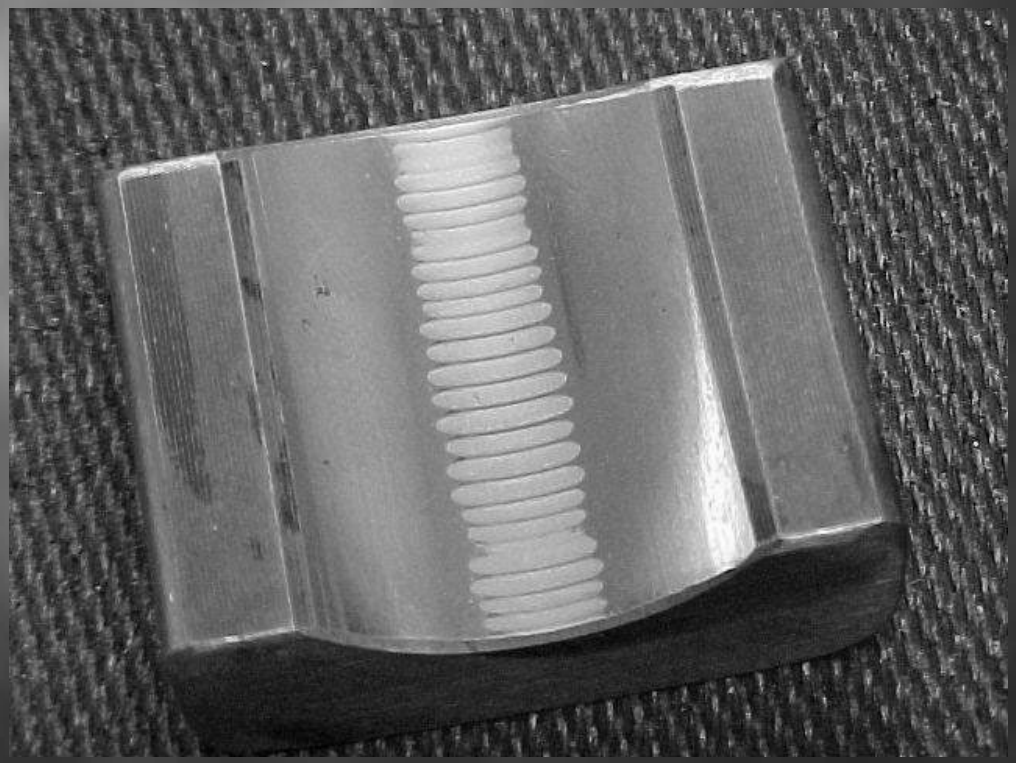
Damage Due To Lubrication Decomposition



EDM
(Electric Discharge Machining)



Bearing "Fluting" Long-Term EDM

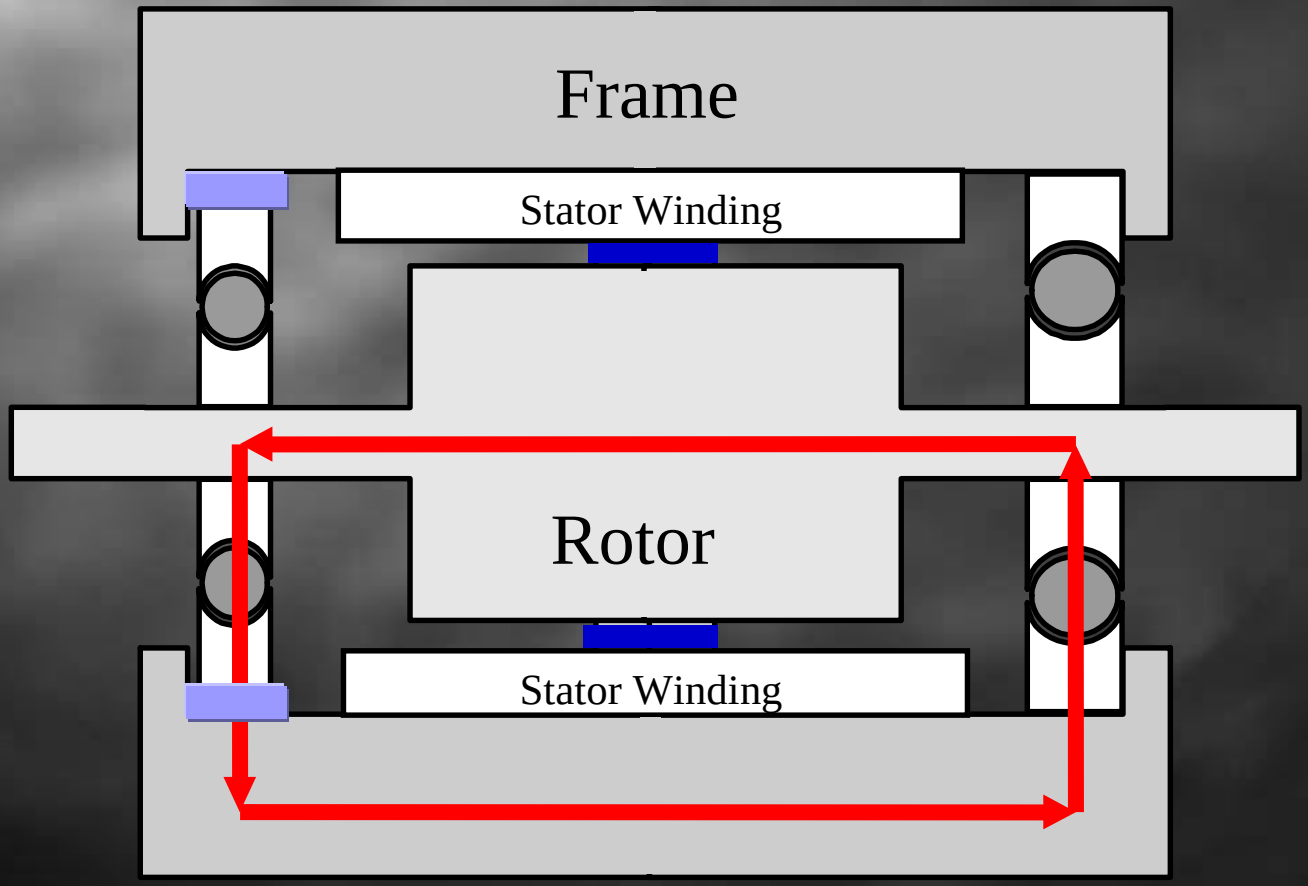


Inverter Technology Transition

- Six Step Technology
  - Six switching states per fundamental cycle
  - 60 Hertz = 360 steps per second (full wave)
  - Variable bus voltage to motor
- PWM Technology
  - Carrier frequency - 2,000 to 12,000 steps per sec.
  - Full bus voltage applied to motor (650 Vdc)

Historical Electromagnetic Induced Path

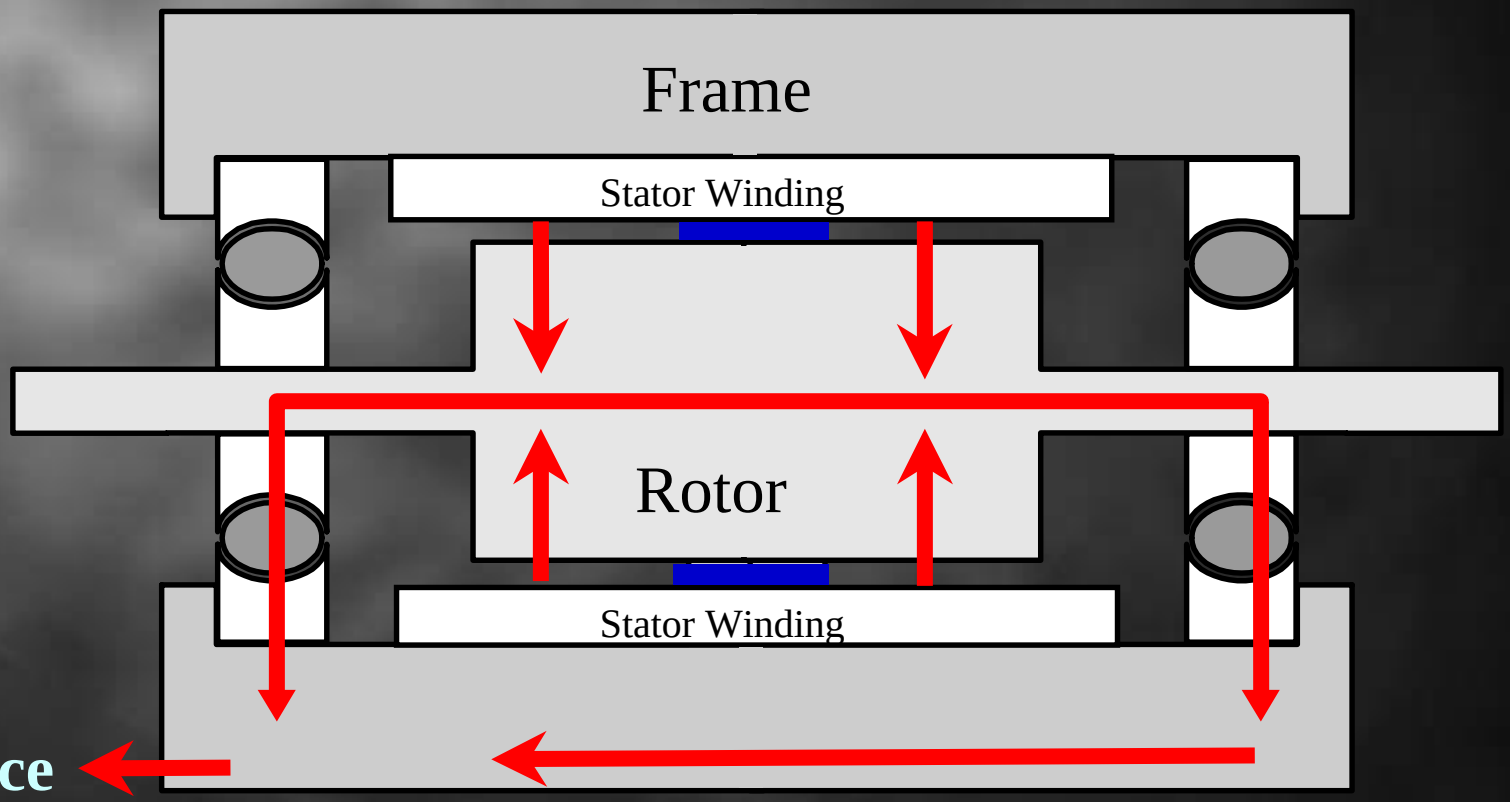
- Problem caused by Electric Asymmetries
- Circulating Current - Insulate ODE Bearing



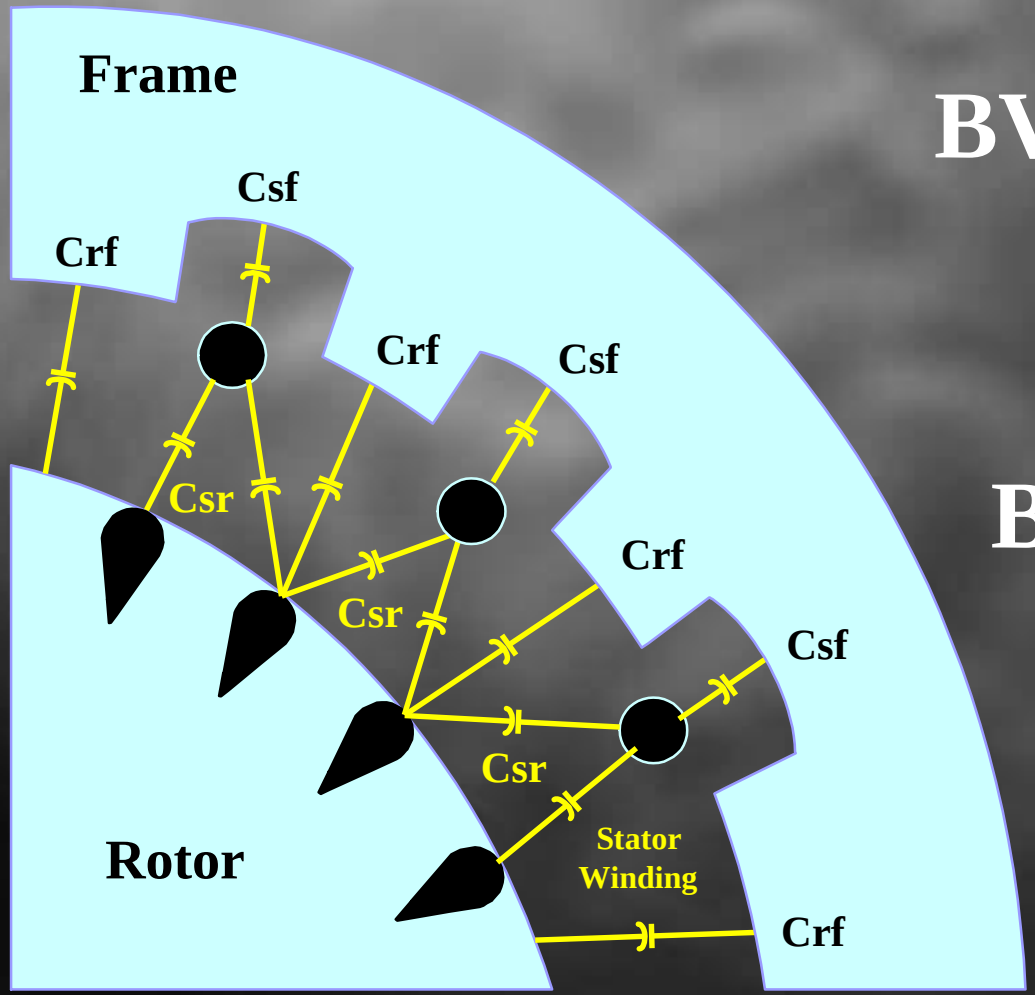
New Electrostatic Induced Path

- Electrostatic Coupling

Stator Windings
Rotor
Bearing
Frame



Electrical Motor Capacitance Model

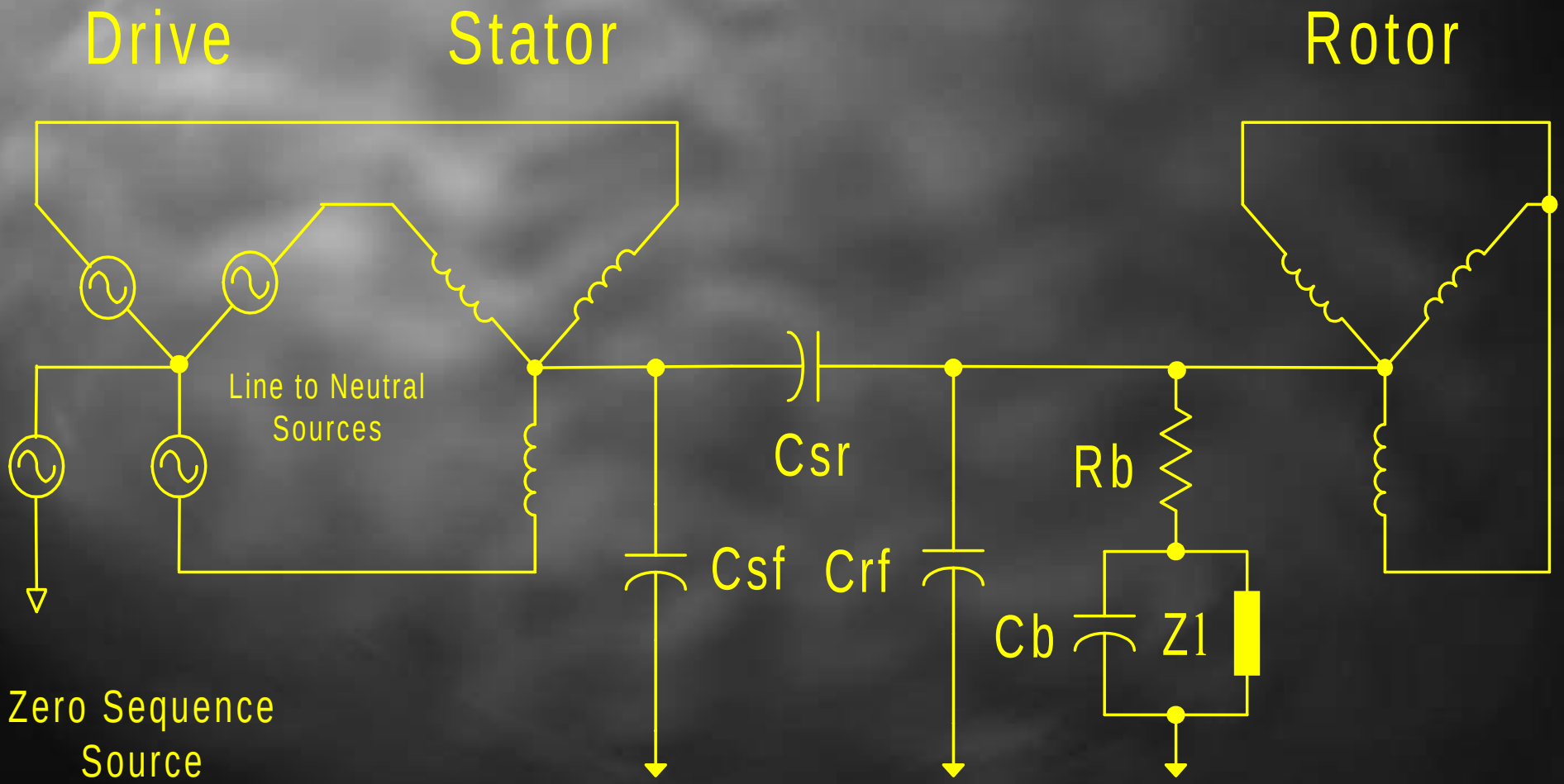


$$BVR = \frac{Csr}{Csr + Cb + Crf}$$

$$BVR = \frac{\text{Shaft voltage}}{\text{Stator neutral voltage}}$$

BVR - “Bearing Voltage Ratio”

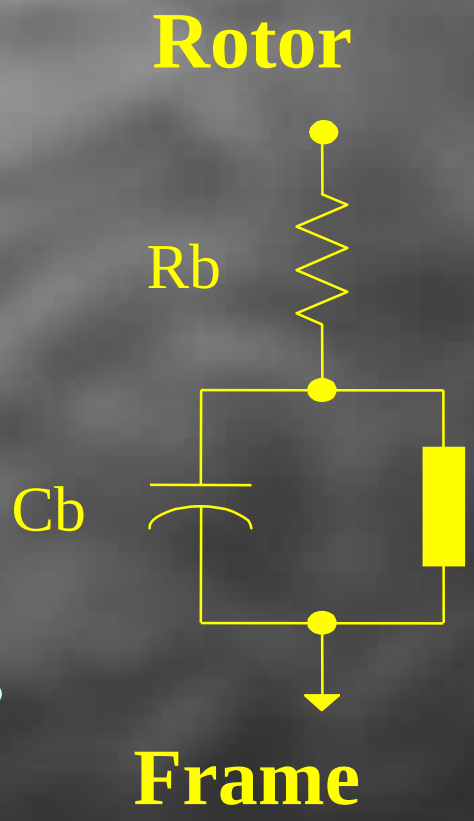
Electrostatic Coupling - Electrical Model



Electrical Bearing Model

Capacitance Variables

- Load
- Speed
- Temperature
- Lubricant
  - Viscosity
  - Additives
  - Oil Film Thickness
  - Dielectric Properties

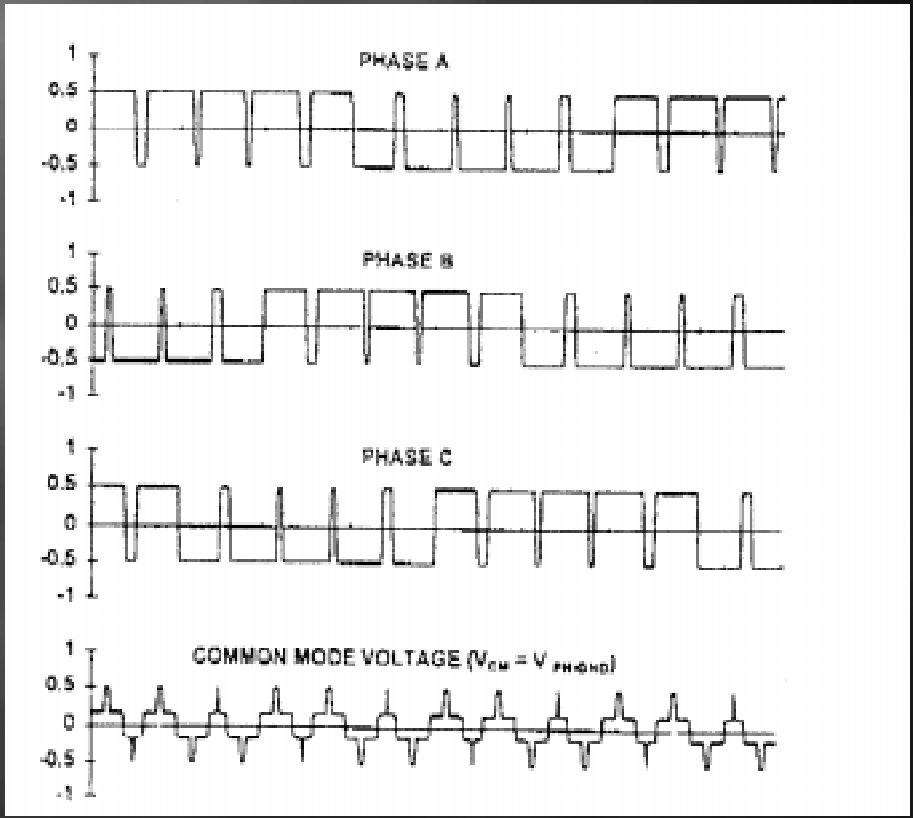


Non Linearity Variables

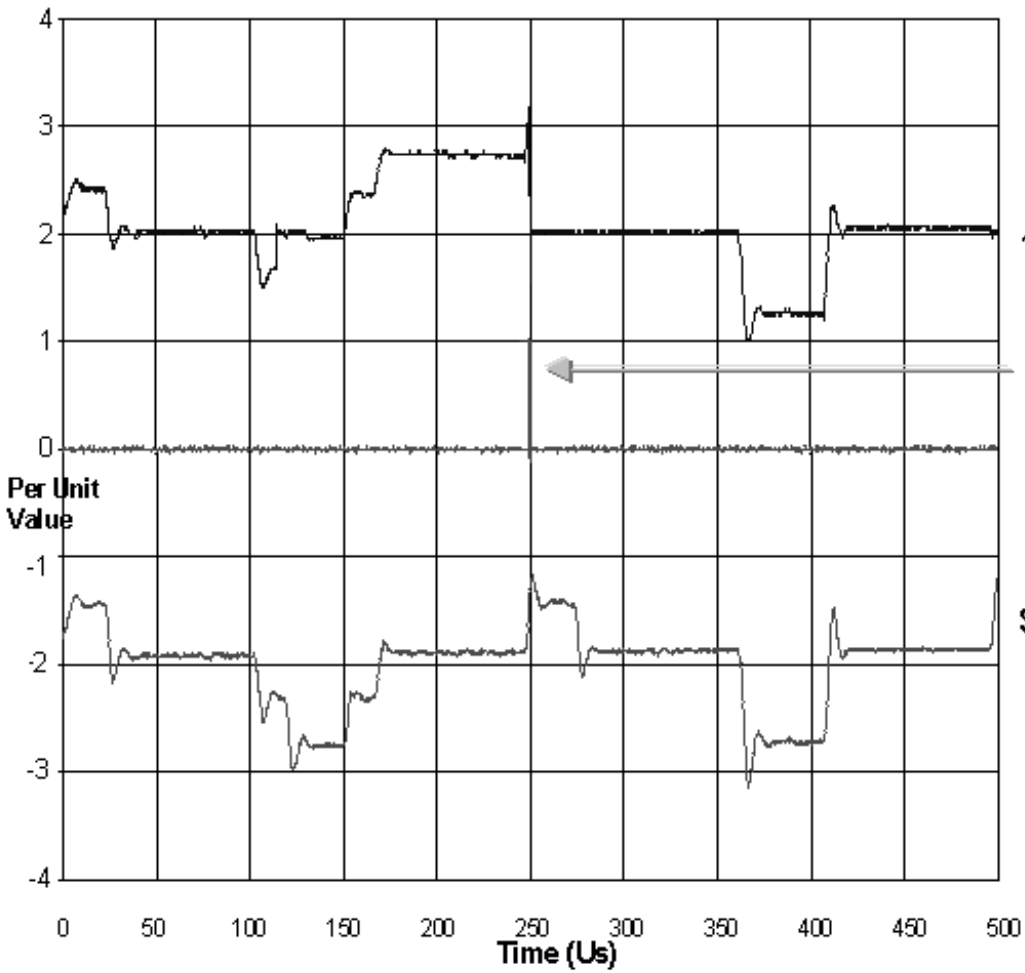
- Asperity Contact Area
- Randomness
  - Mechanical
  - Electrical

PWM Zero Sequence is not Zero

- Sinusoidal Power has a true Zero Neutral
- PWM Zero Sequence reaches DC Bus Voltage
- Frequency is equal to inverter switching frequency

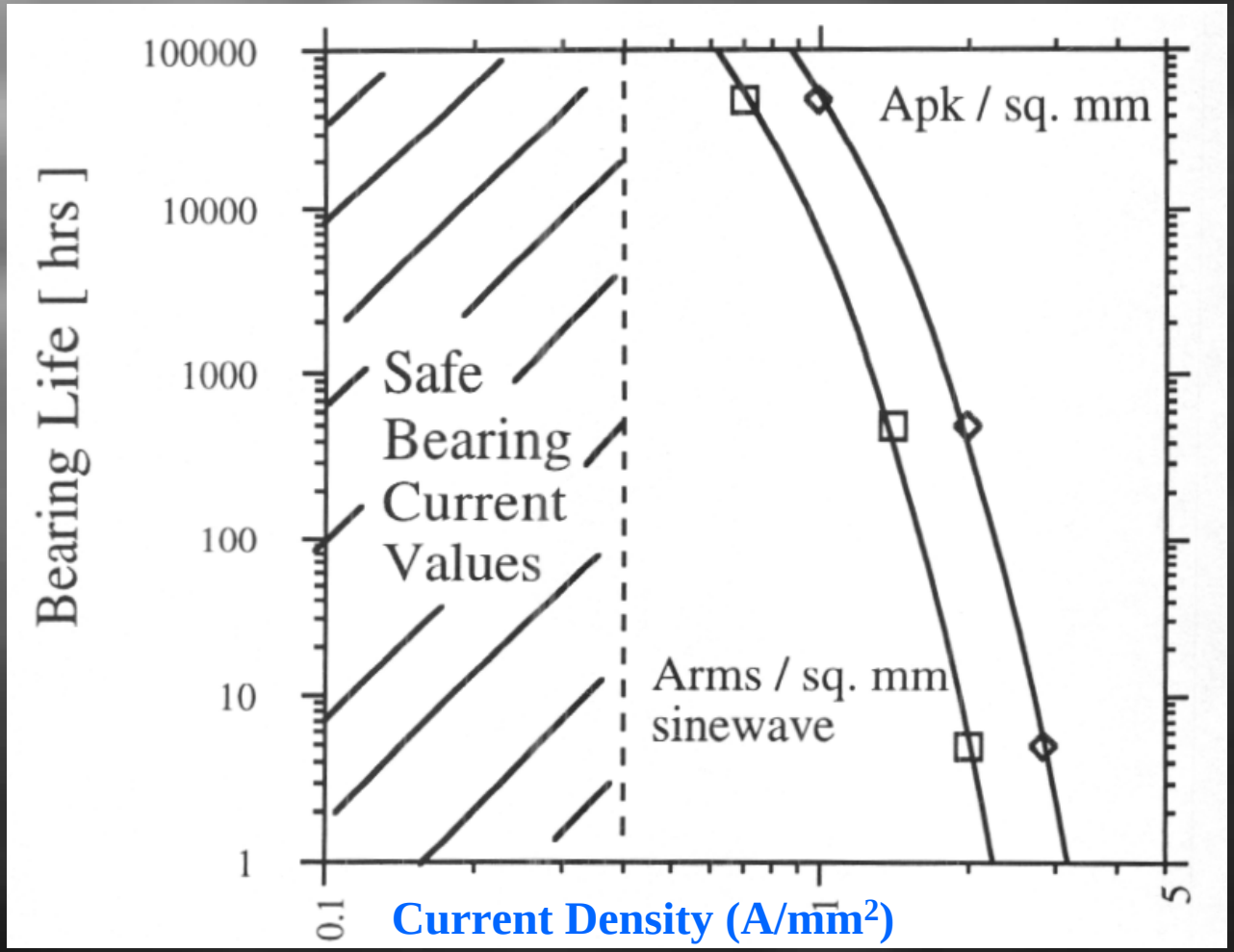


Three Breakdown Mechanisms



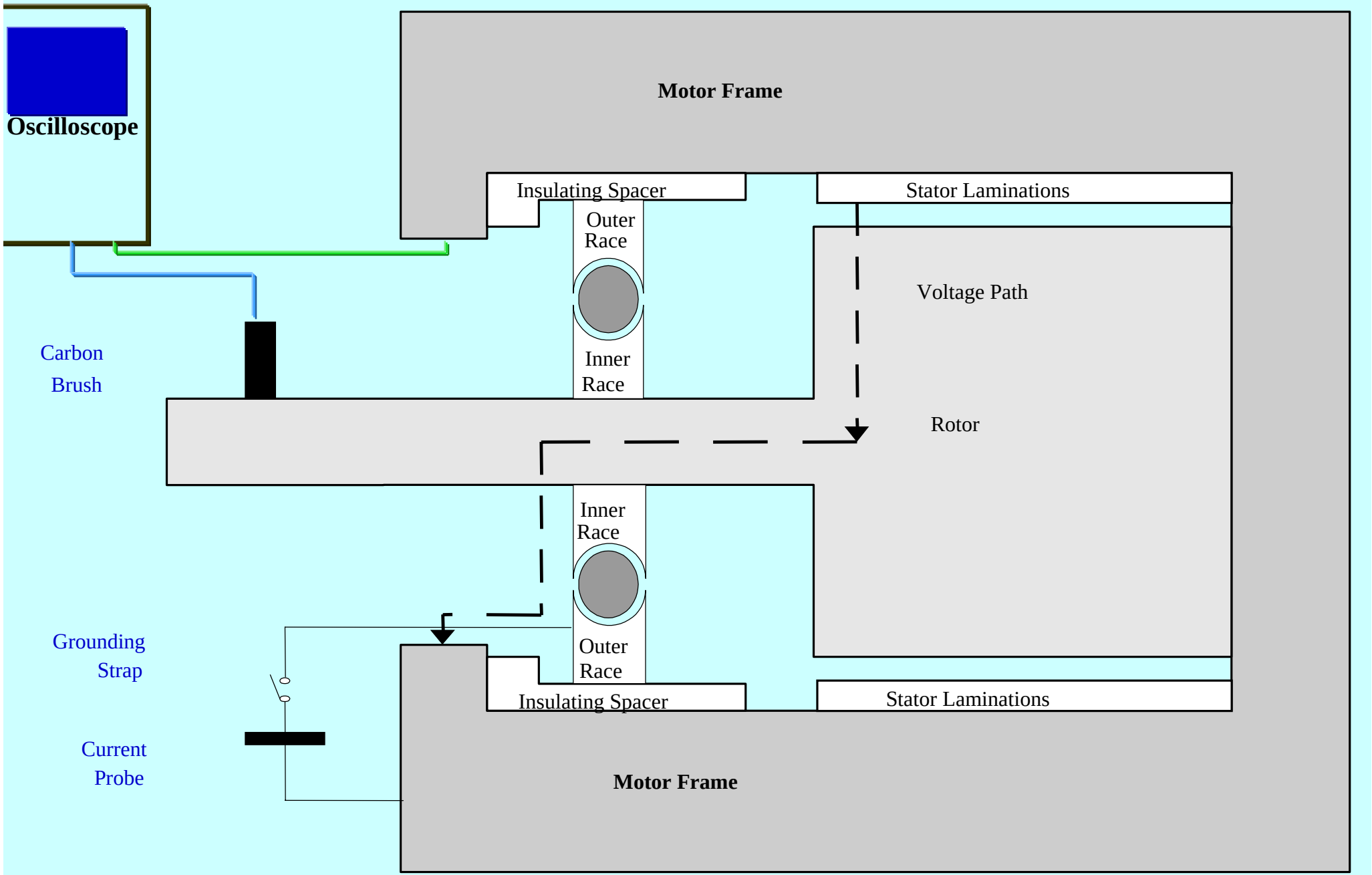
- Chemical
- Mechanical
  - Asperity contact between balls and races
- Electrical
  - EDM - oil film dielectric breakdown
  - dv/dt - induced by the switching transitions of PWM inverter

Bearing Current Density - 60 Hz



Trouble-Shooting Procedure

- Shaft-to-ground voltage taken with oscilloscope and pick-up brush
- Identify voltage spikes

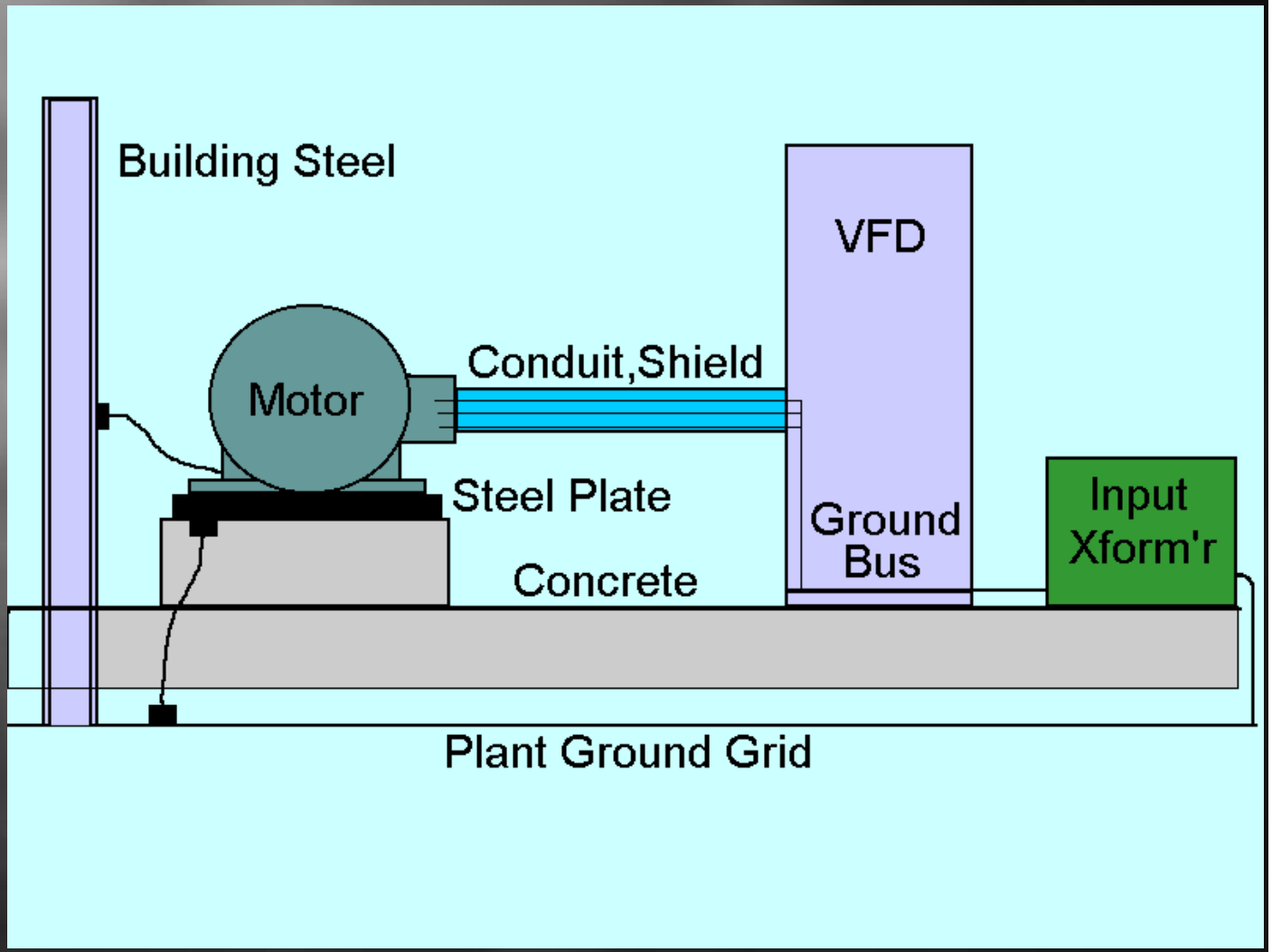

Oscilloscope
Motor Frame
Insulating Spacer
Stator Laminations
Outer Race
Inner Race
Voltage Path
Carbon Brush
Rotor
Inner Race
Outer Race
Grounding Strap
Insulating Spacer
Stator Laminations
Current Probe
Motor Frame

Measurement Techniques to Address Grounding Issues

- Air cored current sensor
- Oscilloscope
- Multiple readings, current and voltage
- Shaft readings taken with brush; ground brush to motor frame for current reading

Current Return Path to VFD

- Shield
- Motor ground wires
- Steel baseplate ground (anybody use these ?)
- Auxiliary motor ground



Measurements

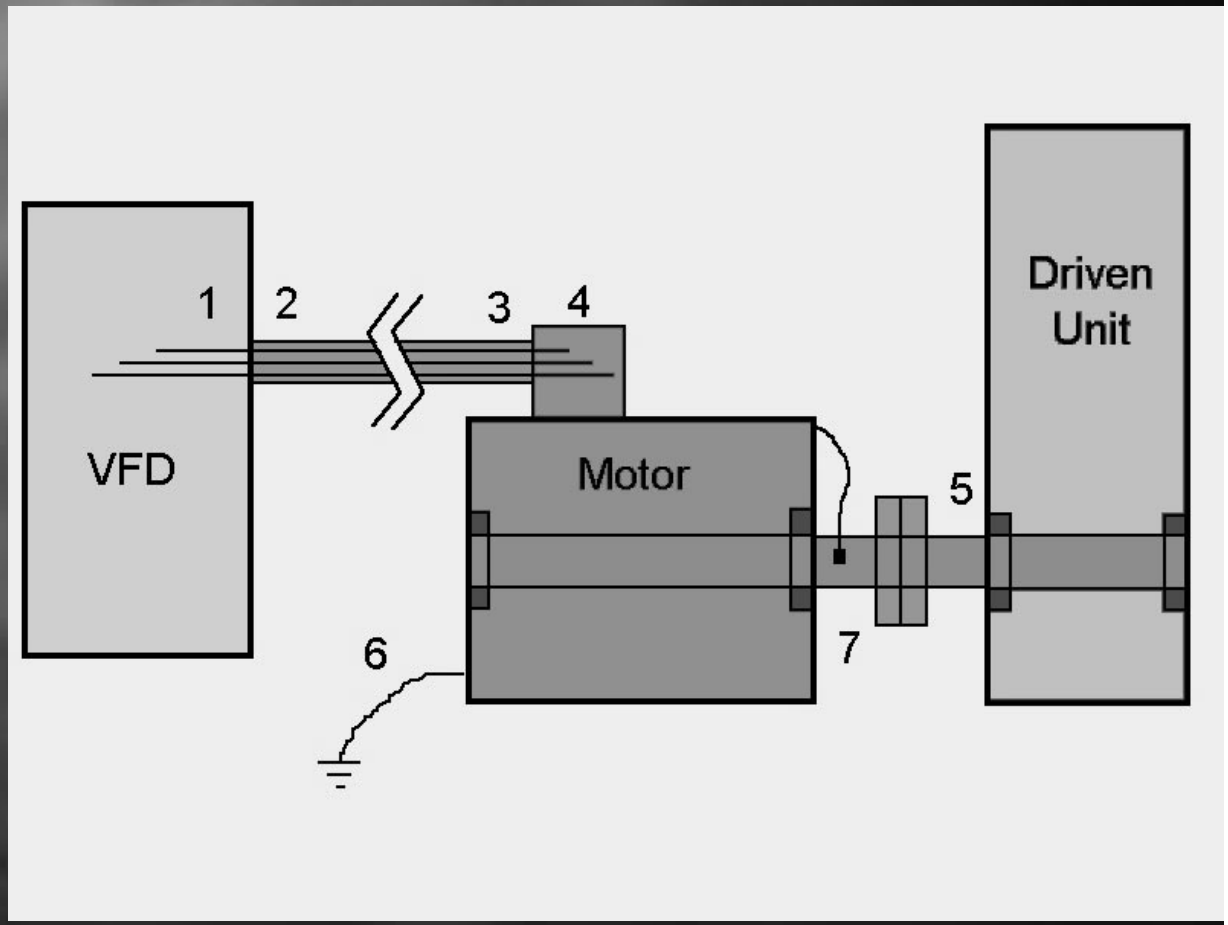
- Current (Common Mode Current)
  - all three VFD output phases inside cabinet
  - all three phase leads, grounds, shields, armor, etc. outside of the VFD cabinet
  - outside the motor terminal box
  - inside the motor terminal box
  - auxiliary ground
  - shaft current

Three major components of CMC

- 10-100 Hz - Due to motor cable asymmetry
- 800-3500 Hz - Most returns to inverter via cable shielding, not through bearings
- 50KHz - 1 MHz - Due to dv/dt of switching.
  - Most damaging to bearings

Measurement Points for Current

- All 3 phases inside Inverter
- Total conduit and ground just outside cabinet
- Total conduit and grounds just outside motor terminal box
- All 3 phases and grounds inside motor terminal box
- Shaft of driven unit
- Auxiliary grounds
- Shaft AND grounding brush of motor



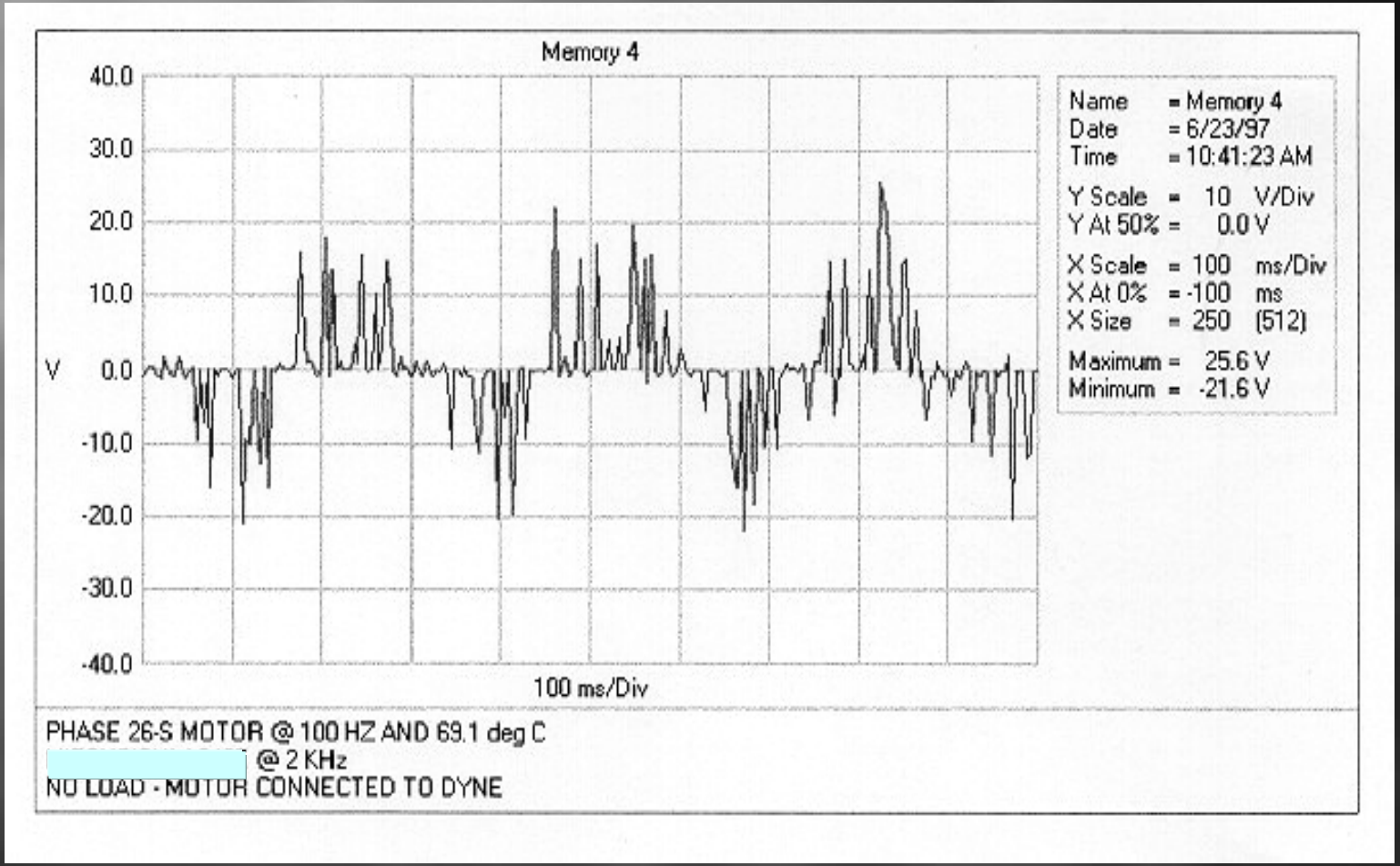
Measurements Cont'd

- Current reading inside VFD cabinet establishes total common mode current
- Reading outside VFD cabinet represents current flowing indirectly back through the motor shaft, and auxiliary grounds
- Reading outside VFD cabinet and motor terminal box should be zero
- Reading inside motor terminal box will include indirect and direct current routes

Measurement Issues

- Shaft voltage & bearing current out to 5 MHz
- Bearing currents not easily measured
  - Estimate current by measuring shaft voltage to frame
- Use brush and holder to provide shaft contact

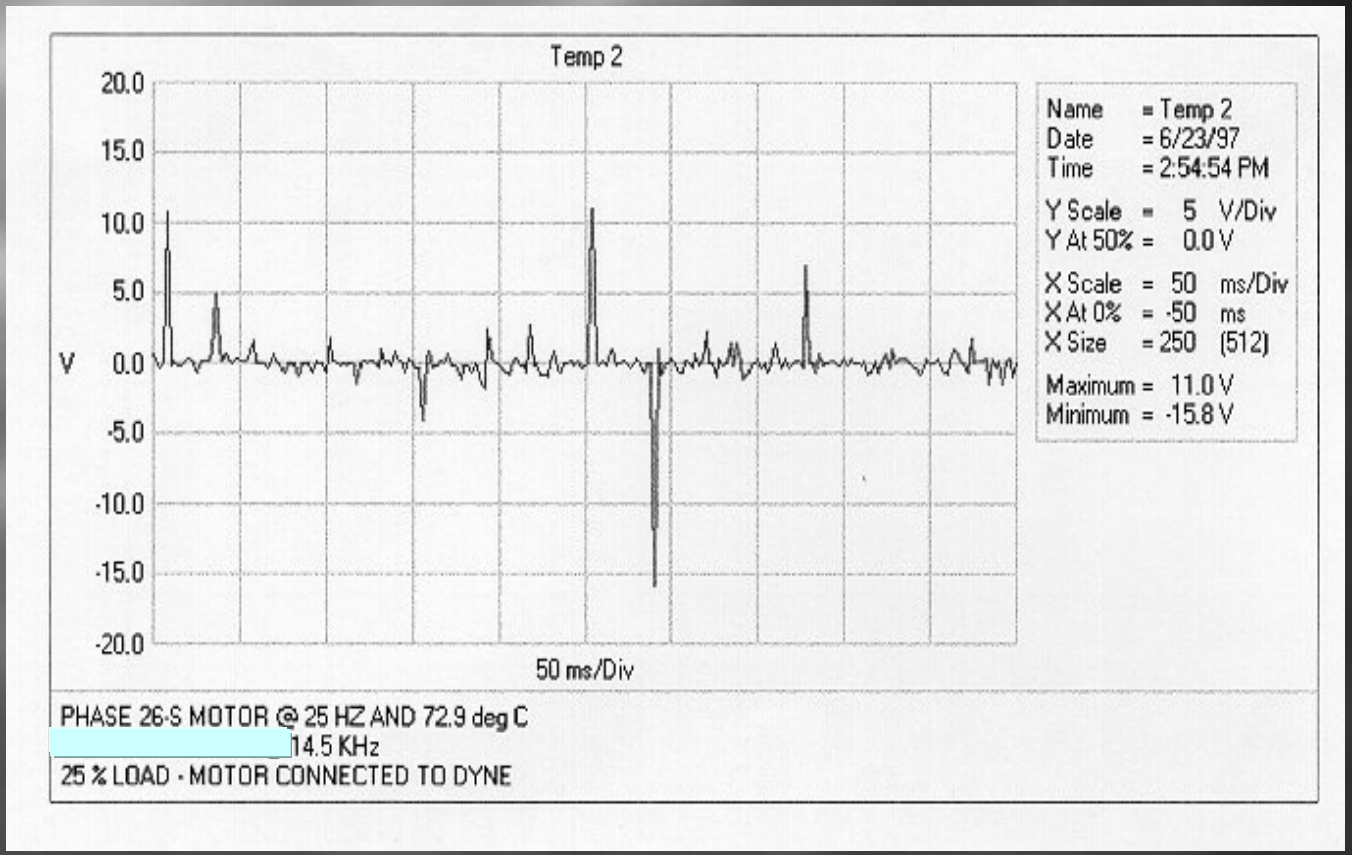
Rotor Shaft Voltage Spikes



Inverter Drive Carrier Frequency set to 2 KHz

Motor Operating at 100 Hertz

Rotor Shaft Voltage Spikes



Inverter Drive Carrier Frequency set to 14 KHz

Motor Operating at 25 Hz

Conclusions From Measurements

- Very difficult to predict bearing current susceptibility
- Tracking bearing life most effective
- Shaft voltage readings can verify initiation of electrical damage
- Pre-failure bearing fault analysis extremely valuable
- Select best approach to alleviate problem

Conclusions Cont'd

- Higher carrier frequencies cause a higher incidence of voltage spiking
- Spiking indicative of unpredictable frequency of capacitive breakdown

Potential Solutions

1. Eliminate problem at source.
2. Motor Faraday shield
3. Ground shaft - bypassing bearing
4. Isolate shaft/bearing
5. Verify grounding

Eliminate at Source

Reduce Drive Voltage

- Pros:
  - Common solution to other IGBT-related issues
  - No additional equipment required
- Cons:
  - Larger capacity (current) drive required
  - Will reduce potential, but not eliminate

Eliminate at Source

Reduce Drive Switching Frequency

- Pros:
  - No additional equipment required
  - Not the cause of harmonic distortion as believed by many
- Cons:
  - Will reduce potential, but not eliminate

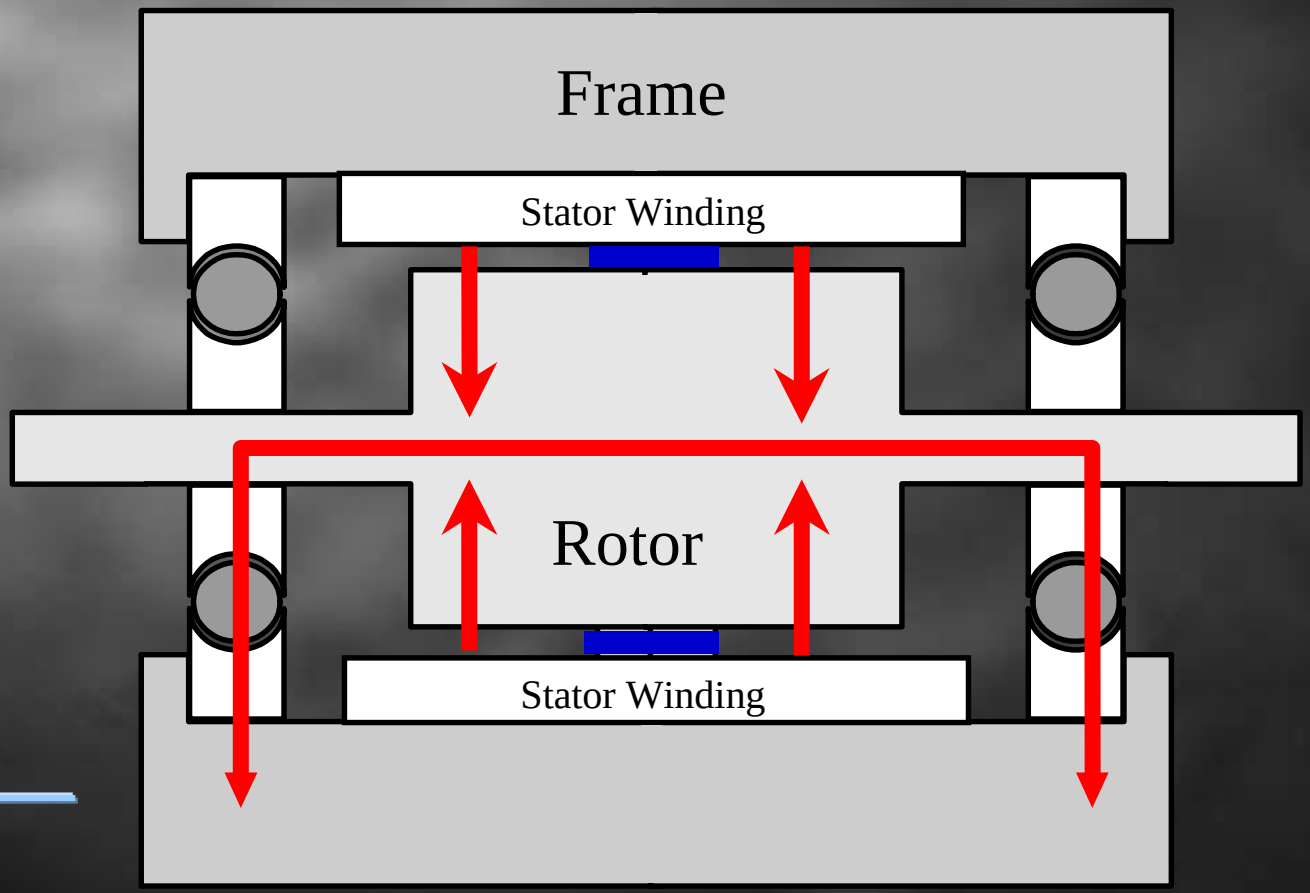
Eliminate at Source

Drive Output Filter/Choke

- Pros:
  - Common solution for other Drive -related issues
  - Retrofitable
- Cons:
  - Cost and space required
  - Reduces, but doesn't eliminate problem

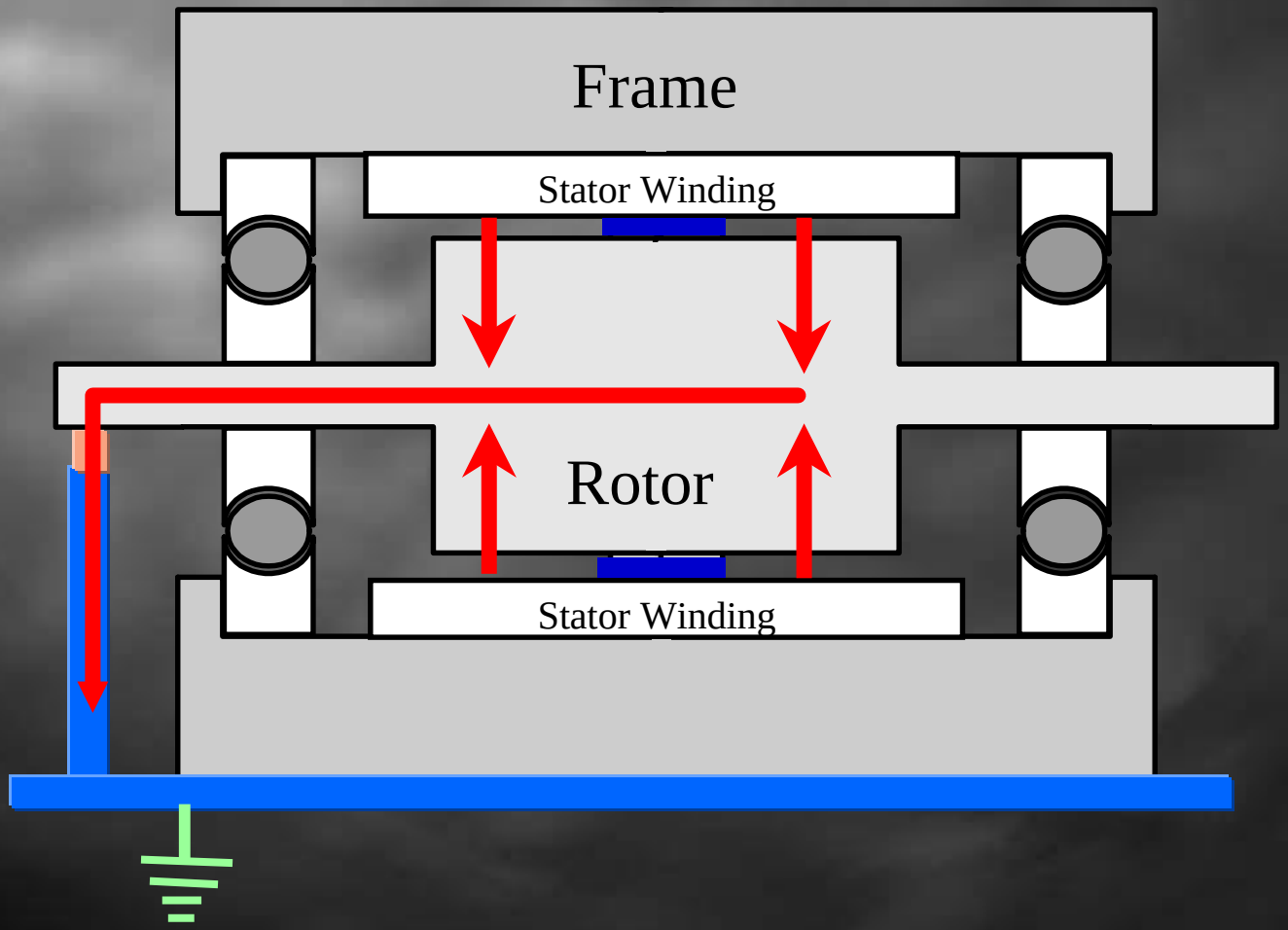
Electrostatic Induced Path

- Electrostatic Coupling



Return to Source

Shaft Grounding



Grounding the Shaft

Shaft Grounding

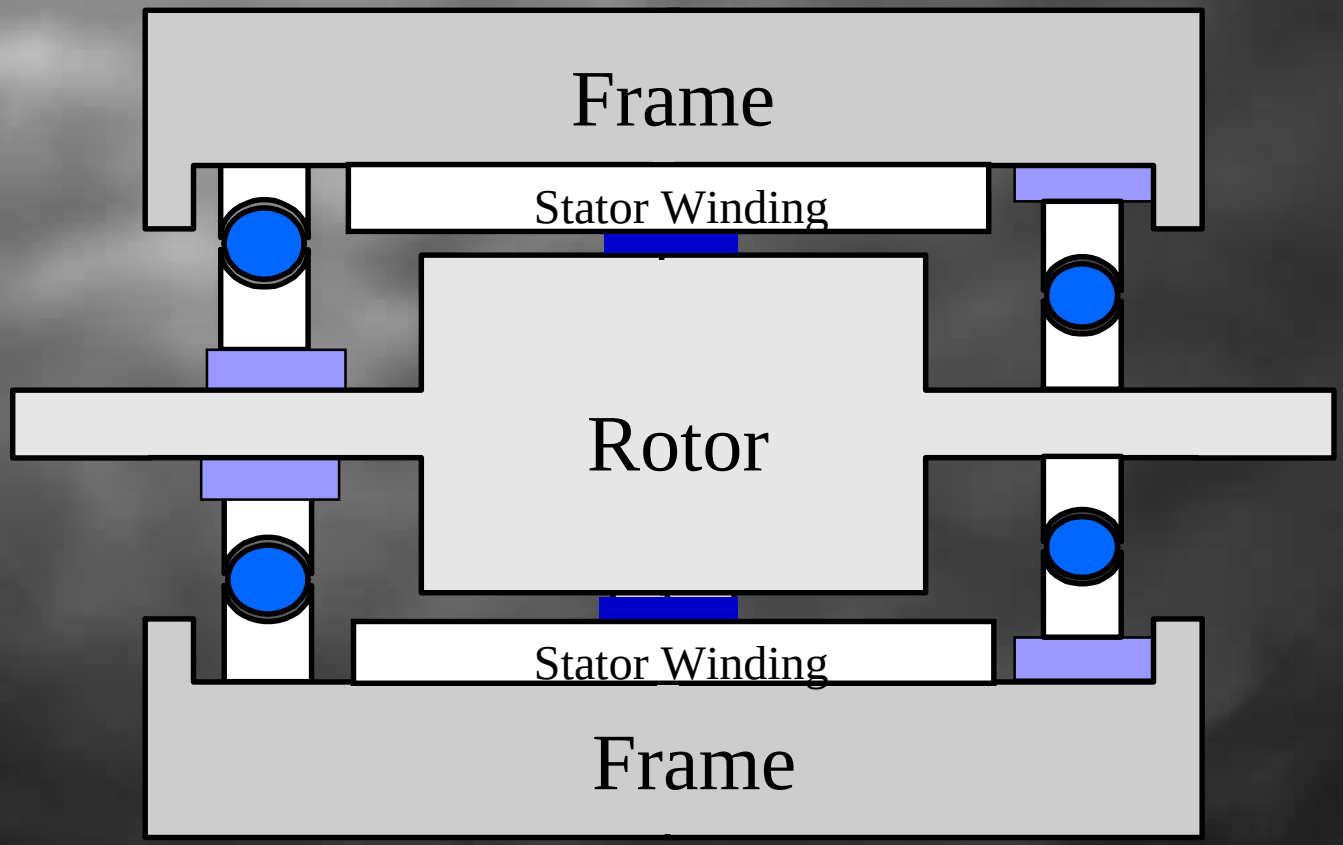
- Pros:
  - Ease of Implementation
- Cons:
  - Poor Life Experienced in high-speed operation > 4,000 rpm
  - Mechanical Maintenance
  - Mechanical fit-up on retrofits

Grounding the Shaft

Conductive Grease

- Pros:
  - Low cost and ease of implementation
  - Retrofitable
- Cons:
  - Separation at higher speeds reduces conductivity effectiveness.
  - Negatively impacts the grease lubricating properties

Bearing Isolation

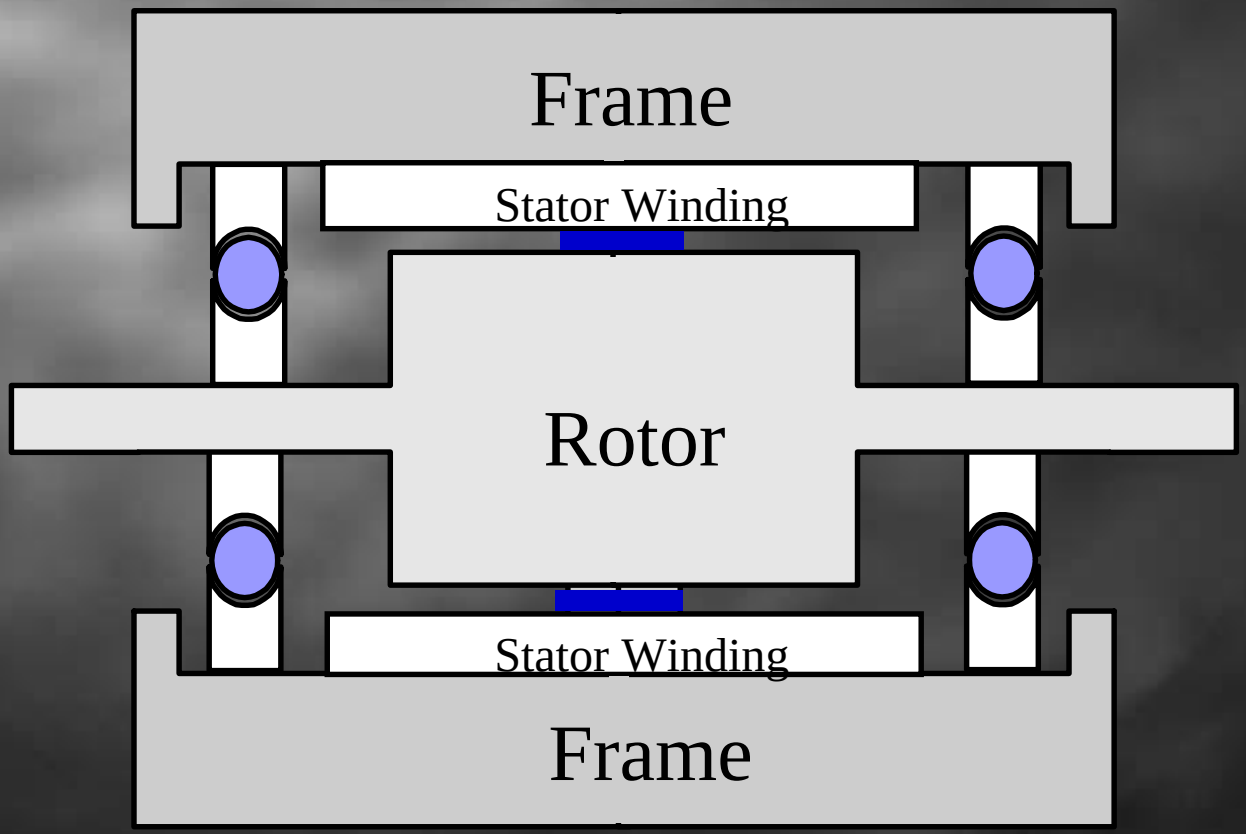


Isolate Shaft

Insulate Bearings

- Pros:
  - Retrofitable except for potential sleeve problems
  - Off-the-shelf fix
- Cons:
  - Does not protect directly-connected equipment
  - Coated Bearings do not prevent capacitive coupling of high frequency currents.
  - Bearing sleeve - downtime and expense of bearing housing modification.

Ceramic Balls

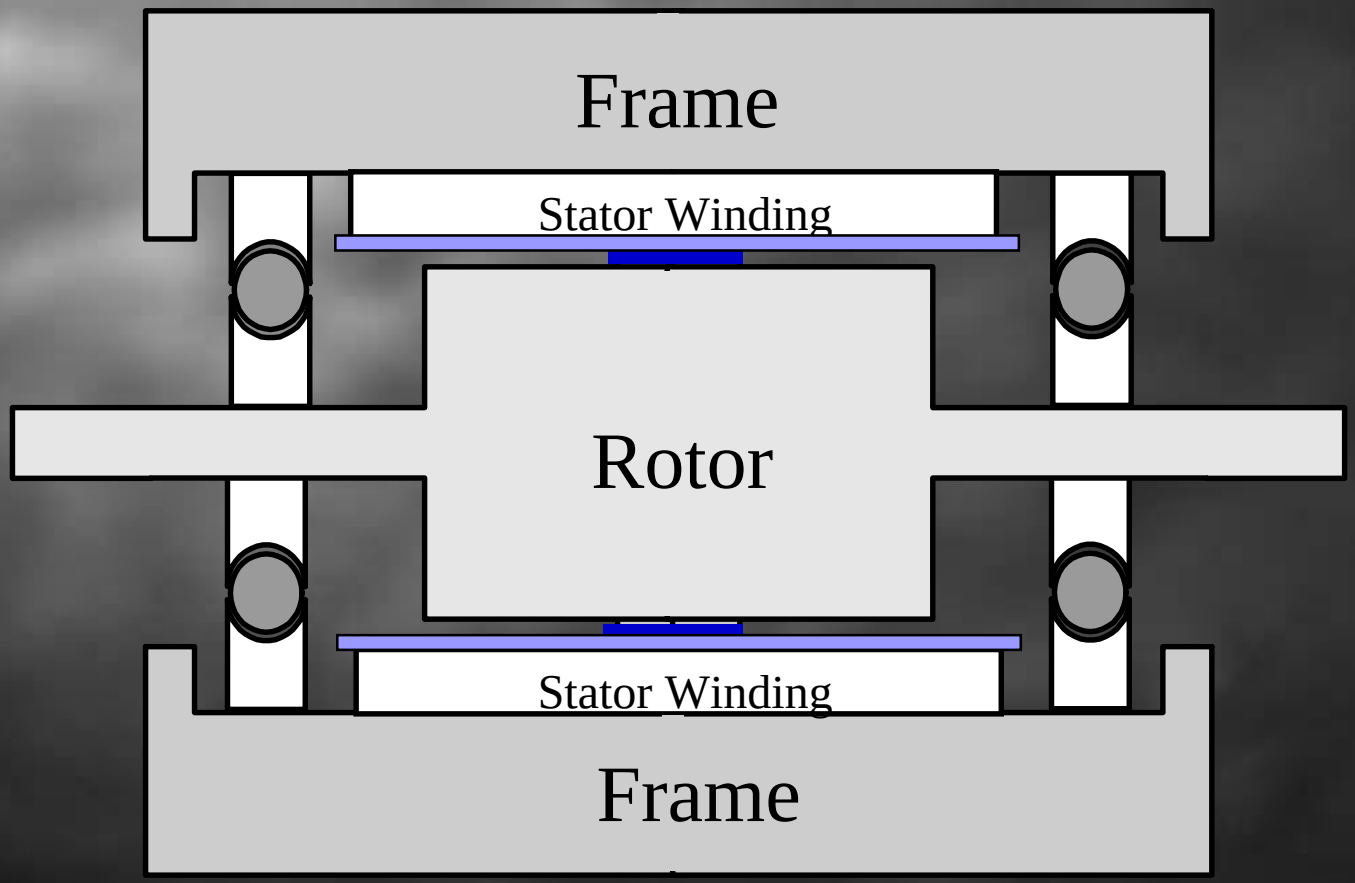


Isolate Shaft

Hybrid Ceramic Bearing

- Pros:
  - –Direct replacement for standard bearing- minimum downtime.
  - –Longer inherent bearing life
- Cons:
  - –Initial expense and potential long delivery.

Shielded Stator



Faraday Motor Shield

- Pros:
  - Permanent internal modification to motor.
- Cons:
  - Difficult (impossible ?) and expensive to retrofit.
  - Not readily available

Conclusions & Recommendations

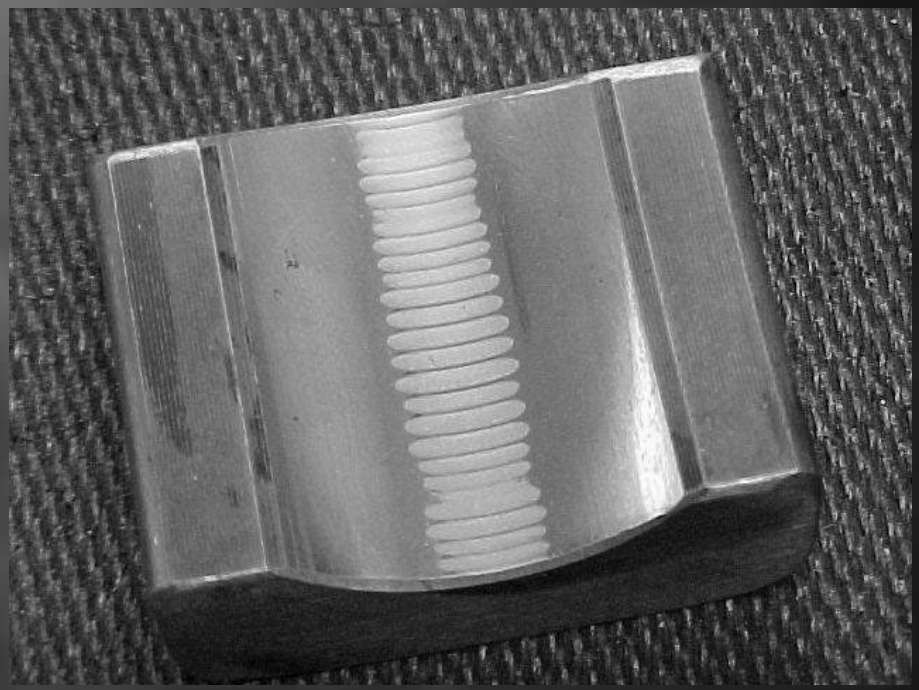
- Bearing current damage is more prevalent on motors driven by IGBT based PWM drives.
- Different causes and solutions than traditional bearing current damage.
- End result of electrically initiated damage is lubrication and/or mechanical failure

Conclusions & Recommendations

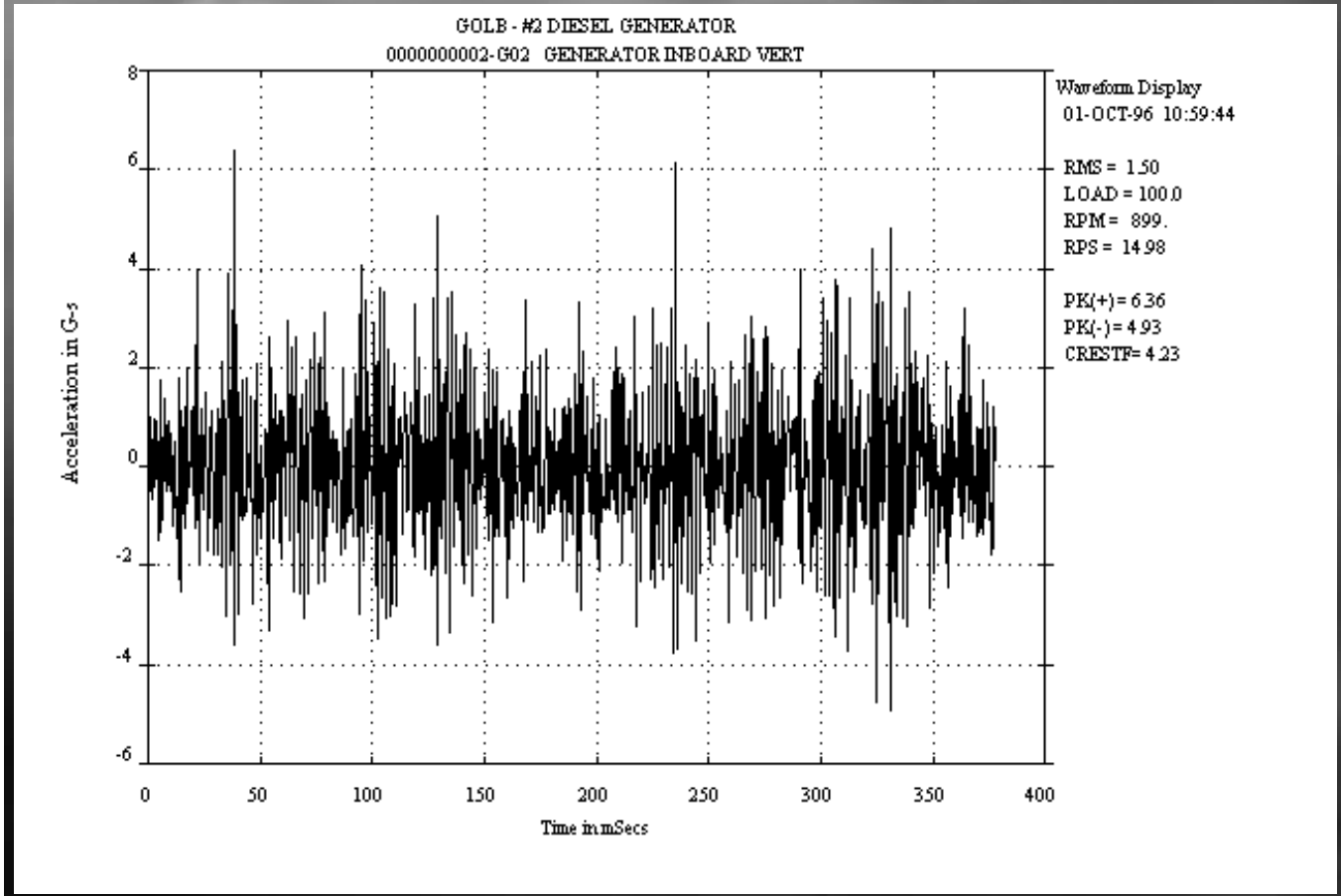
- EDM damage is difficult to predict and measure.
- Problem is REAL and usually assumed to be unavoidable
- Several solution methods
- Selecting the most effective solution will depend upon several applications and technical issues.
- Grounding issues are critical to minimizing problem

Case History #1

- Generator Bearing
- Multiple Failures
- Insulated Outboard Bearing

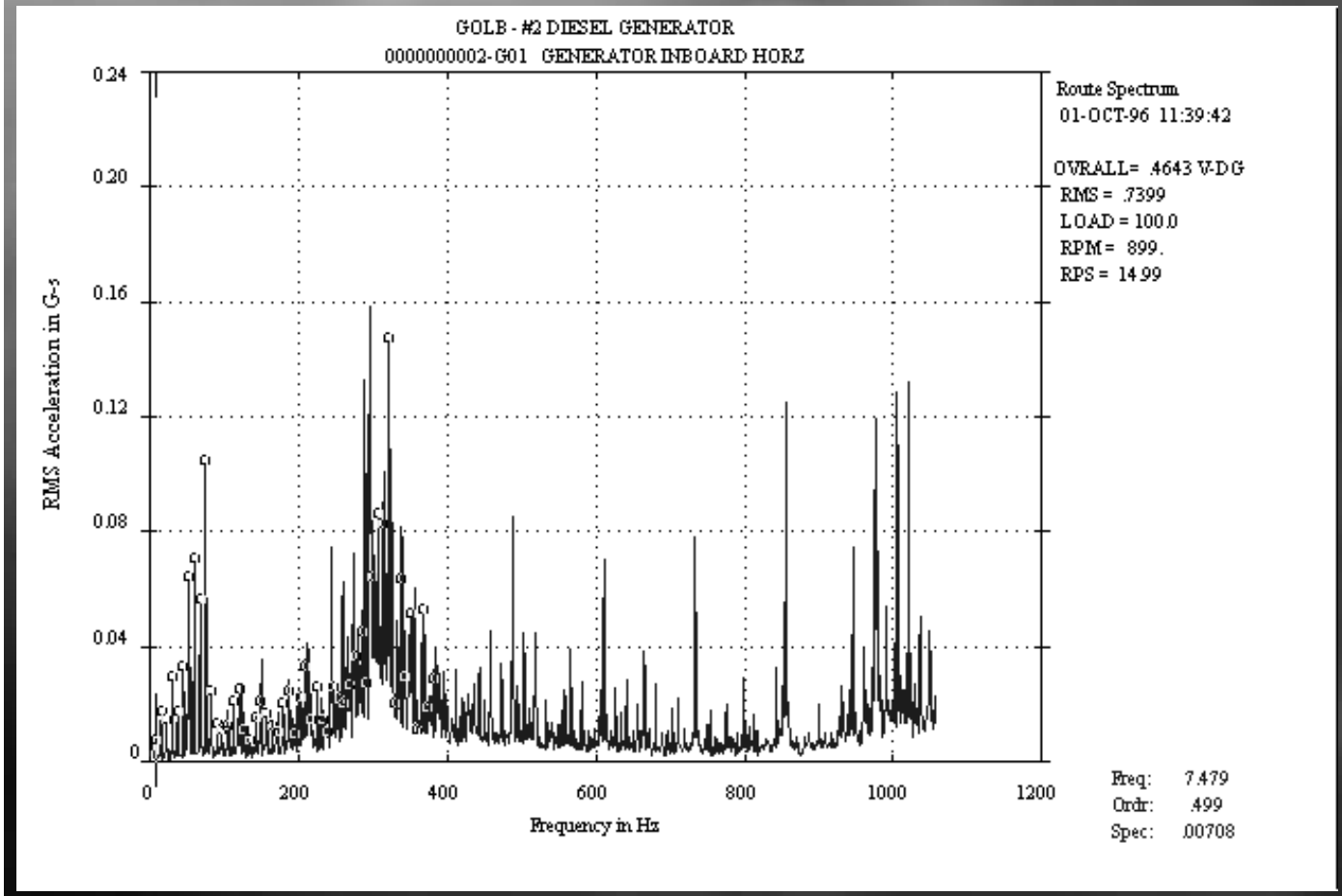


Time Waveform Analysis



- Peaks in excess o 6 G's
- Increase occurred over 3 months
- Third bearing change in less than 2 years

Spectral Analysis



- Low level G's in spectrum
- Non-synchronous vibration
- Higher frequency peaks not related to bearing frequencies

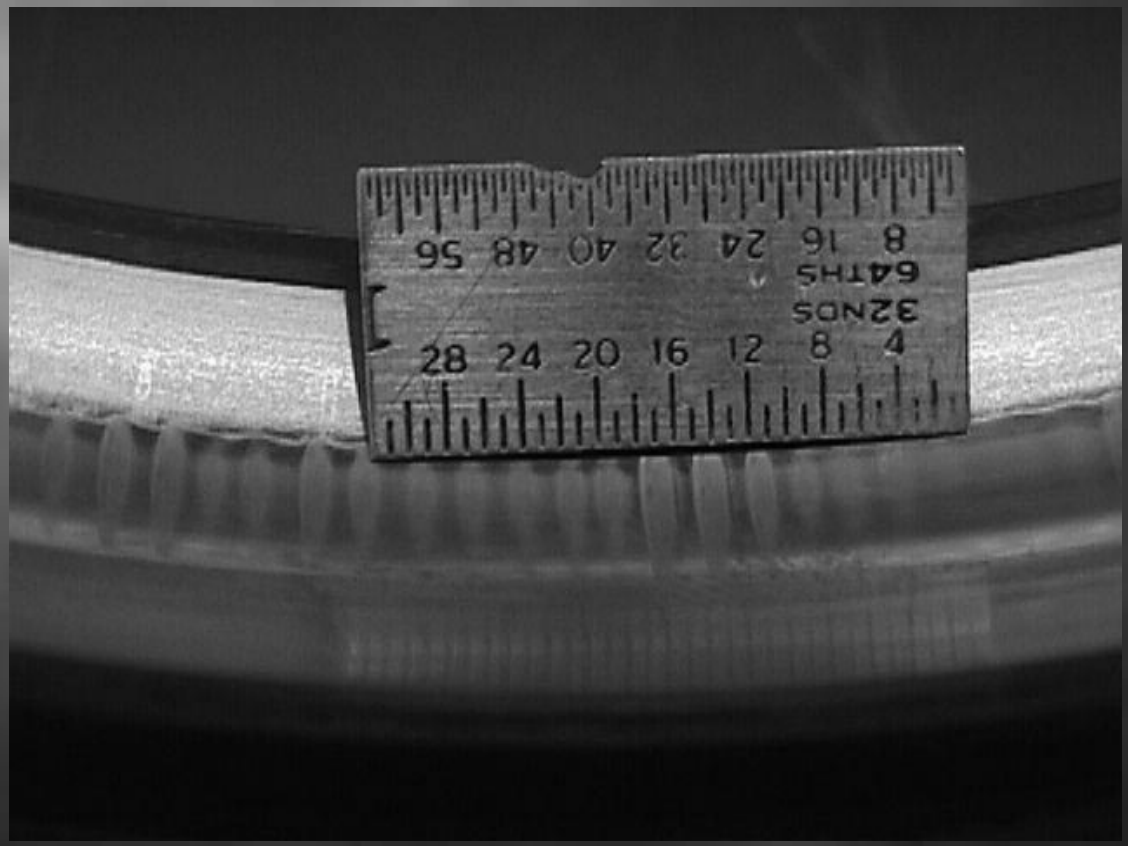
Root Cause Failure Analysis

- Outboard bearing insulation insufficient due to design of spoke - hub support
- 0.010” insulation “peeled” back during bearing installation
- New bracket designed to provide sufficient hub thickness
- New insulation ring over 0.5” thick

Generator Outboard Bearing Hub

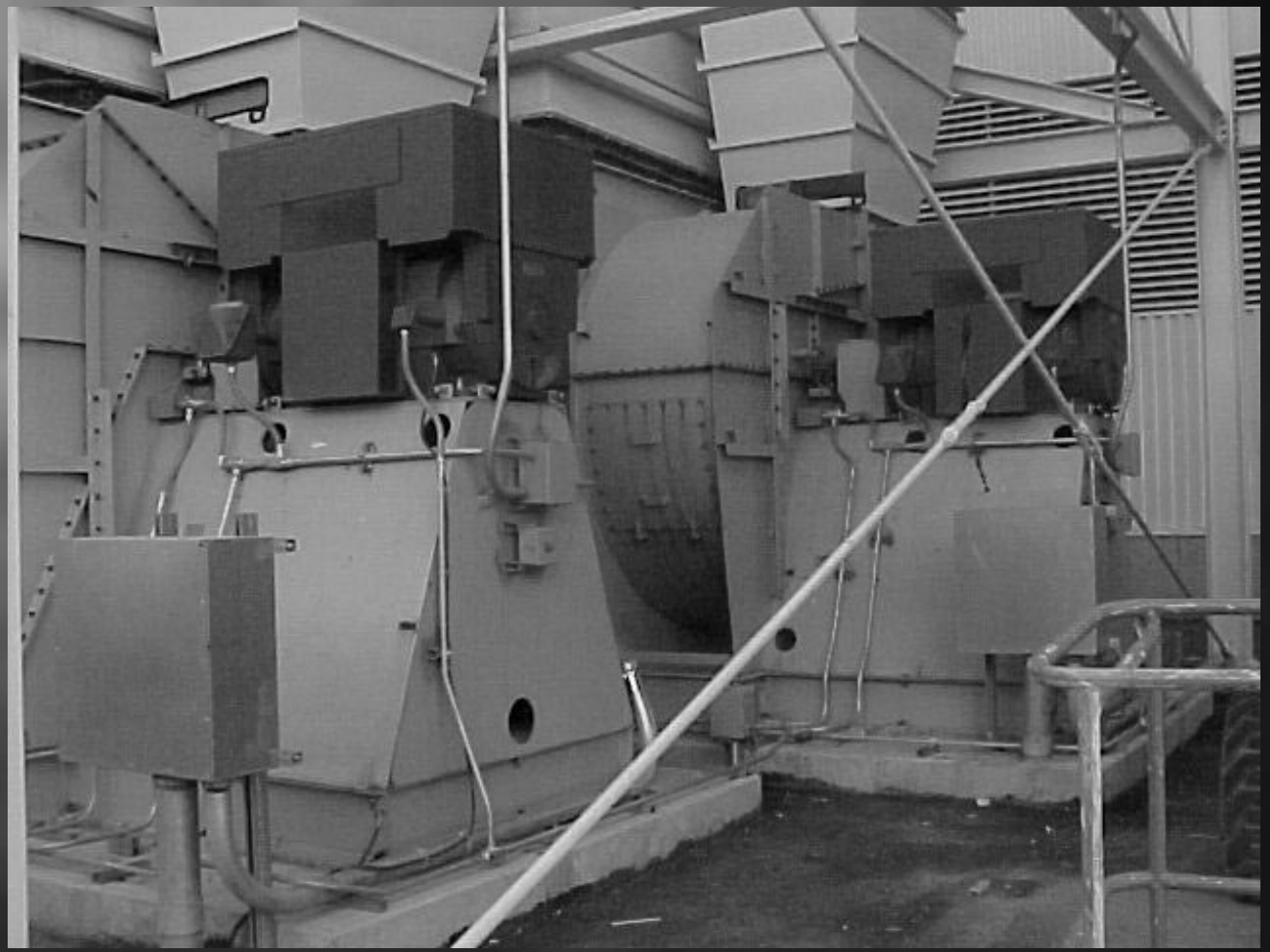
- Thin wall supports outer race
- Grounding brush would also work to solve this problem

Case History #2



Motor-Fan Installation

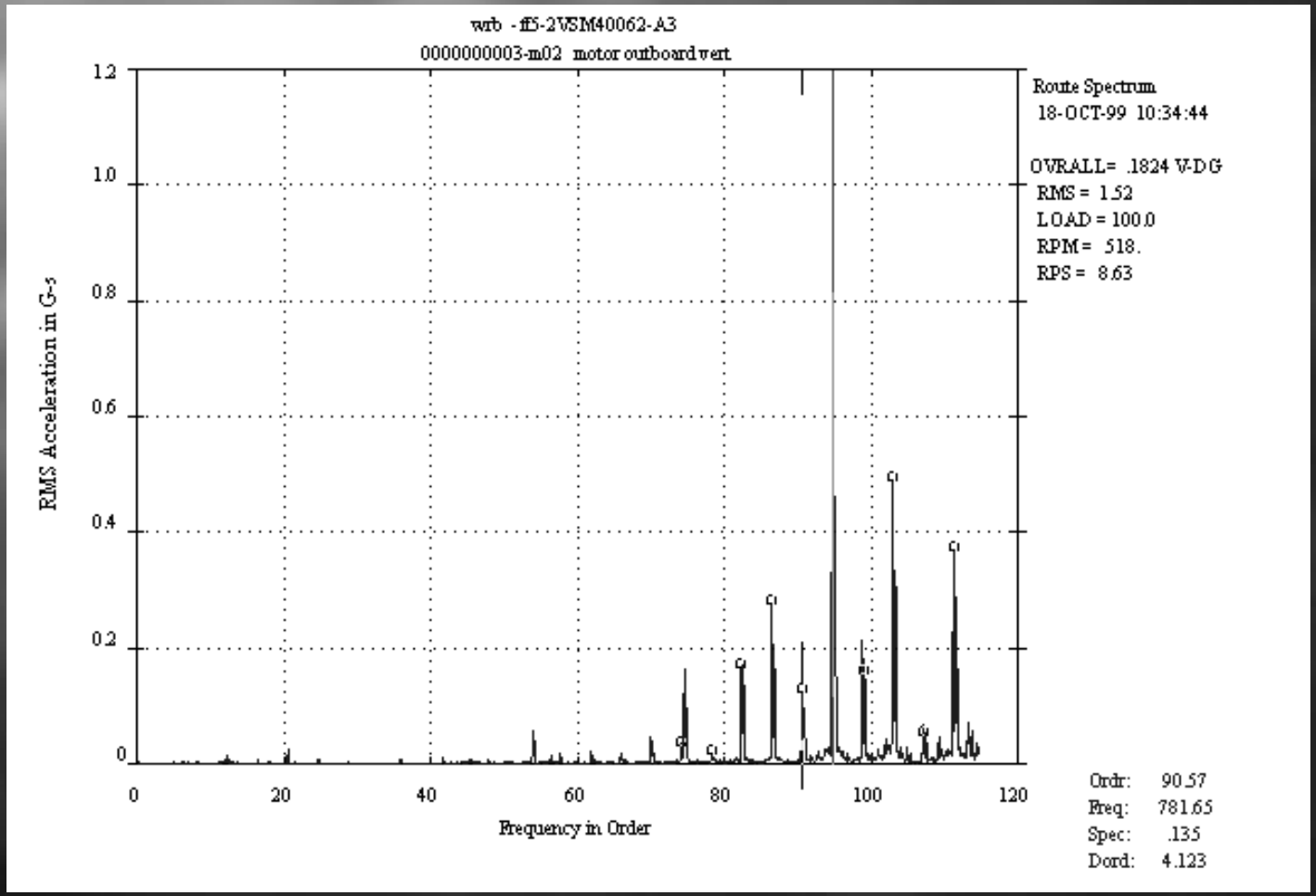
- Typical Installation of Direct Drive Fans



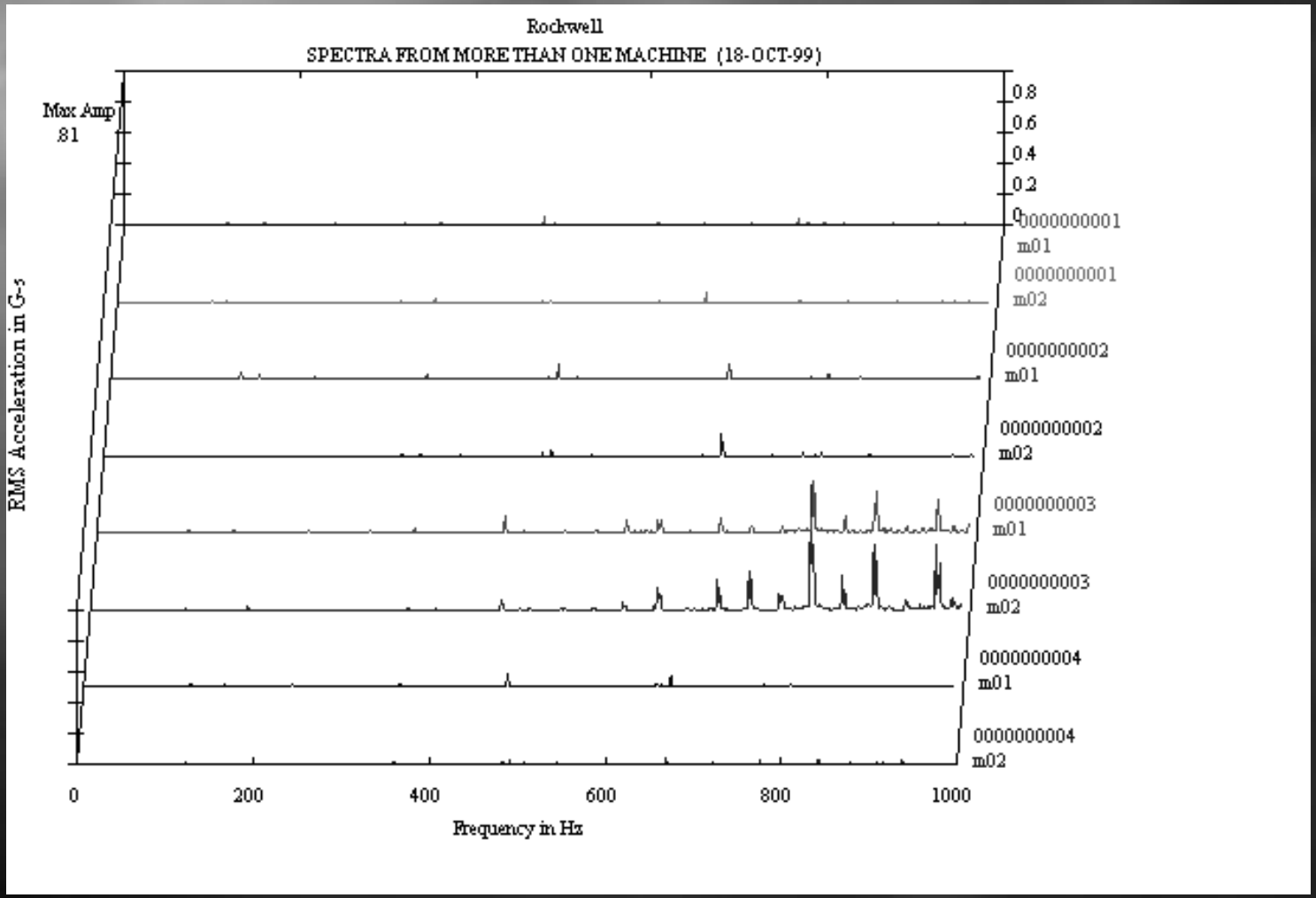
Electrical Fluting of Bearing

- Problem Occurring on Two of Eight Motors
- Outboard Bearing Insulated
- Inboard Bearing Damaged
- IGBT Medium Voltage Drives (460V)
- SCR Driven Heaters in Motor
- Coupling Insulated - Required by Process

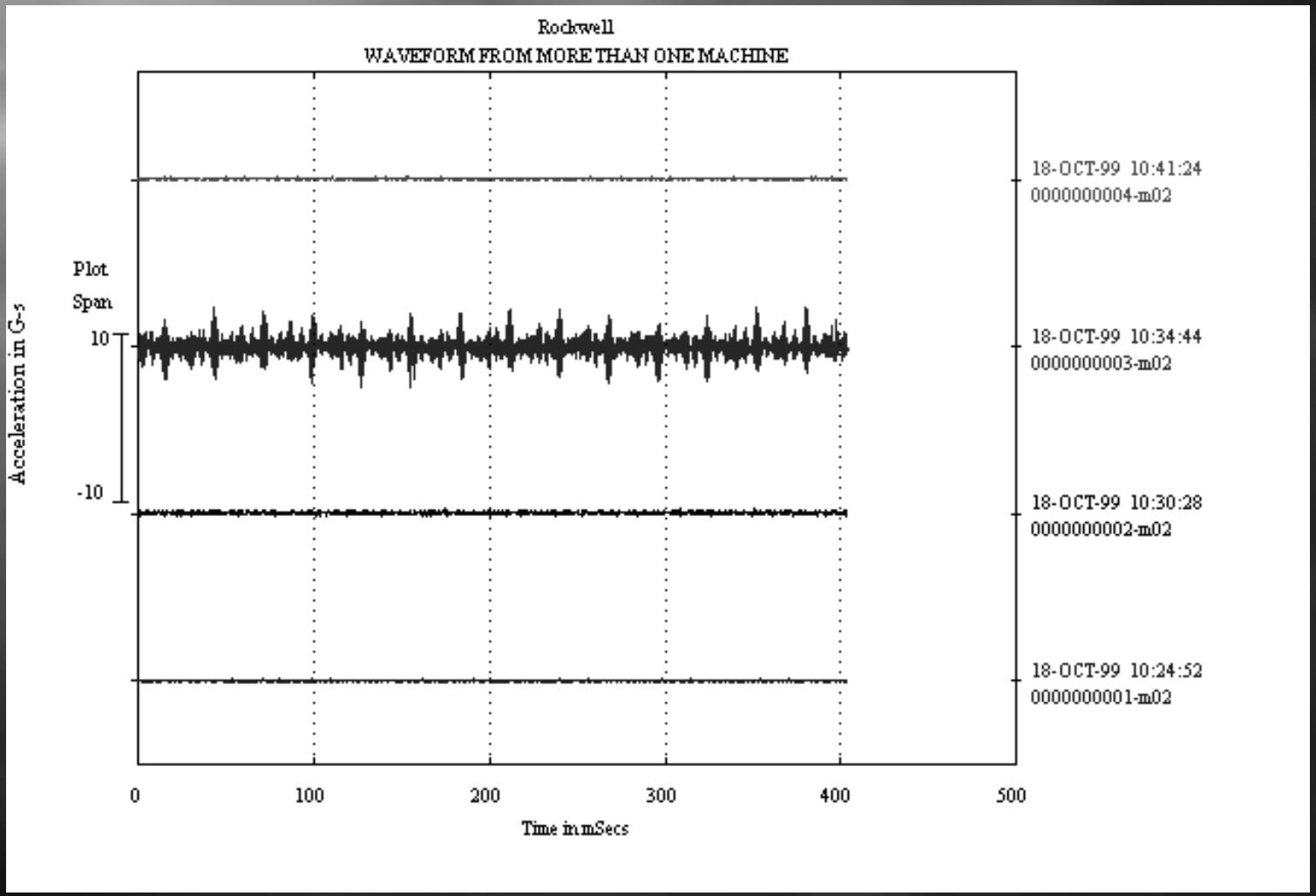
Vibration of Suspect Bearing
4.10 Modulation = BPFO harmonics



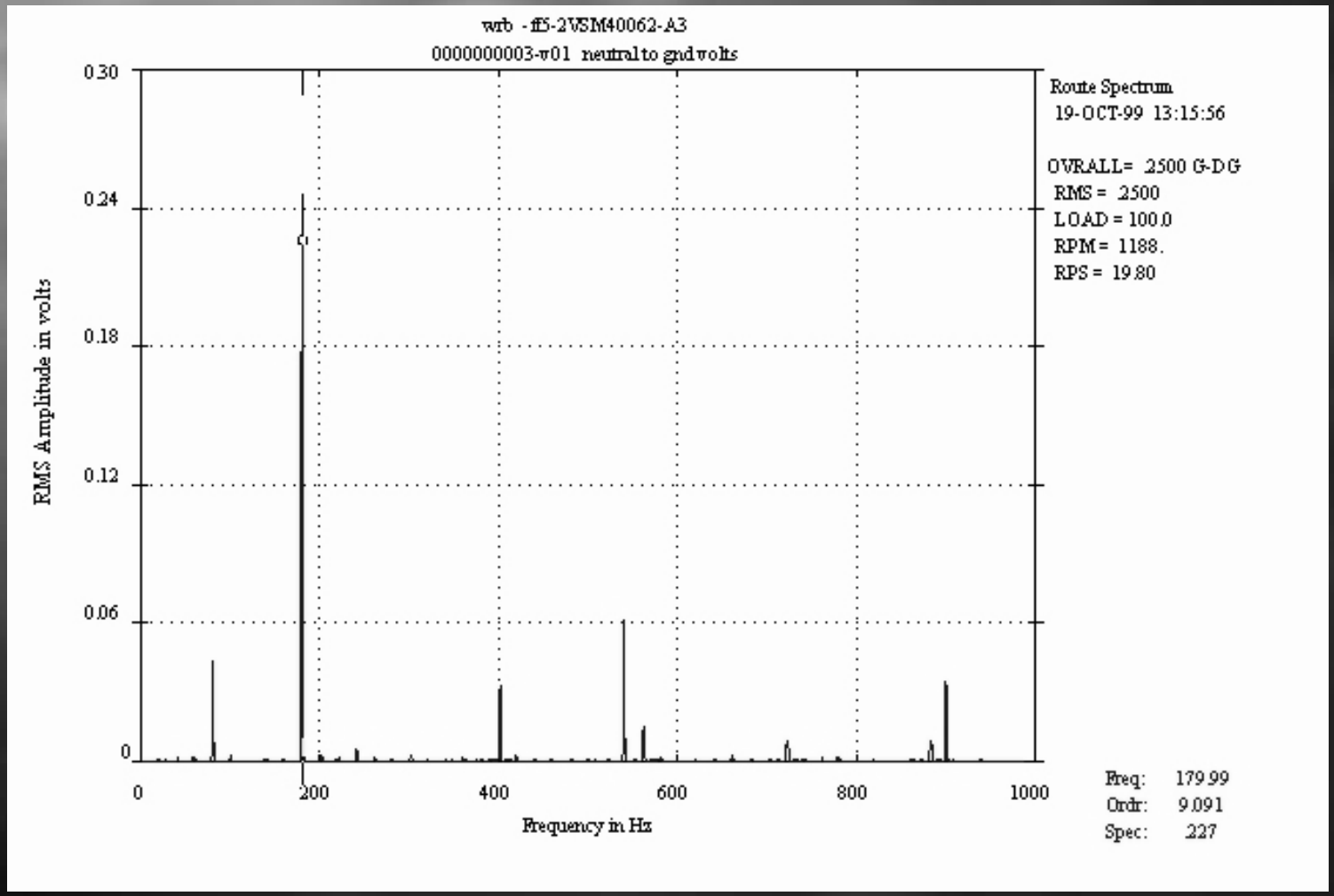
Motors #3, #4, #5, and #6 Acceleration Spectra



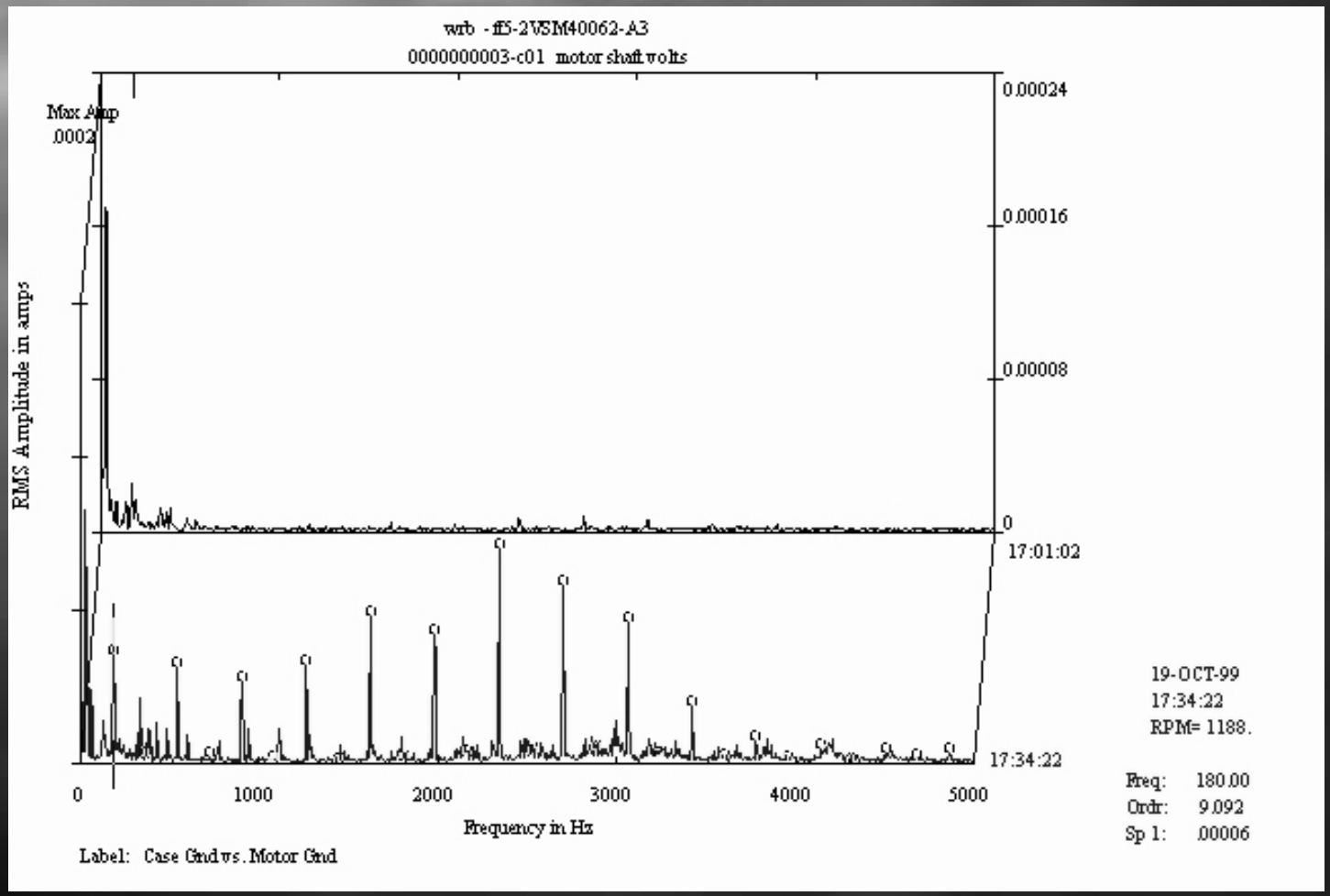
Motors #3,#4,#5, and #6 Acceleration Time Waveform



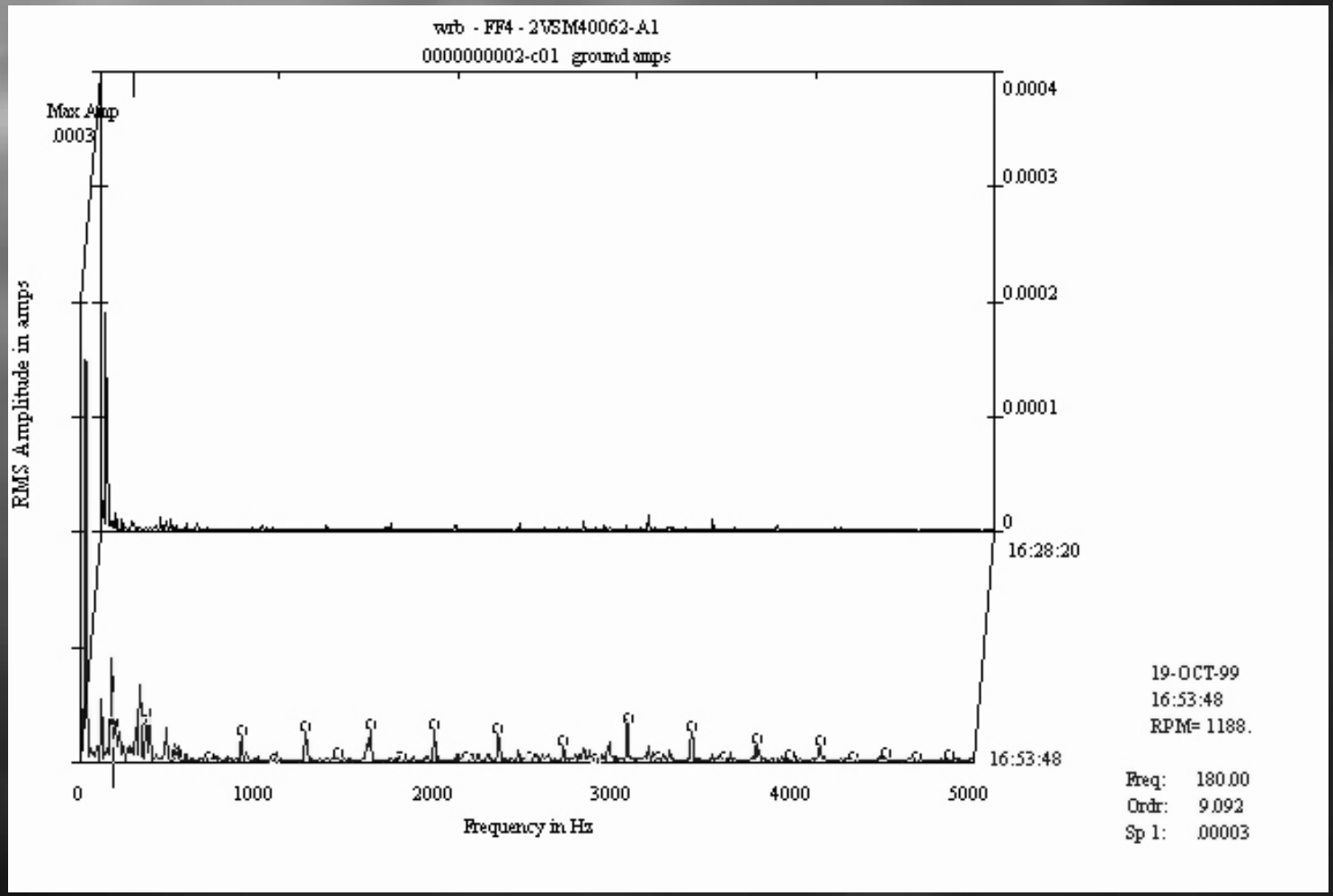
Shaft Voltage



Current on Case Ground vs Motor Ground Lead on #5 Fan Motor

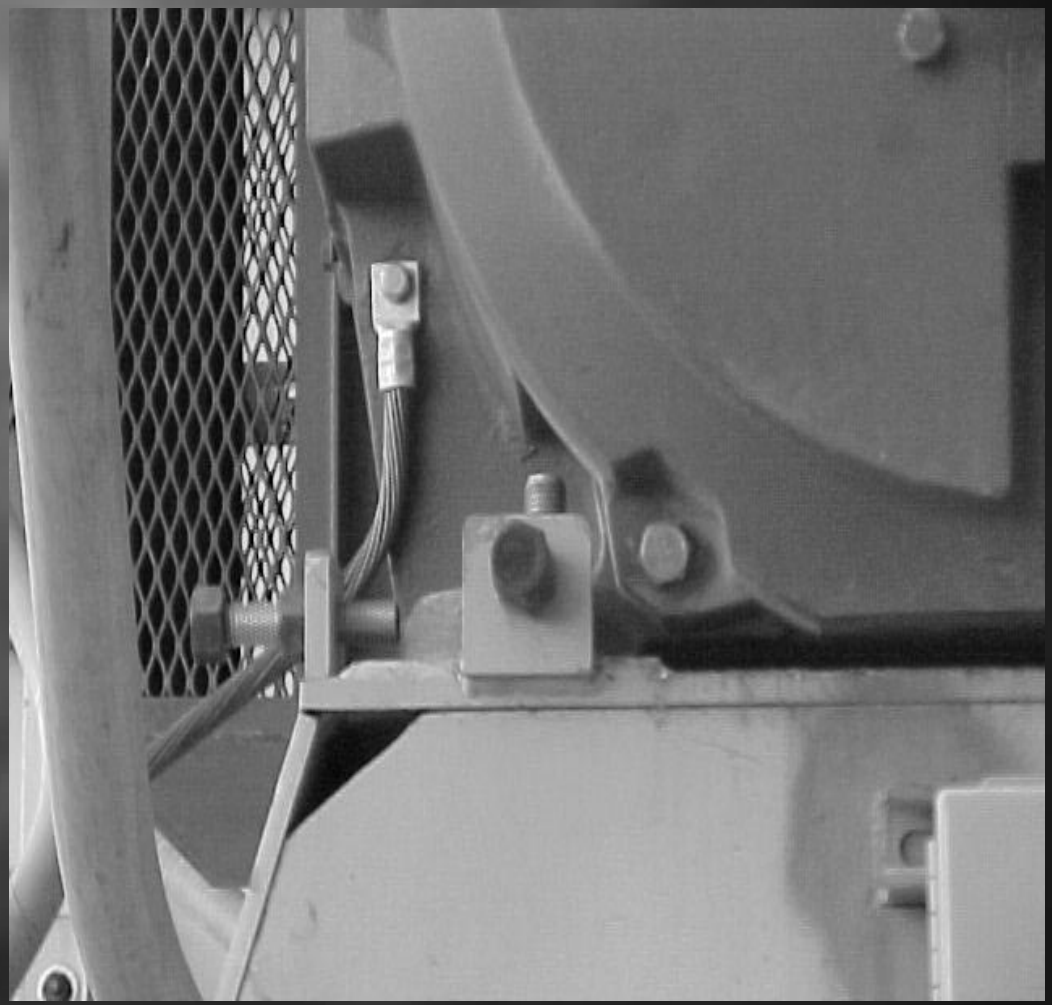


Current on Case Ground vs Motor Ground on #3 Fan Motor



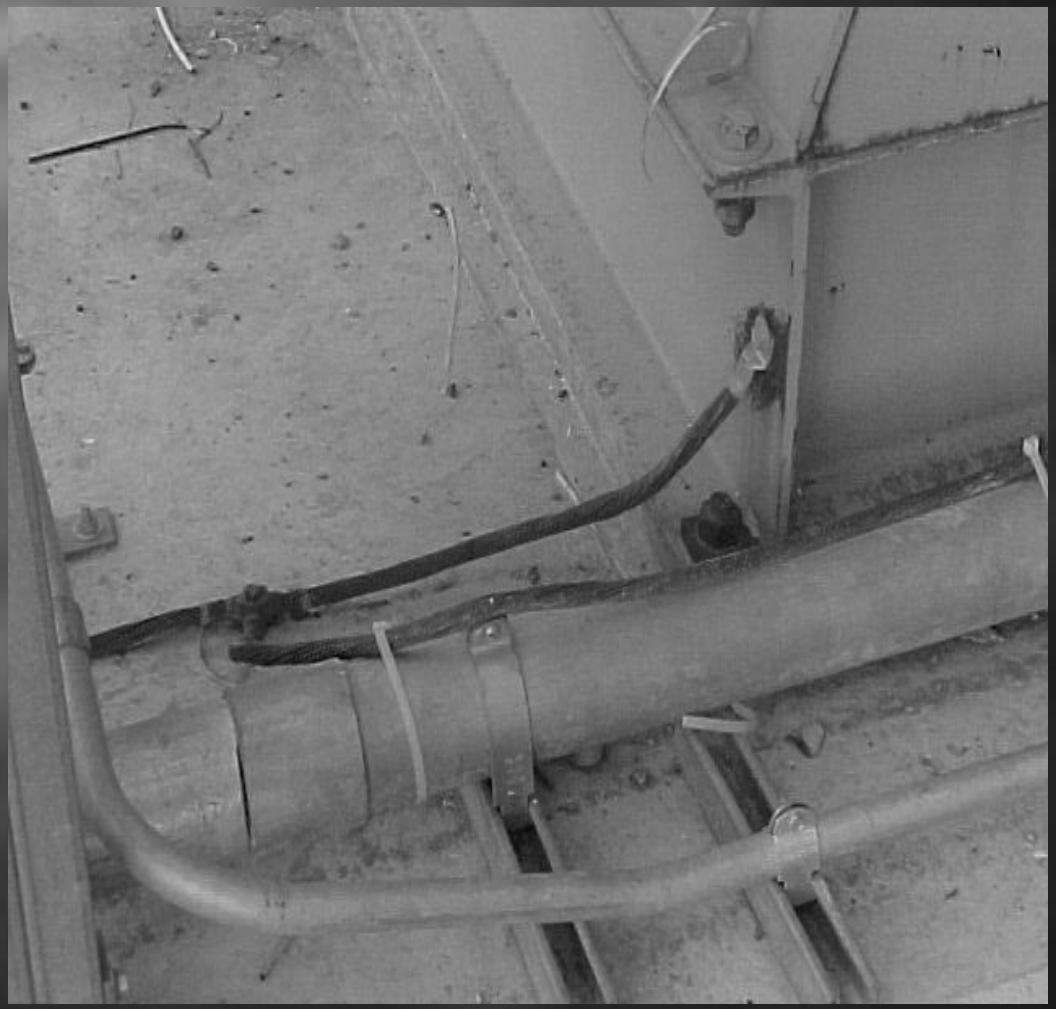
Grounding - Right or Wrong ?

- Cable size good
- Connection point good
- Connection continuity (?)



Grounding - Right or Wrong ?

- Cable weight identical to motor connection (?)
- Connection continuity (?)



Grounding - Right or Wrong ?

- Connected to Plant Ground Grid (?)
- Large difference between #3 and #5 measurements

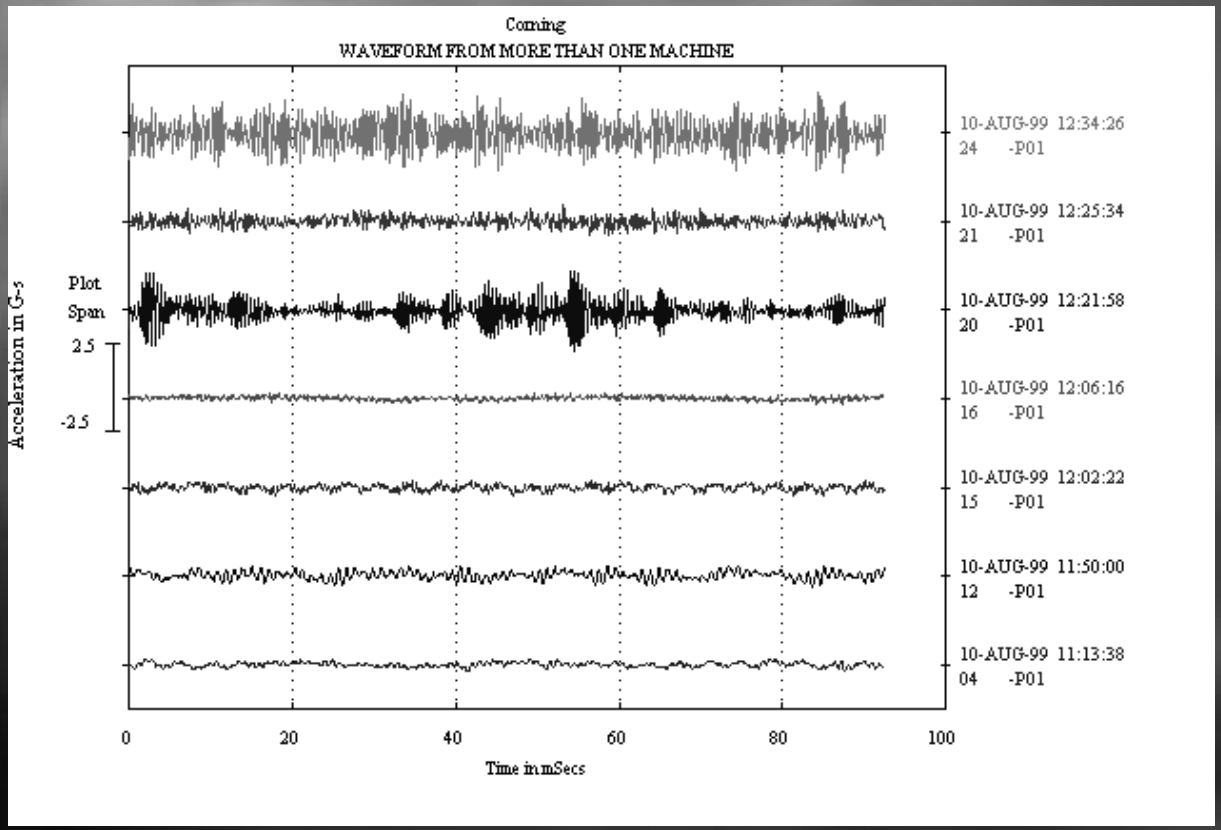
Solution to the Problem

- Insulate both bearings
- Place grounding brush on motor shaft
- An Investigation into grounding issue is pending

Case History #3

- Bearing fluting
- Belt-driven fans
- IGBT drives
- Multiple failures
- Drives mounted within 15 feet of motors

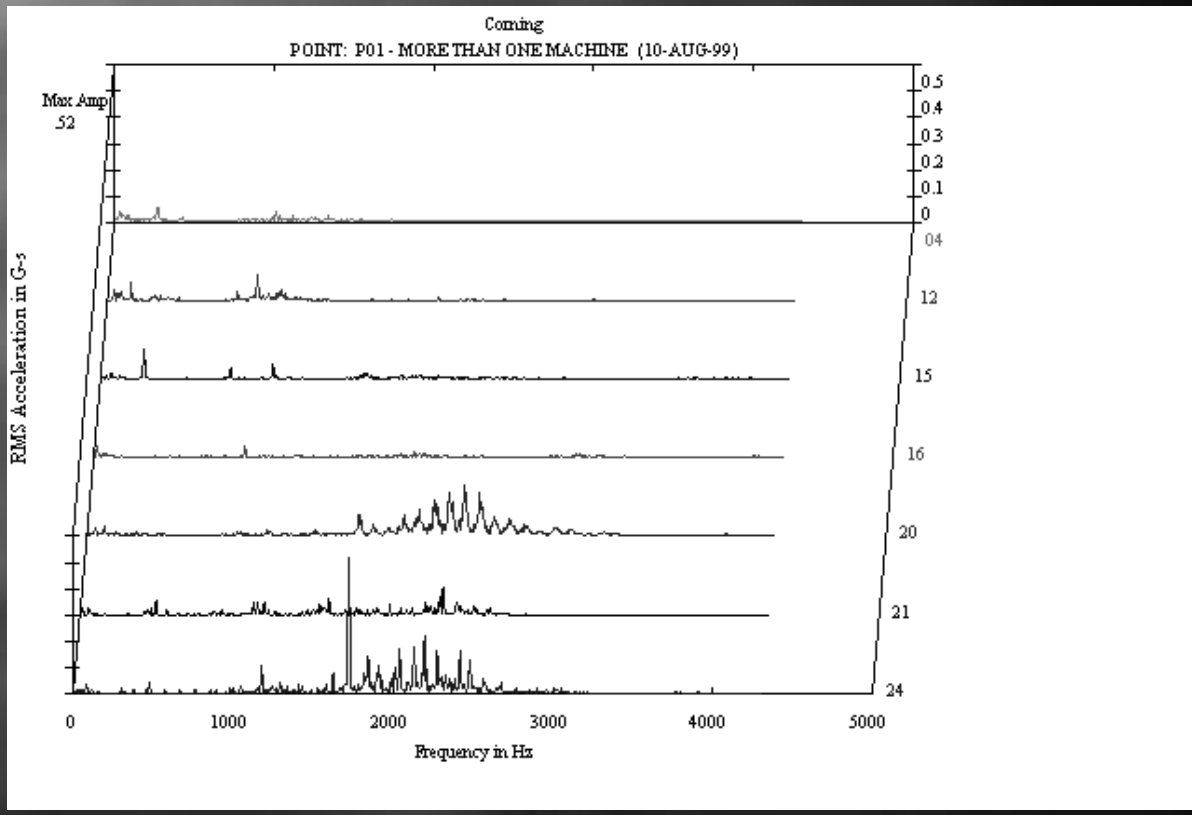
Motors in Service -Good or Bad?



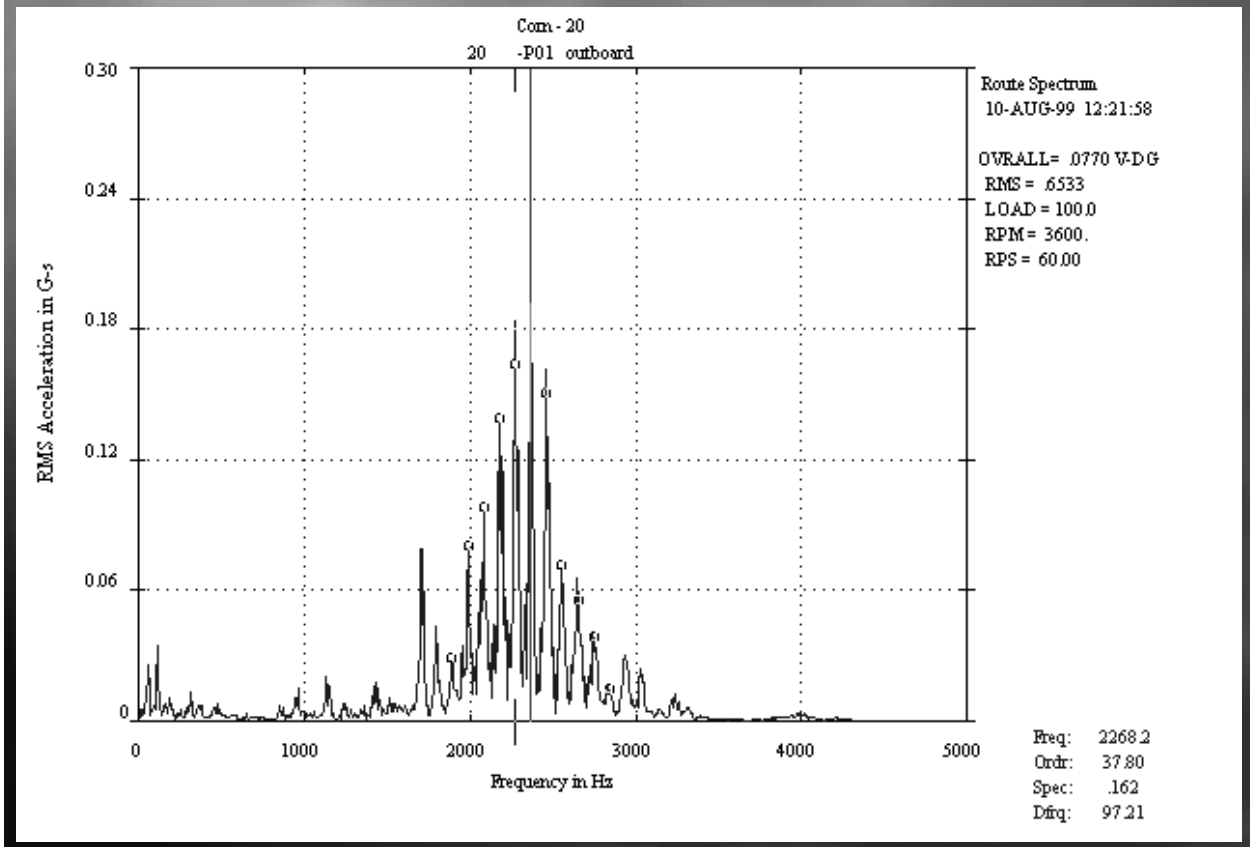
- Evaluate motors in service
- All motors have outboard bearing insulated

Motors in Service - Good or Bad ?

- Fluting evident above 2KHz on three motors
- Not all motors experiencing problems



Identification of Bad Bearing



- Bearing modulation centered above 2kHz
- Sideband modulation occurring at 4.21 orders (BPFO)

Recommendations

- Replace motors with new farraday shield motors
- Investigate grounding (motor adjustable base made of high impact plastic). Only ground on the motor is conduit

References

- Busse,Erdman,Kerkman,Schlegel,Skibinski, "Bearing Currents and Their Relationship to PWM Drives" IECON, Nov. 95
- Link,"Minimizing Electric Bearing Currents in Adjustable Speed Drive Systems"IEEE, 1998
- Bell,Epperly,Cookson,Fischer,Skibinski,Cope, Schlegel"Experience with Variable Frequency Drives and Motor Bearing Reliability" IEEE, 1998