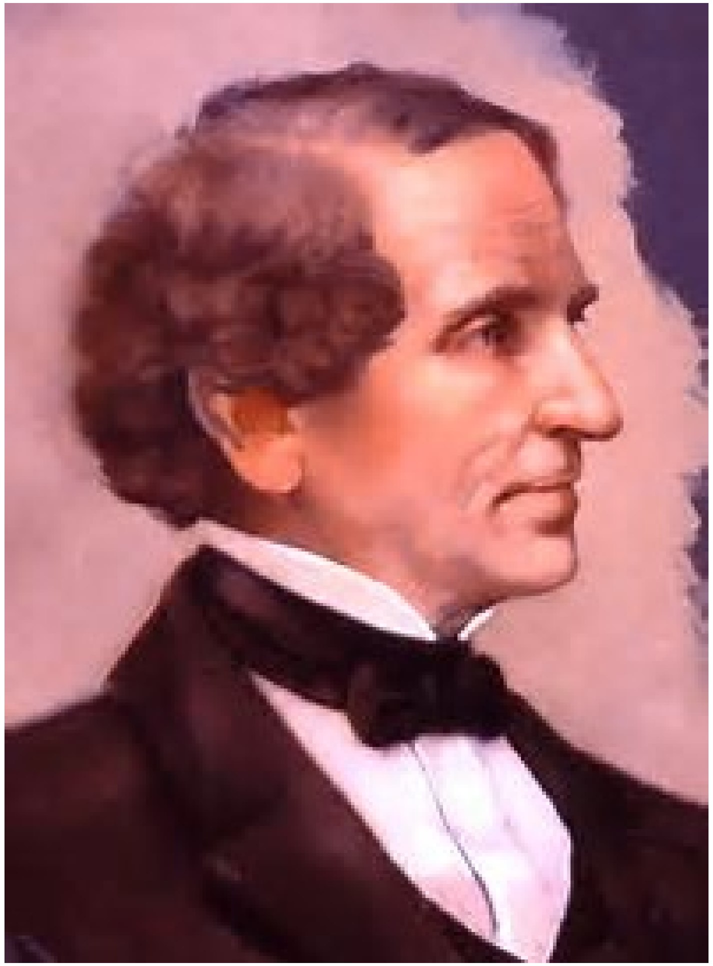
Large Air Cooled Generator Failure

Henry Tarnecky
AVP - Sr. Engineering Specialist, FM Global
2017 IRIS Rotating Machinery Conference

FM Global Basics

- Commercial/Industrial Property Insurer
- Mutual Co., founded in 1835 in USA
- 5,300 employees including 1,800 engineers
- Global – 66 offices serving clients in ~150 countries
- Clients – large organizations, 30% Fortune 1000

Zachariah Allen – Founder



Textile manufacturer, scientist, lawyer, writer, inventor and civil leader

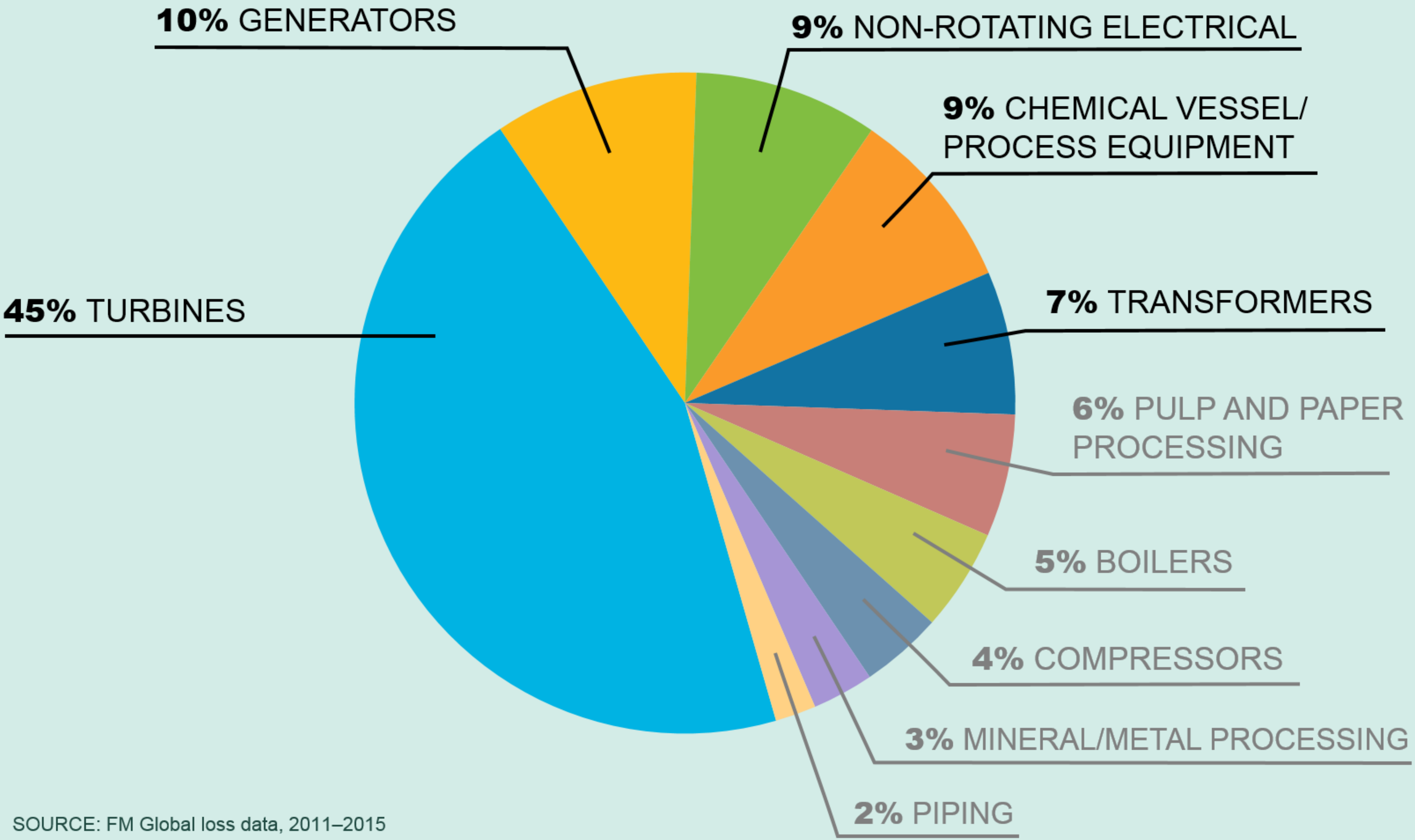
FM Global Basics

FM Global Difference

- “The Majority of Loss is Preventable”
- Mutual with Specialty Focus
- Engineering Services
- Global Product Delivery
- Outstanding Claims Service
- Strong Client Partnerships
- Business Risk Consulting

Loss Prevention Resources

- Dedicated Client Service Team
- Data Sheets
- Specialist Loss Prevention Engineers
- Subject Matter Experts & Industrial Principle Engineers
- Research
- Training (on site, corporate)
- Approval



SOURCE: FM Global loss data, 2011–2015

Outline - This Presentation

- Generator Failure Case Study
- FM Global Loss Prevention Strategy for Generators

Case Study-Generator Failure

- Site Information
  - 600 MW - 2x1 Combined Cycle Plant – (2) CT's & (1) Stm Turbine
  - Cycled 7am to 11pm Monday thru Friday
  - Commissioned in 2005
  - Can operate 1X1 or bypass Stm Turbine @ reduced load

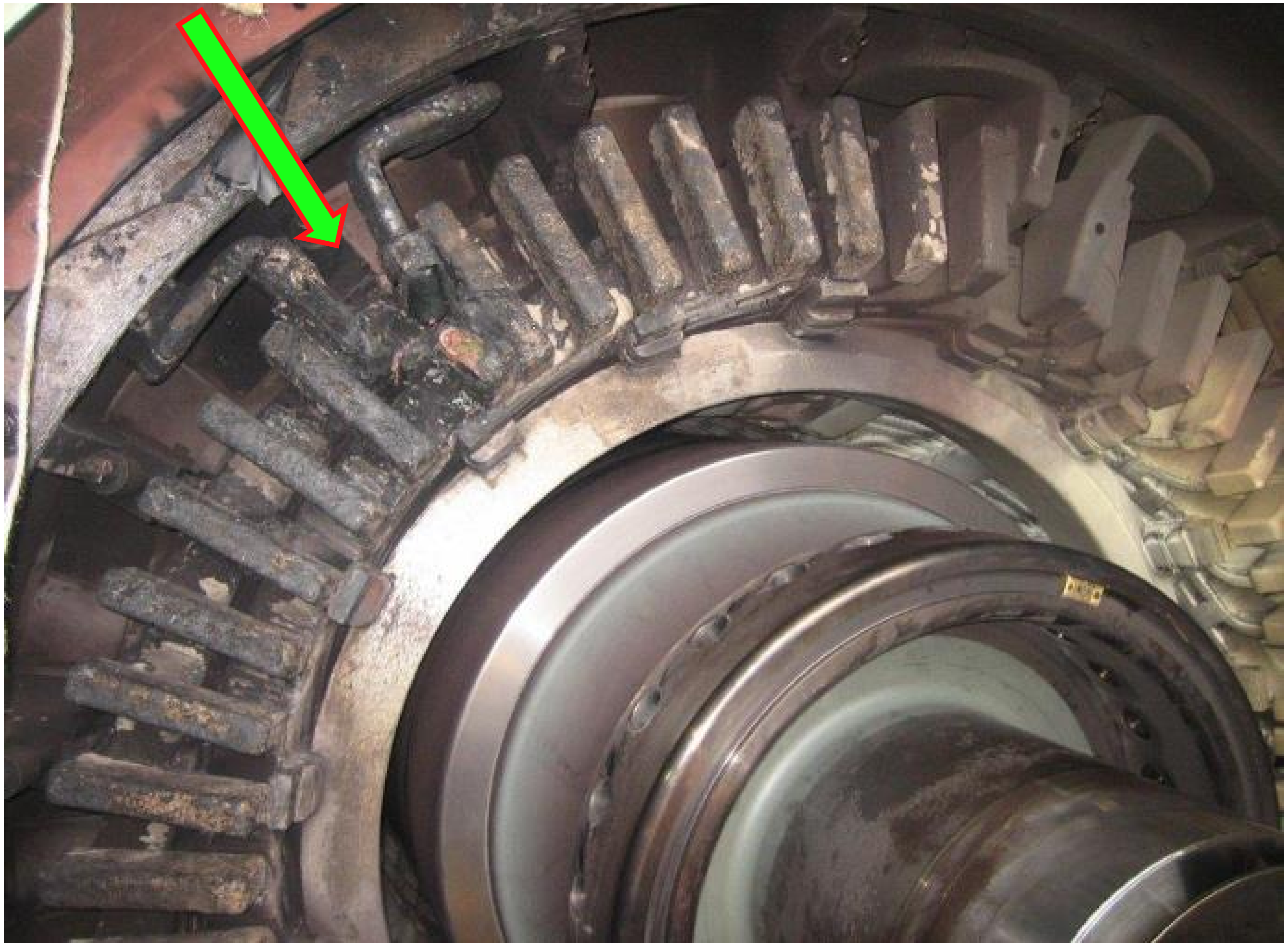
Case Study-Generator Failure

- The Unit
  - 255 MW, 21 kV - 2 pole, air cooled, 60HZ
  - Steam turbine driven
  - Satisfactory acceptance testing @ commissioning
  - Manufactured in 2005
  - 15,000 hours (625 days) of operation at the time of the incident with no significant previous issues

Case Study-Generator Failure

- Unit trips offline suddenly – reportedly differential relay trip (modern digital multi relay package installed)
- Condition assessed by operators and restart attempted three more times – relay tripped each time
- Turbine/Generator secured for damage investigation
- All vital parties notified (Management, OEM, Insurance etc.)

Severe arc fault damage top bar #4 at phase lead connection



Case Study-Generator Failure

- Damage assessment:

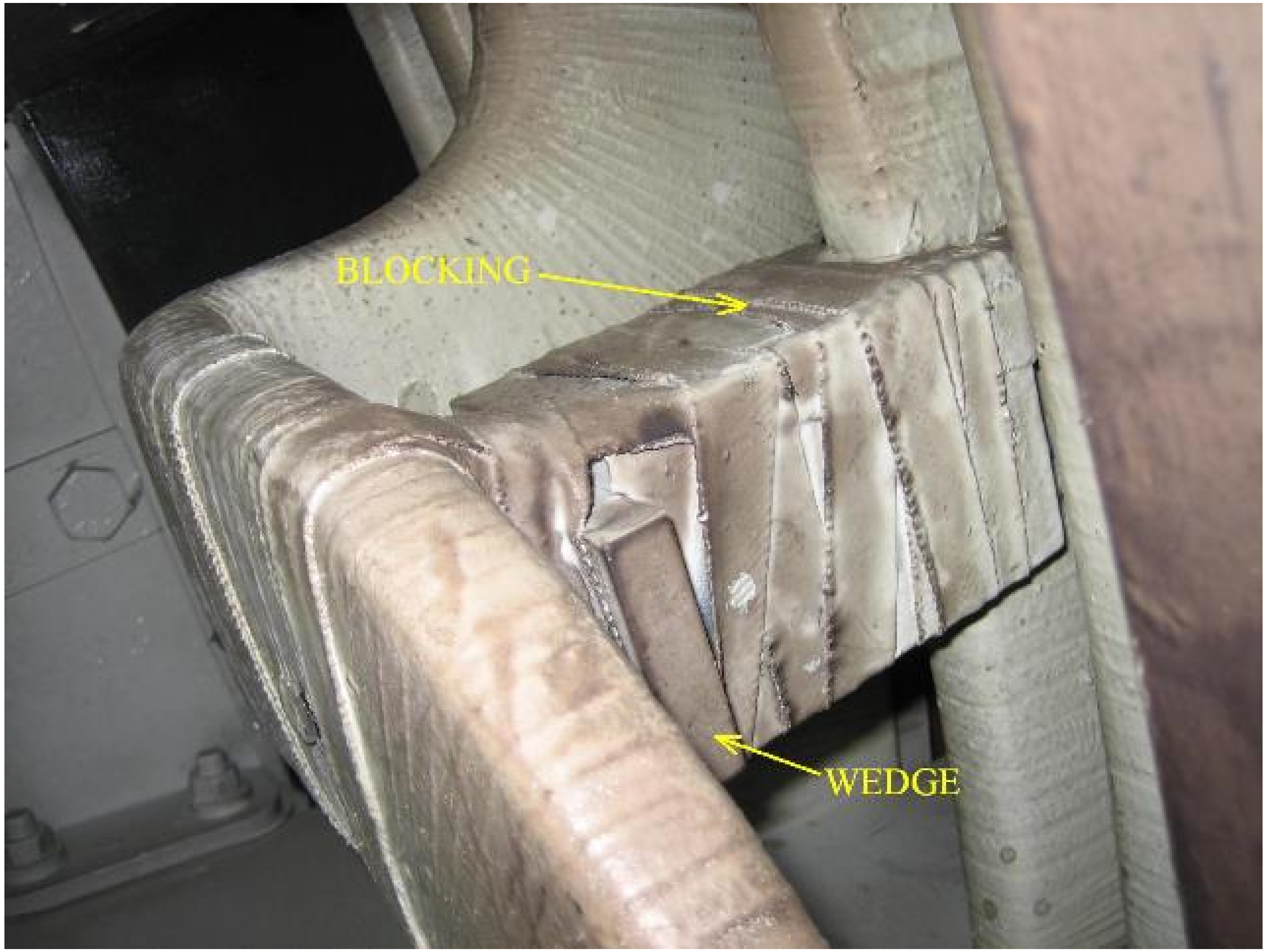
- Stator arc fault damage to “B” phase top bar # 4 insulation noting cracked phase connection (exciter end) flashed over to ‘C” phase

- Operator restart attempts caused more severe arc fault damage and end winding physical movement after the initial fault

- Resulted in retaining ring, rotor forging & field coil overheating & metal loss damage

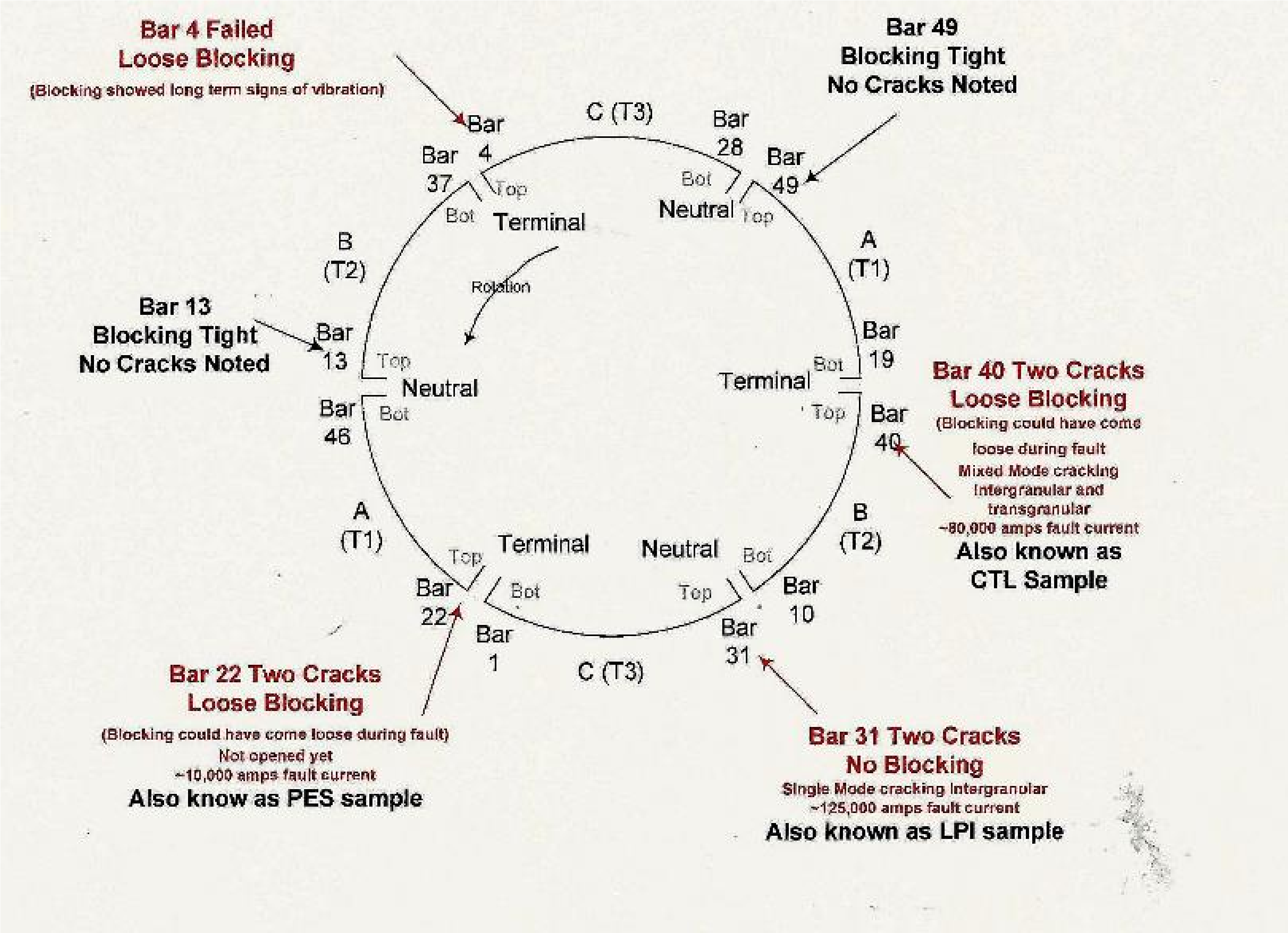
11 o’clock positon where initial arc flash over occurred

Other as found blocking & phase lead connection exciter end



Phase lead blocking - note poor taping and displaced wedge.

Stator Damage Map – Exciter End



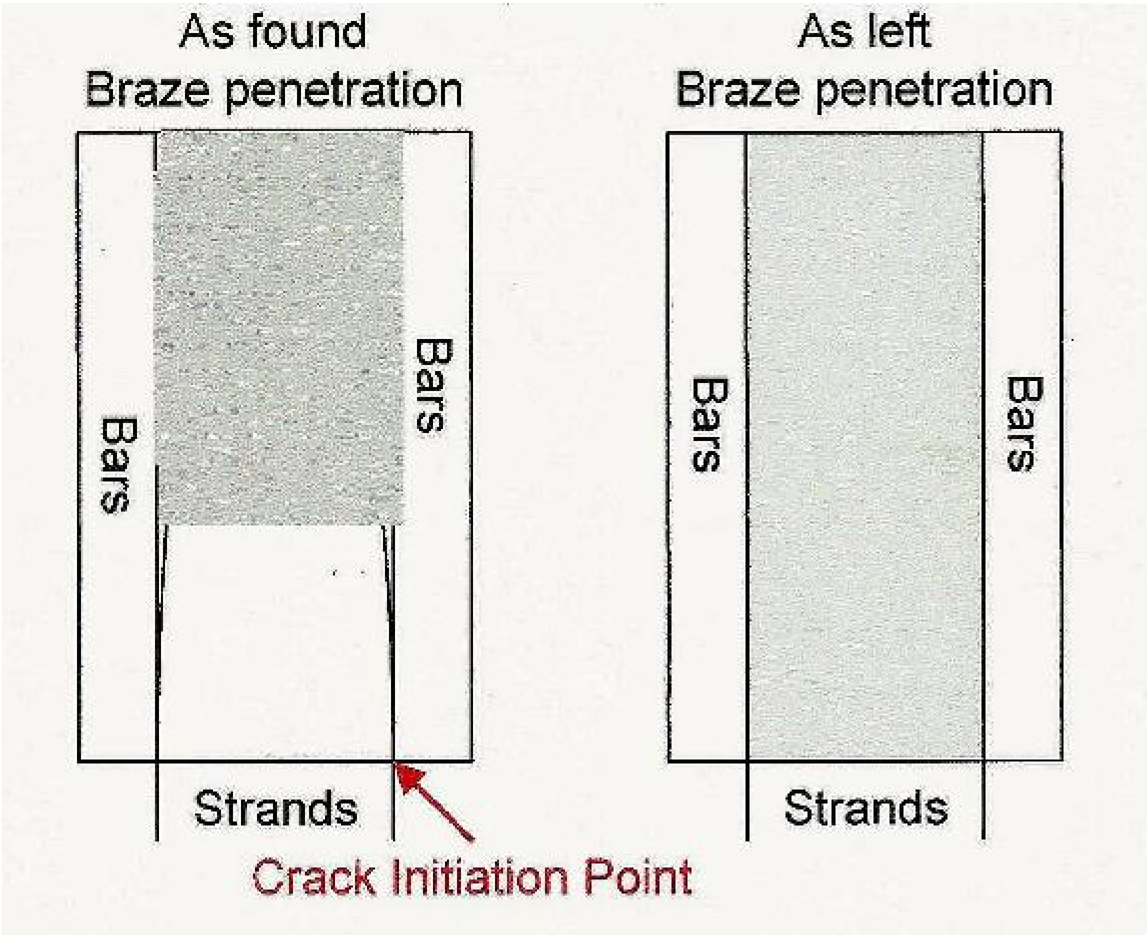
Damage Assessment Continued

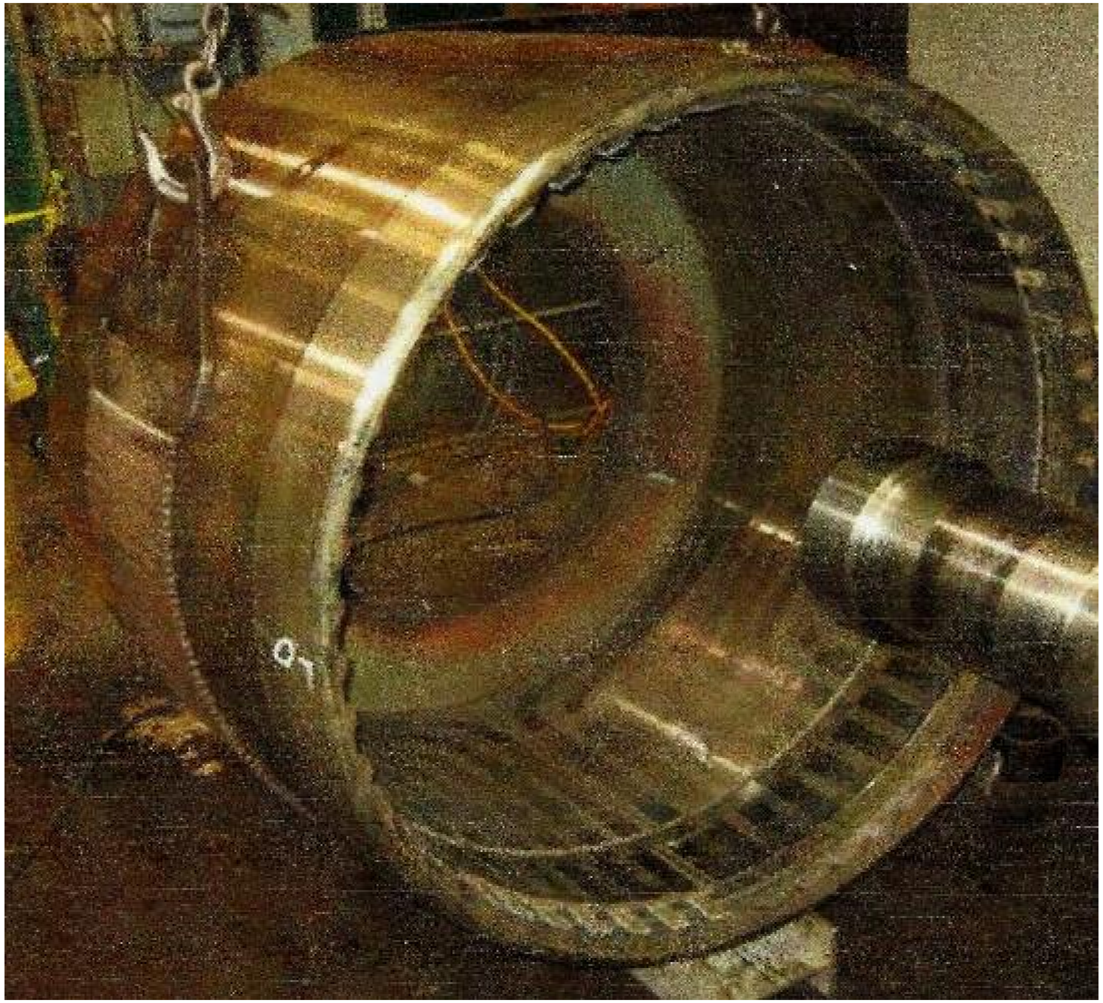
- Found 4 of 6 phase lead connections cracked in the strand braze area where loose or no blocking evident
- Phase lead connections with secure blocking were not cracked
- Long term insulation vibration wear at failed bar # 4 noted
- Bump test found signs of 120 HZ resonance present in end winding suggesting “High Cycle Fatigue”
- Suspect rotor/field & retaining ring arc fault damage (removed for off site evaluation - repair)

"Phase lead connection crack"

(copper lug brazed to the bar end - then trapezoidal intermediate piece & circular phase ring)

Stator - poor strand to phase lead braze connections





Retaining Ring Removed from Rotor at Repair Shop (exciter end)

Retaining Ring & Rotor damage assessment:

- The retaining ring on the exciter end sustained arcing damage at the taper end.

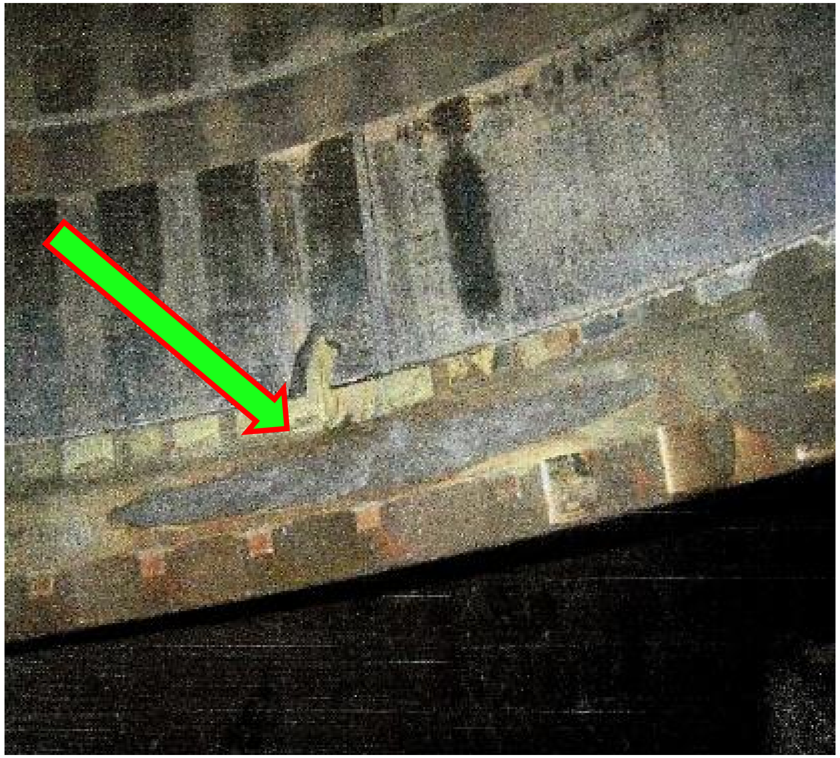
- Splatter debris was found throughout the rotor.

- Ground fault (arcing damage) at exciter end through the damper winding to ground on the face of the slot tooth between coils 1 and 2 & on the same coil on the exact opposite side.

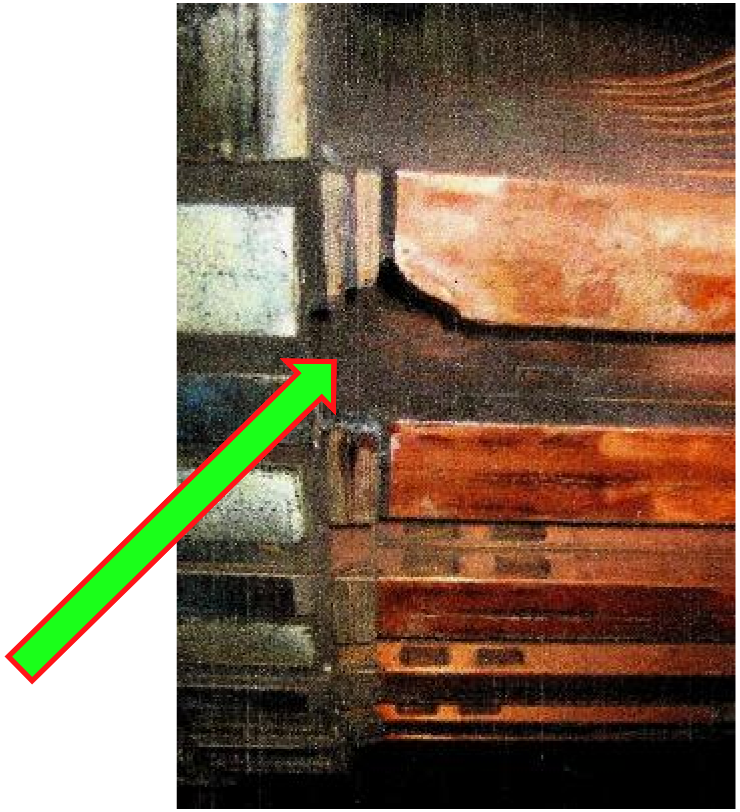
- Arc damage was also found on inboard pole coil Nos. 1 and 2 and outboard pole @ coil No. 1.

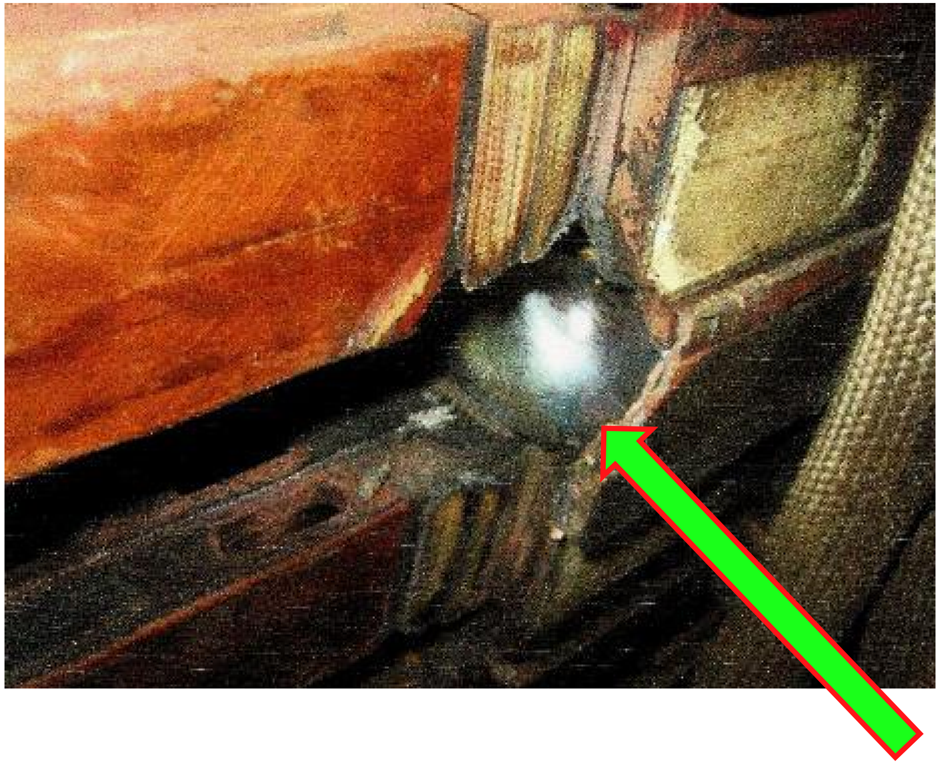
- Arc damage was found on a tooth on the forging.

Retaining ring inside surfaces



Severe arc fault metal loss & overheating damage – ring required replacement becoming long lead time item





Rotor coil and forging arc fault damage (exciter end)

Rotor Repair – off site

- The rotor weighed approximately 130,000 lbs. and was considered a “super load”.

- Regulations about transporting a super load are strict requiring special permits and caused delays.

- Rotor became the critical path in terms of reassembling the generator. (4 months & 5 days later)

- Locating a replacement retaining ring was critical long lead item

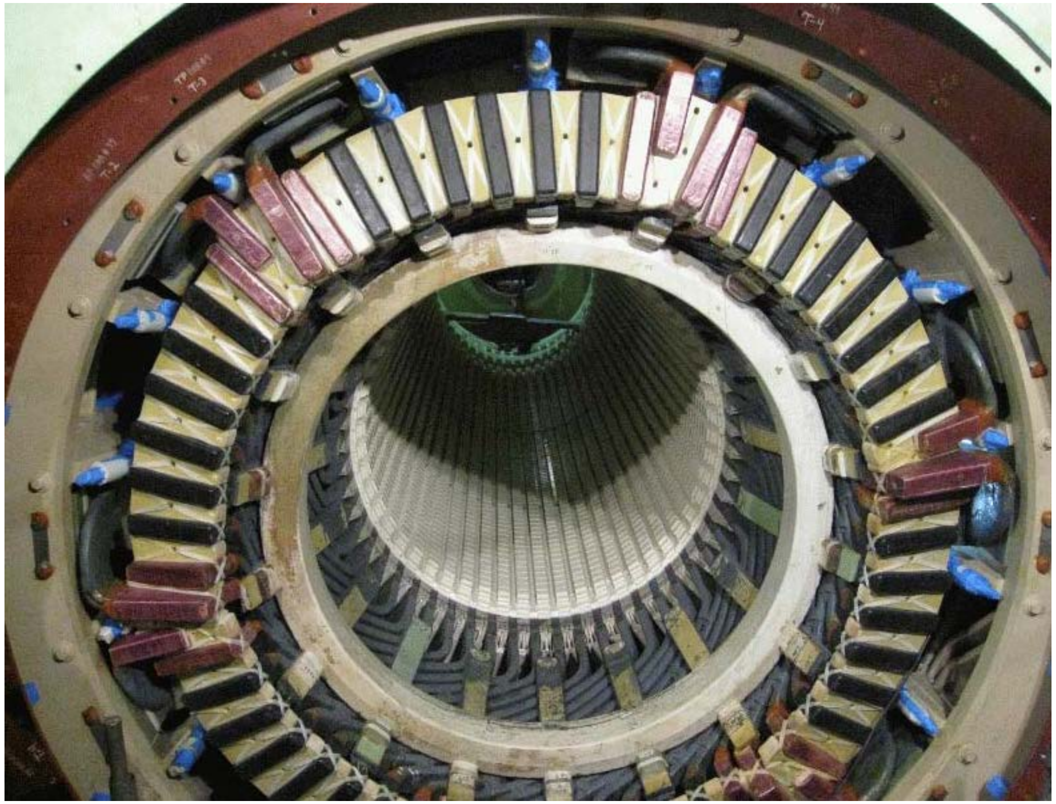
Case Study-Generator Failure - Cause

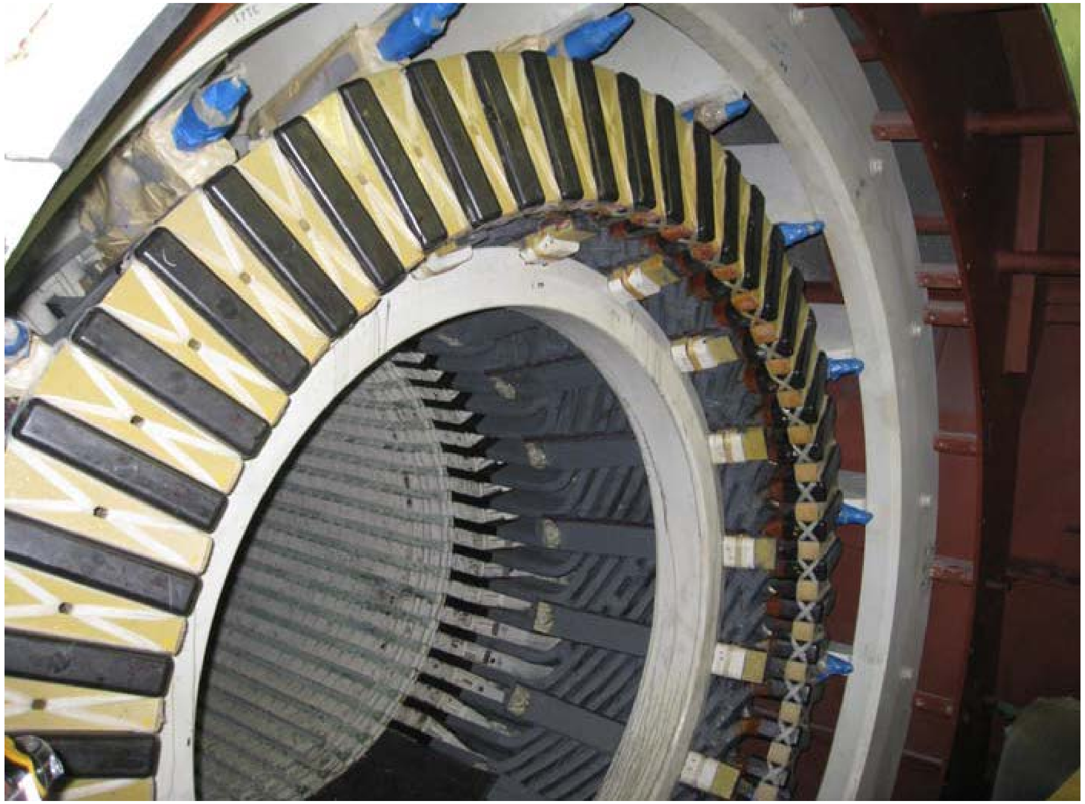
- Root Cause - High Cycle Fatigue due to 120 HZ resonance - induced end turn vibration damage

- Contributing Cause - Inferior strand to phase lead braze connections created crack initiation point and accelerated damage time line to failure.

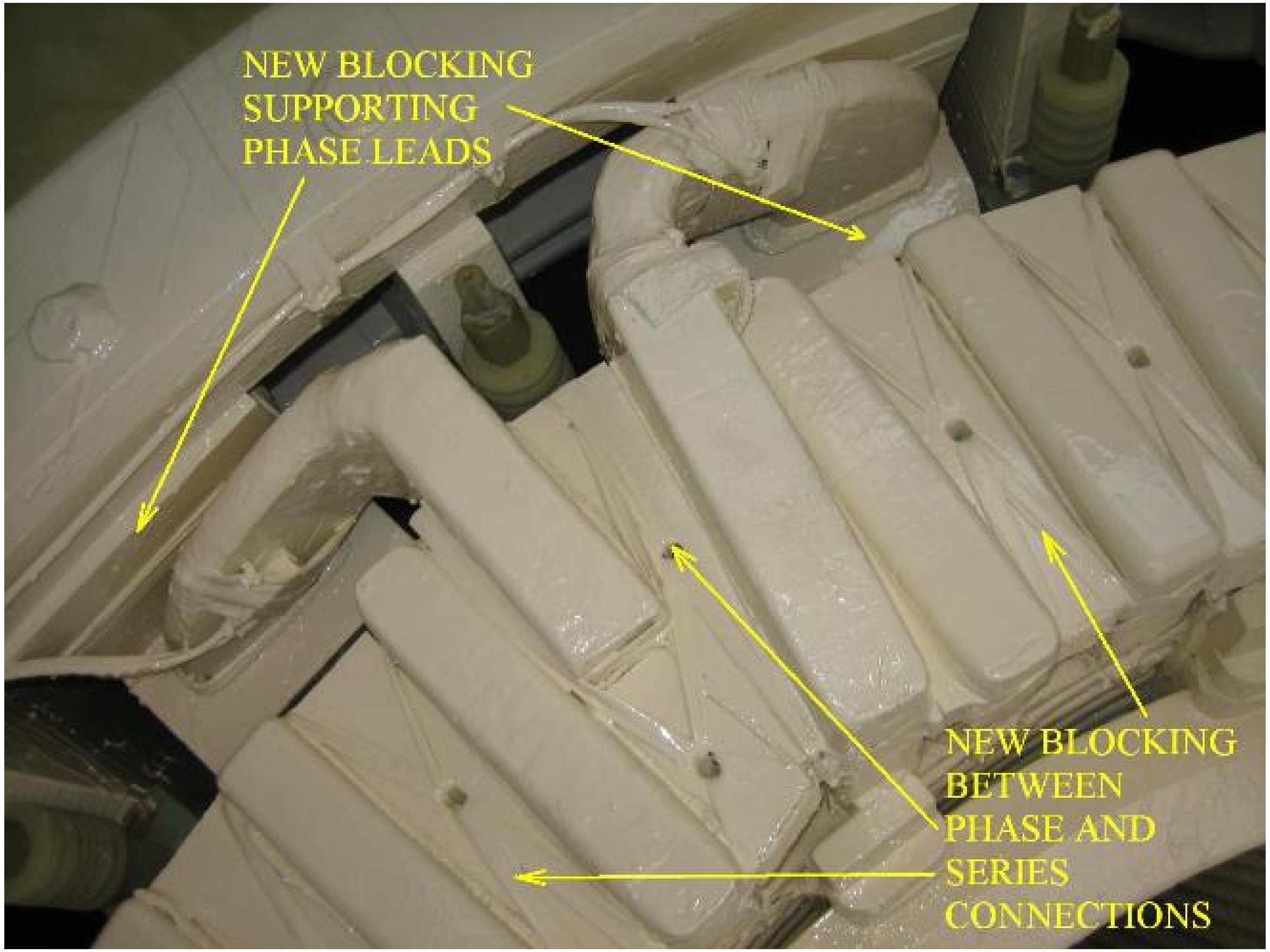
New phase lead connections
(H clip - more rugged design)

Original design





More robust end blocking design to reduce vibration

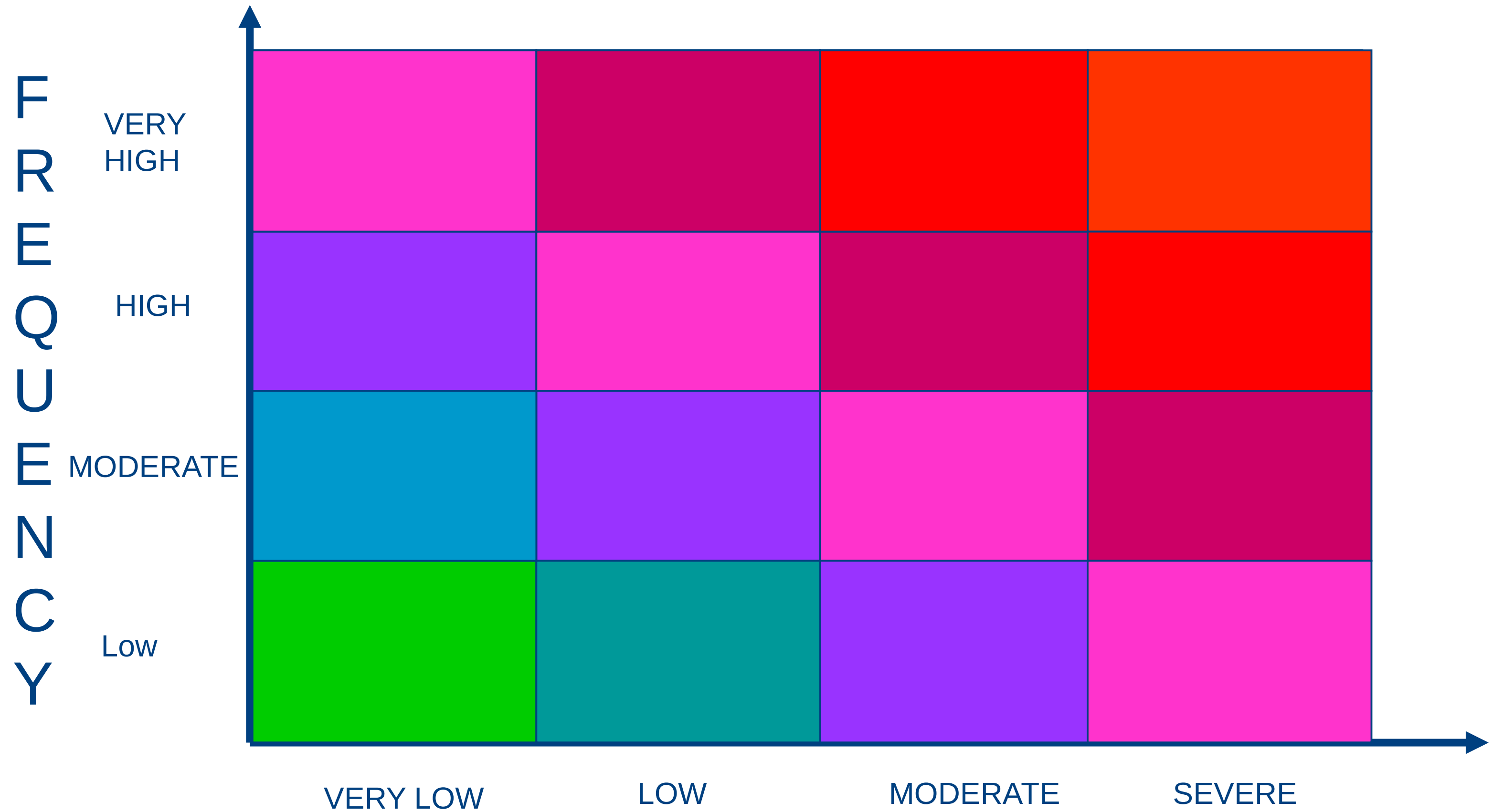

NEW BLOCKING
SUPPORTING
PHASE LEADS
NEW BLOCKING
BETWEEN
PHASE AND
SERIES
CONNECTIONS

Case Study-Generator Failure

- Lessons learned
  - Validated benefit of
    - Modal Analysis – “Bump Testing” phase lead connections & end winding during acceptance test
  - Improvements:
    - Phase lead braze connections improved
    - End winding support blocking improved and eliminated 120 HZ resonance
    - PD monitoring installed
    - Continuous fiber optic end winding vibration monitoring installed (18 exciter end and 6 on drive end)

Generator Failures-Risk Factors

- Environment
- Operating conditions
- Age/history
- Maintenance
- Operator training



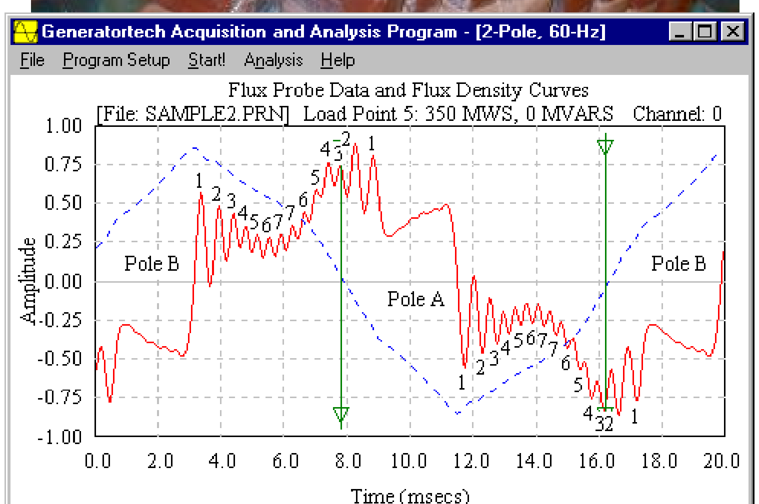
Operator training, contingency plan, safety device

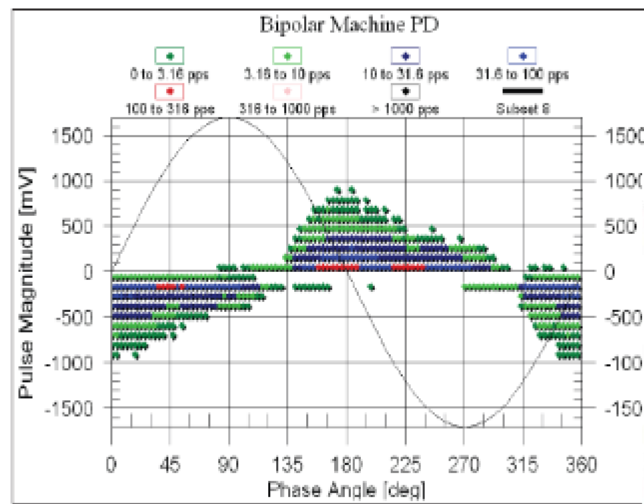
PM program

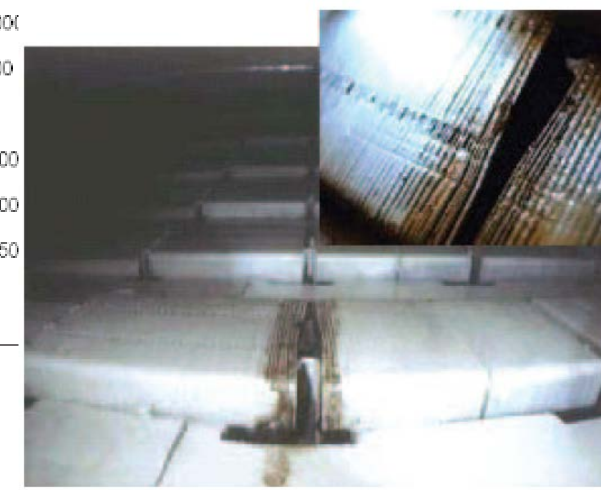
- Every generator is different
  - Design or Manufacturing Issues
  - Operating History
  - Base Load vs. Peaking
  - New versus Old
  - Etc…

Recent trend

Condition Based Approach vs Rotor Out Inspection







View of core damage taken with MAGIC robot

PM program

- FM Global recommends the following as appropriate:
  - Establish generator electrical testing frequency as well as test scope
  - Install on-line condition monitoring systems and consider robotic inspections
  - Closely manage findings (rate of degradation)
  - If test results or trends indicate high risk - plan remedial action & repairs before an in service failure.

PM program

Stator Winding and Core Test	Rotor inspection & test	On-line monitoring
Insulation resistance &polarization index	Insulation resistance/Polarization index(PI)	Partial discharge/EMI
Power factor	Impedance testing/RSO testing/open circuit test	Flux probe
Partial Discharge (power factor tip-up)	DC conductivity	Core monitor/RTD
Core loop test (EL-CID)	Visual inspection	End winding vibration
Semi-conductive coating resistance	NDE on rotor forging and fan	Hydrogen dew point monitor
Wedge tightness	NDE retaining ring	Shaft voltage/current
DC conductivity		
Capacitance mapping (water-cooled unit)		
Pressure/Vacuum decay test(water-cooled unit)		

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Generator Failures

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ELECTRIC AC GENERATORS

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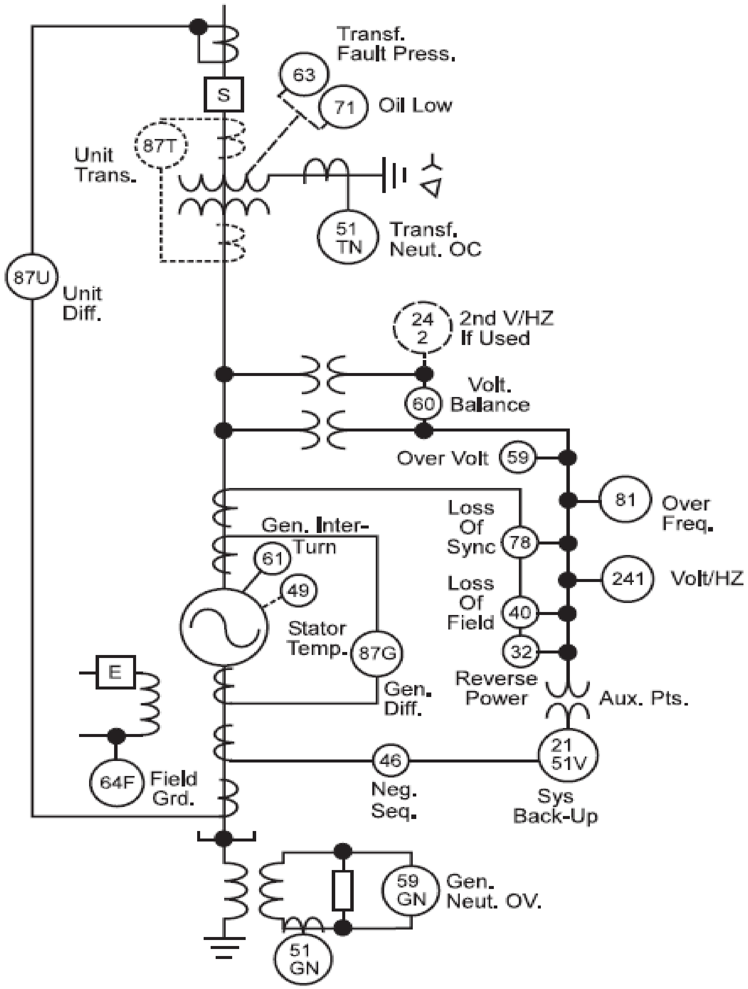
Electrical Protection: The Defense Line



- FM Global focus
  - Adequate Relay Protection

    (ANSI / IEEE C 37.102)
  - Operational As A System

    (RELAYS, DC BATTERIES, CONTROL WIRING etc.)
  - Operator Response/Training

Conclusion

- FM Global Loss Prevention Strategy for Generators
  - Verify Adequate Electrical Protection
  - Emphasize Operating Training
  - Promote Condition Based PM - online monitoring (PD, End winding vibration, flux probe etc.)

FM Global Data Sheet

5-12: Electrical AC Generators

5-19: Switchgear and Circuit Breakers

5-20: Electrical Testing

5-3: Hydro Power Station

7-79: Fire Protection for Gas Turbine and Electric Generators

7-101: Fire Protection for Steam Turbines and Electric Generators

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