Queen's University
Mechanical Engineering

Machine Condition Monitoring

and

Fault Diagnostics

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Course Overview

- Introduction to Machine Condition Monitoring and Condition Based Maintenance
- Basics of Mechanical Vibrations
- Vibration Transducers
- Vibration Signal Measurement and Display
- Machine Vibration Standards and Acceptance Limits (Condition Monitoring)
- Vibration Signal Frequency Analysis (FFT)

Course Overview

- Machinery Vibration Testing and Trouble Shooting
- Fault Diagnostics Based on Forcing Functions
- Fault Diagnostics Based on Specific Machine Components
- Fault Diagnostics Based on Specific Machine Types
- Automatic Diagnostic Techniques
- Non-Vibration Based Machine Condition Monitoring and Fault Diagnosis Methods

Current Topic

- Machinery Vibration Testing and Trouble Shooting
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- Automatic Diagnostic Techniques
- Non-Vibration Based Machine Condition Monitoring and Fault Diagnosis Methods

Non Vibration Based Techniques

- Costs versus Benefits
- Visual Monitoring
- Performance Monitoring
- Thermography (thermal imaging)
- Acoustic Emission

When deciding to employ MCMAD in whatever form consider: Costs versus Benefits

Purchase Prices & Training
Data Collection Costs
Data Storage/Retrieval Costs
Ease of Calibration, Repeatability
Degree of forewarning
Elimination of chronic faults
Improved customer relations
Provision of reliability and maintenance data
Improved competitiveness (less expensive, higher quality product)
Personnel viewpoint

Skill Level Needed
Maintenance Costs
Convenience of use
Range of uses
Unexpected failure avoidance
Improvements in design

Visual Monitoring Techniques

Direct methods:

- human senses
- microscopes, borescopes, stroboscopes.
- extremely sensitive
- often erratic
- requires long experience
- inexpensive (unless equipment is remote)
- difficult to pass on skill
- distractions are a factor
- basically a breakdown strategy

Visual Monitoring Techniques

Indirect methods:

- photographs, videos
- radiographs
- thermographs
- x-rays

Performance Monitoring Techniques

Techniques

- often already available
- requires experience
- variable sensitivity

Primary Parameters

- pressure vs. flow
- temperature differences
- cycle efficiencies
- compression ratios

Performance Monitoring Techniques

Secondary Performance Parameters

- mean effective pressure
- fuel consumption
- steam consumption
- exhaust gas composition
- charge air pressure

Performance Monitoring Techniques

Performance Monitoring Strategies

- Variation in production rate
- Variation in product quality
- Input/output ratios
- Power in
- Power out
- Efficiency

Temperature Monitoring

Applications

- lubricant condition
- insulation condition
- operating conditions
- relatively cheap
- on-line, continuous
- not for incipient damage

Thermography

Heat Transfer

- conduction - through a material
- convection - fluid/solid interface
  (forced and free modes)
- radiation - can be absorbed, emitted, transmitted and reflected

Temperature Monitoring

Techniques

- softening cones/wax/paint
- thermography
- bimetallic strips
- thermistors and thermocouples
- vapour pressure in bulbs
- mercury in glass

Advantages

- relatively inexpensive
- low skill levels required

Temperature Monitoring

Single point sensors

Thermography (thermal mapping)

IR sensors are now

- less expensive
- more reliable
- coupled with signal processing software

Main advantages

- non intrusive
- remote from source
- fast
- measures temperature at the surface

Thermography

Applications

- target in motion
- target is electrically charged (high voltage equipment)
- target fragile
- target small
- target remote
- target temperature changing quickly
- target destructive to thermocouples (jarring, burning, erosion)
- multiple measurements required in a short time

Thermography

Things to consider

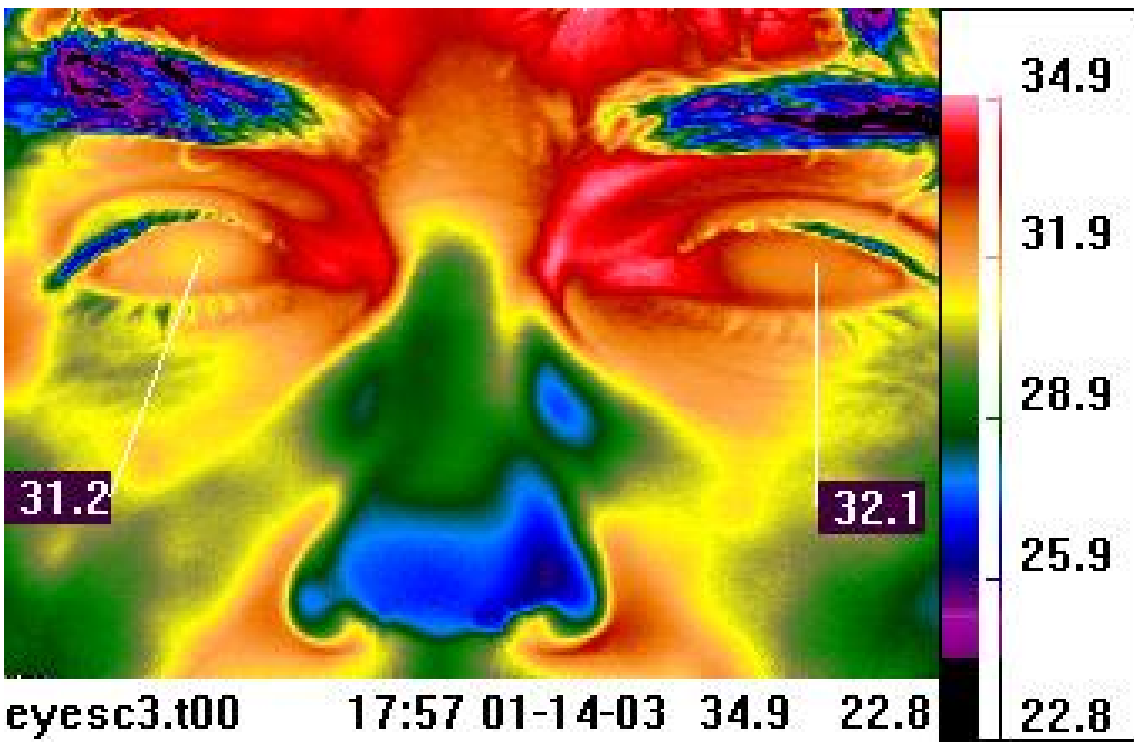
- material type
- surface conditions
- target size
- temperature range
- reflected source
- transmitted source
- ambient conditions (sun)
- calibration

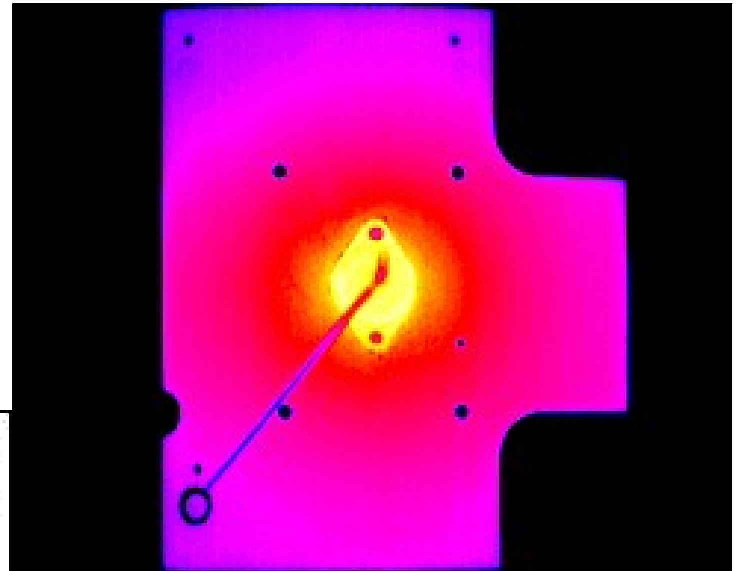
Thermography

Cameras

Thermography

Images

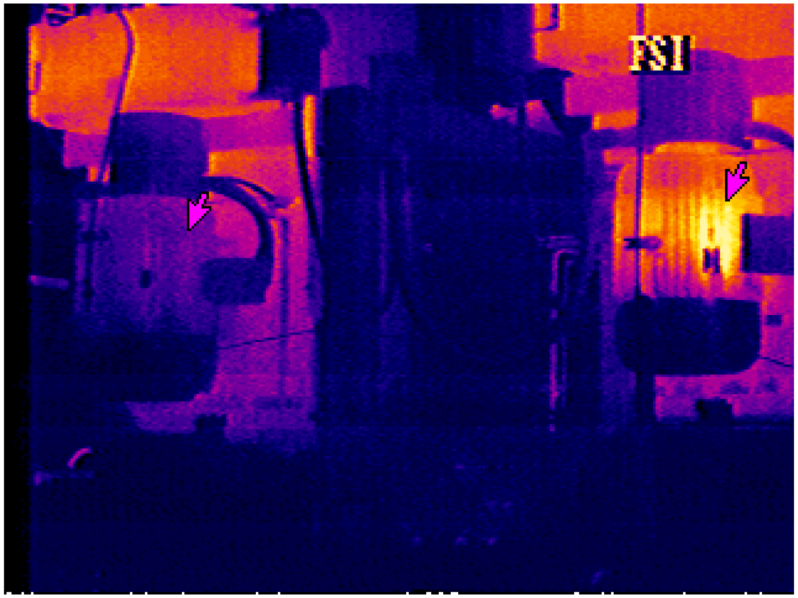


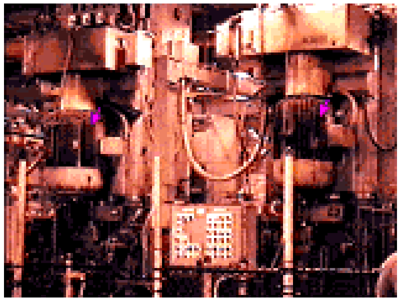


Heat sink with semiconductor mounted to it

Areas of Use

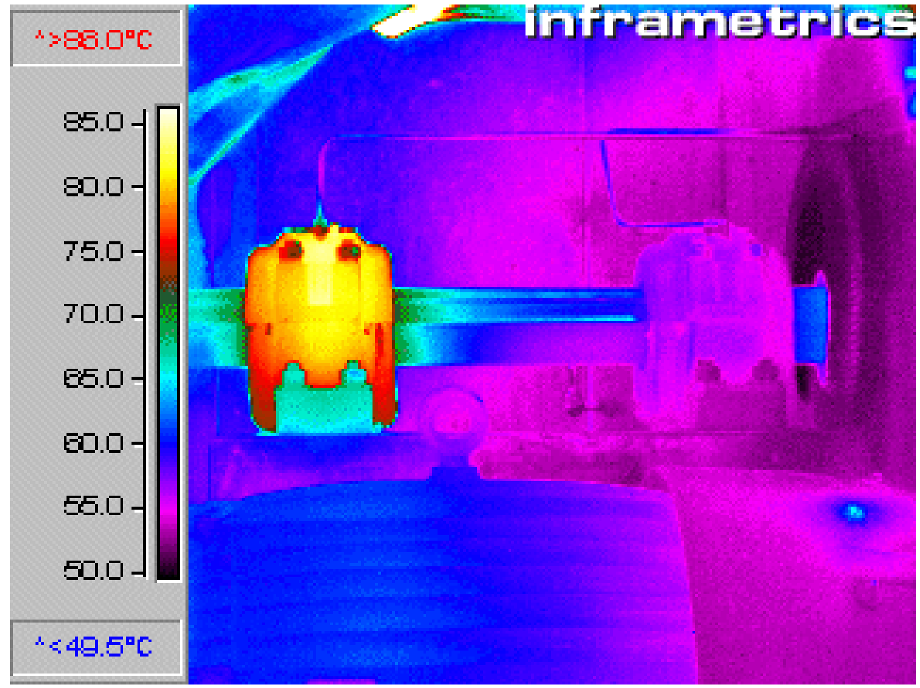
- Electric Motors

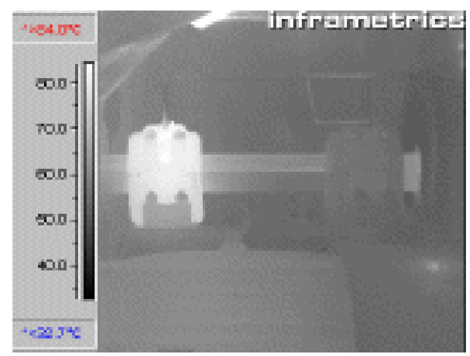




Areas of Use

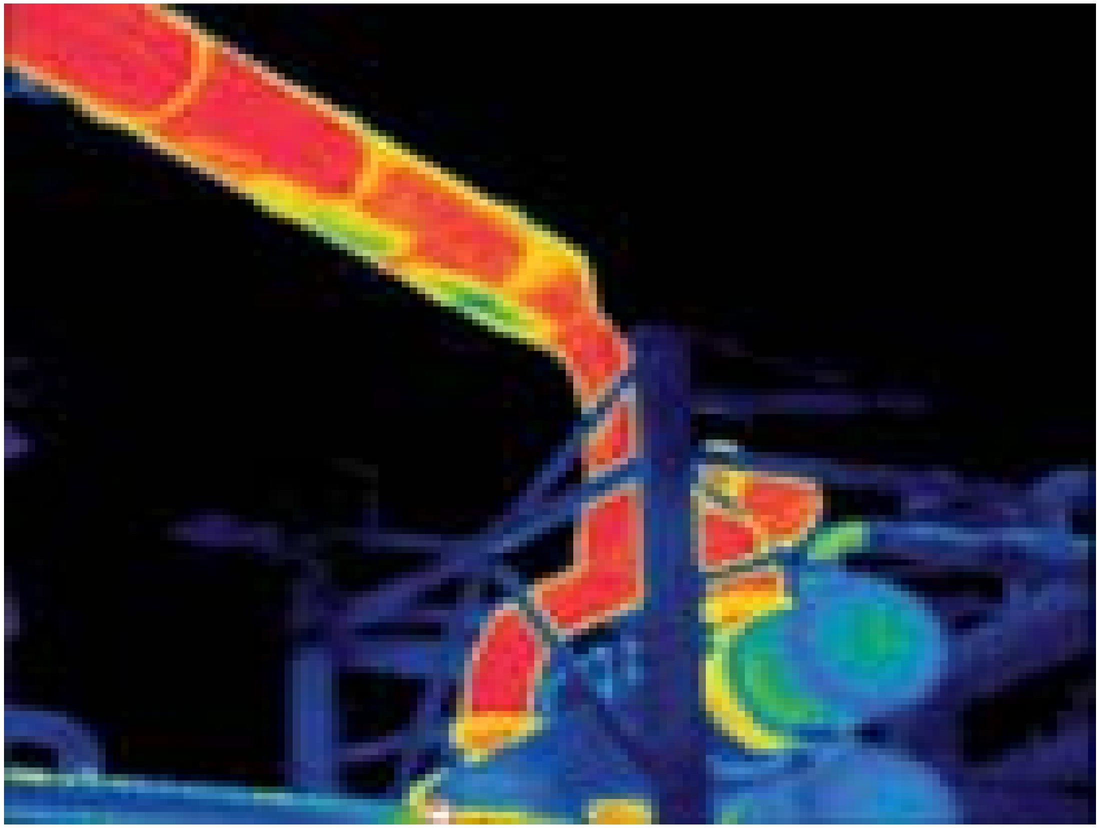
- Couplings, bearings
- shafts





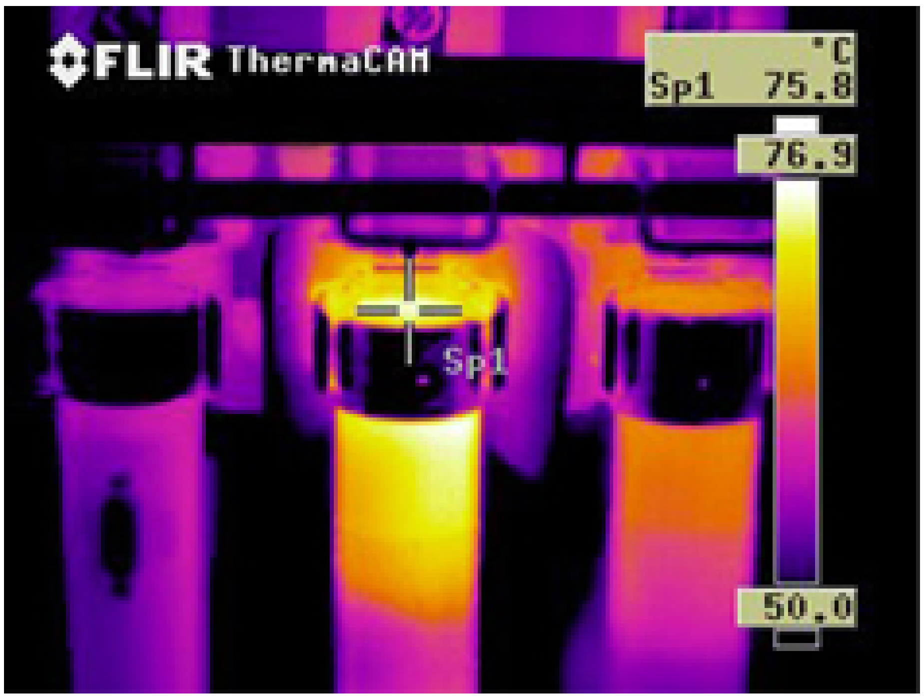
Areas of Use

- Refractory deterioration, Chimney stacks, Pipelines



Areas of Use

- Electrical equipment



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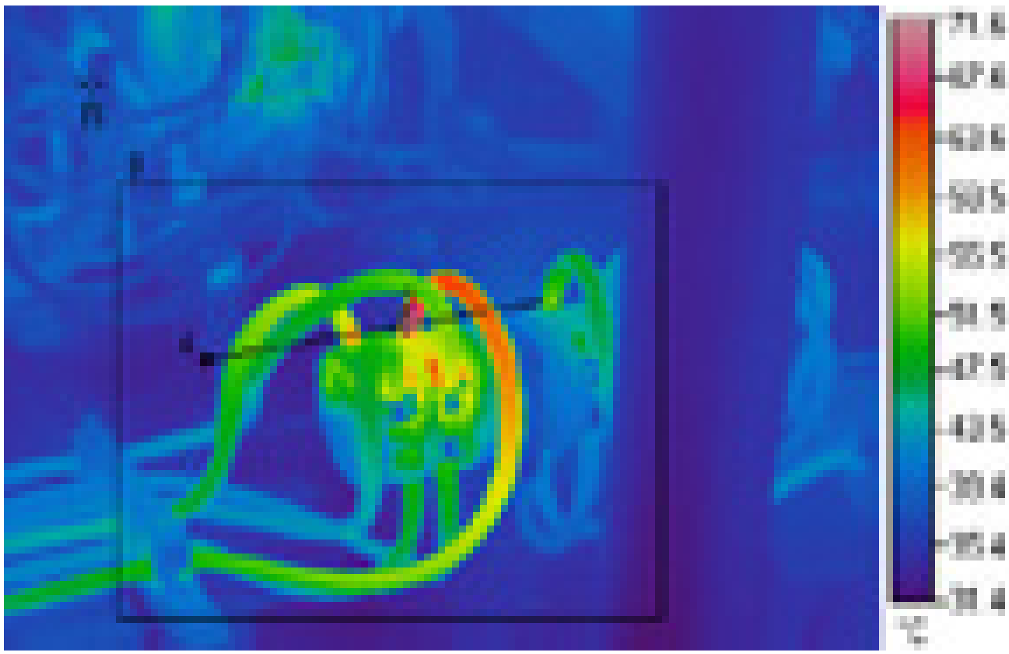


Images show poor connection on
Main Isolator Switch

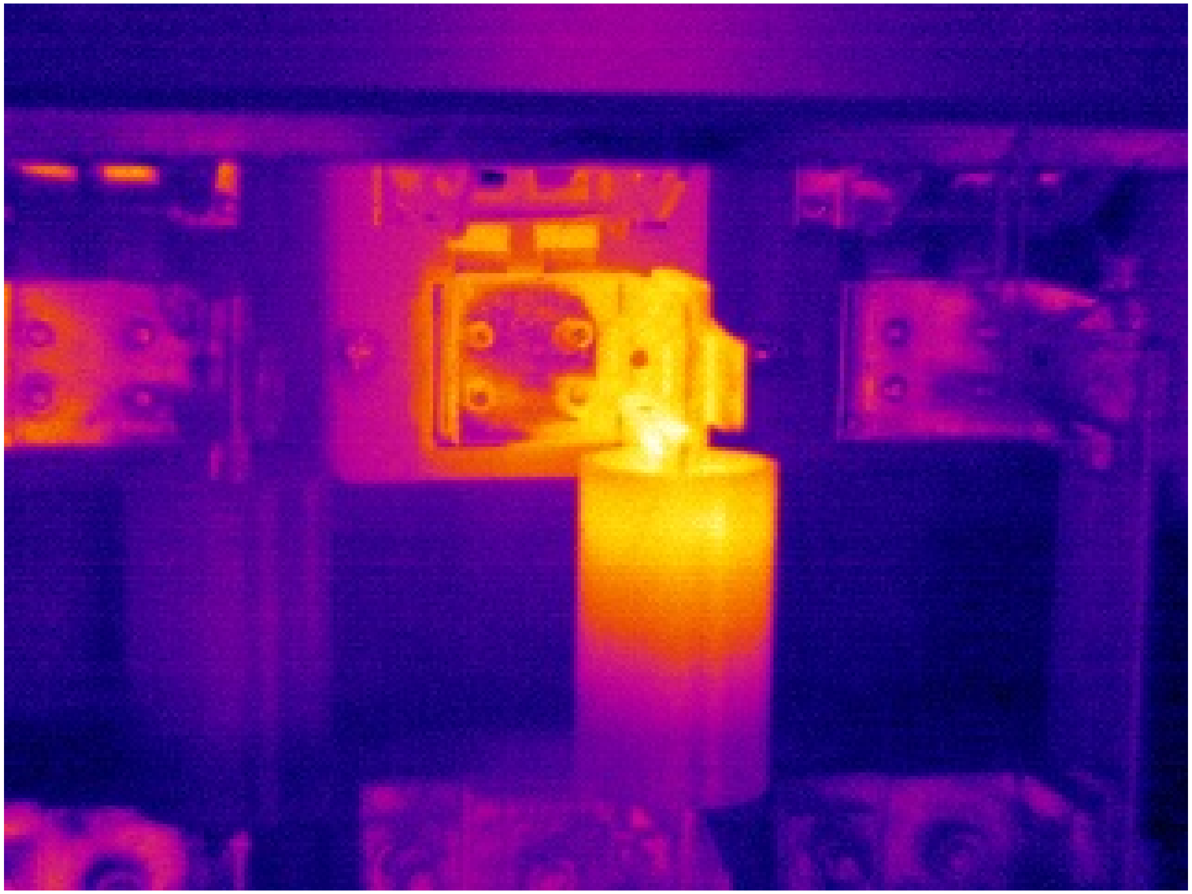
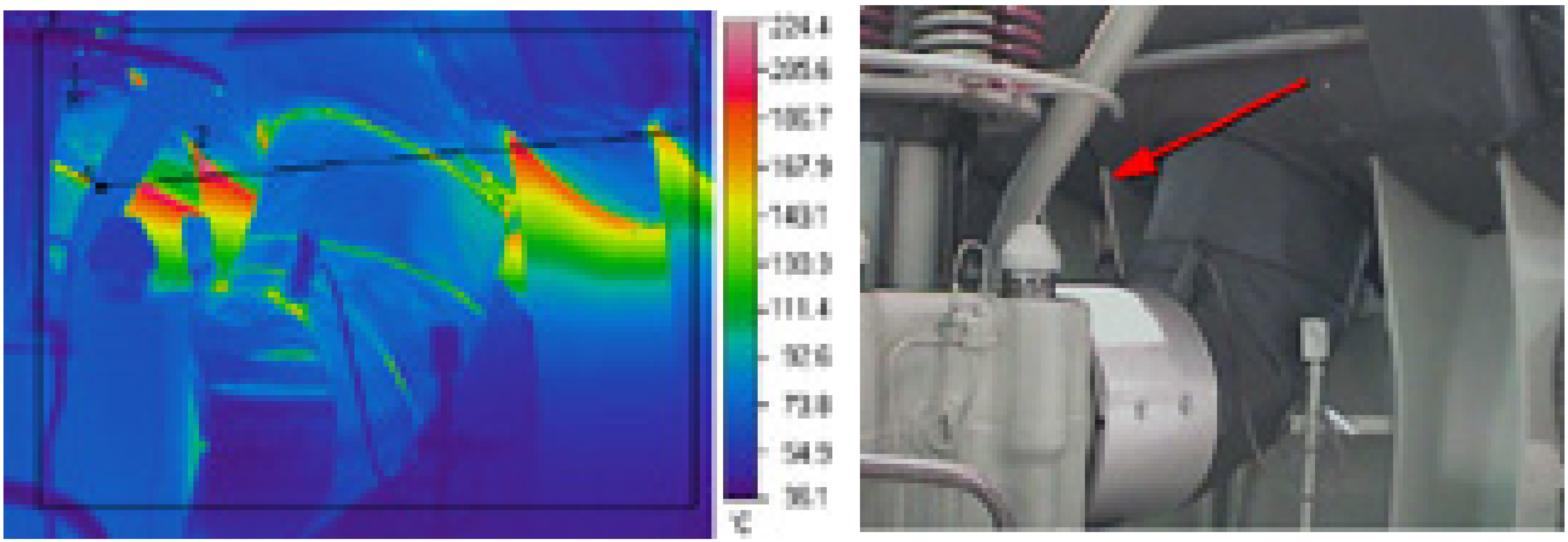


Image shows poor electrical connection

Areas of Use

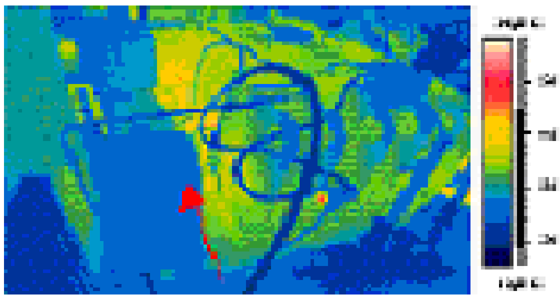
- Engines



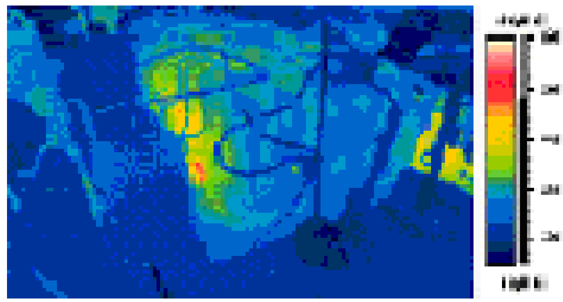
Ship Engine Exhaust

Case Study: Gearbox Monitoring

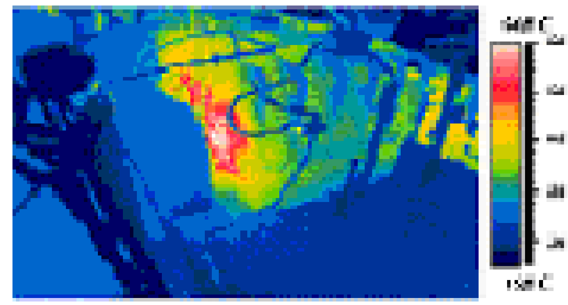
Week 1



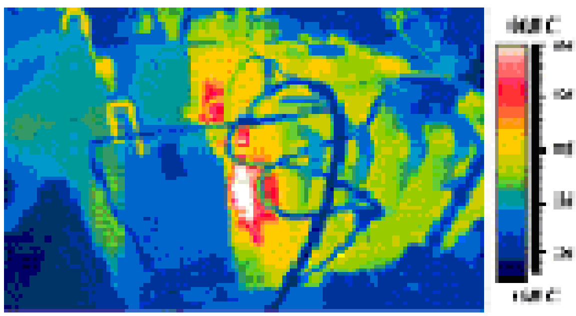
Week 2



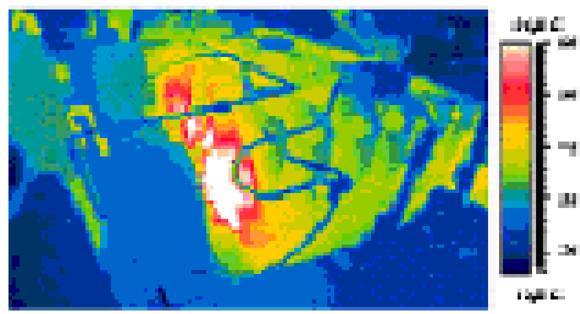
Week 3

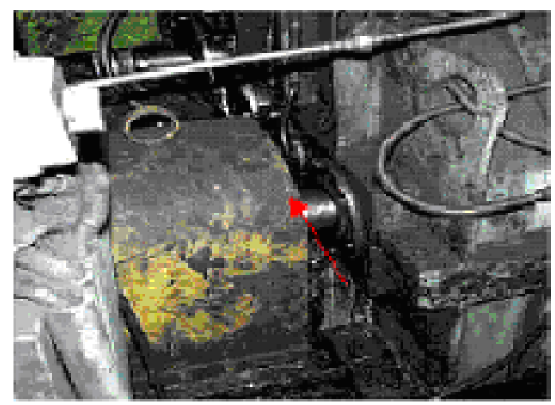


Week 4



Week 5





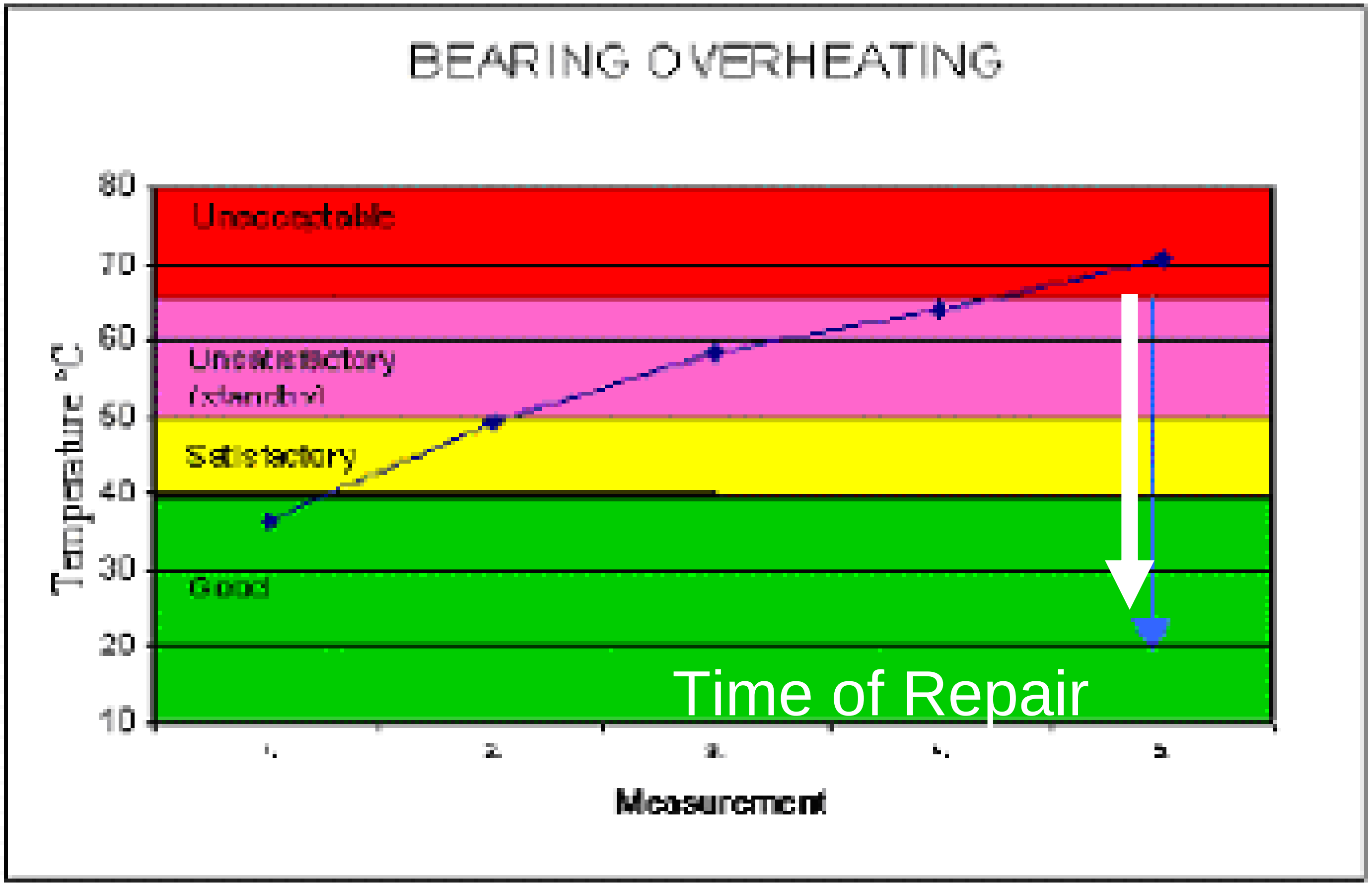
Case Study: Gearbox Monitoring

Severity Criteria for Mechanical Components

Category	Temperature (°C)	RMS result (mm/s)	ENV Result (gE)	Classification	Report: maintenance suggestion)
1	0-40	0 – 1,5	0 – 0,5	Good	Operation
2	40-50	1,5 – 3,5	0,5 – 1,0	Satisfactory	Conditional operation control
3	50-65	3,5 – 7,0	1,0 – 2,0	Unsatisfac-tory (standby)	As soon as possible check or fix
4	65 over	7,0 over	2,0 over	Unaccept-able	Immediately check and fix or stop

Case Study: Gearbox Monitoring

Temperature Plot

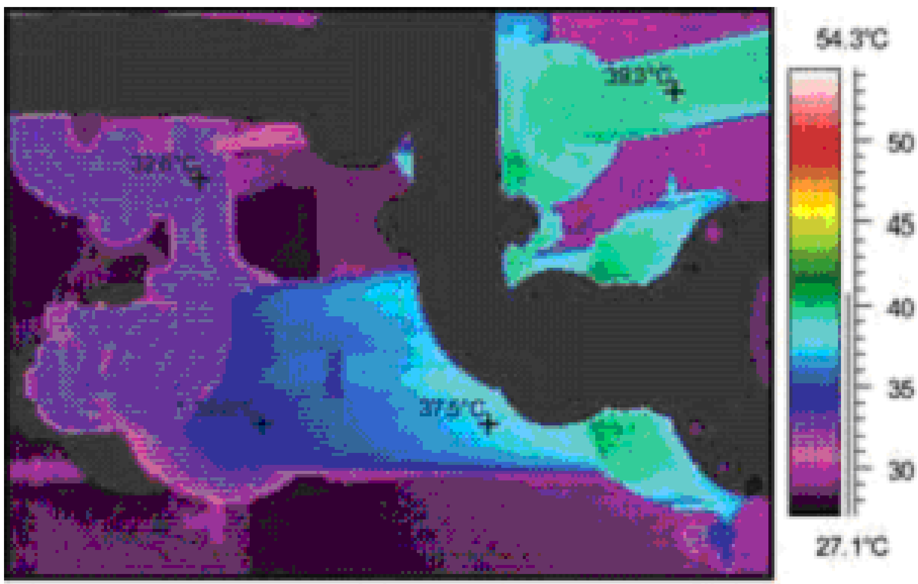


Photos from: Inframation, July, 2004

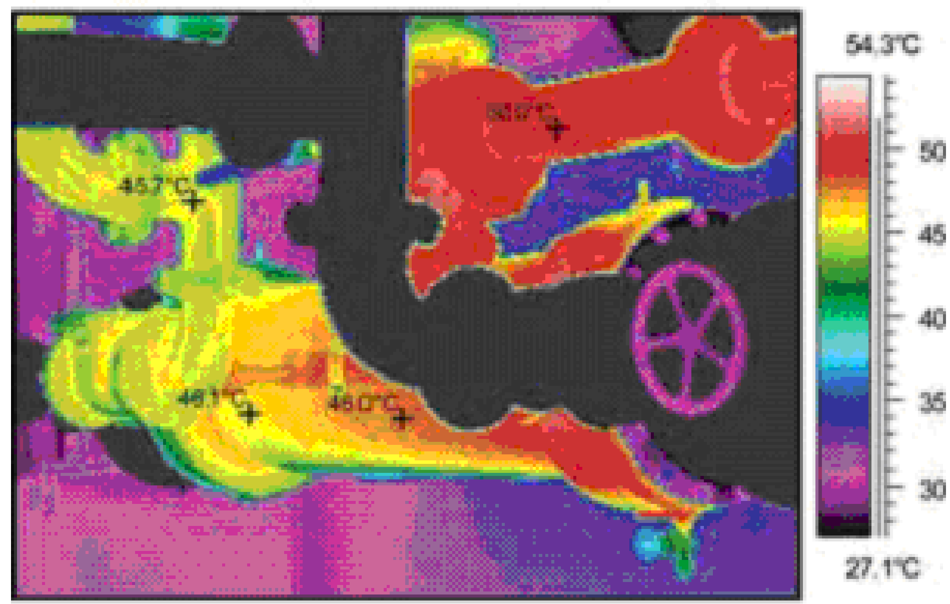
Another Example: Problem Identification

Turbine Oil Coolers

- Identical operating conditions
- Oil flow or water flow problem



Turbine No. 1



Turbine No. 2

Acoustic Emission

Acoustic Emission (AE)

- the elastic wave generated by the release of energy internally stored in a structure
- surface detection of internal stress save
- 100 – 2000kHz range

Two types

- continuous (steady state, random)
- burst (transient, single decaying sinusoids due to resonances in structure and/or transducer)

Acoustic Emission

AE Sources

Dislocation Movements

- displacement of a line imperfection through the crystal lattice of the structure
- very small amplitudes
- many sequentially may cause continuous signal

Phase Transformations

- when stressed, some steels undergo changes to their crystal lattice structure
- 100 times amplitude of dislocations
- single bursts

Acoustic Emission

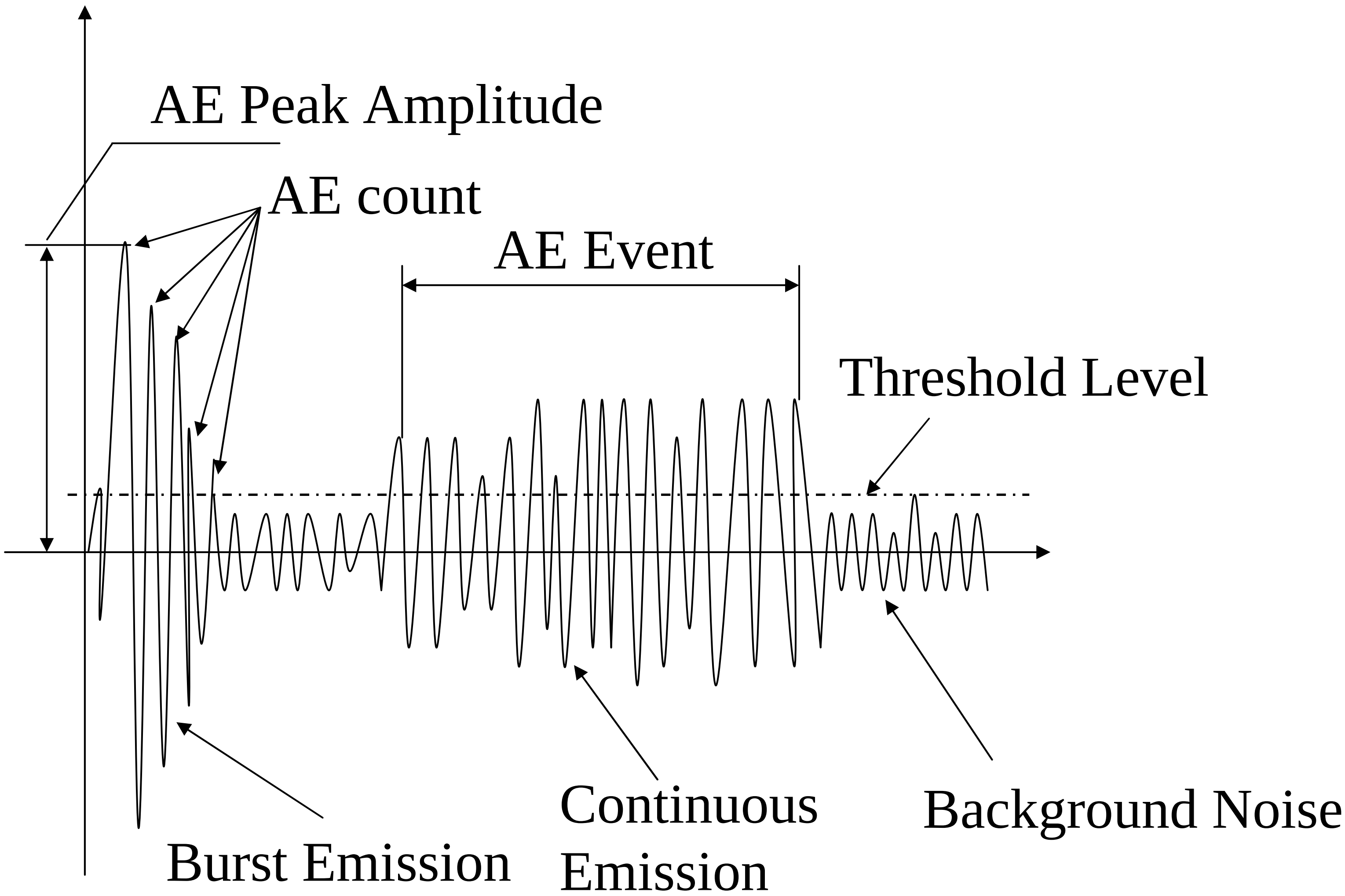
Crack Formation and Extension

- results in new surfaces being formed
- strain energy is released
- partly transformed into AE signal
- burst type signals, often at a high rate
- same amplitude as phase transformations

Friction in Cracks

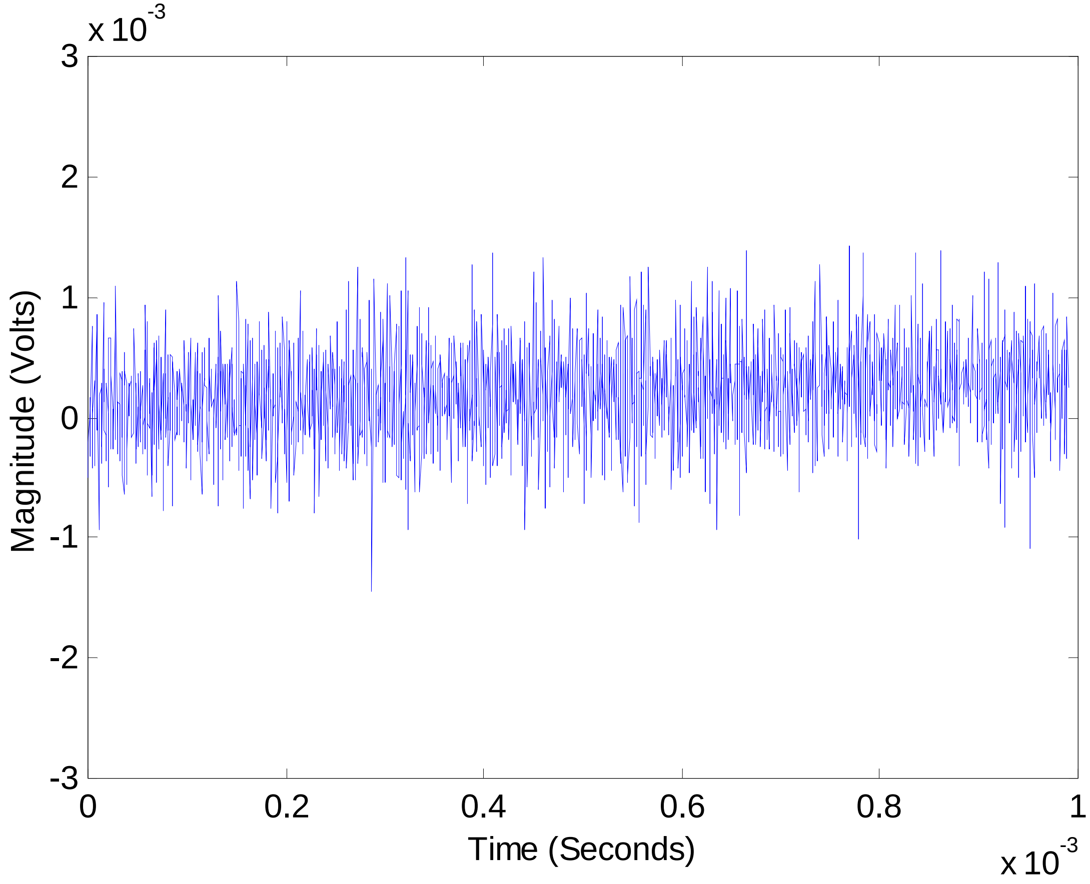
- sudden sliding releases burst type signals
- useful for detecting and locating cracks

Acoustic Emission



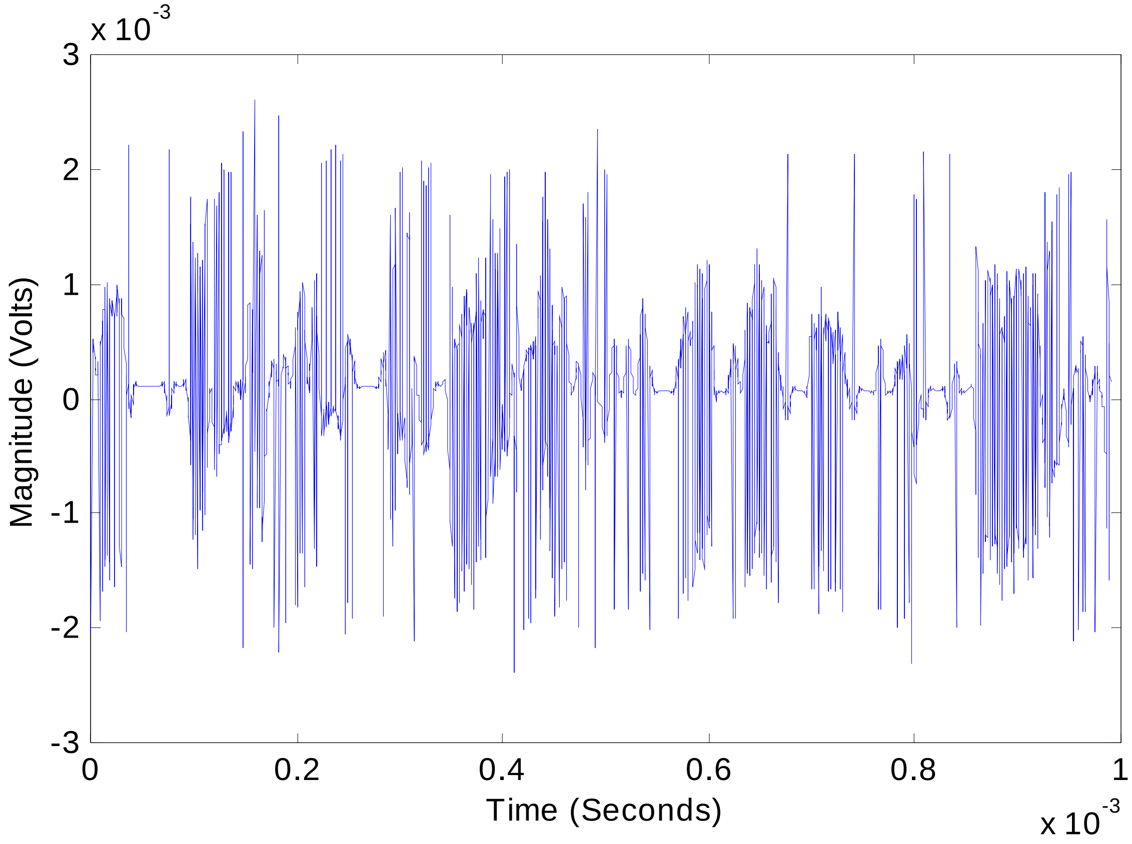
Acoustic Emission

Typical AE signal (continuous)

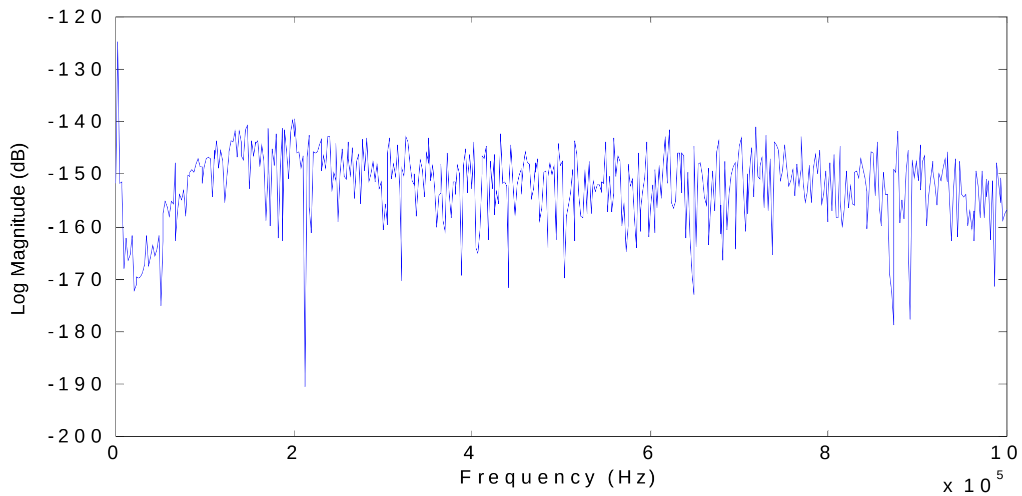


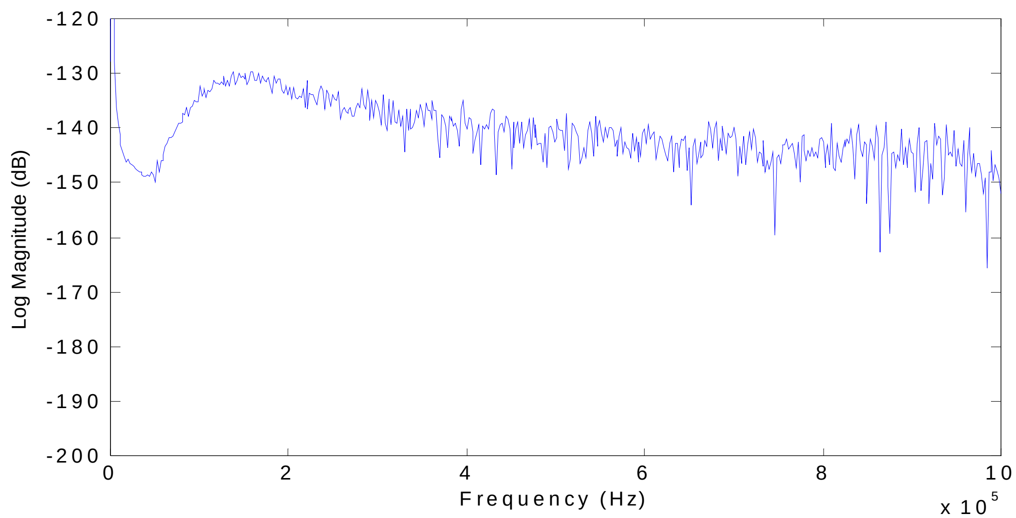
Acoustic Emission

Typical AE signal (burst)



Acoustic Emission





Frequency Spectra from AE signals

Poor lubrication – AE present

Good lubrication – no AE

Acoustic Emission

AE Propagation

- source strength and signal propagation are dependent on material properties, geometry and external strain rates.
- symmetrical waves in isotropic, homogenous, ideally elastic mediums
- surfaces and discontinuities on surfaces create reflections and surface waves
- transducers - special type and mounting
- 100 kHz to + 2 MHz frequency range
- broad band and narrow band (resonance type) accelerometers available (laser vibrometer)

Acoustic Emission

Signal Analysis

- high speed digital scope
- for continuous signals - RMS value (voltmeter)
- for burst signals - counter (total sum/rate)
- tape recorder (high speed)
- transient recorder (peak counter)
- frequency analysis
- amplitude distribution
- pulse area analysis

Acoustic Emission

Applications

- general plant machinery condition
- partial discharge detection and location
- crack location
- materials testing (AE signature prior to failure)

Acoustic Emission

Advantages

- remote detection and location of flaws
- covers entire structure
- quick set-up
- high sensitivity
- limited access required
- relatively low loads required
- can be used to forecast failure load

Acoustic Emission

Disadvantages

- structure must be loaded
- AE signals are highly material specific
- noise can be a problem (electrical & mechanical)
- limited location accuracy
- limited type of flaw information
- signal analysis interpretation may be difficult

Acoustic Emission

Acoustic Emission

Best Measurement

Locations