NATIONAL AERONAUTICS and SPACE ADMINISTRATION

Reliability Centered Building and Equipment Acceptance

June 12, 2000

Develop a NASA Building & Equipment Commissioning Training Course

Using the proposed NASA Building & Equipment Commissioning Guide, the NASA RCM Guide, SPECSINTACT PT&I work from Task Order 123, and other appropriate resources to develop a follow-on Construction of Facilities "Best Practices" type course for project/program managers, planners, designers, and construction management personnel:

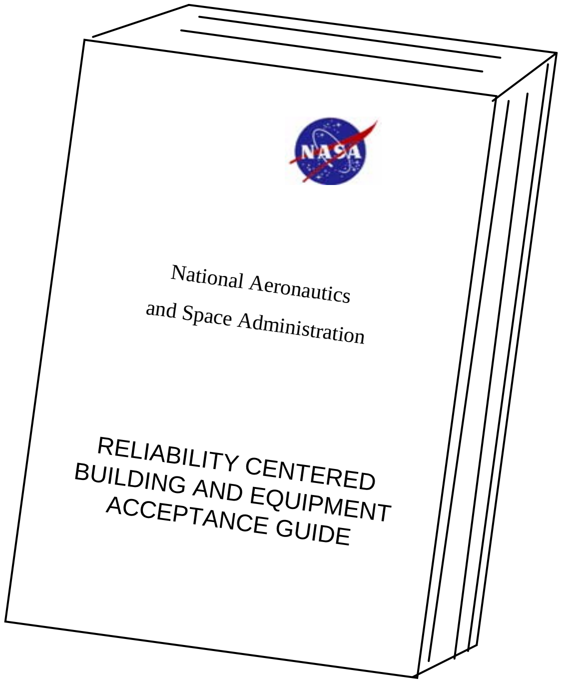
- **Show the relationship of building commissioning using PT&I techniques (by the building contractor)**
- **RCM and performance based maintenance practices to reduced facilities costs, increased reliability, and increased up-time.**
- **Include discussion of a feedback system between the O&M staff and designers for continuous design improvements through lessons learned.**
- **Investigate cooperation with existing CoF best practices training with the Construction Industry Institute.**

Expectations

- **Guidelines/Guidance in terms of design**
  - **Who, what, when, how, what type of equipment?**
- **See actual PT&I criteria**
  - **Specifications**
- **How does M&O communicate with design?**
- **Relationship cost versus savings**
  - **Return on Investment**
- **Is there a real cost savings?**
- **What is the time (how long) to implement?**
- **When/how to write SOW to get contractors on-board?**

Use of Guide

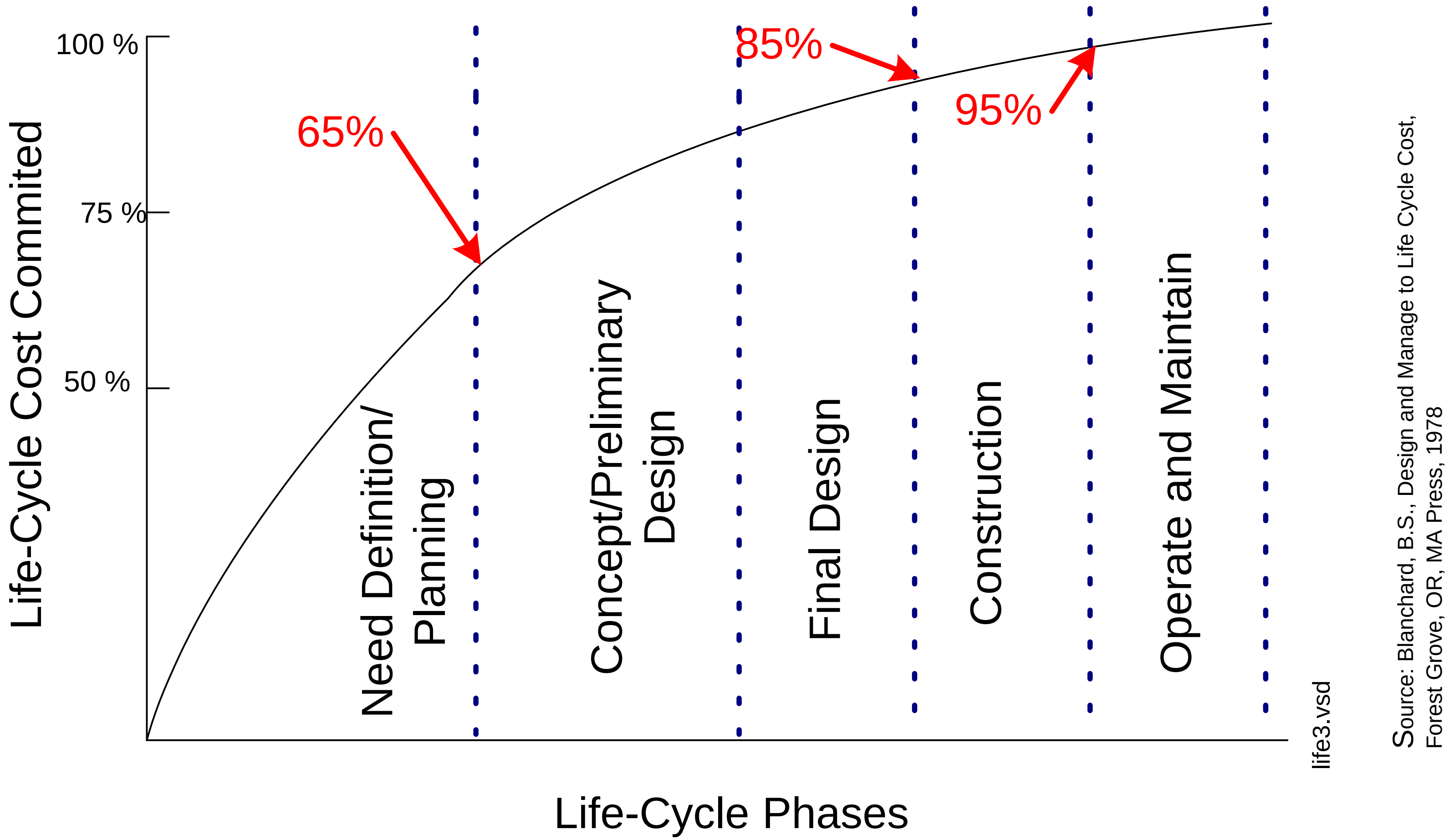
- **Technical Reference**
- **Detect Latent Manufacturing and Installation Defects**
- **Part of Contractor QC Program**
- **NASA Application - i.e. Supplements Existing Commissioning Standards**



This guide should be used in conjunction with The NASA Reliability Centered Maintenance Guide for Facilities and Collateral Equipment.

Summary Of Contents

Life-Cycle Cost Commitment



Planning - Design Phase

- 85% of Life Cycle Cost Determined Here
- Must Consider
  - Safety
  - Accessibility
- Benefits
  - Maintainability
    - 10-10,000 X expensive to retrofit maintainability after construction
  - Improved Reliability
    - Discover impending failure before functional failure and additional collateral damage
  - Reduced Life Cycle Costs
    - Fewer Maintenance Actions & Greater Efficiency

Construction Phase

- **Contractor**
  - **Perform Acceptance Testing (PT&I and Traditional) IAW QC Plan**
  - **Ensure meets spec & establish baselines**
- **Construction Manager**
  - **Ensure PT&I test points & acceptance criteria shown**
  - **Proper test equipment, skills, procedures**
  - **Interim testing performed, OK and documented**
  - **Acceptance testing within tolerances**
  - **Oversee testing**
  - **O&M staff trained**
  - **Maintenance Procedures Prepared**
  - **Nameplate, baseline, etc. data collected & documented**

Commissioning Scope

- Verify Installation IAW Design
- Verify Manufacturer Observation and Approval
- Verify Adjusting, Balancing and Testing
- Assemble Record Drawings
- Assemble & Deliver O&M Manuals
- Verify Equipment Performance
- Train Owners & Users
- Document Warranty Start/End
- Assemble Records of Code Compliance
- Monitor & Enforce Equipment Accessibility
- Identify, Document, Report all Deficiencies

Building Construction: Pre-RCM

- At JSC, 92% of the rotating equipment was found to be improperly installed - primarily balance and alignment.
  - Similar problems were encountered at Goddard Space Flight Center and Kennedy Space Center
- National Security Agency (NSA) discovered 100% of their new rotating equipment had defects
- Department of State found that greater than 80% of the rotating equipment in 3 New Office Buildings had installed defects
- P.T. Badak and Antibioticos, S.p.A experienced significant problems with new construction projects.
- In all cases:
  - the specifications did not address the current best reliability practices.
  - commissioning practices had not been updated to reflect the changes in system/component testing capabilities

Sources:

Report on RCM Implementation Plan, Phase 3, Johnson Space Center, 1994

Reliability Assessment Report, Goddard Space Flight Center, 1997

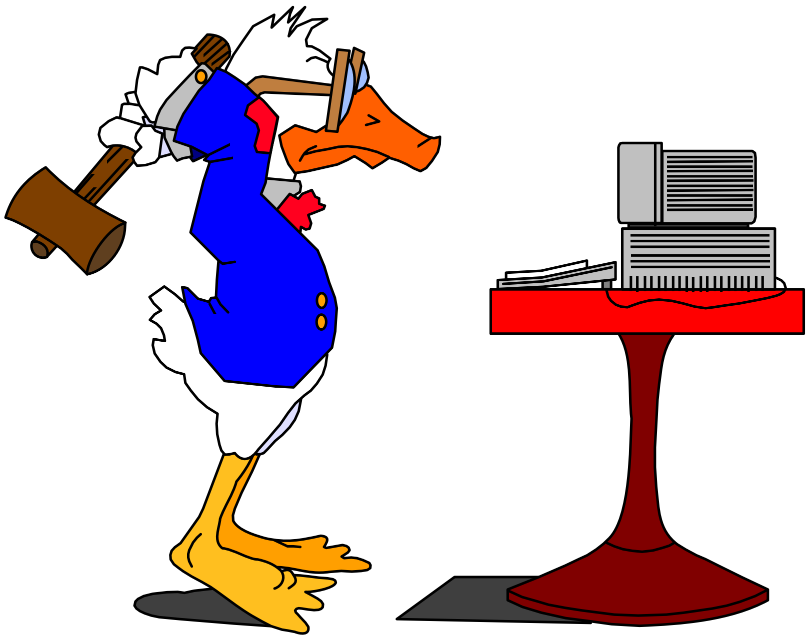
Reliability Maintenance Assessment Report: Antibioticos, S.p.A (Settimo), 1994

Reliability Assessment P.T. Badak, 1996

Why RCM and Commissioning...

Must know system:

- Function in quantifiable terms
- Failure modes
- Consequences of failure (criticality)



Otherwise you do not know:

- What to test
- Acceptance criteria for the test
- Cost effectiveness of testing
- What level of performance is acceptable to both the builder and the owner

The traditional approach is that if it is new it is good. How about new cars, houses, computers, and people?

Reliability Goals and Logic

RCM Goals

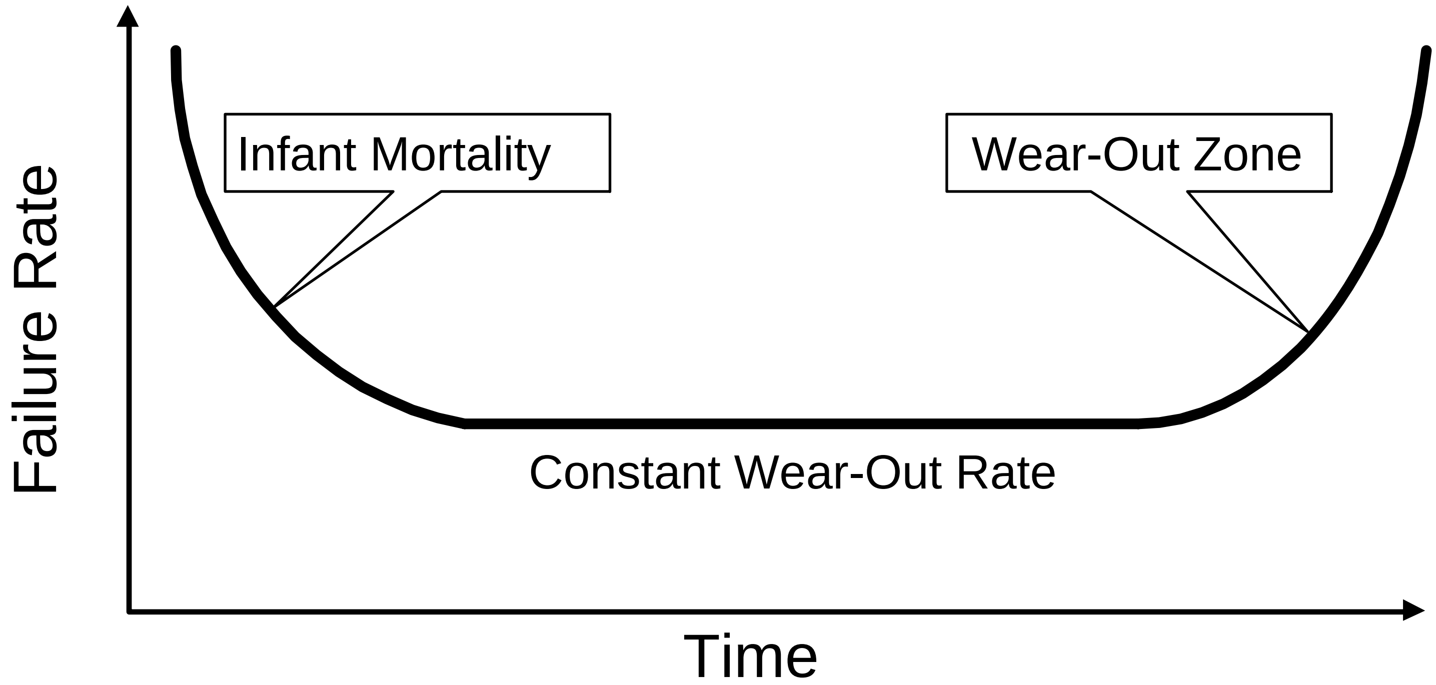
- **Ensure realization of inherent safety and reliability of the equipment**
- **Restore equipment to required levels when deterioration occurs**
- **Obtain the information necessary for design improvements where inherent reliability is insufficient**
- **Accomplish these goals at a minimum total life cycle cost**

RCM Logic

- **Determine the function of the system/component**
- **Define what is a functional failure**
- **Evaluate the consequences of failure**
- **Assign a maintenance task to prevent the failure**

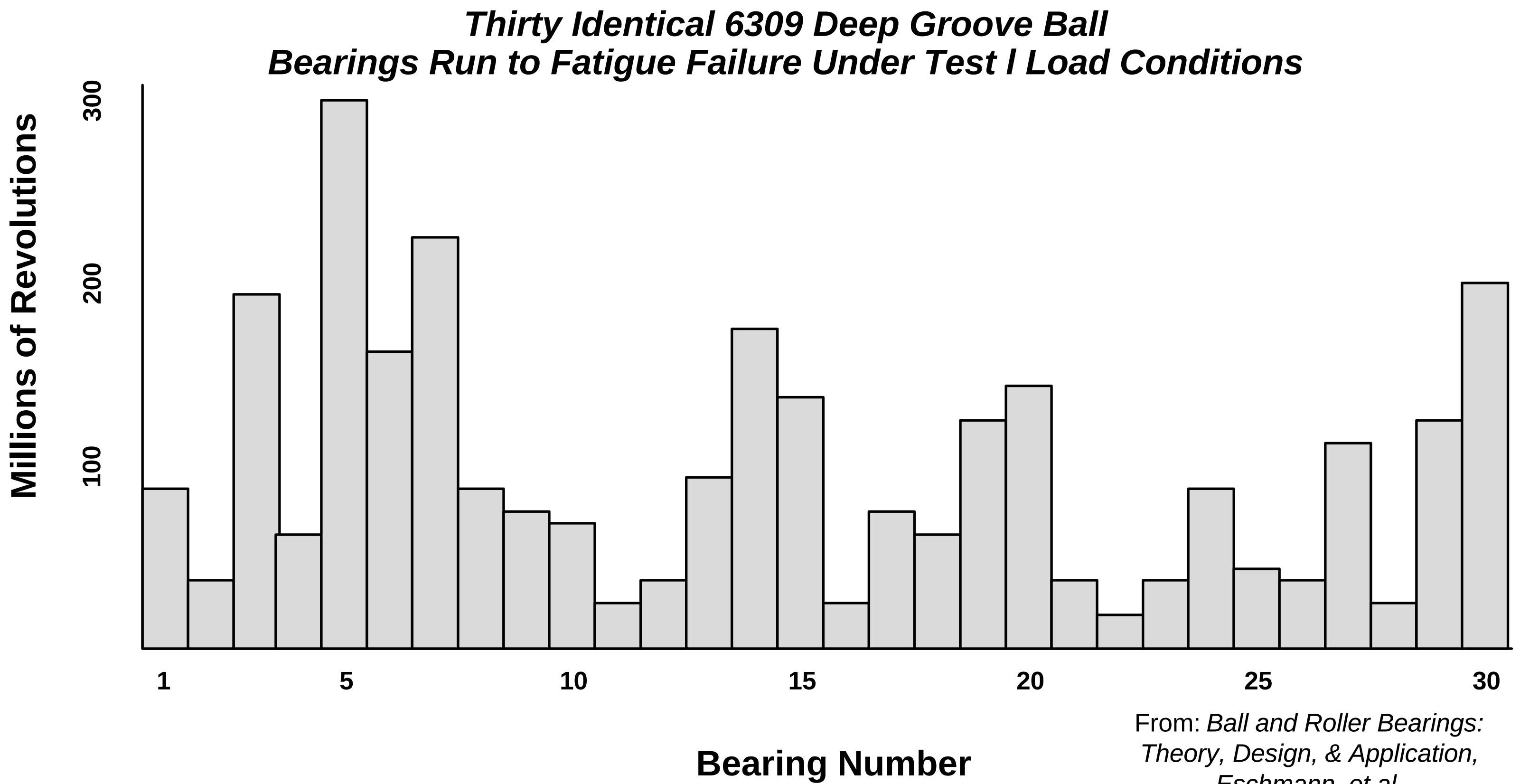
The Perception of Equipment Life is...

Standard "Bathtub" Curve



The traditional approach to maintenance is based on a misunderstanding of failure distributions. Only a small percentage of equipment follows this curve

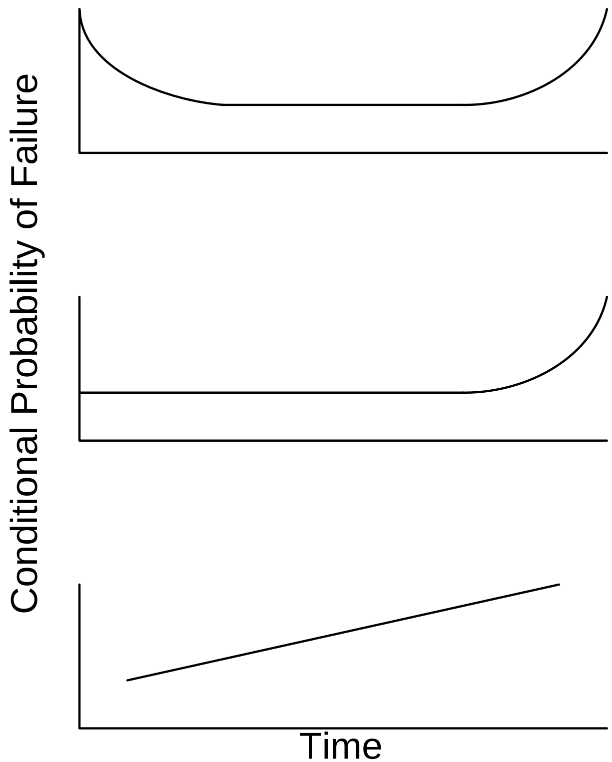
At Times, We Assume the Life of Components is Known



From: *Ball and Roller Bearings: Theory, Design, & Application, Eschmann, et al*
John Wiley & Sons. 1985

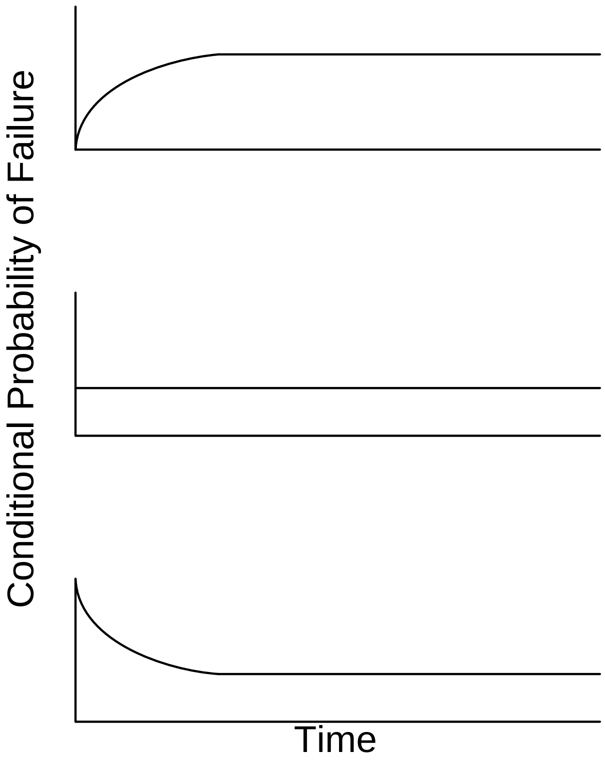
Random failure is the dominant failure distribution

Age Related Failure Curves



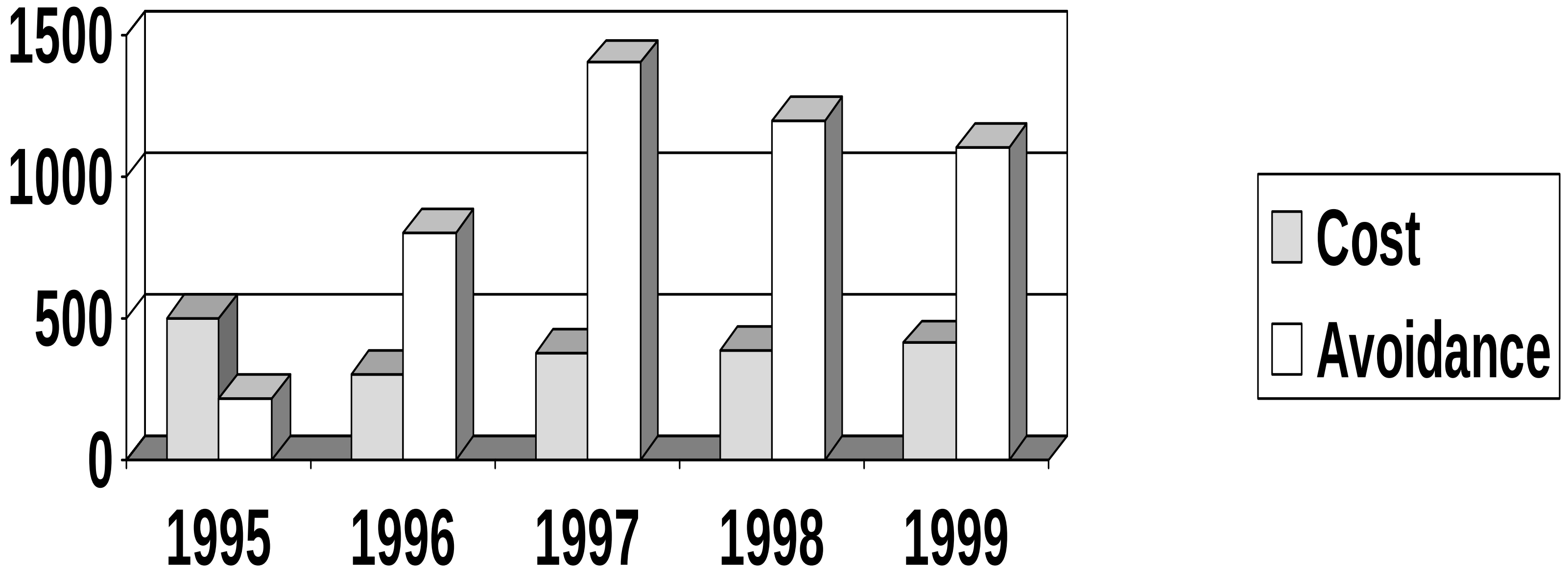
UAL 1968	BROMBERG 1973	U.S. NAVY 1982
4%	3%	3%
2%	1%	17%
5%	4%	3%

Random Failure Curves



UAL 1968	BROMBERG 1973	U.S. NAVY 1982
7%	11%	6%
14%	15%	42%
68%	66%	29%

GRC PT&I Benefit/Cost Analysis



NASA had greater than 3,000 PT&I finds agency-wide.

Failure Definitions

Failure Definitions:

- **A failure is an unsatisfactory condition. It may be catastrophic or merely out-of-tolerance.**
- **A functional failure is the inability of an item or system to meet a specified performance standard.**
- **A potential failure is an identifiable and quantifiable physical condition which indicates a functional failure is imminent.**

What about hidden failures?

Consequences Of Functional Failure

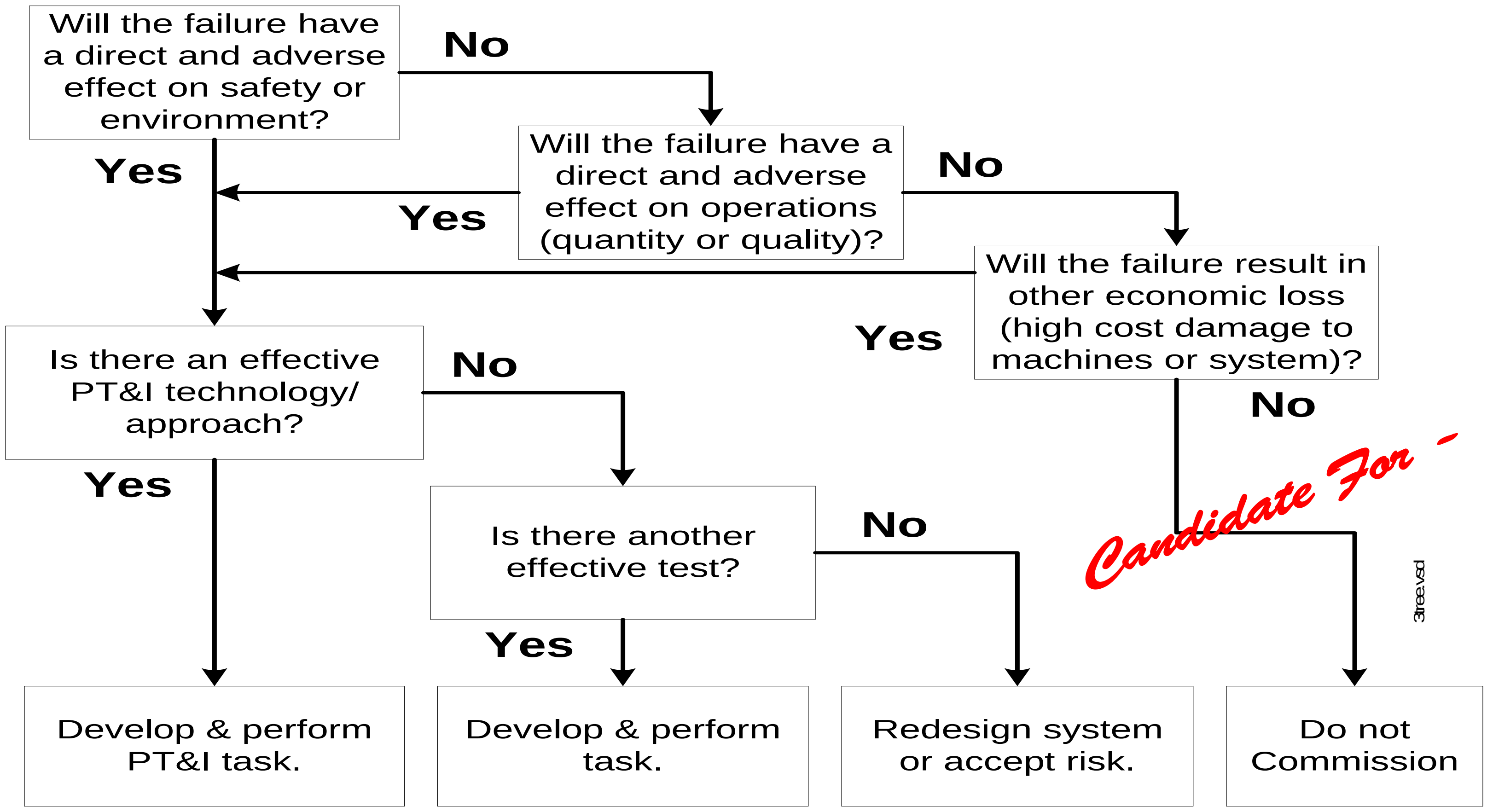
- Production or Mission Impact
  - Quantity
  - Quality
- Environmental, Health or Safety
- Life Cycle Cost
- Morale

Failure Modes And Effects Analysis (FMEA)

- **A failure analysis conducted in the design phase of an equipment or system; also used as a tool for analysis in Reliability Centered Maintenance (RCM).**
- **The FMEA contains:**
  - **Description of Failure Modes**
  - **Cause and Effects of failure**
  - **Probability of Failure**
  - **Criticality of Failure**
  - **Corrective/Preventive Measures**

FMEA is the key to a successful Commissioning Program.

RCM Logic Tree



Failure Mode & Effects Worksheet

Area: Identify Plant Area or Process
System: System Name
FMEA Number: If Used
Team Members: Who prepared this FMEA

Date FMEA Started:

Date FMEA Completed:

fmea1.vsd

Control Number	Name & Function/ Performance Requirement	Potential Failure Mode	Potential Failure Effects	Crit	Prob	MA Code	Maintenance Approach	Remarks/Continue

Sample Failure Modes and Effects Data Sheet

			AREA: Central Utilities			TEAM: Utilities		PAGE 1 0F 1
			SYSTEM: Chilled Water			START:		DATE PRINTED: 3/24/99
			FMEA NO. CW001			END:		
CONTROL NUMBER	NAME & FUNCTION	FAILURE MODE	FAILURE EFFECT	CRIT	PROB	MA CODE	MAINTENANCE ACTION	COMMENTS
CW1	CWP MOTOR 101	SEIZED BEARING	LOSS OF FLOW	8	4	V1	NARROWBAND VIBRATION	QUARTERLY
		STATOR INSUL.	LOSS OF FLOW	8	3	E1	MEGGER	BIENNIAL
		ROTOR BAR	LOW FLOW	4	2	E2	MOTOR CIRCUIT EVALUATION	ANNUAL
			LOSS OF FLOW	8	2			

PT&I and Acceptance Testing

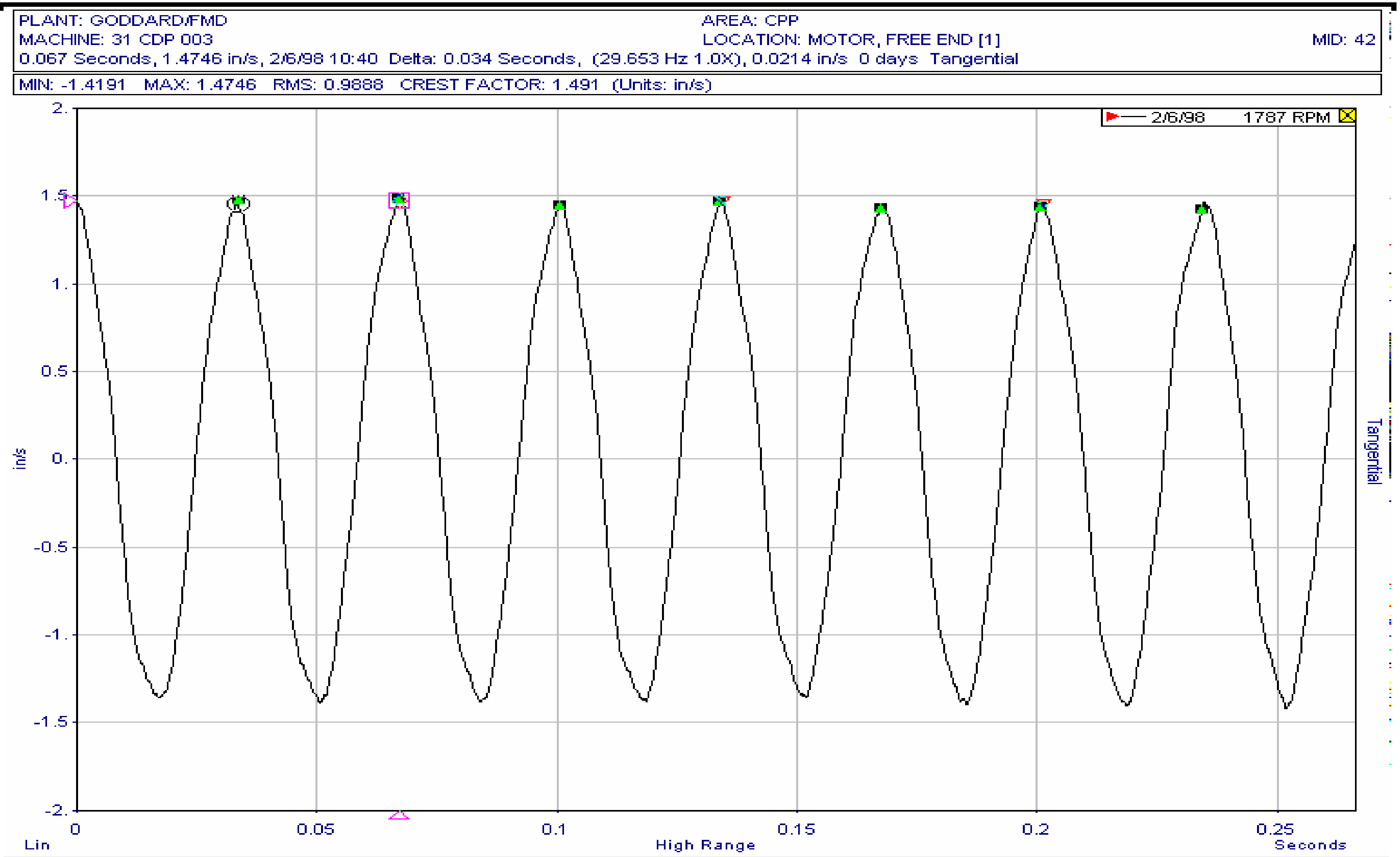
PT&I is the use of advanced technology to sense machinery operating characteristics such as vibration, temperature, pressure, etc. and to compare the measured values of these characteristics with historical data and pre-established criteria (ISO, ASNT, etc.) to assess machinery condition. PT&I permits the quantifiable condition of systems and equipment to be determined rather than rely on opinion.

PT&I provides the data to substantiate warranty claims.

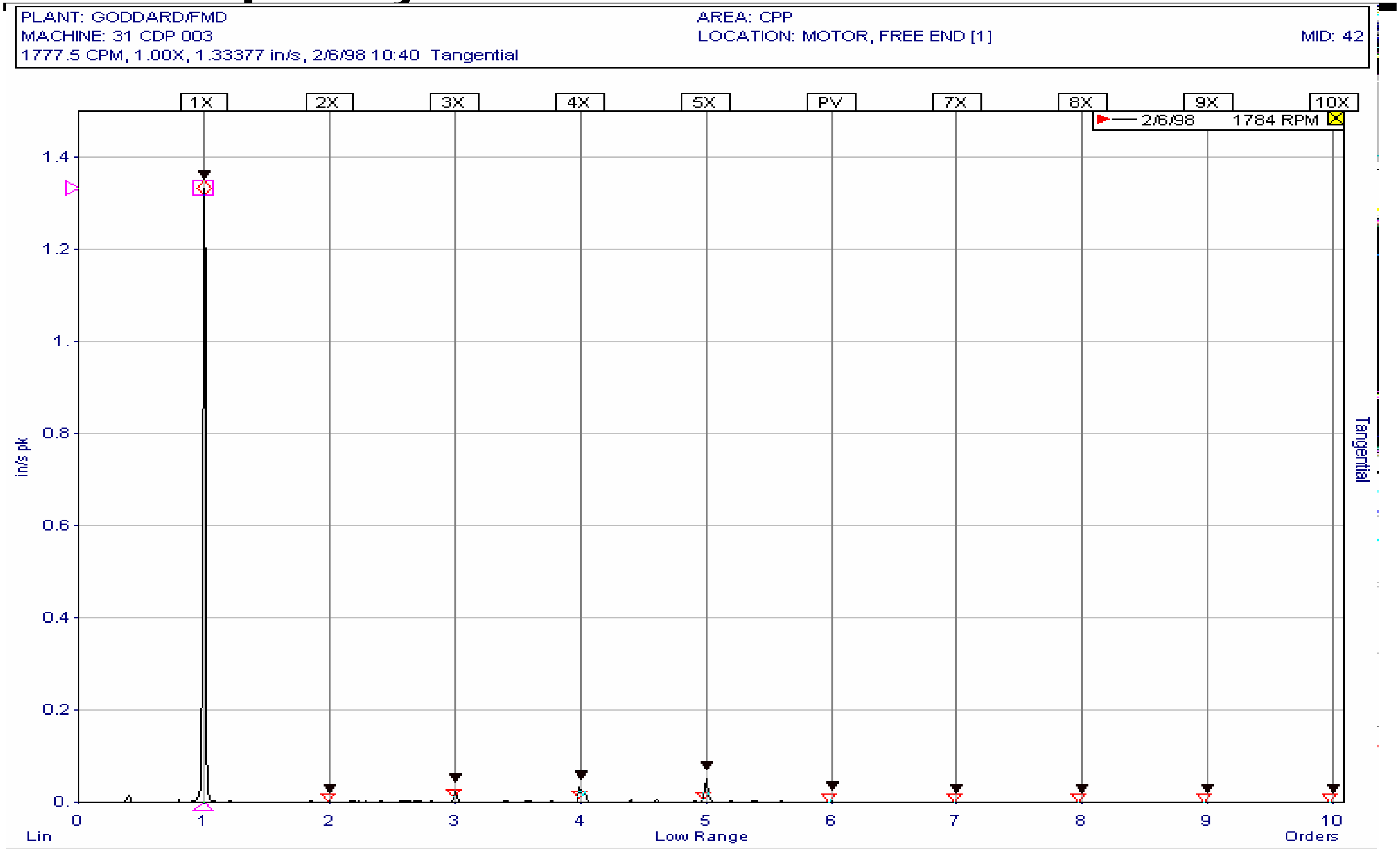
Sources of Vibration

- Imbalance
- Misalignment
- Impeller/Vanes
- Gears/Bearings
- Electrical (Rotor and Stator)
- Mechanical Looseness
- Belts and Sheaves

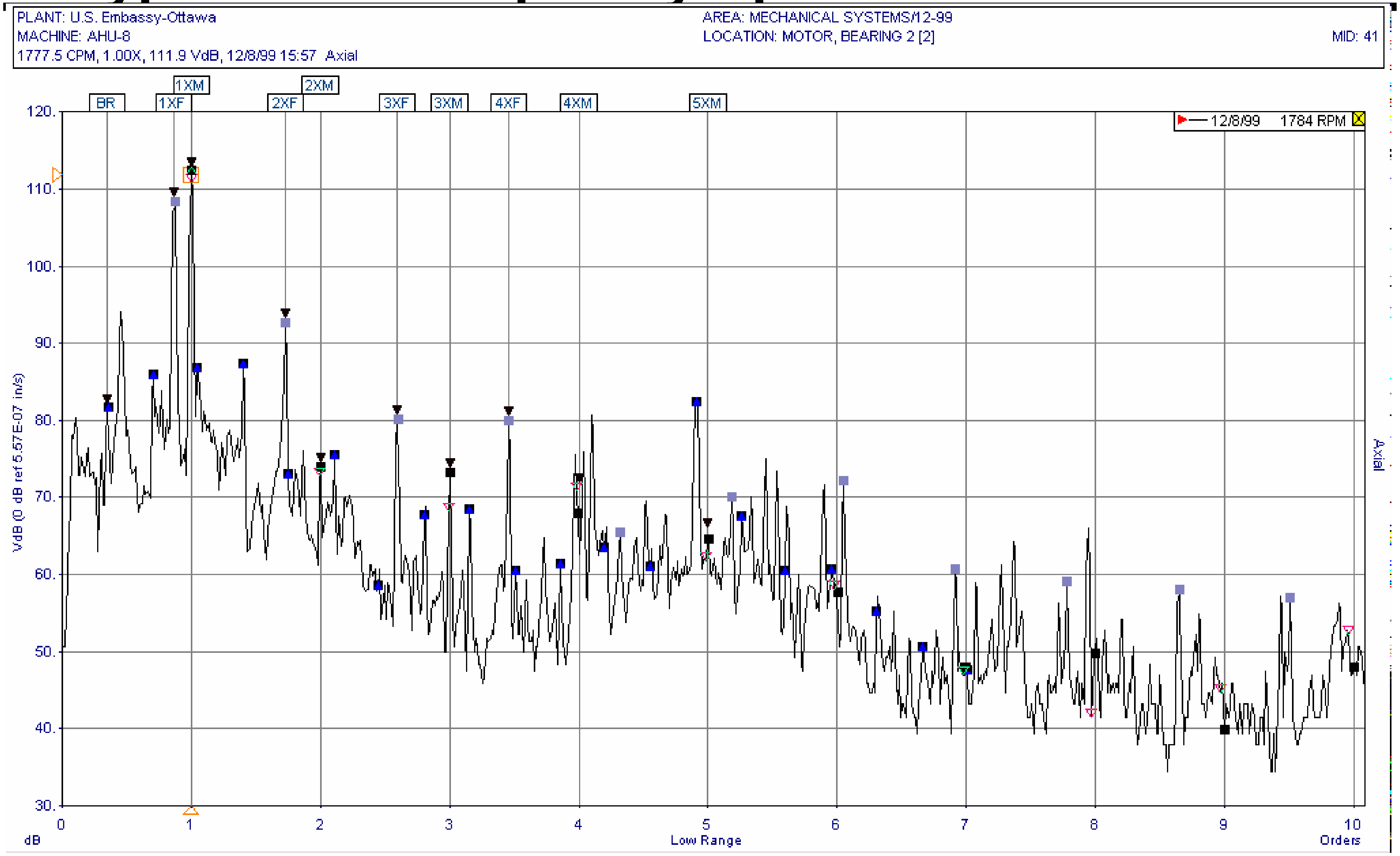
The Time Domain



The Frequency Domain



A Typical Fan Frequency Spectrum



Vibration vs Bearing Life

- **Reducing the forces caused by unbalance, looseness and misalignment will result in lower vibration levels.**
- **Reducing excessive belt tension will reduce machine forces but will not produce an appreciable reduction in vibration levels.**

Impact of Vibration Reduction on Bearing Life

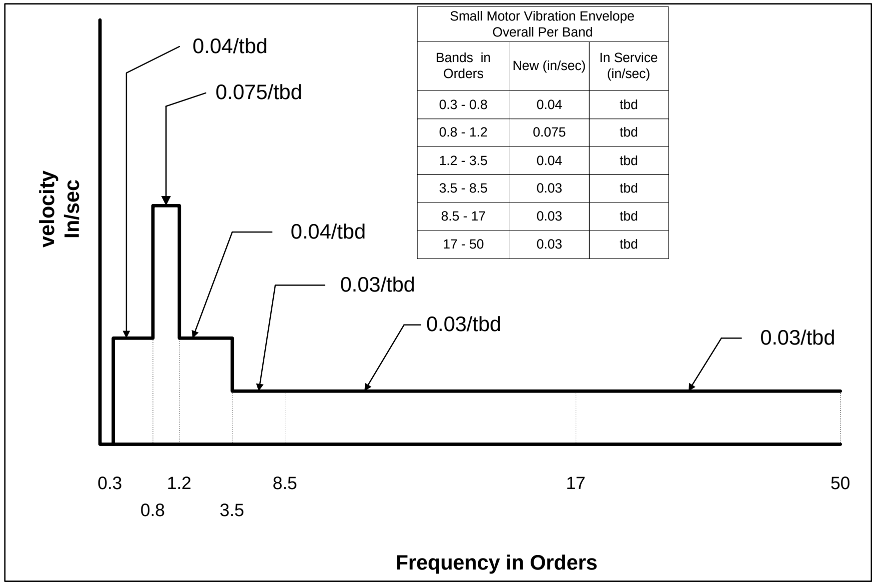
(Assuming Dynamic Load is the Major Force Component)

	% Increase in Bearing Life	
% Reduction in Vibration	Ball Bearings	Other Rolling Element Bearings
5	**17**	**19**
10	**37**	**42**
15	**63**	**72**
20	**95**	**110**
25	**137**	**161**
30	**192**	**228**
40	**363**	**449**
50	**700**	**908**

Source:L. Douglas Berry, Vibration Versus Bearing Life, Reliability, Vol. 2, Issue 4,November 1995

Vibration Acceptance

- Used to verify balance and alignment.
- Will be specified in bands.
- Will require test equipment that is capable of performing measurements.



Small Motor Vibration Envelope Overall Per Band		
Bands in Orders	New (in/sec)	In Service (in/sec)
0.3 - 0.8	0.04	tbd
0.8 - 1.2	0.075	tbd
1.2 - 3.5	0.04	tbd
3.5 - 8.5	0.03	tbd
8.5 - 17	0.03	tbd
17 - 50	0.03	tbd

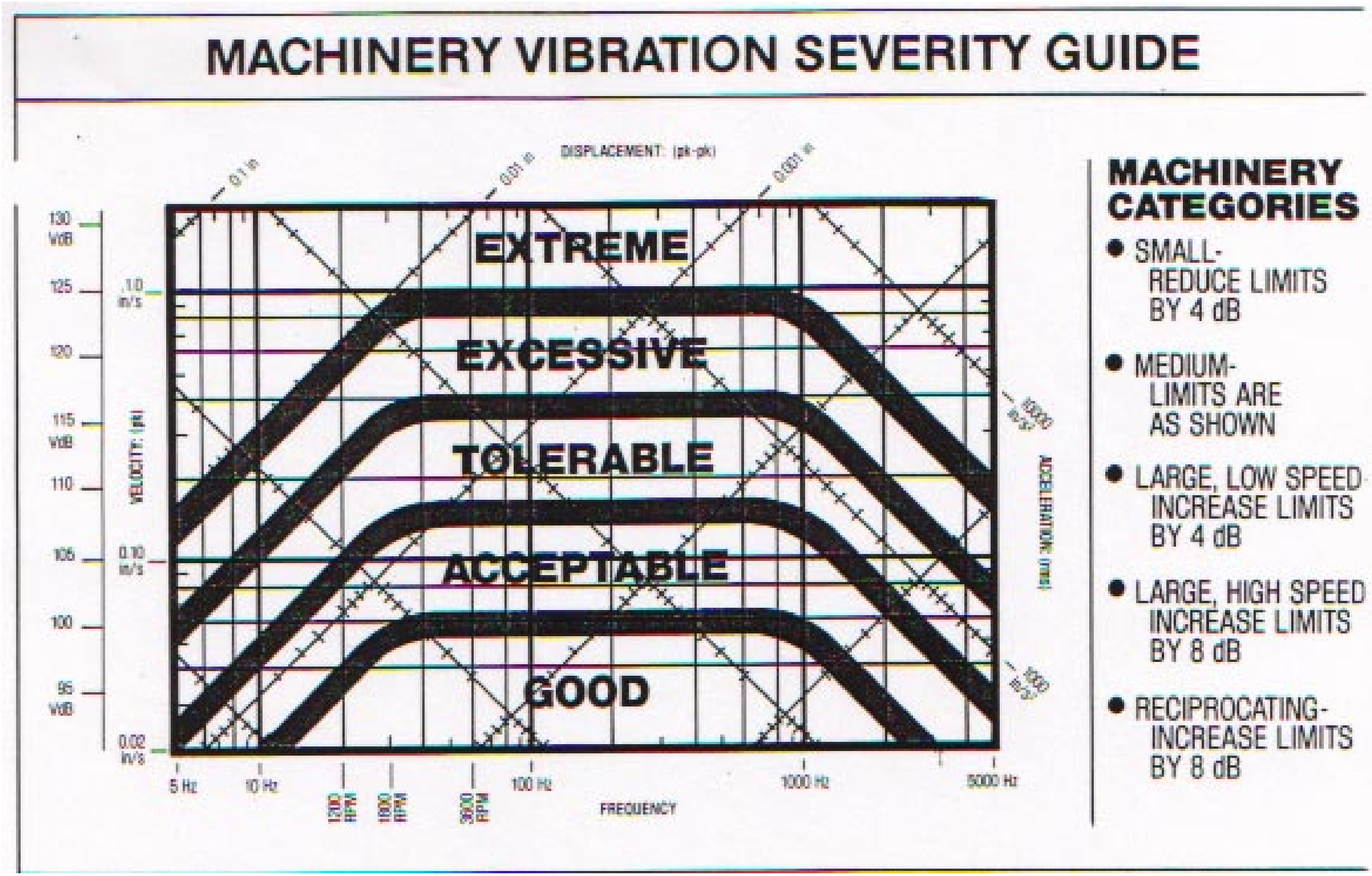
Overall Vibration Limits

MACHINE DYNAMICS, Inc.

VIBRATION LIMITS

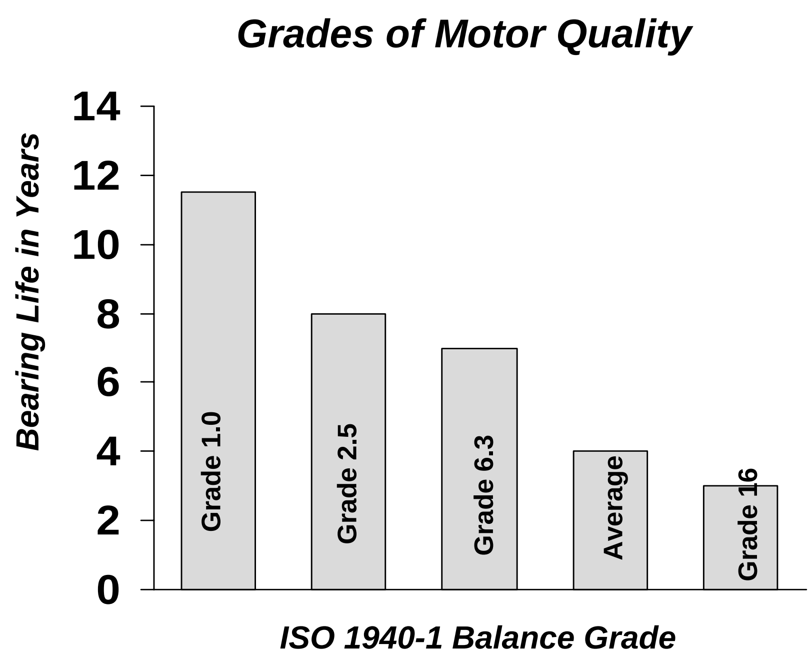
Vibration Limits	Balance Condition Displacement Mils, P-P at 1X rpm	Overall Velocity in/sec Peak 10 - 1,000 Hz	Overall Acceleration g. Peak 0 - 5,000 Hz
Electric Motors 1,000 - 2,000 rpm	2.0	.2	.5
> 2,000 rpm	1.0	.2	1.0
Generators	2.0	.2	.5
Centrifugal Fans < 600 rpm	4.0	.3	.5
600 - 1,000 rpm	3.0	.3	1.0
1,000 - 2,000 rpm	2.0	.3	1.5
> 2,000 rpm	1.0	.3	2.0
Vaneaxial Fans	1.0	.2	.5
Blowers	1.0	.3	.5
Pumps	2.0	.2	.5
Centrifugal Compressors	1.0	.2	3.0
Cooling Tower Gearboxes	3.0	.4	2.0
Reciprocating Engines Gas or Diesel	5.0	1.0	10.0
Turbines	1.0	.2	.5
Gearboxes	1.0	.4	2.0
Twin Screw Compressors	1.0	1.0	15.0

Another Useful Severity Guide



NOB Inspection Identified...

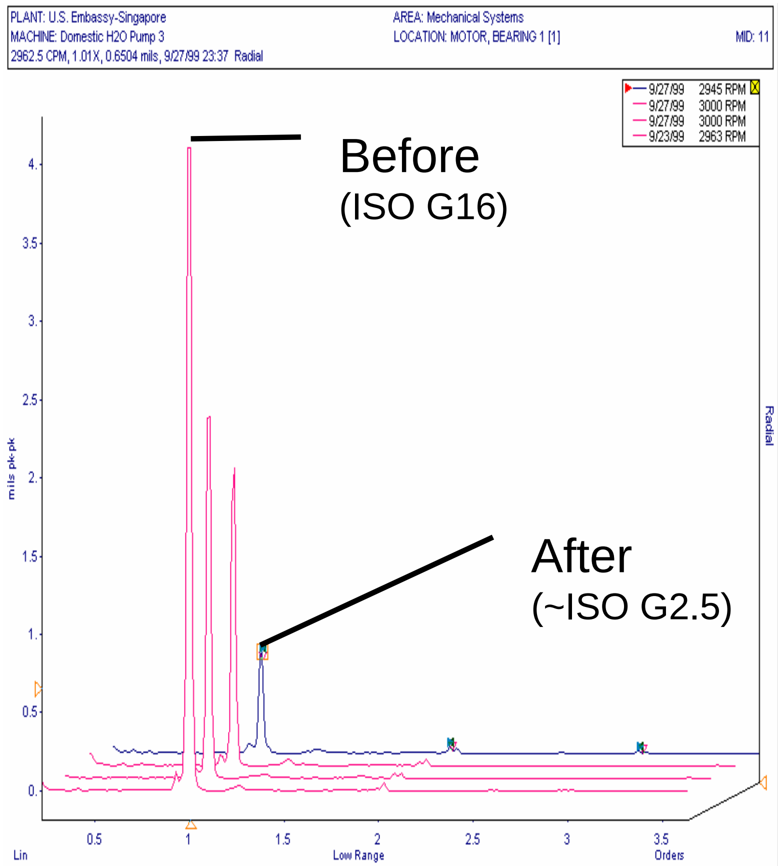
- All HVAC pumps were misaligned at installation
- All HVAC pumps had inadequate shims
- 90% of HVAC fans had improper sheaves specified and installed
- 80% of all fans tested had excessive vibration
- All fan vibration problems were traceable to balance and/or sheave problems
- 2 out of 3 Vertical pumps had extreme vibration caused by imbalance



Source: "Balanced Parts, Waking to Reality", SMRP Winter Newsletter, M. Span, Champion International, Pensacola, FL

These findings are consistent with NASA, NSA, and others prior to RCM implementation.

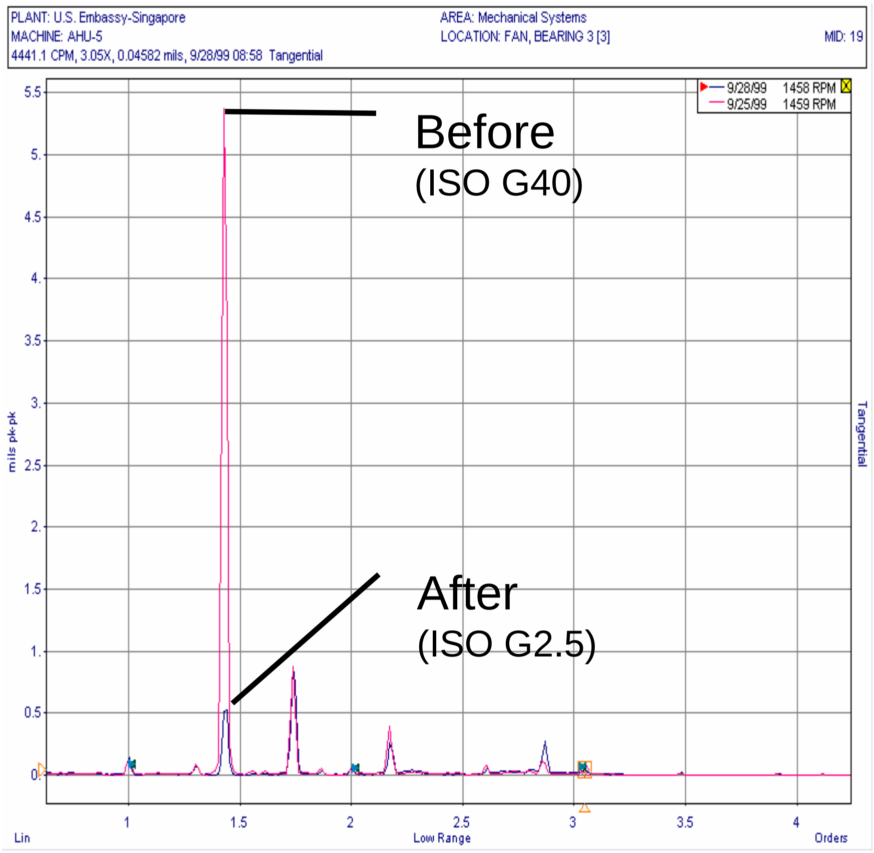
Pump Vibration, Before & After Balancing



Pump Vibration

Domestic H_2O Pumps

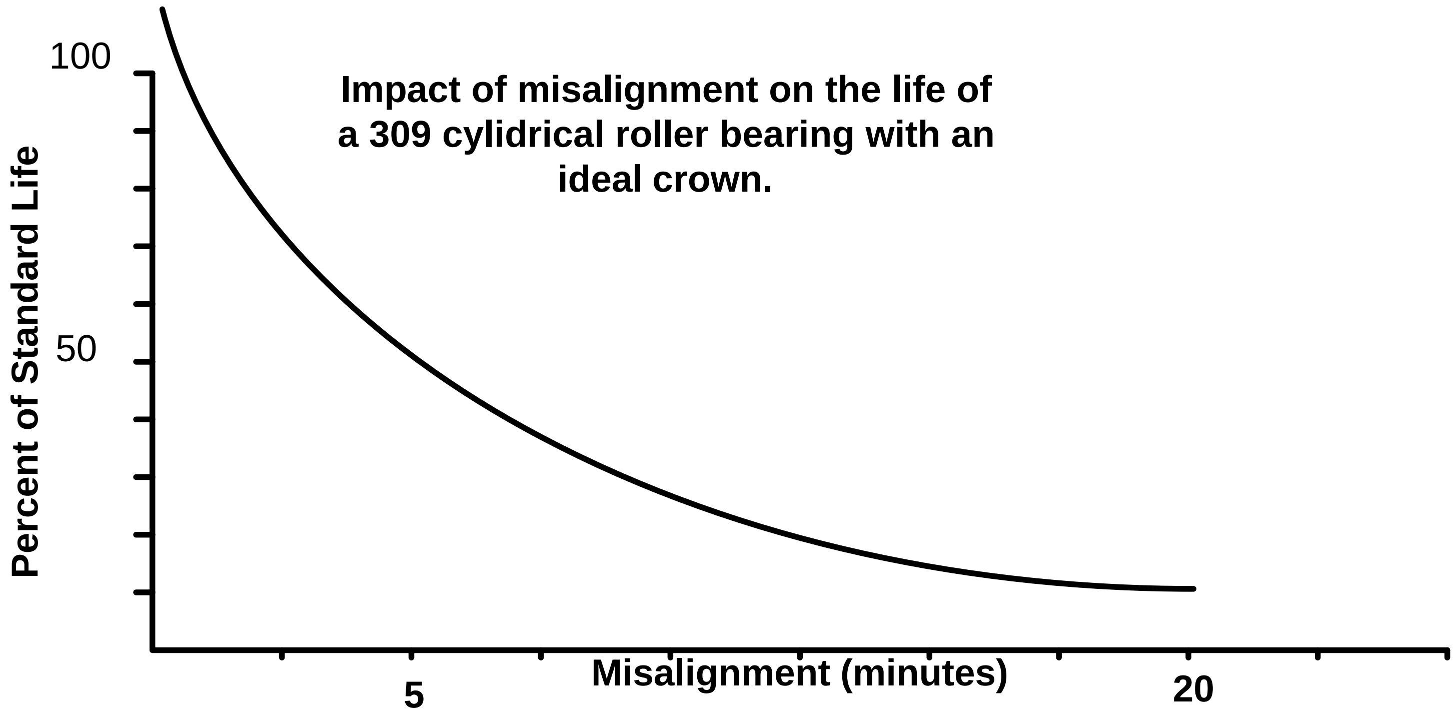
Fan Vibration, Before & After Balancing



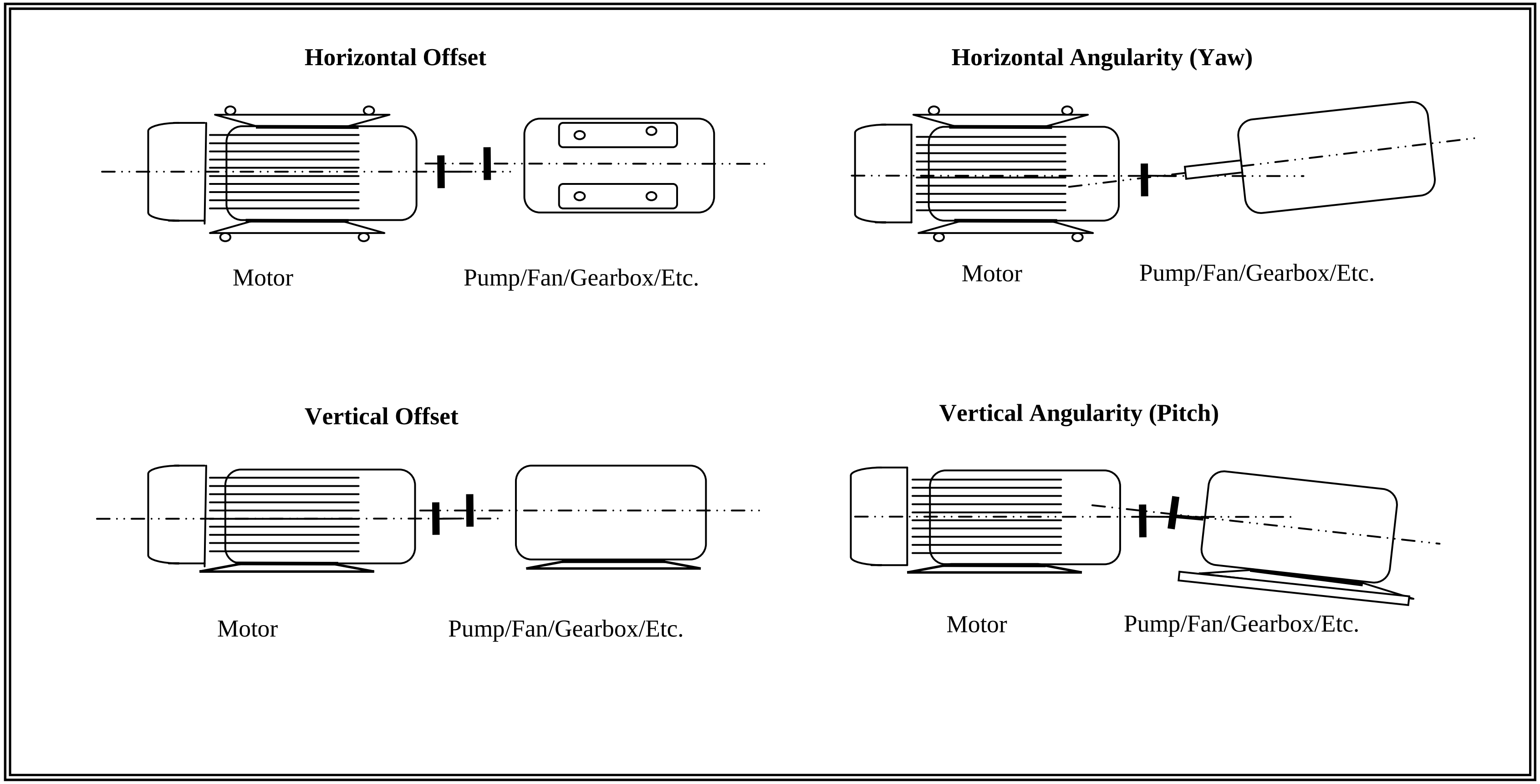
Fan Vibration

Fan

Effects of Misalignment



Types of Misalignment



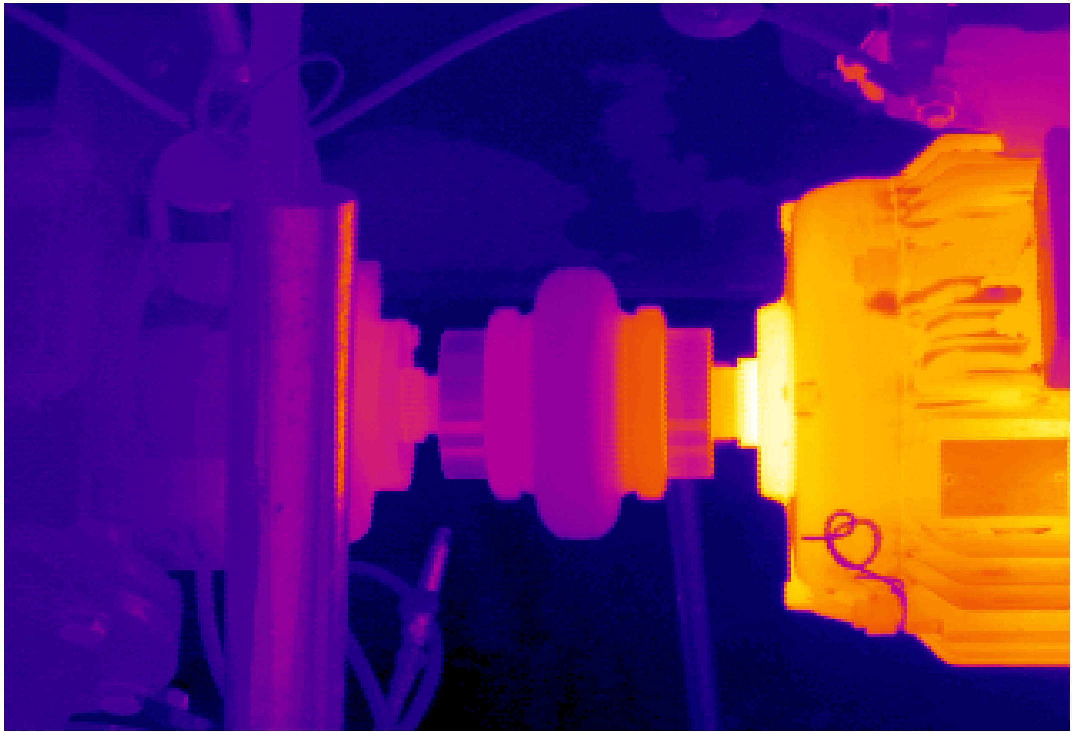
Why Is Misalignment a Problem?

- **ALL machinery is misaligned.**
  - **No alignment is perfect. There is disagreement about the precision required.**
  - **Manufacturers do NOT usually align *equipment*. (They ship components).**
  - **Vendors rarely align equipment, ("it was aligned at the factory").**
  - **Contractors rarely understand alignment importance. (They don't live with the results, either).**
  - **The "manufacturers recommendations" are usually inadequate.**
- **There are usually no real alignment tolerance requirements in the specifications. ("Align to manufacturers recommendations").**
  - **The most common "tolerance" used is supplied by the coupling manufacturer. (Who makes the least expensive and most misalignment tolerant component?).**

Are These What They Gave You?

Or These?

Alternate Methods for Determining Misalignment



Many companies have effectively used thermography to measure misalignment.

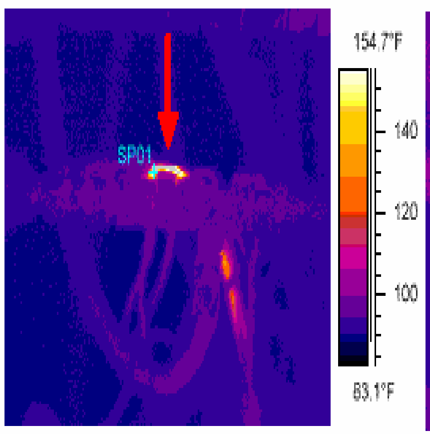
Alignment and Energy Savings

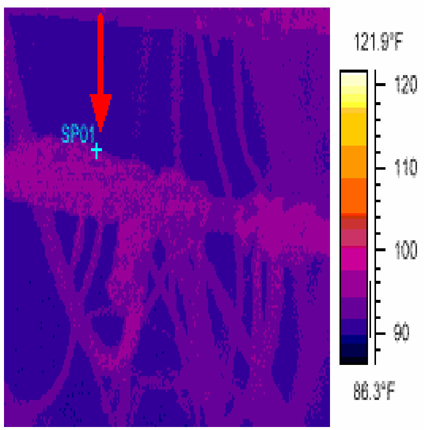
- **Recent work has examined if there is an energy loss when equipment is operated when misaligned.**
  - **University of Tennessee study (reported in P/PM Technology October 1997)**
  - **Naval Facilities Engineering Service Center Study (reported in P/PM Technology, April 1999)**
- **Both studies concluded that energy loss due to misalignment is insignificant.**
- **However, both studies noted that other effects of misalignment due to increased loads on bearings and couplings can be severe.**

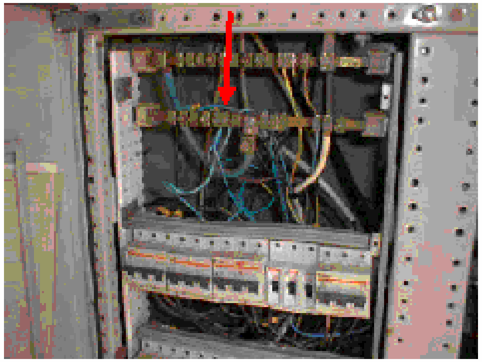
> Although energy conservation is not a reason for alignment, machinery life, shaft, bearing, and coupling loads are. We are convinced that alignment is the most important ingredient in a well run machinery management program.
>
> - Howard Graberson, Ph.D, Energy and Utilities Department, Naval Facilities Engineering Service Center, Port Hueneme, Ca

Infrared Thermography: A Versatile Monitoring Tool

/ Generator Room / Main Distribution Panel

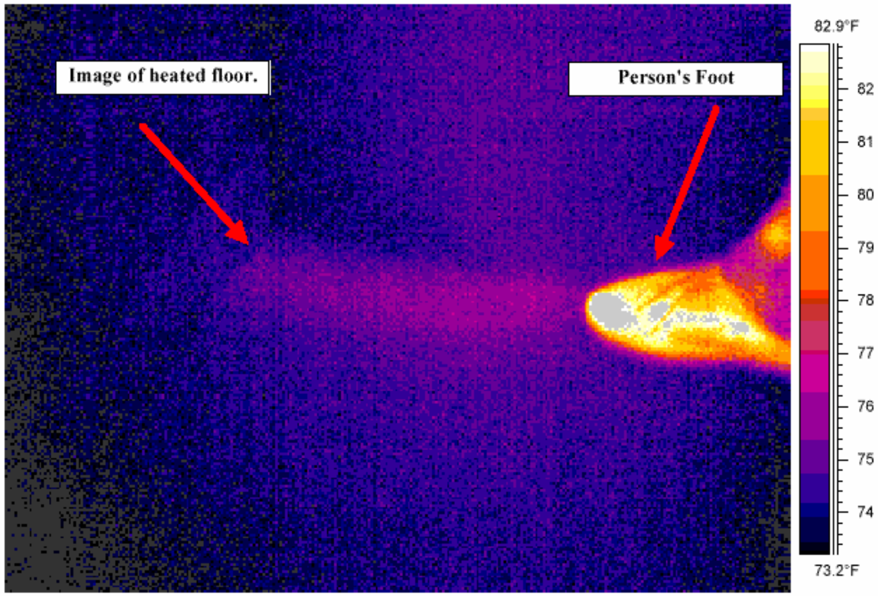






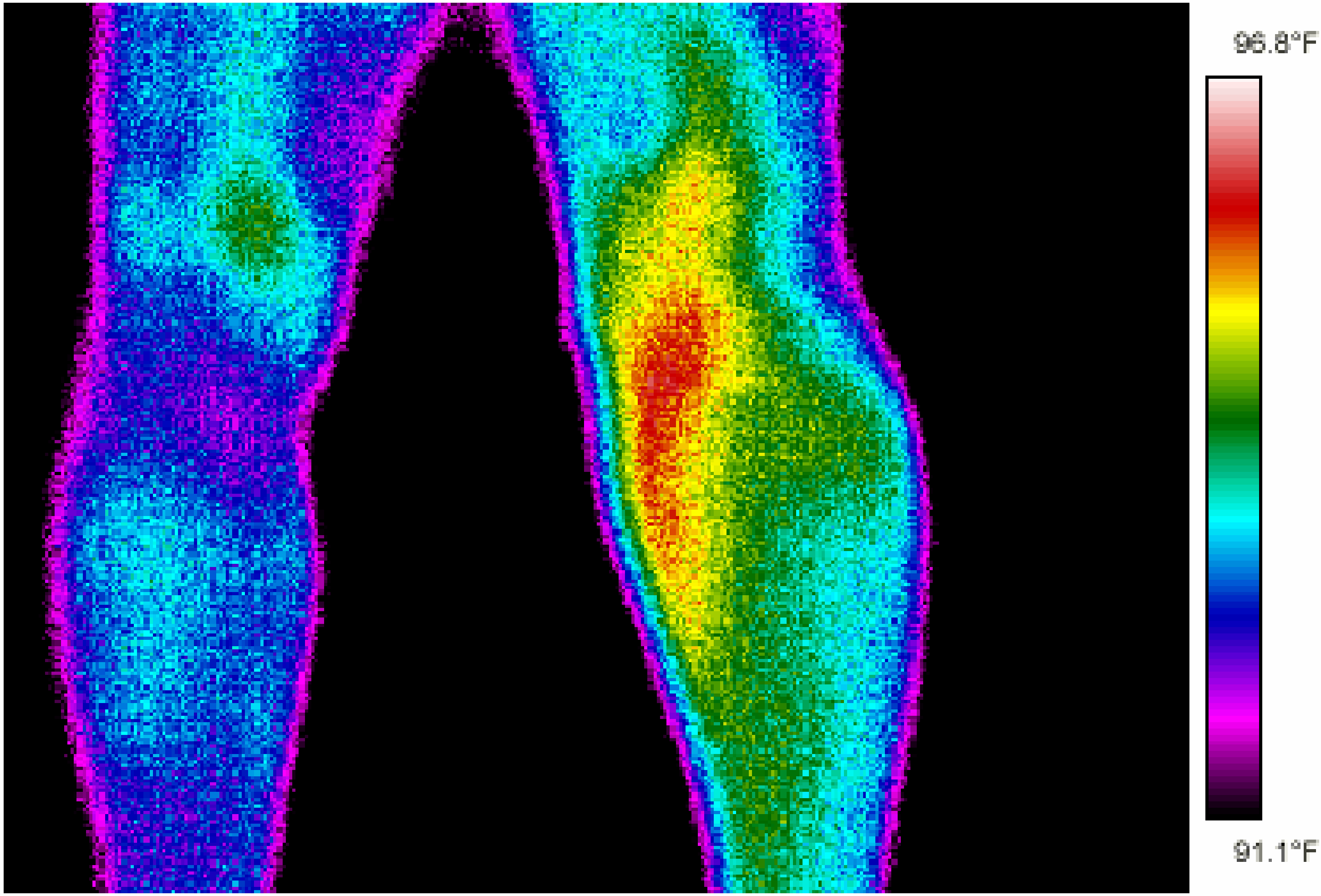
Elevated temperature on a neutral wire caused by loose connection. IR image on right is after repair - tightening of connection

Residence / Pantry



Blocked drain pipe underneath concrete floor. Blockage was located through thermal contrast minimizing excavation area.

Just How Versatile?



Potential Failures Detected in 50% of the Buildings/Areas Inspected

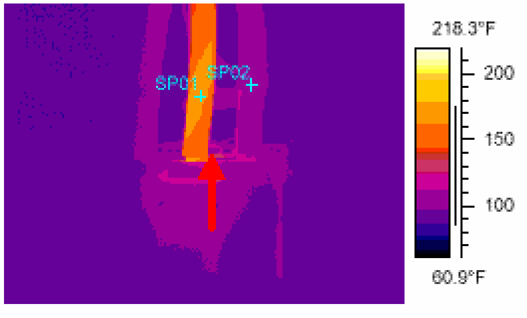
Transfer Switch

Repaired in 5 Hours on Weekend
With Minimum Disruption To Mission

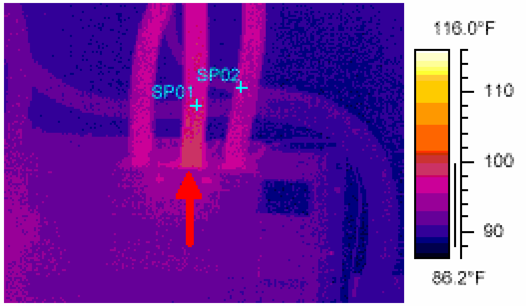
- Over half of the items detected were corrected before the Thermographer left.

10 of the 13 Buildings/Areas had thermography finds (potential failures).

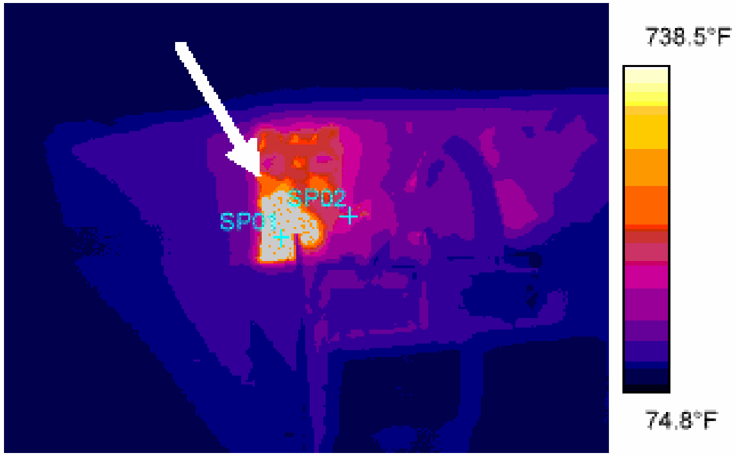
Before: Phase B
Approximately 170 F

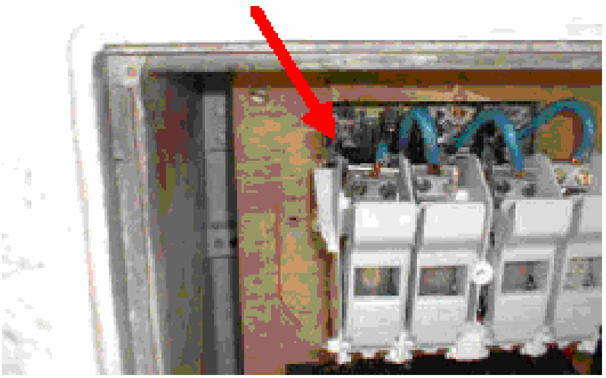


After: All Phases
Approximately 100 F



Outside Gate Meter House

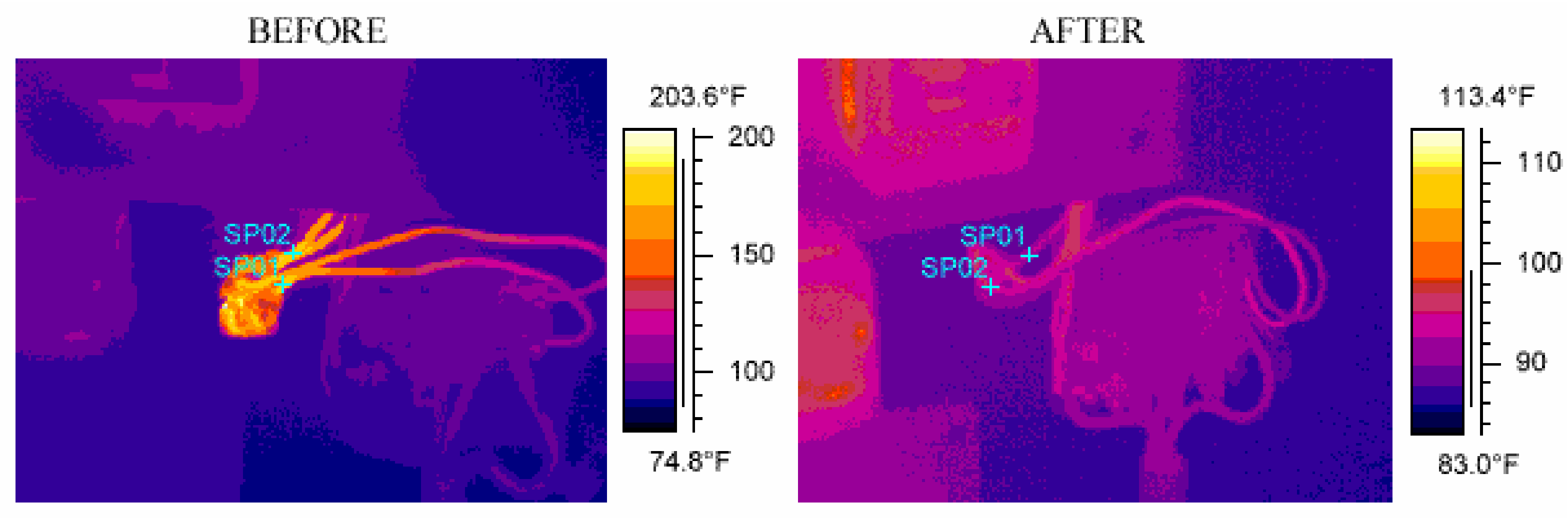




" …extremely elevated temperature …loads put on generator power until the problem is solved."

- From thermographers report, April 1999.

Distribution Connector



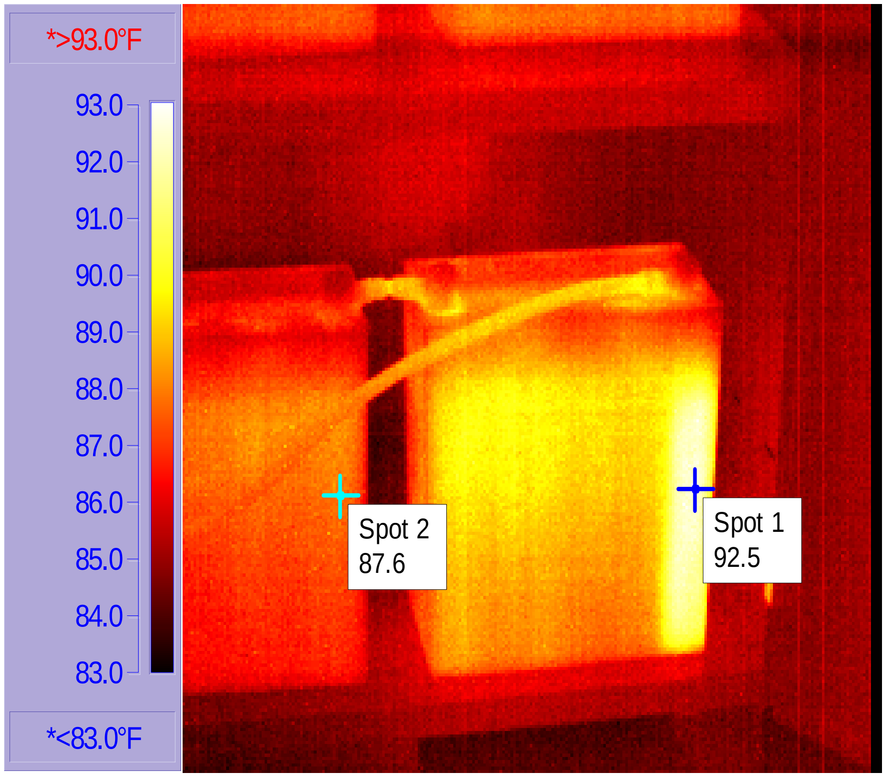
Spot temperature approximately 175 F.

Spot temperature approximately 95 F.

“ …were two separate phases that had melted together … electricians remade the connection… elevated temperature cleared.”

- From thermographers report, April 1999.

Thermography and UPS Testing



GSFC UPS test results 7/20/99

Electrical

- **Estimated 95% of electrical problems are due to connections (loose, corroded, undersized, over tightened).**
- **Unbalanced load.**
- **Inductive heating (eddy current).**
- **Spiral heating in multi-strand wire.**
- **Slip rings, commutators, brush riggings.**

Mechanical

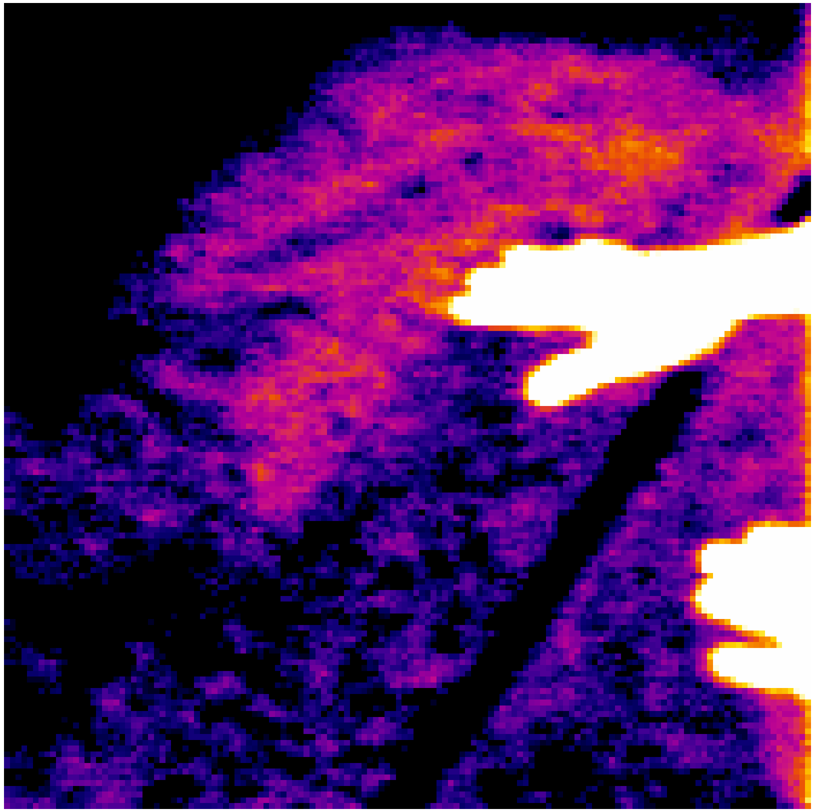
- Ventilation
- Machine casings, couplings, and bearing housings.
- Steam Traps (limited use).
- Underground Fluid Lines
- Tank Levels
- Insulation

Mechanical (Cont'd)

- **Passive thermography - inspects using energy already present.**
- **Active thermography - you add heat to create temperature change.**
  - **Boiler tubes (prior to startup)**
  - **Structure Defects**
  - **Unbonding in laminates, cracks in plastics.**

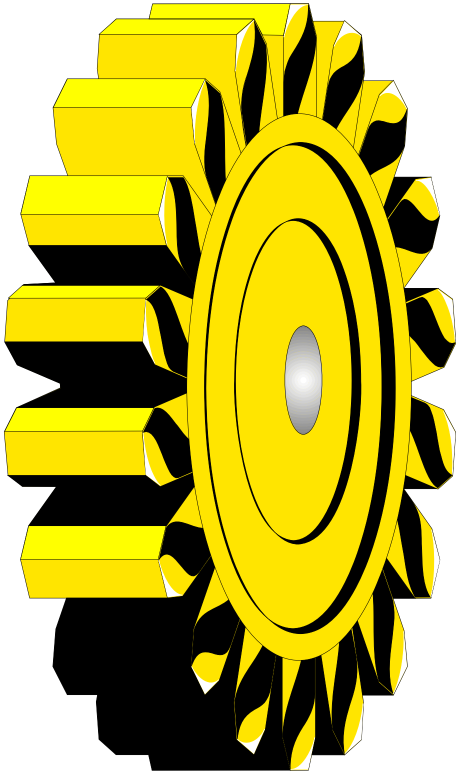
Roofs

- **Most leaks occur at flashing.**
- **Thermal pattern dependent on insulation type.**
  - **Closed Cell Insulation: Window Pane**
  - **Absorbent Panels: Straight Lines/Angles**
  - **Absorbent Tight Fit: Free Form**



Applicability of Lubricant Analysis

- Gearboxes
- Chillers
- Transformers
- Hydraulic Systems
- Diesel Engines
- Bearings



Reasons for Performing Lubrication Analysis

- **Lubricating oil analysis is performed for three reasons:**
  - **To determine the machine mechanical wear condition**
  - **To determine the lubricant condition**
  - **To determine if the lubricant has become contaminated.**
- **There are a wide variety of tests that will provide information regarding one or more of these areas.**

Machine Mechanical Wear Condition

- **The criteria for analyzing the lubricating oil to determine the machine's condition is the same as for analyzing the vibration signature.**
- **All machines with motors 7.5 HP or larger, critical machines, or high cost machines.**

Lubricant Condition

- **Lubricating oil is either discarded or reconditioned through filtering and/or replacing additives.**
- **Analyzing the oil to determine the lubricant condition is therefore driven by costs.**
- **Small reservoirs, usually one gallon or less, have the oil changed on an operating time basis.**

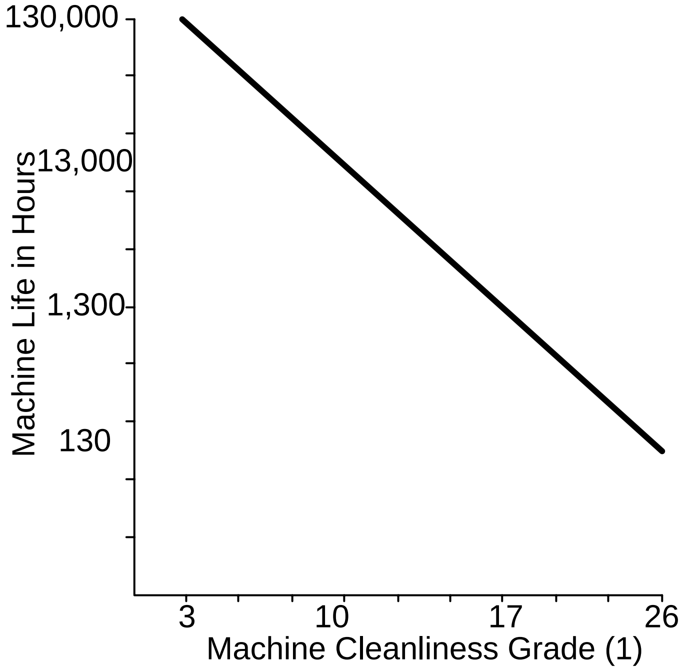
Lubricant Contamination

- **Lubricating oil can become contaminated due to the machines operating environment, improper filling procedures, or through mixing different lubricants.**
- **The routine sampling and analysis periodicity will be the same as discussed for machine condition.**

Particle Counting

- Used to identify metal and non-metal particles over 5 microns and up to 40 to 50 microns.
- Result is particle count (parts per milliliter) by size category.
- Visual Method
  - Time consuming, depends on analyst ability.
  - Able to identify the types of particles such as dirt, seal material, and metal.
- Electronic Counting
  - Faster and does not depend on the analyst’s ability.
  - Does not distinguish or identify the particle make up.

Effect of Hydraulic System Contamination



Notes:

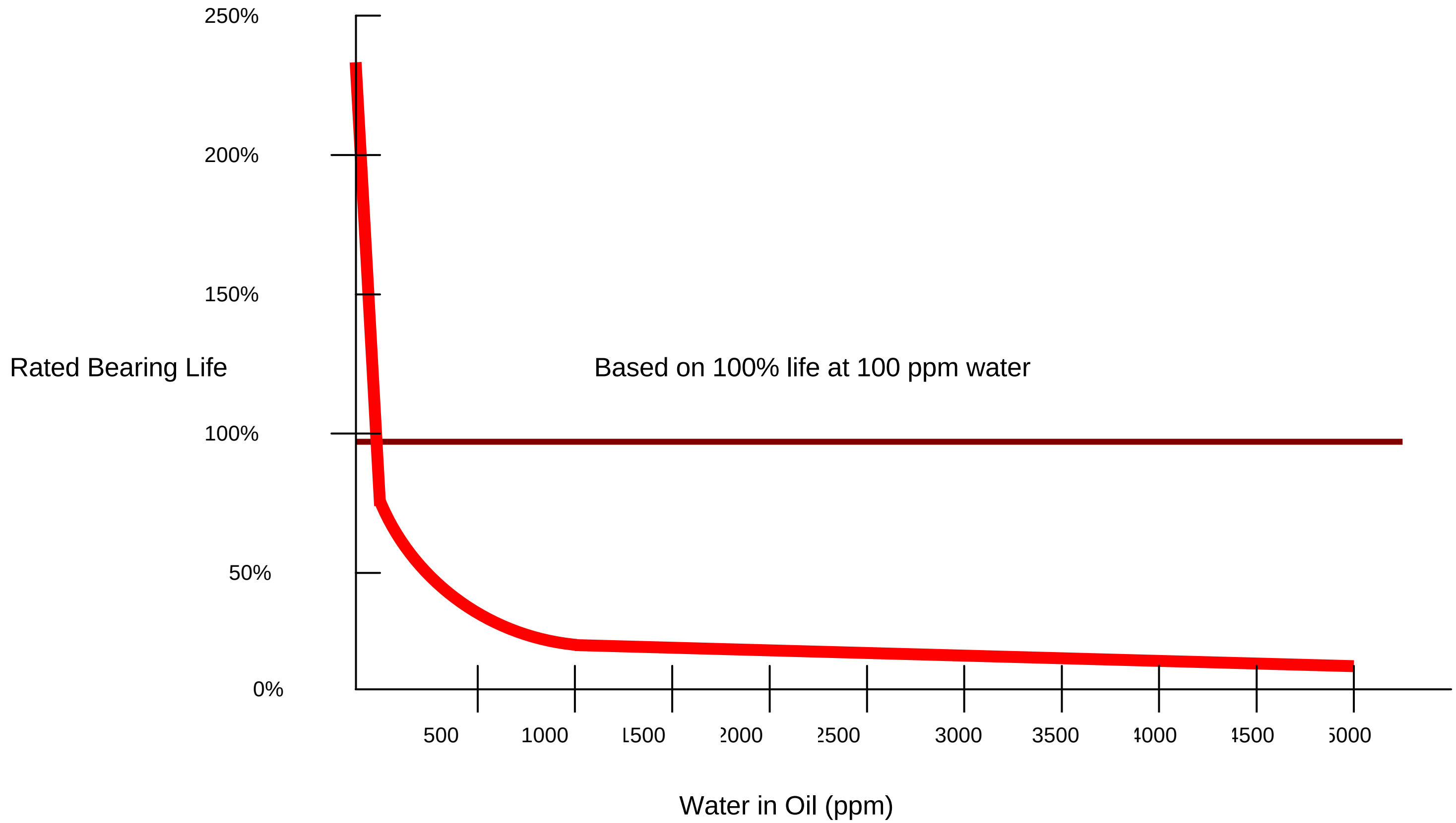
1. **ISO Code - 5 microns**

2. **Rec. ISO code 16/13, i.e., 320-640 particles > 5 microns and 40-80 particles > 15 microns.**

3. **Component annual costs were cut to $0 from $13K.**

Source: "Extending Hydraulic Component Life at Alumax of South Carolina", J. Mayo and D. Troyer, Reliability Magazine, Jan 1995

Effect of Water on Bearing Life



One PPM is one milligram per kilogram.

Analytical Tests

- **Lubricating oil and hydraulic fluid analysis should proceed from simple, subjective techniques such as visual and odor examination through more sophisticated techniques.**
- **The more sophisticated (and expensive) techniques should be used when conditions indicate the need for additional information and the equipment cost or criticality justify the cost.**

Standard Analytical Tests

- **Visual and Odor**
- **Viscosity**
- **Water**
- **Percent Solids/Water**
- **Total Acid Number (TAN)**
- **Total Base Number (TBN)**
- **Spectrometric Metals**
- **Infrared Spectroscopy**
- **Particle Counting**
- **Direct-Reading (DR) Ferrography**
- **Analytical Ferrography**

Visual and Odor

- Simple inspections can be performed weekly by the equipment operator to look at and smell the lubricating oil.
- A visual inspection looks for changes in color, haziness or cloudiness, and particles.
- This test is very subjective but can be an indicator of recent water or dirt contamination and advancing oxidation.

Viscosity

- **Indicates oil flow rate at a specified temperature. An increase or decrease in viscosity over time measures changes in the lubricant condition or lubricant contamination.**
- **Viscosity can be tested using portable equipment, or more accurately in a laboratory using ASTM D445 procedure.**
- **Viscosity is measured in Centistoke (cSt) and minimum and maximum values are identified by ISO grade.**
- **Testing is usually part of a commercial laboratory standard test package.**

Water

- **Water in lubricating oil and hydraulic fluid contributes to corrosion and formation of acids.**
- **Small amounts of water (less than 0.1%) can be dissolved in oil and can be detected using the crackle test or infrared spectroscopy (minimum detectable is .05% or approximately 500 ppm; both methods), the ASTM D95 distillation method (minimum detectable is .01%/100 ppm), or the ASTM D1744 Karl Fischer method (minimum detectable is .001%/10 ppm).**
- **Greater than 0.1% water, if suspended or emulsified in the oil, will appear cloudy or hazy.**
- **Free water in oil collects in the bottom of reservoirs and can found by draining from the bottom.**

Percent Solids/Water

- **A simple, inexpensive test is used to provide a gross estimate of solids and/or water in the oil.**
- **A sample is centrifuged in a calibrated tube and the resulting volume is measured.**
- **The test is effective for amounts in the range of 0.1% to 20% of volume and is usually part of a commercial laboratory standard test package.**

Total Acid Number (TAN)

- **Total acid is an indicator of the lubricating oil condition and is monitored relative to the TAN of new oil.**
- **In some systems the TAN will also be used to indicate acid contamination. TAN is measured in milligrams of potassium hydroxide (KOH) per gram of oil (mgKOH/g).**
- **KOH is used in a titration process and the end point is indicated by color change (ASTM D974) or electrical conductivity change (ASTM D664).**

Total Base Number (TBN)

- Similar to TAN in test method, test measures alkalinity (ability to neutralize acid) of oil sample.
- Test is used on oil with high detergent additives such as diesel and gasoline engines. A titration process is used and the end point is indicated by electrical conductivity change (ASTM D664 or ASTM D2896).
- When comparing test results (for example, against baseline data from the oil supplier), ensure that the same test method is used.
- Results can vary between test methods.

Spectrometric Metals

- **Also know as emission spectroscopy, technique that examines the light (spectrum) emitted from the sample during testing and identifies up to 21 metals.**
- **Metals are categorize as wear, contaminate, or additive metals. The procedure identifies both soluble metal and metal particles up to 5 to 10 microns (5-10 µm).**
- **Test is moderate in cost and is usually part of a commercial laboratory standard test package.**
- **Other techniques, absorption spectroscopy and X-ray spectroscopy, are also used by some laboratories to identify metals.**

Infrared Spectroscopy

- **Also known as infrared analysis, infrared absorption spectroscopy or spectrophotometry, and Fourier Transform Infrared (FTIR) spectroscopy. The technique examines the infrared wavelength that is absorbed by the oil sample.**
- **The test is used to identify non-metallic contamination (see Water, discussed earlier) and lubricant conditions (such as oxidation and anti-oxidant and other additive depletion).**
- **Costs vary depending on the level of sophistication required. Infrared spectroscopy is usually part of a commercial laboratory standard test package.**

Particle Counting

- **Particle counting is used to identify metal and non-metal particles over 5 microns and up to 40 to 50 microns.**
- **Two methods (visual and electronic) are used and each has advantages and drawbacks. Both methods result in particle count (parts per milliliter) by size category. For example, the ISO size categories are greater than 5, 10, 15, 25 and 50 microns.**
- **The visual method of particle counting is time consuming and depends on the analyst. However, the analyst is able to identify the types of particles such as dirt, seal material, and metal.**

Sperry Vickers Table of Suggested Acceptable Contamination Levels for Various Hydraulic Systems

Type of System	System Sensitivity	Maximum Particle Level		
		5 microns	15 microns	ISO
Silt-sensitive control system with very high reliability	Super critical	4000	250	13/9
High-performance servo and high-pressure long-life systems	Critical	16,000	1000	15/11
High-quality reliable systems	Very important	32,000	4000	16/13
General machinery and mobile systems	Important	130,000	8000	18/14
Low-pressure heavy industrial systems	Average	250,000	16,000	19/15
Low-pressure systems with large clearances	Main protection	1,000,000	64,000	21/17

Typical Baseline Cleanliness Targets

MACHINE/ELEMENT	ISO TARGET
Roller Bearing	16/14/12
Journal Bearing	17/15/12
Industrial Gearbox	17/15/12
Mobile Gearbox	17/16/13
Diesel Engine	17/16/13
Steam Turbine	18/15/12

Direct-Reading (DR) Ferrography

- **Ferrography, the analysis of ferrous material, uses a magnetic technique to separate wear particles from the oil sample.**
- **In the DR process the wear particles are further separated into small (5 to 15 microns) and large (greater than 15 microns) categories. This results in two values, a ratio of large to small particles and a total particle concentration.**
- **Both values can be tracked and trended and indicate increases in wear and type of wear.**
- **Test is moderate cost and supplements spectrometric metals test. Note also that test identifies large wear particles that are not identified in spectrometric metals test.**

Analytical Ferrography

- **More detailed than DR ferrography, analytical ferrography is often initiated based on changes in DR, spectrometric metal increases, or increased particle count.**
- **The analysis is sometimes performed on a regular basis on high cost or critical machines. Process is labor intensive and involves the preparation of sample and then examination under magnification.**
- **Results depend on analysts capability but the procedure can provide detailed information regarding wear material such as wear type (rubbing, sliding, cutting), color, particle types (oxide, corrosive, crystalline), and other non-ferrous particles.**
- **Costs are moderately high; test is performed on a fixed price basis (per sample) from a commercial laboratory.**

Special Tests

- Special tests are sometimes needed to monitor lubricant conditions on some high cost or critical systems.
- Usually the special test is monitoring a lubricant contaminate, a characteristic or additive depletion.
- Special tests are rarely needed for routine monitoring of lubricants and the tests listed here are provided as samples.
- Test procedures are constantly being developed and refined.
- The annual ASTM Standards provides a description of current test methods.

Glycol Antifreeze

- **Glycol contamination can be detected using infrared spectroscopy (see Infrared Spectroscopy, discussed earlier) at levels greater than 0.1% (1,000 ppm) which is usually adequate for condition monitoring.**
- **Additional tests can be specified to identify if small amounts of glycol are present.**
- **ASTM test D2982 will indicate if trace amounts are present.**
- **ASTM D4291 uses gas chromatography to quantify small amounts of glycol.**

Karl Fischer Water

- **Water contamination can be detected using infrared spectroscopy (see Infrared Spectroscopy, discussed earlier) at levels greater than 0.05% (500 ppm) which is usually adequate for condition monitoring.**
- **Using a titration process with a Karl Fischer reagent, low levels of water can be quantified.**
- **The test, ASTM D1744, is useful when accepting new oil or evaluating clean up efforts.**
- **Cost of the test is moderate.**

Foaming

- **Some oil may have anti-foam agents added to improve the lubrication capability in specific applications such as gear boxes or mixers.**
- **ASTM test D892 can be used to test the oils foam characteristics.**
- **The test blows air through a sample of the oil and then the foam volume is measured.**
- **Cost of the test is moderately high.**

Rust Prevention

- **Some systems are susceptible to water contamination due to equipment location or the system operating environment.**
- **In those cases, the lubricating oil or hydraulic fluid may be fortified with a corrosion inhibitor to prevent rust.**
- **The effectiveness of rust prevention can be tested using ASTM D665 (or ASTM D3603).**
- **Results are pass/fail and the cost of the test is high.**

Rotating Bomb Oxidation Test (RBOT)

- **Also known as Rotary Bomb Oxidation Test, ASTM D 2272, is used to estimate oxidation stability and therefore identify the remaining useful life of oil.**
- **The test simulates aging to identify when rapid oxidation takes place indicating that anti-oxidants have been depleted.**
- **Test is not a one time test; it must be performed over time, including a baseline test with new oil, in order to develop a trend line.**
- **Because of the high cost, and the multiple tests required, this test is usually only performed on large volume reservoirs or expensive oil.**

New Lubricating Oil Limits

Lubricant Tests	Testing For	Limits
Total Acid Number	pH balance	<.05 gm KOH/ml
Visual	Cloudiness	Non-cloudy
IR Spectral Analysis	Metals	None
Particle Count	Particles >10um	< 100
Water Content	Water	< 25ppm @ $20^{o}C$
Viscosity	Lubricating Quality	Per Spec.

Motors, Generators, Pumps, Blowers, Fans

- **For machines with less than 5 gallons in the lubrication system, the analysts is mostly concerned with machine condition.**
- **Lubricant condition and contamination are of interest in that they contribute to machine condition.**
- **Routinely monitor viscosity, percent solids/water, and spectrometric metals. Monitor trends and discard or refresh the oil when viscosity changes 10% from the baseline. Viscosity normally increases above the baseline with the oil service time.**
- **For machines with more than 5 gallons of oil in the system, add infrared spectroscopy (minimum amount of water detectable is .05%) and particle counting.**
- **Perform DR ferrography for high cost or critical machines. In all machines, changes in spectrometric metals or DR should be investigated further using analytical ferrography and correlated with vibration analysis.**

Gearboxes

- **Same as above, except for gearboxes with less than 5 gallons of oil, add particle counting.**
- **DR ferrography for high cost or critical gearboxes. Monitor trends and correlate with vibration readings**.

Chillers

- In addition to the items identified above, add TAN and DR ferrography. Same as above, except for gearboxes with less than 5 gallons of oil, add particle counting.
- DR ferrography for high cost or critical gearboxes. Monitor trends and correlate with vibration readings.

Diesel Engines and Compressors

- **Same as chillers except substitute TBN for TAN when oil has high detergent additives.**
- **A decrease in viscosity below the baseline may indicate fuel contamination.**
- **Coolant leakage (glycol and other characteristics) is identified from the infrared spectroscopy analysis.**

Hydraulic Systems

- Same as gearboxes.
- Monitor particle count by ISO category. Each hydraulic system will have limiting clearances that will determine critical particle sizes.
- Note that some hydraulic systems use fluids other than oil (water glycol).
- Particle control is the same for these systems.

Large Reservoirs

- **For reservoirs over 500 gallons, consider performing an RBOT to assess the oxygen stability.**
- **Cost is usually the deciding factor.**
- **At least three tests are needed to develop a trend and then additional re-testing at least once a year.**
- **Benefit is derived when replacement or refreshing of a large volume of oil (or smaller volume of expensive oil) can be deferred.**

Airborne Ultrasonics

- **Detects Noise in the 20-100,000 Hertz Range**
- **Hearing Limited to 20-16,000 HZ**
- **Translator - translates ultrasonic to the hearing range.**
- **Non-destructive, On-line, directional.**

Gas Leakage

- **Turbulence from gas pressure or vacuum leak.**
- **Directional**
- **Limited by background noise.**

Helium was being used at an excessive rate. Ultrasonic noise analysis identified source of leak 40 ft above the shop floor. Identification and repair of this leak stopped a $1,500/day loss.

-Lockheed Martin, Michoud Assembly Facility
Association for Facilities Engineering National Conference, 1998

Corona, Tracking, Arcing

- **Corona**
  - **Polarization of air molecules due to electrical energy.**
  - **Occurs at weak insulation points.**
  - **Deteriorates insulation, can form nitrous acid, can lead to arcing.**
- **Tracking and Arcing**
- **All emit ultrasonic noise.**

Steam Traps

- Common Types
  - Inverted Bucket
  - Disc
  - Bellows
  - Float
- Ultrasonic “hears” operation.
  - Float & Thermostatic type difficult to hear.
- Use in combination with temperature.

Electrical Tests

- Insulation Resistance/Polarization Index IEEE Std 43
- High Potential Tests IEEE Std 95
- Motor Surge Testing
- Motor Circuit Analysis
- Motor Current Signature Analysis
- Motor Flux Analysis

Electrical Tests

Electrical Equipment	Power Factor Tests	Excitation Tests	Insulation Resistance	Infrared	Ultrasonic	Battery Impedance	Breaker timing	Insulating Oil Condition	Partial Discharge	Contact Resistance	High Voltage Testing	Motor Circuit Analysis	Turns Ratio Tests	Dissolved Gas Analysis
Transformers	●	●	●	●	●			●					●	●
Circuit Breakers	●		●	●	●		●	●		●	●	●		
Motors	●		●	●					●		●	●		
Batteries				●		●								
Motor Control Centers			●	●	●							●		
Switchgear	●		●	●	●					●	●			
Power Panels			●	●	●									
Power Cables	●		●						●		●			

MOTOR DEGRADATION

Sources and Indicators

Motor Failure Distribution

• Bearing	41%
• Stator	37%
• Rotor	10%
• Other	12%

EPRI Power Industry Study by General Electric, 1985

Reasons for Failure

• Design	39.1%
• Workmanship	26.8%
• Misapplication	13.7%
• Misoperation	20.4%

EPRI Power Industry Study by General Electric, 1985

Failure Causes

- **Thermal Stress**
  - **Insulation Aging**
  - **Differential Expansion**
- **Mechanical Stress**
  - **Vibration**
  - **Abrasion**
- **Environmental Stress**
  - **Chemical Attack & Moisture**
- **Electrical Stress**
  - **Partial Discharge**

Internal Problems

- Inductive Phase Imbalance
- Poor Electrical Connections
- Porosity
- Current Leakage
- Insulation Breakdown
- E-M and Mechanical Vibration

External Problems

- Poor Electrical Connections
- Breaker Contact Pressure
- Corroded Contacts
- Foundations
- Environmental

Principle Stator Failure Mechanisms

• Insulation Breakdown	37%
• Overheating	21%
• Electrical Faults	11%
• Mechanical	10%
• Other	21%

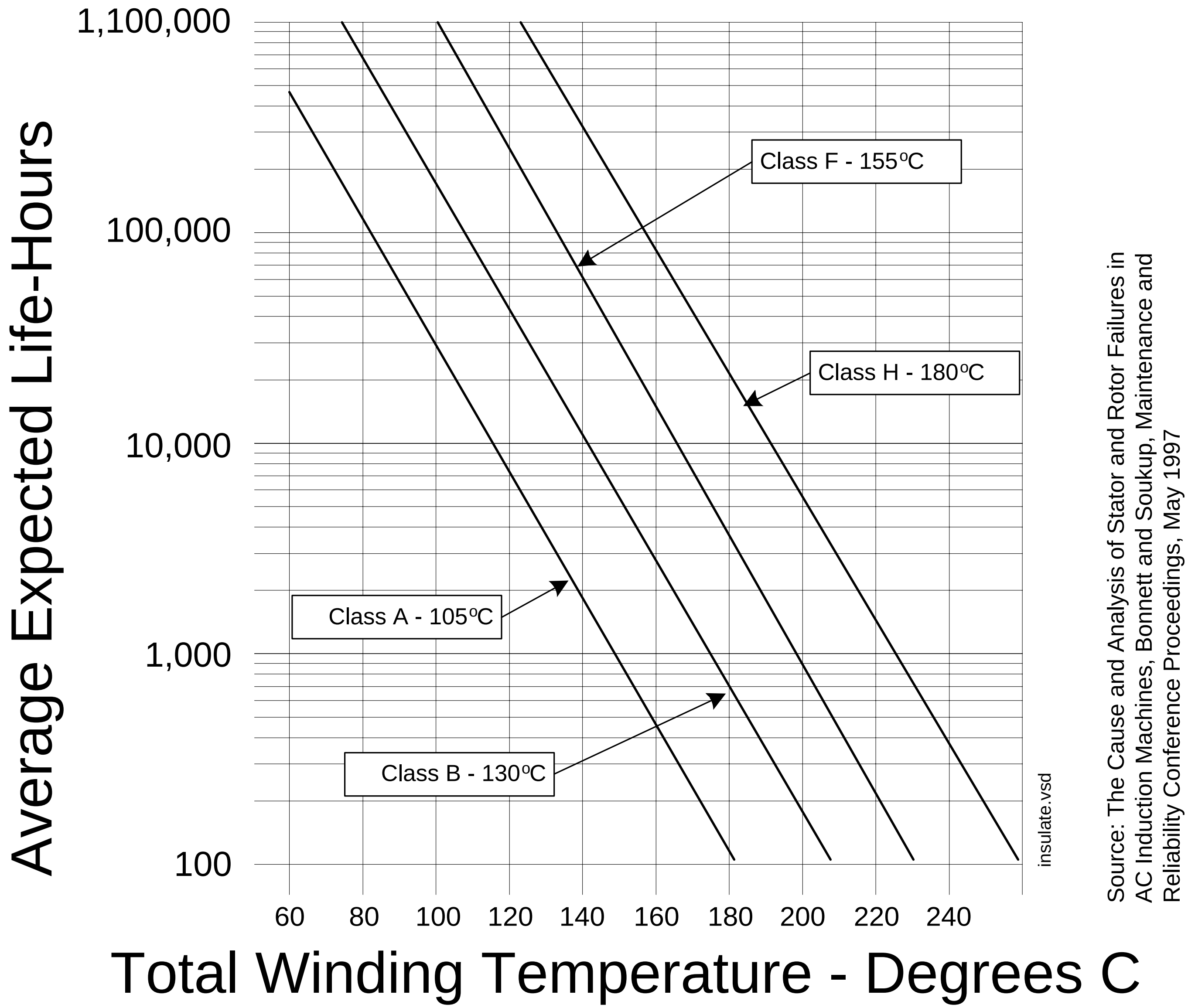
IEEE Maintenance Good Practices Working Group Study of Commercial and Industrial Motors, 1989

Insulation

- **Minimum Insulation Resistance is R_m = kV + 1.**
  - **R_m = megohms at 40°C**
  - **kV = rated machine terminal to terminal voltage (RMS).**
- **Proposed change to IEEE standard will make this 100 megohm.**

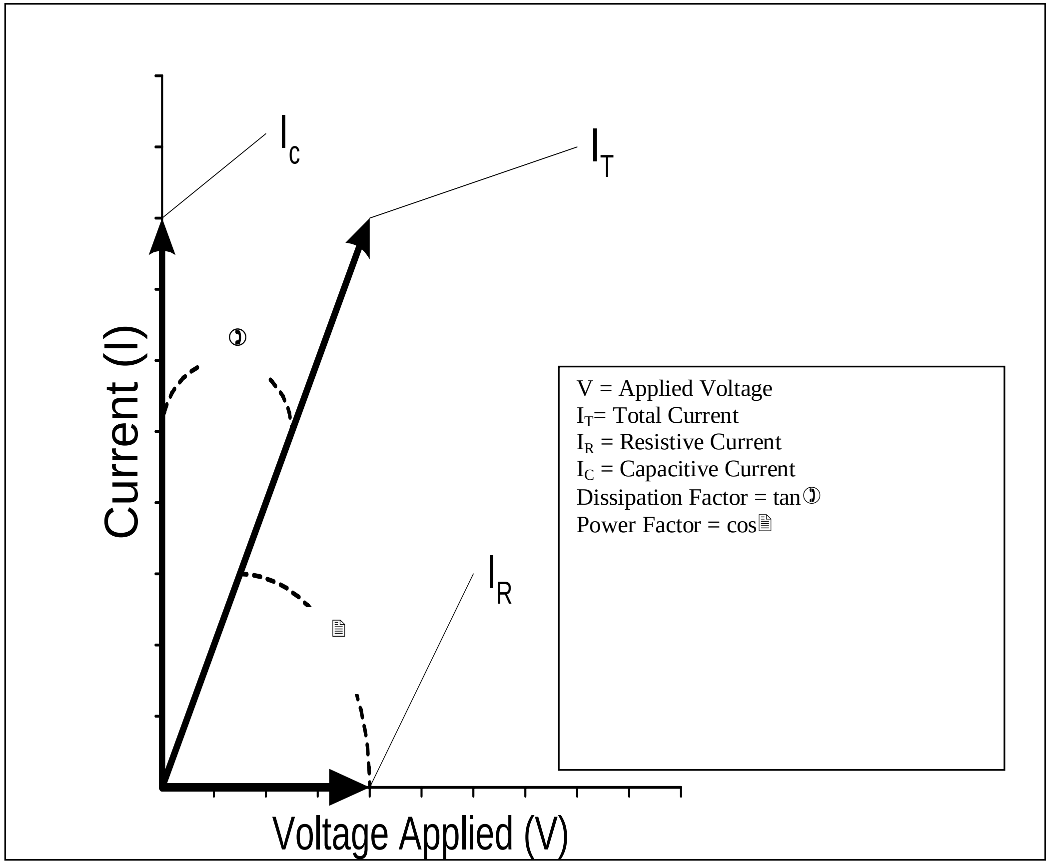
Under ideal conditions, modern insulation systems can be expected to have life cycles in excess of 100,000 operating hours.

- Hodowance and Bezesky, Field Motor Testing: Limiting Risk, IEEE Industry Applications Magazine, May/June 1999


1,100,000
100,000
10,000
1,000
100
Average Expected Life-Hours
Class F - 155ºC
Class H - 180ºC
Class A - 105ºC
Class B - 130ºC
60
80
100
120
140
160
180
200
220
240
Total Winding Temperature - Degrees C
insulate.vsd
Source: The Cause and Analysis of Stator and Rotor Failures in AC Induction Machines, Bonnett and Soukup, Maintenance and Reliability Conference Proceedings, May 1997

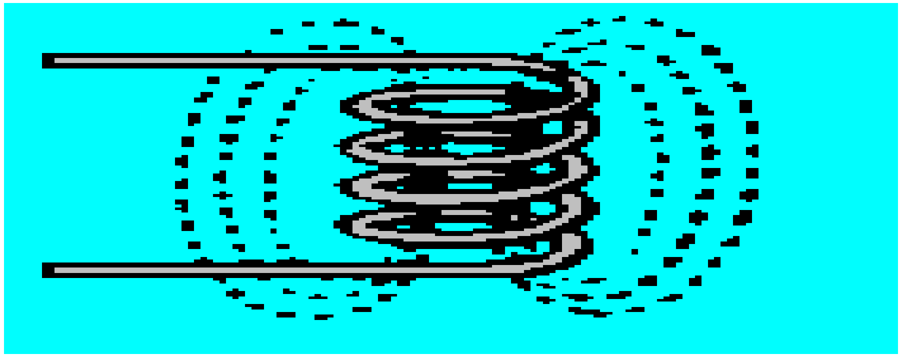
Insulation Power Factor

- **Insulation Power Factor, sometimes referred to as dissipation factor, is the measure of the power loss through the insulation system to ground.**
- **To measure this value a known voltage is applied to the insulation and the resulting current and current/voltage phase angle is measured.**
- **I_R is the resistive current**
- **I_C is the capacitive current**
- **I_T is the resultant, or total current**
- **V is the applied voltage.**



Inductive Imbalance

- Calculated from phase to phase inductance readings measured in mH
- Indicates imbalance generated from rotor or stator anomaly.
- Highly sensitive parameter
- Trendable



Impact of Voltage Imbalance

- **"A modest phase imbalance of 2% can increase losses by 25%."** Nadal, et al, Energy Efficient Motor Systems, 1991
- **"A 3.5% voltage imbalance can produce as much as a 25% increase in temperature rise of at least part of the winding."** Handbook to Assess the Insulation Condition of Large Rotating Machines, EPRI, 1991
- **"Excess heat generation in a motor running on a 2% unbalance can reduce insulation by a factor of 8."** Energy Efficient Electric Motors: Selection and Application, 1982

Oil Tests for Transformers

Oil Condition Tests and Limits for New Oil	
Color	<3.0 on the ASTM D-1524 color scale
Dielectric Breakdown	>30 kV
Power Factor	<0.15 at 25^{o}C
Karl Fischer (Water in the Oil)	<25 ppm at 20^{o}C
Interfacial Tension	>40 dynes/cm
Acidity (Neutralization Number)	<.05mg KOH per gram oil

Why Perform Oil Testing on Transformers

- **Establish a baseline**
- **Ensure transformers have not been damaged during installation**
- **Check for contamination**

IMPLEMENTATION:

Contract Clauses

Procurement Specifications

- Architect/Engineering (A&E) Contracts (Table 7 - 11)
- Construction Contracts (Table 7 - 12)
- Equipment Procurement Contracts (Table 7 - 13)
- Maintenance & Repair Contracts (Table 7 - 14)

Procurement Specifications - Early Wins

- **Equipment requires proper installation to control life cycle costs and maximize reliability.**
- **Poor installation often results in problems routinely faced by both maintenance personnel and operators.**
- **Rotor balance and alignment, two common rework items, are often poorly performed or neglected during initial installation.**
- **The adoption of precision standards can more than double the life of a machine.**

Measurements And Measurement Data

- **When measurements or surveys are required by a contract clause, the contractor shall furnish to the Customer the following information concerning the equipment used to make the specified measurements:**
- **List of all test equipment used including manufacturer, model number, serial number, calibration date, certificate of calibration, and special personnel qualifications required.**
- **If the contractor uses an equivalent test or procedure to meet the requirements of the contract specification, the contractor shall provide to the Customer proof of equivalency.**

Bearing Information

- **The contractor shall provide to the Customer section drawings that show the component arrangement for all rotating equipment supplied under the contract. The section drawings shall accurately depict the bearing support structural arrangement, be drawn to scale, and show the dimensions to the center line of all rotating shafts.**
- **The contractor shall provide to the Customer the bearing manufacturer, part number, and bearing number for all bearings used in all rotating equipment supplied under this contract. The information shall be included on the sectional drawings for each bearing location.**
- **The required equipment data the contractor shall provide the Customer under this contract shall include the operating speed.**

Gearbox Information

- **The contractor shall provide to the Customer the type and number of teeth on each gear used in the gearbox and the input and output speeds and gear ratios. This information shall be included on the sectional drawings which must be to scale and be specific to gear location.**

Pumps

- **The contractor shall provide to the Customer the following information on all pumps supplied under the contract:**
- **Number of pump stages**
- **Number of pump vanes per stage**
- **Number of gear teeth for each pump gear**
- **Type of impeller or gear(s)**
- **Rotating speed**
- **Number of volutes**
- **Number of diffuser vanes**

Centrifugal Compressors

- The contractor shall provide to the Customer the following information on all centrifugal compressors supplied under the contract:
- Number of compressor sections
- Number of blades per section
- Number of diffusers
- Number of vanes per diffuser
- Number of gear teeth on drive gear
- Number of driven shafts
- Number of gear teeth per driven shaft
- Rotating speed

Fans

- Type of fan or blower
- Number of rotating fan blades/vanes
- Number of stationary fan blades/vanes
- Rotating speed(s)
- The contractor shall provide to the Customer the following additional information if the fans/air handlers are belt driven:
- Number of belts & belt lengths
- Diameter of the drive sheave at the drive pitch line
- Diameter of the driven sheave at the drive pitch line
- For all fans supplied under the contract, the contractor shall ensure sufficient access to the fan is present to allow for cleaning and in-place balancing of the fan.

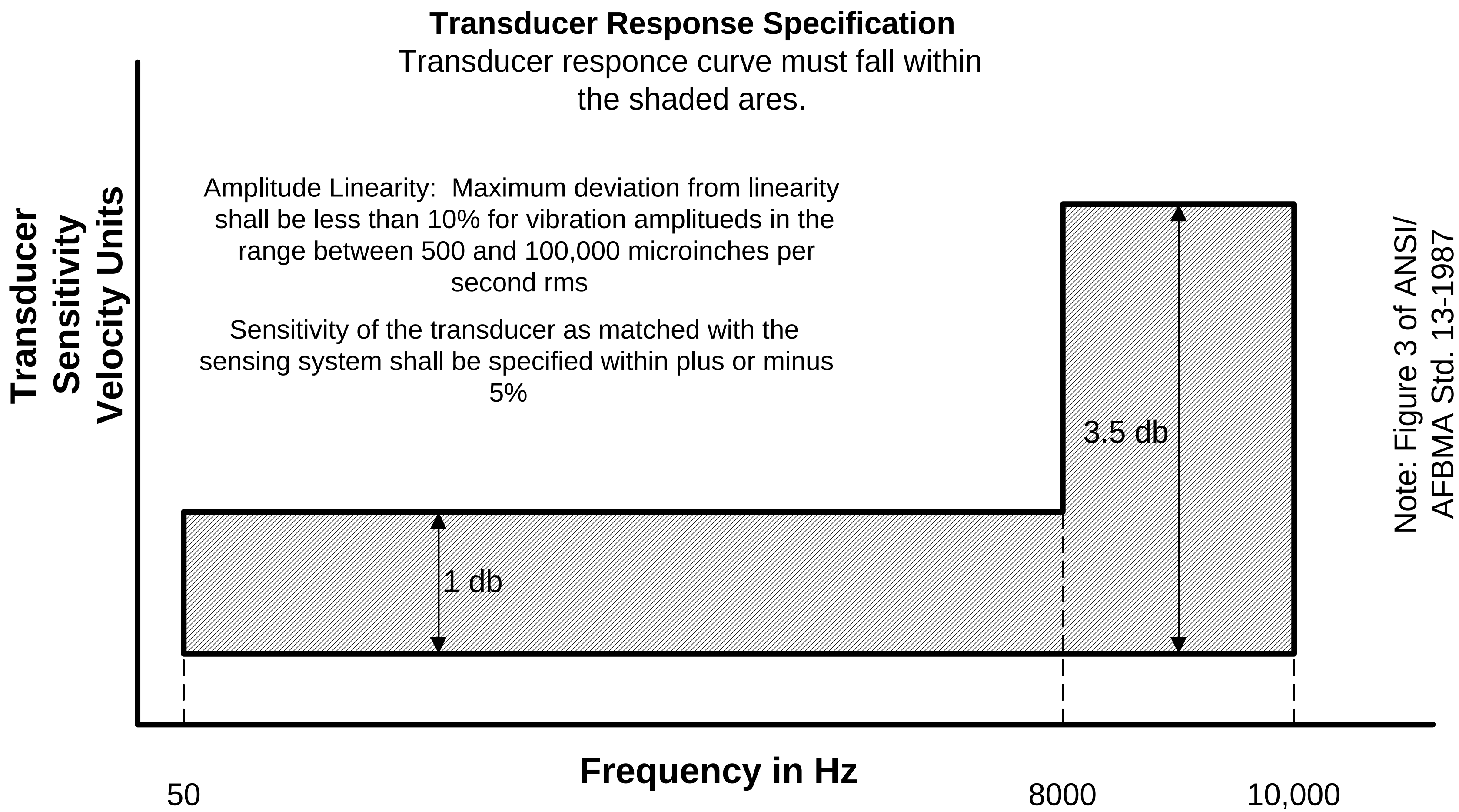
Vibration Monitoring

- **The contractor shall provide to the Customer the following information for all equipment where a vibration specification is included in the contract.**
- **Type of instrumentation and sensors**
  - **The contractor shall use the type of instrumentation and sensors specified. For example, for a 3,600 RPM machine an accelerometer with a sensitivity of 100 mV/g and a resonant frequency of at least 15,000 Hz is required. A rare earth super magnet and a sound disc shall be used in conjunction with any vibration data collector which has the following characteristics:**

Vibration Analyzer

- A dynamic range greater than 70 dB.
- A minimum of 400 lines of resolution.
- A frequency response range of 5Hz-10kHz (300-600,000 cpm).
- The capability to perform ensemble averaging.
- The use of a Hanning window.
- Autoranging.
- Sensor frequency response shall conform to the following figure.

Transducer Response



Vibration Data

(1) For machines operating at or below 1,800 RPM, the frequency spectrum provided shall be in the range of 5 to 2,500 Hz.

(2) For machines operating greater than 1,800 RPM, the frequency spectrum provided shall be in the range of 5 to 5,000 Hz.

(3) Two narrowband spectra for each point shall be obtained in the following manner:

(a) For all machines regardless of operating speed, a 5 to 500 Hz spectrum with 400 lines of resolution.

(b) An additional spectrum of 5 to 2,500 or 5 to 5,000 Hz shall be acquired for machines operating at or below 1800 RPM or greater than 1,800 RPM, respectively.

Vibration (cont.)

- **The contractor shall ensure that the equipment provided meets the following acceptable vibration amplitudes for each machine:**
- **The contractor shall collect vibration data at normal operating load, temperature, and speed.**
- **The contractor shall supply all critical speed calculations.**

Liquid Lubricants

- **Viscosity grade in ISO units**
- **AGMA and/or SAE classification as applicable**
- **Viscosity in Saybolt Universal Seconds (SUS) or centipoise at the standard temperature and at designed normal operating temperature. The following formula should be used to calculate SUS and absolute viscosity:**
- **Z=pt(0.22s-180/s)**
- **where:**
  - **Z = absolute viscosity in centipoise at test temperature**
  - **s = Saybolt Universal Seconds**
  - **pt = specific gravity at test temperature**
  - **t = temperature (F)**

Grease Lubricants

- **NLGI Number**
- **Type and percent of thickener**
- **Dropping point**
- **Base oil viscosity range in SUS or centipoise**
- **The following formula shall be used to calculate SUS and absolute viscosity:**
  - **Z=pt(0.22s-180/s)**

  where:
  - **Z = absolute viscosity in centipoise at test temperature**
  - **S= Saybolt Universal Seconds**
  - **Pt = specific temp @ test temp.**
  - **t = temperature (^{0}F)**

Hydraulic Fluids

- **All bulk and equipment-installed hydraulic fluids supplied under this contract shall meet the cleanliness guidelines of Table 7 - 9. The Customer will specify System Sensitivity.**
- **The particle counting technique utilized shall be quantitative. Patch test results are not acceptable.**

Insulating Fluids

- **The contractor shall identify the type of oil used as an insulating fluid for all oil-filled transformers supplied under the contract. In addition, the contractor shall test the insulating oil using the American Society for Testing Materials (ASTM) standards specified.**
- **Any deviation from the typical properties listed shall be corrected by the contractor before the Customer will accept the transformer.**

Sampling Points

- **The contractor shall install sampling points and lines as recommended by the National Fluid Power Association (NFPA). Method No. 1 is published as NFPA T2.9.1-1972 as follows:**
- **(1) For Pressurized Systems. A ball valve is placed in the fully opened position with a downstream capillary tube (ID> 1.25 mm) of sufficient length to reduce downstream pressure and control flow in the desired range. The sampling point shall be located in a turbulent flow region and upstream of any filters.**
- **(2) For Reservoirs and Non-Pressurized Systems. A 1/8" stainless steel line and ball valve is placed in the side of the oil sump or tank. The line shall be located as close to the midpoint of the structure as feasible and the sample line shall extend internally to as close to the center of the tank as possible.**

IR- Electrical

- The contractor shall perform a thermographic survey on all electrical distribution equipment, motor control centers, and transformers during the start-up phase of the installation unless the thermographic survey is waived by the Customer.
- Any defects noted by an observable difference in temperature of surveyed components or unexplained temperature rise above ambient shall be corrected by the contractor. The contractor shall resurvey repaired areas to assure proper corrective action.

IR - Piping Insulation

- **The contractor shall perform a thermographic survey on all insulated piping during the start-up phase of the installation unless the survey is waived by the Customer.**
- **Any voids in the piping insulation shall be corrected by the contractor at no additional cost to the Customer. The contractor shall resurvey repaired areas to assure proper corrective action has been taken.**

IR - Building Envelope

- **The contractor shall perform a thermographic survey of the building envelope as part of the pre-beneficial occupancy to check for voids in insulation and/or the presence of wetted insulation.**
- **The presence of air gaps in building joints such as seams, door frames, window frames, etc., shall be checked via thermographic survey using an appropriate procedure and specifications described on the following slide.**

IR - Standards

- **ASTM C1060-90 - Thermographic Inspection of Insulation in Envelope Cavities In Wood Frame Buildings**
- **ASTM C1153-90 - Standard Practice for the Location of Wet Insulation in Roofing Systems Using Infrared Imaging**
- **ISO 6781- Thermal Insulation-Qualitative Detection of Thermal Irregularities in Building Envelopes-Infrared Method ASTM E1186-87 Standard Practices for Air Leakage Site Detection in Buildings**

IR - Boilers, Furnaces, And Ovens

- **The contractor shall perform a thermographic survey during the start-up phase of installation of all furnaces, boilers, and ovens as a means of determining voids in insulation or refractory materials. Any voids detected during the survey shall be corrected by the contractor at no expense to the Customer.**
- **The contractor shall perform a thermographic survey of all repaired areas prior to final acceptance by the Customer.**

IR - Motors And Bearings

- Large machines should be scanned closely. Abnormal hot spots on the body may indicate flaws in the stator windings.
- Surface temperature of a motor is normally 7.5% lower than the winding temperature.
- Bearing temperatures are normally 5-20 degrees F higher than housing temperature.

Airborne Ultrasonics

- The contractor shall perform an airborne ultrasonic survey during the start-up phase of the installation unless the airborne ultrasonic survey is waived by the Customer.
- The contractor shall survey electrical equipment for indications of arcing or electrical discharge, including corona.
- Piping systems shall be surveyed for indications of leakage.

Complex Phase Impedance

- **Upon motor installation, the contractor shall take and provide to the Customer the following acceptance/baseline readings and measurements, first for the motor alone, and then, for motor and circuit together:**
  - **Conductor path resistance**
  - **Inductive imbalance**
  - **Capacitance to ground**

Motor Current Spectrum Analysis

- **With the motor installed and operational, the contractor shall conduct an acceptance/baseline spectral analysis on the loaded motor at 75% or greater load when specified by the Customer.**

Insulation Resistance

- **Upon installation, the contractor shall take and provide to the Customer the following acceptance/baseline readings and measurements; first, for the circuit or for the motor alone, and then, for motor and circuit together:**
  - **Polarization Index**
  - **Dielectric Absorption Ratio (for all motors)**
  - **Leakage current at test voltage**

Surge Testing

- **The contractor shall perform surge testing and high potential (high-pot) resistance testing of the motor(s) prior to their installation and Customer acceptance. The contractor shall provide to the Customer documentation of test results, including test voltage, waveforms, and high potential leakage current.**

Start-up Tests

- **With the motor installed and operational, the contractor shall collect and provide to the Customer the following baseline data:**
  - **Coast-down time**
  - **Peak starting current**

Balance (Appendix H)

- **Balance specifications, guideline, and terminology are available in the following International Organization for Standardization (ISO) documents:**
  - **ISO 1925, Balancing - Vocabulary**
  - **ISO 1940/1, Mechanical vibration - Balance quality requirements of rigid rotors - Part 1: Determination of permissible residual imbalance**
  - **ISO 5406, The mechanical balance of flexible rotors**

Pump Reliability

- **Total Pumps** **105**
- **Centrifugal Pumps** **57**
- **Ave. WO per Pump/year(97)** **4.1 - 3.2** **Prealignment/vibration analysis**
- **Ave. WO per Pump/year(98)[1]** **1.9** **Post alignment/vibration analysis**

Projected reduction in centrifugal pump repair work orders -

(4.1 to 3.2 - 1.9) X 57 = 74 to 125

Current MTBF = 12 mo./4.1 = 2.93 mo. Or 12 mo./3.2 = 3.75 mo.

Projected MTBF = 12 mo./1.9 = 6.32 mo.

Percent Change = (6.32 - 2.93)/2.93 or (6.32 - 3.75)/3.75 = 68 - 119%

1 Based on work order data from 4/15/98 - 6/12/98 and normalized for 12 months.

Projected Impact of Pump Reliability

• Total Estimated Pumps	250	
• Estimated Centrifugal Pumps	140	
• Ave. WO per Pump/year(97)	4.1 - 3.2	Pre-alignment/vibration analysis
• Ave. WO per Pump/year(98)[1]	1.9	Post alignment/vibration analysis

Projected reduction in centrifugal pump repair work orders (site-wide) per year:

(4.1 to 3.2 - 1.9) X 140 = 182 to 308

Estimated reduction in labor hours and cost avoidance per year:

2 people X 4 hrs. X (182 to 308) = 1456 to 2464 hrs.

Labor: (1456 to 2464 hrs.) X $30/hr. = $43,680 to 73,920

Parts: Estimated at $2,000/work order = $360,000 to 620,000

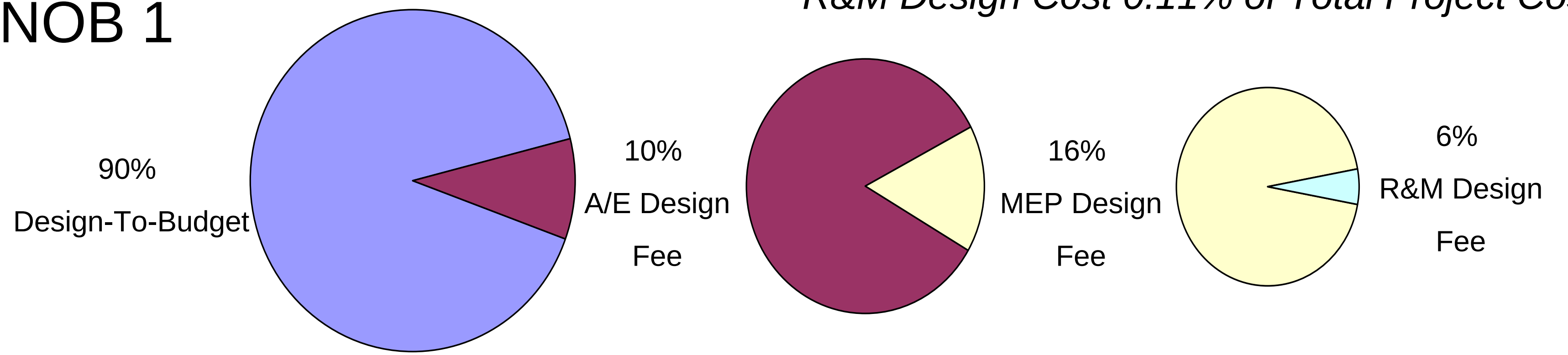
Total: $400,000 to 700,000 p.a.

1 Based on work order data from 4/15/98 - 6/12/98 and normalized for 12 months.

RCM and Design Cost

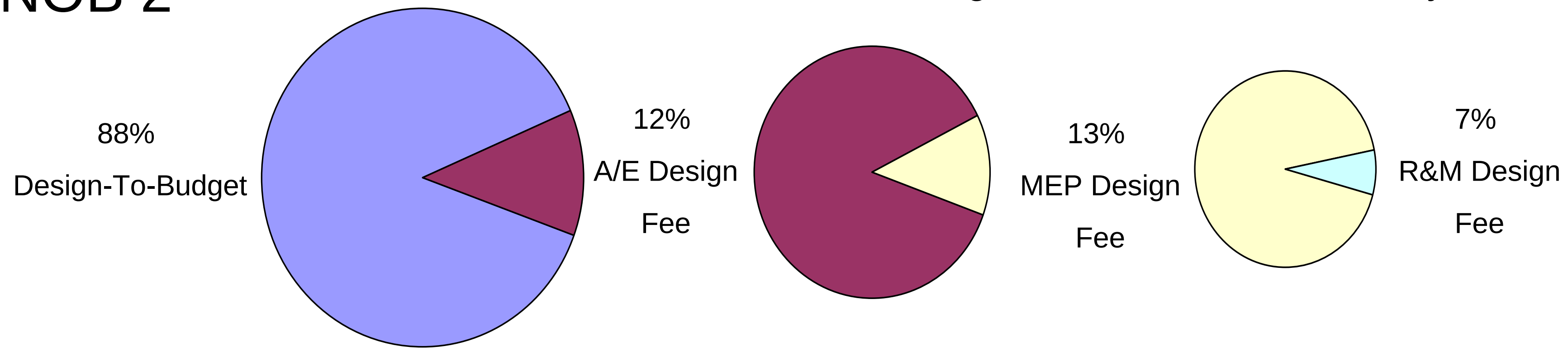
NOB 1

R&M Design Cost 0.11% of Total Project Cost



NOB 2

R&M Design Cost 0.13% of Total Project Cost



Specific Reliability and Maintainability Language has been Inserted in the SOW/RFP's for 9 NOB's and 2 Major Renovations

Source: CO Negotiation

AEDG and RCM Process

A/FBO/FAC RCM Process	AEDG Reliability and Maintainability	Compliant (Y/N)	Comments
The RCM process seeks to attain the required building and system availability at the lowest Life Cycle Cost (LCC) while meeting all standards for Security, Environmental Health and Safety and Post Mission requirements. The RCM process is to be incorporated into all designs.	3.1.3 Design Policy "….The concept of whole-building performance shall be incorporated into the design so that a balance between function, security, safety, environmental, energy, and operational factors is achieved. Sensitivity to economic costs of a building's initial construction and life-cycle operations shall reflect a commitment to providing high standards of comfort, productivity, and quality of life for its occupants." 4.4.1 Design Scope "..define design, construction, operation, and maintenance requirements for the Project." 4.4.16.1 O&M Design Guidelines "…It is during the design phase that operations and maintenance (O&M) considerations must be first addressed		

Design Process Reviewed for Operational Dependability and Maintainability

NOBs	Doha (D/B by Owner)		Dar es Salaam (D/B)		Kampala (D/B)		Istanbul (DBB)		Luan
Project Schedule							●	20-Apr-99	
D/B SOR			●		●				
Draft A/E or D/B Scope of Work			●	14-Apr-99	●		●		
Submittal Requirements			●		●		●		
Final A/E or D/B Scope of Work			●	*26-Apr-99*	●		●	06-May-99	
Revised AEDG Chapter 3.5 Incorporated					○	*May-99*	○	*May-99*	
Space Program			●	*23-Apr-99*			●	*20-Apr-99*	●
Preliminary IGE			●	*23-Apr-99*	●				
Final IGE									
Pre-Proposal Meeting Questionnaire				*21-May-99*				*28-Jun-99*	
Proposal Review				*04-Aug-99*		*07-Jun-99*		*15-Jul-99*	
Re-design document review									●
Value Engineering			●	14-Apr-99					●
Competition Evaluation Summary			●	20-Apr-99					
Competition Presentation					●	06-May-99			
Description of Design Review Process			●	14-Apr-99					
10 % (Concept/Schematic) design review								*13-Dec-99*	●
35% (Design Development) design review								*28-Feb-00*	

Communications

- Design tasks sent to M&O for review
- Accountability defined for review
- Scheduled negotiated and confirmed
- Review tracked by central document control
- No comments by M&O within negotiated time frame means acceptance

Review

1 Background

- Introduction to RCM & Purpose of Guide
- Why Do RCM & Responsibilities
- Reliability Centered Facilities and Equipment Acceptance Intent

2 Acceptance Testing

- What is Acceptance Testing
- PT&I Technologies
- Inspection and Testing Technologies
- Thermodynamic Performance & Operational Tests

3 Acceptance Standards

- Overview of Facilities and Collateral Equipment
- Structures/Mechanical Systems/Electrical Systems

4 Contract Clauses and Specifications

- Predictive Testing and Inspection (PT&I) and Acceptance Testing
- Testing and Measuring Equipment
- Technical Manuals/Data
- Equipment Data

A. Resources

B. Referenced Specifications

C. RCM Acceptance Data Sheets

D. SPECSINTACT Clauses with RCM Applications

E. Glossary

Pre - Acceptance Testing Requirements

- **Must act before building or procuring machines.**
- **Limit the variety of machines and parts.**
  - **Reduce inventory costs.**
  - **Reduce likelihood of installing wrong parts.**
- **Specify Condition Monitoring capability.**
  - **Access for testing or sampling.**
  - **On-line monitoring.**

RCM and Commissioning

- **Process of testing and accepting a facility/system**
- **Use FMEA to determine what to test**
  - **What are all the functions?**
- **Are there hidden failures involved?**
- **System performance. Does the system do what the specification requires?**

Often Overlooked

- **Life-cycle availability issues**
- **Hidden defects (often caused during installation)**
- **Specification errors or substitution by suppliers**
  - **Oversized resulting in inefficiency.**
  - **Incompatible with other components or material.**

PT&I can be a valuable tool in the acceptance of new building systems.

What is the Impact of...

- **Balance**
  - **Mechanical**
  - **Electrical**
  - **System thermodynamics**
- **Alignment**
- **Fluid cleanliness**
- **Electrical performance**
- **Mechanical integrity**

Small differences in performance significantly increase Life Cycle Cost

The First Step: Sample Motor Specifications

- **Max 5% Inductive Reactance in any one phase vs average of all phases.**
- **Max 3% voltage drop due to resistance imbalance.**
- **Min of 500 Megohm insulation resistance.**
- **Polarization Index (IEEE) of 3.**
- **Rebuild - core loss: none. (EASA tech note 17 - Oct 1992)**
- **Balance : ISO Grade G1.0 (ISO 1940/1)**
- **Aligned IAW guidelines of Table 3 - 2 (Appendix I)**
- **Flat feet within 0.005 (IEEE 841-1994)**
- **Sound power level less than 80dBa (IEEE 85 for measuring).**
  - **Also expected for any rotating machine.**

Information from paper presented at the 6th Annual Predictive Maintenance Technology Conference (1994) and printed in P/PM Technology, Volume 8, Issue 4 - August 1995, Developing Corporate Standards and Specifications, Page 68 - 75.

Three Fans… Which One Do You Want To Buy?