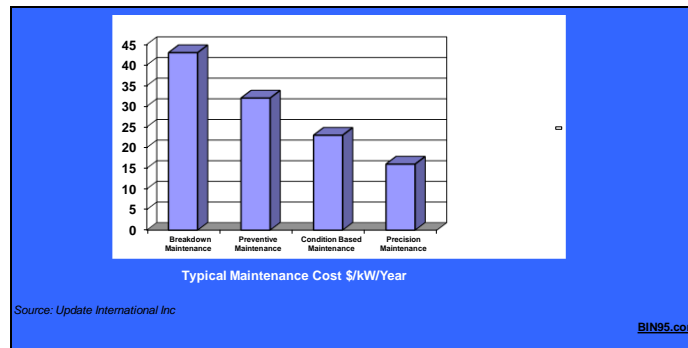


Precision Maintenance Training

This PDF is the precision maintenance training section of the [rotating machinery reliability course](#). For world-class machinery reliability, understanding what is precision maintenance, is critical.

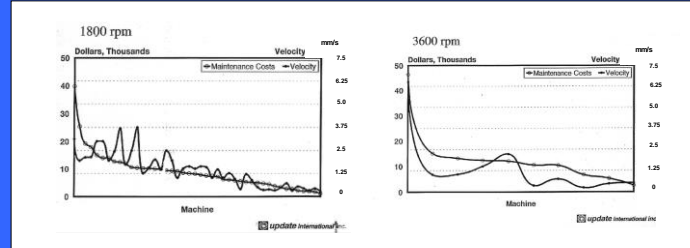
A Powerful Business Case



The graph above shows the relative costs of the maintenance strategies currently available to industry. Precision maintenance cost the least of them all.

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Precision is a Serious Opportunity



Machine Vibration to Maintenance Cost				
Machine Type	Highest Velocity mm/s	Dollars Spent Last Year	Lowest Velocity mm/s	Dollars Spent Last Year
Single Stage Pumps	5.6	\$3,200	2.0	\$650
Multi Stage Pumps	4.8	\$6,100	1.5	\$1,100
Major Fans & Blowers	9.0	\$900	2.8	0
Single Stage Turbines	3.8	\$8,200	1.0	\$2,000
Other Machines	7.8	\$11,850	3.0	\$3,700



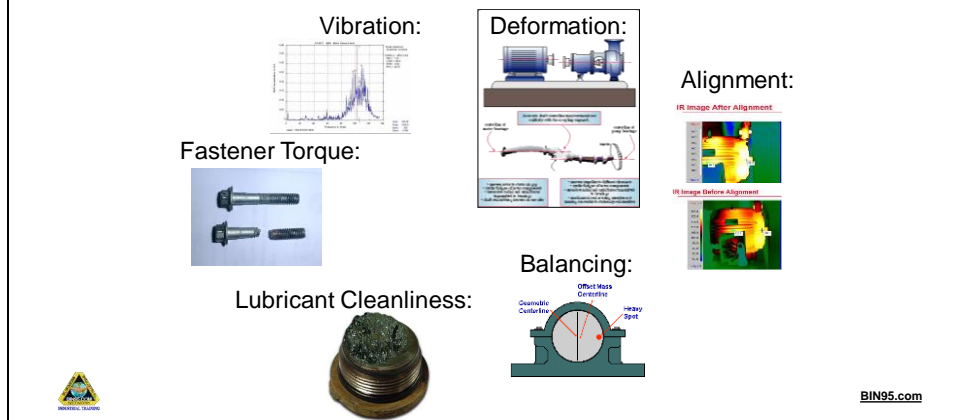
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Precision Maintenance means working to high accuracy. The charts show how the cost of maintenance falls as the vibration levels on a machine falls. They show equipment vibration verses their maintenance costs. They tell a remarkable story – when machine vibration levels fall, so do the maintenance costs; dramatically at first, then gradually and continually, as precision skills and use improve. That means that **your machinery is not breaking down**. It is running brilliantly for longer. Your plant availability, throughput and productivity are maximised when precision maintenance and precision operation are used. You have more time to make more product, at less cost, to sell for more profit.

The table shows results of an equipment vibration survey in a large industrial facility. Vibration levels of equipment in the operation were measured and the maintenance costs for the same items of plant were collected. The table shows that maintenance costs for equipment with low vibration levels was about 75-100% of that for machines that ran rough. The message is clear – getting great reliability is possible if you set and work towards high standards. Insist on:

- precision balance specification of G1.0
- precision alignment standards of 0.002" or less, depending on operating speed.
- precision fit and tolerance standards
- precision torque standards for mechanical and electrical equipment
- precision lubrication standards that include microscopic particle contamination control procedures

Precision Standards to Set, Use and Keep



When it comes to mechanical equipment the 6 critical standards listed in the picture above must be set and kept. It is necessary to spend the effort in researching and specifying them for your operation. Once they are determined, communicate them to the engineering and maintenance staff company wide. Start using them in all situations, and for all subcontractors. If necessary, buy or subcontract with providers whatever equipment is required to meet them and train your people in how to achieve the standards in everything they do. If you want top class reliability from mechanical equipment you have no choice but to get very, very good at continually meeting those standards.

What we Know about the Business Benefits of Precision Maintenance

Ralph Buscarello, Update-International, Inc

"For those who do understand the **practical, easy-to-implement procedures**, they already know that the main results from precision maintenance and machinery improvement are:

Improved machines mean that we can **maintain more machines with less people** (less non-scheduled - less "putting out fires" - less wrong answers)

Precision maintenance allows all involved, including managers, to have **more time to think, to plan** and to **do it right the first time**

Precision maintenance not only **saves money**, but at the same time **enables more production output** as the machines **considerably increase their run time before failure.**"



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Again, precision maintenance not only saves money, but at the same time enables more production output as the machines considerably increase their run time before failure.

Tim Goshert, Cargill Worldwide Reliability and Maintenance Manager

"In the past 15 years, my experience is that few OEMs truly understand what the requirements are to have a precision-built machine. They equate 'precision' with 'it costs a lot more.' Many expect a precision-built, precision-balanced, precision-aligned machine to take much longer to build and install. This is seldom the case. **It takes attention to great detail and an educated, motivated workforce.** Many times in a competitive-bid situation, this extra detail is obtained at no cost. In other words, precision is free.

When specifying equipment to be built and installed, think 'Good Enough Never Is.' Insist on:

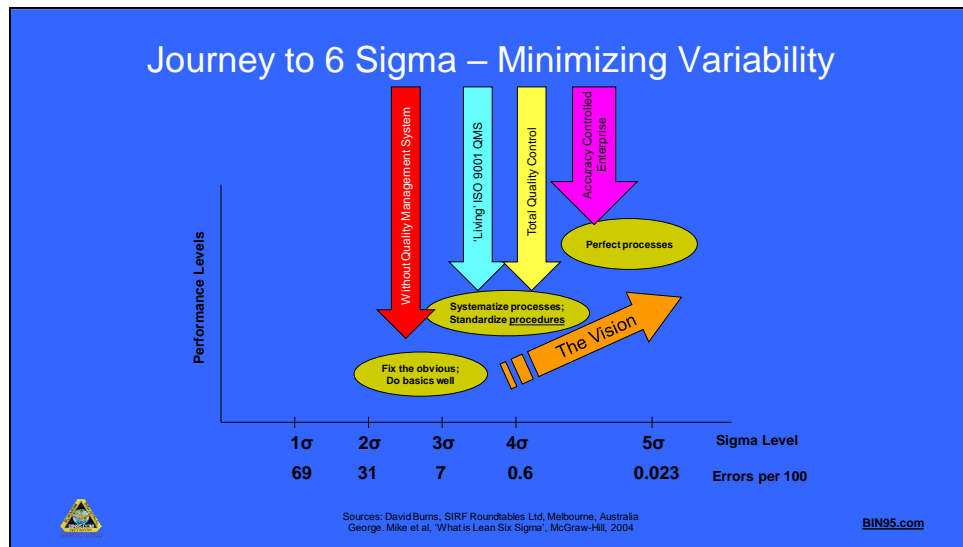
- precision **balance** specification of G1.0
- precision **alignment** standards of 0.002" or less, depending on operating speed
- precision **fit and tolerance** standards
- precision **torque** standards for mechanical and electrical equipment
- precision **lubrication** standards that include microscopic particle contamination control procedures

Precision activities are just as vital during maintenance work. Craftspeople must be educated and motivated to "sweat the details" when repairing and maintaining plant equipment. For most craftspeople, this isn't a tough sell. They want to do work right but normally are held back by the leadership and a work environment that rewards actions motivated by thoughts of 'Good Enough'."



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Summary: Remember, 'Good Enough Never Is.' Insist on precision balance, alignment, fit and tolerance, torque, and lubrication. Maintenance workers should 'sweat the details'.



The graph above illustrates the change in processes needed to reach 6 Sigma by minimizing variability. David sums it up nicely, do basic well, standardize procedures and perfect the process.

The Solution starts when Management set standards, then promote and enforce them

- Distortion
- Looseness
- Lubrication
- Cleanliness
- Shaft alignment
- Balancing
- Vibration
- Assembly
- Installation
- Tools & condition
- Skill & Competency
- Job Records
- ???
- ???
- ???



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You need to set the standards first. Then you train to become that good.

Standards are used to provide clear direction and instruction in how to do a task so that the required outcome results. They are intended to remove uncertainty and variation from performance. If done correctly, to the standard, the result will be suitable for the needs of the situation.

Standards serve a second purpose of setting the benchmark of acceptance. Anything less than the standard is unacceptable. Until the standard is reached development and training continues.

The third purpose of a standard is to provide a baseline against which audits can be compared. Reliability improvement standards are aimed at achieving near-perfection results. With standards set for such issues as those listed on the slide, the aim becomes to always be better. In doing so equipment operates in a near-perfect environment within near-perfect tolerances. This gives plant and equipment maximum chance of operating correctly without failure.

A fourth benefit of working to standards is they can be tightened to set a new level of performance. In this way you can instigate continuous improvement.

You must set the standards for the issues listed in the picture above and then ensure they are known organisation-wide and are applied and practiced by the workforce.

Typical Precision Maintenance Program Content

1. *Accurate Fits and Tolerance at Operating Temperature*
2. *Impeccably Clean, Contaminant-Free Lubricant Life-long*
3. *Distortion-Free Equipment for its Entire Life*
4. *Forces and Loads into Rigid Mounts and Supports*
5. *Laser Accurate Alignment of Shafts at Operating Temperature*
6. *High Quality Balancing of Rotating Parts*
7. *Low Machine Vibration*
8. *Correct Torques and Tensions in all Components*
9. *Correct Tools in the Condition to do the Task Precisely*
10. *Only In-specification Parts*
11. *Failure Cause Removal to Increase Reliability*
12. *A documented system to standardize work and use standards in a successful way*



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The contents of a Precision Maintenance Program (shown above) require high standards encompassing all the factors impacting the entire operating life of plant and equipment.

Alan has a question...

Bill, what do you mean by a system to deliver precision maintenance?

A system is a documented method to produce a selected outcome. You follow the system and it delivers you the outcome that it is designed to produce. When precision maintenance is put into a system, and the system is used the way that it should be used, you get precision results.

So we can build a system to deliver whatever outcome we want?

Yes! In fact you won't get the outcome you want without a system. If you do get the right result then it was just good luck, not good management. The Japanese learnt the secret from Deming – standardise and then systematise!

I can see where this heading Bill. A lot more documentation and a lot more checking.

And a lot more right answers and lot more good choices that will make our plant and equipment operate at world-class performance.

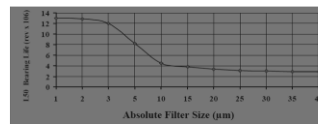


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Improve Lubricant Condition

3- Lubricant Cleanliness Control The Key to Failure Prevention

Note the increase in plant life associated with moving from a 10 micron filter to a 3 micron filter (200%) compared with moving from a 40 micron filter to a 10 micron filter (50%).



Pacific Power International - Advanced Solutions for Outstanding Performance

Water % in oil	% Bearing life remaining
0.01	100
0.05	38
0.15	20



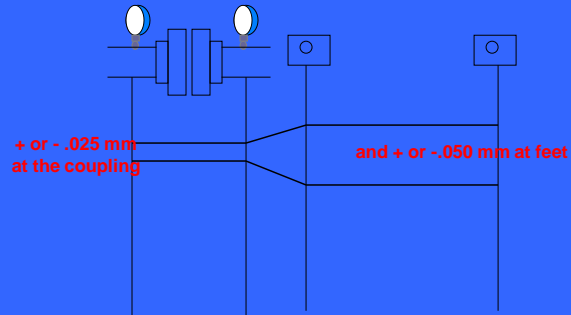
Precision Maintenance

ISO 4406 Scale Number	Particles per milliliter	
	More Than	Less Than
22	20000	40000
21	10000	20000
20	5000	10000
19	2500	5000
18	1300	2500
17	640	1300
16	320	640
15	160	320
14	80	160
13	40	80
12	20	40
11	10	20
10	5	10
9	2.5	5
8	1.25	2.5



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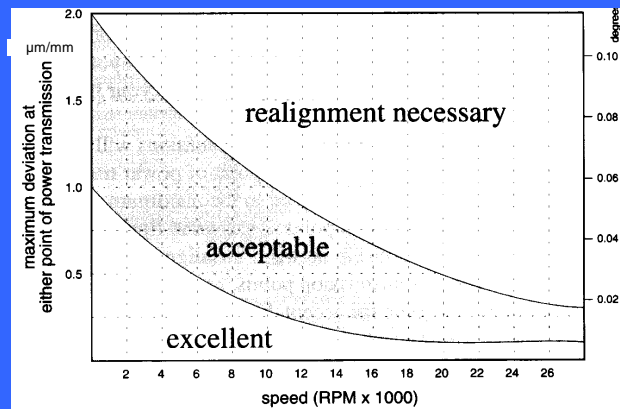
Update International Machinery Improvement Alignment Tolerance Recommendation



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Misalignment Tolerance Guide

By John Piotrowski

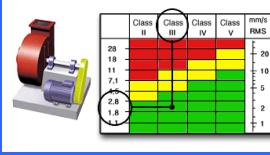


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Define Allowable Vibration Severity

- ISO 7919 – measuring vibration of rotating elements
- ISO 10816 – measuring vibration of non-rotating parts
- ISO 13373 – vibration condition monitoring

RANGES OF VIBRATION SEVERITY		QUALITY JUDGEMENTS			
RMS Velocity (mm/s RMS)		I	II	III	IV
0.28	A				
0.45					
0.71					
1.12	B	A			
1.50	C	B			A
2.00			B		
4.50		C			B
7.10	D		C		
11.2				C	
18.0		D			C
28			D		
45					D



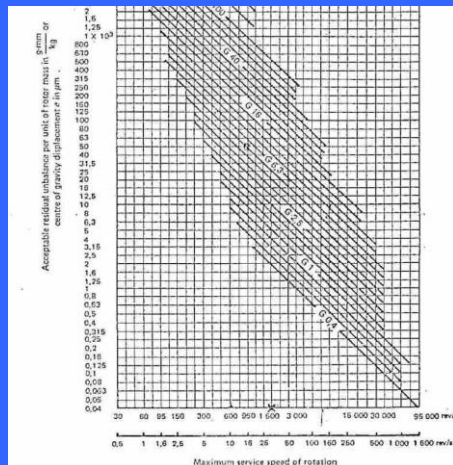
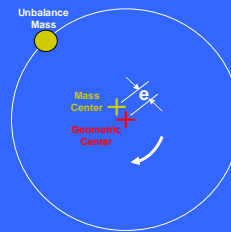
Measure 'base line' vibration at start-up for two reasons;

- 1 Trending future changes
- 2 Monitoring assembly and installation quality



Replace Unbalance with Balance

Unbalance is “the unequal distribution of the weight of a rotor about its rotating Centerline” resulting in the eccentricity ‘e’
The balancing standard ISO 1940 gives the recommended eccentricity to achieve optimum machine life



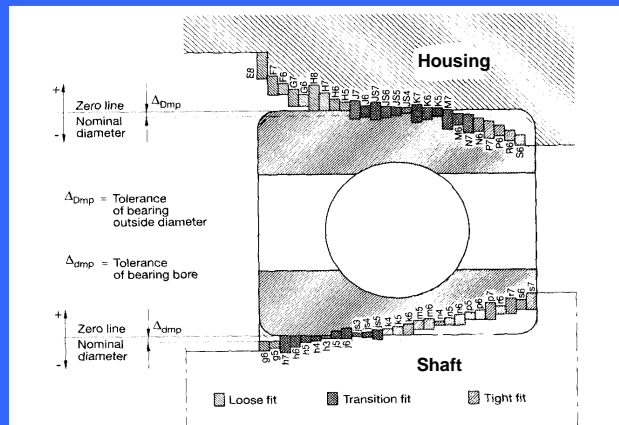
Extract from ISO 1940 showing relationship of rotor eccentricity against service speed to give balance quality.

For optimum results
use G1.0

Note; API uses equivalent of G 0.8



Correct Shaft and Hole Fits



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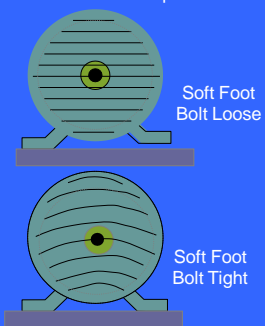
Our modern industrial society depends on international and readily available standards for measuring, interchangeable part manufacture, and mass production manufacturing. Today, most manufacturing, including that of rolling bearings, is done to the ISO System of Limits and Fits.

Soft Foot

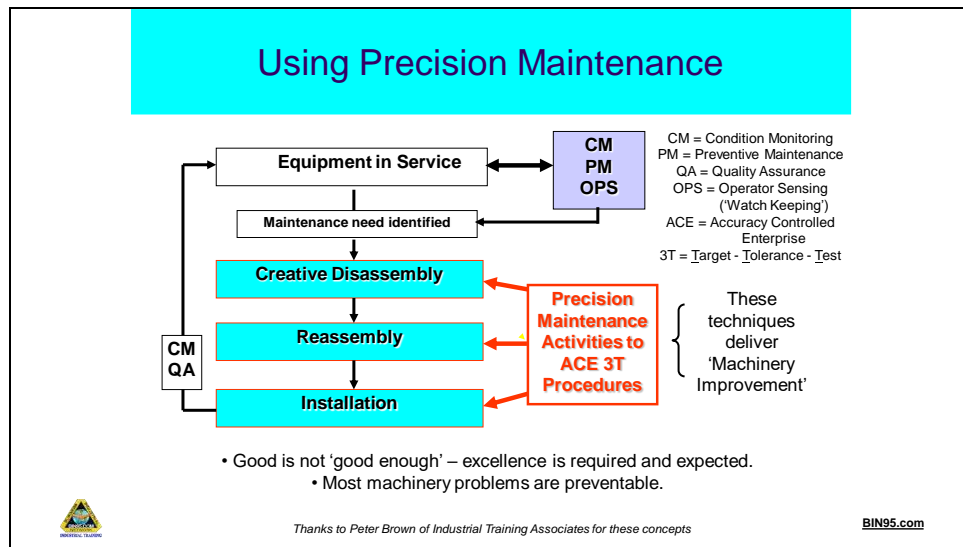
will manifest as excessive vibration

Distorts Armature Air Gap - causes eccentric operation

Affects on Alignment from Soft Foot Distortion



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Precision skills come into play –

- in the disassembly of equipment for maintenance and corrective work. It is when the information is gathered to identify the root causes of failure and to provide feedback information contributing to redesign to eliminate failure and unnecessary maintenance.
- during reassembly and repair of equipment to ensure quality work takes place; attention to fits and tolerances, fitting of bearings and other components etc.
- during installation to ensure foundations and substructures are sound and highest alignment standards are met.

The process of moving **Toward Improved Plant Reliability** through **Precision Skills** requires a significant change in attitude and thinking at all levels in the maintenance organisation.

- A Change in Philosophy
- FROM detecting problems and fixing them, which is REACTIVE.
- TO prevent failures from happening in the first place, which is PROACTIVE.
- Good is no longer good enough – excellence is to be expected.
- Most machinery problems are preventable.
- Everyone in the organization has a role.

Creative Disassembly

Creative disassembly is necessary ...

- to provide information to assist with removing causes of failure
- to ensure a machine or system is not returned to service with the same problems that took it out of service
- as part of the process of improving reliability

Three phases of collecting evidence on equipment are:

- **Prior to shutdown**
- **Shutdown, but prior to Strip-down**
- **Strip-down**



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The Precision Maintenance mind set makes it necessary to remove the causes of failure as part of doing a repair. The process to adopt is known as 'Creative Disassembly'. The equipment parts provide the evidence of their demise. From the failure evidence, an analysis is conducted to identify the causes. Once the causes are known they are permanently corrected. Creative Disassembly follows a three-step process in which evidence is carefully collected to be sure the real cause(s) are found.

Creative Disassembly – Pre-shutdown of Equipment

Gather historical and background data whilst still in service ...

- vibration, bearing, thermography, oil data for diagnostic purposes. Look at this for varied process conditions
- check for running 'soft-foot' (machine distortion when at operating under load)
- look for resonance in machine, structure, pipe work, other attachments
- look at the equipment's maintenance history for tell-tale evidence



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Improving machinery reliability starts with knowing where its current problems are. That information can be found from the equipment's history and by collecting evidence of its poor performance and condition while it is running.

Creative Disassembly – At Shutdown

Before Strip-down ...

- where thermal growth is important for alignment, obtain hot alignment readings while still at operating temperature
- look for witness marks, evidence of shifts or relative movement
- check for static soft foot (machine distortion when at stand-still)
- sample lubricants and other fluids



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When the equipment is shutdown look for evidence of abnormal operation and condition.

Creative Disassembly – At Strip-down

- Look for witness marks, evidence of fretting etc
- Disassemble in clean and well lit areas
- Photograph damage if applicable
- Avoid damaging during removal
- Mark the relative locations of bearings in housings, top and side, inboard and outboard
- Gearing wear patterns - eccentricity, backlash, misalignment etc



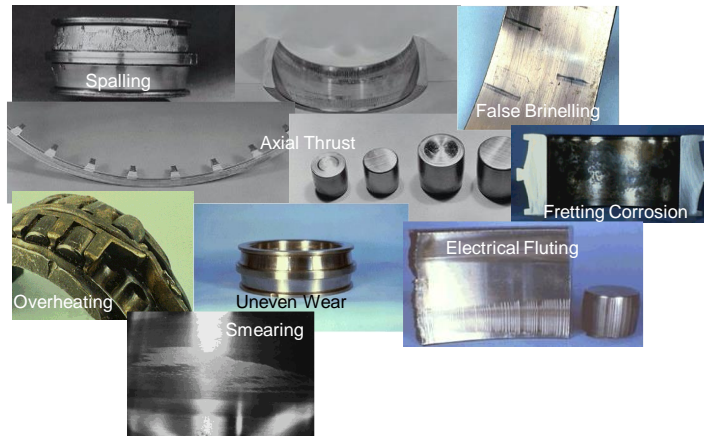
Inspection of bearings ...

- when removed, prior to cutting
- cut the cage/retainer rather than springing it
- cut outer race from top Center to bottom Center
- re-inspect prior to cleaning
- filter solvents to see what is in the bearing
- analyse bearing and ball path patterns
- spalling patterns revealing poor fitting
- fitted surfaces revealing fretting, out of roundness etc

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As the machine is stripped down look for evidence in its parts and assemblies for signs of what has been happening to it during use. Every part 'tells' us the story of its life; if we look for it.

Tell-tale Bearing Failure Signs



Each of these pictures of failed bearings tell the story of what caused its demise. When bearings are removed look at the 'story they tell' before throwing them into the bin. You will very likely be able to find the cause of the failure and fix it while doing the job.

Set Standards for Condition and Use of Tools and Equipment



Calibrated?
When?



Rounded Nuts OK?



A Precision Tool?



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Typical Standards for Precision Maintenance Program

1. *Accurate Fits and Tolerance* – ISO/ANSI Shaft/Hole Tolerance Tables
2. *Clean, Contaminant-Free Lubricant* – ISO 4406
3. *Distortion-Free Equipment* – Shaft Alignment Handbook - Piotrowski
4. *Forces and Loads into Supports* - Shaft Alignment Handbook
5. *Accurate Alignment of Shafts* – Shaft Alignment Handbook
6. *High Quality Balancing of Rotating Parts* – ISO 1940
7. *Machine Vibration* – ISO 10816
8. *Correct Torques and Tensions* – ISO/ASME Bolt, Stud and Nut Standards
9. *Correct Tools in Condition* – 'As-New specification'
10. *Only In-specification Parts* – OEM specifications, Machinery Handbook
11. *Failure Cause Removal* – '5 Why' ; RCFA
12. **A system to use the standards successfully** – ACE 3T Procedures



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Developing Precision Skills

- **In-house precision skills training** *(coaching on-the-job; maximum skill and knowledge transfer)*
- **Third-party training providers** *(classroom training needs to be supported with practice bench)*
- **Center of Excellence** *(The 'Precision Room' is a place to practice doing everything in perfection)*



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3Ts of Failure Prevention



Target Tolerance Test

The Standard

The Degree of Accuracy


Proof of Precision



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The Accuracy Controlled Enterprise

“An organisation that applies 3T accuracy control procedures at every level of operation.”



Task Step No.	Task Step Owner	Task Step Name (Max 3 - 4 words)	Full Description of Task (Include all tables, diagrams and pictures here)	Test for Correctness	Tolerance Range			Record Actual Result	Action if Out of Tolerance	Sign-off After Complete
					Good	Better	Best			

An Accuracy Controlled Procedure Layout



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The way we write our procedures needs to change to the layout shown in the slide. This layout makes it clear to users exactly what they must achieve in every task. Each task has a boundary and test to confirm compliance. The only 'rule' is that no new task is started until the previous task is proven to be done right.

With the ACE 3T layout you still use your current procedures' text. The one new requirement is to incorporate the 3Ts to provide the statistical control needed to ensure task accuracy.

The meeting ends...

None of what we discussed today is beyond us Alan. Companies that have adopted Precision Maintenance and Precision Operation become world-class companies.

I can understand how they do it Bill. It is clearly an excellent system for getting high accuracy.

How do you think the guys will take to it? It's going to be another change for them to make.

I think that you will be pleasantly surprised Bill. There is a lot more goodwill amongst the Crew than you think. For example, they told me their recommendations on trapping good training ideas and putting them to use. They all wanted better procedures written that included the new ideas.

That is great news Alan. It is exactly what we have to do for precision maintenance.

We're all big dreamers too Bill. We all want to do something important in our careers. Your vision is our vision too.

That is humbling to hear.



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We hope you enjoyed this precision maintenance section of the reliability course.

To download the entire [Rotating Machinery Reliability Course](#) << click link