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Setting Maintenance and Reliability Standards to Produce Outstandingly Reliable Equipment

Abstract

Setting Maintenance and Reliability Standards to Produce Outstandingly Reliable Equipment. High equipment reliability and production plant availability is an output of your business processes. A machine's reliable is at its highest when you buy it, if the installed reliability is inadequate for your needs you will suffer poor production and high maintenance costs. The decision to buy machinery is a business process outcome and the way it is installed is a business process result, hence the ensuing reliability is the product of your business processes. When you decide to improve equipment reliability you will need to use correct business processes to deliver that outcome. Be sure that you know what standards you must include in your business process documents to ensure that you get the plant and equipment reliability you want.

Keywords: precision maintenance, proactive maintenance, work quality control, work quality assurance, machinery distortion control

Just because something is built to an internationally recognised standard does not make it good, nor does it make for a risk-free choice. Figure 2 shows the International Tolerance Grade Number Table overlayed with the specified tolerance for baseplate flatness designated in the ANSI pump standard—0.375mm/m (0.005in/ft). Also shown on Figure 2 is the specified tolerance for baseplate flatness designated in the API 610 pump standard—0.150mm/m (0.002in/ft). That difference in precision, with API 610 being two-and-a-half times more demanding than ANSI, produces a real positive difference in pump reliability. API 610 pumps are designed to last many years between breakdowns; for the same service ANSI pumps will most probably last very much less.

If you buy an ANSI pump you are highly likely to buy breakdowns, problems and high maintenance costs because at up to 0.375mm/m un-flatness before the base must be rectified you have massive softfoot distortion. The API 610 pump standard instead demands that flatness be no worse than 0.150mm/m. At that level of quality you are forced to address softfoot and thereby prevent pump distortion, as a consequence you naturally get higher pump reliability. But you can do much better if you want to get really outstanding reliability. A flatness of 0.05mm/m (0.00075in/ft) is readily achievable with modern machining equipment and practices.

Be careful what standards you select for your production equipment because that choice alone can be the cause of high maintenance costs or it can forever deliver low maintenance costs. Once a bad machine selection is made the maintenance crew and the plant operators can do nothing to address it. All that is left for them to do in that situation is to keep fixing the machine when it fails.

Challenge Your Business to Meet IT5 Precision Standards

Renown precision roller bearing manufacturers require IT5 or tighter for bearing shaft journal and housing forms. That indicates that IT5 is the minimum standard of precision in order to get maximum design life from machinery. The value of setting IT5 as a target for reliability creating precision is further evidenced by the ANSI and API 610 pump comparison above—meeting IT5 flatness causes high pump reliability. Setting IT5 as a precision level for your machine parts, assemblies and equipment is a good place to start in creating high reliability equipment in your operation. You should consider setting a more demanding standard when your maintainers, suppliers and contractors can consistently deliver IT5 precision. Because if you can get IT4 precision will have even more reliable machines.

Set Precision Targets for Accuracy Controlled Reliability

It is useful to know what standards will deliver high machinery reliability. In Table 1 are listed suggestions for machinery built to precision maintenance quality. The Target Value is the ideal outcome to get. The Tolerance is the maximum allowance before rectification action must be immediately taken. The range of Tolerance is an engineering choice reflecting the consequence and likelihood of failure. The Table aims to provide advice as to what standards to set for highly reliable machinery. Because machines are designed for a wide variety of situations this table will not be suitable for all machines in all situations. The Original Equipment Manufacturer is best placed to recommend how to get high reliability from their machines.

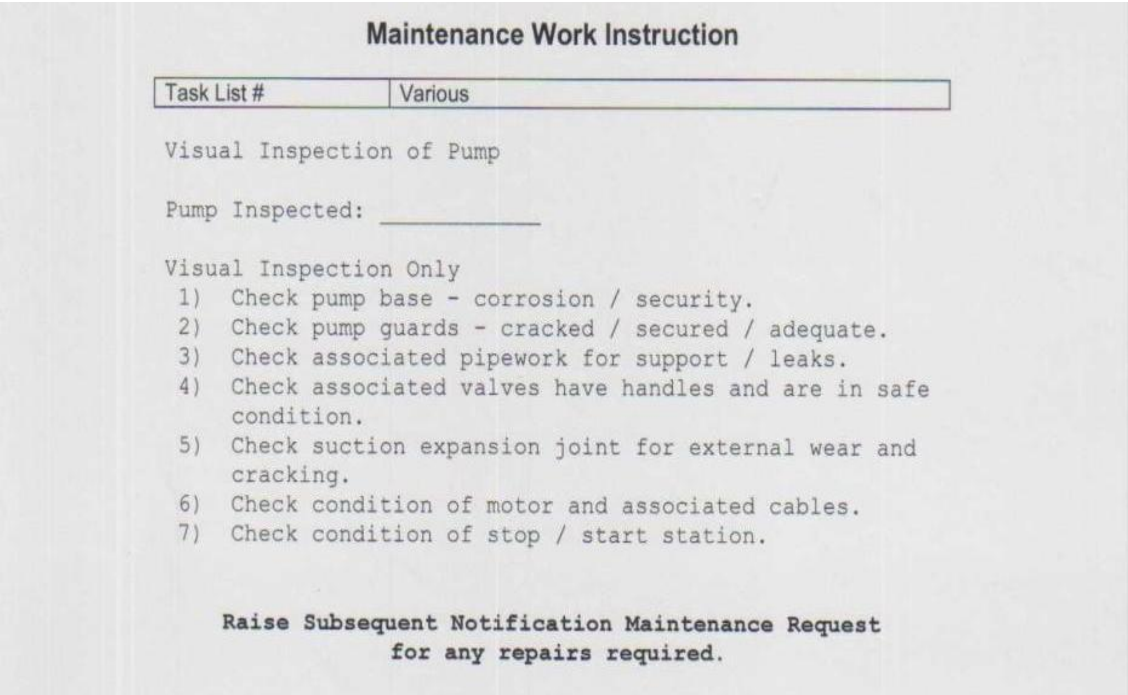
How to Make Use of Precision Standards

An example of using Table 1 is shown in Case Study 1where the quality of a shaft at the location it will carry a bearing is investigated and an unhappy surprise is discovered.

Quickly Improve Procedures with Inspection & Test Plans Specifying Quality Standards

The inspection sheet in Figure 1 will cause disasters every time it is used because there are no quality standards against which to rate the observations. The Maintainer does not know what parameter values are necessary to produce high reliability. The best thing to do is to set specific pass/reject criteria for each inspection. The simplest way out of the dilemma is to add an Inspection and Test Plan (ITP) to the work order and leave this page as is, with an added note to inform the Maintainer to do the quality checks in the ITP and record their pass/reject observations for each test.

Activity 1 at the end of this article is a little challenge for you to try. You might be pleasantly surprised at how much you know about what to do to create outstandingly reliable machinery.



Maintenance Work Instruction

Task List #	Various

Visual Inspection of Pump

Pump Inspected: ____________

Visual Inspection Only
1) Check pump base - corrosion / security.
2) Check pump guards - cracked / secured / adequate.
3) Check associated pipework for support / leaks.
4) Check associated valves have handles and are in safe condition.
5) Check suction expansion joint for external wear and cracking.
6) Check condition of motor and associated cables.
7) Check condition of stop / start station.

Raise Subsequent Notification Maintenance Request for any repairs required.

Figure 1 Roller Bearing Reliability is Compromised by the Shaft Condition

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International Tolerance Grades Table

Basic Sizes (mm)		International Tolerance Grades													
		Measuring Tools			*Materials*										
Over	**Including**	**IT 05**	**IT 06**	**IT 07**	**IT 08**	**IT 09**	**IT 10**	**IT 11**	**IT 12**	**IT 13**	**IT 14**	**IT 15**	**IT 16**	**IT 17**	**IT18**
		Fits for parts in precision and general engineering							*Large Manufacturing and Fabrication*						
1	**3**	0.004	0.006	0.010	0.014	0.025	0.040	0.060	0.100	0.140	0.250	0.400	0.600	1.000	1.400
3	**6**	0.005	0.008	0.012	0.018	0.030	0.048	0.075	0.120	0.180	0.300	0.480	0.750	1.200	1.800
6	**10**	0.006	0.009	0.015	0.022	0.036	0.058	0.090	0.150	0.220	0.360	0.580	0.900	1.500	2.200
10	**18**	0.008	0.011	0.018	0.027	0.043	0.070	0.110	0.180	0.270	0.430	0.700	1.100	1.800	2.700
18	**30**	0.009	0.013	0.021	0.033	0.052	0.084	0.130	0.210	0.330	0.520	0.840	1.300	2.100	3.300
30	**50**	0.011	0.016	0.025	0.039	0.062	0.100	0.160	0.250	0.390	0.620	1.000	1.600	2.500	3.900
50	**80**	0.013	0.019	0.030	0.046	0.074	0.120	0.190	0.300	0.460	0.740	1.200	1.900	3.000	4.600
80	**120**	0.015	0.022	0.035	0.054	0.087	0.140	0.220	0.350	0.540	0.870	1.400	2.200	3.500	5.400
120	**180**	0.018	0.025	0.040	0.063	0.100	0.160	0.250	0.400	0.630	1.000	1.600	2.500	4.000	6.300
180	**250**	0.020	0.029	0.046	0.072	0.115	0.185	0.290	0.460	0.720	1.150	1.850	2.900	4.600	7.200
250	**315**	0.023	0.032	0.052	0.081	0.130	0.210	0.320	0.520	0.810	1.300	2.100	3.200	5.200	8.100
315	**400**	0.025	0.036	0.057	0.089	0.140	0.230	0.360	0.570	0.890	1.400	2.300	3.600	5.700	8.900
400	**500**	0.027	0.040	0.063	0.097	0.155	0.250	0.400	0.630	0.970	1.550	2.500	4.000	6.300	9.700
500	**630**	0.032	0.044	0.070	0.110	0.175	0.280	0.440	0.700	1.100	1.750	2.800	4.400		
630	**800**	0.036	0.050	0.080	0.125	0.200	0.320	0.500	0.800	1.250	2.000	3.200	5.000		
800	**1000**	0.040	0.056	0.090	0.140 [API]	0.230	0.360 [ANSI]	0.560	0.900	1.400	2.300	3.600	5.600		
1000	**1250**	0.047	0.066	0.105	0.165	0.260	0.420	0.660	1.050	1.650	2.600	4.200	6.600		
1250	**1800**	0.055	0.078	0.125	0.195	0.310	0.500	0.780	1.250	1.950	3.100	5.000	7.800		
1800	**2000**	0.065	0.092	0.150	0.230	0.370	0.600	0.920	1.500	2.300	3.700	6.000	9.200		
2000	**2500**	0.078	0.110	0.175	0.280	0.440	0.700	1.100	1.750	2.800	4.400	7.000	11.000		
2500	**3160**	0.093	0.135	0.210	0.330	0.540	0.880	1.350	2.100	3.300	5.400	8.000	13.500		

Figure 2 Comparison of ANSI Pump and API 610 Pump Baseplate Flatness Standards

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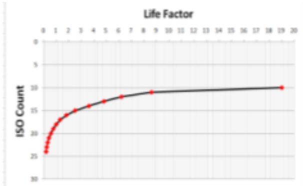
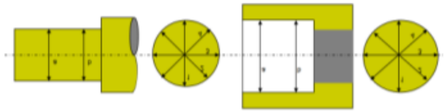
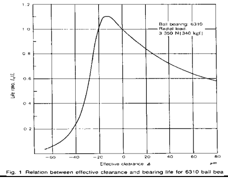
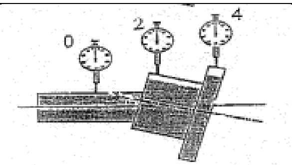
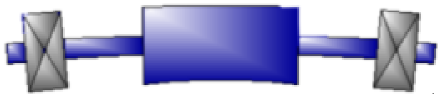
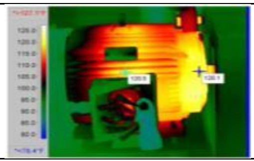
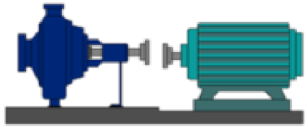
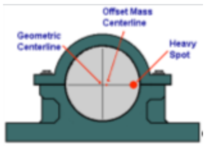
Accuracy Controlled Enterprise Standards for Creating Plant and Equipment Wellness and Machine Reliability

No	BUSINESS PROCESS FAILURE	VISUAL OBSERVATION	EFFECT ON MACHINE	LIFE PRECISION REQUIREMENT	PARAMETERS	TARGET VALUE	TOLERANCE
1	**Poor lubrication condition**	 		Chemically correct, contaminant-free lubricant	VISCOSITY, ADDITIVES, DISSOLVED WATER, WEAR PARTICLE COUNT	**Right viscosity at operating temperature; Correct proportion of additives; <100ppm water; ISO 4406 12/9 cleanliness**	ISO 4406 14/11 cleanliness
2	**Wrong fits and tolerance**			Accurate fits and tolerance at operating temperature	INTERFERENCE FIT, OPERATING TEMPERATURE	**Form IT5, Operating temperature at design conditions**	IT7
3	**Running off-centre**			Shafts, bearings and couplings running true to centre	CENTRE OF ROTATION, RUN-OUT, TOLERANCE & FORM ACCURACY	**IT5**	IT7
4	**Deformed, bent, buckled parts**			Distortion-free equipment for its entire lifetime	SOFTFOOT, STRUCTURAL DISTORTION	**IT5**	IT7
5	**Excessive loads and forces**			Forces and loads into rigid mounts and supports	DESIGN LOAD, FORCES INTO SOLID LOCATIONS, FOUNDATION RIGIDITY	**No Looseness; Safely absorb/dampen forces**	
6	**Misaligned shafts**			Accurate alignment of shafts at operating temperature	SHAFT ALIGNMENT, STRAIGHTNESS, DEFLECTION	**Coupling/Feet offset 10µm/20µm**	20µm/40µm
7	**Unbalanced rotors**			High quality balanced rotating parts	ROTOR BALANCE, CENTRE OF MASS	**G1**	G2.5

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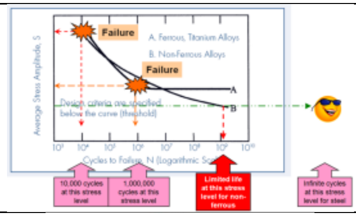
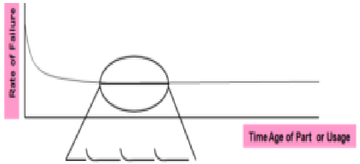
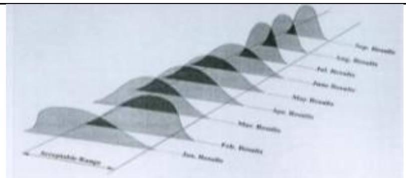
8	**Induced and forced vibration**			Total machine vibration low	MACHINE VIBRATION, MACHINE DISTORTION, STRUCTURAL RIGIDITY	**1.5mm/s rms**	4mm/s rms
9	**Incorrectly tightened fasteners**			Correct torques and tensions in all components	SHANK TENSION, LOOSENESS, FASTENER GRADE	**± 5% of correct tension**	± 10%
10	**Poor condition tools and measures**			Correct tools in precise condition to do task to proper standards	GOOD-AS-NEW CONDITION, RELIABLY CALIBRATED	**As new condition/correctly calibrated**	
11	**Inappropriate materials of construction**			Only in-specification parts	MATERIAL OF CONSTRUCTION, DIMENSIONAL SPECIFICATION	**OEM approved material and design specs**	
12	**Root cause not removed**			Failure cause removal during maintenance	CREATIVE DISASSEMBLY, DEFECT ELIMINATION	**Use Creative Disassembly and Precision Assembly**	
13	**Assembly quality below standard**			Proof test for precision assembly quality	INSPECTION TEST ACCURACY, PRECISION STANDARD	**Ensure every activity is proven correct (apply the Carpenter's Creed)**	Milestone Tasks Tested
14	**Process out-of-control and/or not capable**			A quality assurance system to make all the above happen	QUALITY CONTROL STANDARDS, PROCESS IN STATISTICAL CONTROL	**ACE 3T Procedures**	ITP (Inspection & Test Plan)
NOTE: *These parameters are indicative and may not apply to a particular machine. Confirm actual requirements with the manufacturer.*							

Table 1 Indicative Target Values for Creating High Machine Reliability

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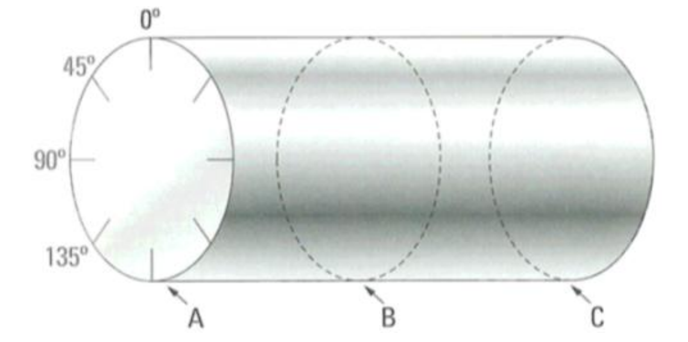
Case Study 1 – Shaft Quality Control for Bearing Reliability

With a micrometer the dimensions of a journal can be checked for suitability to remain in service. The diagram shows the positions on the journal to measure and the required tolerances that must be met. In the example a **150mm diameter** shaft is checked before mounting a bearing adaptor sleeve for a spherical roller bearing.



Shaft Diameter mm		Tolerance h9 µm		Form IT5 µm	Form IT7 µm
over	incl	high	low	max	max
18	30	0	-52	9	21
30	50	0	-62	11	25
50	80	0	-74	13	30
80	120	0	-87	15	35
120	180	0	-100	18	40
180	250	0	-115	20	46
250	315	0	-130	23	62

Tolerance Evaluation

	0°	45°	90°	135°	Required Tolerance h9
Plane A	149.98	149.99	149.98	149.99	>149.900 <150.000
Plane B	149.97	149.94	149.98	149.95	
Plane C	149.98	149.98	149.95	149.99	

Shaft tolerance is ________________________________

Cylindricity Evaluation

	0°	45°	90°	135°	Plane Average	Required IT Grade 5	IT Grade 7
Plane A	149.98	149.99	149.98	149.99		<0.018	0.040
Plane B	149.97	149.94	149.98	149.95			
Plane C	149.98	149.98	149.95	149.99			
Max-Min	**0.01**	**0.05**	**0.03**	**0.04**			

Shaft cylindricity is ________________________________

Roundness Evaluation

	0°	45°	90°	135°	Plane Max-Min	Required IT Grade 5	IT Grade 7
Plane A	149.98	149.99	149.98	149.99	**0.01**	<0.018	0.040
Plane B	149.97	149.94	149.98	149.95	**0.04**		
Plane C	149.98	149.98	149.95	149.99	**0.04**		

Shaft roundness is ________________________________

The shaft passed on tolerance but failed on form shape—it is not cylindrical enough, it is not round enough and it is tapered from the centre to each end. The roller bearing will not reach its full design life because the journal is too badly deformed. The shaft cannot support the bearing sleeve sufficiently to prevent the sleeve flexing under the load of the rollers. Figure 3 shows the problem.

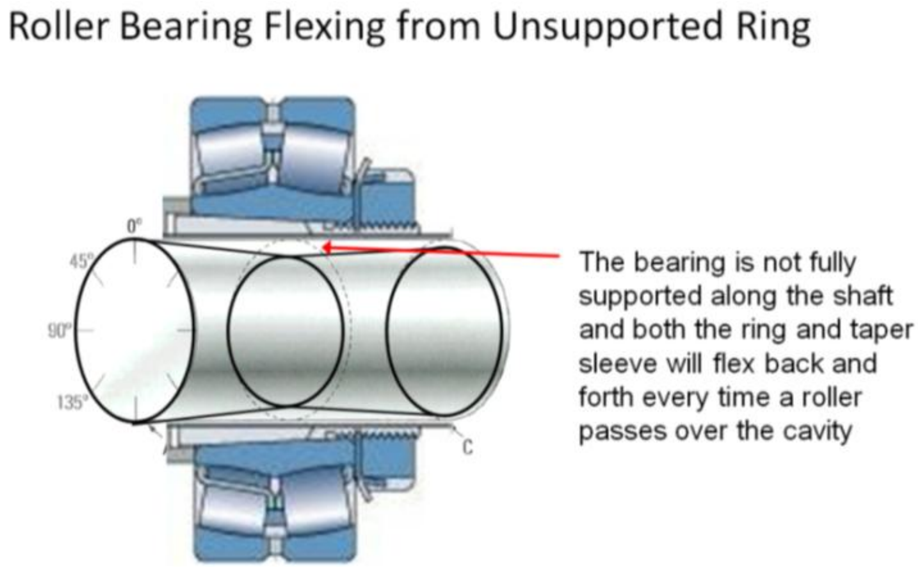


Figure 3 Roller Bearing Reliability is Compromised by the Shaft Condition

Once the problem is discovered there are very few rectification options available to us. We can leave things as we find them; we can replace the shaft with a new one; we can sleeve the shaft and make a new journal. The ideal answer is to use a new shaft if you have one, but it unlikely that you will carry that particular shaft in store (unless the Maintenance Planner had reason to buy a shaft because of just this very problem). Sleeving the shaft is feasible but that adds time to the job and it has high potential to be made wrong when people are in a hurry. Once a shaft is sleeved you have added another item into the design to trigger additional failure causes. Fitting the sleeve adds more opportunities to make the machine unreliable. Lastly, the journal can be left as is on the understanding that the machine will soon have to be taken out of service and a new shaft installed.

Notice that an IT7 value is given in the form tables. This is an engineering decision made to allow the shaft to be reused unless the form exceeds IT7. Once past IT7 the rule is the shaft must be sleeved. It is not a manufacture's recommendation; it is a risk-based site decision to keep the operation going temporarily. That choice lets the maintainers use the out-of-specification shaft to get production back in operation on the understanding that the problem will be reported so that a new shaft is purchased to be later installed. But should the shaft form be beyond IT7 the shaft will be sleeved and put back in service until a new replacement shaft is available.

If the old shaft is retained as-found or a sleeve is fitted the bearing would be immediately put under condition monitoring and performance observation to ensure that we are always aware of its condition. We might be lucky and with controlled conditions get many months of service from the shaft, or we might be unlucky and a severe operating incident will rapidly cause bearing failure.

What about Base Plate Orientation?

The use of precision standards applies to every part and configuration of a machine. Everyone in engineering, maintenance and operations needs to know what quality standards must be achieved for every part number used in a machine to ensure they get high machine reliability. An example is the baseplate on which a machine stands and provides rigid support to its structure. How flat, straight and true must a baseplate be? The allowable range of the values identified in Figure 4 must be known so that the machine baseplate can be measured and proven to be within the necessary quality that is sure to deliver the reliability that you want from that equipment item.

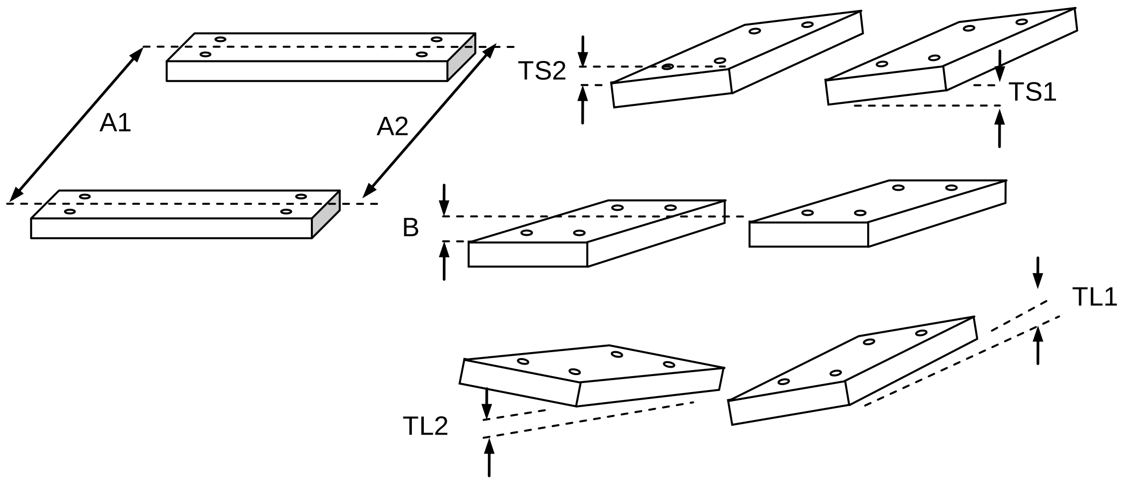
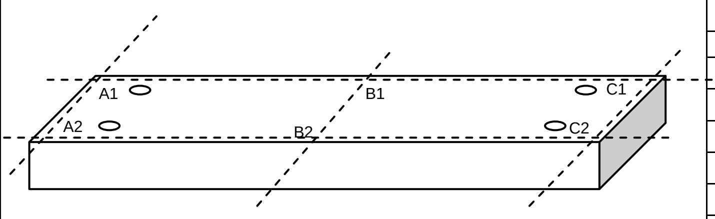


Figure 4 Baseplate Orientation Parameters to Check are within Minimum Quality Standards

A table of allowable flatness and for recording the actual form, like Table 2 shown below, is a must for every machine so that you can check if a poor baseplate is a cause of your machinery failures. As we saw with the API610 vs. ANSI pump example: you must remove softfoot distortion if you want high machinery reliability.

Measuring and Recording Base Plate Flatness



Length mm		Flatness IT5 µm	Flatness IT7 µm
over	incl	max	max
80	120	15	35
120	180	18	40
180	250	20	46
250	315	23	62
315	400	25	57
400	500	27	63
500	630	30	70
630	800	35	80
800	1000	40	90

Length of base (mm): ________________________________

Width of Base (mm): ________________________________

	Point 1	Point 2	Max-Min	Plane Average	Target IT Grade 5	Tolerance IT Grade 7
Plane A						
Plane B						
Plane C						
Max-Min						

Table 2 Prove that Baseplate Flatness is Within the Required Standard

There are many other factors to consider in order to get highly reliable machinery. To help you learn and understand what they are you can buy our comprehensive and detailed All Machinery Maintenance Training CD at our online web store that is full of PowerPoint training materials and articles on this vital maintenance and reliability subject.

Activity 1 – Improve the Procedure with Inspection & Test Plan Standards

The inspection sheet in Figure 5 (same as Figure 1) needs to be turned into a truly useful and valuable inspection document that detects problems and rectifies them before the machine reaches unacceptable levels of operational and safety risk.

As a little challenge for you, define and specify exactly the necessary standards that must be met for the pumps in your operation by completing Table 3.

Maintenance Work Instruction

Task List #	Various

Visual Inspection of Pump

Pump Inspected: ___________

Visual Inspection Only

1) Check pump base - corrosion / security.
2) Check pump guards - cracked / secured / adequate.
3) Check associated pipework for support / leaks.
4) Check associated valves have handles and are in safe condition.
5) Check suction expansion joint for external wear and cracking.
6) Check condition of motor and associated cables.
7) Check condition of stop / start station.

Raise Subsequent Notification Maintenance Request for any repairs required.

Inspected by: ___________

Date: ___/___/_____

Figure 5 This Procedure will NOT Protect Pumps from Failing, it will Let Them Fail

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No	Task	Minimum Reliability and Quality Standard Includes Photos, Tables, Charts	Proof Test that Confirms Standard is Met	Actual Result
1.	Check pump base:			
	Corrosion			
	Security			
2.	Check pump guards:			
	Cracked			
	Secured			
	Adequate			
3.	Check associated pipe work for:			
	Support			
	Leaks			
4.	Check associated valves have:			
	Handles			
	Safe Condition			
5.	Check suction expansion joint for:			
	External Wear			

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No	Task	Minimum Reliability and Quality Standard Includes Photos, Tables, Charts	Proof Test that Confirms Standard is Met	Actual Result
	Cracking			
6.	Check condition of:			
	Motor			
	Associated Cables			
7.	Check condition of:			
	stop/start station			

Table 3 Set the Quality Standards that Prove the Pump Set is in Reliable Condition

If you have any questions about the above please ask me.

My best regards to you,

Mike Sondalini
www.lifetime-reliability.com