Coordinated Root Cause, Failure Analysis and other Specialty Services by MST Corporation

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- Failure Analysis with Option Recommendations
- Root Cause Analysis
- Metallurgical Analysis
- Manufacturing Process Technology Procedure Papers

COVER PAGE

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MST Specialty Services:

Analyses generally are more expensive than they need to be because most analyst organizations work in specialty areas. For example, they specialize in specific aspects of metallurgical analysis, etcetera. MSTs expertise is in the process technology of manufacturing, how a component is used and how the component may be adversely affected in the actual service environment, based on metallurgical and manufacturing process variables.

MST has analyses capabilities that include process, installation technologies, systems effects and related factors that affect parts and equipment. Most failures or damage of parts and equipment is traceable to how the process technologies were used; how the parts are made, repaired or used incorrectly.

MSTs technical staff provides consulting, systems analysis techniques, reverse engineering and overall coordination in the analysis process; including the organization and use of specialized outsource services. This gives the customer a single source for organizing the analysis into a coherent examination at the least cost to the user.

The following is an example of an actual root cause analysis performed for an end-user on behalf of a rebuilding organization. The names have been redacted at the request of the user and rebuilding organizations involved.

1659 SW Baldwin Road
Prineville, OR 97754
(541) 416-9000
www.mstcorp.com

ROOT CAUSE ANALYSIS – 400 THICK STOCK PUMP SHAFT FAILURE

16 August 2009: CONSOLIDATED REPORT BY MST CORPORATION

NOTE

There are ancillary documents that are a part of this report. We have included them as addendums or links to this document.

SUMMARY PHOTO RECORD OF BROKEN PUMP ROTOR AS RECEIVED

Photo # 1 – SHAFT SIDE WITH SLEEVE STILL ON SHAFT

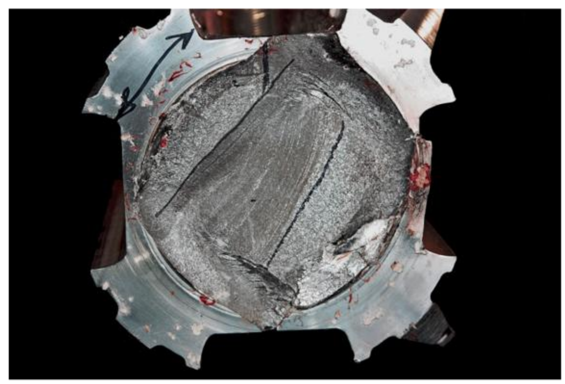


Photo # 2 – ROTOR SIDE OF BREAK

The reader will find additional detailed photo documentation within supplemental reports, etcetera, in this presentation. Plus, and extensive photo record of the break was sent prior to starting this analysis

DETERMINING THE LIKELY ROOT CAUSE OF THIS FAILURE REQUIRED THE FOLLOWING FACTORS BE FORENSICALLY ANALYZED AND ACCOUNTED FOR TO NARROW THE ANALYSIS TO THE MORE PROBABLE

1. The break, visually, displayed all the characteristics of a reverse bending fatigue failure. The following was done to analyze for this and analyses performed to include or exclude other possible contributing factors:

    A. Visual inspection, which includes magnification, to identify probable initiation sites for fatigue.

    B. Chemical and micro analysis of the base metal(s) to verify whether or not there were metallurgical causations that would have acted as initiation sites for fatigue.

    C. The base material was purported to be Alloy 2205 duplex stainless steel. The microstructure of Alloy 2205 is highly dependent on the thermal history during manufacturing. SEM and metallographic analysis was conducted to determine that the base material microstructure is consistent with a properly processed material of the type represented.

    D. Perform microanalysis using SEM techniques to verify the presents of fatigue and the nature of the progression at the granular level.

    E. Determine if there are alignments, mounting and vibration factors that may have increased the stress on the fillets that would shorten the natural fatigue life of the rotor design.

    F. Analyze to determine if any process method such as welding, machining and final design form may have contributed to a shortened fatigue life

THE FOLLOWING IS THE RESULT OF THE TESTING AND ANALYSIS RELATIVE TO ITEMS A THROUGH F ON THE PREVIOUS SLIDE:

A. Crack initiation sites: Three main initiation sites were identified at the outset. The arrows and markings in the original photos and the Lisin Metallurgical report point to the sites. See the Lisin Metallurgical attachment, page 3:

B. Chemical and metallurgical analysis of base material: The chemical makeup of the base material is consistent with Alloy 2205. The metallographic work shows the alloy microstructure is consistent with a properly heat treated 2205 material. A chemical analysis report was sent in advance of this report and there is another analysis contained in the Lisin Metallurgical report, page 2.

C. Alloy microstructure of broken shaft: with this type of alloy, if the manufacturing process heat treatments or thermal effects involving weld repairs, etcetera, are not carried out properly, the alloy is prone to precipitate unwanted metallurgical phases that can be exciter mechanisms for fatigue crack initiation and propagation. No unusual or damaging precipitates were found using metallographic and SEM analysis. Precipitates' were not contributors to the failure.

D. SEM: the SEM magnification of individual grains in the metal revealed typical transgranualar cracking consistent with cyclic loading, fatigue failure.

E. Engineering Dynamics, Inc: Mr. Charles Hill with Engineering Dynamics, Inc. had been to the mill and had checked the alignment, etcetera, for the pump installation. Charles passed on a simulation showing the differential movement of the drive, reducer and pump. Click HERE to open the .avi file and view the video.

F. Welding, machining, design: There is no evidence that any process step like welding or machining contributed to the break. Design wise, the fillet for these pumps are historically undersized for the service nowadays. There is no room to change that factor significantly. As such the base mounting and alignment integrity becomes especially important in reducing extraneous load factors that increase the probability of a premature (shortened) fatigue lifecycle.

BASED ON THE OBSERVATION AND FINDINGS WE WRAP-UP AS FOLLOWS WHERE A THROUGH F HERE CORRESPONDS TO THE A THROUGH F DATA ABOVE:

A. Intrinsic design issue: There is nothing metallurgically or physically that would explain the specific fatigue start sites. However, note that the net cross sectional area in the center of the rotor represented by the diameter at the base of the lobe pockets is about 1-¾” smaller in diameter compared to the fillet diameter.

   Based on their design these types of rotors see a varying stress exchange every 22.5 degrees because of the bending loads transferring through the varying cross sectional areas. By the nature of the design, they are prone to fatigue failure based on this particular cyclic stress as it affects the fillet.

B. 2205 duplex stainless steel alloy: The alloy is adequate for the application as long as processing technology is taken into account when manufacturing and rebuilding the rotors.

C. Alloy microstructure: The alloy microstructure is correct for this material and did not contribute to the failure.

D. Fatigue evidence: The SEM shows that the nature of the cracking was due to reverse bending fatigue. Reverse bending is normal for these rotors. The total force due to bending and misalignment and excessive vibration or piping strain loads would increase the normal bending force stress, shortening the usual lifecycle.

E. Machinery alignment and movement: The simulated dynamics illustrated in Engineering Dynamics’ .avi video in combination with the analysis work indicates: (1) there is an alignment problem, (2) the bolts are likely loosening either because the base is defective or not designed correctly, (3) the drive, reducer and the pump are not prevented from minute differential slip at the mountings either due to a lack of, or improper dowelling as designated by IMPCO and/or the use of clamping to prevent slip. Differential slip at the bolt locations will cause the bolts to loosen.

   Slip as described here causes the bolts to loosen by a mechanism like that illustrated at this site: click on this link http://www.boltscience.com/pages/junkertestvideo.htm. then watch the video The importance of proper dowelling or side clamping to affect a correct hold-down methodology is scientifically illustrated in the video.

F. Manufacturing and rebuilding process technology: The process technology used to manufacture and restore the rotor units is adequate and not a direct cause for the failure. We have issued a drawing showing slight changes in how the fillets are formed and finished that likely will provide added resistance to fatigue failure based on surface science fillet preparation technique. This will provide additional insurance or resistance to fatigue cracking starts.

BASED ON THE OBSERVATION AND FINDINGS THE CONCLUSIONS AND RECOMMENDATIONS ARE AS FOLLOWS:

1) The more probable contributor to accelerated fatigue failure in this case is likely related to the following primary candidates. The analysis calls for these factors to be checked and that it be verified each factor is controlled based on best-practice Standards.

   The findings of the analyses here effectively points to the kind of detrimental factors modeled in the Engineering Dynamics, Inc. video and the related causes. Each of the following should be checked and corrected to the correct Standard:

   a) Verify that the base-plate mounting for each machine component is to specifications. Make sure the sliding action as depicted in the "Bolt Science" video is prevented by dowelling and/or effective lateral clamping methods.

   b) Verify the base-plate to foundation mounting has not deteriorated and is in need of restoration.

   c) Check for possible piping strain problems and isolate as required.

   d) Eliminate any possibility of soft-foot on all drive-pump system components.

   e) Alignment of the machine components to a Standard.

      i. By chance I received my electronic copy of Pump Digest today. A vendor on page one is offering a brochure regarding misalignment affects on machine components. A copy of that (timely) document is attached.

         Note, in that brochure, they describe and graph the effects on the *energy* of the system when misalignment is involved. Energy is conserved. As such, one must realize some of the missing energy is doing work on the rotor fillets.

2) Other considerations that will help increase fatigue cracking resistance in general:

   a) Machine the rotor fillets and transverse grind until the circumferential tooling marks are eliminated and the surface smoothness of the transverse grind is 32 RMS of better.

      i. Inspect using a 10X loop magnifier.

LISIN
METALLURGICAL
SERVICES

August 10, 2009

MST Corporation
Attn: Ray Lackey
PO Box 381
Marylhurst, OR 97036

Subject: Examination of a Fractured Pump Shaft
Lisin Metallurgical Services 402-09-002

Dear Ray,

A section of fractured shaft from a pump identified as IMPCO 400 stock pump was submitted for failure analysis. The shaft was reportedly manufactured from a 2205 duplex stainless steel forging. It was reported that the motor and pump suffered from misalignment and rocking during service. We were asked to identify the cause of the shaft failure. Significant results of our analysis are as follows:

1) Macroscopic and microscopic fracture surface features are indicative of fatigue fracture. Fatigue refers to crack initiation and propagation due to the presence of excessive cyclic stresses (e.g., high-low-high-low… or on-off-on-off).
2) Multiple fracture initiation sites on the circumference of the shaft and fracture propagation toward the center of the shaft are consistent with cyclic stresses due to rotating bending.
3) The large area of fatigue fracture relative to final overload fracture is indicative of a high number of stress cycles (hundreds of thousands to millions) at a low stress amplitude.
4) Failure is best described as high cycle rotating bending fatigue.
5) The microstructure and alloy composition of the shaft were consistent with a properly solution annealed Grade 2205 duplex stainless steel forging.
6) Pitting corrosion or evidence of corrosion related cracking was not revealed by the analysis.

Significant results of our analysis are shown in the attached figures and tables. Thank you for working with us on this analysis. Please feel free to call with any comments or questions about these results.

Sincerely,

Mark Lisin

Mark A. Lisin, P.E.
Lisin Metallurgical Services

THIS CERTIFICATE SHALL NOT BE REPRODUCED EXCEPT IN FULL, WITHOUT OUR WRITTEN APP

CERTIFICATION

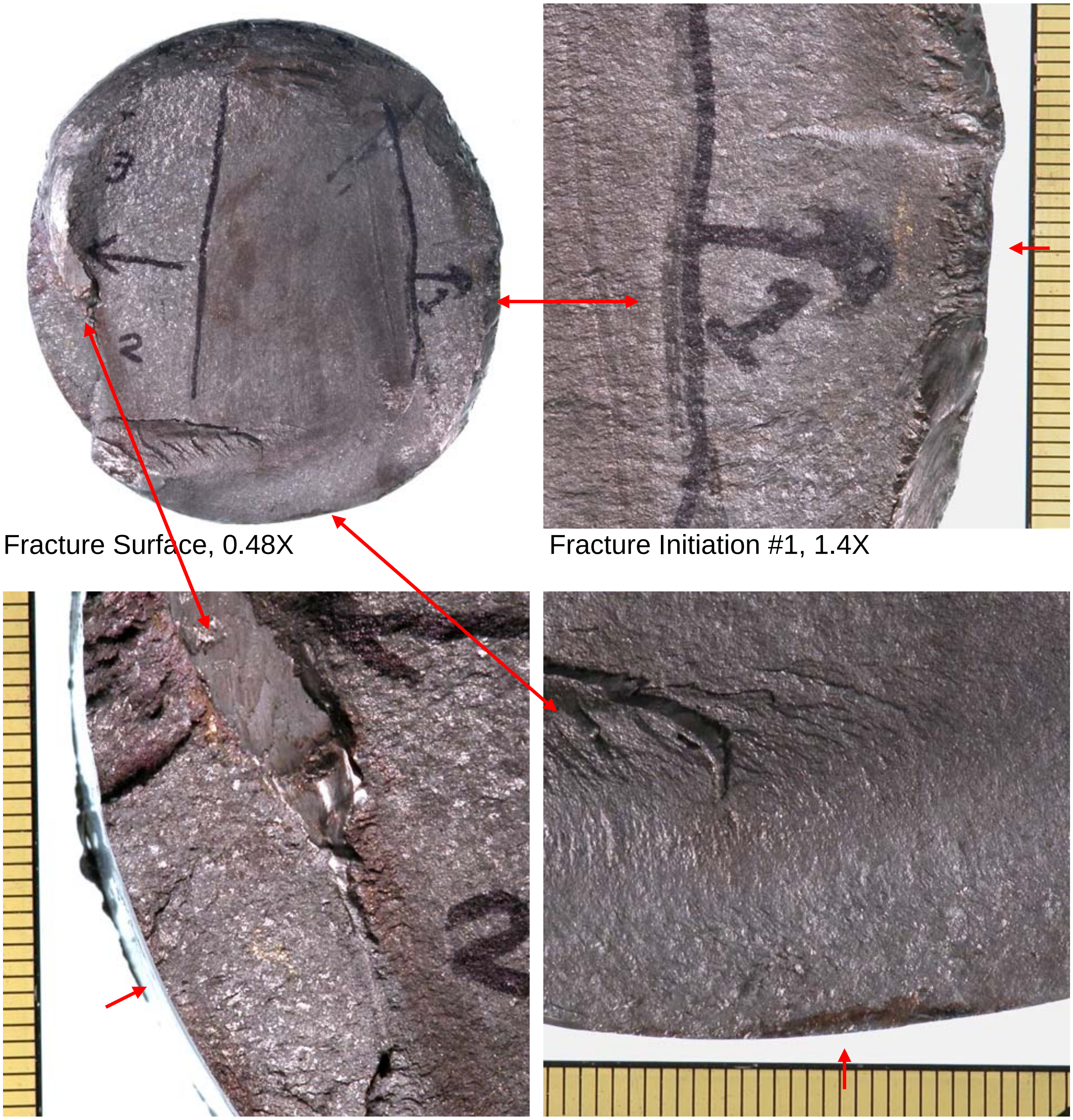
LABORATORY NUMBER	CHEMISTRY (%) 5112-CHM	SPECIFIED REQUIREMENTS MINIMUM	MAXIMUM
CARBON	0.023	---	0.030
MANGANESE	1.39	---	2.00
PHOSPHORUS	0.023	---	0.030
SULFUR	<0.001	---	0.020
SILICON	0.38	---	1.00
CHROMIUM	22.4	22.0	23.0
NICKEL	5.4	4.5	6.5
MOLYBDENUM	3.1	3.0	3.5
NITROGEN (1)	0.16	0.14	0.20
COPPER	0.19	---	---
ALUMINUM	<0.01	---	---
NIOBIUM	0.008	---	---
TITANIUM	<0.01	---	---
VANADIUM	0.055	---	---
IRON	BALANCE		

The measured alloy composition meets the requirements of the specified material, Grade 2205 stainless steel.

Fracture, 0.68X

Side View, 0.68X

Figure 1
Fracture surface and side view of the fractured shaft. Fracture was predominantly transverse and occurred in the fillet radius. The faint parallel lines of the fracture appear characteristic of crack arrest marks. The transverse fracture orientation, faint crack arrest marks, and absence of significant deformation are consistent with bending fatigue.



Fracture Surface, 0.48X

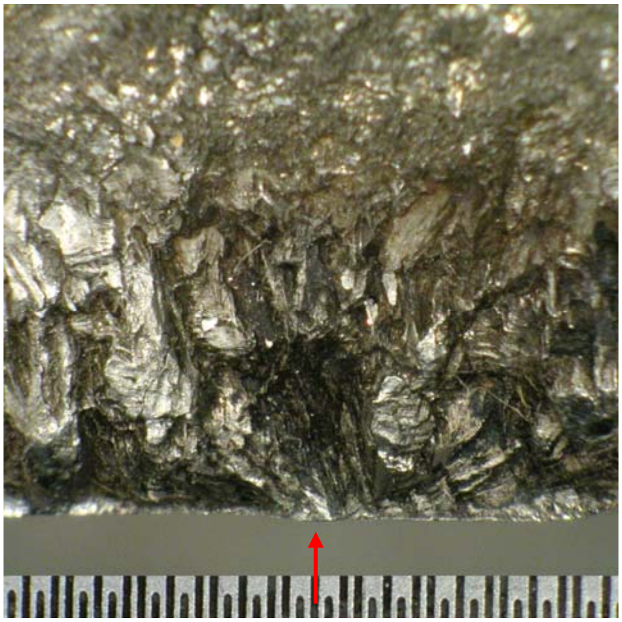
Fracture Initiation #1, 1.4X

Fracture Initiation #2, 1.6X

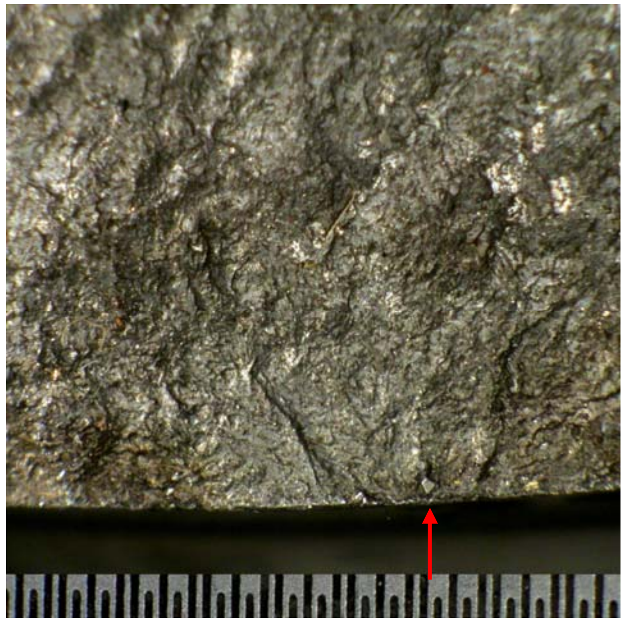
Fracture Initiation #3, 1.6X

Figure 2

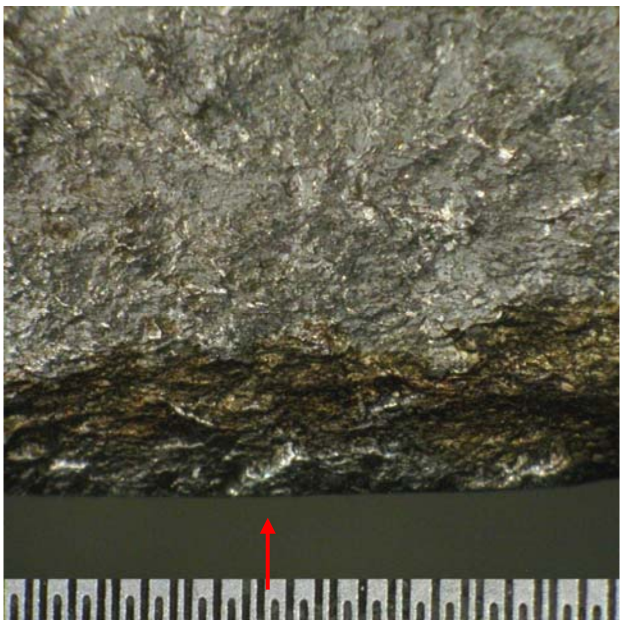
Higher magnification views of apparent fracture initiation sites. The locations of fracture initiation are indicated by faint ridges radiating from locations on the cylindrical surface. The crack arrest marks shown in the upper right photograph are consistent with fatigue crack propagation. The multiple fracture initiation sites spaced around the circumference are consistent with rotating bending fatigue. The large area of fatigue fracture relative to the area of ductile overload fracture is consistent with a high cycle, low stress fatigue fracture.



Fracture Initiation #1, 7.6X

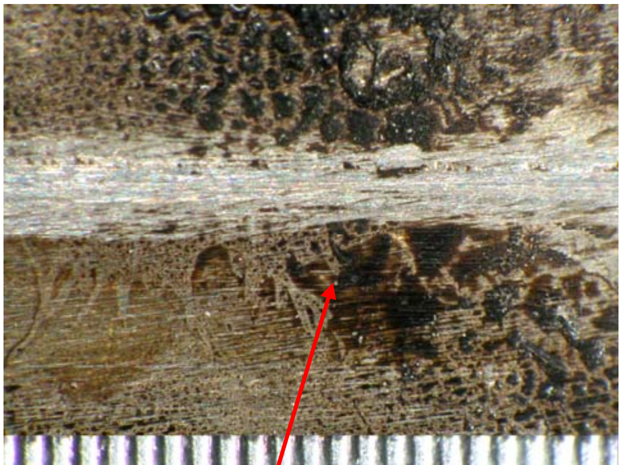


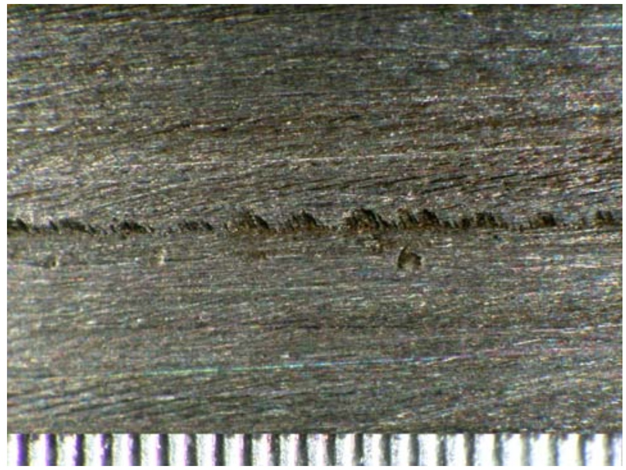
Fracture Initiation #2, 7.6X

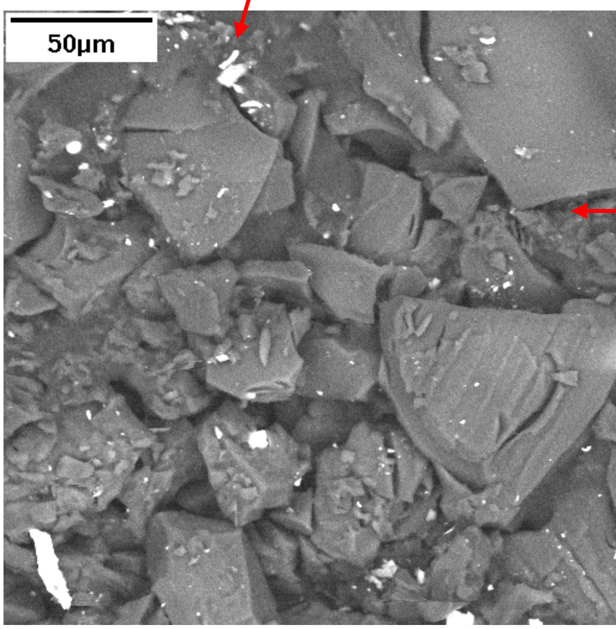


Fracture Initiation #3, 7.6X

Figure 3
Higher magnification views of apparent fracture initiation sites. The designations #1, #2, and #3 are arbitrary and do not indicate a sequence of fracture. Fracture initiation sites #1 and #2 appear to have initiated at the point of tangency between the radius and the cylindrical surface of the shaft. Fracture initiation site #3 appears to have initiated within the radius.


Radius at Fracture Initiation #1, 14X


Radius at Fracture Initiation #1 after Cleaning, 14X



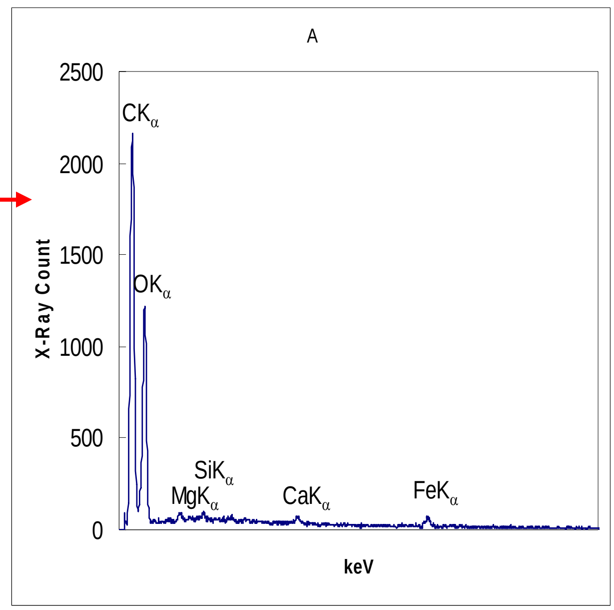


Figure 4

Optical microscope inspection of the filler radius adjacent to the fracture initiation sites revealed a loosely adherent brown deposit. Removal of the deposit by wire brushing revealed fine circumferential scoring characteristic of a ground surface. A single circumferential score mark may be the remnants of an as-machined surface that was not cleaned up by grinding. The feature would predictably act as a stress concentration and promote fatigue fracture. The feature did not appear to be the result of corrosion or localized wear. Pitting corrosion or additional cracking was not revealed by low magnification inspection of the cleaned radius.

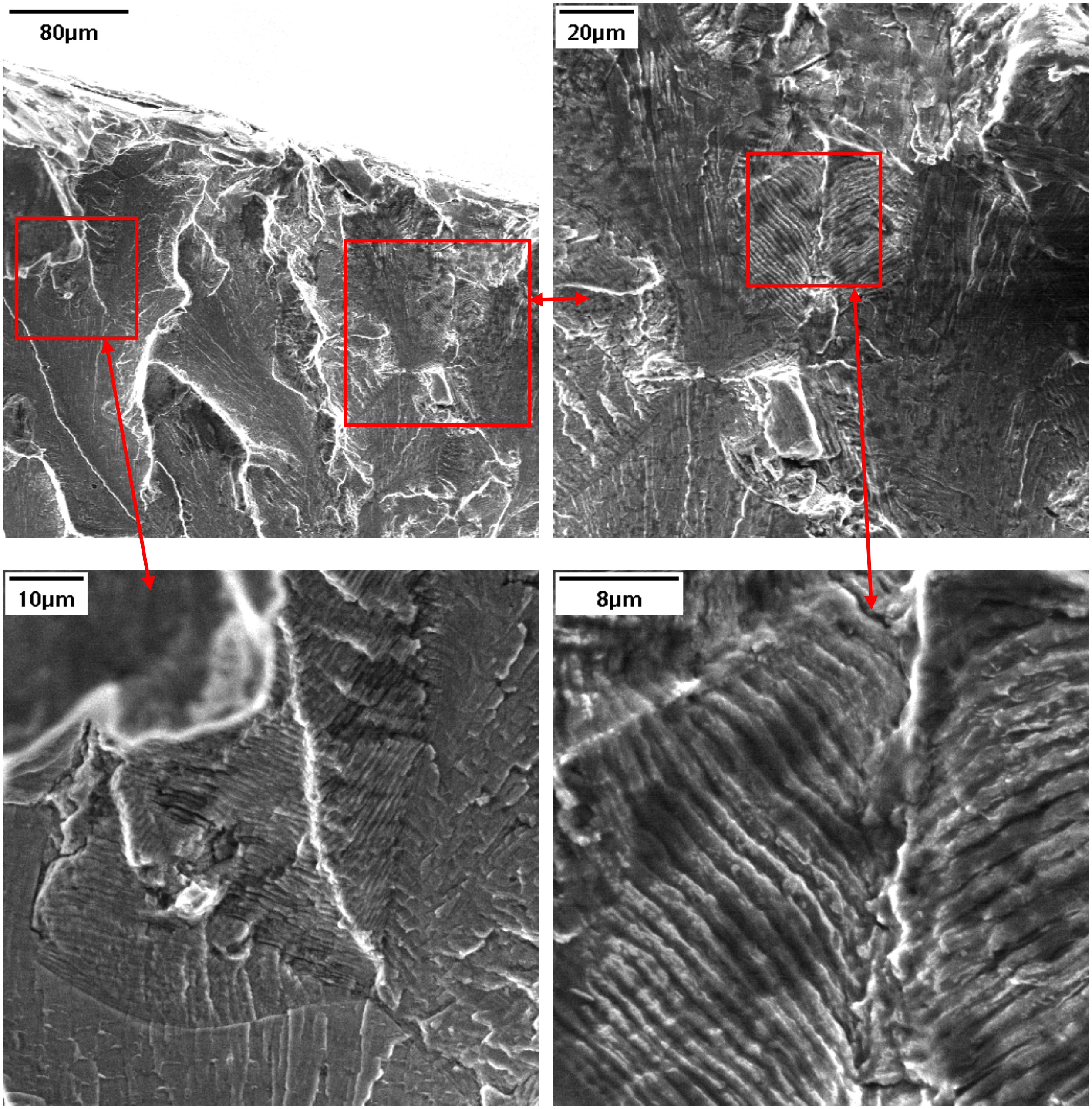


Figure 5
Backscattered electron images acquired from fracture initiation #2.

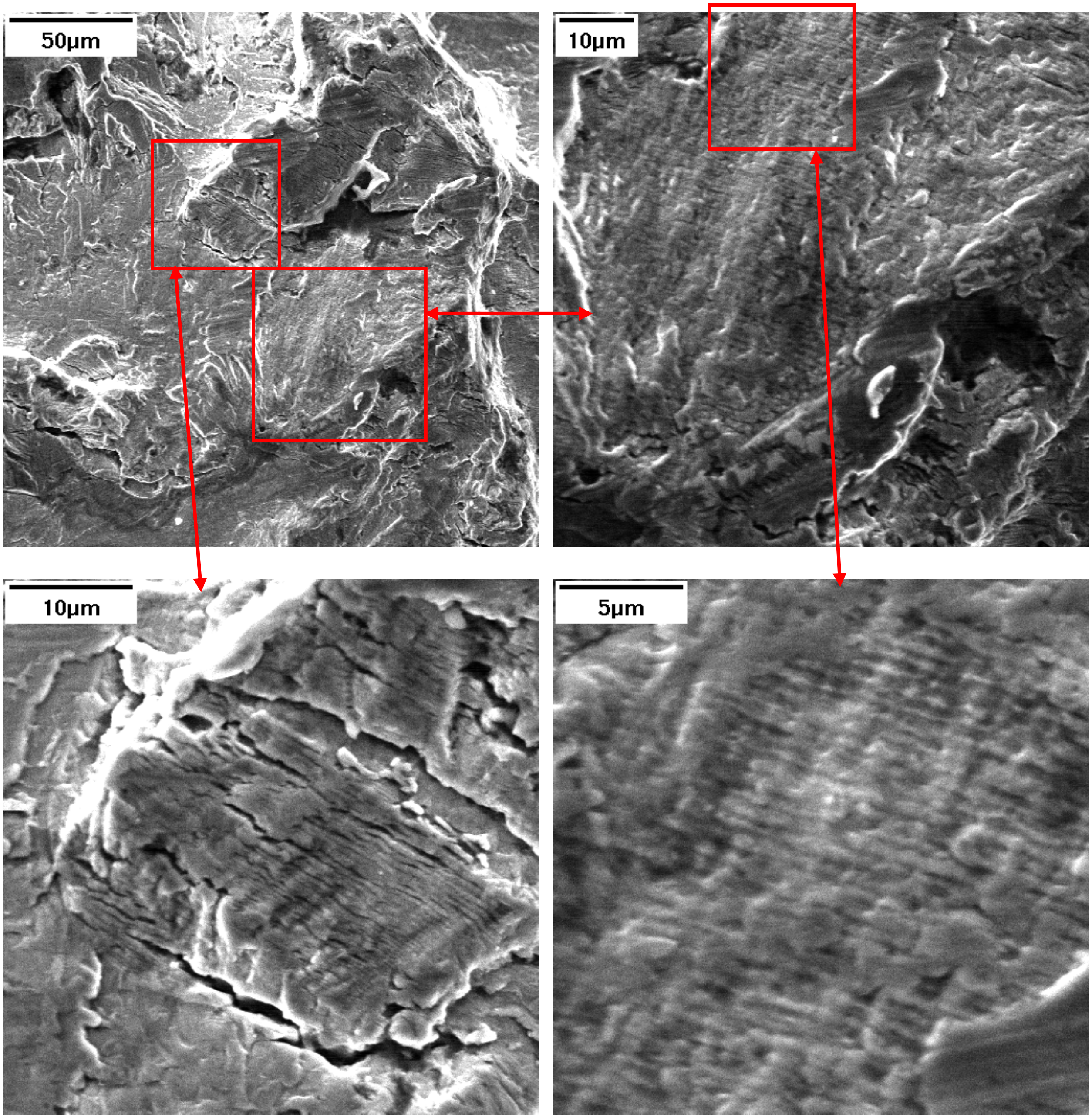
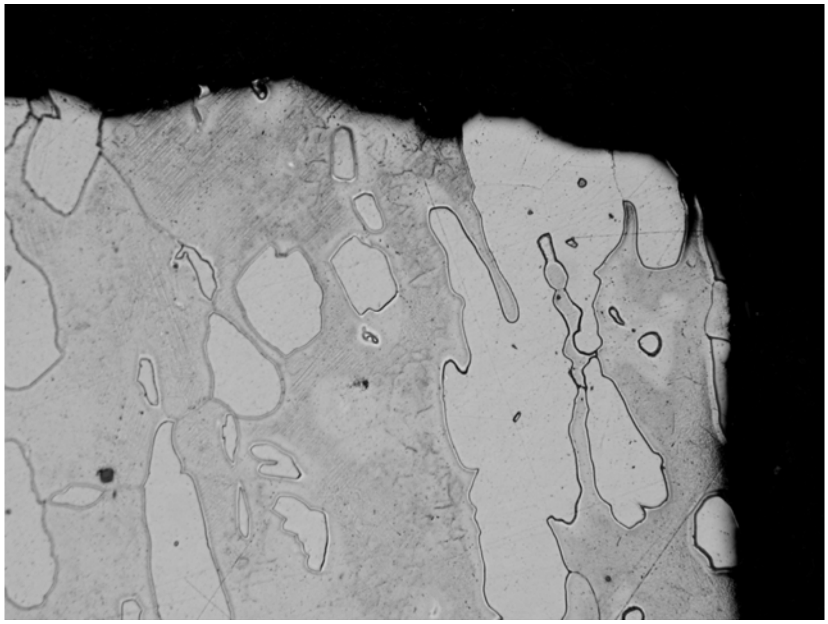
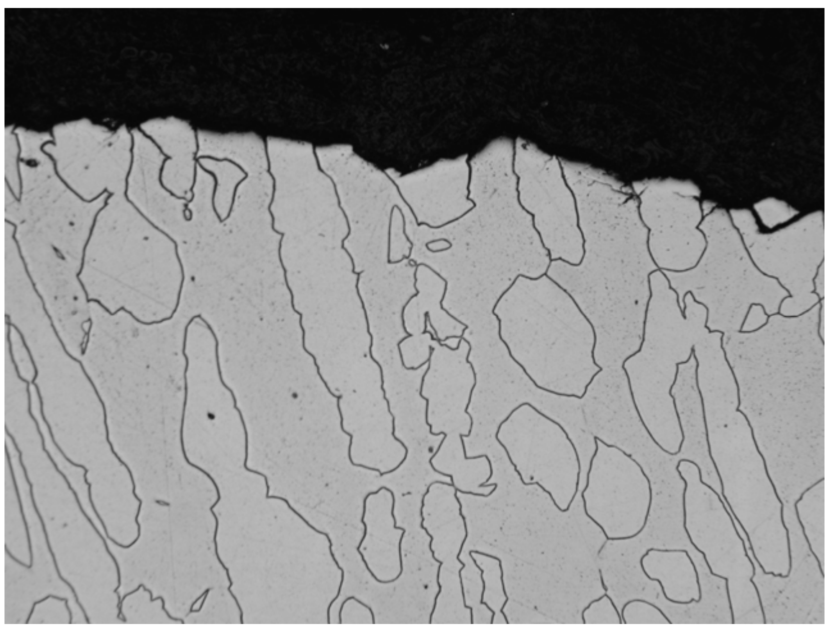


Figure 6
Backscattered electron images acquired from fracture propagation.

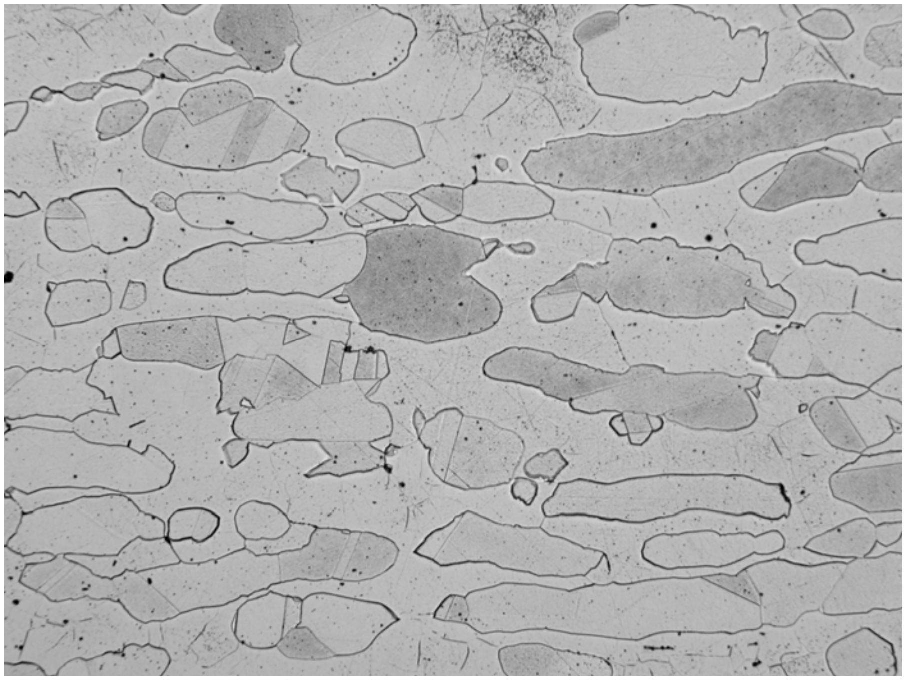


Fracture Initiation #1, 100X



Fracture Propagation, 100X

Figure 7
Representative microstructures revealed by radial-longitudinal metallographic sections through fracture initiation site #1 and an area of fracture propagation. The microstructure consists of a roughly equal mix of austenite islands in a ferrite matrix. Precipitation of carbides or intermetallic phases is not apparent. Cracking followed a straight, un-branched, transgranular crack path. The crack path is consistent with fatigue crack initiation and propagation. An absence of pitting or intergranular fracture indicates that fracture was not the result of corrosion. 40% NaOH Electrolytic, ASTM A 923 Practice A,



10% Oxalic Acid Electrolytic, ASTM A 262 Practice A, 100X

40% NaOH Electrolytic, ASTM A 923 Practice A, 100X

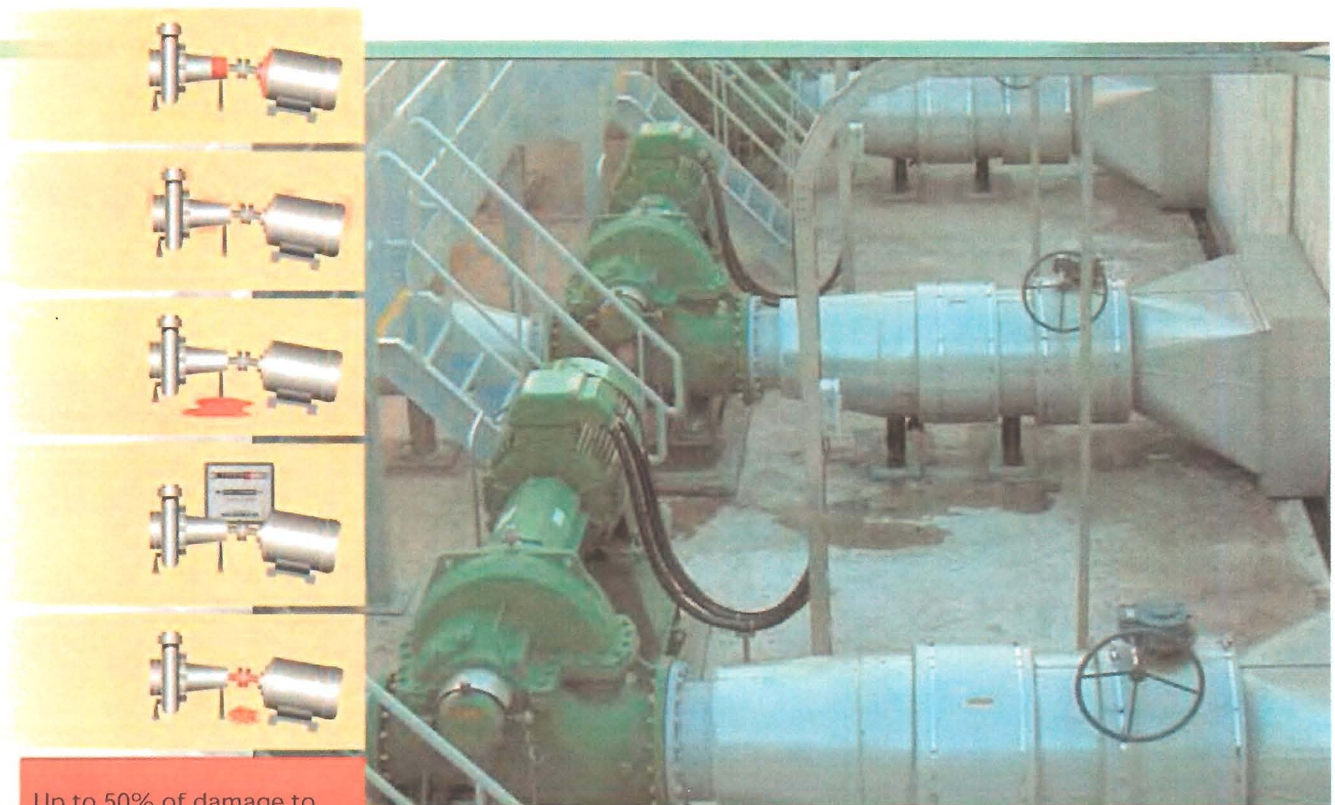
Figure 8
Representative microstructures of the fractured pump shaft at a near surface location. The microstructure consists of austenite islands in a ferrite matrix. The ratio of austenite to ferrite is roughly 1:1. No precipitation of carbides or detrimental intermetallic phases is apparent. The microstructure is consistent with a properly solution annealed 2205 duplex stainless steel alloy.

LUDECA INC.

PRÜFTECHNIK Alignment Systems

Why pump money down the drain?

Reliability requires precision alignment



Up to 50% of damage to rotating machinery is directly related to misalignment!

Well aligned machines reduce operating costs!

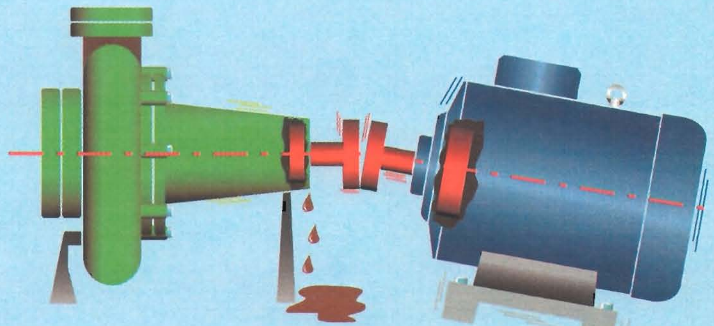
Why Alignment

Click to Return to Index

The biggest contribution one can make to lower the operating costs of rotating systems is to align them correctly in the first place.

When misaligned, the loading of shafts dramatically increases due to the reaction forces created within the coupling. This effect leads to:

- Premature bearing, seal, shaft and coupling failures
- High bearing and coupling temperatures
- Excessive vibration
- The breaking (or cracking) of shafts at, or close to the inboard
- High power consumption



Out of alignment tolerance | Within alignment tolerance

Infrared thermograms courtesy of Infraspection Institute®

The effect of increased coupling loading due to misalignment can readily be shown using infrared thermography. Not only does the flexible element coupling heat up, but the machines also develop elevated temperatures, particularly around the bearing housings.

Are your machines aligned to within the specified tolerances?

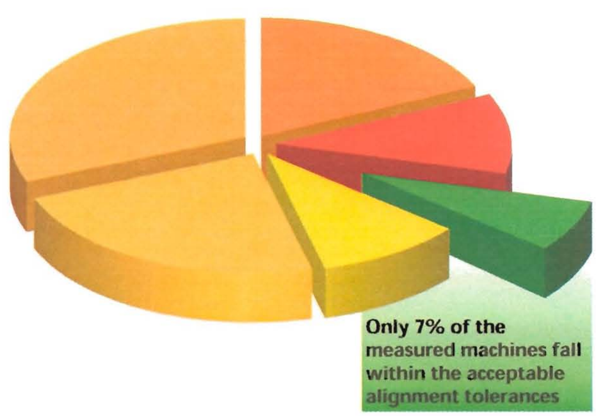
See Next Page

A survey conducted by one of the world's leading rotating equipment service organizations shows that less than 10% of the 160 machines randomly chosen for measurement were found to be aligned within acceptable limits. Under which category do your machines fall?

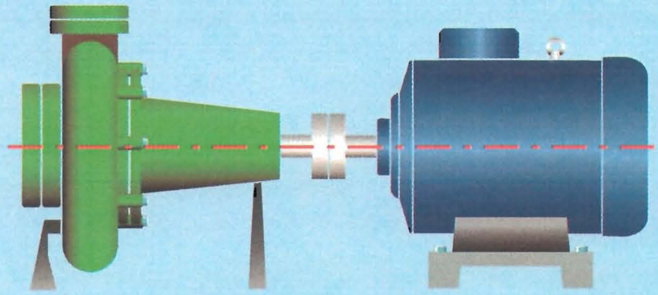
Offset (mils)	Machines measured (%)
0.0 - 2.0	7% acceptable alignment
2.1 - 4.0	10% out of tolerance
4.1 - 8.0	23% out of tolerance
8.1 - 20.0	31% out of tolerance
20.1 - 40.0	18% out of tolerance
> 40.0	11% out of tolerance

The above tolerances are for equipment running at 3600 rpm.

Statistics courtesy of a major UK chemical company



Benefits of precision alignment



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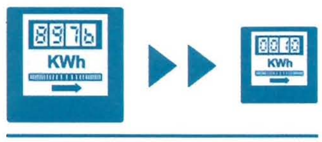
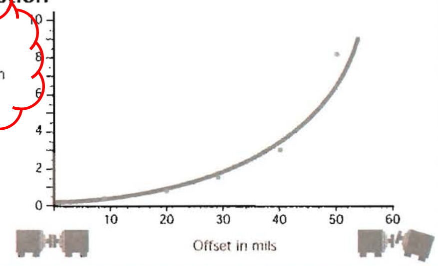
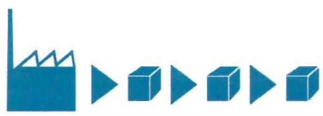


Eliminates reaction forces and therefore reduces energy consumption.

Effects on power consumption

Significant power savings can be made through accurate alignment

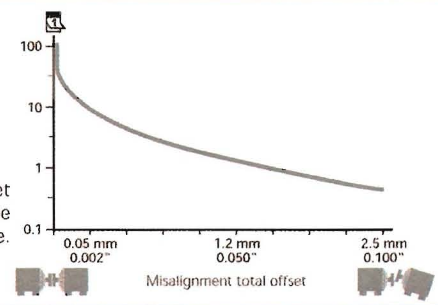


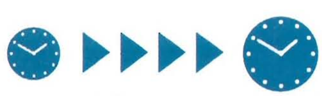


Protects the asset and increases the product quality as vibration is reduced to a very low level.

Relation between offset misalignment and mechanical seal life

The larger the offset misalignment, the greater the reduction of mechanical seal life.

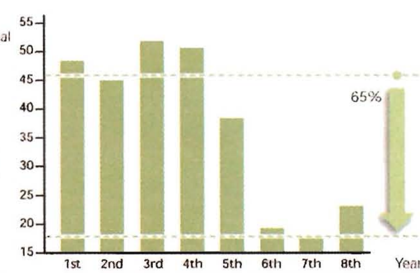


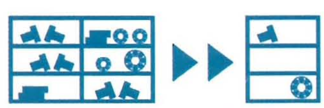


Extends machine availability as the Mean Time Between Failure (MTBF) increases.

Rate of seal repairs

Mechanical seal repairs declined by 65% following the introduction of precision alignment.

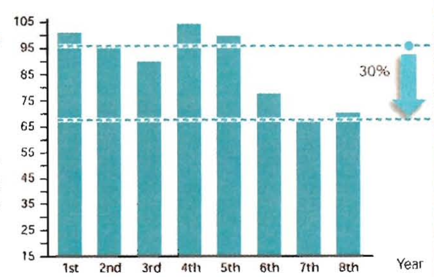


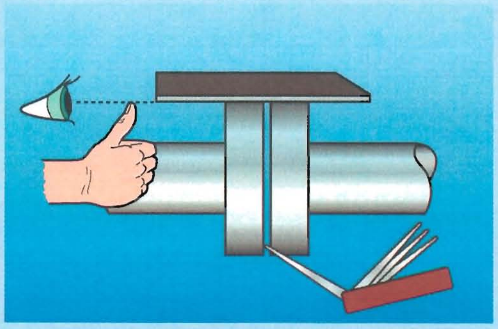


Increases maintenance savings through reduced parts consumption.

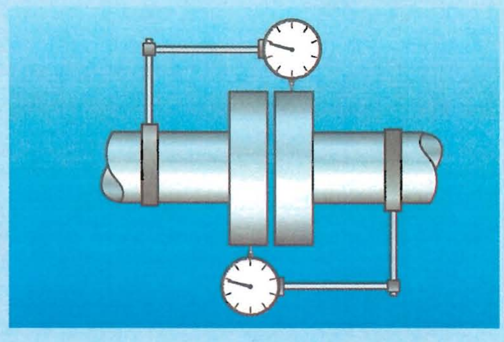
Rate of pump repairs

The rate of repairs was seen to decline as laser shaft alignment became an integral part of the pump repair schedule.



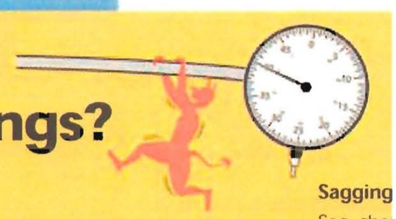


The straightedge/feeler gauge methods which depend on the limited resolution of the human eye, produce a resolution of 1/10 mm (0.004"). This is far too inaccurate for most machines.



Although dial gauges have a resolution of 1/100 mm (0.0004"), their use is cumbersome and requires experience to obtain good results.

How accurate are dial indicator readings?

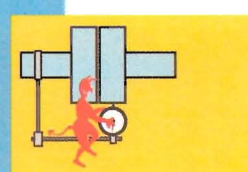


Sagging indicator brackets

Sag should always be measured before actual alignment readings are taken irrespective of how solid the bracket appears.

Low resolution

Up to 0.2 mils rounding error may occur with each reading - for a total of up to 1.6 mils error in values used for result calculations.

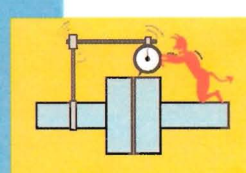


Reading errors

Simple human errors that occur all too often when dials must be read under cramped, poorly-lit conditions and severe time constraints.

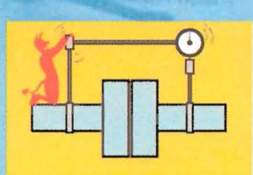
Sticking/jumping dial needles

Sometimes the gauge must be tapped in order for the indicator needle to settle on its final value (which may still not be the correct one).



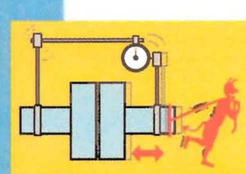
Tilted dial indicator

The gauge may not be mounted perpendicular to the measurement surface so that part of the displacement reading is lost.



Play in mechanical linkages

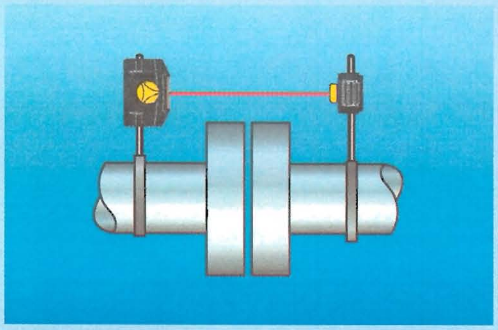
Slight amounts may not be noticed, yet produce large errors in results.



Axial shaft play

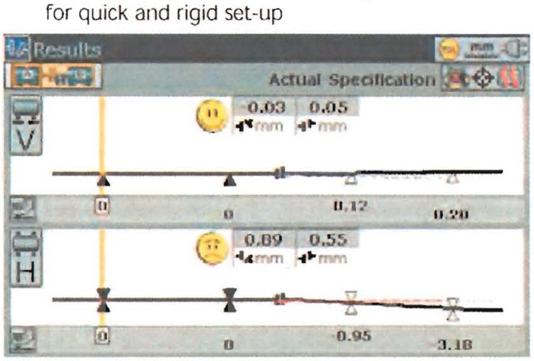
This can affect face readings taken to measure angularity unless two axially mounted gauges are used.

In addition to providing a resolution of 1/1000 mm (0.00004"), PRÜFTECHNIK laser alignment systems are fast, accurate, reliable and with optimally documented results.



Advantages of laser alignment

- Error free and accurate measurement: No human uncertainties, no bracket sag influence and no reading errors
- Straightforward alignment procedure: System can be used by different operators yielding identical results
- Quick on-screen laser beam adjustment
- Universal precision brackets designed for quick and rigid set-up
- Automatic computation of horizontal and vertical coupling and foot values
- Clear graphical representation of the machines with the corresponding foot correction value and direction
- "Live move" shows updated values and the direction of the correction
- Reports generated directly from instrument, in conformity with ISO 9001 documentation requirements



Powerful PC Software

- Prepare measurement files with all machine, coupling and alignment specifications on a PC
- Build up a hierarchy alignment file structure based on machine identification and location
- Transfer measurement files to and from the instrument
- Review measurement files on a PC. Produce professional and customized color reports in various formats (e.g. HTML), including own company logo & application pictures

Why PRÜFTECHNIK laser systems

PRÜFTECHNIK, the inventors of laser shaft alignment, possess well over 200 patents worldwide. These patents have been incorporated in our alignment systems, hence providing the user with a wide range of features, and huge benefits when aligning rotating machinery.

You can rely on these technologies

Simplicity of operation – simple 3-key-operation means that it is easy to remember

Continuous Sweep mode enables measurement by shaft rotation of 60° only, independent of starting position or direction of rotation.

Tolerances (TolCheck®) – automatic and dynamic check of the alignment condition. No tables or guesswork needed.

Patented InfiniRange® extends effective detector measurement range to handle gross misalignment or align machines that are distant from each other. Rough aligning of machines is not necessary.

Wireless communication for secure, convenient and flexible operation.

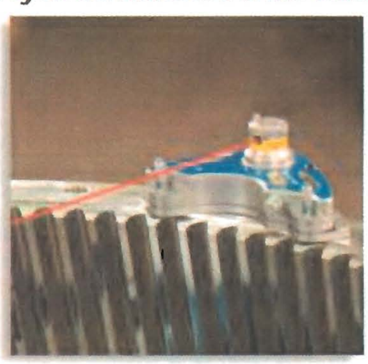
Patented UniBeam® implies one laser, one cable, quick set-up and laser beam adjustment, and no tangle of cables.

Power management options to meet user requirements and extend the availability of the system

Designed and manufactured for industrial applications. Specifically engineered to tolerate harsh maintenance and weather conditions.

Intrinsically safe versions require neither a hot work permit nor gas detecting equipment.

PRÜFTECHNIK measurement systems handle a wide variety of alignment applications



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From the inventors of laser shaft alignment