Implementing Reliability Improvements…a team approach

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Abstract

The progress of machinery and component condition monitoring during the past twenty years due to technology advancement and information gained from statistical analysis of equipment failures is remarkable. Many companies have evolved to the point where breakdown maintenance and preventive maintenance are the predominant maintenance approaches only when reliability-centered maintenance (RCM), Streamlined Reliability Centered Maintenance (SRCM), and other maintenance review processes indicate that these more rudimentary approaches are justified.

Despite these improvements in technology, and a seemingly endless stream of new "maintenance management strategies", plant / maintenance performance is in many cases not where it should be… Why?

This paper explores the common pitfalls and barriers to implementing real improvements in machinery reliability and plant / maintenance performance and presents **practical** real world procedures and processes for improving machinery reliability. We will examine the problem from several perspectives including:

- Costs and benefits
- The decision making process
- Who should be involved?
- Standards, tolerances and specifications
- Required procedures, processes and documentation
- Training and task qualification requirements
- Implementing quality assurance checks
- Dealing with motivational/cultural issues
- A 12 step road map to reliability improvement

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Introduction

The progress of machinery and component condition monitoring during the past twenty years is remarkable. This is largely due to technology advancement and information gained from statistical analysis of equipment failures. Most companies have now evolved to the point where breakdown maintenance and preventive maintenance are the pre-dominant maintenance approaches only when detailed studies such as reliability-centered maintenance (RCM), Streamlined Reliability Centered Maintenance (SRCM), and other maintenance review processes indicate that these more rudimentary approaches are justified. On critical equipment, repetitive failures, and machinery where repair costs are high, a multitude of technologies are available for diagnosing the failures.

Using such technologies as vibration data collection and analysis, oil analysis, ultrasonics, infrared thermography, performance monitoring, and motor current signature analysis, we have the ability to accurately and effectively monitor machinery condition and schedule repairs only when machine symptoms indicate deterioration. This ability alone will result in improvements in effectiveness of the maintenance organization. However, most companies have begun to realize the need to go further…not just to accurately detect impending machinery and component failures, but to pinpoint and correct the root causes of failure. After all, most failures are preventable…if we find and correct the root cause, rather than just treat the symptoms.

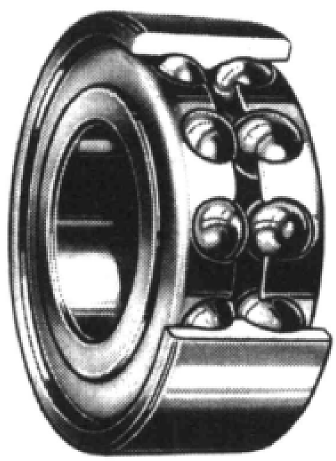
Even when we succeed in selecting and implementing the correct maintenance approaches, implementing appropriate condition monitoring technologies, and performing maintenance tasks in a precision manner, premature equipment failures continue to dominate. Reliability goals are not achieved, mean times between failures are too low, maintenance costs are too high, and production goals are not met. For even the most successful programs, opportunities for improvement are tremendous.

As specialists in the development and delivery of technical training related to maximizing the life of rotating machinery, we at Universal Technologies have experience with a variety of personnel and condition-based reliability programs from a wide diversity of industries, ranging from power generation, petrochemical, automotive, mining, paper, steel, and other manufacturing. We conduct over a hundred technical training seminars per year. Yet our primary goal IS NOT to conduct training, but to ensure the subjects of our seminars are effectively put into practice.

Much too often, having attended a seminar or training course that shared sound technical information, the attendees return to the plant with new information and the motivation and inspiration to make a change. They then, for a variety of reasons, hit a brick wall and the concepts learned are never implemented. Why?

Consider a few scenarios that may sound much too familiar:

Case 1: A repetitive rolling element bearing failure in a critical centrifugal pump.



The bearing is a double row angular contact bearing, serving as the fixed bearing in the pump. It is a catastrophic failure. Examination of the most recent bearing shows build up of cage material in the raceways, one of the two steel cages destroyed. High heat multiple-color discoloration is present. Vibration data collection has been performed, but no fundamental bearing defect frequencies were noted in the vibration spectrum. During the last repair, technicians replaced the bearing with one from a different manufacturer, but the vibration analysis department was not informed of the change. The software was setup to look for defect frequencies of the old bearing type. Further investigation reveals that the application requires a bearing with no shields or seals, yet all that are stocked are shielded bearings. Further inspection shows where a technician pried out the shields with a screwdriver, most likely bending the cage in the process.

To prevent recurrence of this failure, where do we begin? Do we train all technicians at the facility how to properly remove shields without damaging the cage? How do we ensure that when bearing types or manufacturers are changed that the reliability department is informed so that vibration software can be updated? Why do we only stock shielded and sealed bearings of this type when all the pump applications in this particular facility are oil-lubricated and require no seals or shields? Is only one type of bearing stocked by purchasing to reduce inventory?

Case 2: Four repetitive mechanical seal failures in one week.

These mechanical seals lasted less than a day. After the first two failures, the seal manufacturer is contacted to verify the seal is correct for this application. Two highly trained mechanical technicians are selected to install the new seals while being supervised by an engineer from the seal manufacturer. Root cause analysis reveals the reason for the seal failure to be a lack of seal flush. Further investigation shows that this pump is being started from the control room with no operator at the pump. The correct pump operating procedure requires an operator to start the pump locally after opening the seal flush line.

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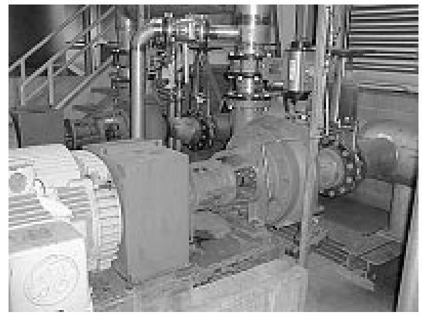
Case 3:Successive motor failures on two new chiller pumps shortly after being installed by a contractor.

Symptoms include:



1. Horizontal misalignment at the rear feet of the machine of 0.233”.
2. Motor is bolt bound.
3. Mounting pads have been welded, warping surfaces and inducing soft foot of 0.022.
4. Pipe strain moves pump 0.042 at non-drive end bearing. The problem is resolved by on-site maintenance personnel after the second failure on one of the motors.

In this case, the real root cause is a lack of acceptance standards between engineering and the contractor regarding machinery installation and alignment procedures.

Cases like these occur daily. Many more examples could be cited. The bottom line is that there are many challenges that must be dealt with in order to effectively implement reliability-centered programs. Having studied this subject carefully we have found several common areas where the process breaks down. Several key aspects must be addressed, such as:

- Costs and Benefits
- Maintenance Decision Making Process
- Who Should Be Involved
- Standards, Tolerances and Specifications
- Required Procedures, Processes and Documentation
- Implementing Quality Assurance Processes
- Training and Task Qualification Requirements
- Dealing with Motivational and Cultural Issues

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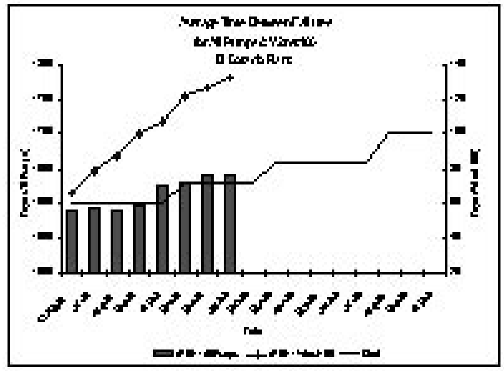
Costs and Benefits



Essentially, we must make maintenance decisions based on business sense, not emotion or past practices. There are many different ways to calculate costs and determine the pro's and con's associated with different forms of maintenance. Some of the factors to be considered are described below.

- It is not cost effective to apply all precision techniques across the board. Though certain elements of precision maintenance do not result in higher maintenance costs and can be applied for all maintenance tasks, care must be taken to ensure "full blown" precision maintenance tasks are carefully selected. For example, consider key length. When installing any keyed component, a key must be cut. To cut it to the correct length involves no additional cost. On the other hand, consider a repetitive failure of a boiler feed pump due to severe misalignment and excessive pipe strain. To correct this problem will require the pump to be out-of-service for an extended period of time and involve costly piping modifications. The latter task must be very carefully planned and a cost benefit analysis performed.

- Effective key performance indicators (KPI's) must be established and maintained to track progress of reliability efforts. Without use of KPI's many successful programs are eventually terminated. As reliability and production goals increase, often the perceived need of precision maintenance subsides.

- There is no "default" set of KPI's. They must be selected for each facility and even for certain systems and components within the facility. Be careful of establishing maintenance costs as a KPI. It is easy to cut maintenance costs by stopping maintenance, but the long term consequences are obviously adverse.

- Use risk management principles to determine the most appropriate maintenance strategy for each system and component. Risk can be defined as:

Risk = Probability x Consequence

A variety of risk management processes are available for making risk based decisions. Essentially, the task involves weighing the consequences of failure as well as the probability of failure. A thorough look at all of the consequences of failure is important, Typical consequences in a plant environment include:

  - Production losses
  - Production opportunity losses
  - Costs of repair due to catastrophic failure vs. a scheduled repair
  - Environmental costs
  - Safety costs

- It should be noted that the consequences of failure are frequently in transition due to factors that are often beyond the control of any plant level personnel. Such factors include market forces, regulatory requirements, etc. As these variables change, failure consequences change and therefore risk changes.

- One model for communicating risk is to track “at risk” maintenance dollars.

  1. This can be done by creating a “watch list” of all machines that are in a failure mode and being monitored by the Condition Monitoring group.

  2. Assign a cost figure to failures that are currently on the watch list. Determine the cost of each failure assuming that an “unscheduled” failure will occur, and include estimated production losses, maintenance costs, and safety/environmental costs.

  3. Add all the failure costs for all “at risk” machines to get a total figure. This is the amount of money that is currently “at risk” due to machinery failure.

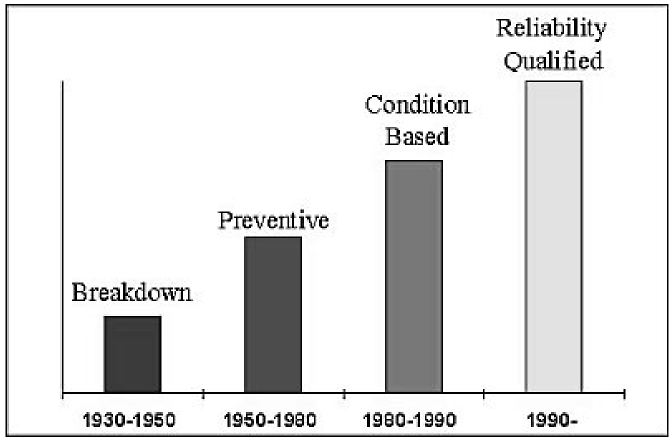
  4. This total can then be compared to production and or profit figures to establish what percentage of plant production or profit is currently at risk.

  5. Work with management to determine a “risk” percentage figure that they feel comfortable carrying in the current operating context. Use the above calculations to manage the risk.

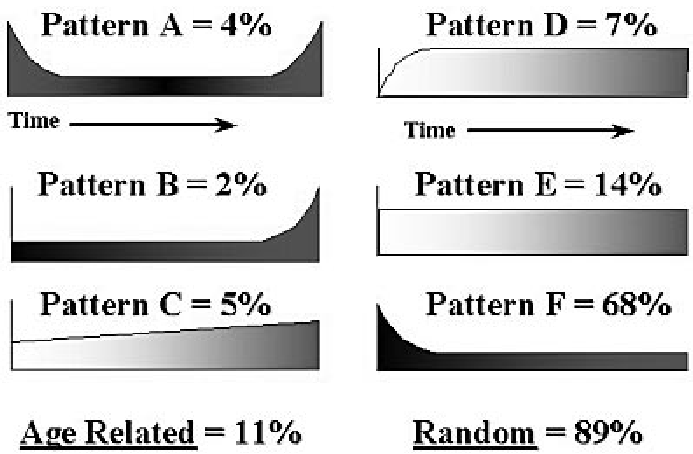
As operating context and failure consequences change the “at risk” percentage will change. By prioritizing the machines on the list by failure cost it is possible to determine the appropriate repairs to perform that will have the biggest impact on the amount of risk that the plant is currently carrying.

The Maintenance Decision Making Process

While everyone at a facility has some impact on reliability, it is essential that all plant personnel who directly or indirectly influence the maintenance decision making process or are involved in maintenance or operations understand how and why machines fail and reliability concepts.



An overview of machinery failures is provided by 6 common failure patterns, as shown below:



Use a recognized logical process such as Reliability Centered Maintenance (RCM) to help in determining the appropriate strategy. There are seven (7) questions for studying machines/systems from an RCM perspective:

A. What are its' functions and what do its' users want it to do?
B. In what ways can it fail? FEMA (failure effects and modes analysis)
C. What causes it to fail? RCFA (root cause failure analysis)
D. What happens when it fails? FEMA
E. Does it matter if it fails? FEMA
F. Can anything be done to detect/predict/prevent the failure?
G. What if we cannot detect/predict/prevent the failure?

Determine the costs of condition monitoring in your facility. To accomplish this, calculate the sum of the following:

- Salaries plus benefits of condition monitoring personnel
- Condition Monitoring Department Overhead
- Instrumentation and Software Costs amortized over 2-3 years
- Software Support and Upgrades
- Condition Monitoring Personnel Training Costs

Divide this sum by the number of points monitored per month to derive a per point or per machine cost.

Calculate or estimate the consequences of failure. These can include lost production, lost production opportunity, maintenance costs, environmental and safety costs.

This will enable you to make good business decisions regarding whether or not it is appropriate to perform condition monitoring or use some other maintenance strategy on a specific piece of equipment or system at your facility.

Once detailed decision making processes are established at your facility, ensure everyone has a basic understanding of how the process works. Select a small group of machines historically demonstrating a reliability problem; apply these processes; document and evaluate successes; and, fine-tune the process.

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Who should be involved?

Everyone in the organization has a role in reliability improvement. A common misconception is that the Maintenance department is solely responsible for solving machinery reliability problems. While it is obviously true that the Maintenance department has primary responsibility for actual performance of maintenance tasks, results of failure analysis prove that the true root causes of premature component failure often lie outside the maintenance department.

To illustrate the need for all parties to be involved, consider the following questions:

1. Who determines the general time frame in which the task will be performed and how much time the equipment can be out of service?
2. Who decides if the amount of time allotted will be sufficient for the type of work that needs to be performed in order to truly correct the root cause?
3. Who determines the quality of replacement parts, e.g., that all rolling element bearings meet or exceed ABEC and RBEC grades of precision for the application?
4. Who ensures that before contracts are issued on new equipment installations the contractor will meet or exceed the quality standards and specifications used by maintenance for follow-up tasks.
5. Who ensures that before the sign-off occurs on a new installation that these standards have indeed been satisfied?
6. Who ensures that start-up and operating procedures do not contribute to premature component failure?
7. Are maintenance personnel informed prior to performing a repair the nature of a pump's poor performance from a production perspective?
8. Are consultants who determine lubrication requirements provided the details needed to select the right type of lubricant for specific applications, for example the bearing operating temperatures?
9. If contractors are used to provide services with various PdM technologies, how are they informed when a pump impeller with five (5) vanes is changes to one with six (6) vanes or that an SKF 7203A bearing is replaced with a Fafnir 7203?
10. Who ensures that when bearings arrive at the door of the shipping and receiving department, they are not dropped or mishandled in a manner that destroys the bearing due to true brinelling of the bearing material?

Even without answering all these questions, it is hopefully evident that a team approach is not only desirable; it is a mandatory element of effective machinery reliability programs.

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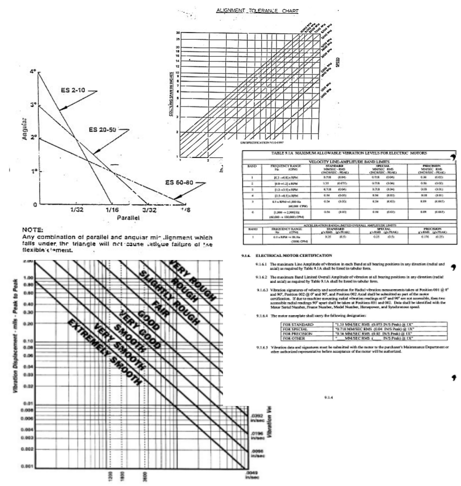
Standards, Tolerances and Specifications



An unfortunate reality is that in a majority of cases, when we purchase a new piece of equipment, send an existing machine out for repair, or even perform a particular task in-house, the quality of work performed varies significantly based on who's performing the task, what parts are available, and the methods of work performance which are commonly accepted. Indeed many of the sources of premature machinery and component failure are traced back to poor parts, poor tolerances, poor practices, and poor standards.

Consider as an example a new or rebuilt electric motor. Are the bearings that are installed the correct bearings? Were the bearings damaged before they were installed? How were they installed? Heated with a torch? Drove on with a hammer? If an induction heater was used, were the bearings demagnetized after they were heated? Was the rotor balanced? If so to what quality balance grade? And was the balance a single plane or two plane balance? Was a precision soft foot check performed on the motor feet? How was the motor transported? Did false brinelling or true brinelling occur during transport? And if any of the above are in question, did we detect the problem by running the motor solo and checking the vibration before installing the motor?

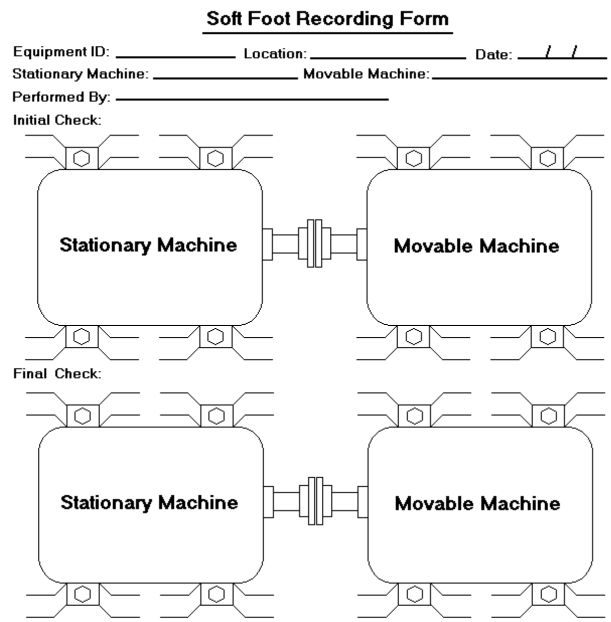
Among the standards, tolerances and specifications that should be established and implemented are the following:

1. Approved Balancing Methods
2. Precision Balancing Tolerances
3. Precision Balancing Standards
4. Motor Solo Vibration Standards
5. Installed Component Vibration Standards
6. Condition Monitoring Tolerances
7. Foundation, Base and Machine Frame Standards
8. Approved Alignment Methods
9. Precision Alignment Tolerances
10. Precision Pipe Strain and Soft Foot Method and Standards
11. Approved Methods for Measuring Dynamic Movement
12. Component Part Specifications an Substitution Policies
13. New and Rebuilt Machinery Specification Requirements

With such detailed standards, tolerances, and specifications in place, our suppliers, vendors and contractors, and internal personnel will know our expectations…that we expect reliability to be built in from the start. Beyond establishing these standards, tolerances, and specifications, appropriate processes must be implemented to train all involved parties on the rationale for the standards, as well as how to interpret and apply them. Finally, mechanisms must be established to monitor compliance with these standards and hold appropriate personnel accountable.

Required Procedures, Processes and Documentation

In addition to establishing and implementing precision standards, tolerances and specifications, essential to successful implementation of reliability programs is the development and implementation of required procedures and processes for certain tasks, including adequate documentation requirements. Use of these guidelines creates expectations that things will be done a certain way.



In addition, craftsman should view these procedures as valuable tools. While certain tasks, such as precision alignment using a certain laser system, may be performed on a regular basis by certain personnel, there are many times when an individual is assigned to perform a task not recently performed. In such cases, a written procedure provides guidance on key elements of task performance and helps to ensure efficient and high quality task performance.

While very detailed step-by-step procedures are needed for certain tasks, shorter working procedures providing an overview of major steps are sufficient in many cases. The level of detail needed should be determined according to the nature of specific tasks and the frequency of task performance.

A critical part of this process is inclusion of appropriate documentation. For example, for a precision alignment task, documentation typically required includes a completed pre-alignment checklist, as-found shaft alignment conditions, initial and final precision soft foot records, and final alignment conditions. These documents create vital formal history sorely lacking in most facilities. Wherever possible, we should utilize modern technology to create effective documentation processes, e.g., electronic log sheets.

The specific list of written procedures, processes and documentation requirements needed varies from facility to facility, largely based on how the organization is structured, the total number of people who may be assigned a specific task, and the history of machinery failures due to poor quality task performance. In general, a procedure or other formal process is recommended for any task where inconsistency in work quality is predominant.

Procedures and processes are not limited to maintenance activities. Effective procurement processes should be established to ensure that the correct parts and components of the required quality are purchased. Examples include components balanced to the required quality grade, bearings of the correct type and precision grade, belts that are matched, etc. Processes should be in place to ensure machine start up procedures for specific equipment do not lead to catastrophic failure of components such as mechanical seals, and that certain preventive maintenance tasks performed by operations personnel are proper for the equipment.

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Again, the goal here is not to create a mountain of unneeded paperwork or additional Administrative burdens. The goal is to first identify specific tasks where inconsistent human performance is a key factor in the mode of failure. Then, in addition to training of personnel, development of effective procedural guidelines is often an effective alternative.

Training/Task Qualification Requirements

Appropriate processes must be in place to ensure all personnel that effect machinery reliability are properly trained, and more importantly, are qualified to perform assigned tasks. Effective training is outcome based and is developed, delivered, and evaluated using a Systematic Approach.

1. **Identify Key Tasks**

First, key tasks must be identified for various personnel. For each work group, there are common tasks that are performed on a regular basis. For example, common tasks for maintenance personnel include repair of pumps, installation and alignment of pumps, repair of valves, installation or modification of piping, etc.
There are also infrequently performed tasks that often fall under a high risk with respect to reliability.
Key tasks, both common and infrequently performed that affect reliability should be identified for each work group.

2. Analyze Key Tasks

After the tasks for each work group are identified, a detailed analysis of each task is performed to identify key elements of task performance.

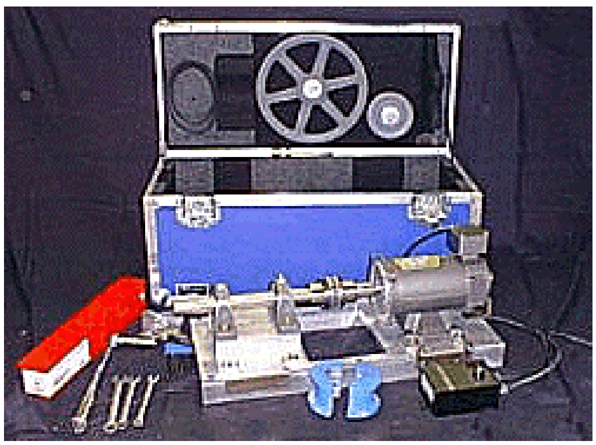
3. Perform Needs Analysis

Once each task is analyzed in such a manner, individual needs analysis is conducted to assess the individuals' abilities to perform assigned tasks.

4. Develop Action Plan

Results of this needs analysis and individual assessments are then used to develop an action plan, including how areas where improvement is desired will be addressed.

This process can be conducted to various levels of detail based on numerous variables beyond the scope of this article. At first glance, the process briefly described here may appear a bit complex. However, even if this process is shortened to a "table top" format, it is highly recommended. And the main reason is that this Systematic Approach serves as the foundation for development of a training plan that will be cost effective and truly contribute to increased machinery reliability goals.

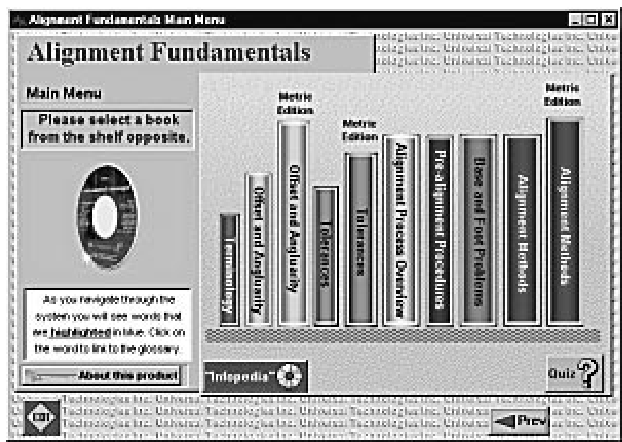


In addition, from such an analysis, clear learning objectives are identified for each subject. These objectives serve as the foundation for training. Whether the training is developed and conducted by in-house personnel or whether vendor courses are selected, the objectives provide a clear means by which the training content can be evaluated based on the desired learning outcomes.

Additional variables that should be considered relative to training include the nature of the training itself. Training providers should be flexible in delivering training that is:

- **Activity-Based**,
- **Customized** according to your specific needs,
- Applies sound conceptual information to **your specific instrumentation** and **internal procedures.**
- In addition, plans must be in-place for effectively evaluating the success of training that is conducted, and identifying and addressing continuing training needs in each subject area.

Typically, it is the infrequently performed tasks are often key candidates for continuing training as well as tasks that may need procedures or job aids. For the purposes of this continuing training, a variety of alternatives and delivery mechanisms should be considered, including periodic task assessments, Computer-based training products, and performance support tools.



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Implementing Quality Assurance Checks

Another essential component of reliability improvement is implementation of some form of quality assurance checks. The degree to which these checks are implemented is largely dependent on the industry in which you are involved. For certain industries, such as the military, the airline industry, and nuclear power, almost every task performed is carefully monitored by an independent quality assurance organization. On the other extreme, throughout most industries, such stringent measures are not typically in place. The question is to what degree are these measures needed at your facility?

Quality assurance checks create an essential expectation for performance. To achieve this, they do not have to be conducted by an independent organization as long as appropriate personnel conducting these checks are equipped with whatever mechanisms are needed to conduct the checks in a consistent and qualified manner.

Assuming that the above elements of a good reliability program are in place, the real question is how do we demonstrate compliance with what has been established. For example:

- How do we know that the maintenance decision making process is consistently applied?
- How do we know that written procedures are being properly used?
- How do we ensure all work by vendors, contractors, and in-house personnel complies with established standards, tolerances, and specifications?

As important, on a daily basis, how do we prove that we are seeing the maximum benefit from our reliability efforts? There are several practical processes that can be used to document the results. Among them are the following:

- Pre-repair and post-repair vibration readings. (See appendix for sample.)

  It is recommended that the craftsman who performs the repair perform the initial vibration check after a repair has been completed. There are many simple inexpensive vibration measurement devices that can be used for this procedure.
  In addition, with such a process in place, maintenance personnel are embraced by Condition Monitoring, rather than feeling alienated from the program. In addition, this process can reduce the workload on full-time PdM personnel and at the same time increase the number of vibration measurements obtained for the facility.

- Motor solo vibration checks. (See appendix for sample.)

  Many organizations are reaping tremendous benefits by checking new and rebuilt motors before putting them into service. These checks again create an expectation for performance. They can be performed at the facility or, if a good relationship exists with the vendor, at the vendor facility. A half key should be installed and the motor set on a rubber pad during these checks. Remember that these checks will only confirm mechanical integrity. Some companies have invested in dynamometers to load test motors that also checks electrical integrity.

- Balance reports. (See appendix for sample.)

  Many companies now specify precision balancing tolerances, but how do we know that these tolerances are being met. A simple balance record form containing as a minimum rotor weight, RPM, and residual unbalance sets an expectation to be achieved. Larger, more critical machines may warrant witnessing of the balancing process.

- Maintenance repair records. (See appendix for sample.)

  Teaching people to perform precision maintenance tasks does not necessarily create an expectation that the tasks be performed correctly outside of the classroom. While we find most attendees leave the classroom highly motivated and excited about precision maintenance, if we do not continue to nurture that motivation by creating an expectation that real change will occur, the training is often wasted. By creating a group of practical, easy to use forms to document results of a repair task, the expectation is communicated and adequate documentation is obtained for machinery history files, two elements missing from most industrial facilities today.

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Dealing with Motivational and Cultural Issues

In many cases cultural and motivational problems stem from a lack of communication. As managers and supervisors, we rarely have or make the time to explain the reasoning behind certain decisions. Failure to do clearly communicate often results in distrust between management and the workforce. By sharing information about the basic concepts of reliability, financial issues, and how the maintenance decision making process works, employees will feel less alienated and more empowered.

Be aware that it is a basic human instinct to resist change. The immediate response to any new idea is often negative. **Expect this response; it is normal.** In order to truly effect change, it is necessary to make the new idea or concept more attractive than the current way of doing business. Most plant personnel genuinely want to do good work. More importantly, they want to be seen as doing good work. By establishing measures that clearly demonstrate the quality of work, these personal goals are often achieved.

Understanding resistance to change explains why cultural changes are slow. Expect changes to occur slowly. Far too many plants attempt to implement radical changes in a short period of time, only to find that the culture soon reverts back to its original, more comfortable state.

When trying to influence culture, many companies find more success by making small incremental changes as opposed to sweeping monumental changes. For example, after deciding to implement a new procedure for performing a maintenance task, e.g., shaft alignment, choose a group of ten or so machines. Gather initial vibration data. Assign groups of individuals to perform the tasks on these machines to new precision standards, using record forms, etc. Gather post-repair vibration data and share the results.

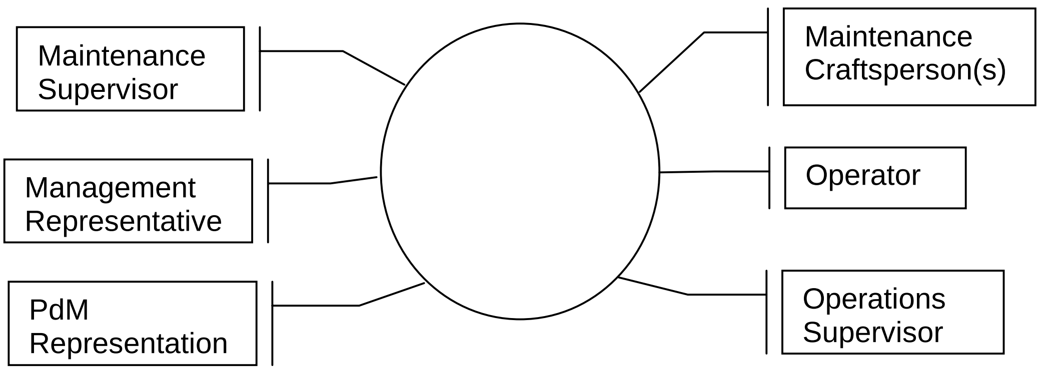
Cultural change is all about momentum. Once well underway, renewed energy for reliability improvement tends to be self-sustaining. However, especially in the early stage, it is extremely important to be aware that even what might appear to be a minor setback can have disastrous consequences. In every facility, there are certain individuals whose resistance to change is stronger than average. Usually, these people are waiting for an excuse to criticize what's new and encourage the masses to return to the old status quo, where their comfort level is highest.

Conversely, once these particular individuals are converted to the cause, they often become the program's strongest champions.

Change is a process, not a program… A program, by definition, has a start and a finish.

Be sensitive to inter-departmental issues. In many facilities a certain amount of “friction” exists between the various departments, in particular between operations and maintenance. One traditional perspective is that maintenance is somewhat subservient to production. This relationship must become a true partnership if reliability goals are to be met.

To facilitate this, when planning and making important decisions regarding maintenance strategy a group such as the one illustrated below should be utilized to ensure that all interested parties are represented. This will help validate the group’s findings.



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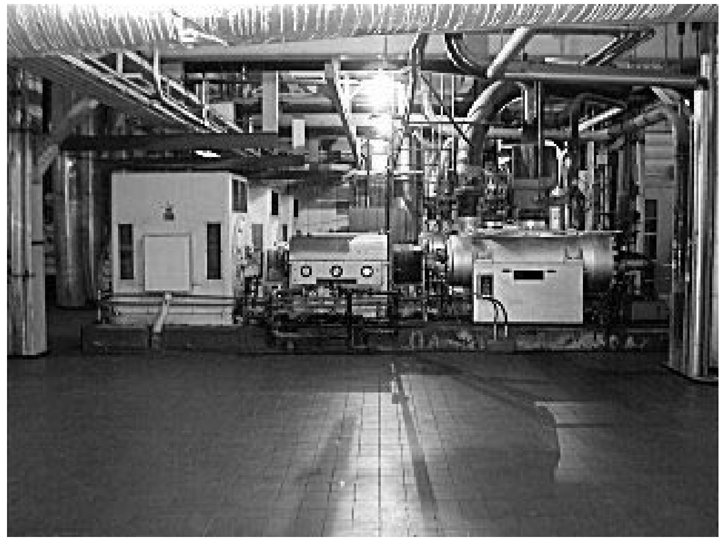
It is essential that personnel understand how the above factors relate to the reliability efforts at the plant level.

Reliability Scenario



As an example of how the lack of a team approach to reliability can cause confusion amongst the ranks, consider how market forces affect a reliability problem on a boiler feed pump in a coal-fired power station. There are 2 feed pumps both of which are required to operate the plant at full capacity. Mean time between failure on these units is only 12 months. FEMA analysis reveals repetitive seal and bearing failures on the pump. The root cause is determined as misalignment due to excessive pipe strain.

Deregulation of the utility industry has created an open market for power in the US. Currently capacity exceeds demand significantly. As a purchaser of wholesale power from a generation system one of the key indicators I use in making the decision to purchase power is the efficiency of the plant or heat rate. At the corporate and plant level senior management being aware of this instigate programs to improve efficiency and heat rate. Because of a reduction in maintenance personnel these projects are conducted at the expense of reliability issues. The feed pump reliability is still poor.

6 months later regulatory changes result in the temporary closure of several nuclear power plants. The resulting reduction in capacity creates conditions where capacity and demand are evenly balanced. As a purchaser my new need it to purchase from the most reliable source possible. In this way I can provide my customers with the power they need when they need it. I would therefore prefer to buy from the most reliable provider and hence at the plant level reliability now becomes a major issue. I even apply penalty clauses of $10,000 per MW per day to the supplier contact. At the plant level it now becomes necessary and appropriate to spend upwards of several hundred thousand dollars to redesign the piping system for the boiler feed pump to eliminate a pipe strain induced alignment problem that has reduced the reliability of that pump.

It is now 12 months after completion of the repairs to the boiler feed pump #1. All condition based indications are that the reliability of this machine is now excellent. A new change has occurred in the market place. Country wide generation capacity has increased to the point that reliability is no longer the critical Issue, having been replaced by environmental issues. The plant plans, prepares, then cancels repairs to the second feed pump in favor of some boiler work that improves emissions. Now, consider the perspective of the craftsman:

- I recently have been subjected to a significant changes in maintenance philosophy (Predictive / Precision Maintenance)
- I am naturally skeptical of the changes in maintenance environment, after all I have been in maintenance for 20 years and have seen a lot of “programs” come and go

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- I am also already suspicious of management decisions regarding maintenance as recent re-organizations have placed personnel from a non-maintenance environment in control of maintenance activities.
- We have spent thousands of dollars improving insulation in the plant yet one of the most expensive machines in the place as been “allowed to fail regularly.
- We are finally “allowed” to solve the feed pump problem and I derive a lot of satisfaction from the improvements made.
- I was prepared and keen to make the same improvements to the sister machine.
- Just before the improvements were to be made to the sister machine the project gets cancelled.
- The company sends me to “precision” maintenance training.

Is there any wonder frustration sets in ? In order to prevent these issues it is very important to explain the reasoning behind certain plans processes and strategies not just the strategies themselves.

12 Step Roadmap

1. Understand the concepts of machinery reliability.
2. Determine the most appropriate maintenance approach for particular machines, systems, or areas.
3. Establish key performance indicators and a system for tracking progress.
4. Properly plan and schedule maintenance activities.
5. Implement a condition monitoring program as required
6. Establish approved maintenance standards, procedures, and acceptance criteria.
7. Establish an effective maintenance Management information system
8. Establish effective quality assurance processes.
9. Procure necessary tools and equipment.
10. Ensure personnel are properly trained and qualified.
11. Repair machines in accordance with approved “reliability qualification” processes.
12. Verify and evaluate the qualification process and make improvements as required.

Appendix

Sample Forms and Procedures

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New/Rebuilt Motor Vibration Test Form (0- 20 HP)

Scope

This form is to used to record the shop test data taken on motors running solo in the shop.

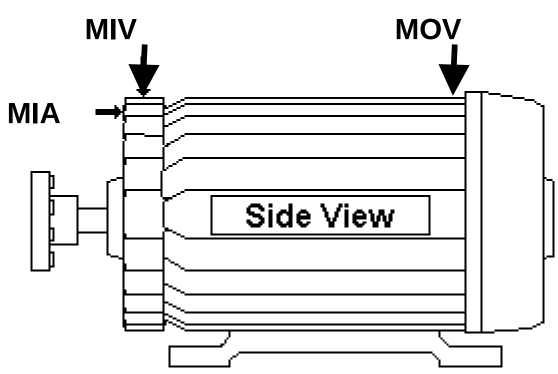
Set up

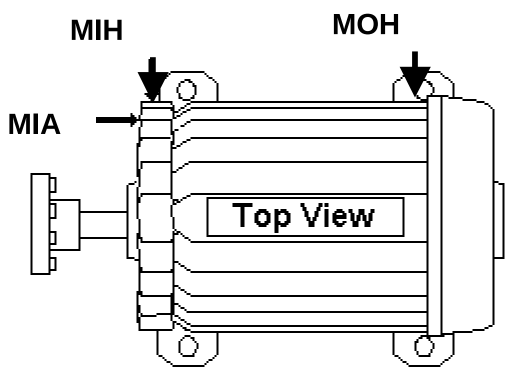
- Motor to have a ½ key installed.
- Motor to be placed on rubber mat at least ¼" thick.
- Where possible motor to be tested at full service speed.
- Maximum line amplitude is the amplitude value of the highest discrete frequency component within the stated frequency range in any direction (HVA).
- Scope of this criteria is 2, 4, & 6 pole motors.

Equipment ID: ________________________

Acceptance Criteria 0-20 HP Motors		**Vibration Test Data New/Rebuilt Motors**				
Frequency Range	**Max Line Amplitude ips pk**	**MOV**	**MIV**	**MOH**	**MIH**	**MIA**
Sub-harmonic (< 1x RPM)	0.02					
1 x RPM	0.03					
Lower Multiples (1x RPM – 10x RPM)	0.02					
Higher Frequencies (10x – 50x RPM)	0.01					
Overall Acceleration g pk (0- 20kHz)	0.5					

Measurement locations





New/Rebuilt Motor Vibration Test Form (20 - 400 HP)

Scope

This form is to used to record the shop test data taken on motors running solo in the shop.

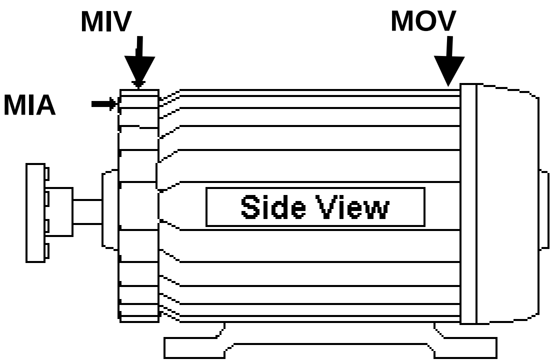
Set up

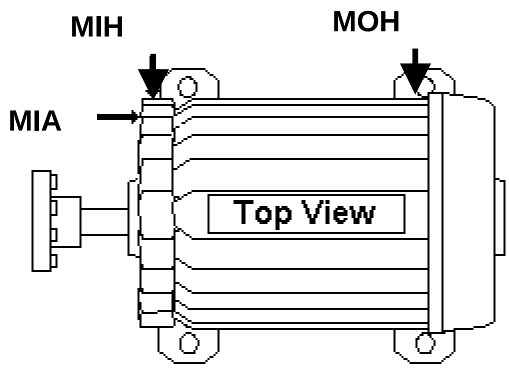
- Motor to have a ½ key installed.
- Motor to be placed on rubber mat at least ¼" thick.
- Where possible motor to be tested at full service speed.
- Maximum line amplitude is the amplitude value of the highest discrete frequency component within the stated frequency range in any direction (HVA).
- Scope of this criteria is 2, 4, & 6 pole motors.

Equipment ID: __________________________

Acceptance Criteria 0-20 HP Motors		Vibration Test Data New/Rebuilt Motors				
Frequency Range	**Max Line Amplitude ips pk**	**MOV**	**MIV**	**MOH**	**MIH**	**MIA**
Sub-harmonic (< 1x RPM)	0.02					
1 x RPM	0.05					
Lower Multiples (1x RPM – 10x RPM)	0.03					
Higher Frequencies (10x – 50x RPM)	0.01					
Overall Acceleration g pk (0- 20kHz)	0.5					

Measurement locations





New/Rebuilt Motor Vibration Test Form (400 HP +)

Scope

This form is to used to record the shop test data taken on motors running solo in the shop.

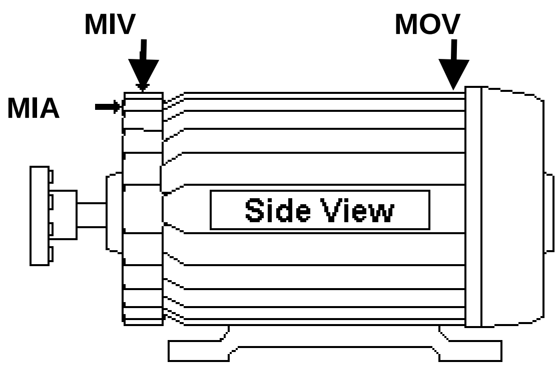
Set up

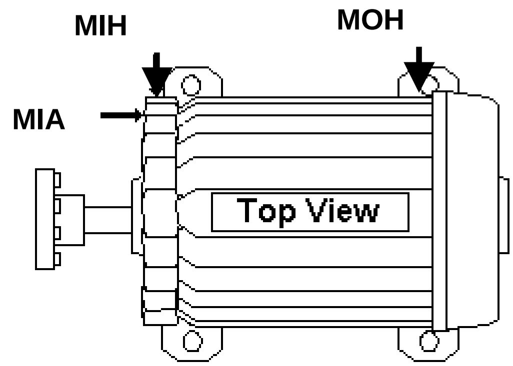
- Motor to have a ½ key installed.
- Motor to be placed on rubber mat at least ¼" thick.
- Where possible motor to be tested at full service speed.
- Maximum line amplitude is the amplitude value of the highest discrete frequency component within the stated frequency range in any direction (HVA).
- Scope of this criteria is 2, 4, & 6 pole motors.

Equipment ID: __________________________

Acceptance Criteria 400 HP + Motors		**Vibration Test Data New/Rebuilt Motors**				
Frequency Range	**Max Line Amplitude ips pk**	**MOV**	**MIV**	**MOH**	**MIH**	**MIA**
Sub-harmonic (< 1x RPM)	0.02					
1 x RPM	0.08					
Lower Multiples (1x RPM – 10x RPM)	0.03					
Higher Frequencies (10x – 50x RPM)	0.01					
Overall Acceleration g pk (0- 20kHz)	0.5					

Measurement locations





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Sample Balance Record Form

Rotor Balance Data Sheet (Shop Balancing)

1.0 ROTOR INFORMATION			
(1.1) Equipment ID		(1.2) Date	
(1.3) Serial #		(1.4) Manufacturer	
(1.5) Rotor Type (ie fan, blower,cplg, shaft, impeller etc)		(1.6) Service RPM	
(1.7) Rotor Weight (lbs)			
(1.8) Service Configuration (circle one) *(see note i.)* Centerhung Overhung		(1.9) Balancing Configuration (circle one) *(see note i.)* Centerhung Overhung	
2.0 BALANCE TOLERANCE CALCULATION			
(2.1) Desired Tolerance (circle one) 4W/N W/N		(2.2) Stack Balance Required ? (circle one) Yes No	
Plane 1		**Plane 2**	
(2.3) Journal Load [W] *(see note ii.)* (50% of rotor weight from (1.7) if symmetrical) Lbs		*(2.4) Journal Load [W]* (see note ii.) (50% of rotor weight from 1.7 if symmetrical) Lbs	
(2.5) RPM [N] (from item (1.6))		(2.51) RPM [N] (from item (1.6))	
(2.6) Max Permissible Unbalance [U] (Calculate based on 4W/N or 1W/N as reqd.) U_{MAX} = Oz.in		(2.7) Max Permissible Unbalance [U] (Calculate based on 4W/N or 1W/N as reqd.) U_{MAX} = Oz.in	
(2.8) Convert to g.in if required U x 28.35 = g.in g.in		(2.9) Convert to g.in. if required U x 28.35 = g.in g.in	
3.0 BALANCE DATA			
(3.1) Balancing RPM	½ key Used ? yes no	(3.2) Balancing Machine Type (circle one) Hard Bearing Soft Bearing	
Plane 1		**Plane 2**	
(3.3) Correction radius inches		(3.4) Correction Radius inches	
(3.51) 1ST Correction	g / deg	(3.61) 1ST Correction	g / deg
(3.52) 2ND Correction	g / deg	(3.62) 2ND Correction	g / deg
(3.53) 3RD Correction	g / deg	(3.63) 3RD Correction	g / deg
(3.54) 4TH Correction	g / deg	(3.64) 4TH Correction	g / deg
(3.7) Actual Balance Achieved (next correction wt x radius) g. in oz.in		(3.8) Actual Balance Achieved (next correction wt x radius) g. in oz.in	
(3.9) Desired Unbalance from item (2.6) g. in oz.in		(3.91) Desired Unbalance From item (2.7) g. in oz.in	

Notes / Comments

Name Signature

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The purpose of this form is to convey important information about the balance quality of rotors that are balanced in a balancing machine.

This form to accompany every rotor to be balanced

The recommended standard for general machinery is that of the American Petroleum Institute (API) which states that:

$$\mathbf{U_{MAX} = 4\ W/N}$$

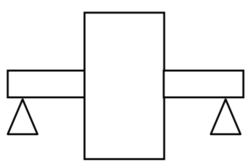
Where:

U_{MAX} = the maximum allowable unbalance per plane in oz-in.
W = static journal load in lbs. (for symmetrical rotors, ½ rotor weight)
N = the maximum continuous rotating speed in RPM

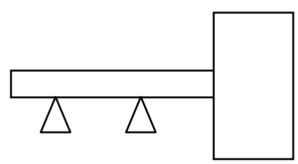
In some special cases a standard of 1 W/N may be requested

<u>Notes</u>

i. **Configuration** Items (1.8) ; (1.9)

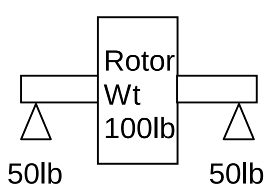


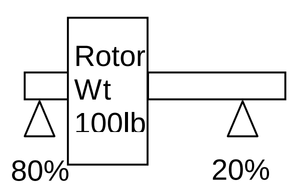
Centerhung configuration



Overhung configuration

ii. **Journal Load** Items (2.3) ; (2.4)
For symmetrical rotors the journal load is 50% of rotor weight
For Non-symmetrical rotors the individual journal load must be calculated.





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Sample Centrifugal Pump Repair Form

Equipment Number		Work Order Number		Date	
Pump description		**Running Hrs**			
Machine History Checked ?		**Clearance #**	**Isolation Points**		
			Valves	**Breakers**	
Pump Manufacturer		**Pump Size**			

Reason that Work Order was Written for Pump

Inspection Section

Pump Foundation & Piping

Item	Condition		Comments
Grout/Foundation	Good	Bad	Not Checked
Anchor Bolts	Good	Bad	Not Checked
Base Condition	Good	Bad	Not Checked
Pusher Bolts	Yes	No	Not Checked
Suction Piping Strained	Yes	No	Not Checked
Discharge Piping Strained	Yes	No	Not Checked

Pump Coupling

Coupling Spacer	Good	Bad	Not Checked
Coupling Flanges	Good	Bad	Not Checked
Coupling Hubs	Good	Bad	Not Checked
Key Length	Good	Bad	Not Checked
Lubricant Condition	Good	Bad	Not Checked

Pump Bowl

Impeller Rub	Yes	No	Not Checked
Corroded/Eroded	Yes	No	Not Checked
Gasket Leak	Yes	No	Not Checked
Plugged in Suction/Discharge	Yes	No	Not Checked
Wear Ring Condition	Good	Bad	Not Checked

Pump Impeller

Impeller Rub	Yes	No	Not Checked
Corroded/Eroded	Yes	No	Not Checked
Impeller Gasket Condition	Good	Bad	Not Checked
Cavitation Wear	Yes	No	Not Checked
Impeller Tips Bent/Worn	Yes	No	Not Checked

Rear Cover

Backplate Corroded/Eroded	Yes	No	Not Checked
Stuffing Box Corroded	Yes	No	Not Checked
Gland Gasket Leaking	Yes	No	Not Checked

Mechanical Seal

Seal Leaking	Yes	No	Not Checked
O-rings	Good	Bad	Not Checked
Rotating Face	Good	Bad	Not Checked
Stationary Face	Good	Bad	Not Checked
Seal Flush Operational	Yes	No	Not Checked

Shaft

Sleeve	Yes	No	Not Checked
Fretted	Yes	No	Not Checked
Grooved	Yes	No	Not Checked
Corroded/Pitted	Yes	No	Not Checked
Threads Worn	Yes	No	Not Checked
Bent/Broken	Yes	No	Not Checked

Cartridge

Front Bearings	Good	Bad	Bearing Manuf. & #
Rear Bearings	Good	Bad	Bearing Manuf. & #
Oil Seals/Isolators	Good	Bad	
Oil Level	Good	Low	
Oil Contaminated	Yes	No	

Measurement Section

Dial Indicator Readings/ Run out Checks

	Description	Total Indicator Reading (NOT TO EXCEED)	As Found Reading	Rebuilt Reading
Shaft End Play	Check and measure the thrust bearing and its fit in the housing.	.002”		
Radial Deflection	Check and measure the condition of the bearings and their fit in the housing & shaft.	.002”		
Shaft Run Out	Check and measure that the shaft is straight and round.	.002”		
Stuffing Box Face Perpendicularly	Check and measure that the rear cover is square with the shaft	.002”		
Concentricity	Check and measure the rear cover is concentric to the shaft.	.005”		

Bearing Fits

	Bearing	Shaft/Housing	Fit
Inside Diameter of Outboard Bearing vs Outside Diameter of Shaft			
Inside Diameter of Inboard Bearing vs Outside Diameter of Shaft			
Outside Diameter of Outboard Bearing vs Inside Diameter of Housing			
Outside Diameter of Inboard Bearing vs Inside Diameter of Housing			
Internal Clearance (tapered adapter sleeve bearings)			

Note: The bearing ‘FIT’ is the difference between the ‘Bearing’ reading and the ‘Shaft/Housing’ reading.

Impeller Setting

For Open Vane Impellers		For Reverse Vane Impellers	
Distance Set Off Front Casing		Distance Set Off Rear Cover	
Impeller Diameter		Wear ring Clearance	

Mechanical Seal

Seal Number		Manufacturer	
Seal Distance from Rear Cover			

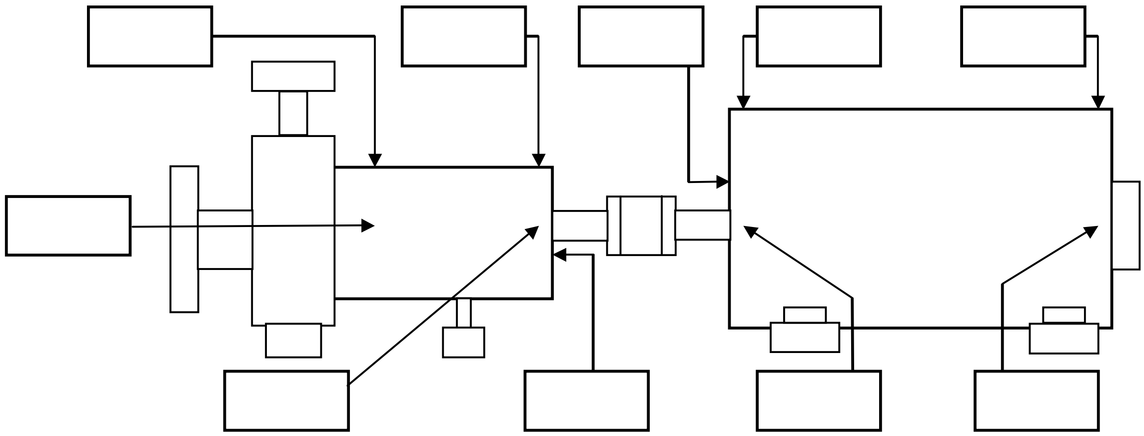
Final Alignment Readings

Vertical Readings		Horizontal Readings	
Front foot Reading		Front foot Reading	
Back foot Reading		Back foot Reading	
Vertical Offset	Vertical Angularity	Horiz Offset	Horiz Anglularity
Hold Down Bolt Torque Values			

Operational and Quality Checks

Operation Checkout

Dead Head Pressure Reading		
Normal Operation Pressure Reading		
Vibration Readings Overall ips pk	Drive End	Non Drive End



Recommendations/Comments

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