INSPECTION AND QUALITY CONTROL

by

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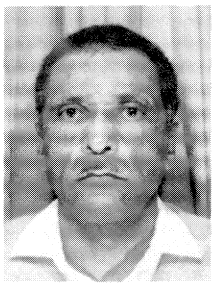

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ABSTRACT

Petrochemical companies are confronted daily with the need for greater equipment reliability and a decrease in the overall maintenance cost. The philosophy and objectives behind inspection and quality control of rotating machinery maintenance are discussed. The goal of Inspection and Quality Control is stated. Inspector and Quality Controller's fundamental qualifications and duties are defined.

The presentation also addresses key elements to help the maintenance program evolve from the present day symptom/cure syndrome to the identification and elimination of root cause problems. Some of the key elements that are identified are thorough documentation with field and shop repair cards, development of pump repair, removal, and installation standards, pump surveillance and audits, training the repair person to identify root cause problems and to take corrective action, and having each action occur at the proper time by the proper person. Setting minimum standards for equipment maintenance and implementing them with trained personnel can ensure that the work is done right the first time.

INTRODUCTION

The main objective in repairing equipment is to maximize the run time between failures in a cost effective manner. Past practice has been to repair the equipment as fast and as inexpensively as possible, which has often resulted in increased pump failure rates and decreased inspection and quality control. In today's competitive business environment, the industry requires greater equipment reliability and an increase in pump service life.

In general, it will be cost effective to spend extra time and money during a repair to increase the potential run time for the equipment and to reduce the probability of failure.

PHILOSOPHY

Inspection and Quality Control

A comprehensive inspection and quality control program is a continuous process, when properly applied throughout the entire repair, can lead to improved equipment reliability. In pump repairs, inspection and quality control starts the moment the pump is identified as needing repair and is not complete until the pump is started up successfully. Once an equipment repair has begun, *ALL* parts must be thoroughly inspected, not just those that are obviously damaged. Inspection is needed to ensure that all parts are in good condition, within the established specifications and tolerances; that they fit together properly; that the entire machine is assembled properly; and that all required checks and tests have been completed.

Equally important, Inspection and Quality Control means taking the time and effort to determine the *ROOT CAUSE* of failure and to initiate corrective action to prevent the failure from recurring. This last point, determining the root cause of the failure, cannot be overlooked in any stage of the repair process. Without determining the root cause and taking the proper corrective action, the pump problems are likely to be reinstalled.

An inspection program should describe the "as found" state or condition of the entire pump before removal, the condition of the parts during disassembly, and the "as-built" or installed condition. The "as found" and disassembly inspection information should be used to help determine the root cause failure. Using the inspection results, a quality control program can allow you to repair the equipment according to established standards and procedures.

Who does the inspection and is it done?

Most repair inspection programs are "after the fact" type inspections. Typically, inspections are performed by a machinery foreman, a machinery inspector, or a machinery engineer who usually sees the parts *AFTER* the equipment is disassembled when most of the important clues are already lost. Likewise, assembly inspections are usually made after repairs are completed. Assembly problems frequently go undetected. This type of inspection is very expensive, but rework for incorrect repairs can cost more.

Inspections should be made throughout the entire repair beginning with a visual inspection before disassembly and including checks during disassembly, repair, reassembly, and installation.

The repair person is the best person to perform the inspection, once he is given the proper training on what items to look for during a repair and understands how to apply the data. Training a repair person on how to do inspection while performing the repairs, allowing him to make recommendations to correct the problem, or allowing him to correct the problem will generally eliminate the problem and be cost effective. Getting the repair person involved in the inspection and decision making process develops a sense of pride and ownership for the quality of the repairs.

Who does the quality control and when is it done?

In most programs today, Quality Control is typically a function of an inspector or engineer who usually has access to some standard by which the repairs are measured. In addition to inspecting equipment repairs, the quality control person usually has other duties and responsibilities that keep him away from the immediate repair work. This type quality control system is generally a periodic audit and inspection of the repairs whenever he is able to break away from his other duties.

The most effective quality assurance program is one which allows the repair person to perform his own inspection and quality control. The repair person is the only one who is on the job site from start to finish, making him available to ensure that all checks are made.

Establishing repair standards by which repairs are made is one means of ensuring that a quality repair is made the first time, every time. While Quality Control during repairs affects all involved in the repair process, the ultimate quality assurance role should belong to the repair person. A properly trained person who knows and understands repair standards and has a general idea of what to do about problems that come up during the repairs is the best one to ensure quality control during repairs. The repair person may not have all of the technical expertise, understanding, or skills necessary to make technical decisions, but the key to quality repairs is to ensure that he is properly trained to recognize the decisions that he should make and those that he should not make without further assistance. Simply put, he needs an understanding of his limitations and must know when to call for help.

Documentation

Documentation is an important ingredient in the repair process. The very act of documenting the work serves as a reminder to the person doing the repair to help ensure that key steps or checks are not overlooked, as well as verifying what work was done. Written records are an extremely valuable source of information for future repairs and future troubleshooting. For premature equipment failure data, this information can be used to help troubleshoot the cause of failure because all the "as-built" data can be analyzed and a determination of why the equipment failed can be made if the repair work was improper. For successful repairs, this data can be used as a guide to a future identical repair.

Standardize or Alter

There is a need to maintain standard dimensions when making repairs. Repairs which alter dimensions from standard are often less expensive in the short run, but they can be very expensive in the long run. Frequently, parts are altered from standard to accommodate priorities or schedules. The decision to alter the part is normally made on a case-by-case basis relative to the circumstances and the business needs at the time. This will serve its purpose for the short run, but if the equipment with the altered parts should need repairs again, it will probably take more time and money to repair, since these parts will most probably have to be altered again requiring extensive machine work.

Moreover, when new replacement parts are bought either from inventory, the original equipment manufacturer, or other vendors who fabricate standard parts for the equipment, the part(s) usually do not fit the altered parts.

If during equipment repairs, priorities or schedules justify the need to alter standard parts, a plan or strategy should be developed to bring the parts back to standard at the next repair. Generally, standard parts require no machine work or alterations; they fit properly and are within standard dimensions, sizes, fits, clearances and tolerances.

Common sense and good judgement should always be used in any equipment repair.

Prevention/Corrective Action

Preventative maintenance programs are the best tools to use for ensuring longevity in pump service life. Operator surveillance and equipment audits are two sources of preventative maintenance. Fixing what caused the problem is too late; the failure has already occurred, and you are caught pouring money into something you could have prevented. Prevention is the key item here. Once a pump has failed, however, it is essential that we prevent a recurrence.

Performing a root cause failure analysis of a pump failure and taking the proper corrective action are keys to eliminating future problems.

Once the root cause has been identified, a corrective action plan must be developed and the plan implemented, such that the cause of the failure is eliminated. Although eliminating root causes of a failure is a reactive type prevention step, it works and is necessary. Correct what caused the failure and the problem should go away.

Immediate corrective action may not be possible due to schedules, priorities, or other reasons. If the root cause is not correctable during this repair, document the problem and formulate a corrective action plan to eliminate the problem at the next available opportunity, such as during the next turnaround.

Quality—"Do It Right The First Time"

Common sense tells us that it is more economical to do something right the first time, every time. What is right is often an interpretation by those who are involved with the repairs at that time. Right means different things to different people. What are right clearances or tolerances to one person may be different to another. Unless standards are developed that establish what is right for all of us, doing it right could mean anything.

Generally, standards information; i.e., fits, clearances, and tolerances, and generic inspection recommendations, can be obtained from equipment files or from the equipment manufacturer for relatively new types of pumps. For older type pumps, however, equipment files are generally void of such vital data. Fits, clearances, and tolerances are subject to interpretation. Old repair cards if they exist, older more experienced repair people, one's own experiences, and guesswork are some of the resources often used to determine what is right.

Quality begins with developing standards to define what is right or required. Repairing pumps per the standards is a sure way of doing it right the first time. Documenting what is done is good data to use for future evaluation of whether the standards are letting us do it right the first time.

THE PROCESS TO QUALITY CONTROL

Surveillance and Audits

A periodic pump surveillance and an audit program are keys to prevention of pump failures. Generally, the operator should conduct a daily surveillance of each piece of rotating equipment to ensure that all of the systems are functioning properly. A checklist should be designed to detect and document the general condition of the pump and its supporting system(s), and to indicate pump operating deficiencies. The data generated by the checklist can then be used to eliminate potential equipment problems.

The survey should require checks of the equipment lubrication system, seal flush system, the cooling water system, equipment and piping vibration, process conditions, process and auxiliary piping, bearings, etc.

Typical lubrication checks include:

- Proper oil level.
- Dirty, discolored or contaminated oil in the equipment or main oil reservoir.
- Oil mist operating properly.
- Clean bulk oil reservoir, oil transfer devices (cans, drums, etc.) and equipment oilers (bulbs, sight glasses, etc).

Typical seal flush system checks include:

- Seal flush flow and temperature.
- Seal leaks.
- Seal pot levels and pressures.
- Clean sight glasses and gauges.
- Steam quenches on and operating properly.

Other checks include:

- Properly operating and clean pressure gauges on the process side along with auxiliary systems.
- Cooling water temperature and flow.
- Bearing temperature.
- Vibration and noise.

Only a small percentage (15-20 percent) of the rotating equipment in an operating unit needs to be on a monthly audit program. The audit program should give a general overview of the condition of the rotating equipment for that operating unit. The greater the number of deficiencies, the greater the risk of failure, and the higher the priority for corrective action. Having such a program reduces the risks of rotating equipment failure; thus reducing the repair rate.

Equipment Troubleshooting

Many pump problems in the field can be resolved while the pump is still in service. This is not always possible, since the business pressures resulting in reduced manpower levels and lower experience levels have made it difficult to get the people with the experience necessary to properly analyze (troubleshoot) the pump problem and to do the analysis when it is needed.

When a pump failure has occurred, several troubleshooting checks can be made that can help to identify or lead to the root cause of the failure. The inspection to determine the root cause should start before the pump is shutdown, if possible, and before pump removal. If you are unable to analyze a problem before the pump is shutdown, a visual inspection of the pump condition and its auxiliary system(s) before and during removal can reveal helpful clues in determining the cause of failure.

Typical checks should include:

- *Trying to determine the sequence of events that took place that could have caused the problem or failure.* Probe deeper into the failure analysis. Ask yourself questions concerning the failure. What could have caused the pump or part to fail? How long has the equipment been in service? Is this a recurring failure? What were the process conditions prior to the failure? What were the design conditions? What were the early symptoms of the failure? To accept that a failure has occurred without further investigation into why it failed is not enough troubleshooting.

One must ask *WHY* it failed and *WHAT* caused it to fail. For example, a pump bearing has failed. It may be obvious that the bearing is the cause of the pump failure, but why did the bearing fail and what could have caused it to fail? There are numerous possibilities that should come to mind. List all of them in some written form. Don't overlook any item until each has been thoroughly and completely studied and you are certain that it did not contribute to or cause the failure.

Systematically eliminate the possible causes that are definitely *NOT* related to the failure. Once you have narrowed the possibilities down to a few or one, again ask the question why would that problem occur and what could have caused it to happen. Once the root cause is determined, corrective action can be taken to eliminate the root cause.

- *In the field prior to removal, inspecting all the parts of the pump and its auxiliary system(s), not just those that are obviously damaged.* Check the general condition of the lube oil, seal oil, cooling water, and steam quench systems, paying particular attention to plugged or restricted openings. Check the pump base and foundation for structural integrity. Visually inspect the piping system for any unusual or excessive piping loads or strain. Piping checks are best made when the pipe is being disconnected from the pump. Remember, piping should line up and be parallel with the pump flanges. The pump should never be used as a piping anchor or support.

The Field-Removal and Installation Repair Card (Figure 1) can serve as a guideline on what items should be checked before and during the removal process.

Pump Repair Standards

Inspection and quality control is very effective if a repair standard has been established and the repair person knows and understand the standards. Standards establish minimum requirements for repairs, ensure consistency in repairs, promote standardization of parts and help to improve the reliability of the equipment. Parts standardization can help you maintain the proper spare parts levels in your warehouse.

Repair standards also help repair people to become more familiar with the repair methods, thereby increasing their ability and efficiency. Tooling becomes more commonplace and more familiar to the user. Specialized tooling becomes unnecessary. Pump repair terminology becomes easier to understand resulting in the development of better communication channels between the repair people themselves and between the repair person and the person requesting the repairs.

Standards also establish and define the minimum expectation for a quality repair. Every one associated or involved with the repair becomes familiar with, gets to know, and finally understands the requirements which promote increased productivity for the company and job satisfaction for the repair person.

The four major phases of the repair are:

- Pump Removal.
- Pump Repair and Overhaul.
- Pump Installation.
- Pump Startup/Standby.

The last phase, startup/standby, ensures that the time and money spent on the quality repair will not be wasted. Any one of these phases, if not properly performed, can produce costly results.

Without proper field analysis and inspection of the pump and its associated equipment during the removal phase, items which contribute to or cause the failure could be reinstalled. Shop repairs that are performed without checking the condition, dimensions, and sizes of the parts for proper fits, clearances and tolerances and without correcting those defects will cause reassembling of past problems. Improper installation, installation without ensuring that all problems found during removal are not corrected, or installations without a standard system of checks to ensure that keys steps are not overlooked will almost assure pump rework. Removal, repair, and installation Standards and methods for documenting these phases are essential elements in a quality repair.

At the Shell Oil Deer Park Manufacturing Complex, Pump Removal, Repair, and Installation Standards for single stage overhung centrifugal process pumps have been developed.

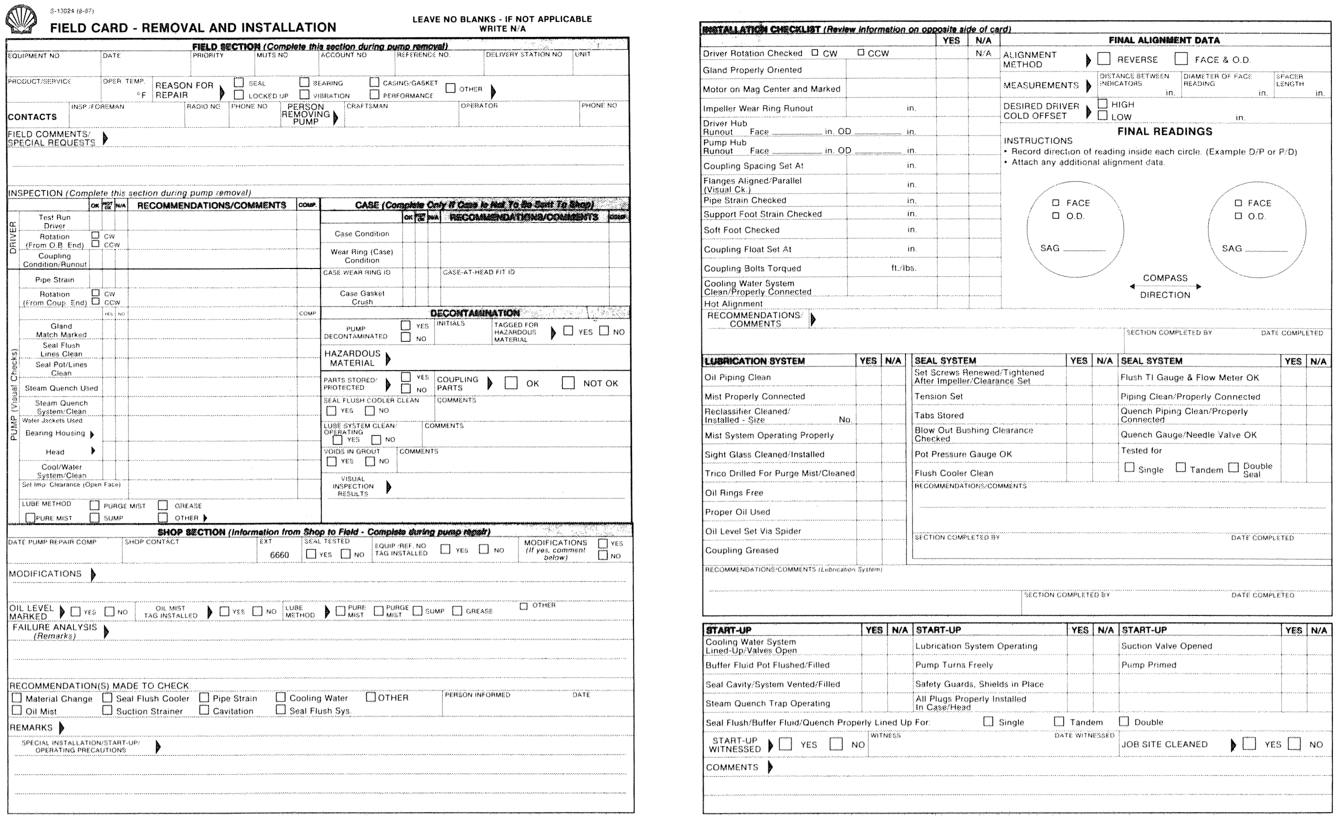

Figure 1. Field Repair Card.

These standards allow all repair personnel to remove, repair and install pumps using the same guidelines every time. Many of the items in the standards are common to other types of pumps as well.

Implementing the standards required development of "Machinery Repair Standards Awareness" training programs for all machinery craftsmen, machinery inspectors and foremen, non-machinery craftsmen and foremen who are effected by the standards, process operators and foremen, and supervisors of the above groups. These Awareness training programs were designed to introduce and explain the need for the standards. Each session was structured to address the audience. The Awareness training has been completed.

Implementing the standards also required development of an intensive classroom training program for the machinery craftsmen, foremen, and inspectors. Training of all machinery personnel on the contents of the standards and the expectation of all machinery personnel was essential to ensuring that all hear the same message, use consistency of repairs and the same criteria. This training has been completed.

Several forms to document how well the standards are working were developed. One of the forms is the Variance Form, which has to be filled out and approved whenever a repair must deviate from the standards or whenever the standards cannot be met. Many helpful clues and solutions to problems have been and can be generated from the form.

A Field Card (Figure 1) for documenting data during removal and installation and a Pump Repair Card (Figure 2) for documenting data during the repair of the pump have been developed at the Deer Park facility. The purpose of each card is to document the "as-found," the "as-built" and the "as-installed" condition of the pump and its associated and auxiliary equipment, to communicate to others what needs to be done and what has been done, and to record information that will be helpful in future repairs.

Removal

Standards for pump removal are key areas to performing a quality pump repair. Removal standards should have guidelines to use and checks to make when removing pumps for repairs. A field repair card used for documenting the "as found" condition, the workscope, the recommended corrective actions, and the "as built/corrected" or "as left" condition, must also be developed.

The standards define those tasks that must be performed during removal. These items include, but are not limited to:

- A general inspection.
- Checking for and correcting pipe strain.
- Checking and inspecting the:
  - Seal and seal flush system.
  - Lube oil and lubrication system.
  - Steam quench system.
  - Cooling water system.
- Checking and correcting pump base voids.
- Coupling condition.
- Inspection of all parts.
- Piping line-ups on product and auxiliary piping systems.

All these items should be checked during removal to ensure that they did not contribute to the failure and that in the future, they will not reduce the service life of the pump once repaired.

The standards also require that you measure and record all of the critical sizes, clearances, and dimensions during field re-

DISASSEMBLY			OK	NOT OK	REASSEMBLY		OK
Impeller Backside Clearance (Gap)					(Gap)		
INDICATOR CHECKS:	CONCENTRICITY	ANGULARITY	OK	NOT OK	CONCENTRICITY	ANGULARITY	OK
Impeller							
Impeller Wear Ring (Case)		N/A				N/A	
Head-at-Case Fit							
Bearing Bracket-at-Head Fit						N/A	
Shaft-at-Impeller		N/A					
Sleeve		N/A				N/A	
Shaft-at-Sleeve		N/A				N/A	
Coupling							
Shaft-at-Coupling		N/A				N/A	
End Play (Thrust Float)							

DIMENSIONAL CHECKS:	SIZE	CLEARANCE	OK	NOT OK	(Record if part is replaced or repaired) SIZE	CLEARANCE	OK
Impeller		N/A				N/A	
Case Wear Ring							
Impeller Wear Ring (Case)	=				=		
Head Wear Ring							
Impeller Wear Ring (Head)	=				=		
Throat Bushing							
Case-at-Head Fit							
Head-at-Case Fit	=				=		
Bracket-at-Head Fit							
Head-at-Bracket Fit	=				=		
Impeller-at-Shaft							
Shaft-at-Impeller	=				=		
Coupling-at-Shaft							
Shaft-at-Coupling	=				=		
Sleeve-at-Shaft							
Shaft-at-Sleeve	=				=		
Stuffing Box Fit							
Gland Boss Fit	=				=		
Gland Throttle Bushing							

BEARING FIT	DISASSEMBLY SHAFT SIZE	HOUSING SIZE	OK	NOT OK	REASSEMBLY SHAFT SIZE	HOUSING SIZE	BEARING SIZE INSIDE DIAMETER	OUTSIDE DIAMETER	OK
Radial									
Thrust									

	DISASSEMBLY MFG. NAME	MFG. NUMBER	REASSEMBLY MFG. NAME	MFG. NUMBER	REUSED	NEW
Lip Seal - Inboard					N/A	
Lip Seal - Outboard					N/A	
Radial Bearing						
Thrust Bearing						

CASE GASKET SIZE ▶	OUTSIDE DIAMETER	INSIDE DIAMETER	THICKNESS	TYPE	MATERIAL

REASON FOR REPAIR ▶ ☐ SEAL ☐ LOCKED UP ☐ BEARING ☐ VIBRATION ☐ CASING/GASKET ☐ PERFORMANCE OTHER

EQUIPMENT NO. | DATE ASSIGNED | PRIORITY | ACCOUNT NO. | REFERENCE NO. | PUMP MFG. | UNIT

PARTS MATCH MARKED ☐ YES ☐ NO

PUMP REPAIR CARD

SEAL PORTS CLEANED ☐ YES ☐ NO	SEAL MFG.	SEAL TYPE	DRAWING NO

LEAVE NO BLANKS - IF NOT APPLICABLE WRITE N/A

VISUAL INSPECTION RESULTS ▶

PROBABLE CAUSE OF FAILURE ▶

INSPECTION AND WORKSCOPE

PART	CONDITION OK	CONDITION DEFEC.	RECOMMENDATIONS Specify recommended material. Attach additional sheets if necessary.	PART STATUS CUT FOR REPAIR	ORDERED FROM STOCK	ORDERED FROM VENDOR	DATE DUE	DATE RECEIVED	COMPLETE
Impeller									
Impeller Balance			Balance Impeller						
Impeller Wear Ring (Case)									
Impeller Wear Ring (Head)									
Case Wear Ring									
Head Wear Ring									
Throat Bushing									
Case									
Head									
Bearing Housing									
Bracket-at-Head Fit									
Shaft									
Bearings									
Slinger(s)									
Oil Ring(s)									
Lip Seal(s)									
Seal(s)									
Sleeve									
Gland									
Coupling									
Case Gasket									
OTHER (Specify) ( )									

COMMENTS (Please Initial)

MODIFICATIONS (Please Initial)

BEARING HOUSING MARKED/TAGGED ▶ ☐ PURE MIST ☐ PURGE MIST ☐ SUMP ☐ GREASE

TYPE OF FAILURE ▶ ☐ SEAL ☐ BEARING ☐ RADIAL ☐ THRUST ☐ OTHER

ASSEMBLY COMPLETED BY ▶	DATE ASSEMBLED	SEAL TESTED BY	DATE TESTED	PUMP PROTECTED BY

D = Disassembly, I=Inspection, R=Reassembly

CRAFTSMAN'S NAME	CODE	SHIFT	DATE SIGNED	DEVIATION(S) IF YES, ATTACH DEVIATION FORM YES	NO

SPECIAL INSTRUCTIONS FOR NEXT REPAIR ▶ ☐ YES ☐ NO

IF YES WHERE ARE INSTRUCTIONS? ▶ ☐ EQUIP FILE ☐ RED FOLDER ☐ OTHER (Explain)

REMEMBER

- DO NOT LEAVE ANY BLANKS - FILL WITH N/A
- ATTACH ALL FORMS AND/OR REPORTS

Figure 2. Pump Repair Card.

moval and repairs. Some of these items include:

- Gasket depths (rotor removal only).
- Wear ring sizes (rotor removal only).
- Wear ring clearances (rotor removal only).
- Coupling spacing.
- Seal tension.
- Impeller-to-case clearance (rotor removal only).

Once the condition of all parts that you are able to inspect are completed and a most probable cause of the failure or problem is found, develop a complete written workscope of the pump repair work. A complete written workscope should ensure that problems are not overlooked and that the repairs are done right the first time.

If the auxiliary equipment needs corrective action or repair, correct the problem or initiate corrective action to have the problem corrected. You should document the corrections recommended and the corrections made on the Field Repair Card.

The Field Repair Card (Figure 1) can serve as a reference on what checks should be performed and how they can be documented and communicated for future action.

Overhauls/Repairs

The second phase in performing a quality repair is the actual work that is usually performed in a repair shop. As the repairs are being made, an overall visual inspection of the pump should be made and its condition documented on a Pump Repair Card. Again, the Repair Card serves as a check to ensure that critical information is not overlooked. Runouts, sizes, clearances of the critical fits should be made and documented. A cause of failure should be determined and a workscope for repairs developed. A report on all parts must be kept so that anyone concerned with the repair will be able to identify the current status of the repair.

Other items that will help communicate what is being done and who is doing it should be documented also. This documentation data will help in troubleshooting future pump problems or in determining future repairs.

Some repair work can also be performed in the field. The standards for field repair, however, should be no different than for shop repair. If the checks and tolerances for a shop repair are to ensure that the pump is properly repaired in the shop, then they should apply to field repairs as well.

The argument that field repairs should be different than shop repairs since tooling and equipment necessary to make the checks or repairs are not readily accessible to the field repair crew is an unnecessary and a costly compromise. If the proper tools and equipment to repair pumps cannot be provided, then the repair should be completed in a properly outfitted repair shop. Not having the proper tooling or facilities to do the right repair is not justification for doing incomplete or improper repairs. Why is it that we never seem to have the time to do something right the first time but always have the time to redo it?

See the Pump Repair Card (Figure 2) for examples of some of the information contained in the shop repair standards.

Installation

The third phase of a quality pump repair is the proper installation of the pump once the repairs are completed. These standards define the minimum requirements for installing the pump. The standards give guidelines for tolerances on pipe strain, alignment, and other field installation checks that will ensure proper installation of the pump so that it will perform according to its designed service life expectancy.

Some items that the standards address are related to the auxiliary equipment and to the driver. A key problem in field installation that is often overlooked is the driver rotation, especially on electric motors. Electric motors can generally rotate in either direction. For three phase electric motors, the direction of rotation is determined by the connection of the three lead wires. If the lead wires are crossed, the pump could startup and run backward.

Once again, the Field Repair Card (Figure 1) should be used as a checklist for tasks that should be performed and checked during installation.

Startup/Standby

After a proper repair and installation is completed, proper start-up is the next critical step in the quality control process. Startup/standby should be witnessed by the machinery repair person and someone who is familiar with the process. This step requires cooperation between the process unit operator, who understands the operation of his unit, and the machinery or millwright person to ensure that all of the time and effort spent ensuring a proper repair is not wasted because of improper start-up. The machinery person or millwright should ensure that the proper pump line ups are made and that all auxiliary systems are lined up and functioning properly.

While some may feel that this is not an efficient use of machinery manpower, results indicate otherwise. During the first two months of standards implementation, a small percentage of pumps started up after repairs were "saved" from startup failure by the cooperate efforts of the operator and craftsman.

The field standards should have general guidelines to use including items to look for before and during startup of the repaired pump. The Field Repair Card can also serve as a check to ensure that startup coverage is performed.

CONCLUSION

Obviously, a comprehensive inspection and quality control program is a key to maximizing pump service life and to reducing repair costs. By utilizing operators to implement pump surveillance and audit programs, by identifying repair requirements and developing repair standards, and by making the trained repair person responsible for implementing the repair standards, for taking the necessary corrective action, and for documenting the repairs throughout the entire process, you will ensure that quality repairs are done right the first time. Quality must be ensured if we are to remain competitive in today's business environment.

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