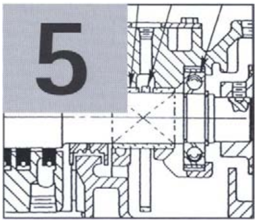

# 5 Effective predictive maintenance

## (including root cause analysis techniques)

- Introduction
- Troubleshooting procedure overview
- Initial fact finding
- Thorough knowledge of equipment, component and system functions
- Defining abnormal conditions
- Listing all possible causes
- Eliminating causes not related to the problem
- State root causes of the problem
- Develop an action plan to eliminate root cause

## Introduction

In this chapter, we will present the procedure used for both predictive maintenance and root cause analysis. You will find that many of the concepts covered in this section, and those required for effective troubleshooting have been previously mentioned and discussed. We have included exercises at the end of this chapter that will aid in the implementation of the principles discussed.

### What is troubleshooting?

Troubleshooting is the action of discovering and eliminating causes of trouble. Figure 5.1 presents the definition.

**Definition**

**Troubleshoot** - To **discover** and **eliminate (root)** causes of trouble

Figure 5.1 Definition

Troubleshooting can be as simple as discovering why a light bulb does not function to as complicated as debugging modern day computer software. In this chapter we will deal with the important aspects of troubleshooting and practice those aspects to develop troubleshooting skills. Do not expect to acquire these skills immediately. Like any skills, they require practice. This chapter will introduce you to all of the important aspects and practice exercises. Reader's are encouraged to use the principles presented immediately and continue to implement these principles in order to perfect these skills. Figure 5.2 presents the basic requirements of troubleshooting.

- Troubleshooting requires that all **abnormal** conditions be defined
- However, to determine **abnormal** conditions, the **normal** conditions must be known
- Therefore **baseline (normal)** conditions must be known

Figure 5.2 The basic requirements of troubleshooting

We must first find abnormal conditions. To define abnormal conditions, the normal condition must be known. Therefore the baseline conditions are required. As mentioned in the beginning of this chapter the concept of normal condition and change of condition have been covered in the Chapter 4. We must be sure to define all abnormal conditions, consequently full condition monitoring must be practiced.

## Predictive maintenance and troubleshooting

When the word troubleshooting is mentioned, most people immediately assume there has been some type of significant problem or failure. It is important to understand that the procedure of troubleshooting is exactly the same used in predictive maintenance. Figure 5.3 presents the similarity between predictive maintenance and troubleshooting.

**Predictive maintenance and troubleshooting**

- **Predictive maintenance** requires baseline and trend data to predict the root cause of the **change in condition**
- **Troubleshooting** requires baseline and trend data to predict the root cause of **failure**

Figure 5.3 Predictive maintenance and troubleshooting

The objective of any operating unit should be to practice predictive maintenance in order to eliminate the practice of troubleshooting. In this manner significant savings can be gained to the operating unit by eliminating unnecessary process unit downtime.

## Obtaining and maintaining management support

As previously stated, management support must be obtained for any significant site activity. Especially in the case of troubleshooting when effective measures are required in a short period of time, management support is a must. The troubleshooting team must have the ability to ask required questions and use effective personnel during the initial phases of troubleshooting. Lack of management support will severely hamper this effort. Figure 5.4 presents the ways to obtain management support.

**Obtaining and maintaining management support**

Troubleshooting goes nowhere without continued management support

- Define impact of problem on profit
- Prepare brief outline of plan for management
- Include target dates

Figure 5.4 Obtaining and maintaining management support

Maintaining management support requires that the troubleshooting team provide management with frequent updates on the status of the troubleshooting effort.

## Obtaining all the pertinent facts

In my experience, most troubleshooting exercises that fail do so because of incomplete facts or insufficient information. In the rush to define what the problem is many troubleshooting teams do not take sufficient time to obtain all of the facts. One of our team members once made the following statement when entering the refinery gates after a significant failure and speaking to the refinery manager. Note refinery was located (as most refineries) on a river. When the refinery manager asked what the problem was and what did he think the cause was, the representative promptly answered 'Harry, if I knew the answer to that question I would have walked across the river and not come in the gate'. We can see from the above statement that effective troubleshooting requires a thorough factual analysis. **Take your time**. Do not waste time, however, be complete and thorough in obtaining all of the facts. In addition, during the troubleshooting process it is usually necessary to go back and obtain more facts or test (substantiate) the facts already obtained. Figure 5.5 presents some ideas to consider when obtaining all the facts.

**'Just all the facts please'**

Most troubleshooting exercises that fail do so because of incomplete facts.

Consider the following:

- What has changed?
- Look at the total system
- Include all groups (maintenance, operation, engineering, contractor, vendor, etc.)
- Be informal (do not tape record!)

Figure 5.5 'Just all the facts please'

## Thoroughly understanding the equipment and component functions

As mentioned, you will not become a troubleshooting expert in one week. The main reason for this fact is the knowledge required to define equipment function. This is precisely why many troubleshooters have gray hair. Seriously, effective troubleshooting must be based on a thorough knowledge of the equipment function. That is, what is the equipment supposed to do. In my experience, I have found it very effective to go one step further and divide the equipment into its various component and component systems. Then I ask the question what is the component and each of the components in its associated system supposed to do. It is obvious that a vast amount of knowledge is required to accomplish this fact. Remember, you may not have all of the knowledge required. Obtain it. Figure 5.6 presents sources of where the information may be obtained.

**What is it supposed to do?**

Thoroughly understand the function of each component by:

- Reading the instruction book
- Referring to reference books
- Asking questions of:
  - Peers
  - Vendors
  - Consultants

Figure 5.6 What is it supposed to do?

One final word. Do not be afraid to admit to management that you do not know certain aspects of the problem. But be sure to state that you will find out. After all, management must understand that trouble-shooting is also a learning process and does require time.

To aid in the understanding of component function definition, we have included an example for a tilt pad bearing in Figure 5.7. As an exercise, state the required instruments that would have to be monitored to determine the bearing condition.

**Component function example**

A tilt pad bearing continuously supports all static and dynamic forces of a rotor by providing sufficient bearing area and oil flow to remove the generated frictional heat.

This statement then defines the parameters that must be monitored to determine the bearing's condition:

- Static and dynamic forces
- Bearing area
- Oil flow
- Frictional heat

Figure 5.7 Component function example

## Defining effect, causes and root causes

Frequently troubleshooting confuses effect, cause and root cause. It is important that these three items are fully understood. Stop and think for a minute regarding troubleshooting problems that you have encountered, and ask the question, what is the first item identified? You will find on examination that problems are usually defined by their effects, the car won't start, the washer will not wash clothes, the television will not turn on. We can also examine typical machinery problems as follows: high vibration caused a shutdown, the bearing temperature high trip caused a shutdown, the extremely high seal leakage required a shutdown. All of these items are effects of the problem. Granted, they are causes of the shutdown, but remember, troubleshooting requires the effective definition of root causes for the problem. Figure 5.8 presents the differences between effects, causes and root cause. An exercise is included at the end of this chapter on determining the difference between effects, causes and root causes.

**Effect, cause and root cause**

- Problems are usually defined by effects
- An effect is a condition traceable to a cause
- A cause is the reason for a condition
- A root cause is the first cause in the chain of events

Figure 5.8 Effect, cause and root cause

## The concept of system

I have found that after the problem of obtaining all the facts, the next most common pitfall in effective troubleshooting is failure to consider the system in which the component operates. Most root causes are in the system. Every major component that you will encounter is part of a system. Figure 5.9 presents these facts.

**The concept of a system**

- Each major equipment component is a part of a system
- Its condition is directly influenced by any system component's condition

Figure 5.9 The concept of a system

Always remember to first define the components involved and then thoroughly define the system in which the component acts. Frequently this system will be the process system, the lubrication system, the buffer gas system, etc. If it is an existing system, obtain that drawing (P&ID) and confirm the condition of each major component in that system. If it is not a common system (coupling system, etc.) sketch a schematic of that system noting each major component and again, confirm the condition of each component in that system.

## Troubleshooting procedure overview

The intent of this subsection is to provide an overview concerning the troubleshooting procedure. In subsequent subsections specific details concerning each major item will be covered. Figure 5.10 presents the troubleshooting process logic diagram.

It is important that each step be thoroughly completed before proceeding to the next. Certainly there may be instances where it will be required to recycle and go back to a proceeding step to obtain more information or correct misinformation that exists. Remember this procedure is generic and may be slightly refined for specific problems. However, I have found this procedure to be the most consistent in effectively defining root causes and correcting those problems in a cost

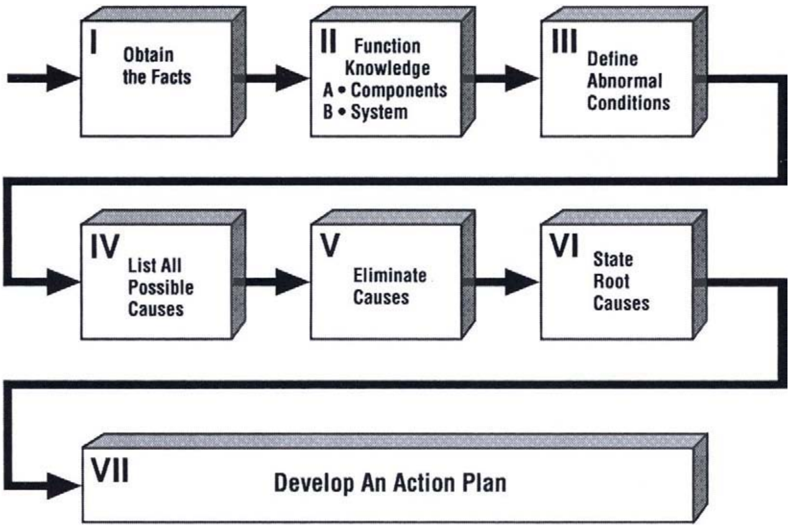


Figure 5.10 The troubleshooting process

effective manner. Following are some thoughts that may be helpful in the overall troubleshooting procedure.

### Initial fact finding

Do not leave any stone unturned. Ask all affected groups (operations, maintenance, engineering, contractor, vendor, etc.).

### Thoroughly understanding affected component and system function

Do not be afraid to admit lack of knowledge. Obtain knowledge through experienced sources, instruction book and other publications. Confirm proper understanding of the facts before proceeding.

### Defining abnormal conditions

Abnormal conditions may not mean that the condition is in alarm. It is helpful to use percentage to define deviation from baseline. Any significant deviation may define an abnormal condition.

### Listing all possible causes

Note all causes, even if they appear to be highly improbable, causes can be eliminated when reviewing causes based on facts.

### Eliminating causes based on facts

Review each cause listed in light of all facts. Eliminate causes that are not possible based on information.

### Stating root cause(s)

In this area be sure to thoroughly investigate all systems and subsystems of components. Identify any subcomponents that are operating in abnormal conditions. Root causes are usually found in subsystems of components.

### Developing an action plan

Include a concise action plan that can be presented to management to obtain full management support and aid in the implementation of the action plan.

## Initial fact finding

As previously mentioned, this phase is the most important phase in the troubleshooting process.

### Stating the apparent problem

Remember the apparent problem is usually an effect and not a cause. Figure 5.11 presents the major items involved in obtaining the apparent problem.

**State the apparent problem**

- Ask the involved personnel
- Inspect affected parts
- Confirm the apparent problem

Figure 5.11 State the apparent problem

### Defining the affected components

Once the apparent problem is stated, all affected components must be defined. Figure 5.12 presents the action required to define these components.

**Define all affected components**

- Thoroughly inspect for all affected components
- List all affected components

Figure 5.12 Define all affected components

### Obtaining all important facts

Once the problem and affected components are defined all the important facts surrounding these components must be known. Figure 5.13 is a suggested question list that has proven to be effective in fact finding. Remember, this is a generic list. Some questions may not be appropriate or additional questions may be required in specific cases.

### Fact finding guidelines

**Suggested question list**

1. What is the problem?
2. What components failed?
3. What are facts concerning failed components?
4. How long has unit been operating without this component failure?
5. Has this component failed before?
6. What were component system parameters prior to failure?
7. What parameters exceeded normal values?
8. What changed?
   A. Process conditions
   B. Operating procedure
   C. New components (equipment and system)
   D. Piping system
   E. Foundation
9. Parts out of tolerance
10. Has this type of failure occurred in other locations?
    (Network - Users' groups)

Figure 5.13 Fact finding guidelines

## Baseline conditions and trends

During fact finding activity it is extremely important to define all baseline conditions concerning the parameters around each major component involved. Refer back to the information in Chapter 4 regarding condition monitoring parameters and be sure that all of these parameters are checked for baseline condition and trends. This procedure may be very frustrating and may take a long time based on the data that the affected plant has available. Remember, be patient. Figure 5.14 lists the requirements to obtain baseline conditions and trends.

**Baseline conditions and trends**

- Establish conditions before failure (baseline)
- Utilize distributed control system, operator's logs and reliability data for baseline and trend data
- Establish changes from baseline conditions prior to failure
- Express condition changes in percent

Figure 5.14 Baseline conditions and trends

## Inspection

Each affected component must be thoroughly inspected. This inspection will either add facts or possibly eliminate a component from consideration. Figure 5.15 presents information concerning component inspection.

**Failed component inspection**

- Thoroughly inspect all parts
- List all facts
- Utilize site experience
- Obtain vendor and/or consultant opinion if required
- Fully define inspection procedure and provide all facts if 'outside' inspection source is used

Figure 5.15 Failed component inspection

It may be necessary in this activity to enlist the help of additional associates as a check to inspection thoroughness. In addition, it may be necessary to call on outside sources (non-destructive testing companies, troubleshooting specialists, consultants, etc.). In this event, the effectiveness of their activity will significantly depend on how well their work effort is defined and how complete the information given to them is. Keep this in mind. Take the time required to thoroughly define what is required of outside sources and provide all of the information required.

## Thorough knowledge of equipment, component and system functions

This area requires careful consideration. It also requires a significant amount of paperwork to first define the function of each component, define the system and list all of the effective parameters. Figure 5.16 presents these facts.

**Component and system functions**

- Define the function of each affected component
- Define the system in which each affected component operates
- List the normal parameters for each affected component and system component

Figure 5.16 Component and system functions

This activity will, most of the time, require confirmation of component function from instruction book sources, outside material, articles etc. or discussion with equipment experts. Be sure that the function of each component is properly defined in a simple manner before proceeding, but the definition must be complete. Once the component function is defined, then list all systems in which the affected component operates. Next list each parameter for the affected component that must be checked for condition. Again, the information contained in Chapter 4 concerning component parameters will be helpful.

## Defining abnormal conditions

Once all component conditions are listed obtain information concerning baseline and trends. Figure 5.17 presents these facts. Again, it is cautioned that an abnormal condition may not necessarily be an alarmed condition. This could occur for many reasons; improper instrument setting, improper instrumentation functioning, high setting, etc. It is helpful to list in percentage the deviation between normal (baseline) and abnormal conditions. It may be necessary to consult other experienced sources regarding a certain deviation to determine if in fact, this abnormality is significant.

**Define abnormal conditions**

- Note value of each abnormal condition based on facts
- Express abnormal conditions in percent above normal limits
- State when each abnormal condition appeared

Figure 5.17 Define abnormal conditions

## Listing all possible causes

Figure 5.18 presents information concerning causes.

**Listing all possible causes**

- Start with most obvious causes
- Obtain additional information if necessary
- List remaining causes
- Sub divide into possible cause sources

Figure 5.18 Listing all possible causes

It has been my experience that in many instances people start with very complicated causes and causes that are difficult to prove. Start with the most obvious causes from the fact finding phase and obtain more facts if necessary in order to list a cause. Again, be thorough and take your time. Insufficient information is the cause of most troubleshooting activity failures.

Once the possible causes are noted the sources for these causes must be defined. Subdivide the causes into the possible cause sources. The major causes of machine failure, as previously defined in Chapter 2 are:

- The effects of the process
- Assembly/Installation
- Operating procedures
- Design and manufacturing deficiencies
- Component wear out.

Use the facts obtained to determine if the causes qualify for the above sources. As an example, a design problem usually shows up from the first day of operation. If the problem has recently occurred, design and manufacturing can be eliminated (if a new part was not recently installed). In this case, the operating procedures and process conditions should be checked.

## Eliminating causes not related to the problem

Refer to Figure 5.19. Review each cause noted and test this cause against all of the facts. Again, in this section it may be necessary to recycle and obtain additional facts or confirm facts previously stated.

| Eliminate causes not completely supported by facts |
|---|

Figure 5.19 Eliminate causes

## State root causes of the problem

Figure 5.20 presents the facts concerning root causes. It is important to mention in this section that the thorough definition of component systems and subsystems must be completed. If the affected component systems and subsystems are not thoroughly defined important information regarding root causes may be neglected. Once the systems are defined all of the components in those systems must be investigated for abnormalities.

**State root cause(s)**

- Consider cause sources
- Obtain additional input if necessary
- Be sure all component systems and sub systems are considered

Figure 5.20 State root cause(s)

## Develop an action plan to eliminate root cause

Figure 5.21 presents guidelines in developing an action plan.

**Develop an action plan**

- Clearly state root cause
- Define revenue loss if problem is not corrected
- Clearly state action plan and define responsibilities
- Present plan to management

Figure 5.21 Develop an action plan

It is important to develop the plan in an outline fashion that can be effectively presented to management. The method in which the action plan is defined, written and presented will have a significant effect on whether the action plan is implemented. Be sure to emphasize the impact on profit to management in presentation of the plan.

Before an action plan is presented it may be necessary to hold meetings with contractors, vendors and/or consultants to thoroughly define all action required. The more complete an action plan, the better the chances for its success.

**Exercise 1**

| | |
|---|---|
| Title: | Fact finding |
| Purpose: | Demonstrate fact finding procedure |
| Task: | List all facts obtained from case history and questions to plant personnel. List all facts using the outlined procedure. |
| Given: | Case history:<br>A single stage steam turbine driving a main lube oil pump in a NGL unit process centrifugal compressor tripped. The auxiliary pump did not start in time causing the compressor to trip on low lube oil pressure. |

**Exercise 2**

Title: Component function exercise

Purpose: To demonstrate how a concise component function statement can define required component condition parameters

Task: Complete exercise by:

1. Stating component function
2. Circle key component condition parameters
3. Defining all instruments and/or components that must be condition monitored

Complete this exercise for the following components:

A. Radial bearing

B. Pump shaft seal

C. Single stage steam turbine shaft seal

D. Governor system for a single stage turbine

E. Pump rotor

1. Component function:

   A. ______________________________

   ______________________________

   ______________________________

   ______________________________

2. Circle key component condition parameters

   ______________________________

   ______________________________

   ______________________________

3. Define all instruments and/or components that must be condition monitored

   ______________ ______________

   ______________ ______________

   ______________ ______________

**Exercise 3**

Title: Component system exercise

Purpose: To enable the reader to define an entire component system

Task: Complete exercise by defining all the systems and system components that affect the condition of the noted component

Given:
A. Radial bearings
B. Balance drum
C. Sump pump rotor
D. Pump mechanical shaft seal
E. Single stage steam turbine shaft (floating carbon ring) seal

1. Component

______________________________

______________________________

______________________________

2. Define all systems affecting the component in item 1

______________________________

______________________________

______________________________

3. Define the major components in each system

______________ ______________

______________ ______________

______________ ______________

**Exercise 4**

Title: Effect, cause and root cause exercise

Purpose: To enable the reader to define cause, effects and root causes of problems

Task: Review the attached fact list and separate each fact into its appropriate category

Given:

A. High vibration pump inboard radial bearing

B. Pump cavitation

C. Plugged pump suction screen

D. Low (almost zero pump) discharge pressure

E. Failed mechanical seal

F. Low seal housing pressure

G. Plugged seal flush line

H. Failed radial bearing

I. Single stage steam turbine trips on start-up

J. Increased balance line $\Delta P$

Review fact list and put fact in appropriate column:

| Effect | Cause | Root cause |
|---|---|---|
| ________ | ________ | ________ |
| ________ | ________ | ________ |
| ________ | ________ | ________ |
| ________ | ________ | ________ |