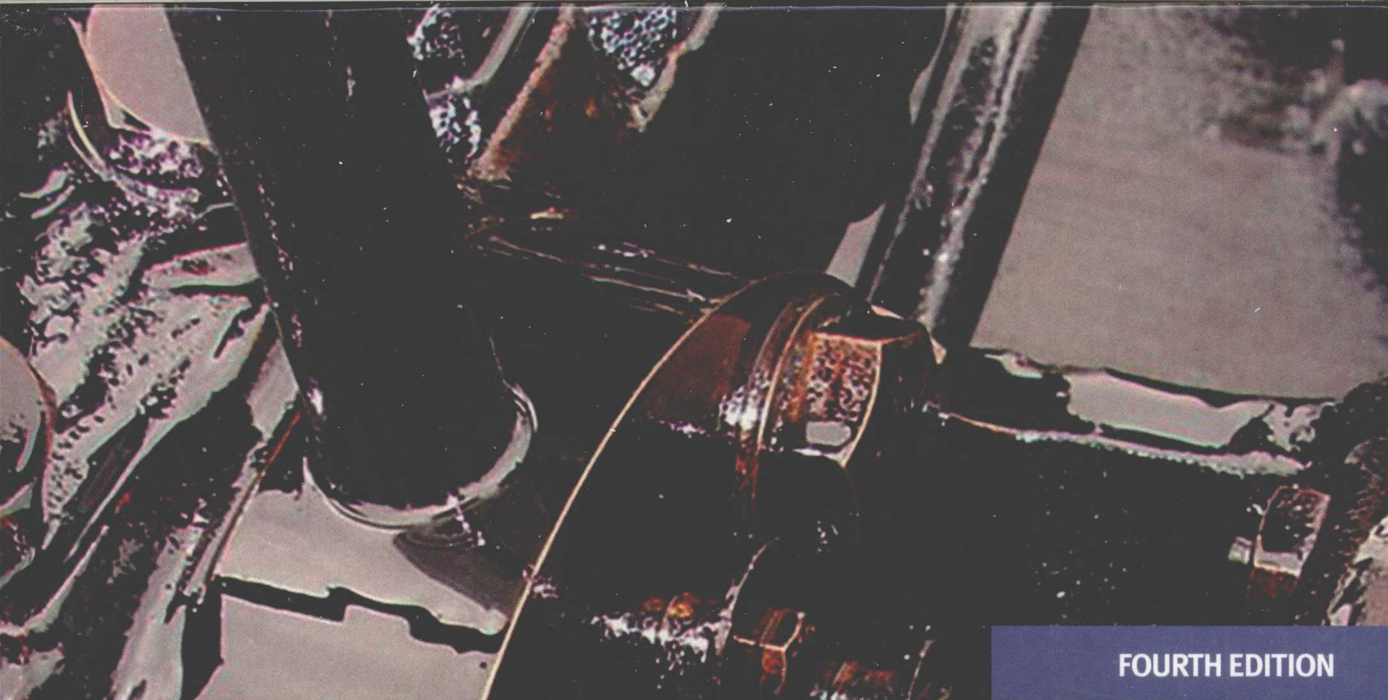

FOURTH EDITION

MACHINERY FAILURE ANALYSIS AND TROUBLESHOOTING

Practical Machinery Management for Process Plants

FRED K. GEITNER
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Volume 2 ▪ Fourth Edition

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Machinery Failure Analysis and Troubleshooting

To Gerritt, Callan and Jillian Bloch, Courtney Bravender,
And Peter, Lena, Derek and Chloe Geitner

As encouragement to go the full distance,
and then the extra mile. You will not encounter
any traffic jams on your way.

(Freely quoted from Ecclesiastes 9:10)

Acknowledgments

An experienced machinery engineer usually has a few file cabinets filled with technical reports, course notes, failure reports, and a host of other machinery-related data. But these files are rarely complete enough to illustrate all bearing failure modes, all manners of gear distress, etc. Likewise, we may have taken problem-solving courses, but cannot lay claim to recalling all the mechanics of problem-solving approaches without going back to the formal literature.

Recognizing these limitations, we went to some very knowledgeable companies and individuals and requested permission to use some of their source materials for portions of this book. We gratefully acknowledge the help and cooperation we received from:

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Preface

The prevention of potential damage to machinery is necessary for safe, reliable operation of process plants. Failure prevention can be achieved by sound specification, selection, review, and design audit routines. When failures do occur, accurate definition of the root cause is an absolute prerequisite to the prevention of future failure events.

This book concerns itself with proven approaches to failure definition. It presents a liberal cross section of documented failure events and analyzes the procedures employed to define the sequence of events that led to component or systems failure. Because it is simply impossible to deal with every conceivable type of failure, this book is structured to teach failure identification and analysis methods that can be applied to virtually all problem situations that might arise. A uniform methodology of failure analysis and troubleshooting is necessary because experience shows that all too often process machinery problems are never defined sufficiently; they are merely "solved" to "get back on stream." Production pressures often override the need to analyze a situation thoroughly, and the problem and its underlying cause come back and haunt us later.

Equipment downtime and component failure risk can be reduced only if potential problems are anticipated and avoided. Often, this is not possible if we apply only traditional methods of analysis. It is thus appropriate to employ other means of precluding or reducing consequential damage to plant, equipment, and personnel. This objective includes, among others, application of redundant components or systems and application of highly computerized analysis techniques for electrical/electronic systems.

The organizational environment and management style found in process plants often permits a "routine" level of machinery failures and breakdowns. This book shows how to arrive at a uniform method of assessing what level of failure experience should be considered acceptable and achievable. In addition, it shows how the organizational environment can be better prepared to address the task of thorough machinery failure analysis and troubleshooting, with resulting maintenance incident reduction. Finally, by way of successful examples, this book demonstrates how the progress and results of failure analysis and troubleshooting efforts can be documented and thus monitored.

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Contents

CHAPTER 1

The Failure Analysis and Troubleshooting System

Chapter Outline

Troubleshooting as an Extension of Failure Analysis

For years, the term "failure analysis" has had a specific meaning in connection with fracture mechanics and corrosion failure analysis activities carried out by static process equipment inspection groups. Figure 1-1 shows a basic outline of materials failure analysis steps.[1] The methods applied in our context of process machinery failure analysis are basically the same; however, they are not limited to metallurgic investigations. Here, failure analysis is the determination of failure modes of machinery components and their most probable causes. Figure 1-2 illustrates the general significance of machinery component failure mode analysis as it relates to quality, reliability, and safety efforts in the product development of a major turbine manufacturer.[2]

Very often, machinery failures reveal a reaction chain of cause and effect. The end of the chain is usually a performance deficiency commonly referred to as the symptom, trouble, or simply "the problem." Troubleshooting works backward to define the elements of the reaction chain and then proceeds to link the most probable failure cause based on failure (appearance) analysis with a root cause of an existing or potential problem. For all practical purposes, failure analysis and troubleshooting activities will quite often mesh with one another without any clear-cut transition.

However, as we will see later, there are numerous cases where troubleshooting alone will have to suffice to get to the root cause of the problem. These are the cases that present themselves as performance deficiencies with no apparent failure modes. Intermittent malfunctions and faults are typical examples and will tax even the most experienced troubleshooter. In these

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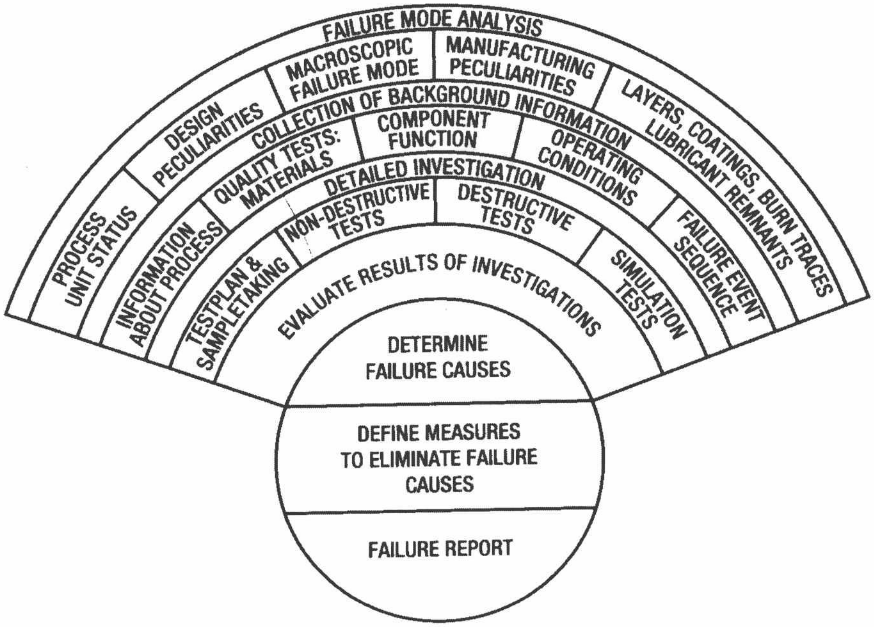

Figure 1-1:
Failure analysis steps—materials technology *(modified from Ref. 1).*

cases, troubleshooting will be successful only if the investigator knows the system he is dealing with. Unless he is thoroughly familiar with component interaction, operating or failure modes, and functional characteristics, his efforts may be unsuccessful.

There are certain objectives of machinery failure analysis and troubleshooting:

1. Prevention of future failure events.
2. Assurance of safety, reliability, and maintainability of machinery as it passes through its life cycles of:
   a. Process design and specification.
   b. Original equipment design, manufacture, and testing.
   c. Shipping and storage.
   d. Installation and commissioning.
   e. Operation and maintenance.
   f. Replacement.

From this it becomes very obvious that failure analysis and troubleshooting are highly co-operative processes. Because many different parties will be involved and their objectives will sometimes differ, a systematic and uniform description and understanding of process machinery failure events is important.

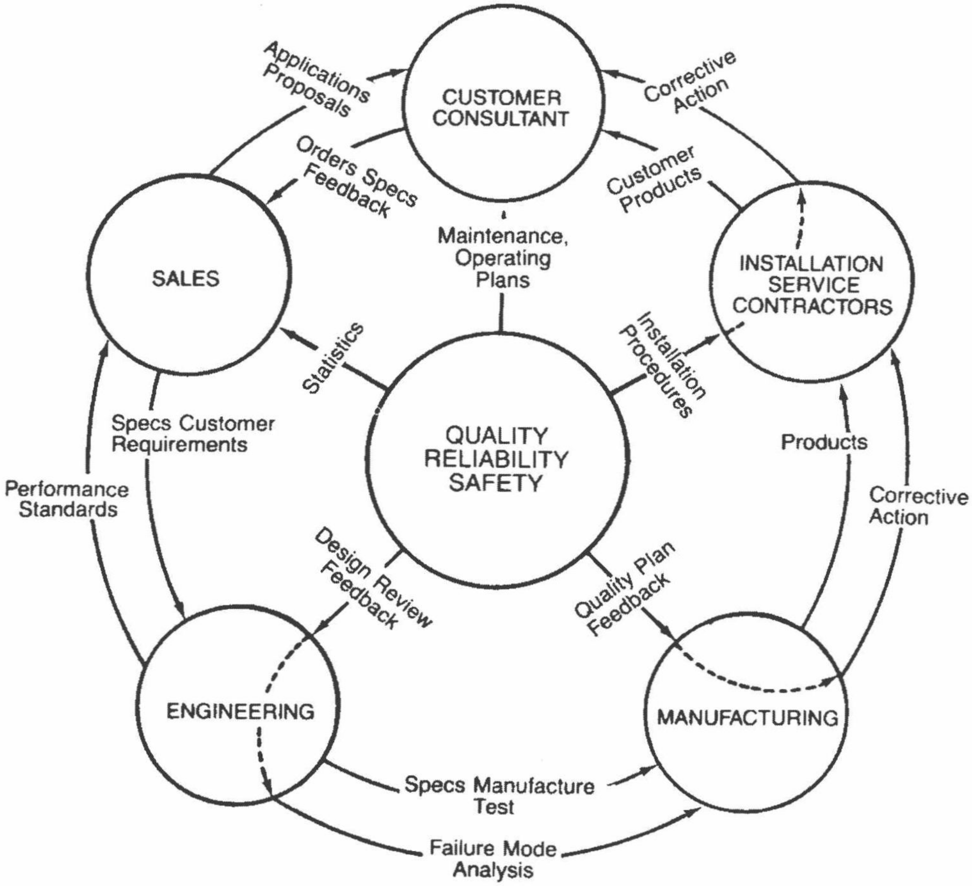

Figure 1-2:
Failure analysis and the "wheel of quality."[2]

Causes of Machinery Failures

In its simplest form, failure can be defined as any change in a machinery part or component which causes it to be unable to perform its intended function satisfactorily. Familiar stages preceding final failure are "incipient failure," "incipient damage," "distress," "deterioration," and "damage," all of which eventually make the part or component unreliable or unsafe for continued use.

Meaningful classifications of failure causes are:

1. Faulty design.
2. Material defects.
3. Processing and manufacturing deficiencies.

4. Assembly or installation defects.
5. Off-design or unintended service conditions.
6. Maintenance deficiencies (neglect, procedures).
7. Improper operation.

All statistics and references dealing with machinery failures, their sources and causes, generally use these classifications. And, as will be shown in Chapter 4, remembering these seven classifications may be extremely helpful in failure analysis and troubleshooting of equipment.

For practical failure analysis, an expansion of this list seems necessary. Table 1-1 shows a representative collection of process machinery failure causes. The table makes it clear that failure causes should be allocated to areas of responsibilities. If this allocation is not made, the previously listed objectives of most failure analyses will probably not be met.

Failure causes are usually determined by relating them to one or more specific failure modes. This becomes the central idea of any failure analysis activity. Failure mode (FM) in our context is the appearance, manner, or form in which a machinery component or unit failure manifests itself. Table 1-2 lists the basic failure modes encountered in 99 percent of all petrochemical process plant machinery failures.

In the following sections, this list will be expanded so that it can be used for day-to-day failure analysis. Failure mode should not be confused with failure cause, as the former is the *effect* and the latter is the *cause* of a failure event. Failure mode can also be the result of a long chain of causes and effects, ultimately leading to a functional failure, i.e. a symptom, trouble, or operational complaint pertaining to a piece of machinery equipment as an entity.

Other terms frequently used in the preceding context are "kind of defect," "defect," or "failure mechanism." The term "failure mechanism" is often described as the metallurgical, chemical, and tribological process leading to a particular failure mode. For instance, failure mechanisms have been developed to describe the chain of cause and effect for fretting wear (FM) in roller bearing assemblies, cavitation (FM) in pump impellers, and initial pitting (FM) on the surface of a gear tooth, to name a few. The basic agents of machinery component and part failure mechanisms are *always* force, a reactive environment, time and temperature. This important concept can be easily remembered by using the acronym "FRETT". Each of these agents can be subdivided as indicated in Table 1-3.

For our purpose, failure mechanisms thus defined will have to stay part of the failure mode definition: They will tell how and why a failure mode might have occurred in chemical or metallurgical terms, but in so doing, the root cause of the failure will remain undefined.