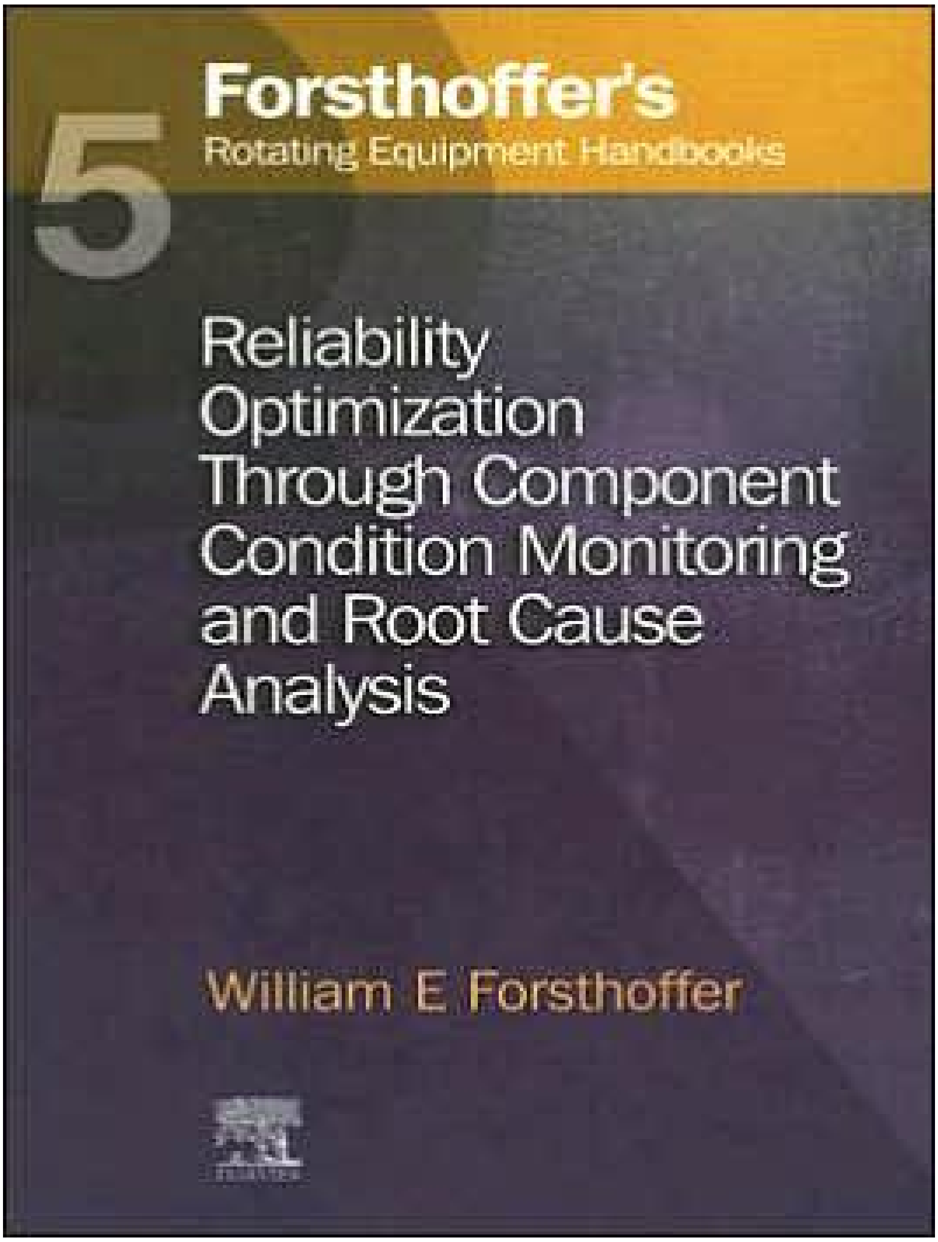
Forsthoffer's Rotating Equipment Handbooks

Vol 5: Reliability Optimization through Component Condition and Root Cause Analysis



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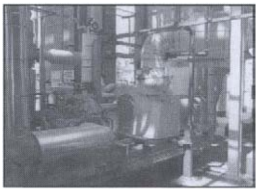


Preface

This Series has evolved from my personal experience over the last 40 years with the design, selection, testing, start-up and condition monitoring of Rotating Equipment. Most of the concept figures were originally written on a blackboard or whiteboard during a training session and on a spare piece of paper or I beam during a start-up or a problem solving plant visit.

My entire career has been devoted to this interesting and important field. Then and now more than ever, the cost of rotating equipment downtime can severely limit revenue and profits. A large process unit today can produce daily revenues in excess of 5 million US dollars. And yet, the Operators, Millwrights and Engineers responsible for the safety and reliability of this equipment have not been afforded the opportunity to learn the design basis for this equipment in practical terms. I have also observed in the last ten years or so, that the number of experienced personnel in this field is diminishing rapidly.

Therefore the series objective is to present, in User friendly (easy to access), practical terms (using familiar analogies), the key facts concerning rotating equipment design basis, operation, maintenance, installation and condition monitoring to enable the reader (Engineer, Operator and Millwright) to:

- Understand the effect of process and environmental changes on equipment operation, maintenance and reliability
- Condition Monitor equipment on a component basis to optimize up-time, mean time between failure (MTBF) and mean time to repair (MTTR)
- Select, audit and test the Equipment that will produce highest safety and reliability in the field for the lowest life cycle cost.

The hope is that the knowledge contained in this series will enable

Plant Operations, Maintenance and Engineering Personnel to easily access the material that will allow them to present their recommendations to management to solve existing costly problems and produce new projects of optimum reliability.

This volume, Reliability Optimization thru Component Condition Monitoring and Root Cause Analysis, details the effective method of component condition monitoring for use as both a predictive maintenance and root cause analysis tool. It also details the major failure causes, the authors proven root cause analysis procedure with exercises and case histories, installation, pre-commissioning planning, functional testing and commissioning, preventive maintenance strategies and more.

Acknowledgements

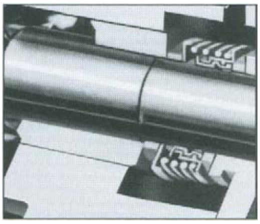
This series is a result of interactions with literally thousands of dedicated engineers, machinists, operators, vendors, contractors and students who have been an integral part of my career.

I consider myself very fortunate to have been associated with the best of the best mentors, business associates and dear friends throughout my career. Most especially, in chronological order Dick Salzmann, Bob Aimone, Merle Crane, Walt Neibel, the late Murray Rost, Mike Sweeney and Jimmy Trice. Bob, Merle, Murray and Mike have contributed specifically to the material in this series while Dick, Walt and Jimmy have tactfully kept me on track when necessary.

Special thanks to all of the global machinery vendors who have allowed me to use their material for my training manuals and now this publication.

Last but certainly not least; my career would not have been possible without the support, encouragement and assistance from my wife Doris and our children Jennifer, Brian, Eric, Michael and Dara.

A special additional note of thanks to Michael who helped assemble the material, and hopefully learned some in doing so, since he has elected to pursue a career in rotating machinery.



About the author

Bill Forsthoffer began his life-time career in rotating machinery in 1962 with De Laval Turbine Inc. as a summer trainee. After obtaining a Bachelor of Arts degree in Mathematics and Bachelor of Science degree in Mechanical Engineering, during which time he worked for De Laval part time in the Test, Compressor and Steam Turbine Departments, he joined De Laval full time in the Compressor Engineering Department in 1968. He was responsible for all phases of centrifugal compressor component and auxiliary design and also made many site visits to provide field engineering assistance for start up and problem resolution.

Bill joined Mobil Oil Corporate Engineering in 1974 and was responsible for all aspects of rotating equipment specification, technical procurement, design audits, test, field construction, commissioning, start-up and troubleshooting.

After 15 years at Mobil, Bill founded his own consulting company in 1990 and has provided rotating equipment consulting services to over 100 companies. Services include: project reliability assurance, training (over 7,000 people trained) and troubleshooting.

Bill is active in the industry as President of Forsthoffer Associates Inc., frequently writes articles for Turbo Machinery International Magazine and conducts many site specific and public workshops each year.

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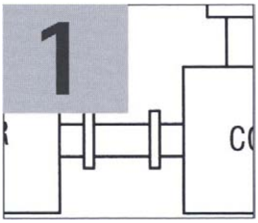

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Reliability overview

- Introduction
- The end user's objectives
- Reliability terms and definitions
- Optimizing reliability

Introduction

Reliability optimization is an important part of plant revenue and profit. The objective of this volume is to provide information that will enable the reader to optimize reliability by implementing proven methods I have used throughout my career. The major components of reliability improvement are shown in Figure 1.1.

Volume objective

'To optimize site rotating equipment availability by implementation of practical'

- Site reliability audits
- Assessment methods
- Availability improvement plans
- Condition monitoring techniques
- Preventive and predictive maintenance plans
- Troubleshooting techniques

Figure 1.1 Volume objective

Before these objectives can be met and implemented, a number of important concepts and terms need to be reviewed and presented.

The end user's objectives

The objectives of the end user are shown in Figure 1.2.

The objectives

- Maximum reliability (on stream time)
- Maximum product throughput
- Minimum operating costs

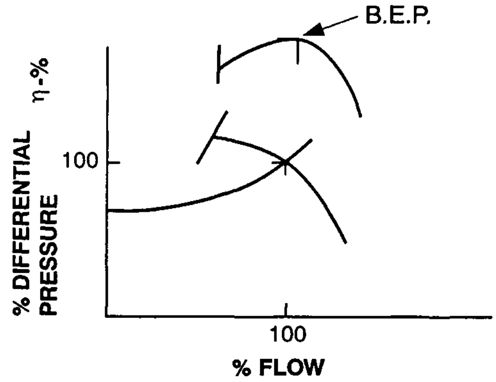


Figure 1.2 The objectives

In order to maximize profit, a piece of machinery must have maximum reliability, maximum product throughput and minimum operating cost (maximum efficiency). In order to achieve these objectives, the end user must play a significant part in the project during the specification and design phase and not only after the installation of the equipment in the field. Effective field maintenance starts with the specification phase of a project. Inadequate specifications in terms of instrumentation and the location of instrumentation will impact equipment reliability.

It is important to understand that the life span of rotating equipment is extremely long compared to the specification, design and installation phase. Refer to Figure 1.3.

A typical installation will have a specification, design and installation

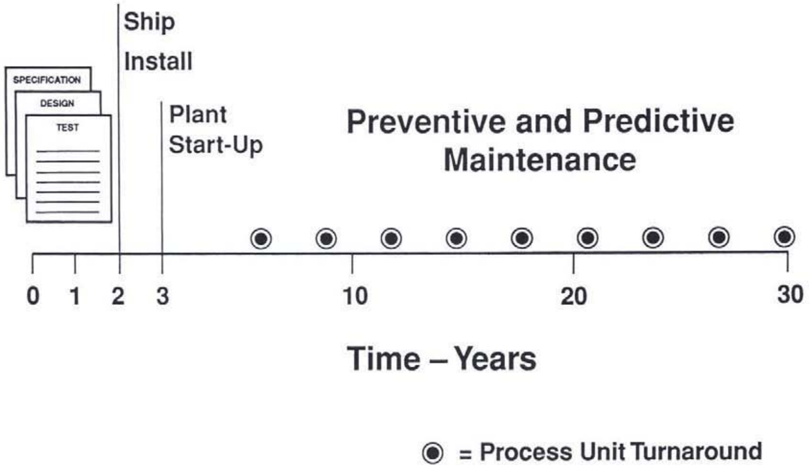


Figure 1.3 The life span of rotating equipment

phase of only approximately 10% of the total life of the process unit. Improper specification, design or installation will significantly impact the maintenance requirements, maintenance cost and availability of a particular piece of machinery. Proper screening of equipment design (pre-bid technical meetings etc.) prior to equipment vendor selection establishes the foundation on which reliability is built. Likewise, enforcing shipment, construction, installation and commissioning specifications optimizes reliability and truly makes it 'cost effective' in terms of the life cycle of the equipment.

Reliability terms and definitions

Before we can optimize reliability, certain terms and definitions need to be presented. These terms are shown in Figure 1.4.

Reliability terms

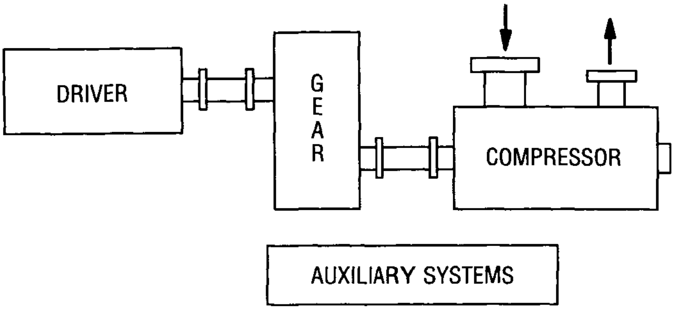
- Reliability
- Availability
- Maintainability
- Cost of unavailability

Figure 1.4 Reliability terms

Reliability

Reliability is the ability of the equipment unit to perform its stated duty without a forced (unscheduled) outage in a given period of time (see Figure 1.5).

The rotating equipment unit



Every piece of rotating equipment is part of a unit which consists of:

- The driver
- The driven
- The transmission devices
- The auxiliary systems

Figure 1.5 The rotating equipment unit

The definition of reliability for critical (unspared) equipment is presented in Figure 1.6.

Reliability – critical equipment

The amount of time equipment operates in one year

$$\text{Reliability (\% =)} \left(\frac{\text{Operating hours per year}}{\text{8760 hours}}\right) 100$$

Figure 1.6 Reliability – critical equipment

In the case of general purpose equipment (spared), reliability is not usually calculated since a spare unit should be available for operation if required. In the case of unreliable general purpose units, reliability could be defined as shown in Figure 1.7.

Reliability – general purpose (spared) equipment

Hours per year spared equipment operated as a percentage of the hours it was required to operate

$$\text{Reliability (\% =)} \left(\frac{\text{Yearly hours in operation}}{\text{Yearly main unit forced outage hours}}\right) 100$$

Figure 1.7 Reliability – general purpose (spared) equipment

Note in Figure 1.6 and 1.7 that reliability does not account for planned downtime for preventive and/or predictive maintenance.

Availability

Availability considers preventive and predictive maintenance downtime as shown in Figure 1.8.

Availability

The amount of time equipment operates in one year as a percentage of the available hours per year

$$\text{Availability (\% =)} \left(\frac{\text{Yearly operating hours}}{\text{8760 – planned downtime}}\right) 100$$

(T & Is or turnarounds)

Figure 1.8 Availability

One measure of both reliability and availability is mean time between failure or MTBF. See Figure 1.9.

Mean time between failure

$$\text{MTBF} = \frac{\text{Total operating hours}}{\text{Number of failures}}$$

Figure 1.9 Mean time between failure

Maintainability

Simply stated, maintainability is the ability to perform all maintenance activities; preventive, predictive and forced outage in a minimum time that requires rotating equipment unit shutdown. It is understood that the total maintenance time required will restore the unit to its original 'new' condition.

One parameter that can be used to measure maintainability is mean time to repair – MTTR as shown in Figure 1.10. The lower the MTTR, the greater the maintainability.

Mean time to repair

$$\text{MTTR} = \frac{\text{Total repair hours*}}{\text{Number of repair events}}$$

* includes corrective maintenance time

(actual labor hours as a result of design modifications)

Figure 1.10 Mean time to repair

Cost of unavailability

All terms discussed so far, reliability, availability and maintainability directly affect the product revenue of the plant. Product revenue is the value obtained from one days production expressed in local currency. At this point, note the amount of daily revenue from a process unit in your plant in Figure 1.11. Note that typical amounts can vary from $100,000 to over $5,000,000.00 per day depending on the process and the size of the unit.

Daily product revenue for a process unit

Date: ______________

Amount: ______________

Process unit type: ______________

Figure 1.11 Daily product revenue for a process unit

If a critical equipment unit suffers a forced outage or is out of service due to poor maintainability (extended repair time), the product revenue shown in Figure 1.11 will be lost for each day the critical equipment unit remains out of service.

Therefore, the cost of unavailability is the total of the values shown in Figure 1.12.

The cost of unavailability critical rotating equipment (per year)

- Lost product revenue x days forced outage
- Maintenance costs
- Replacement part cost
- Labor cost
- Unnecessary turnaround time*

* Assumes process unit start-up is delayed by activity

Figure 1.12 The cost of unavailability critical rotating equipment (per year)

The cost of unavailability can be a powerful tool to use in preparing reliability improvement plans.

Optimizing reliability

The key to reliability improvement is to build a solid program foundation. Figure 1.13 shows the reliability pyramid.

The success or failure of any reliability improvement program directly depends on obtaining and maintaining management support. Figure 1.14 presents guidelines for meeting this important objective.

Figure 1.13 The Reliability Pyramid

Obtain and maintain management support by...

1. Clearly stating impact of problem on plant profit (cost of unavailability)
2. Prepare a brief statement of:
   - Problem
   - Impact on plant
   - Reliability improvement plan
3. Be confident!
4. Be professional
5. Be autonomous (do not expect management to do your job!!)
6. Provide timely updates

Figure 1.14 Obtain and maintain management support by...

Input data

Once management support is obtained, input data forms the foundation of the program. Figure 1.15 presents important guidelines concerning input data.

Reliability input data

- Include all the facts (operation, reliability, maintenance failure analysis, etc.)
  - Consider the machinery environment
  - Consider the entire system
- Only use proven data (don't guess!)
- Accuracy is most important – confirm data is correct

Figure 1.15 Reliability input data

The environment or surroundings for any piece of rotating equipment play an important part in determining the availability of that particular item (refer to Figure 1.16).

The rotating equipment environment

- Process condition change
- Piping and foundation change
- 'Unit' (driven, driver, transmission, auxiliaries)
- Ambient conditions

Figure 1.16 The rotating equipment environment

This figure shows that the rotating equipment environment is the process unit in which the equipment is installed. If any of these items are not taken into account, the accuracy of the conclusions reached during the assessment phase will be significantly reduced.

In my experience, most failures in predictive maintenance and troubleshooting exercises occur because the entire system in which the component operates is not considered. Every component in every piece of machinery operates in a system. Defining the system and all of the components contained therein is a very important step in successful problem analysis. Refer to Figure 1.17.

The concept of a system

- Think system!
- Every component is a part of a system
- In order to determine root causes, systems and not just components must be considered

Figure 1.17 The concept of a system

Experience counts!

Having experienced analysts to determine root causes of low reliability is the next step in building a strong program. Figure 1.18 suggests ways to build and develop a practical, strong analyst group.

Analyst development strategy

- Select experienced rotating equipment personnel
- Ideally, design and field experience are the best combination
- Provide site specific training
- Measure results
- Provide opportunities for networking with other specialists within and outside the company
  - User groups
  - Industry conferences
  - Regional conferences
- Include analysts in all phases of new projects

Figure 1.18 Analyst development strategy

Utilize practical, correlated assessment techniques whenever possible

Today, many statistical methods are available to the analyst to determine causes of failure and to predict equipment and component life. The personal computer makes the use of these methods quick and easy.

However, the reader is cautioned to regard all statistical methods as only a part of the process. Whenever possible, actual data concerning failure rates should be used and the correlation of statistical methods should be defined. It should always be remembered that the basis for most statistical methods have evolved from industries where 'production components' are used, i.e. the electronics, automotive industries, etc. However, the rotating equipment unit regardless of type always becomes customized by virtue of its environment. That is, each rotating equipment unit has its own signature. Consequently, care must be exercised when applying statistical methods to rotating equipment reliability assessment. Figure 1.19 presents this important fact.

Statistical methods and rotating equipment

Since every rotating equipment unit, regardless of size represents a 'customized system' care must be exercised when assessing the results obtained by statistical methods.

Figure 1.19 Statistical methods and rotating equipment