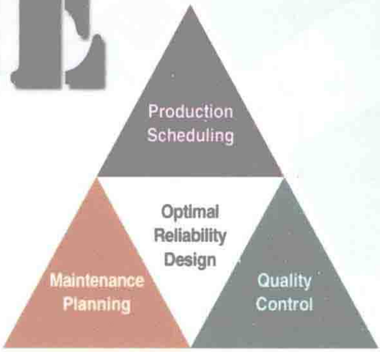
PERFORMABILITY ENGINEERING SERIES

Series Editors: Krishna B Misra and John Andrews

MACHINE TOOL RELIABILITY



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Machine Tool Reliability

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Performability Engineering Series

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Scope: A true performance of a product, or system, or service must be judged over the entire life cycle activities connected with design, manufacture, use and disposal in relation to the economics of maximization of dependability, and minimizing its impact on the environment. The concept of performability allows us to take a holistic assessment of performance and provides an aggregate attribute that reflects an entire engineering effort of a product, system, or service designer in achieving dependability and sustainability. Performance should not just be indicative of achieving quality, reliability, maintainability and safety for a product, system, or service, but achieving sustainability as well. The conventional perspective of dependability ignores the environmental impact considerations that accompany the development of products, systems, and services. However, any industrial activity in creating a product, system, or service is always associated with certain environmental impacts that follow at each phase of development. These considerations have become all the more necessary in the 21st century as the world resources continue to become scarce and the cost of materials and energy keep rising. It is not difficult to visualize that by employing the strategy of dematerialization, minimum energy and minimum waste, while maximizing the yield and developing economically viable and safe processes (clean production and clean technologies), we will create minimal adverse effect on the environment during production and disposal at the end of the life. This is basically the goal of performability engineering.

It may be observed that the above-mentioned performance attributes are interrelated and should not be considered in isolation for optimization of performance. Each book in the series should endeavor to include most, if not all, of the attributes of this web of interrelationship and have the objective to help create optimal and sustainable products, systems, and services.

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Preface

Reliability engineering as a subject matter is developed vastly in last few decades. Numerous books have been published on the subject, discussing basic principles, theories, models, tools and techniques, in general. However, every system is unique and some of them may require specific treatment while applying various tools and techniques of reliability engineering. This book explores the domain of reliability engineering for one such very important industrial system, called machine tools.

Machine tools are at the heart of the manufacturing systems. Manufacturing industries rely on machine tools to fulfil their customers' demand. Failure of machine tool hampers their production efficiency and creates uncertainties in managing the shop floor operations resulting into significant economic losses. Moreover, the users of such systems are now sharing the risk of failures with the machine tool manufacturers by engaging into long term maintenance or availability contracts. This has created new business avenue for machine tool manufacturers for "Servicizing" their traditionally product focused business. Machine tool manufacturers have the opportunity to package effective life cycle maintenance services with the hardware products, i.e. machine tools. It is therefore important for machine tool manufactures as well as users to focus on core of reliability engineering to model machine tool's failure/repair and its interaction with other measures of system performances.

This advanced text on machine tool reliability modelling aims to provide a consolidated volume on various dimensions of machine tool reliability and its implications from manufacturers and users point of view. From manufacturers point of view novel methodologies for reliability and maintenance based design of machine tools are covered. From users point of view novel methodologies are presented to integrate reliability and maintenance of machine tools with production scheduling and quality control. Application area, i.e. machine tools is very important and it covers entire manufacturing sector.

The target audience of the book are researchers and practicing engineers in the field of reliability engineering and operations management. The book can also be helpful to undergraduate students in the area of reliability to get an application flavour of the subject. It opens up various research dimensions for researchers. All the approaches are illustrated with the help of numerical examples. This makes the approaches easy to understand.

This book does not intend to provide coverage to basic of reliability engineering. It is expected here that the readers have some basic knowledge of the reliability engineering, probability and statistics. However, Chapter 2 is provided for the reader to refresh their basic of probability and statistics required to follow the text.

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Contents

1

Introduction

Reduced cost of production, timely delivery and high quality of products are the prime objectives for manufacturing industries. Breakdowns of production machinery or machine tools affect the manufacturer's ability to meet the goals of Cost, Time and Quality (CTQ). One of the studies suggests that the economic loss due to an unexpected stoppage in industry can be as high as US $70,000 to US $420,000 per day [1]. Application of reliability engineering tools and techniques to machine tools for improving the manufacturing system performance is therefore a vital area of study.

The machine tool industry is one of the supporting pillars for the competitiveness of the entire manufacturing sector since it produces capital goods which in turn may produce manufactured goods. Customers of machine tool manufacturers (termed as "users" in this book) are, in many cases, vendors to other customers and have commitments to meet. Breakdowns of machine tools may jeopardize their ability to meet these commitments and also cost a lot of money to the users in terms of poor quality, slower production, downtime, etc. Since poor reliability and improper maintenance of a machine tool greatly increase the life cycle cost to the users, many machine tool users have changed their purchase criteria for a machine tool from initial acquisition cost to Life Cycle Cost (LCC) or Total Cost of Ownership (TCO).

As reliability engineering plays an important role in reducing the LCC of machine tools, this book will be equally appealing to machine tool manufacturers and users.

The book covers both the manufacturer's and user's viewpoint of machine tool reliability. Decisions made during the design phase of a product have the largest impact on the life cycle cost of a system. The inherent failure and repair characteristics of components and assemblies are frozen with the selection of the machine tool configuration at the design stage. Therefore, the maintenance requirements of the machine tools are also fixed at the design stage itself. For example, a higher reliability component may require a lower replacement frequency for the same operating profile compared to a lower reliability component. Therefore, machine tool manufacturers need to consider the reliability and maintenance aspects at the design stage itself. On the other hand, the cost effectiveness of machine tools at the user's end also depends on the shop-floor level operations planning decisions, i.e., scheduling, inventory, quality control, etc. These shop-floor level operations planning decisions have interaction effect with machine tool reliability and maintenance. Therefore, machine tool users need to consider the reliability and maintenance aspects during operations planning. The goal of this book is to provide a consolidated volume on various dimensions of machine tool reliability and its implications from the manufacturer's and user's point of view.

The introductory chapter of the book describes basic reliability terms and defines machine tool failures. The importance of machine tool reliability from the manufacturers' and users' point of view is also discussed.

1.1 Basic Reliability Terms and Concepts

This section introduces important reliability terms and concepts which will help the reader in following the rest of the sections of the book.

Reliability: This is the probability that an item can perform its intended function for a specified interval under stated conditions [2].

In other words, it is the probability of survival over time. To determine the reliability of a particular component or system, an unambiguous and observable description of failure is essential. The machine tool failures are defined in the next section.

If T is a random variable, representing time to failure of the system or component, then reliability can be expressed as:

$$R(t) = Pr\{T \geq t\} \tag{1.1}$$

It is contextual here to clearly differentiate the term "quality" and "reliability." If quality is the conformance to the specifications at $t = 0$, then reliability can be considered as conformance to the specifications at t > 0. However, in this book, "reliability" is used in the context of the machine tools, while "quality" is used in the context of the products produced using machine tools.

Failure Rate (Hazard Rate): Failure rate or hazard rate is the instantaneous (at time *t*) rate of failure [3]. It is the instantaneous failure rate. This index is normally used for non-repairable components. A component of the system may have increasing, decreasing, or constant failure rate. It is further discussed in Chapter 2.

Rate of Occurrence of Failure (ROCOF): This index is often used in place of hazard rate for repairable system. Failures occur as a given system ages and the system is repaired to a state that may be the same as new, or better, or worse. Let N(t) be a counting function that keeps track of the cumulative number of failures a given system has had from time zero to time t. N(t) is a step function that jumps up one every time a failure occurs and stays at the new level until the next failure. The ROCOF is the total number of failures within an item population, divided by the total number of life units expended by that population during a particular measurement period under stated conditions [2].

Every system will have its own observed N(t) function over time. If we observed the N(t) curves for a large number of similar systems and "averaged" these curves, we would have an estimate of M(t) = the expected number (average number) of cumulative failures by time t for these systems.

Maintenance: All actions necessary for retaining an item in or restoring it to a specified condition [2].

Corrective Maintenance (CM): All actions performed as a result of failure, to restore an item to a specified condition [2]. Corrective maintenance can include any or all of the following steps: localization, isolation, disassembly, interchange, reassembly, alignment and checkout.

Preventive Maintenance (PM): All actions performed to retain an item in a specified condition by providing systematic inspection, detection, and prevention of incipient failures [2].

Predictive Maintenance: Predictive maintenance or Condition Based Maintenance (CBM) is carried out only after collecting and evaluating enough physical data on performance or condition of equipment, such as temperature, vibration, particulate matter in oil, etc., by performing periodic or continuous (online) equipment monitoring [4].

Maintainability: It is the relative ease and economy of time and resources with which maintenance can be performed. More precisely, it is the probability that an item can be retained in, or restored to, a specified condition within a specified time when maintenance is performed by personnel having specified skill levels, using prescribed procedures and resources, at each prescribed level of maintenance and repair [2].

Availability: Depending on the purpose of analysis, a number of different definitions are used in the literature, some of which are given below [3]:

Instantaneous or Point Availability, $A(t)$: It is the probability that a system will be operational at any random time t. Unlike reliability, the instantaneous availability measure incorporates maintainability information.

Average Availability: It is the proportion of time a system is available for use during a mission. Mathematically, it is calculated as the mean value of the instantaneous availability function over the period $(0, T)$.

$$A(T) = \frac{1}{T}\int_0^T A(t)dt \tag{1.2}$$

Steady State Availability: The steady state availability of the system is the limit of the instantaneous availability function as the time approaches infinity.

$$A = \lim_{T \to \infty} A(T) \tag{1.3}$$

Inherent Availability: It is the steady state availability when considering only the corrective maintenance downtime of the system. It does not include delays due to unavailability of maintenance personnel, unavailability of spare parts, administrative procedures, etc. The inherent availability of a system is a function of the reliability of its components and maintainability, which more or less get defined at the design stage of the equipment.

$$A = \lim_{T \to \infty} A(T) = \frac{MTBF}{MTBF + MTTR} \tag{1.4}$$

where MTBF is the mean time between failures and MTTR is the mean time to repair.

Operational Availability: It is a measure of the average availability over a period of time, including all the delays due to unavailability of maintenance personnel, spare parts, administrative procedures, etc. Operational availability is the availability that the customer actually experiences.

$$A_o = \frac{MTBM}{MTBM + MTTR + SDT + MDT} \tag{1.5}$$

where MTBM is the mean time between maintenance, SDT and MDT are the supply and maintenance delays respectively.

Inherent availability and operational availability are used in this book and are discussed further in Chapter 3.

Life Cycle Cost (LCC): It is the sum of acquisition, logistics support, operating, and retirement and phase-out expenses [2].