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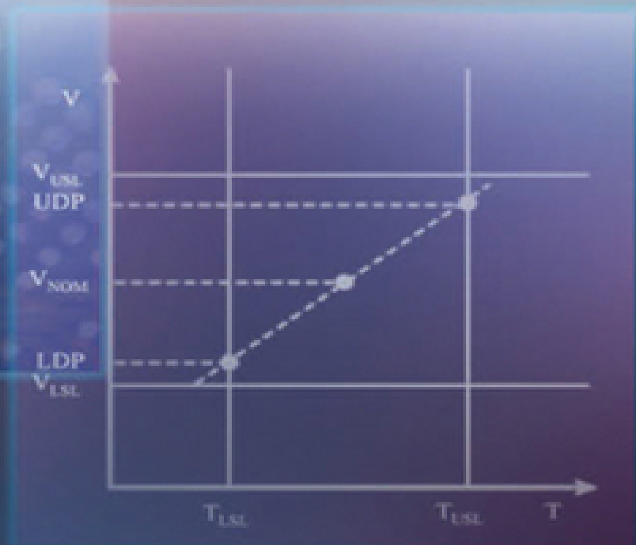

Reliability Technology

Principles and Practice of Failure Prevention in Electronic Systems

WILEY

Norman Pascoe

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Reliability Technology:

Principles and Practice of Failure Prevention in Electronic Systems

Norman Pascoe

RELIABILITY TECHNOLOGY

PRINCIPLES AND PRACTICE OF FAILURE PREVENTION IN ELECTRONIC SYSTEMS

Norman Pascoe

Northern Telecomm Europe Ltd.

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Foreword by Michael Pecht

Two subway trains collide in Washington, D.C., killing nine; an Airbus A330 airliner crashes into the Atlantic Ocean with no survivors; the FAA computer system goes down, paralyzing air traffic in a large region of the U.S. for half a day and for the third time in two years. While these failures dominated the front pages in 2009 and 2010, other major system failures have occurred in telecom network systems, computer systems, data servers, electrical power grids, energy generation systems, and healthcare systems. The costs of such incidents were enormous. In the worst cases, lives were lost and people were injured; in all cases, people were adversely affected. The economic repercussions were also staggering (e.g., in one case, the failure of a point-of-sale information verification system resulted in losses of $5,000,000 per minute in lost sales). They also present, as President Obama noted, "[some] of the most serious economic and national security challenges face[d] as a nation".

Today's systems perform very important societal functions in such diverse areas as communications, transportation, energy networks, financial transactions, and healthcare. But these systems fail, and the consequences can be serious: transportation paralysis, airplane accidents, electrical power outages, and telecom system crashes, to name a few. Appropriate reliability methods are critical to ensure highly available and safe systems, however some methods are more beneficial than others, and some reliability methods are now outdated, inefficient at quickly achieving the maximum reliability capability, and should no longer be used.

This new book on reliability, titled "Reliability Technology" examines the methods and challenges associated with reliability practices. The author, Norman Pascoe, then presents a strong set of realistic and practical methods for reliability design, manufacture and testing of systems. This book is must reading for all of today's practicing engineers.

Michael Pecht
Chair Professor and Director
CALCE Center, University of Maryland

Series Editor's Preface

The book you are about to read re-launches the Wiley Series in Quality and Reliability Engineering. The importance of quality and reliability to a system can hardly be disputed. Product failures in the field inevitably lead to losses in the form of repair cost, warranty claims, customer dissatisfaction, product recalls, loss of sale, and in extreme cases, loss of life.

As quality and reliability science evolves, it reflects the trends and transformations of the technologies it supports. For example, continuous development of semiconductor technologies such as system-on-chip devices brings about unique design, test and manufacturing challenges. Silicon-based sensors and micromachines require the development of new accelerated tests along with advanced techniques of failure analysis. A device utilizing a new technology, whether it be a solar power panel, a stealth aircraft or a state-of-the-art medical device, needs to function properly and without failure throughout its mission life. New technologies bring about: new failure mechanisms (chemical, electrical, physical, mechanical, structural, etc.); new failure sites; and new failure modes. Therefore, continuous advancement of the physics of failure combined with a multi-disciplinary approach is essential to our ability to address those challenges in the future.

The introduction and implementation of Restriction of Hazardous Substances Directive (RoHS) in Europe has seriously impacted the electronics industry as a whole. This directive restricts the use of several hazardous materials in electronic equipment; most notably, it forces manufacturers to remove lead from the soldering process. This transformation has seriously affected manufacturing processes, validation procedures, failure mechanisms and many engineering practices associated with lead-free electronics. As the transition continues, reliability is expected to remain a major concern in this process.

In addition to the transformations associated with changes in technology, the field of quality and reliability engineering has been going through its own evolution developing new techniques and methodologies aimed at process improvement and reduction of the number of design- and manufacturing-related failures.

The concepts of Design for Reliability (DfR) were introduced in the 1990’s but their development is expected to continue for years to come. DfR methods shift the focus from reliability demonstration and ‘Test-Analyze-Fix' philosophy to designing reliability into products and processes using the best available science-based methods. These concepts intertwine with probabilistic design and design for six sigma (DFSS) methods, focusing on reducing variability at the design and manufacturing level. As such, the industry is expected to increase the use of simulation techniques, enhance the applications of reliability modeling and integrate reliability engineering earlier and earlier in the design process.

Continuous globalization and outsourcing affect most industries and complicate the work of quality and reliability professionals. Having various engineering functions distributed around the globe adds a layer of complexity to design co-ordination and logistics. Also moving design and production into regions with little knowledge depth regarding design and manufacturing processes, with a less robust quality system in place, and where low cost is often the primary driver of product development affects a company's ability to produce reliable and defect-free parts.

The past decade has shown a significant increase of the role of warranty analysis in improving the quality and reliability of design. Aimed at preventing existing problems from recurring in new products, product development process is becoming more and more attuned to engineering analysis of returned parts. Effective warranty engineering and management can greatly improve design and reduce costs, positively affecting the bottom line and a company's reputation.

Several other emerging and continuing trends in quality and reliability engineering are also worth mentioning here. Six Sigma methods including Lean and DFSS are expected to continue their successful quest to improve engineering practices and facilitate innovation and product improvement. For an increasing number of applications, risk assessment will replace reliability analysis, addressing not only the probability of failure, but also the quantitative consequences of that failure. Life cycle engineering concepts are expected to find wider applications to reduce life cycle risks and minimize the combined cost of design, manufacturing, quality, warranty and service. Reliability Centered Maintenance will remain a core tool to address equipment failures and create the most cost-effective maintenance strategy. Advances in Prognostics and Health Management will bring about the development of new models and algorithms that can predict the future reliability of a product by assessing the extent of degradation from its expected operating conditions. Other advancing areas include human reliability analysis and software reliability.

This discussion of the challenges facing quality and reliability engineers is neither complete nor exhaustive; there are myriad methods and practices the professionals must consider every day to effectively perform their jobs. The key to meeting those challenges is continued development of state-of-the-art techniques and continuous education.

Despite its obvious importance, quality and reliability education is paradoxically lacking in today's engineering curriculum. Few engineering schools offer degree programs or even a sufficient variety of courses in quality or reliability methods. Therefore, a majority of the quality and reliability practitioners receive their professional training from colleagues, professional seminars, publications and technical books. The lack of formal education opportunities in this field greatly emphasizes the importance of technical publications for professional development.

The main objective of Wiley Series in Quality & Reliability Engineering is to provide a solid educational foundation for both practitioners and researchers in quality and reliability and to expand the readers' knowledge base to include the latest developments in this field. This series continues Wiley's tradition of excellence in technical publishing and provides a lasting and positive contribution to the teaching and practice of engineering.

Dr Andre Kleyner,
Editor of the Wiley Series in Quality & Reliability Engineering

Preface

> "It takes less time to do a thing right than it does to explain why you did it wrong"
>
> *Henry Wadsworth Longfellow*

The title of this book has been carefully chosen in order to encourage awareness of the very clear distinction that exists between the concepts of *Reliability Technology* and *Reliability Theory*.

Reliability Technology is concerned with the application of managerial, scientific, and engineering principles in pursuit of the delivery of failure-free product. Reliability Technology addresses the practical application of tools and processes that target *failure prevention*, and pays particular attention to the many sources of threat to product reliability that cannot be addressed by mathematical modelling. Unreliable products can be (and often are) manufactured from a kit of reliable parts. *Reliability Theory* on the other hand, as described in many texts, is predominantly concerned with the application of statistical techniques and the manipulation of test data in order to meet, with some estimated degree of accuracy, a contractually agreed failure rate probability target. This approach can be interpreted as"*planning for failure*".

It is hoped that this book will be read as a companion volume to Patrick D. T. O'Connor's book *Practical Reliability Engineering, Fifth Edition*, to which numerous references are made. This textbook includes a substantial chapter devoted to the development and implementation of cost-effective Environmental Stress Screening methodologies based upon both the author's thirty five years of practical experience, and the proven performance of a number of Quality-driven companies. The reader will hopefully use this textbook to gain a better understanding of the interdependency of the many disciplines and processes that are essential to the delivery of failure-free product. No single reliability growth initiative will yield maximum effect if applied in isolation from any of the other related disciplines and processes described in the chapters that follow.

Although this book is written primarily for design, manufacturing and test engineers, it is also intended to provide practical, demonstrable guidance to those readers with responsibility for project bid preparation and project management. The author holds the optimistic view that readers will already have acquired an understanding of their personal role in contributing to best achievable quality. In response to informed comment on the proposed content of this book, the author has included a summary and review questions at the end of each chapter. It is hoped that this inclusion will appeal to both students and practicing engineers.

Chapter 1 reviews the origins and evolution of electronic equipment technology, and manufacturing process engineering development, dating from the early to mid-twentieth century. If the reader is to play an effective role in contributing to failure-free targets, then it is vital that the myths embedded within much of the twentieth-century reliability folklore are properly recognised and appropriately discarded. On the other hand, the legacies bequeathed by the Quality pioneers and gurus of the twentieth century should, based upon their proven merit, be studied, understood and applied with earnest enthusiasm. For this reason, particular attention is devoted in this chapter to the evolution of effective quality management.

Chapter 2 studies the essential requirements for successful product lifecycle management. Key contributors to failure in product lifecycle management are identified. Particular emphasis is placed upon the importance of well structured project funding profiles and of thorough Manufacturing Process Capability reviews for both in-house and outsourced manufacturing strategies. Emphasis is placed upon the totally different roles of the project manager, the programme manager and the progress chaser. The readers' attention is also drawn to the many hazards, both obvious and subtle, to which new product is exposed from the commencement of manufacture through to end-of-life disposal. In view of the substantial volume of literature that exists in relation to software reliability, the author has chosen not to include this topic in the current text. However, for a clear insight into the construction, checking and testing of software in engineering systems, the reader is recommended to read Chapter 10 of O'Connor's *Practical Reliability Engineering*.

Chapter 3 is devoted to establishing procedures necessary for identifying and understanding potential failure mechanisms in materials and components. Failure modes and mechanisms associated with modern semiconductor devices are reviewed, together with typical failure-analysis technologies commonly used in solving design- and process-related problems. Particular attention is paid in this chapter to the nature of both steady-state and cyclic stresses induced in component leads and attachments as a result of the application of thermal and mechanical forcing functions. A review of recent developments in digital electronic hardware, together with associated hardware reliability features, is also included.

Chapters 4 and 5 describe the physical concepts governing the response of electronic products to steady-state temperature extremes, temperature cycling, thermal shock, mechanical shock and vibration. The mathematical modelling of the response of mechanical structures to shock and vibration excitation has been the subject of vast numbers of theses for Master's degrees and engineering Doctorates. In keeping with the author's wish to provide guidelines that will support best practice in achieving failure-free electronic system performance, mathematical modelling and analyses are included only where deemed to be helpful in gaining a proper understanding of the thermomechanical mechanisms that contribute to the erosion of both hardware and functional robustness and durability. References are included for students who wish to explore the complex mathematical background that supports the development of modern thermal and mechanical analysis software packages.

Chapter 6 provides a summary of other sources of environmental stress together with their possible effect on product performance, robustness and ageing. Emphasis is placed upon the need to recognise"*test realism*" in order to distinguish between meeting the requirements of a test specification and meeting the requirements of assured product survival in the real world.

Chapters 7, 8 and 9 describe the essential Reliability Technology disciplines that contribute to failure-free product in design, development and manufacturing respectively. Chapter 8 explains the very clear distinction between accelerated ageing and accelerated life testing. Emphasis is repeatedly placed upon the need to pay meticulous attention to detail throughout each phase of the product lifecycle.

Chapter 10 includes details of proven methodologies for developing and proving cost effective stress-screening programmes covering different levels of product assembly. The minimum performance requirements of stress-screening laboratory and manufacturing facilities are discussed in some detail. A detailed study of cost effectiveness for a high volume manufacturing thermal-stress-screening programme is included in order to demonstrate the scope of work necessary in order to thoroughly plan such a process, and to assign a meaningful value to the achievable return on investment for such a process.

The reader is urged to study claims for the superiority of certain “accelerated stress screening processes” with due caution and investigative thoroughness.

“*Conventional*” stress screening stimuli are not based upon anticipated operational stresses. These stimuli are derived from a scientific knowledge of the manner in which hardware responses may precipitate an accelerated ageing process that does not lead to overstress or unacceptable life consumption. All properly developed “conventional” stress-screening profiles are based upon an accelerated ageing process. If this were not the case, they would take years to perform.

Some worked examples are provided in Chapter 11 that will hopefully assist the reader in performing calculations for estimating peak stresses that occur due to thermomechanical and mechanical stress cycling in component leads and attachment interfaces. These stress values provide a necessary input to the calculation of product robustness, product ageing behaviour and product life expectation. The worked examples will enable the reader to examine, in some detail, the precise physical properties of individual electronic hardware designs. In a number of cases, engineers will choose, quite sensibly, to use design and evaluation software packages that have been developed to obviate the need for laborious calculation. It is intended that this chapter will at least contribute in some measure to a deeper understanding of the mathematical processes that describe the magnitude and shape of the environmental stimuli and consequent electronic hardware and functional responses in the real world.

The author sincerely trusts that the following message will serve as a pervading theme within this book:

> *Electronic systems must be proven to be mechanically and functionally robust* ***before*** *delivery into service. The*

culture of “early life failure inevitability” must be consigned to history. Customers are no longer willing to accept that new product “teething” problems are a natural feature of the acquisition contract, to be corrected at their own expense and inconvenience. Unrecognised environmental stresses that cause failure during the whole lifecycle of a product reside within the margin of neglect and human error, not the realm of random behaviour.

Reliability demonstration must be based upon knowledge of precisely how product responds to the application of relevant environmental forcing functions of measured and controlled shape, amplitude and duration, and not based solely upon the fact that product has survived a contractually inspired test.

Effective project management of failure free electronic systems derives from a sound knowledge and understanding of all the processes that are required to be managed.

Norman Pascoe, UK, October 2010

About the Author

Norman Pascoe is a Reliability Technology consultant. He has more than fifty years of experience in the disciplines of design, qualification, accelerated ageing, accelerated life testing, manufacturing, and environmental stress screening of electronic components, equipment and systems. He was elected a Fellow of the Society of Environmental Engineers in 1998, and has chaired a number of technical groups within the Society. He played a leading role in delivering an annual three-day course of “Stress Screening for Reliability” lectures at Cranfield University. The author has contributed to reliability growth initiatives that have been cost effectively introduced within the consumer, automotive, communications and military industries.

Acknowledgements

After a lifetime in the engineering industry, it is virtually impossible to name all of the individuals who have contributed to the knowledge gained by the author. In fact, the learning process continues on a daily basis.

I must gratefully acknowledge the encouragement given to me some years ago by Pat O'Connor, who on many occasions urged me to write this book. Within my library of indispensable engineering literature, I assign particular value to the “Vibration Analysis” and “Cooling Techniques” for Electronic Equipment authored by Dave Steinberg. My long-standing association with Dr Michael Pecht and the CALCE Electronic Packaging Center at the University of Maryland has been both educational and inspirational.

At a time when my enthusiasm for solving the riddle of conventional “failure inevitability” as defined by reliability prediction statistics was at its very lowest, Group Captain James Stewart and Ian Knowles of the Ministry of Defence Procurement Executive introduced me to a fundamental and incontrovertible change in paradigm. Simply stated the old paradigm “if it fails no more than an allowable number of times during a given period it is reliable”, must be changed to the new paradigm “if it operates for a given time without failure, it is reliable”. This was the moment at which I fully appreciated that reliability is achieved by failure prevention, not by failure prediction.

In pursuit of the goal of failure prevention I have been privileged to work with colleagues whose experience and enthusiasm has sustained me. My special gratitude is due to Roger Hoodless - BAE Systems, Pat Ferrie - Teledyne Defence Limited, Martin Cull – Rolls Royce Goodrich Limited, Dr Eddy Weir – ETIC, Phil Mason – BAE Systems, Chris Walker – BAE Systems, Geoff Murphy – Data Physics (UK) Limited, Andy Tomlinson – Society of Environmental Engineers, Geoff Lake – Martin-Baker Aircraft Company Limited, John Perryman – Martin-Baker Aircraft Company Limited, Brian Wharton, Gabor Martell and George Korosi.

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