

# THERMODYNAMIC DEGRADATION SCIENCE

## *PHYSICS OF FAILURE, FATIGUE, RELIABILITY, AND ACCELERATED TESTING APPLICATIONS*

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### PREFACE

Thermodynamic degradation science is a new and exciting discipline. There are many different ways to approach the science of degradation. However, since thermodynamics uses an energy perspective, it is a great way to analyze such problems. There is something in this book for everyone who is interested in degradation problems. Even if you are just interested in reliability or accelerated testing, there is a lot of new and highly informative material. We also go beyond traditional physics of failure methods and develop conjugate work models and methods. It is important to have new tools like “Mesoscopic” noise degradation measurements for complex systems and a conjugate work approach to solving physics of failure problems. We cover a number of original key topics. These include:

- Thermodynamic principles of degradation
- Conjugate work, entropy damage and free energy degradation analysis
- Physics of failure using conjugate work approach
- Complex systems degradation analysis using noise analysis
- *Mesoscopic* noise entropy measurement for disorder in operating systems
- Human heart degradation measurements
- Cumulative entropy damage, cyclic work and fatigue analysis
- Miner’s rule derivation for fatigue and Miner’s rule for batteries
- Engines and efficiency degradation
- Aging Laws, Cumulative Accelerated Stress Test (CAST) Plans, and acceleration factors for
  - Creep
  - Wear
  - Fatigue
  - Thermal Cycle
  - Vibration (sine and random)
  - Temperature
  - Humidity & temperature
- Transistor aging laws (Bipolar and FET models)
- New accelerated test environmental profiling CAST planning method
- Vibration cumulative damage (sine and random)
- FDS (Fatigue Damage Spectrum) analysis (sine and random)
- Chemical corrosion and activations aging laws
- Diffusion aging laws
- Reliability statistics
- How aging laws affect reliability distributions
- Human engine degradation
- Human heart vs. metal cyclic fatigue
- Human growth and repair model
- Negative entropy & spontaneous negative entropy
- Environmental degradation and pollution

When we think of thermodynamic degradation, whether it be for complex systems, devices, or even human aging, we begin to realize that it is all about “order” being converted to “disorder” due to the natural spontaneous

tendencies described by the Second Law of thermodynamics to come to equilibrium with the neighboring environment. Although most people who study thermodynamics are familiar with its second law, not many think of it as a good explanation of why a product degrades over time. However, we can manipulate and phrase it as:

***Second law in terms of system thermodynamic degradation: The spontaneous irreversible degradation processes that take place in a system interacting with its environment; will do so in order to go towards thermodynamic equilibrium with its environment.***

We see that the science presents us with a gift, for its second law actually explains the aging processes. When I first realized this, I started to combine the science of degradation with thermodynamics. I presented these concepts in a number of papers and conferences, and in the book called *Design for Reliability* first published in 2000. The initial work was done with Prof. Alan Widom at Northeastern University. Recently I was invited to write a chapter in a book edited with Prof. Swingler at Heriot-Watt University, England, entitled, *The Physics of Degradation in Engineered Materials and Device*. That gave me a chance to start to work on applications and how to find new ways to perform degradation analysis. We see that this science is starting to catch on. This book presents the fundamentals and goes beyond including new ways to make measurements as well provides many examples so the reader will learn the value of how this science can be used. I believe this science will significantly expand soon and it is my hope that this book will provide the spark to help inspire others. I believe there are a lot of new opportunities to enhance and use thermodynamic degradation methods. We should find that prognostics, using a thermodynamic energy approach, should advance our capabilities immensely. I have included such a measurement system in the book.

The fact is that in many situations, failure is simply not an option and it can take immense planning to prevent failure. We simply need all the tools we can get to assist us. Thermodynamic degradation science offers new tools, new ways to solve physics of failure problems and new ways to do prognostics and prevent failure.

## TABLE OF CONTENTS

### **Chapter 1      Equilibrium Thermodynamic Degradation Science**

- 1.0      Introduction
- 1.2      Categorizing Physics of Failure Mechanisms
- 1.3      Entropy Damage Concept
  - 1.3.1      The System and Its Environment
  - 1.3.2      Irreversible Thermodynamic Processes Cause Damage
- 1.4      Thermodynamic Work
- 1.5      Thermodynamic State Variables and Their Characteristics
- 1.6      Thermodynamic Second Law in Terms of System Entropy Damage
  - 1.6.1      Thermodynamic Entropy Damage Axiom
  - 1.6.2      Entropy and Free Energy
- 1.7      Work, Resistance and Generated Entropy
  - 1.7.1      Entropy Maximize Principle – Combined First and Second Law
  - 1.7.2      *Example 1-1: Thermal Equilibrium*
  - 1.7.3      *Example 1-2: Thermal with Charge Exchange*
  - 1.7.4      *Example 1-3: Diffusion Equilibrium*
  - 1.7.5      *Example 1-4: Available Work*
- 1.8      Thermodynamic Catastrophic & Parametric Failure
  - 1.8.1      Equilibrium and Non-Equilibrium (NE) Aging States in Terms of the Free Energy or Entropy Change
- 1.9      Repair Entropy
  - 1.9.1      *Example 1-5 Repair Entropy - Relating Non Damage Entropy To Damage Entropy*
- Chapter Summary
- References

### **2. Applications of Equilibrium Thermodynamic Degradation Science to Complex Systems – Damage Entropy, Vibration, Temperature, & Noise Analysis**

- 2.1      Cumulative Entropy Damage

- 2.1.1 *Example 2-1 – Miner’s Rule Derivation*
  - 2.1.2 *Example 2-2: Miner’s Rule Example*
  - 2.1.3 Non Cyclic Applications of Cumulative Damage
  - 2.2 Measuring Damage Entropy Processes
  - 2.3 Intermediate Thermodynamic Aging States & Sampling
  - 2.4 Measures for System Level Entropy Damage
    - 2.4.1 Measuring System Entropy Damage with Temperature
    - 2.4.2 *Example 2-3: Resistor Aging*
    - 2.4.3 *Example 2-4: Complex Resistor Bank*
    - 2.4.4 System Entropy Damage with Temperature Observations
    - 2.4.5 *Example 2-5: Temperature Aging of an Operating System*
  - 2.4.6 Comment on High Temperature Aging for Operating and Non Operating Systems
  - 2.5 Measuring Randomness Due To System Entropy Damage with Mesoscopic Noise Analysis in an Operating Systems
    - 2.5.1 *Example 2-6: Gaussian Noise Vibration Damage*
    - 2.5.2 *Example 2-7: System Vibration Damage Observed with Noise Analysis*
  - 2.6 How System Entropy Damage Leads to Random Processes
    - 2.6.1 Stationary vs. Non Stationary Entropy Process
  - 2.7 *Example 2-8: Human Heart Rate Noise Degradation*
  - 2.8 Entropy Damage Noise Assessment Using Autocorrelation & the Power Spectral Density
    - 2.8.1 Literature Review of Traditional Noise Measurement
    - 2.8.2 Literature Review for Resistor Noise
  - 2.9 Noise Detection Measurement System
    - 2.9.1 System Noise Temperature
    - 2.9.2 Environmental Noise Due to Pollution
    - 2.9.3 Measuring System Damage Entropy Using Failure Rate
  - 2.10 Thermodynamic Potentials & Energy States
    - 2.10.1 The Helmholtz Free Energy
    - 2.10.2 The Enthalpy Free Energy
    - 2.10.3 The Gibbs Free Energy
    - 2.10.4 Summary of Common Thermodynamic State Energies
    - 2.10.5 *Example 2-9 Work, Entropy Damage and Free Energy Change*
      - 2.10.5.1 Full Expression for Potential with Entropy Damage
- Chapter Summary  
References

### **Chapter 3 NE Thermodynamic Degradation Science Assessment Using the Work Concept**

- 3.1 Equilibrium versus Non Equilibrium (NE) Aging Approach:
    - 3.1.1 Conjugate Work & Free Energy Approach to Understanding NE Thermodynamic Degradation
  - 3.2 Application to Cyclic Work and Cumulative Damage
  - 3.3 Cyclic Work Process, Heat engines, the Carnot cycle
  - 3.4 *Example 3-1 Cyclic Engine Damage Quantified Using Efficiency*
  - 3.5 The Thermodynamic Damage Ratio Method for Tracking Degradation
  - 3.6 Acceleration Factors – Obtained Through the Damage Principal
- Chapter Summary  
References

### **Chapter 4 Applications of NE Thermodynamic Degradation to Mechanical Systems – Accelerated Test Equations, Miner’s Rule, FDS**

- 4.0 Introduction
  - 4.1 *Example 4-1: Miner’s Rule*
    - 4.1.1 Acceleration Factor Modification of Miner’s Damage Rule
- 4.2 Thermodynamic Damage in Mechanical Systems
  - 4.2.1 *Example 4-2: Creep Cumulative Damage and Acceleration Factors*

- 4.2.2 *Example 4-3: Wear Cumulative Damage and Acceleration Factors*
- 4.2.3 *Example 4-4: Thermal Cycle Fatigue and Acceleration Factors*
- 4.2.4 *Example 4-5: A Mechanical Cycle Vibration Fatigue and Acceleration Factors*
- 4.2.5 *Example 4-6: Cycles to Failure under a Resonance Condition – Q effect*
- 4.3 Cumulative Damage Accelerated Stress Test Goal – Environmental Profiling & CAST Equations
- 4.4 FDS - Fatigue Damage Spectrum Analysis for Vibration Accelerated Testing
  - 4.4.1 FDS - Fatigue Damage Spectrum for Sine Vibration Accelerated Testing
    - 4.4.1.1 FDS - Fatigue Damage Spectrum for Sine Vibration at and across Resonance
  - 4.4.2 FDS - Fatigue Damage Spectrum for Random Vibration Accelerated Testing
- Chapter Summary
- References

## **Chapter 5 Corrosion Applications in NE Thermodynamic Degradation**

- 5.1 Corrosion Damage in Electrochemistry
  - 5.1.1 *Example 5-1: Miner's Rule for Secondary Batteries*
- 5.2 *Example 5-2: Chemical Corrosion Processes*
  - 5.2.1 *Example 5-3: Numerical example of linear corrosion*
  - 5.2.2 *Example 5-4: Corrosion Rate Comparison of Different Metals*
- 5.2.3 Thermal Arrhenius Activation and Peukert's Law
- 5.3 Corrosion current in primary batteries
  - 5.3.1 Equilibrium Thermodynamic Condition– Nernst Equation
- 5.4 Corrosion Rate in Microelectronics
  - 5.4.1 Corrosion and Chemical Rate Processes Due To Temperature
- Chapter Summary
- References

## **Chapter 6 Thermal Activation Free Energy Approach**

- 6.1 Free Energy Roller Coaster
- 6.2 Thermal Activation TAT Degradation Model
  - 6.2.1 Arrhenius Aging Due to Small Parametric Change
- 6.3 Free Energy Use in Parametric Degradation and the Partition Function
- 6.4 Parametric Aging at End of Life Due to the Arrhenius Mechanism – Large Parametric Change
- Chapter Summary
- References

## **Chapter 7 TAT Model Applications – Wear, Creep and Transistor Aging**

- 7.0 Introduction
- 7.1 *Example 7-1: Activation Wear*
- 7.2 *Example 7-2: Activation Creep Model*
- 7.3 Transistor Aging
  - 7.3.1 Bipolar Transistor Beta Aging Mechanism
  - 7.3.2 Capacitor Leakage Model for Base Leakage Current
  - 7.3.3 TAT Model for Transistors and Dielectric Leakage
  - 7.3.3 FET Transistor Parameter Degradation
- Chapter Summary
- References

## **Chapter 8 Diffusion**

- 8.0 The Diffusion Process
  - 8.1 *Example 8-1: Describing Diffusion Using Equilibrium Thermodynamics*
- 8.2 Describing Diffusion Using Probability
- 8.3 Diffusion Acceleration Factor with and without Temperature Dependence

- 8.4 Diffusion Entropy Damage
- 8.4.1 *Example 8-1: Package Moisture Diffusion*
- 8.5 General Form of the Diffusion Equation
- Chapter Summary
- References

## **Chapter 9 How Aging Laws Influence Parametric and Catastrophic Reliability Distributions**

- 9.1 Introduction
- 9.2 Log Time Aging (or Power Aging Laws) and the Lognormal Distribution
- 9.3 Aging Power Laws and the Weibull Distribution – Influence on Beta
- 9.4 Stress and Life Distributions
- 9.5 Time (or Stress) Dependent Standard Deviation
- Chapter Summary
- References

## **Special Topics**

### **Special Topics A: Key Reliability Statistics**

- A.1 Introduction
- A.1.1 Reliability and Accelerated Testing Software to Aid the Reader
- A.2 The Key Reliability Functions
- A.3 More Information on the Failure Rate
- A.4 The Bathtub Curve And Reliability Distributions
- A.4.1 Exponential Distribution
- A.4.1.1 *Example A-1 Some Basic Math of the Exponential Distribution*
- A.4.1.2 *Example A-2 Estimating the Number of Failures and Availability with Exponential Reliability Function*
- A.4.2 Weibull Distribution
- A.4.3 Normal (Gaussian) Distribution
- A.4.3.1 *Example A-3 Power Amplifiers*
- A.4.4 The Log-Normal Reliability Function
- A.5 Confidence Interval for Normal Parametric Analysis
- A.5.1 *Example A-4 Power Amplifier Confidence Interval*
- A.6 Central Limit Theorem and Cpk Analysis
- A.6.1 *Cpk Analysis*
- A.6.2 *Example A-5 Cpk and Yield for the Power Amplifiers*
- A.7 Catastrophic Analysis
- A.7.1 Censored Data
- A.7.2 *Example A-6 Weibull and Log-Normal Analysis of Semiconductors*
- A.7.3 *Example A-7 Mixed Modal Analysis Inflection Point Method*
- A.8 Reliability Objectives and Confidence Testing
- A.8.1 Chi-Squared Confidence Test Planning for few Failures – The Exponential Case
- A.8.1.1 Chi-Squared Validity
- A.8.2 *Example A-8 Chi-Squared Accelerated Test Plan*
- A.9 Comprehensive Accelerated Test Planning
- References

### **Special Topics B: Applications to Accelerated Testing**

- B.1 Introduction
- B.1.1 Reliability and Accelerated Testing Software to Aid The Reader
- B.1.2 Using the Arrhenius Acceleration Model For Temperature
- B.1.2.1 *Example B-1 Using the Arrhenius Acceleration Model*
- B.1.3 *Example B-2 Estimating the Activation Energy*
- B.1.4 *Example B-3 Estimating MTTF from Life Test*
- B.2 Power Law Acceleration Factors

- B.2.1 *Example B-4 Generalize Power Law Acceleration Factors*
  - B.3 Temperature-Humidity Life Test Model
  - B.3.1 *Temperature-Humidity-Bias and Local Relative Humidity*
  - B.3.1.1 *Example B-5 Using the Temperature-Humidity Model*
  - B.4 Temperature Cycle Testing
  - B.4.1 *Example B-6 Using the Temperature Cycle Model*
  - B.5 Vibration Acceleration
  - B.5.1 *Example B-7 Accelerated Testing Using Sine and Random Vibration*
  - B.6 How To Do Multiple-Stress Accelerated Test Plans for Demonstrating Reliability
  - B.6.1 *Example B-8 Designing Multi-Accelerated Tests Plans - Failure-Free etc.*
  - B.7 Cast Goals in Environmental Profiling
  - B.7.1 *Example B-9 CAST Goals in Environmental Profiling*
- References

### **Special Topics C: Negative Entropy and the Perfect Human Engine**

- C.1 Spontaneous Negative Entropy – Growth & Repair
  - C.2.0 The Perfect Human Engine – How to Live Longer
  - C.2.1 Differences and Similarities of The Human Engine to Other Systems
  - C.2.2 Knowledge of Cyclic Work to Improve Our Chances for A Longer Lifetime
  - C.2.3 *Example 3-1 Exercise and the Human Heart Life Cycle*
  - C.3 Growth and Self-Repair Part of the Human Engine
  - C.3.1 *Example 3-2: Work for Human Repair*
  - C.4 Act of Spontaneous Negative Entropy
  - C.4.1 Repair Aging Rate - An RC Electrical Model
- References