THERMODYNAMIC DEGRADATION SCIENCE

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

Alec Feinberg, Ph.D.

Publisher: John Wiley & Sons, Due out August-September 2016

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 enviroment. 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