Degradation Models for Life Time Estimation of Serial and Parallel Connected Lithium-ion Battery Packs

<u>Shuen-Lin Jeng</u>, Yi-No Tseng

Department of Statistics and Institute of Data Science, National Cheng Kung University

ABSTRACT

This study utilized capacity loss datasets from Lithium-ion battery cells and packs to calculate the State of Health (SoH) after each discharge cycle. To more accurately depict the degradation paths of cell batteries within a pack and of the pack itself, we introduced the concept of the discharge rate factor to describe the impact of variations in discharge rates during each discharge cycle. This factor was incorporated into a random coefficient degradation model. We proposed several Cell-to-Pack methods to estimate the reliability of serial and parallel connected battery packs by using the cell data. The results indicate that compared to traditional reliability methods, such as the Reliability Block Diagram, our Cell-to-Pack methods yield a more accurate battery pack reliability estimation

Keywords: Cell-to-Pack methods; random coefficient degradation model; reliability; State of Health

Optimal Designs for Gamma Degradation Tests

Hung-Ping Tung[1], Yu-Wen Chen[1]

Department of Industrial Engineering and Management, National Yang Ming Chiao Tung University

ABSTRACT

This study analytically investigates the optimal design of gamma degradation tests, including the number of test units, the number of inspections, and inspection times. We first derive optimal designs with periodic inspection times under various scenarios. Unlike previous studies that typically rely on numerical methods or fix certain design parameters, our approach provides an analytical framework to determine optimal designs. In addition, the results are directly applicable to destructive degradation tests when number of inspection is one. The investigation is then extended to designs with aperiodic inspection times, a topic that has not been thoroughly explored in the existing literature. Interestingly, we show that designs with periodic inspection times are the least efficient. We then derive the optimal aperiodic inspection times and the corresponding optimal designs under two cost constraints.

Keywords: Reliability; Degradation tests; Gamma process; Inspection time; Optimal design

Shrinkage Estimation for the Rate Parameter under the Exponential Distribution with Censored Survival Data

Nanami Taketomi[1], Kosuke Nakazono[2], Akane Okada[3], and Takeshi Emura[4]

[1] *School of Information and Data Sciences, Nagasaki University*

[2] *Department of Industrial Engineering and Economics, School of Engineering, Institute of Science Tokyo*

[3] *Department of Biostatistics, Graduate school of medicine, Kurume University*

[4] *School of Informatics and Data Science, Hiroshima University*

ABSTRACT

The exponential distribution is widely applied in survival and reliability analyses. To estimate the rate parameter of the exponential distribution with censored survival data, maximum likelihood estimation is usually employed. However, in case the number of events or subjects is small for the data, the maximum likelihood estimator (MLE) can have large bias and variance. In this talk, we present a shrinkage estimator for the rate parameter of the exponential distribution using a penalized log-likelihood by adding a penalty for a large parameter value. The value of the shrinkage parameter is selected by maximizing the likelihood cross validation. We also derive theoretical properties of the penalized maximum likelihood estimator. Simulation results show that the proposed method provides the smaller mean squared error than the maximum likelihood estimation. Finally, we apply the proposed method to the reliability data and the prostate cancer data. In the reliability dataset, failure events account for only 0.25% of the total observations, indicating a highly censored data structure. The prostate cancer data contains 7.2% events of the total observations. In the analysis, the reliability functions by the MLE and the shrinkage estimator were drawn. The reliability function by the PML estimator is expected to have the smaller MSE than the ML estimator.

Keywords: Exponential distribution, Maximum likelihood estimation, Mean squared error, Shrinkage estimation, Survival data

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Reliability Analysis for Small Ball Bearings by Considering the Correlation of Their Lifetimes

Shuhei Ota[1]

[1]Department of Industrial Engineering and Management, Kanagawa University, Japan

ABSTRACT

Ball bearings are crucial components in rotating machinery, and their failure can have a significant impact on the reliability of the machinery. Although many life test rigs for bearings have been developed to assess their reliability, few studies have focused on small bearings or multiple bearings tested simultaneously, where dependent failures may occur due to shared loads. This study extends our previous work on developing a life test rig for two small ball bearings (inner diameter 10 mm) operated under radial load and monitored by acceleration and temperature sensors. We conducted accelerated life tests to investigate the correlation between the bearings' lifetimes. Statistical analysis of temperature data revealed both positive and negative correlations between the two bearings, suggesting the presence of dependent failures due to load transfer and shaft wear. Lifetime data were fitted using Weibull, Gamma, and lognormal distributions, with the lognormal model showing the best fit. Based on the estimated dependence structure, a reliability model considering correlated lifetimes was formulated. The proposed analysis provides insights into how the interaction between components affects overall system reliability. The results contribute to the development of more accurate methods for predicting the remaining useful life of systems with multiple dependent components.

Keywords: Reliability analysis; Condition monitoring data; Dependence; Copula