Failure Characteristics Analysis and Fault Diagnosis for Liquid Rocket Engines

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Preface

Being composed of different components working with different programs, the liquid rocket engine (LRE) is a complex system that is widely used in the aerospace field. It can provide thrust for a vehicle outside of the atmosphere. However, the LRE is always working in execrable conditions with high temperatures and heavy corrosion. Therefore, it is necessary to monitor the condition of an LRE to enhance the reliability and safety of the thrust system and understand its working performance; it would also be useful to establish an advanced condition monitoring and fault diagnosis system for the LRE. Involving several disciplines and technologies, the core of LRE health monitoring is the technologies of fault detection and fault diagnosis. In recent decades, a special theory of fault detection and diagnosis was developed using digital computer technology, the theory of automatic control, signal processing, artificial intelligence, reliability theory, and engineering to provide a theoretical foundation for the development of fault detection and diagnosis in the LRE.

In this book, the mode, model, and characteristics of the LRE's fault are investigated. Then, the corresponding fault diagnosis methods, including methods based on the model, signal processing, and artificial intelligence are studied. Developed under the guidance of modern control theory and the modern optimization method, the model-based method carries out fault diagnosis by analyzing the residual obtained by the Luenberger observer, equivalent space equation, Kalman filter, parameter estimation, and identification based on the specialized criterion or threshold. It has attracted much attention because the model-based method can be closely combined with the control system and is a precondition of condition monitoring, fault tolerance control, system modification, and reconstruction.

By referring to the production of the residual, the model-based method can be divided into several methods, including the condition estimation method, parameter estimation method, and the equivalent space method. Comparatively, the method based on signal processing does not rely on an accurate model and has good suitability. Although most parts of signal processing-based methods are proposed

on the assumption that the system is linear, they are easily expanded to nonlinear systems. The methods involving Kullback information criterion, wavelet transform, time series analysis, and information fusion are included in the signal processing-based methods. With the development of the system, the system is becoming more and more complex and it is very difficult to establish an accurate model. In this instance, an artificial intelligence-based method, which does not rely on an accurate model, can be used for fault diagnosis. For example, the artificial neural net (ANN), expert system, pattern recognition, revolution algorithm, fuzzy logic method, and a combination of these methods are included in the intelligence-based method.

An LRE is a complex system involving high temperatures, high pressure, heavy corrosion, and strong power release. It is very difficult to establish an accurate model for the whole system, and the model-based method may be restricted in the engineering application. Comparatively, the signal processing-based method and the artificial intelligence-based method are advanced in the processing of the complex character of the object. In this instance, by combining the character and developing trends of the LRE fault diagnosis, wavelet transform, artificial intelligence, fuzzy logic, statistic learning theory, and gray theory are applied in the fault diagnosis of the LRE. This book concentrates on the subjects of monitoring technology of a healthy LRE, including its failure analysis, fault diagnosis, and fault prediction; several fault diagnosis methods have been investigated by combining the fault cases of LRE. We hope to have achieved the following characteristics in the writing of this book:

Advanced. The latest investigation achievements are summarized in this book and corresponding content is advanced and novel.
Applicable. As it is focused on the application of the fault character analysis and diagnosis technology in the LRE, this book can be used as the reference by researchers and engineers.
Readable. Although the theory is very complex, the content of this book, including the basic mechanisms, synthesis methods, and application cases, are logically arranged for the sake of understanding.

The content of this book is the culmination of research by our group. Many graduate students, including Tian Gan, Xu Zhi-gao, Yang Zheng-wei, Li Ming, Lin Xiang-jin, Gao Zheng-ming, Liu Chong-yang, Tian Lu, Xu Hai-bo, and Ming An-bo, worked on different parts of this book. All authors of references are appreciated because they provide rich material for the content in this book. We also thank the publishers for their help in the publishing process.

Because of restrictions in the knowledge of the authors, errors may appear in this book. All comments and corrections are cordially accepted!

January 2016 Wei Zhang

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Prologue

Astronautical technology is a type of synthesis engineering technology that aims to explore, develop, and use celestial bodies in outer space; it is an integrative sign of modern technology development. Moreover, military astronautical technology—an important part of the national defense industry—is very important for improvement in military information levels and national safety. However, the structure of an astronautical vehicle is very large and the environment of space flights is very complex. The launch and reclamation of the vehicle is very difficult. Furthermore, the demand for astronautical technology that carries people is increasing, while maintaining the safety and reliability of these vehicle faces great challenges.

Generally, a liquid rocket engine (LRE)—a kind of heat hydrodynamic system—is the main power source for space shuttles; its running condition is critical for the safety and reliability of the vehicle. Therefore, the investigation of the fault diagnosis and prediction of an LRE is very important for the improvement of astronautical activities. Using achievements in the areas of propulsion theory, signal processing, pattern recognition, artificial intelligence, sensor technology, and computer technology, the aim of the investigation of the fault diagnosis and prediction of an LRE is to enhance running reliability and flight safety. Recently, investigations on the fault diagnosis and prediction of LREs have achieved great improvements in China. The theoretical system of fault diagnosis and prediction was founded on the background of LREs and successfully applied in a ground test of space vehicle and military LREs. However, a systematical technical monograph on fault character and fault diagnosis technology has not yet been written in the area of military LREs. I am very pleased to see that this monograph on the basic theory and methods of the fault character, diagnosis, and prediction of military LREs summarizes the basis of the investigation and engineering practice of the past decades. This book is very significant for the improvement of military LRE fault diagnosis and engineering applications throughout the world.

Based on the LRE model with fault and characteristic analysis, the achievements on the fault characteristics and diagnosis technology of military LREs have been introduced. In particular, theoretical methods, including the artificial neural net, wavelet analysis, intelligence computing, fuzzy theory, statistic learning theory,

time series analysis, and the gray system model, are applied on the fault diagnosis and prediction of LREs and provide technological support for the novel design, scientific maintenance, and safe operation of weapons.

This book will help in the expansion and dissemination of fault diagnosis technology of military LREs and space vehicles. It will play an important role in the future of engineering.

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