Investigations on Failures of Defence Hardware Components

Fundamentals and Case Histories

KP Balan

Defence Research & Development Organisation
Ministry of Defence, New Delhi – 110 001

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INVESTIGATIONS ON FAILURES OF DEFENCE HARDWARE COMPONENTS FUNDAMENTALS AND CASE HISTORIES

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This Monograph is dedicated to my teachers,
mentors and colleagues of
Defence Metallurgical Research Laboratory,
Hyderabad.

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Foreword

I remember the days when Dr KP Balan, I and a few other young scientists had joined Defence Metallurgical Research Laboratory (DMRL)/ DRDO, Hyderabad, during early Eighties, with great enthusiasm to work in projects related to development of materials technology for defence hardware. During our induction training programme at Defence Institute of Armament Technologies (DIAT), Pune and subsequently, at erstwhile Defence Institute of Work Study (DIWS), Mussoorie, Dr Balan and I had developed a good friendship and camaraderie. Dr Balan's keen observation and vast knowledge in both technical and non-technical areas had always attracted me to discuss and learn from him various topics of common interest, including life disciplines, meticulous living style, Yoga and Health.

Soon after the induction programme at the Laboratory, the then Director Dr P Rama Rao found among all of us only Dr Balan to be most suitable, probably due to his aptitude, for the Failure Analysis Group of DMRL. Like an obedient soldier Dr Balan joined the group and started his relentless and untiring efforts to learn the science and art of the subject, being mentored under renowned Failure Analyst Dr DP Lahiri, and contribute to the ongoing works of the Laboratory in the field of Failure Analysis. With passing time, Dr Balan not only attained perfection in the field of Failure Investigation but also contributed in solving major failures of safety critical aerospace, defence and weapon platforms, that really helped in preventing similar catastrophic failures in future, thus saving strategic defence platforms. Dr Balan's hands-on hard work of almost three decades brought excellence in this field and that led his elevation from a young scientist to the Head of Failure Analysis Group, leading his team in DMRL. During his tenure, he has analysed over 500 failure cases of defence hardware components, acting as team leader in a large number of investigations and sensitive Court of Inquiries, related to accidents. He has been responsible for establishment

of several advanced infrastructural facilities at DMRL/DRDO. Based on his rich experience, Dr Balan led several projects at DMRL related to gun barrels, aerospace grade bearing, pneumatic and hydraulic pipes for submarines and armour technologies. He has also carried out metallurgical investigations of over 2000 metallic components of aircraft engine and structure, weapons and weapon systems for their indigenisation. The technology documents provided by him for indigenisation programmes have helped in self-reliance of the country in the stores of spares and accessories of expensive aircrafts and weapon systems.

Dr Balan has provided Failure Analysis services not only to Defence establishments, viz., Indian Air Force, Indian Army, Indian Navy, Ordnance factories, and DRDO Labs, but also to railways, power plants and mines. Some of the Failure Analysis as case studies were not only limited to metallurgical reasons but also have extended to highly complex multidisciplinary investigations. The recommendations given through his failure analysis have helped in imparting new lease of life to a number of components and systems at various stages of manufacture and operation, thus saving large amount of revenue for the country.

He has over 50 publications in national and international journals and conference proceedings. A book authored by Dr KP Balan on 'Metallurgical Failure Analysis - Techniques and Case Studies' published by Elsevier, Amsterdam in 2018 has been one of the best sellers around the world in this field. His vast experience and expertise of over three decades in the field of Failure Analysis makes him most suitable to write a monograph in this subject.

I remember the day when as Director of the Laboratory, I had called a meeting of former scientists of DMRL, to my chamber to express my thought that they must attempt writing monographs in their field of expertise based on their rich experience. Such monographs will go a long way recording history of development of various research fields at DMRL, and in long term motivate young scientist to take the field forward. This had kindled the thought in Dr Balan's mind to pen a monograph in the subject of Investigations on Failures of Defence Hardware Components, which he later revealed to me. Today as his colleague, friend, Former Division Head and Director, I feel highly privileged, proud and happy to present this very well documented monograph to the readers.

The objective of this monograph is to introduce to the readers the fundamentals of failure analysis and develop an understanding of various

causes triggering in-service failures along with remedial actions for avoidance of similar failures in future. There are very few books where a reader can find investigations on real time failures of critical components, especially operating in highly complex, hostile environment used in defence hardware. The present monograph is an effort by the author in this direction, wherein he shares his rich experience of handling investigations on real time failures of defence hardware components. The monograph addresses Failure Analysis issues at all levels of the product Life Cycle: material-design-manufacturing process-deployment.

The monograph has been very well structured in to two different parts. Part-I deals with the general principles and practice of Failure Analysis. This part initially introduces the subject of Failure Analysis which is followed by a brief understanding on various types of fractures and related fractography of metals. Tools and techniques used in failure analysis of metallic components are described in another chapter. The major sources, causes and mechanisms of metallic component failures in a hardware system, are brought out with examples and illustrations in a separate chapter. Part-II is a compilation of some typical Case Histories investigated by the author and his team pertaining to components of aircraft engine and structure, Main Battle Tanks (MBTs), weapons and weapon systems. The case histories presented here are classified based on the cause of failure such as (a) Manufacturing related issues - improper material processing, heat treatment, pre-existing defects, weld related defects; and (b) Service operating conditions - overload, fatigue, corrosion, hydrogen embrittlement and stress corrosion cracking, wear and elevated temperature failures.

The monograph is an invaluable record of some excellent works carried out by Dr KP Balan and his team at Defence Metallurgical Research Laboratory (DMRL), DRDO, Hyderabad. The present monograph will be extremely useful in creating an awareness and interest for failure analysis in the minds of students, teachers, metallurgists, scientists and engineers engaged in the design, development, manufacture, and inspection of metallic components for various engineering and aerospace applications.

Date : 08 April 2024
Place : Hyderabad

Dr Vikas Kumar, FNAE
Distinguished Scientist & Former Director
DMRL, DRDO
Hyderabad

Preface

Failure analysis is an important field of engineering. The knowledge of failure analysis should be of professional interest not only to metallurgists but also to engineers of other discipline, as metals and alloys constitute the major materials in all engineering applications.

Engineering systems and equipment employed by the three defence services are developed by different defence research and development establishments across the country. On successful completion of the project the technology is transferred to an ordnance factory or a defence production unit either under government or public sector. The components used in these hardware are largely made of metallic materials. However, it is not necessary that either during its development stage or while production a materials expert or a metallurgist was engaged in the project whose expertise is used for quality control and approval of the materials and processes involved in the selection and manufacturing of the hardware. The repercussion of this negligence are invariably seen in the failures of defence hardware components even during the present day, when there is so much advancement in technology.

There are different causes that singly or in combination contribute to failure of a component. The major causes of component failures are design faults, improper material selection, manufacturing defects, overheating, overload, fatigue, wear and erosion, corrosion, hydrogen embrittlement and stress corrosion cracking, improper/inadequate maintenance and improper handling/human error.

The objective of the monograph is to present how different causes trigger a failure and what remedial actions should be taken in order to prevent recurrence of similar failures in future. There are very few books where a reader can find investigations on real time failures of engineering

components. This is (a) due to lack of awareness among engineers and technologists about failure analysis and (b) due to very few professionals and bodies who carry out investigations of component failures. The field of failure analysis has also not found any kind of promotion either by the state or its funded engineering institutions, at least in this country. Being practicing failure analysts, it is therefore our responsibility to share experiences of real time component failure investigations. The present monograph is an effort by the author in this direction.

Today science and technology of materials have advanced to a great extent but failures do occur. To develop an understanding of, how components fail and what measures should be taken to avoid future failures, one needs references of case studies on component failures. A few available literatures in this field mainly discuss failures due to a single cause. Case histories found in literature are also not classified based on any category. The author has addressed both the issues while presenting case studies in the present monograph. The case studies are categorised based on major cause of failures. However, in a number of cases the reader can find failures taking place due to multiple causes pertaining to design, manufacture, maintenance and environment of exploitation.

The present monograph has been divided in to two parts. Part One introduces the subject of failure analysis to the readers followed by a chapter on mechanisms of fractures and fractography of metallic materials. The art of handling a failure case study can be understood by a chapter dedicated to steps, methodology, techniques and tools of failure analysis. It is pertinent to know what are the major sources, causes and mechanisms of metallic component failures in a hardware system, which are brought out with examples and illustrations in a separate chapter. Part Two, comprising the major portion of the present monograph, is a compilation of some typical case studies carried out by the author in his laboratory. The case histories presented are classified based on the cause of failure. The real time cases pertain to components of aircraft engine and structure, main battle tanks, weapons and weapon systems. The knowledge gained through case histories can help in understanding key factors that influence the properties, life and functioning of the component. It will also help in design, development and manufacture of components that will live the desired service. Bibliography will help the readers in locating reference books and literatures relevant to the subjects for further reading.

The monograph will be invaluable not only in creating an awareness in the field of failure analysis but also towards kindling an interest for the same in the minds of students, young practicing metallurgists and other engineering professionals engaged in the design, development, manufacture, and inspection of metallic components for various engineering and aerospace applications.

Dr KP Balan

Acknowledgements

I am indebted to workshop, chemical analysis, electron microscopy, metallography, electron probe micro analysis and mechanical behaviour groups of Defence Metallurgical Research Laboratory (DMRL), Hyderabad, for their support while carrying out failure investigations. I acknowledge my sincere thanks to the staff of Failure Analysis Group of DMRL for their assistance in specimen preparation and experimental work.

I am thankful to all previous Directors of DMRL, Hyderabad for encouraging me to practice failure analysis as a profession. I acknowledge my sincere thanks to Dr G Madhusudhan Reddy, Outstanding Scientist, Former Director and Dr R Balamuralikrishnan, Outstanding Scientist/ Scientist 'H', the present Director of Defence Metallurgical Research Laboratory, Hyderabad, for according permission to publish this monograph.

List of Acronyms

ACV	Air Compressor Vehicle
CMB	Centre Main Bearing
CVIS	Canisterised Vertical Integration System
EDAX	Energy Dispersive Analysis by X-Ray
EMRU	Electro-Mechanical Release Unit
EPMA	Electron Probe Micro Analysis
FNDA	Front Nozzle Diaphragm Assembly
HAZ	Heat Affected Zone
HPBP	High Pressure Bypass
HPCR	High Pressure Compressor Rotor
MBT	Main Battle Tank
SCC	Stress Corrosion Cracking
SE	Secondary Electron
SEM	Scanning Electron Microscope
TME	Tempered Martensite Embrittlement
VHU	Vertical Handling Unit
XRD	X-Ray Diffraction

PART – 1

General Principles and Practice

CHAPTER 1

Introduction

Failure analysis is an important field of engineering. The knowledge of failure analysis of metallic components should be of professional interest to engineers irrespective of their areas of expertise as metals and alloys constitute the most important materials in all engineering applications.

A component or a system is expected to meet its functional requirement over a total technical life with a specified reliability. A component or a system is said to have failed when it no longer is able to perform its intended function satisfactorily and becomes unsafe for its continued use. A failure is manifested in different forms, viz., breakage, crack, fracture, wear, distortion, corrosion or oxidation, etc. Apart from these, there can be many other forms of failure, which may not be that obvious but affect the utilization of the component with time. For example, a leakage in a pipe line or a tank carrying fluid is certainly a failure that needs an investigation and prevention. The siezure of a moving component in a machine due to distortion, lack of lubrication, etc., is another example of a failure. Tarnishing of surface due to environmental effects that mars the appearance of a component can also be considered as a failure.

A systematic and scientific analysis carried out in order to arrive at a cause of failure and also suggest suitable remedial measures to prevent occurrence of similar failures in future is called failure analysis.

Manufacture and utilization of a component in an assembly goes through several stages, viz., design, selection of material, processing, fabrication, acceptance tests, assembly, use and maintenance. Processing and fabrication are some of the stages in which the material encounters variations in working conditions. The working stresses may vary from static

to dynamic, the temperature may vary from sub-zero to elevated and the environment may vary from vacuum to extremely corrosive. Defects in any of the above stages of manufacture or use could be responsible for a failure.

Adequate knowledge in drafting the specification and following the protocol honestly are the two major factors that can avoid failures due to design, material selection, acceptance tests, assembly, use and maintenance of a component in a system. Human error is a major cause of failure related to these factors. Therefore, a failure analysis should aim at identifying the source that caused the failure. Suitable remedial measure has to be suggested as a solution to avoid recurrence of the failure.

It has been observed at times that a well designed, developed and fabricated system had failed due to failure of small components, viz., a nut or a bolt. Background information collected during investigation revealed that although much care was exercised during fabrication of the main system the same was not done for small components used for its assembly. The development team procures the small components from familiar vendors who source them from unknown agencies. It is later discovered during the course of failure analysis that adequate care regarding material, its cleanliness and coating were not taken in making these small components. Small scale industries where these components are made do not always stick to quality norms.

Component failures can paralyse functioning of major systems be it defence hardware or civilian plant, equipment and infrastructure. In both cases the loss due to failures will be immense and a big blow to the economy of a nation. The money, time and effort spent in carrying out a thorough failure analysis by experts in the field is worthy of the benefits reaped that needs no emphasis.

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About the Monograph

The objective of the monograph entitled 'Investigations on Failures of Defence Hardware Components: Fundamentals and Case Histories' is to present how different causes trigger a failure and what remedial actions should be taken to prevent recurrence of similar failures in future. There are very few books where a reader can find investigations on real time failures of engineering components especially those used in defence hardware. The present monograph is an effort by the author to fulfil this need.

The monograph is structured in to two different parts. Part 1 guides the readers through general principles and practice of the science and art of Failure Analysis. The major sources, causes and mechanisms of component failures in a hardware system are brought out with examples and illustrations in a separate chapter. Part 2 is a compilation of some real time case studies. The cases pertain to components of aircraft engine and structure, main battle tanks, weapons and weapon systems.

The monograph will be immensely useful for students, young practicing metallurgists and engineering professionals engaged in the design, development, manufacture, and inspection of metallic components for various engineering and aerospace applications.

About the Author

Dr KP Balan obtained his MTech, from IIT, Kharagpur and PhD from IT, BHU, Varanasi in Metallurgical Engineering. He has held the post of Scientist 'G' and Head of 'Failure Analysis Group' in DMRL (DRDO), Hyderabad. During a tenure of over three decades he has handled over 500 failure investigations pertaining to sensitive court of inquiries of accidents, components of defence hardware, railways, thermal power stations, mines, etc. The recommendations given by him have helped in avoiding future recurrence of similar failures. He has executed R&D projects pertaining to small arms barrels, pneumatic and hydraulic pipes for submarines and bearing steels for aerospace applications. He has also carried out metallurgical investigations of over 2000 metallic components of aircraft engine and structure, weapons and weapon systems for their indigenisation which have helped in self-reliance of the country in the stores of spares and accessories of expensive aircrafts and weapon systems.

He has been a member of some of the renowned national committees on Failure Analysis and Materials Standardisation. He has about 50 publications in national and international journals and conference proceedings on topics related to failure analysis and structure-property correlations in steels. He has made about 25 presentations on technical topics in conferences and workshops held within and outside DRDO.

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