Non-Destructive Evaluation of Solid Rockets and Missiles Systems

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Defence Research & Development Organisation
Ministry of Defence, New Delhi – 110 011

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We Wish to Dedicate
this Monograph
to the Fond Memories of
Our Parents

Contents

Synopsis

Non-Destructive Evaluation (NDE) is an indispensable tool in quality assurance programme of any engineering product and rockets and missiles are no exception. Due to their unique nature of functioning more stringent NDE methods are applied at every stage of their manufacture. Owing to their strategic importance, unlike in other industries, no published standards or codes are available especially in NDE area of Solid Rocket/Missile (SRM) motors. Thus, it has been always a bottle-neck and an intriguing issue in the production plants of Rocket/Missile motors, to inspect and assess their quality for end use. With an idea to provide an insight into the NDE aspects of SRMs, the authors with their rich experience behind, have undertaken the task of preparing this monograph. To the extent possible, the chapters are written in a structured manner as introductory general topics to SRM-specific sub-topics. While conventional NDE methods are covered in detail, advanced and state-of-the-art techniques are dealt-with illustrations. Emphasis is given to practical aspects of NDE for the benefit of shop-floor engineers/scientists. The authors believe that, in a way, the monograph would serve as a practical book to the NDT practitioners, especially to the newly inducted personnel who are entrusted with the task of NDE of solid rocket/missile motors.

Foreword

Space activities involve primarily Science, Technology, and Applications. The countries which have Space programs in all these three areas are very few. India is one of the six countries in the world, which have these capabilities of their own in the Space field. This distinction is achieved by India because of the efforts of two kinds of people–visionary leaders, and highly dedicated professionals. The dreams, visions, and practical targets of visionary leaders are achieved by thousands of professionals, each dedicated to his own field and striving for perfection. All these professionals in India who created Indian Space Research Organisation (ISRO) to the present level started practically from scratch and also mostly learning through doing. These professionals achieved successes of missions in very challenging conditions.

The success of any Space Mission–a Launch Vehicle, or a Satellite or a interplanetary mission, depends on functioning of thousands of systems, subsystems, and parts. There is nothing like "Partial Success" in Space missions, everything should work to 100 % perfection for the total mission to be successful. Hence, testing of different systems and parts and qualifying them on the ground is a big activity in Space field (which is not directly visible to the outsiders, or users of the Space systems and services). Practically, every part of the subsystems is qualified on the ground through thorough testing before integrating into the Space systems. The test facilities for ground testing of all these components and subsystems are vast in nature and testing facilities are as complex as manufacturing facilities. Hence, test and evaluation on the ground is a key element which ensures success of Space missions, be it either a big launch vehicle, or a satellite, or a payload carried by the satellite.

The subsystems which are part of launch vehicles or a satellite or missile get tested in the ground for functional and environment withstanding capabilities before they are assembled for the final mission. However, some exact flight systems or components which fly in a launch vehicle or a satellite cannot be tested on the ground. The examples are rocket stages, other propulsion elements, or stage separation systems, etc. These subsystems function once and only once during the flight. They must function 100 % perfect for the total mission to succeed. For example a solid rocket stage, which we popularly call as solid motor, has an igniter, propellant, nozzle, steel or composite casing, and insulations – all of these should function perfectly only once, that too in the flight. The testing of such subsystems and components on the ground to certify them as 'flight worthy' is the most challenging job. The equivalent models can be tested to evaluate the manufacturing process but still each stage which flies cannot be tested on the ground. This is where the relevance and importance of Non-Destruction Testing comes in to the picture in the Aerospace field. The NDT is widely used to certify solid propellant motors, motor cases, propulsion elements like Pyro systems, etc., before they are used for a mission. The NDT is also used to screen the material inputs and also to finalise manufacturing processes.

The NDT systems, testing procedures, evaluation standards, and the acceptance criteria evolved in ISRO through trials and experiments on experimental models and on actual flight components. They evolved only through practical experience, and through lessons learned. In this area, a lot depended on the expertise of individual professionals.

I am very happy the authors of the book are the professionals who spent all their career in developing NDT methods and evaluation procedures over forty years of their career in ISRO. Both of them contributed significantly for the missions under taken by ISRO. They have put down their experience and understanding into this book which is a good contribution for this complex area, and for future learning. The organisation of chapters in the book from the fundamentals to the latest techniques and testing methods look like going through the evolution of the authors themselves in their career.

The NDT contributes to the success of every Space mission. I confidently say that the authors, along with their teams, contributed a lot for every success of satellite missions and launch vehicle missions of ISRO. Through this book they are institutionalising their knowledge and experience. I enjoyed reading through this book, sometimes recollecting my own difficulties in

ISRO while taking tough decisions when there was no definite data available to take decisions. The NDT still continues to be partly technology, and partly art.

My high appreciation to the authors for bringing out this book, and best wishes for them to contribute more in the future.

Dr MYS Prasad
Vice-Chancellor,
Vignan's Foundation for Science, Technology & Research
(Deemed to be University),
Former Distinguished Scientist (APEX) ISRO, &
Former Director, Satish Dhawan Space Centre, Sriharikota

Place : Guntur

Foreword

Rockets and Missiles are single shot devices demanding highest mission reliability. Solid Rocket motors are critical subsystems and hence to be designed and manufactured with adequate quality requirements. Quality control and quality assurance plays crucial role in design and processing of Rocket motors. Non-Destructive Testing and Evaluation is the essential tool to ensure the quality of Rocket motors before they are integrated with launch vehicle or missile. It is also required to monitor the health of missiles during their deployment periodically by NDE. Any flaw in the propellant or casing will lead to disastrous consequences during the mission. Many NDE tools are available, viz., X-Ray, Ultrasonic, Acoustic Emission, Thermo Vision, Neutron Radiography, etc. Many are complimentary/supplementary in inspection of Propellant, Casing and Pyro devices in rocket motors. The Technology of NDT involves Methodology, Equipment, Quality Assurance methods, Quality control standards, etc. No standard book exists so far which will address holistically all the NDE methods and techniques.

India is self reliant in Solid Rocket Motor Technology both in Space and Defence sectors due to visionary leadership of people like Dr Vikram Sarabai, Dr VR Gowarikar, Dr APJ Abdul Kalam, Mr MR Kurup, Dr Rajaram Nagappa, Mr MC Uttam and others. Solid Rocket Motors up to 3.2 M diameter and 205 T propellant weight for GSLV-LVM3 were developed for Space application. Varieties of propellants with varied compositions and burn rates as high as 40 mm/sec and Rocket motors with metallic and composite casings were developed in DRDO for various Tactical and Strategic systems like Akash Surface-to-Air missile, Nag 3rd generation anti- tank missile, AGNI missiles up to range of 5000 km, submarine launched systems like B-05 and K-4. Without the development of NDE technology, it would not have been possible for development of these rocket motors for Space and Defence.

Shri K Viswanathan was the Head of NDE group in SHAR Centre in ISRO. He was instrumental in Developing various NDE techniques and standards for Non-Destructive testing of Rocket motors in ISRO and there by contributed immensely for development and production of Solid Rocket Motors for SLV, PSLV, GSLV and many other missions in ISRO. I have no doubt in saying that he is the authority in the field of NDE in India. I was fortunate to associate with him right from 1980 onwards. In my initial days in DRDO I was involved in indigenous development of Propellant for PECHORA missile and development of propellant for Booster for Pilotless Target Aircraft. The propellants were vibration tested in SHAR, Sriharikota as part of their qualification process. The propellant grains are to be NDT tested before and after vibration. Shri K Viswnathan's NDT group has helped in doing this in his facility. I personally had understood the technology of NDE during this exercise and various discussions I used to have with him.

Mr Sai Suryanarayana has also vast experience in this field and worked with Mr Viswanathan in the NDT group for many years. He has associated with him in the development of NDE techniques for solid motors and their sub-systems.

In the monograph, the authors have explained various types of NDE techniques, their advantages and limitations in chapter 2. This will be useful for selection of the appropriate technique depending on the size and type of article to be tested. Technical details of each technique and comparison of the capabilities to detect the flaws and discontinuities are presented nicely. For NDE of large rocket motors more than 1 M diameter, high energy machines like LINAC and Betatron are required. They dealt with these systems in chapter 3. Metallic casings and composites casings also are to be tested for NDE before they are offered for propellant processing. Weld defects in metallic casings are critical. In composite casings defects like delaminations, de-bonds, humps, depressions, voids, resin rich and resin starved regions, cracks and foreign material inclusions are common. Rocket motors are to be proof pressure tested after their fabrication. Acoustic emission technique is used to study the growth of flaws during pressurisation. These aspects are dealt with in chapter 4 and chapter 8. Selection of parameters like double wall or single wall, type and size of film, grain shots, tangential shots, exposure time, Image Quality Indicators, etc., are to be done before carrying out NDE by X-ray of propellants and motors. These details are covered in chapter 5. Digital radiography is common now to reduce the time, wide coverage and saving the cost of films. Manipulator is another equipment to be designed for manipulating the position of article during X-Ray. In chapter 6, these topics are also included. Tomography is another technique to find out the radial and depth location of critical defects in small grains. This aspect is detailed in chapter 7. NDE of pyro devices by Neutron Radiography is presented in chapter 9. Characterisation of defects are very important to assess their impact on performance, which is covered in chapter 10. Acceptance criteria and failure modes is another aspect in addition to Selection and use of equipment which is dealt by the authors in chapter 11. These are very valuable informations that were given out of wide experience of the authors in this field.

One of the present limitation is to evaluate the health of the bond between propellant and inhibition by ultrasonic technique as X-Ray technique is not foolproof. This is being developed both in DRDO and ISRO. This also is covered in chapter 12 in addition to advanced NDE methods like Microwave, Digital Shearography, Holography.

Thus, this book is a beautiful narration of NDE technologies for inspection of Solid Rocket Motors in holistic manner and probably the only book available in the market globally.

I am delighted to go through this book "NDE of Solid Rockets and Missile Systems" and recollect my memories of journey of Development of Solid Rocket Motors for Tactical and Strategic Systems in DRDO including failures and successes I experienced.

I am sure this book will be a standard monograph and good reference in NDE and will be useful to budding Propellant and Rocket Scientists and Engineers in their pursuit of developing solid rocket motors for future advanced missions in ISRO and DRDO.

Dr A Subhananda Rao
Former Director, HEMRL & DG, DRDO

Preface

NDE plays a very important role in the quality evaluation and qualification of almost all industrial products world over. The history of NDE is centuries old as our forefathers and great grandfathers used this technique in the selection of products, the fine example being the inspection of Earthen pots by tapping and observing the acoustic emission. However, with the advancement in modern industries, the inspection and product qualification requirements became complex and challenging. This paves way for innovation and invention of advanced and newer NDE technologies.

Initially, there were only six major NDE techniques, viz., Visual, X-Ray, Ultrasonic testing, Eddy Current Testing, Magnetic Particle Testing and Dye Penetrant Testing. However, with the industrial revolution now there are more than 30 NDT techniques available. NDE is not only used for product qualification but also for in-process and stage inspection, raw material screening, etc.

Some of the main uses of NDE are:

- Defect/flaw detection, characterisation and evaluation.
- Estimation of physical and mechanical properties.
- Determination of chemical composition.
- Characterisation of structures and micro structures.
- Stress measurement, etc.

NDE is commonly applied in many cases and some of them are:

- Inspection of raw materials/components.
- Evaluation of process operations like annealing, heat treatment, welding, etc.
- Condition monitoring in process industries.

- By giving a timely feed-back, helping in correcting/improving process operations.
- Product development, etc.

Missiles and rockets are no exception to the requirement of NDE and in fact they are ought to be more stringent. In every missile or rocket, there are thousands of systems and sub-systems and they have to perform precisely according to prediction. From the time, a rocket or a missile takes off from the launch pad and by the time the satellite is injected into the orbit or the warhead is delivered, it takes only a few minutes. In those few minutes, all the systems and subsystems have to perform precisely to the predication at their designated moment. Otherwise, the mission will be a failure. It is here, NDE plays a crucial role in assessing and determining the quality of all the components and subsystems to ensure the predicted performance most reliably.

There is no standard book or a reference manual on NDE of missiles and rockets and even if it is available, they are classified and inaccessible. Hence, we undertook the task of writing a monograph with our rich experience in this field to serve as a guideline document for the practitioners of NDE in these industries. Besides, it will be very helpful in enhancing the knowledge of the young scientists/technicians working in the field of NDE in the Defence and Space programmes. We believe that, as we have dealt with some typical case studies and elucidated certain practical aspects of the NDE of solid rocket motors and missiles, it would be beneficial to the NDE practitioners in these specialised areas.

K Viswanathan
Sai Suryanarayana

Acknowledgements

It was in March 1970, when late Dr Gowarikar (former Director VSSC and Secretary DST), the then Project Leader for establishing one of the largest Solid Propellant Plants (SPROB) at Sriharikota, called me (first author), to his cabin and threw a challenge to prepare a project report for the NDE of huge solid boosters to be produced at SPROB. It was really a big challenge because the solid propellant plant itself was the first of its kind in the country, leave alone the NDE aspects. I just joined Propellant Engineering Division (PED) of the then Space Science and Technology Centre (SSTC) of ISRO, after my graduation from IIT, Madras in Chemical Engineering. That challenge made me to go deep into the subject of NDE and he supported me strongly and motivated throughout my work. That helped me to become an expert later on, in the field of NDE particularly for the qualification of huge solid rockets and missiles and their subsystems. Thus, it is the first and foremost responsibility to thank from my deep heart and acknowledge Dr Gowarikar's motivation and support.

I would also like to immensely thank Sh PD Mujumdar, the then Principal Technical Officer of SPROB for his guidance and encouragement during the crucial period of establishment of NDT facilities and thereafter in the day to day work. Sh MC Uttam and late Sh SK Athithan, former Deputy Directors of SPROB had confidence in my ability and supported me all through my tenure at SPROB. I offer my sincere and heartfelt thanks to them.

Late Sh MR Kurup, former Director SDSC, SHAR had special interest in NDE Technologies and was mainly responsible for the indigenisation of High Energy Linear Accelerator in the country. He always motivated us and had been ever helpful in our pursuit to be experts in this vital field and our sincere thanks to him.

In the preparation of this monograph, we have drawn support and information from our former colleagues in the NDT facility of SPROB, both serving and retired. First and foremost, we would like to convey our special thanks to Sh C Subbiah, for sparing his valuable time in providing inputs and reviewing the Chapters. We would also thank profusely Sh K Venkata Rao, Sh PK Chaturvedi, Sh G Ramesh Babu, Sh VN Misale, Sh B Muniratnam, Sh KM Reddy, Sh M Ramesh, Sh R Viswanathan Sh Manikantan, Sh PVS Kurmanath, Sh B Karthikeyan, Sh B Srinivasa Rao, Sh V Ramesh Babu and the other NDT technicians Sh Hanumantha Rao, Sh Raghaviah, Sh P Subramanyam Reddy and Late Sh Munaswamy. The authors are grateful to Dr SV Subba Rao, former Associate Director, SDSC SHAR, for his useful discussions, especially on Acoustic Emission Techniques.

We would like to thank the DRDO and VSSC and CMSE Scientists for their valuable information and inputs in the preparation of this monograph, particularly, Dr Bikash Ghosh of HEMRL for his valuable inputs in the field of Digital Radiography and advances in the NDE of solid motors, Dr C Muralidhar and Sh P Subramanian of Directorate of NDE, DRDL for their useful information on Computed Tomography, Dr K Srinivas, Sh SK Sahoo of ASL for their inputs in MWNDE and ultrasonic testing and to Dr Ranganathan, Structures group, VSSC, for his valuable input in the area of propellant grain failure modes. The authors also express their sincere thanks to Sh VK Ravindran, Sh Sekar Nataraj, Sh Somanathan, Dr Achuthananda Parhi, Sh S Sridhar, Sh S Hari Krishna (Composites Entity), Sh V Eswaran and Sh G Levin of VSSC for sharing information and providing suggestions whenever sought. Special thanks are also due to Sh PJ Abraham, retired Group Director, VSSC, for providing information and useful discussions in person.

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We also would like to thank the Chairman ISRO and all the Directors of VSSC and SDSC, SHAR for their support and encouragement during our tenure in ISRO and also for the valuable information of this monograph.

Dr K Nageswara Rao, Director DESIDOC, DRDO and his colleagues have done everything possible to make this publication a reality. We convey our sincere and special appreciation to Mrs Anitha Saravanan, Mrs Kavita Narwal, Mrs Alka Bansal, Mr NK Chawla, Mr Rakesh Kumar, Mrs Gunjan Bakshi and the entire editorial team of DESIDOC, for ensuring the quality of manuscripts, tables and figures in a professional way.

We express our sincere gratitude to Dr MYS Prasad, DS and former Director, SDSC, SHAR, who always has shown special interest in NDE activities and played a pivotal role in establishing key facilities in SDSC SHAR. We convey our special thanks to Dr Prasad for his kind gesture of consenting to write foreword for this monograph. Dr Subhananda Rao, DS and former Director, HEMRL has always encouraged and motivated us to write this monograph. In addition, he has given valuable inputs, suggestions in the preparation of this book and has kindly consented to give his foreword. We are deeply indebted to him.

We would like to thank Mrs Divya Muralikrishnan (daughter of 1st author), for her untiring effort to enter some of the chapters manuscripts, figures and tables and for formatting them. We also convey our special thanks to Mr D Shiv Prasad and Mrs Spandana (son-in-law and daughter of the second author) for helping in the preparation of the text and adaptation of figures during the course of preparation of the manuscript. We express deep gratitude to Sh PLN Murthy and Dr P Krishnaveni (brother and sister of the second author) for their constant encouragement and guidance all-through. We also would like to thank Prof Rajaram Nagappa (author of the monograph on "Evolution of Solid Propellant Rockets in India") for inspiring us to undertake this project.

We would like to thank M/S Varian, USA; Waygate technologies, Germany; ASTM International, Elsevier Publishing Company; Electronic & Engineering Co., Mumbai and Indian Society for Non-Destructive Testing (ISNT) for permitting us to use some of their information, figures, graphs, etc., from their publications. We would also like to thank all the authors (especially, S/Sh Thakkar, Karthikeyan, AVSSSR Sarma, Nitin Ahire, Sambamurthy, P Revindran, C,B, Kartha, Kumar and Behra) of various articles and publications, from where we shared data/information and references made in the Monograph.

Above all, we also want to thank our life-partners Mrs Usha Viswanathan (wife of K Viswanathan) and Mrs Sathya (wife of Sai Suryanarayana) for

their encouragement, patience, helping in writing the manuscript and keeping us company in late hours during the course of the preparation of this monograph.

Finally, we are very thankful to the authors of all the references made in this monograph as this monograph will be mainly used for educational purposes of the young scientists and NDT technicians in carrying out their assignments. Last but not the least, we also acknowledge the unknown sources from where the references are made.

K Viswanathan
PV Sai Suryanarayana

List of Acronyms

µ	Linear Absorption Co-efficient
A/D	Analog to Digital
ADR	Automatic Defect Recognition
AERB	Atomic Energy Regulatory Board
AET	Acoustic Emission Testing
AFNOR	Association Francaise de Normalisation (French National Organization for Standardisation)
ALARA	As Low As Reasonably Achievable
AMS	Aerospace Materials Standard
ASM	American Society for Metals
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
AUS	Acousto-Ultrasonic System
BB	Broad Beam
BIS	Bureau of Indian Standards
B-KNO3	Born Potassium Nitrate
BPI	Beam Purity Indicator
BS	British Standard
CCD	Charged Couple Device
CCTV	Closed Circuit Tele Vision
CPMG	Carr-Purcell-Meiboom-Gill
CMOS	Complementary Metal Oxide Semiconductor
CP	Carbon Phenolic
CR	Computed Radiography
CRT	Cathode Ray Tube
CT	Computed Tomography
DAC	Distance Amplitude Correction

dB	Decibel
DIN	DeutschesInstitut fur Normung (German Institute for Standardization)
DIS	Digital Imaging System
DPT	Dye Penetrant Testing
DR	Digital Radiography
Dy	Dysprosium
ECT	Eddy Current Testing
EN	European Norm (European Standard)
FBH	Flat Bottom Hole
FFD	Focus to Film Distance
FFT	Fast Fourier Transform
FPD	Flat Panel Detector
FPS	Film Positioning System
GFRP	Glass Fibre Reinforced Plastic
He-Ne	Helium–Neon
HNDE	Holographic Non-Destructive Evaluation
HVL	Half Value Layer
IIW	International Institute of Welding
In	Indium
IP	Imaging Plate
IQI	Image Quality Indicator
IRT	Infra Red Testing
ISNT	Indian Society for Non-Destructive Testing
ISO	International Standards Organization
KV	Kilo Voltage
L/D	Length to Diameter ratio
LCD	Liquid Crystal Display
LDA	Linear Detector Array
LED	Light Emitting Diode
LF	Loose Flap
LINAC	Linear Accelerator
MEOP	Maximum Expected Operating Pressure

MeV	Million Electron Volts
MMI	Man Machine Interface
MOUSE	MObile Universal Surface Explorer
MPT	Magnetic Particle Testing
MWNDE	Microwave Non-Destructive Evaluation
NB	Narrow Beam
NC	Nitro Cellulose
NDE	Non-Destructive Evaluation
NDT	Non-Destructive Testing
NMR	Nuclear Magnetic Resonance
NR	Neutron Radiography
OEWG	Open-Ended rectangular Wave Guide
PETN	Penta Erythritol Tetra Nitrate
PLC	Programmable Logic Control
PMT	Photo Multiplier Tube
PoD	Probability of Detection
PPT	Proof Pressure Testing
PSL	Photo-Stimulated Luminescence
QA	Quality Assurance
QC	Quality Control
RDX	Research and Development Explosive or (1,3,5 – Trinitroperhydro – 1,3,5-Triazine)
RF	Radio Frequency
RPM	Revolutions per Minute
RT	Radiographic Testing
RTR	Real Time Radiography
S/N ratio	Signal to Noise ratio
SFD	Source-to-Film Distance
SNT-TC	ASNT standard for Personnel Qualification
SNR	Signal to Noise Ratio
SRM	Solid Rocket Motor
TBI	Through Bulkhead Initiator
TFT	Thin Film Transistor

TLV	Threshold Limit Value
TPS	Thermal Protection System
Ug	Geometric Un-sharpness
Ui	Inherent Un-sharpness
UT	Ultrasonic Testing
UTM	Universal Testing Machine
UV	Ultra Violet
General :	
ACEM	Advanced Centre for Energetic Materials
ARDE	Armament Research and Development Establishment
ASL	Advanced Systems Laboratory
BARC	Bhabha Atomic Research Centre
DRDL	Defence Research and Development Laboratory
DRDO	Defence Research and Development Organisation
HEMRL	High Energy Materials Research Laboratory
ISRO	Indian Space Research Organization
NFC	Nuclear Fuel Complex
SDSC SHAR	Satish Dhawan Space Centre SHAR
SFC	Solid Fuel Complex
VSSC	Vikram Sarabhai Space Centre

CHAPTER 1

Introduction

1.1 NEED FOR NDE AND ITS EVOLUTION IN SPACE/MISSILE PROGRAM

For any engineering component quality assurance is mandatory before putting it into its intended use. Initially during the process of manufacturing, the raw materials, intermediate products and their ancillary components undergo the prescribed QC/QA procedures followed by NDE of the finished products. Unlike in other engineering products, rocket and missiles components, besides process QC checks, are also to be subjected to stringent screening and QA by NDE methods at every stage of manufacture as these Space components perform only once. This is to say that the rocket and missile launch is a one-shot affair. Especially the solid rocket motors once fired have to perform precisely as per their specifications as they cannot be easily controlled or shut off after ignition. Thus there is a tremendous demand on NDE methodologies to evolve suitably to deliver a defect-free product. Due to their complex shape, size and configuration, the NDE of solid rocket and missile motors is highly challenging task. Thus it calls for appropriate planning and execution of NDE at every particular stage of manufacture so that the required quality of the final product is assured.

To achieve this goal, the feasibility of applying appropriate NDE technique is considered at the design stage itself. Thus the complexity of various configurations can be mitigated to ensure that the end product is amenable to NDE techniques, yet not compromising the launch mission requirements. This calls for knowledge of NDE for design engineers as well as involvement of NDE experts in the planning and design stage itself of the component so that ultimately a defect-free end product is delivered.

In fact the advent of Space era forced the introduction of the concept of Probability of Detection (PoD) of defects and incorporation into the design requirements. PoD concept and associated methodologies are getting wide spread importance of late, and enabling continual improvements in the process and products. This concept not only assures quantification of NDE capabilities but also enables utilisation of wide range of NDE techniques to ensure integrity of critical Space and Missile components.

In the earlier days, only visual and dimensional checks besides conventional NDT were employed to qualify components and materials of rockets/missiles. However, when the space/defence programs grow, the size of rockets/missiles become huge with complex assemblies and newer materials, necessitating the use of advanced NDT techniques/machines. This paves way for introduction of advanced ultrasonic technique, acoustic emission testing, high energy radiographic facilities, Real Time Radiography (RTR), Digital Radiography (DR), Computed Tomography (CT), Neutron Radiography (NR) besides improvements in signal processing, defect characterisation and analysis.

In the present scenario, the design of the solid rocket case hardware is based on fracture mechanics criteria and it requires detection of very tight crack. Suitable ultrasonic testing technique has been evolved with the help of various R&D and academic institutions of the country for the above purpose. Acoustic Emission Testing (AET) was also introduced during proof-pressure testing of hardware to detect any growth of an existing crack which escaped detection in the initial inspection of the motor case or nucleation of a new crack under pressurised condition. The satisfactory completion of Proof Pressure Testing (PPT) and the real-time monitoring of the rocket hardware (case) by AET during PPT, assures the reliable performance of the case within Maximum Estimated Operating Pressure (MEOP) and in turn the solid rocket propellant that contained in the hardware. Due to their high strength to weight ratio, composite materials are also used in the construction of lunch vehicles and their subsystems. Besides conventional X-radiography, and Ultrasonic Testing (UT), infrared thermography and dry coupling ultrasonic testing are also introduced for the NDE of these components. Ultrasonic testing is also used for determining the elastic constants of composite materials.

The RTR was developed to detect any crack in the propellant grain as the orientation of the crack with the X-ray beam is very important for

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About the Monograph

Non-Destructive Evaluation (NDE) is an indispensable tool in quality assurance programme of any Engineering product and Rockets and Missiles are no exception. Due to their unique nature of functioning more stringent NDE methods are applied at every stage of their manufacture. Owing to their strategic importance, unlike in other industries, no published standards or codes are available especially in NDE area of Solid Rocket/Missile motors. Thus, it has been always a bottle-neck and an intriguing issue in the production plants of Rocket/Missile motors, to inspect and assess their quality for end use. With an idea to provide an insight into the NDE aspects of SRMs, the authors with their rich experience behind, have undertaken the task of preparing this monograph. To the extent possible, the chapters are written in a structured manner as introductory general topics to SRM-specific sub-topics. While conventional NDE methods are covered in detail, advanced and state-of-the-art techniques are dealt-with illustrations. Emphasis is given to practical aspects of NDE for the benefit of shop-floor engineers/scientists. The authors believe that, in a way, the monograph would serve as a practical book to the NDT practitioners, especially to the newly inducted personnel who are entrusted with the task of NDE of solid Rocket/Missile motors.

About the Authors

Shri K Viswanathan joined Indian Space Research Organisation (ISRO), then Space Science and Technology Centre (SSTC), Thumba, Tiruvanandapuram in 1969 after graduating in Chemical Engineering from IIT Madras, Chennai. He was immediately inducted into the core project team to establish one of the largest solid propellant plants at Sriharikota, AP. He has contributed significantly in the conceptual design, detailed engineering, plant layout, equipments finalisation, procurement, installation and successful commissioning of the plant in 1977. There, he was involved in the productionisation of large solid boosters of different sizes weighing from 3T to 150T for ISRO's launch vehicles, their quality control & assessment and testing programs. He held various key positions before becoming GM in 1998 and later on elevated to the position of Dy Director of the Space Centre. He retired in 2008 after 40 years of distinguished service for ISRO. He has acquired expertise in Non-Destructive Testing/Evaluation of space components as part of reliability and quality assessment of solid motors, nozzles, motor cases, igniters and other related subsystems. He was instrumental in the development of NDE methodologies and standards for the critical inspection of huge solid rocket motors and related sub-systems in SDSC SHAR.

He has presented and published more than 100 Plenary/Keynote/Technical papers in national & international conferences and journals and has won many national and international Awards/Honors. He is a Honorary Fellow of ISNT, Australian Institute of High Energy Materials (AIHEM) and High Energy Materials Society of India (HEMSI). He is responsible for the preparation of BIS Standard on "Recommended practice in thermal Neutron Radiography".

Shri PV Sai Suryanarayana has more than 38 years experience in the NDT systems for qualification of all solid rocket motors, related components like nozzles, igniters, and other critical items used in Indian Space Programme. One of the key team members responsible for establishing and commissioning of the first-ever Accelerator-based System for Neutron Radiography of pyro components employed in Space Missions. Jointly won NRDC award and WIPO Gold Medal for "Development of accelerator-based system for Neutron Radiography of Space pyro components". Also awarded Team Excellence Award for contributions to Mars Orbiter Mission (MoM) in 2015. He has more than 60 technical papers presented in various National/International seminars/conferences and published in journals. Co-authored a book on "Practical Neutron Radiography" which is used as prescribed course material under IS-13805. He is a Life Member of many professional institutions/societies such as ISNT, ASI, HEMSI, ISSE.

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