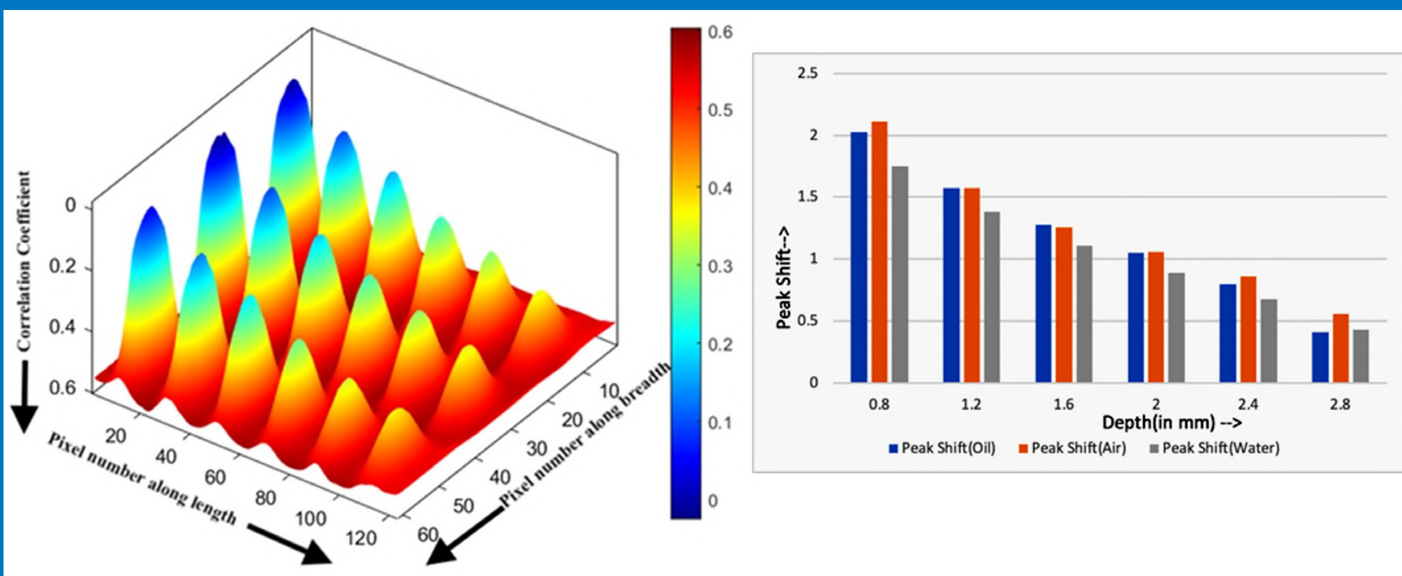
Journal of
nde
Non Destructive Testing and Evaluation

ISSN 0973 - 9610

September 2022
Volume 19 ● Issue 3

An Official Journal of the Indian Society for Non Destructive Testing



If Undelivered Return To :

Indian Society For Non-Destructive Testing
Module Nos.60 & 61,
Readymade Garment Complex,
Sidco Industrial Estate,
Guindy, Chennai-600032.
Tel: 044-22500412

An ISNT Publication

www.isnt.in

Indian Society for
ISNT
Non Destructive Testing

ORGANISED BY

INDIAN SOCIETY FOR
NON-DESTRUCTIVE TESTING

NDE 2022

NOVEMBER 24-26, 2022

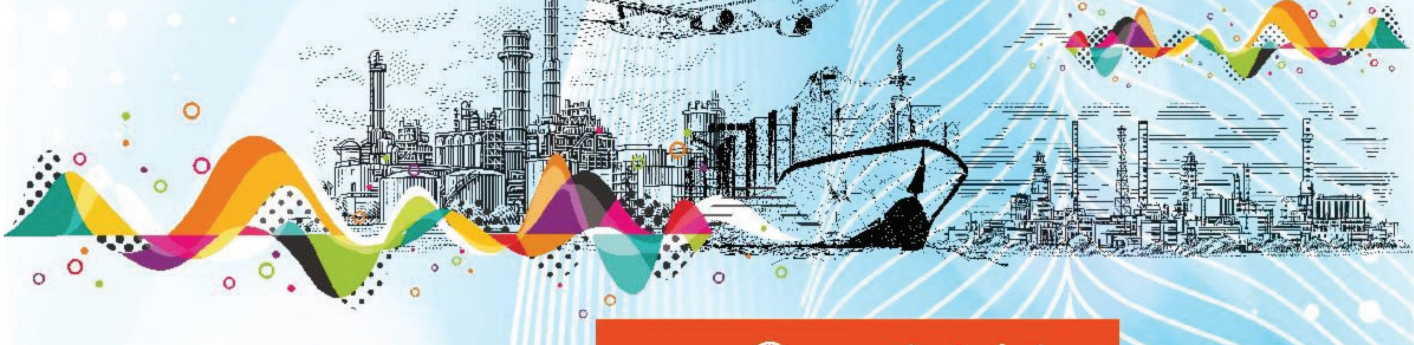
Conference & Exhibition on

NON DESTRUCTIVE EVALUATION

24-26
NOV 2022

Mahatma Mandir
Convention & Exhibition
Centre

GANDHINAGAR, GUJARAT



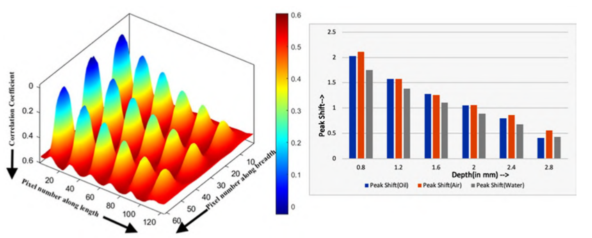
FOR MORE INFO www.isntnde.in

Contents

Journal of NDE — Non Destructive Testing and Evaluation

SEPTEMBER 2022
Volume 19 - Issue 3

on the COVER Page



COVER PAGE - depicts the detection capabilities of the correlation based pulse compression image obtained from the thermal data used as training set (left) and the variation of peak shifts with depth for three different types of inclusions (right).

OBJECTIVE - This Journal of Non Destructive Tesing & Evaluation (JNDE) is published quarterly by the Indian Society for Non Destructive Testing (ISNT) for promoting NDT Science & Technology. The objective of this Journal is to provide a forum for dissemination of knowledge in NDE & related fields. Papers will be accepted on the basis of their contribution to the growth of NDE Science & Technology.

PUBLISHED BY: Mr. Bikash Ghose - Managing Editor, JNDE

For JNDE Subscription / Advertisement / New / Renewal of ISNT Membership Inquiries Contact:
Indian Society for Non-Destructive Testing (ISNT)
Modules 60& 61, 3rd Floor, Readymade Garment Complex,
SIDCO Industrial Estate,
Guindy, Chennai - 600 032, India
Tel: 044-2250 0412 / 4203 8175 Email: headoffice@isnt.in

PRESIDENT TALK

DIWAKAR JOSHI
President – ISNT
president@isnt.in

Dear Friends

Greetings!

At the outset let me greet all of you on the 75th Anniversary of India's Independence!

I am sure you all have either attended or gone through the U tube link of the beautiful Webinar organized by ISNT on 15th August, 2022. I am certain that this online program, with twenty-plus experts in their respective areas delivering their talks, was of great interest to the listeners.

June 22 issue of JNDE was well received by the readers; thanks to the Editorial board in releasing this issue in time.

As usual our Training and Certification activities are showing an upward trend. I am happy to inform you that the mandatory authorization of Chapters and Training centres by Training Management Board (TMB) has started from 16th August, 2022 and a few chapters and training centres are already on board. This is a very important step taken by ISNT to standardize the Training activity throughout the country.

The chapter activities are showing good progress in the last few months, and the webinars, workshops training programs and certifications conducted by different chapters are really worth appreciating.

We all know ISNT works through dedicated and passionate individuals, which is our biggest strength. These people are experts, with multiple talents and knowledge. We are really speaking about an excellent pool of resources. But maybe we can add still better value to any field of working when we channelize these resources through team work. We in ISNT are thinking of many innovative things to make ISNT a leading society in the world, where the NDT community and the society at large will be benefited. Your feedback and suggestions on this are always welcome.

As an event, the Annual Conference and Exhibition of ISNT is the biggest, with networking, knowledge sharing and latest technology on the display; filled with NDT to the fullest extent, and with international reach. The upcoming Annual Conference and Exhibition will be from 24th to 26th November 2022 in Gandhinagar, Gujarat and I am sure we all will be meeting there.

This September 2022 issue deals in a few out-of-the-box ideas that are of significance to the NDT community. One paper covers reliability evaluations of the NDE techniques used in India, in comparison to those performed in the western countries, with data of POD done for better understanding of the subject. Another paper details the application of Infrared Thermography on the high voltage lamp assembly in the periscope used in Prototype Fast breeder Reactor, to investigate the thermal distribution across the fin with different coolant flow rates. One paper deals into the use of NDT in medical field, using active thermography with iron oxide nanoscale biomaterial to detect bone density. Another paper introduces a revolutionary device built to achieve superresolution ultrasonic imaging with the use of conventional transducers.

It is really a pleasure to see papers of such caliber in our journal. Such wonderful topics reconfirm ISNT's technical superiority, and throws open further challenges to the NDT thinkers.

I am sure the issue will be of a great interest to our readers!

I thank all authors, the editorial board, advertisers and the whole team for keeping up the momentum!

Diwakar D. Joshi
President
president@isnt.in

MANAGING DIRECTOR TALK

BIKASH GHOSE
Managing Editor, JNDE
me.jnde@isnt.in

Another exciting issue of JNDE is now on the table.

This issue of JNDE presents four exciting original papers on Reliability evaluations for the future of NDE 4.0 in India, Temperature measurement on periscope assembly, thermography with effective biomaterial for Bone Density Diagnosis and development of a device for achieving super-resolution ultrasonic imaging using conventional transducers. Authors are now invited to submit their original research articles to JNDE through the online portal of JNDE http://jnde.isnt.in. The online version of the journal will soon have the ISSN number, and it is planned to have the DOI number for each journal article.

The chapter activities section summarizes the activities conducted by various chapters in the last three months (Jun – Aug 2022).

ISNT has celebrated the Azadi Ka Amrut Mahotsav and conducted a memorable and thrilling webinar on "Role & Journey of ISNT in Nation Building" on 15th Aug 2022. The brief of the event is also part of this issue. The recording of the exciting webinar is now available at https://isnt.in/isnt-webinar-calendar/ for interested readers.

The preparation of NDE-2022 to be conducted at Mahatma Mandir Convention and Exhibition Center (MMCEC), Gandhinagar, Gujarat, INDIA, from 24th -26th November 2022, is in full swing. Get an update on the landmark event at www.isntnde.in.

Profuse thanks to all the advertisers and contributors of this issue to be released on time. Thanks to Dr Ravibabu Mulaveesala for readily agreeing to be the guest editor for the September 2022 issue.

Happy reading!!

Bikash Ghose
Managing Editor, JNDE
me.jnde@isnt.in

GUEST EDITOR'S TALK

DR. RAVIBABU MULAVEESALA
Guest Editor, JNDE
Email: mulaveesala@sense.iitd.ac.in

This volume of the Journal of Non-destructive Testing and Evaluation (NDT&E) contains research articles within the common denominator of Testing and Evaluation methods, in particular for inspection studies for characterization andreliabilityof various components/materials used in nuclear, defence, manufacturing and biomedical industries. This issue tried to demonstrate the breadth of applications for which one can use NDT&E, together with very recent research developments, some clear demonstrations of the method at work in applications and some of the necessary background theory that underpins the basic testing techniques.

The aim of this issue is to provide a snap-shot of state-of-the-art research from wide selection of key researchers involved in this area from various researchand academicinstitutes. Contributors have also been encouraged to submit high standard relevant articles that act as a review of their own work up to the current boundaries of their focused research specialization.

I am sure that the readers will find theissue as highly informativeand useful reference. Finally, I would like to thank all thecontributing authors for providing their valuable piece of research work to this issue. It has been a great pleasure for us to prepare thisissue and we hope that you will enjoy its reading as much as we enjoyed its preparation.

Dr. Ravibabu Mulaveesala
Email: mulaveesala@sense.iitd.ac.in

CHAPTER Chairmen & Secretary

Ahmedabad Chapter
Shri Hemant Kumar
Chairman– ISNT-Ahmedabad Chapter
Head – Reliability Static
CAB-1st Floor, SEZ Refinery,
Reliance Industries Ltd, VP-CES,
Jamnagar-361142, Gujarat, India,
(Off)+91 288 6621826 / Mobile:0'9998215033
hemantk.kumar@ril.com / hemant.ril2013@gmail.com

Shri Jayesh Prajapati
Secretary– ISNT-Ahmedabad Chapter
CEO, Ultratech Engineers, 28, N.K. Industrial Park Part-1,
Bakrol-Dhamatvan Road, Bakrol (Bujrang), Ahmedabad-382430
Mobile: 9824396155
jayeshprajapati82@gmail.com

Bangalore Chapter
Shri Shashidhar P. Pallaki
Chairman- ISNT-Bangalore Chapter
CEO, Pallakki NDT Excellence Center
No-411, A, 4th Phase, Peenya Industrial Area
Bangalore – 560058 / Cell: 0'9448060717
pallakki@pallakkindt.com

Shri Prakash Balasubramanian
Hon. Secretary, ISNT-Bangalore Chapter
Mb:9845192860
prakash@sasthascientific.com

Chennai Chapter
Shri RG. Ganesan
Chairman- ISNT -Chennai Chapter
Chief Executive,
BETZ ENGINEERING & TECHNOLOGY ZONE,
Door # 21, Dharakeshwari Nagar,
1st Street, Sembakkam, Tambaram to Velacherry Main Road, .
Chennai – 600 073
Mb: 9840175179
rg_ganesan@yahoo.com

Shri P. Anandan
Hon. Secretary, ISNT-Chennai Chapter
Technical Manager & NDT Level-III
Scaanray Metallurgical Services, Plot C-12,
Industrial Estate, Mogappair West, Chennai – 600 037
Mb: 9884036985
ap@scaanray.com

Coimbatore Chapter
Shri P. Murali
Chairman, ISNT- Coimbatore Chapter
Mb: 9443491823
murlinaveen@gmail.com

Shri A. Rathinam
Hon. Secretary, ISNT-Coimbatore Chapter
Cell:0'9843011031
everestndt@gmail.com
isntcoimbatorechapter@gmail.com

Delhi Chapter
Shri Raj Kumar Singh
Chairman, ISNT-Delhi Chapter
Cell : 0'9312433853
rajinspection001@gmail.com

Shri F. Siddiqui
Hon. Secretary, ISNT-Delhi Chapter
541/2, Group-I, Hastal, Uttam Nagar,
New Delhi – 110059
Cell: 0'9811466220
isntdelhi@gmail.com / delhindt@yahoo.com

Hyderabad Chapter
Dr S.K Jha
Chairman, ISNT Hyderabad Chapter
Chairman & Managing Director of Midhani
Mob: 9100033949
skjha@midhani-india.in

Dr Phani Surya Kiran
Secretary, ISNT Hyderabad Chapter
Mob:8106609567
kiranmps@gmail.com

Jamshedpur Chapter
Dr. Sarmishtha P Sagar
Chairman, ISNT-Jamshedpur Chapter
Chief Scientist & Group Leader, NDE & MM Group,
Advanced Materials & Processes Division
CSIR-National Metallurgical Laboratory
Jamshedpur 831 007/ Phone: 0657 2345023(O), 9431521144(M)
sarmishtha.sagar@gmail.com / sarmi@nmlindia.org

Dr. A K Panda
Hon. Secretary, ISNT- Jamshedpur Chapter
Senior Principal Scientist, Non-Destructive Evaluation & Magnetic Materials, (NDEMM) Group, Advanced Materials & Processes (AMP) Division
CSIR-National Metallurgical Laboratory, Jamshedpur 831007
Phone (O) : 0657-2345002, 9431569804(M)
akpanda@nmlindia.org

Kalpakkam Chapter
Shri S. Athmalingam
Chairman, ISNT Kalpakkam Chapter,
Associate Director, HSEG & Head - QAD
IGCAR, Kalpakkam - 603 102
Ph: 044-27480071/27480500 (Ext.23490)
Cell:0'9444501819
athma@igcar.gov.in

Shri M.V. Kuppusamy
Hon. Secretary, ISNT Kalpakkam Chapter
Head-QA Projects Section
Quality Assurance Division, SQ & RMG,
IGCAR, Kalpakkam 603 102
(Off) Phone:044-27480500 Extn. : 22388
Cell:0'8056090071
masikuppu@igcar.gov.in

Kochi Chapter
Shri Sathyan V
Chairman, ISNT- Kochi Chapter
SM (Project), Bharat Petroleum Corp. Ltd. (Kochi Refinery)
PO Ambalamugal 682 302, Ernakulam, Kochi
0484-2822109 (O)
Cell:0'9446086345
sathyanv@bharatpetroleum.in

Shri Sibi Ignatius
Hon. Secretary, ISNT-Kochi Chapter
BPCL Kochi Refinery,
Ambalamugal 682302, Ernakulam, Kochi
Ph. No. 0484-2821121 / Cell:0'9446385611
sibiignatius@bharatpetroleum.in

Kolkata Chapter
Shri Dipankar Gautam
Chairman, ISNT- Kolkata Chapter
AB 121, Salt Lake, Kolkata – 700 064
Ph. No. 033 23581072
Cell: 98048 13030 / 98302 03223
dgautam1956@gmail.com / dipankargautam@yahoo.co.in

Shri Sreemoy Saha
Hon. Secretary, ISNT- Kolkata Chapter
No. 123 Ramlal Agrawal Lane
Megdoot Apartment, Block A, Flat 2B,
Kolkata 700050.
Cell: 9830291416
sreemoy4u@gmail.com

Kota Chapter
Shri S.K. Verma
Chairman, ISNT- Kota Chapter
NPCIL, PO - Anushakti,
Via - Kota (Raj) - 323 307
Cell:0'9413356402
surendrakverma@npcil.co.in

Shri Ranjeet Singh Rajpurohit
Hon. Secretary, ISNT Kota Chapter
Scientific Officer-E, -Quality Assurance Section
Rawatbhata Rajasthan Site, Unit 3&4
Nuclear Power Corporation of India
Ph. No. 01475-242052
Cell:9413358189
rsrajpurohit@npcil.co.in

Mumbai Chapter
Dr. P.P. Nanekar
Chairman–ISNT Mumbai Chapter
Head, Post Irradiation Examination Division
BARC, Trombay, Mumbai – 400 085
Off: 022-25594867 / 25564258
Cell: 0'9892161750
pnanekar@barc.gov.in / paritoshn@yahoo.com

Shri Samir K. Choksi
Hon. Secretary, ISNT - Mumbai Chapter
Choksi Imaging Ltd., 4 & 5, Western India House,
Sir P. M. Road, Fort, Mumbai- 400 001
Ph. No. 022-2610 1113 / Cell: 0'9821011113
Choksiindia@yahoo.co.in

Nagpur Chapter
Shri Jeevan Ghime
Chairman, ISNT-Nagpur Chapter
M/s. Becquerel Industries Pvt. Ltd.
33, Rushikesh Modern Co-op. Hsg. Society
Ingole Nagar, Wardha Road, Nagpur - 440005
Cell: 0'9822565879 / jeevan@biplndt.com

Shri Parag W. Pathak
Hon. Secretary, ISNT - Nagpur Chapter
M/s. NDT Solutions Saket - Pruthvi Appt
Plot No-. A+ B, Second Floor, Surendra Nagar, Nagpur - 440015
Cell: 0' 7709047371/ paragwpathak@yahoo.com

Pune Chapter
Shri Jayaprakash Hiremath
Chairman –ISNT Pune Chapter
C2, 301, Woodsville Phase 1,
Borhadewadi , Near Gail Pump
House, Moshi, Pune, Maharashtra, 412105
Mb: 9423569802
hiremath@tuv-nord.com

Shri Rahul Kulkarni
Hon. Secretary –ISNT Pune Chapter
C / O - KQSPL, Plot No. 55, Scheme
No. 4, Sector No. 4, Yamunanagar, Nigdi, Pune- 411044
Mb: 9822547797
hon.secretaryisntpune@gmail.com / rahul.kulkarni@kqspl.com

Sriharikota Chapter
Shri B. Munirathinam
Chairman, ISNT Sriharikota Chapter
General Manager, QCCF, SPROB&SPP
Sriharikota – 524124
(Off) Phone:08623-225711
(Mobile):0'9490439735 / bmuni@shar.gov.in

Shri V. Rajasekhar
Hon. Secretary, ISNT Sriharikota Chapter
Chapter Sci/Eng.-SD, NDT, SPP,
SDSC – SHAR, Sriharikota – 524124
Off) Phone:08623-225923 / (Mobile):0'9989898932
rajasekhar.v@shar.gov.in /vrajasekhar55@gmail.com

Tarapur Chapter
Shri Vinay Thattey
Chairman, –ISNT Tarapur Chapter
Scientific Officer H+ and Training Superintendent ,
Tarapur Atomic Power Station -1&2 ,
Nuclear Power Corporation of India Limited
Type A-2/21, Anushri Township, PO: TAPP,
TAL & DIST.: PALGHAR, PIN -401 504, MAHARASHTRA STATE,
Cell: 9423982722 / vthattey@npcil.co.in

Shri S. K. Acharya
Hon. Secretary –ISNT Tarapur Chapter
Scientific Officer, Tarapur Atomic Power Station 1&2 ,
Nuclear Power Corporation of India Limited
Type A-2/21, Anushri Township, PO: TAPP,
TAL & DIST.: PALGHAR, PIN -401 504, MAHARASHTRA,
Cell: 8552000192
skacharya@npcil.co.in /skacharya17@gmail.com

Trichy Chapter
Dr. T Gurunathan
Chairman, ISNT -Trichy Chapter,
General Manager/Quality & BE,
BHEL/Trichy, Tamilnadu, PIN-620014
Mobile: 9442627082 /Ph-0431-2575877
tguru@bhel.in

Dilip Kumar Singh
Hon. Secretary, ISNT -Trichy Chapter,
Deputy Manager/ATP-NDTL Quality
BHEL/Trichy, Tamilnadu, PIN-620014
Phone: 0431-2575826 / Mb:7845462025
isnt.trichy@gmail.com / dksingh@bhel.in

Trivandrum Chapter
Dr. Mohan Kumar L
Chairman-ISNT- Trivandrum Chapter
GENERAL MANAGER, ROCKET PROPELLANT PLANT,
VSSC, ISRO P.O. THIRUVANANTHAPURAM, PIN – 695 022
Ph. No. 0471-256 3822 (O)
Mob. No. 94461 77376
l_mohankumar@vssc.gov.in / lmkdrn@yahoo.com

Shri Girish N Namboodri
Hon. Secretary, ISNT- Trivandrum Chapter
SCI/ENGR SE, NDTF/RPP,
VSSC, ISRO P.O. THIRUVANANTHAPURAM-PIN – 695 022
Ph. No. 0471-256 2599/3340
Mob. No. 75618 39768
girish.nampoothiri@gmail.com / isnttvm@gmail.com

Vadodara Chapter
Shri R. Venkatasubramanian
Chairman-ISNT-Vadodara Chapter
C/o Industrial X-Ray and Allied Radiographers India Pvt. Ltd.,
C-17 / 78, Krishana Industrial Estate,
Opposite to BIDC, Gorwa,
Vadodara – 390 016 Gujarat, India
(O) 0265 – 2280756 / Mb: 9825244941
rmani1511@gmail.com / chairmanisntvc@gmail.com

Shri Kashyap Niranjan Bhatt
Hon. Secretary, ISNT - Vadodara Chapter
Rushikesh Engineering Resources
306, Vrajsiddhi Tower, Market Char Rasta,
Rajmahel Road, Vadodara: 390001
GUJARAT, INDIA.
(Mb:) 9825245886
info@rushikeshengg.com / secretaryisntvc@gmail.com

NGC/NCB Members

NATIONAL GOVERNING COUNCIL (NGC)

1. Shri Diwakar D. Joshi
President
Mb- 9822263475
president@isnt.in

2. Dr. Krishnan Balasubramaniam
President Elect
Mb: 9840200369
balas@iitm.ac.in

3. Dr. Jaiteerth R. Joshi
Vice President
Mb: 9440049272
joshidrdl@gmail.com

4. Shri Rajul R. Parikh
Vice President
Mb: 9820192953
rajulparikh@eecindia.com

5. Dr. M.T. Shyamsunder
Vice President
Mb: 9880508266
mandayam.shyamsunder@gmail.com

6. Shri Bikash Ghose
Hon. Gen. Secretary
Mb: 91 9890127524
secretary@isnt.in

7. Shri R. Vivek
Hon. Jt. Secretary
Mb: 9840023015
vivek@electromagfield.com

8. Shri Nerurkar K.A
Hon. Treasurer
Mb: 9822525518
treasurer@isnt.in

9. Shri S. Viswanathan
Hon. Co-Treasurer
Mb: 9894945482
viswa@igcar.gov.in

10. Dr. B. Venkatraman
Immediate Past President
Ph: (Off) 044-27480240
qadbvr@gmail.com

11. Dr. R.J. Pardikar
Past President
Cell: 9003096843
r.j.pardikar@gmail.com

MEMBERS

12. Shri Anil V. Jain
13. Shri Anandan. P
14. Balamurugan. S
15. Shri V. Deepesh
16. Shri Dharmveer Singh
17. Shri R.G. Ganesan
18. Prof. S. Gopalakrishnan
19. Shri S. Hari Krishna
20. Shri P. Mohan
21. Shri Mukesh Arora
22. Ms. Menaka. M
23. Ms. Navita Gupta
24. Shri Bhausaheb K Pangare
25. Shri Partha Pratim Brahma
26. Dr. Ravibabu Mulaveesala
27. Shri Ravindran S.R
28. Shri Sadasivan. N
29. Shri Samir K. Choksi
30. Shri G. Surya Prakash (Co-opt)
31. Shri Raja Narendra Mallampati (Co-opt)
32. Shri Shashidar Pallaki
33. Shri M.S. Shendkar
34. Shri Uday Kale
35. Shri Umakanthan Anand
36. Shri R. Venkatasubramanian
37. Shri M.N.V. Viswanath

Permanent Invitee:

38. Shri G. Ramachandran

PAST PRESIDENTS

39. Shri V.R. Deenadayalu
40. Shri K. Balaramamoorthy
41. Shri A. Srinivasulu
42. Shri K. Viswanathan
43. Shri S. I. Sanklecha
44. Shri Dilip P. Takbhate
45. Dr. P. Kalyanasundaram
46. Shri V. Pari
47. Shri D.J. Varde

Ex-Officio members

48. Dr. P. P. Nanekar, Chairman, NCB
49. Shri V. Manoharan, Chief Controller of Exams
50. Prof. Krishnan Balasubramaniam,
President, QUNEST Fdn.

NATIONAL CERTIFICATION BOARD (NCB)

1. Dr. Paritosh P. Nanekar
Chairman, NCB
Bhabha Atomic Research Centre
Chairman.ncb@isnt.in

2. Shri M.V. Kuppusamy
Hon. Secretary, NCB
Indira Gandhi Centre for Atomic Research
secretary.ncb@isnt.in

3. Shri V. Manoharan
Chief Controller of Examinations, NCB
Principal Technologist
VisiConsult-X-Ray Systems & Solutions
coe.ncb@isnt.in

4. Shri S. Viswanathan
Hon. Treasurer, NCB
Indira Gandhi Centre for Atomic Research
treasurer.ncb@isnt.in

Members

5. Shri G.V. Shiva Rao, DRDL, Hyderabad
6. Shri A.K. Das, National Thermal Power Corporation Ltd
7. Shri S. Ramakrishnan, Brakes India Ltd.
8. Shri Umakanthan Anand, Reliance Industries Ltd.
9. Shri Tushar Mukherjee, Reliance Industries Ltd.
10. Shri Anand Bagdare, Godrej & Boyce Mfg. Co. Ltd.
11. Shri Sathyan. V , BPCL Kochi Refinery
12. Shri Sanjay Narang, Larsen & Toubro Ltd.
13. Shri Raghvendra. P, Larsen & Toubro Ltd.
14. Shri Jayaprakash Hiremath, TUV India Pvt. Ltd.
15. Shri Uday Kale, KUB Quality Services Pvt. Ltd.

Potential NCB authorized Examination Center

16. Shri R.G. Ganesan, ISNT Chennai Chapter
17. Shri N. Sadasivan, ISNT Mumbai Chapter
18. Ms. Navita Gupta, Satyakiran School for NDT, Delhi

Ex-officio Members

Shri Diwakar D. Joshi, President, ISNT
Shri Bikash Ghose, Hon. Gen. Secy., ISNT
Prof. Krishnan Balasubramaniam,
President-Elect, ISNT
Dr. B. Venkatraman, Immediate Past
President, ISNT
Dr. M.T. Shyam Sunder, Chairman, TMB
Shri Partha Pratim Brahma,
Controller of Authorisation, TMB

CHAPTER ACTIVITIES For the period from July 2022 to Sept 2022

BENGALURU

Technical programme is planned on 17th September 2022.

EC-Meeting conducted on 02nd July 2022.

AGM Conducted on 23rd July 2022.

EC Meeting planned on 27th Aug 2022.

JAMSHEDPUR

UT II Re-exam conducted on 18th & 19th August.

KOLKATA

UT Level II – IS 13805 Certification Programme was conducted. 05 candidates attended Course started from 22 august, Exam on 5 & 6 Sep 22.

KOTA

Re-examination of Eddy current Testing level- II and Ultrasonic Testing level-I&II certification course (From 23.08.2022 to 24.08.2022)

MUMBAI

PT samples was provided to BARC for PT Examination.

UT samples was sent to Rajasthan, Kota for Examination.

LPT and UT Samples was provided to Satyakiran Delhi.

EC Meeting – 06th Aug, 2021. 14 members attended the meeting.

TRIVANDRUM

Technical Talk on the topic, "Recovery and Reuse of Rocket Stages" by Shri J Paul Murugan, Deputy Project Director, Test Vehicle Project, VSSC Through Online Platform on 16.07.2022

Inauguration by Director, VSSC

EXERTUS CIRCA 80

Se-75 Close Proximity Projector

SILFLEX SHIELDING MATERIAL

EXERTUS DUAL 120

Ir-192 & Se-75 compatible Projector

REPLACEMENT SOURCES

IRIDIUM 192	COBALT 60	SELENIUM 75

SPEC-150

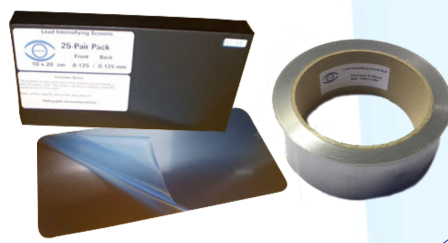
Iridium-192/Se-75 Projector

SPEC-300

Cobalt-60 Projector

LASER INDUSTRIAL X-RAY FILM & CHEMICAL

RADAC LEAD INTENSIFYING SCREEN



TELEDYNE ICM GO-SCAN C-VIEW REAL TIME X-RAY INSPECTION

TELEDYNE ICM CPSERIES & CP BATTERY PORTABLE X-RAY GENERATORS

CHOKSI Quality Our Passion

CHOKSI ASIA PRIVATE LIMITED

Ground Floor, Choksi Bhuvan, Nehru Road & Nariman Road, Vile Parle (E), Mumbai - 57

+91 90224 45544 / 93228 94243 choksindt@gmail.com www.choksi-asia.com

spec SOURCE OF QUALITY | LASER X-Ray Film & Chemical | Silflex SHIELDING | TELEDYNE ICM Everywhereyoulook | RADAC | oserix

CHAPTER ACTIVITIES For the period from July 2022 to Sept 2022

Conducted Seminar and Exhibition on NDE and Allied Methods- SENDAM 2022 on 29th and 30th July 2022. The theme of the seminar was "Advances in NDE and Mechanical testing". Around 120 participants attended the program which was conducted at VSSC premises.

Inaugural Address by Director, VSSC

Release of Souvenir of SENDAM 2022 and Image Newsletter

Inauguration of Exhibition by Director, IISU & IIST

ARORA

ISO 9001: 2015 Certified Company

Manufacturing
of NDT Products & Accessories

Distribution
of NDT Solutions

Automated
Systems

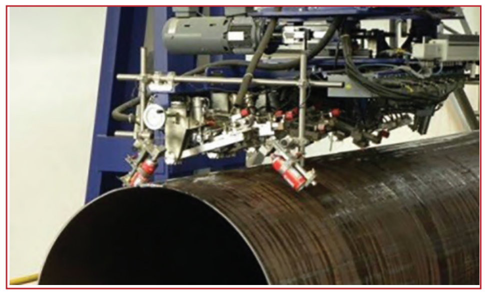

LED UV Lamps


Ultrasonic Phased Array


Radiography Systems

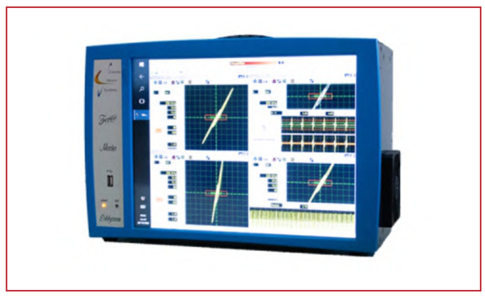

MPT/LPT Chemicals


Permanently Installed Sensors


Ultrasonic Systems


Film Viewers & Densitometer


Wire Rope Tester


Eddy Current Systems

Arora Technologies (P) Limited
Plot No. D-183/8, MIDC, TTC Nerul, Navi Mumbai, Maharashtra 400706, India
T: +91-22 6138 0600, 2770 3913 | E: info@arorandt.com | W: www.arorandt.com

CHAPTER ACTIVITIES For the period from July 2022 to Sept 2022

TIRUCHIRAPALLI

LEVEL-II Programs-As per SNT-TC-1A 2016 of ASNT

1. FOR WRI - PSG TRAINEES-2022
   - 01.06.2022 to 05.06.2022 - Magnetic Particle Testing
   - 06.06.2022 to 26.06.2022 - Radiography Testing
   - 18.05.2022 to 21.05.2022 - Ultrasonic Testing

Workshops / Lectures Program Conducted

1. Additive Technology - a step towards Smart Manufacturing
2. AWARENESS CAMPAIGN
3. Productivity Improvement in Pre Weld, Post Weld using Induction Heating Solutions. S.W.AT accelerating GTAW 10x productivity.
4. Manufacturing Process Inspection.

SEMINAR

1. 25-06-2022, A seminar conducted on Advance Ultrasonic in association with M/s Evident and M/s Blue star.
2. SENDAM 2022 Seminar & Exhibition on NDE & Allied Methodology EC Meeting Held on 11-05-2022.

OTHERS

Membership addition: 1 LIFE MEMBER Added

ISNT DAY CELEBRATIONS & TECHINICAL SEMINAR: 25.06.2022

GLIMPSE OF SEMINAR

In association with M/s Evident and M/s Blue star On 25-06-2022

A seminar conducted on Advance Ultrasonic

VADODARA

ISNT Vadodara Chapter EC Committee meeting had on 02-July-2022.

AGM of ISNT Vadodara Chapter has planned on 10-September-2022.

PUNE

EC meeting No. 6 Conducted on dated 09.07.2022

TRAINING MANAGEMENT BOARD

TRAINING MANAGEMENT BOARD

Office Bearers

Dr. M.T. Shyamsunder- Chairman
Mr. S. Harikrishna-Hon. Secretary
Mr. Partha Pratim Brahma-Controller of Authorisation

Members :

Ms. Navita Gupta
Mr. N. Sadasivan
Mr. Mincheri Ravi
Mr. Thamanna Ravikumar
Mr. M. Manimohan
Ms. Sangita Kapote
Mr. Arbind Kumar
Mr. Chintamani Khade
Mr. R.V.S. Mani
Mr. Anandan Pari
Dr. R.J. Pardikar
Mr. V. Pari

Ex-Officio Members

President, ISNT
President Elect, ISNT
Hon. Gen. Secretary, ISNT
Hon. Treasurer, ISNT
Immediate Past President -ISNT
Chairman –NCB
Chief Controller of Exams –NCB

Training Management Board (TMB) – ISNT

Over the last three decades, the training and certification activities of ISNT have been coordinated mainly by the National Certification Board (NCB) of ISNT, especially for the IS 13805 scheme, where BIS had authorized ISNT to be the sole body for this purpose. With NCB-ISNT getting formal accreditation by NABCB in accordance with ISO 17024 for initiating a new scheme based on ISO 9712 and having an international reach in the name of International Certification in NDT (ICN), it also became imperative that the training and the certification activities have to be operated independently to avoid conflict-of-interest and confidentiality issues. In view of this, ISNT has decided to form a Training Management Board (TMB) with the below-given objectives and scope,whose sole responsibility would be to manage all the training related activities and policies for the certification schemes of ISNT.The National Governing Council (NGC) of ISNT has formally approved the formation of TMBin the meeting held on 29th January 2022, and it was put in place immediately thereafter with a set of 15 members and 7 Ex-Officio members.

Objectives of TMB

Training

- Standardize and Harmonize the Content, Quality and Delivery of Training courses (leading to certification) being conducted by any authorized entity under the ISNT banner
- Key focus on Level 1, 2 and 3 certification courses being conducted by ISNT Chapters and Other Institutes
- Act as a nodal agency for addressing all NDT/Inspection related special Training needs of the Indian industry

Authorization of Training Centre's

- Streamline and create a Robust process to establish Authorized Training Centres (ATC) for IS13805 and ICN across the country (and abroad if needed) to help spread ISNT's schemes more widely

Scope

- Training activities related to IS13805 certification
- Training activities related to ICN certification
- Any Special Training programs of interest and relevance to be organized by ISNT based on current trends OR on request from Industry to help spread NDE Science and Technology across the country
- Developing, implementing and executing the method and process of Authorizing Training Centre's for both IS 13805 and ICN
- Establishing a self-sustaining model for revenue generation for continued operations and growth of TMB

INDIAN SOCIETY FOR NON – DESTRUCTIVE TESTING
NDT AWARDS-2022

- ISNT Invites nominations/ applications for the National NDT Awards-2022 from Indian Nationals for their significant contributions and excellence in the field of NDT and the Best Chapter award from all the chapters of ISNT.
- An announcement to this effect is already circulated to eligible members / chapters.
- The various categories of awards are listed in every issue of the JNDE.

All these Awards will be declared to the individual Awardee through email and also announced in the official website of ISNT (www.isnt.in).

As this year's **Annual Conference & Exhibition in NDE (NDE 2022)** is **scheduled to be held at Gandhi Nagar, Gujarat from November 24 - 26, 2022, a**ll these Awards will only be given during the inaugural session of the NDE 2022.

- **These Awards will comprise of a Certificate and a Cash Award.**
- The prescribed Application form can be downloaded from https://isnt.in/isnt-awards/
- **Soft copy of the duly filled-in application may be sent only to awards@isnt.in on or before by 31st October 2022.**


MR®
CHEMIE
has recieved the AMS 2644 approval
& is now listed in the
QPL SAE AMS 2644
CELEBRATING
50
YEARS
MAGNETIC PARTICLE TESTING
• EN ISO 9934-1
• ASME Code V, Art. 7
• ASTM E1444/1444M
• PMUC (EDF)
• RCC-M
• ASME Boiler & Pressure Vessel Code
• AS 4792
• TLV 9612 01
• Low in Halogens & Sulphur according to EN ISO 9934-2
• AMS 2641
• AMS 3040
• AMS 3041
• AMS 3042
• AMS 3043
• AMS 3044
• AMS 3045
• AMS 306
DYE PENETRANT TESTING
• ASME Code V, Art. 6T-641
• AMS 2644
• QPL SAE AMS 2644
• EN ISO 3452-2
• EN ISO 3452-5
• EN ISO 3452-6
• PMUC (EDF)
• TLV 9017 01
• NPCIL
GERMAN
TECHNOLOGY

Reliability Evaluations for the future of NDT/NDE4.0 in India

Vamsi Krishna Rentala[1,*], Daniel Kanzler[1,], Phani Mylavarapu[2,***], Johannes Vrana[3,****]**
[1]Applied Validation of NDT (AV-NDT), Berlin, Germany
[2]Defence Metallurgical Research Laboratory (DMRL), NDTG, Hyderabad, India
[3]Vrana GmbH, Rimsting, Germany
Email: *RentalaV@av-ndt.com, **KanzlerD@av-ndt.com, ***phanimylavarapu.dmrl@gov.in, ****johannes@vrana.net

Abstract

Usage of non-destructive testing or evaluation (NDT/E) techniques is widely accepted across various industries all over the world in order to maintain certain safety and quality standards. However, not many countries really perform the reliability evaluation of their NDT techniques. In this context, this article discusses the importance of reliability evaluations and state of reliability programs performed in India versus the reliability activities performed in the western countries. In addition, brief results from one of the POD programs carried out at DMRL are also presented for understanding the challenges involved in pursuing reliability programs in India. Moreover, remarks on the possible direction of POD especially under the context of transforming the industry towards NDE 4.0 were made.

KEYWORDS: NDT, Reliability, Probability of Detection, NDE 4.0

1. Motivation

Quality assurance approaches and in specific non-destructive testing or evaluation (NDT/E) methods are within the most unloved things within a modern production line or within maintenance operations. From a superficial point of view the feeling is understandable: It is impossible to imagine the world safety without the implementation of varied inspection protocols such as NDT. Specifically, in the case of NDT, there are a lot of costs (repair, scrapping, etc.) and in spite of which accidents happen day in and day out. Therefore, the perennial question which arises is "Why should anyone do NDT? ".

The answer is as easy as obvious: Because without NDT a modern world could not exists. A modern production company could not stand a chance and a modern infrastructure would break down may not be on day One. But it will fail all around the world. This is basically a question of luck and time. Annals of history do present the NDT community with worldwide examples indicating the importance of NDT [1].

Two accidents in aviation industry almost brought Malaysian Airlines to their knees [2]. Similarly, two incidents did cost Boeing almost $1 bn [3]. The Surfside accident in 2021 [4] at Florida, USA focused more on importance of testing in civil engineering. Amidst all these, 5 deadly accidents of MIG-21 in India within the last 1 and ½ years continuously haunts the regulators in terms of fleet reliability and maintenance [5].

Not in every accident NDT is the solution, but in a lot of it. It is the cheapest way to stay alive as a company and as a country. However, for this to happen, industry is often posed with an essential question: "How good is the method being used?" or more specifically: "How well does the NDT perform?".

By choosing a possible answer to these intruding queries in a modern company/organization/facility, etc., there is a decent chance to transform a cost issue in to a treasure resulting in delivering a product which is competitive with the best technology companies in the world. Performance in NDT was defined with the term reliability: "the degree that an NDT system is capable of achieving its purpose regarding detection, characterization and false calls" [6].

And in all of them the discussion rather than being about an estimated magnitude of sizes, revolves around an objective which is aimed to determine probabilistic characteristic for a specific application. The most familiar one is the Probability of Detection. The only characteristic which allows estimating the capability of a system either to detect or not detect the critical defect in an application. No Thumb-rule, standard, has the power to evaluate the true status after NDT. Due to this characteristic, the switch from safe-life application approaches to slightly pragmatic damage tolerance models is possible, a movement, which allowed to save billions of dollars in just a decade. For the benefit of the user, in safe life approach, conservatively it is assumed that 1 in 1000 components may have a crack after its intended life, whereas in damage tolerance based approach, presence of undetectable crack is assumed and inspection intervals which are safe for detecting them is predicted.

However, this approach usually comes with a price:

a) Cost involved in learning the capabilities of the NDT application

b) Cost involved in assessing and discussing them in probabilistic terms

c) Finally, cost involved in thinking out of the typical technical box and the very basic need to start understanding statistics.

Therefore, in this article, an attempt is made to show this august NDT community, an ideology which is being practiced regularly in a large area of industrial sectors in Europe and the USA, for companies such as Porsche, Airbus, different Railway Companies in Europe (SBB, Deutsche Bahn, Trenitalia, etc) and which can pay rich dividends if implemented in India.

The authors would like to request the reader to just invest a paltry time for reading the article and further build up his/her own mind. This may be an essential approach as about 5 decades ago, the USA had an issue with their F-111 which is very similar with what being faced by India today with the MIG-21. Their solution was the reliability evaluation. Therefore, in a lot of quality issues – "reliable NDT" rather than "just NDT" is the solution.

2. Introduction

Ever since the start of industrial revolutions, non-destructive testing (NDT) techniques play a major role in terms of safety of the components, products or the complete assets of the industries. However, outcomes of any NDT technique have lot of uncertainties in providing consistent results. For example, when different numbers of flaws of same size are inspected, the NDT outcomes have different detection probabilities. Alternatively, repeated inspections of same flaw also do not provide consistent hit (detected) or miss (not detected) indications. Hence, it can be noted that the NDT outcomes are influenced by several uncertainties and are probabilistic in nature. This kind of probabilistic nature of NDT outcomes as well as its capability and reliability are well studied using probability of detection (POD) techniques.

These POD studies can be carried out using both non-parametric and parametric based approaches. The non-parametric POD approaches are based on binomial distributions for example, the 29/29 method [7] etc. However, these methods are highly dependent on very large number of sample sizes for obtaining reasonable confidence bounds on the POD curve. Under the absence of large number of samples, parametric based POD functions such as a log odds function or cumulative log normal distribution functions can be used [8]. However, these parametric methods are mainly divided in to two types, namely, the binary [8, 9] and the signal response [8] methods depending on the type of NDT outcome i.e., either qualitative or quantitative. In the case of NDT techniques producing qualitative outcome in terms of the binary responses such as the "1 or HIT" (defect detected) or "0 or MISS" (defect undetected) (in case of penetrant inspection, magnetic particle, etc.), HIT-MISS methods are used. In the case of NDT techniques producing quantitative outcome in terms of a signal response such as an amplitude (in case of Ultrasonic inspection) or volt (in case of eddy current inspection), â (signal response) vs. a (defect size) approaches are used. POD curves can be generated using either of the approaches i.e., hit-miss or signal response methods and the outcome of a POD curve is the $a_{90/95}$ (reliably detectable crack size with 90% probability and 95% confidence) value. This $a_{90/95}$ value helps in taking right decisions for approving components during inspection, identifying maintenance schedules, etc and is obtained from the intersection of the lower 95% confidence curve of the POD curve at 90% probability level as shown in Figure 1 [10].

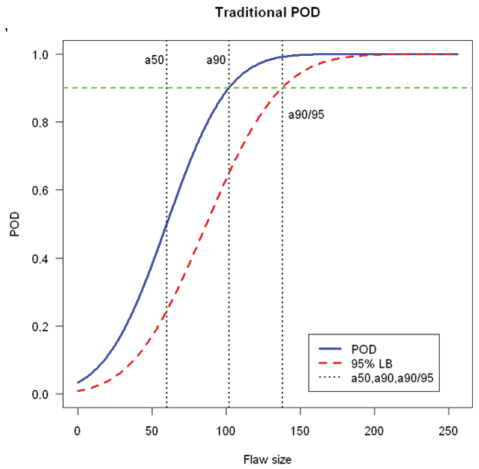


Fig.1: POD curve showing a50, a90 and a90/95 points [10]

2.1 Global (Western) Scenario towards POD Concepts

As part of the NASA space shuttle program and the US Air force programs for implementing damage tolerance concepts, initial reliability studies for understanding the probabilistic nature and capabilities of NDT techniques have been developed in the early 1970's. These reliability studies have been carried out using POD methods and are initially confined to the aviation industries. After the initial attempts on POD activity by NASA, several other POD related projects such as SISTAE [11], PICASSO [12], etc. were carried out in different industrial sectors. Apart from the aviation industry, these POD concepts were also well recognised for several other different fields of applications such as the nuclear, oil and gas, railways, automotives, civil engineering, etc. in the western countries. Eventually, this has led to the development of several standards and documents for carrying out POD studies for evaluating the capabilities of NDT techniques. Some of the most famous standards on POD concepts include, the

Berens POD models from 1989 [8], MIL-HDBK 1823 [13] and 1823A [9], ENIQ reports [14], ASTM [15] standards, etc. By the year 2004, a dedicated group named as the model assisted POD (MAPOD) group came into existence for carrying out POD activities by using model-based methods. The major outcome of these POD studies is the a90/95 (detecting a flaw with 90% probability and 95% confidence) metric, which is typically used for the critical information under the damage tolerant concepts. In addition to the damage tolerant applications, this POD information is also used for qualifying NDT techniques, procedures, NDT inspection personnel, etc.

2.2 Indian scenario towards POD concepts:

Even though Western countries were successful enough to generate POD curves for damage tolerance assessment from the early 1970's, no such effort was in place in India even till 2013. This can be either attributed mainly due to the limited understanding of the importance of POD studies or due to the lack of proper expertise in the field, specifically for generating POD curves. Further, these POD studies require huge number of representative samples and are considered to be laborious, time consuming and costly tasks. Considering the extreme importance of this procedure on life revision studies for aero platforms, in 2013, an indigenous effort was initiated at Defence Metallurgical Research Lab (DMRL), a R&D laboratory under the Defence Research and Development Organization for understanding the worldwide accepted and followed approaches for generating POD curves for the systems, equipment's and materials. The main goal of the exercise was to further extend it to techniques, equipment's and materials used within Indian Armed Forces.

During this initiative, several efforts have been carried out for estimating the POD of NDT techniques in terms of both experimental and model-based approaches. In addition, efforts have also been carried out in terms of estimating the remnant life calculations by using the POD information produced from these studies. Apart from many other challenges, these POD studies mainly rely on the representative samples comprising of laboratory generated fatigue cracks at DMRL mimicking those originating from the bolt hole locations of an aero-engine turbine disc. By using these representative cracks, POD of penetrant and eddy current inspection techniques have been estimated under the laboratory scenario [16]. In addition, proper statistical methodologies have also been well demonstrated using model-based procedures in the case of ultrasonic inspection technique. Parallelly and independently, around the same time, CNDE at IIT Madras have also initiated POD related projects which mainly confined to the development of model-based studies and in order to achieve this task ultrasonic testing was chosen as a representative metric [17].

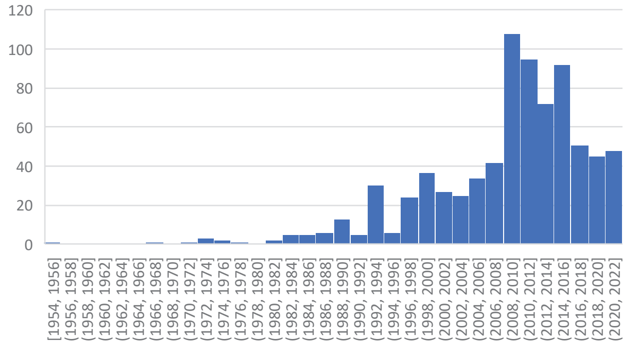


Fig.2: POD publications in the field of NDE [18]

Even though sporadic POD activities were initiated at DMRL and IIT Madras, the total amount of POD activity carried out in India was and still is in its infantry stage. This can be clearly observed from the number of total global publications on POD worldwide as shown in Figure 2 [18]. As shown in Figure 2, the total number of publications accounts to approximately 800 amongst which the publications from India accounts to approximately 20 (from the POD activities carried out from both DMRL and IIT Madras). Moreover, to the best of authors knowledge, it is also observed that approximately from the last 1 year, new publications related to POD activity were missing from India.

Considering the severe importance of this activity in India, in the current paper, an attempt is made to briefly demonstrate the results obtained at DMRL on POD studies. This is also followed by the discussion on the importance of reliability evaluation for the future of NDT/E as well as NDE 4.0 in India.

3. Experimental POD efforts and results

One of the main requirements for any POD activity lies in the availability of representative samples with cracks or defect features. Initial studies in this direction directly dealt with failed components or components which are anticipated to fail shortly. These components gave the early studies luxury to have cracks and start the reliability assessment procedure.

3.1 Room Temperature Fatigue Cycling

Under the absence of such retired aero-engine components in India, specimens with representative defects were to be generated with morphological features being exactly similar to the defects originating in service. Therefore, the efforts at DMRL dealt with modifying the design present in Appendix F of MIL-HDBK 1823A (2009) standard [9] in a nickel based superalloy material. Using this design, fatigue cracks emanating from the bolt hole locations of a turbine disc was mimicked with a 3-point bend fatigue loading using the design mentioned above. Specific details of the specimen geometry, loading protocols adopted, etc., are all described in literature [19] The major outcome of this study is a demonstrable and repeatable procedure for generating representative fatigue cracks as observed in engines with identical morphological features such as crack tightness as low as 1 μm, crack tortuosity, trans-granular nature and multiple initiation sites of cracks (Figure 3), etc.

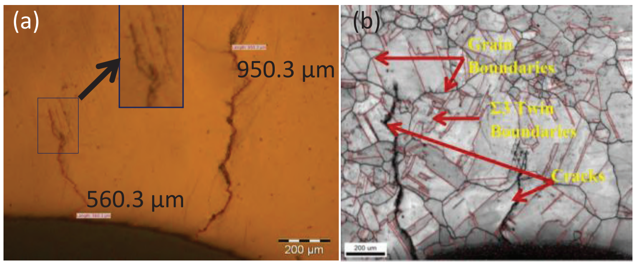


Fig. 3: (a) Micrographs of one of the room temperature tested samples with crack lengths indicated (0.95 mm and 0.56 mm) (b) its EBSD grain boundary map

In spite of this approach, several specific features such as in-situ crack oxidation could not be replicated as the testing was carried out at room temperature. This is essential as the engine operating at high temperatures undergoes predominant oxidation in fatigue cracks at high stress concentration locations of the turbine components. In order to circumvent these issues, attempts were carried out to exactly generate fatigue cracks with in-situ oxidation.

3.2 High Temperature Fatigue Cycling

This issue was addressed with the help of thermo-mechanical simulator Gleeble system present at DMRL. A notable outcome of this effort is its first-time demonstrability of the feasibility of generating these oxidized cracks. Considering the operating temperature of ~650°C, typically observed in an aeroengine, in-situ oxidized fatigue cracks were generated using Gleeble system. Detailed description of the procedure involved, load optimization, etc., are discussed in [16, 20]. Figure 4(a) shows a typical micrograph of one of the high temperature fatigue

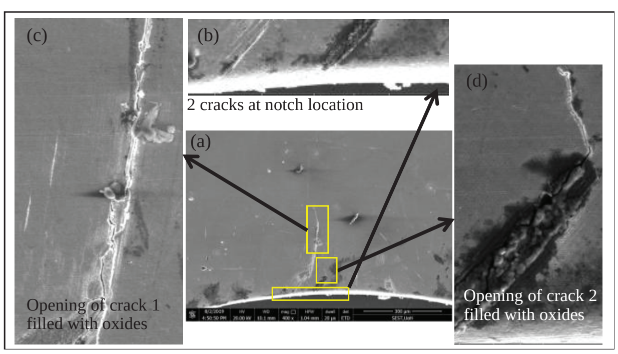


Fig.4: High temperature multiple fatigue cracks at (a) single notch location (b) crack 1 filled with oxides (c) crack 2 filled with oxides and (d) two cracks at notch location in zoomed view

cracked samples showing crack initiation at the notch. Similar cracks initiating from the notch are observed in all the test specimens. From Figure 4(a), it can be observed that two cracks (shown in Figure inset 4(b)) are initiated from the notch location due to the stress concentration at the circular notch. In addition, it can also be observed that the crack surfaces are fully oxidized (shown in Figure insets 4(c) and (d)) due to the high temperature fatigue cycling in air environment. This results in the filling of crack widths with oxides as shown in Figure 4 (c) & (d).

This phenomenon of oxidation of nickel based superalloys at higher temperatures is similar to that of observed in literature [21]. Considering (a) log-normally distributed crack sizes (b) narrow, tortuous and multiple fatigue cracks at a location and (c) formation of oxides in the fatigue crack surfaces, observed from this study, it was concluded that the Gleeble® based novel methodology adopted for fatigue crack generation can produce fatigue cracks similar to that of expected from in-service conditions [22].

3.3 Statistical Analysis of NDT Inspection Data for Plotting POD Curves

Considering the fatigue cracks generated in room temperature and high temperature conditions, NDT inspection using fluorescent liquid penetrant technique (FLPT) and eddy current technique (ECT) (detailed procedure on FLPT and ECT inspection of fatigue cracks is provided in the reference) was carried out. In addition, different HIT/MISS based POD approaches [23] such as Type 1 (maximum flaw size approach) and Type 2 (sum of flaw sizes approach) approaches were also developed and adopted for the FLPT HIT/MISS data of room temperature cracks. For all the HIT/MISS data obtained from FLPT inspection of room temperature cracks, the POD is estimated using log-odds distribution function (Detailed statistical procedure for HIT/MISS POD data is provided in reference). Figure 5 shows a typical POD curve plotted using Type 1 and Type 2 approaches for FLPT inspection of room temperature cracks data indicating $a_{90/95}$ values of 1.13 mm and 2.38 mm for Type 1 and Type 2 approaches, respectively.

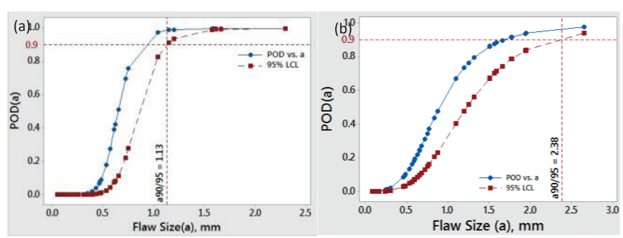


Fig.5: POD curves using different approaches for multiple cracks at a site for FLPT with (a) Type 1 and (b) Type 2 approaches indicating a90/95 values.

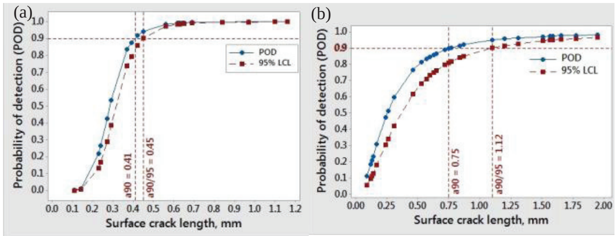


Fig. 6: POD vs. surface crack length for (a) oxidized cracks indicating a90 = 0.41 mm and a90/95 = 0.45 mm (b) non-oxidized cracks indicating a90 = 0.75 mm and a90/95 = 1.12 mm

Similar procedure for plotting POD curves was adopted for ECT results and as shown in Figures 6(a) & (b), $a_{90/95}$ values for ECT inspection of high temperature and room temperature surface crack length sizes are 0.45 mm and 1.12 mm, respectively. In all the cases, the $a_{90/95}$ values of high temperature cracks are sensitive compared to that of room temperature cracks due to the higher detectability of oxide cracks. Further, these $a_{90/95}$ values are incorporated into the damage tolerance based life calculations for estimating the remnant fatigue cycles the component which can withstand before failure.

3.4 Remnant life calculations using DT Methodology

Inspite of availability of several studies on generating POD curves for NDT techniques, the actual manifestation of this $a_{90/95}$ on the remnant life is not addressed in the open literature. Efforts were also made to demonstrate this significance and using three-point bend geometry as the candidate testing protocol and $a_{90/95}$ values generated, remnant life was estimated [20, 24]. Figure 7 shows the remnant fatigue cycles corresponding to different $a_{90/95}$ values of both the NDT techniques. From Figure 7, it can be observed that the remnant fatigue cycle decreases exponentially with an increase in the $a_{90/95}$ values.

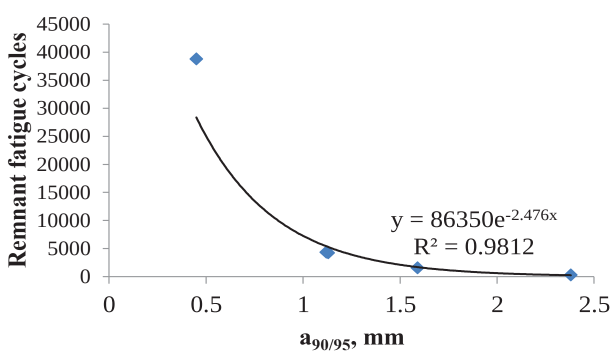


Fig.7: Effect of a90/95 on remnant fatigue cycles

The major challenge in POD curves is its superior dependence on material, geometry, defect characteristics, inspection technique, etc. This would result in re-generating POD curves, which are extremely laborious and cost-intensive. Due to this limitation, modeling approaches were also developed by simulating NDT process using physics based models for predicting NDT response [25]. The mentioned approach for generating cracks similar to that originating from bolt hole locations of an aero-engine turbine disk can be readily used by users working for aeroengine platforms. However, in case of users working for other platforms such as nuclear, space, similar programs can be initiated to first generate cracks and then establish POD curves.

4. Reliability Under the Context of NDE 4.0 in India

Even though very few POD activities have been carried out in India, it can be clearly noted that these studies have not fully considered the different influences on the reliability estimation of NDT techniques as explained from the modular model as shown in Figure 8. Hence, it can be noted that these POD studies can be brought to realistic scenarios only when all these different influences are considered. As shown by the modular system, the major sources of various influences can be broadly classified as (a) the intrinsic capability, (b) the application parameters, (c) the Human Factors in the organisation context as well as (d) the influence of algorithms under the context of NDE 4.0 [26].

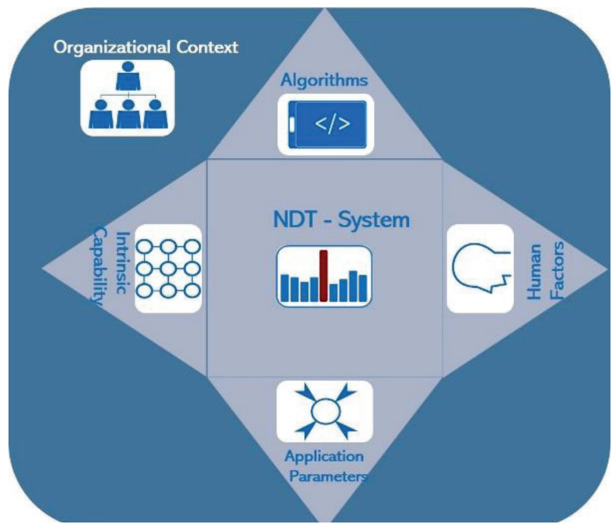


Fig. 8: Modular model under the context of NDE 4.0 [26]

NDE 4.0 is the confluence of the emerging technologies from the environment of Industry 4.0 with the physical inspection methods of non-destructive testing & evaluation as well as non-destructive sensors [27]. Depending on the informatization stage [28, 29] the use cases of NDE 4.0 can be divided into two groups as shown in Figure 9:

a) "Digitalization Solutions for NDE" or "Industry 4.0 for NDE": Use of Emerging Technologies to "improve" NDT and NDE - e.g., the use of artificial intelligence for a more reliable classification of

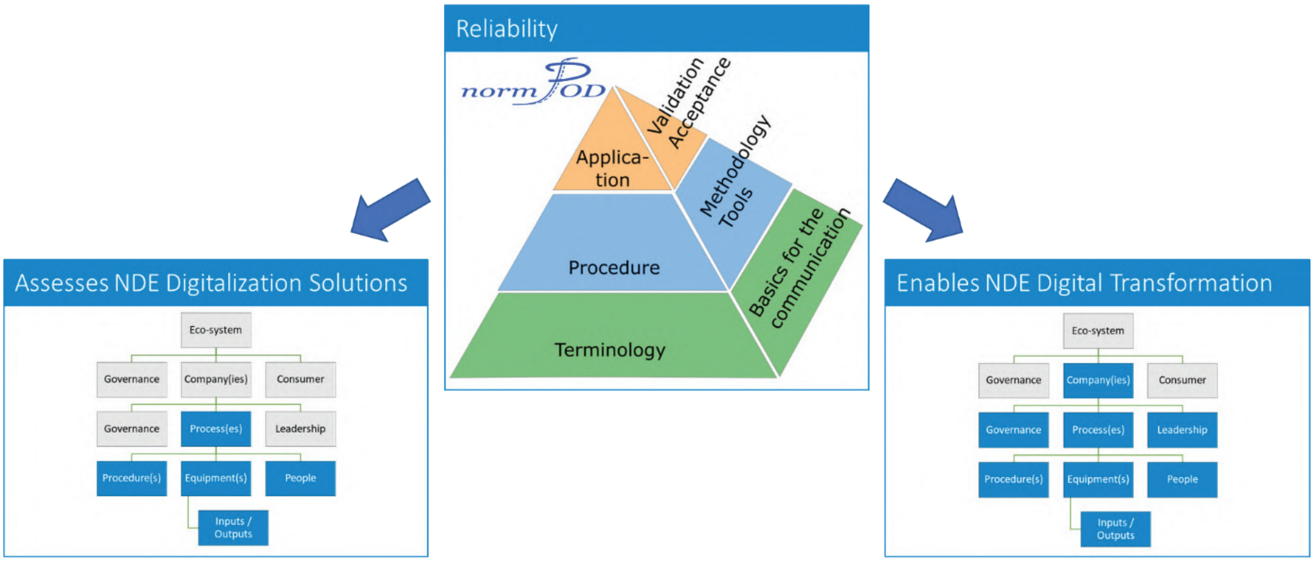


Fig. 9: Reliability is a Key-Success Factor for Both Faces of NDE 4.0

indications, the use of augmented reality for more intuitive visualization, or digital machine identification of a component and use of NDE workflow systems to ensure revision safe, audit-proof correlation of results.

b) "Digital Transformation of NDE Ecosystem" or "NDE for Industry 4.0": Using NDE data which has got the real value to define may be in-terms of "Value Index" [30] to improve production, maintenance, and design of assets using cyber-physical loops and digital twins [31] - i.e., using NDE data for holistic predictive maintenance [32] or to use more accurate knowledge in a probabilistic fracture mechanics implementation, for example [33].

In the first use case group "Digitalization Solutions for NDE", the focus is on improving the reliability of the inspection and its documentation. However, such automated methods must be tested and certified before they can be used. The degree of improvement must be demonstrated. In the "Digital Transformation of NDE Ecosystem" use case group, the aim is to establish NDE as a data basis for engineering. Any data source has an inherent accuracy that should be included in the various approaches to transform data into knowledge [34]. Thus, the reliability information of data should be included in the metadata record that describes the actual measurement data. For NDE, this means that for a use of NDE data in digital twins and other data refinement methods, the reliability of the measurement method should be determined and transmitted as well. These approaches will lead to reliability assessment gaining importance - in classical NDE, in condition and structural health monitoring and more generally in sensor technology. More information on NDE 4.0 can be found in the books "Handbook of Nondestructive Evaluation 4.0" [35] and "The World of NDE 4.0" [36].

5. Closing Remarks

From the author's perspective, it is observed that Indian NDT community is highly involved in the development of new NDT techniques, new probes or new procedures for efficient NDT results. This is one way or the other very much beneficial for transformation to NDE 4.0 as the 4th generation of NDE is mainly based on the adaptation of several of the advanced technologies from the industry 4.0 such as the digital twin, automation, robotics, machine learning, artificial intelligence, etc. However, the biggest challenge lies with the qualification of new NDT techniques or methods or probes when planned for the actual industrial application. At present, most of the test systems are qualified based on several standards that are capable of technical justification or the POD based reliability methods. Hence, it is the need of the hour to qualify the test systems for the successful transformation to the NDE 4.0. In general, the transformation to NDE 4.0 is not an instant task and rather based on understanding the reliability of the existing systems. This will help in identifying the setbacks of the current techniques, methods or procedures and can be rectified by slowly adopting the industry 4.0 technologies eventually leading to the transformation of NDE 4.0 in the long run.

6. Way Ahead for the ISNT NDE Community

As mentioned earlier, studies in India have definitely showed the potential of Indian NDT community to gear up to the occasion of generating NDT reliability information by innovatively taking certain steps required for that. It is definitely agreed that the requirements for generating NDT reliability information for later use as transformation to NDE 4.0 is expensive, laborious and time consuming. However, as explained in the article, its impact on

Indian community to catch the NDE 4.0 band wagon is itself a major boost for national level programs to be initiated. ISNT could take an active role in this direction and form task groups across organizations for initiating the discussion or generating test blocks with defects so as to use them for POD generation, etc.

Alternatively, services of consultant companies exclusively working on NDT or NDE reliability can be opted and with their help, enough leads into this fantastic area can be achieved.

Acknowledgment: The authors specially acknowledge Dr. Ripi Singh for all the fruitful discussions on the topic of reliability and NDE 4.0. One of the authors Phani Mylavarapu thanks Director, DMRL, Hyderabad for permitting to publish this work.

7. References

1. The Importance of Nondestructive Testing, Richard H. Bossi, Focus, The NDT Technician, Vol. 17, No. 4, October 2018, pp. 6–8.
2. ASN Accident Description (Malaysian Airlines -370)". Aviation Safety Network. 8 March 2014. Retrieved 24 March 2014.
3. https://www.justice.gov/opa/pr/boeing-charged-737-max-fraud-conspiracy-and-agrees-pay-over-25-billion, Accessed on 28th August 2022
4. Hollie Silverman; Melissa Alonso (July 12, 2021). "Death toll in Surfside condo building collapse reaches 94". CNN. Retrieved July 12, 2021.
5. https://indianexpress.com/article/explained/another-mig-21-crash-indias-fleet-past-accidents-future-phase-out-8059506/ , Accessed on 28th August 2022.
6. T. Taylor and C. Nockemann, "Summary of American-European Workshop on NDE Reliability," in Paper summaries book - American-European Workshop on Nondestructive Inspection Reliability, 21-24 September 1999, Boulder, Columbus, OH: The American Society for Nondestructive Testing, Inc., 1999, pp. 7–8
7. Rummel Ward, D., Rathke Richard, A.: Flaw Detection Reliability Assessment and Analysis. DTIC Report-ADP000013 (1982).
8. Berens, A.P.: NDE reliability data analysis: non-destructive evaluation and quality control. In: Metals Handbook. 9./17, pp. 689–701. Materials Park, Ohio: ASM International (1989).
9. Department of Defense. MIL-HDBK-1823A: Nondestructive evaluation system reliability assessment. Handbook (2009)
10. Meeker, W.Q.: R.B.Thompson's contribution to model assisted probability of detection. AIP Conf. Proc. 1430, 83–94 (2012)
11. Frédéric Jenson, et.al., "The SISTAE Project: Simulation and Statistics for Non Destructive Evaluation", 4th European-American Workshop on Reliability of NDE, June 2009, Berlin, Germany (Reliability 2009)
12. Nancy Maleo, "PICASSO imProved reliablity inspeCtion of Aeronautic Structure through Simulation Supported POD", 4th International Symposium on NDT in Aerospace 2012, Nov 13-14, Augsburg, Germany (AeroNDT 2012)
13. Department of Defense. MIL-HDBK-1823: Nondestructive evaluation system reliability assessment. Handbook (1999)
14. Gandossi, L., Annis, Ch.: Probability of Detection Curves: Statistical Best-Practices. ENIQ report No 41. ENIQ. 24429 EN (2010)
15. ASTM E3023-15: Standard Practice for Probability of Detection Analysis for â Versus a Data. ASTM International (2015)
16. Vamsi Krishna Rentala, "Effect of Fatigue Crack Surface Oxidation on Reliability of Non Destructive Testing Techniques", Ph.D Thesis, University of Hyderabad/DMRL, Oct 2020.
17. Mohamed Subair Syed Akbar Ali, et. al. "Bayesian synthesis for simulation-based generation of probability of detection (PoD) curves", Ultrasonics, Volume 84, March 2018, Pages 210-222
18. Rentala, V.K., Kanzler, D. & Fuchs, P. POD Evaluation: The Key Performance Indicator for NDE 4.0. J Nondestruct Eval 41, 20 (2022). https://doi.org/10.1007/s10921-022-00843-8
19. Vamsi Krishna Rentala, Phani Mylavarapu, Jai Prakash Gautam, Vikas Kumar, "Generation of POD Curves in the Absence of Service Induced Cracked Components- An Experimental Approach", Insight-Nondestructive testing and condition monitoring, Vol 61, No 1, January 2019. https://doi.org/10.1784/insi.2019.61.1.28
20. Vamsi Krishna Rentala, Phani Mylavarapu, Atul Kumar, Jai Prakash Gautam, Gopinath Kakkropath, T. Jaya Kumar, "POD of NDT Techniques Using High Temperature Oxidized Fatigue Cracks in an Aero Engine Alloy", Journal of Nondestructive Evaluation, 40, 41 (2021). https://doi.org/10.1007/s10921-021-00769-7
21. S. Cruchley, H.E. Evans and M.P. Taylor, An overview of the oxidation of Ni-based superalloys for turbine disc applications: surface condition, applied load and mechanical performance, materials at High Temperatures, April 2016
22. A A Shanyavskiy, 'Fatigue crack propagation in turbine discs of EI698 superalloy', Fratturaed Integritá Strutturale, Vol 24,pp 13-25, 2013.

23. F W Spencer, 'Probability of detection estimation for HIT/MISS data when detection cannot be attributed to specific flaws: an exploratory data analysis', Review of Progress in Quantitative Nondestructive Evaluation, Portland, Oregon, USA, Vol 25, 20 July-4 August 2006.
24. Vamsi Krishna Rentala, Phani Mylavarapu, J.P.Gautam, Gp.Capt.B.V.N.Shiva, K.Gopinath, Vikas Kumar, "Physical Manifestation of a90/95 in Remnant Life Revision Studies of Aero-engine Components", Procedia Structural Intergrity (Elsevier), 14 (2019) 597–604. https://doi.org/10.1016/j.prostr.2019.05.073
25. Vamsi Krishna Rentala, Phani Mylavarapu, Jai Prakash Gautam, "Issues in Estimating Probability of Detection of NDT Techniques – A Model Assisted Approach", (Elsevier) Ultrasonics 87 (2018) 59–70. https://doi.org/10.1016/j.ultras.2018.02.012
26. Daniel Kanzler, Vamsi Krishna Rentala, (2021) "Reliability Evaluation of Testing Systems and Their Connection to NDE 4.0", In: Meyendorf N., Ida N., Singh R., Vrana J. (eds) Handbook of Nondestructive Evaluation 4.0, pp 1-34. Springer, Journal of Nondestructive Evaluation. https://doi.org/10.1007/978-3-030-48200-8_3-1
27. Vrana, J., Singh, R. NDE 4.0—A Design Thinking Perspective. J Nondestruct Eval 40, 8 (2021). https://doi.org/10.1007/s10921-020-00735-9
28. Vrana, J., Singh, R. (2022). Digitization, Digitalization, and Digital Transformation. In: Meyendorf, N., Ida, N., Singh, R., Vrana, J. (eds) Handbook of Nondestructive Evaluation 4.0. Springer, Cham. https://doi.org/10.1007/978-3-030-73206-6_39
29. Vrana J, Singh R. (2022) Welcome to the World of NDE 4.0: Basics and Early Success Stories. J JPN SOC NDI 71, to be published.
30. Daniel Kanzler, Vamsi Krishna Rentala, "NDE data: The Real Value", NDE Outlook, Materials Evaluation, ASNT, August 2022
31. Vrana, J., Singh, R. Cyber-Physical Loops as Drivers of Value Creation in NDE 4.0. J Nondestruct Eval 40, 61 (2021). https://doi.org/10.1007/s10921-021-00793-7
32. Vrana, J., Singh, R. NDE 4.0: NDT and sensors becoming natural allies by digital transformation and IoT . Proc. SPIE 11594, NDE 4.0 and Smart Structures for Industry, Smart Cities, Communication, and Energy, 1159404 (2021). http://dx.doi.org/10.1117/12.2581400
33. Vrana, J., Kadau, K., Amann C. Smart data analysis of the results of ultrasonic inspections for probabilistic fracture mechanics. VGB PowerTech 2018(7):38-42 (2018).
34. Vrana, J. The Core of the Fourth Revolutions: Industrial Internet of Things, Digital Twin, and Cyber-Physical Loops. J Nondestruct Eval 40, 46 (2021). https://doi.org/10.1007/s10921-021-00777-7
35. Meyendorf N., Ida N., Singh R., Vrana J. Handbook of Nondestructive Evaluation 4.0. Springer, Cham (2022). https://doi.org/10.1007/978-3-030-73206-6
36. Singh R., Vrana J. The World of NDE 4.0: Let the Journey Begin. Amazon (2021).

Thermal Transient Measurements of Optical Periscope Lamp Assembly for Different Flow Rates using Thermal Imaging

M.Menaka, P. Visweswaran, S. Sakthivel, S. Joesph Winston, V.Subramanian, B.Venkatraman
Indira Gandhi Centre for Atomic Research, Kalpakkam-603102
menaka@igcar.gov.in

Abstract:

Optical Periscope is an instrument used for visual inspection if any obstacles are present in the direct line of sight of the observer. In a nuclear reactor where the visual inspection is limited by many factors, instruments like periscope are very vital for in-service inspections. In Prototype Fast Breeder Reactor (PFBR) the Periscope is used for the inspection of reactor internals at cover gas region above the liquid Sodium level. It is of 400mm diameter and 10m length housing image channel and two Xenon lamps for illuminating the region of inspection. The lamps operate at high voltage, 24kV and switches to 14V during regular operation. Due to the high voltage, excess heat generation was observed which was causing frequent failures of the lamp. Remote Handling & Irradiation Experiments Division (RHIED) of IGCAR carried out design modification for optimizing the proper coolant flow and other geometrical parameters. For validation of design modifications and ensuring better heat transfer efficiency Infrared Thermography was carried out on the lamp assembly of the periscope. The main objectives of present study is to evaluate thermal profiles of the system at different flow rates of coolant (800 lpm, 1000 lpm & 1200 lpm) and investigate thermal distribution across the fin. This paper discusses temperature measurement on the lamp and fin region of periscope assembly. The effect of flow rate to facilitate cooling of the lamp on the temperature distribution of the lamp assembly was investigated.

KEYWORDS: Optical Periscope, Prototype Fast Breeder Reactor, Non-Destructive Evaluation, Infrared Thermography

1. Introduction:

An optical periscope is a device that enables visual inspection of objects which are not in the direct line of sight. The periscope can be an essential in-service inspection tool for routine maintenance and other activities in a nuclear reactor. It is a mandatory requirement to carry out visual inspection of reactor vessel internals during periodic in-service, under shut down conditions and in pre-commissioning of any nuclear reactor. In this connection, an indigenously designed Optical Periscope has been used for visual examination of the Prototype Fast Breeder Reactor (PFBR) in Kalpakkam [1]. PFBR is a 500 MWe, sodium cooled, pool type, mixed oxide (MOX) fuelled reactor with two secondary loops. The primary objective of PFBR is to demonstrate techno-economic viability of fast breeder reactors on an industrial scale [3]. During operation, the periscope will be inserted into the reactor from the top of roof slab vertically for inspecting objects present in the space above the liquid sodium level filled with argon cover gas.

Illuminating system is housed just beside the viewing canal at the periscope end for illuminating the objects under inspection. Two xenon arc lamps of 300 W powers consisting of an integral reflector are used. The xenon lamps used in the illuminator has heat-sinks mounted on copper electrodes operating with 25 kV striking pulse. The lamps are originally designed for operation in air with forced cooling. Since the periscope is a sealed device and has argon as operating environment, an additional arrangement with ceramic enclosure on the lamp for electrically isolating the electrodes, while facilitating cooling with argon flow has been designed.

The periscope's xenon lamp had frequent failures even at room temperature operations and hence Remote Handling and Irradiation Experiments Division have taken up to study the system and to carry out the design modifications to make the lamp holder assembly and to ensure successful working of the lamp. The pulse voltage for the starting of the lamp has changed from 24kV to 15kV, and then switches back to 14V during regular operation. A technology modification has been done by placing an RTD temperature sensor close to the lamp terminal [4]. The validation of the design modification was carried out through comprehensive temperature profiling of the system using thermal imaging.

2. Material and Methods

The PFBR periscope optical instrument is of 400mm diameter and about 10 meter length, housing image canal and two lamps for illuminating the area of interest. The image canal (optical tube), contains prisms and zoom lens, relay lens, focusing lens and eye piece. The illuminator has two lamps, light directing prisms and argon cooling system for the lamps. The periscope will be fixed in the IVTP port of PFBR for the visual inspection [3]. The lamp used in the illuminator of the Periscope is a Xenon arc lamp, with a luminous flux of 5000 lumens and 300W power [2].

The anode and cathode side cooling of the fins are separated with proper insulation to avoid any discharge through the cooling gas. The lamp holder assembly has separate cooling loops from a common cooling gas header. The xenon strike voltage during the start of the lamp is 15kV DC and the lamp holder assembly is fabricated in Teflon material. The upper and lower heat sinks have been machined through a wire cut EDM machine to the required precision. Fig.1 shows the lamp assembly with cooling arrangement. The designed maximum temperature for this system is 150°C. An RTD is placed in the cathode side for temperature measurement and it is designed to cut off the lamp if the temperature goes above the preferred level.

The coolant inlet of 3/8 inch is modified to 3 numbers of inlets of diameter ¼ inch in the header.

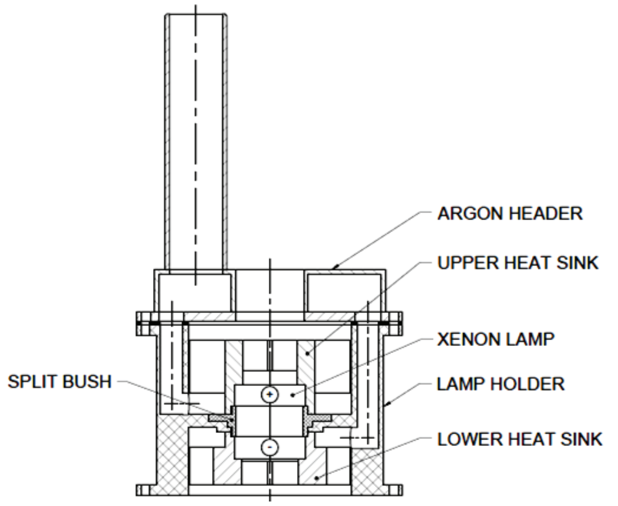


Fig. 1: Lamp assembly with cooling arrangement

For our experiment, Passive thermal mapping was carried out using T400 Infrared Camera (Fig. 2) which has an uncooled micro-bolometer detector. The spectral range of the system is 7-13 μm in wavelength. The system was mounted on a tripod stand having a distance of 50 cm from the sample. Factors like emissivity, relative humidity and ambient temperature influencing temperature measurement are taken into consideration while obtaining images [5]. The thermograms were obtained at regular interval of times, which was later analyzed using FLIR Tools software.

Fig. 2: FLIR T400 Infrared camera.

A total of three experiments were carried out for the non contact temperature mapping of the surface of xenon flash lamp and the Fin Region (Fig: 3), at three different flow rates- 800lpm, 1000lpm and 1200lpm.

Fig.3: shows the Periscope Lamp Assembly during the operation with Lamp and Fin Region.

3. Results and Discussions:

The acquired images were analysed after appropriate radiometric corrections. The measurement tools such as area profiling- circle or rectangle, line profiling were chosen for the analysis. The spot and area measurement tool provides the spot temperature and mean, maximum and minimum temperature over an area respectively. Line profile provides the temperature at the particular pixels lying in the given line. Using the data obtained from the images, graphs were plotted and analysed.

The figure 4 shows the 3D surface plot of the lamp assembly with fin region. It can be observed from the image that the maximum temperature recorded is on the lamp compared to fin region.

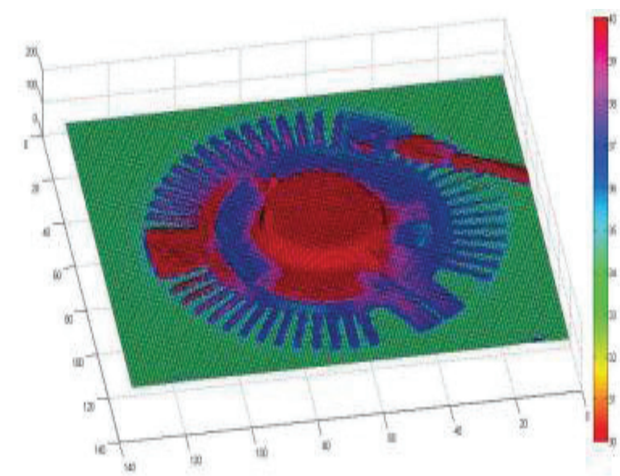


Fig. 4: 3D surface plot of the thermal image taken during the operation of the lamp.

Typical thermal Images (fig 5) acquired during operation of the lamp have been given below. This clearly shows that the maximum temperature recorded was always on the lamp surface.

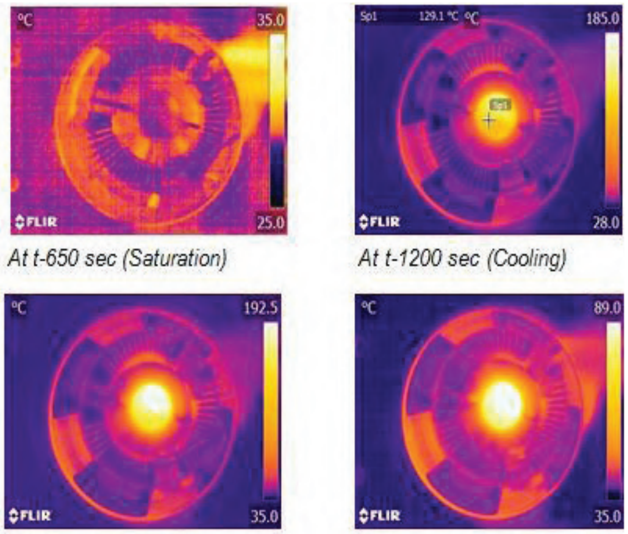


Fig. 5: Typical thermal images of the lamp assembly at different time during operation of the lamp for 1000lpm flow rate

The closure look of thermal image indicates that Fin Region exhibits uniform temperature (fig.6) and no significant hot spot was observed in the thermal image during operation of the lamp.

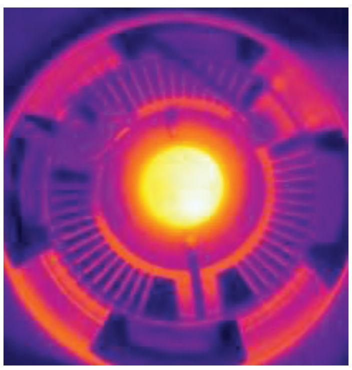


Fig. 6: Close up view of the Fin Region of a typical IR Thermal image

Temperature Profiles on Lamp

The maximum temperatures mapped on the outer glass surface of the lamp during the operation and during the cooling phase at each flow rate is plotted (fig. 7) against time. It was observed from the plot, the increase in temperature was high for the initial few minutes (heating region). After the initial rise in temperature, saturation region has been observed in which there was no significant temperature rise. During the cooling phase (cooling region), temperature fall has been observed to have steep slope.

The overall temperature profile of the lamp with respect to time is same for all three flow rates- 800lpm, 1000lpm and 1200lpm.

The effect of flow rate was observed in the maximum temperature recorded on the lamp and in the thermal decay rates

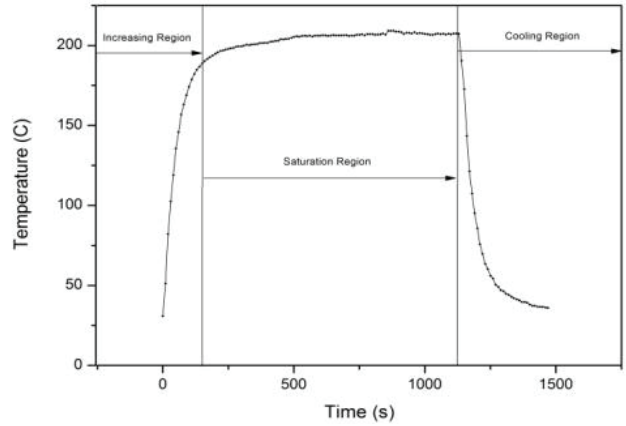


Fig. 7: Plot of maximum temperature at the Lamp surface during the operation of the lamp and switch off state with respect to time at a flow rate of 1000lpm.

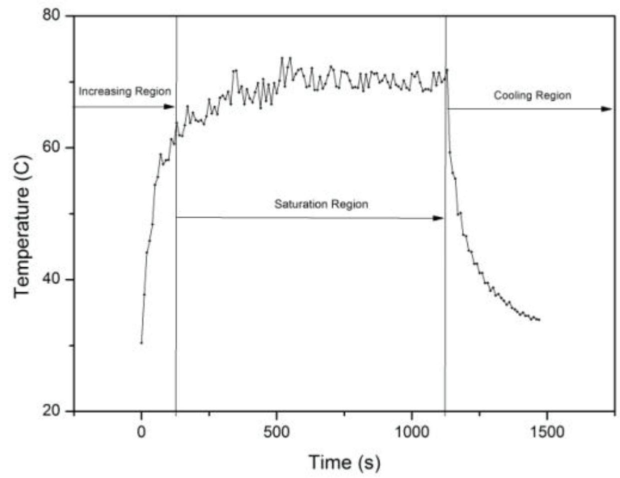


Fig. 8: Plot of maximum temperature at the Fin Region during operation of the lamp and switch off state with respect to time at 1000lpm

Temperature Profiles on Fin Region

The maximum temperature of the surface of Fin Region during the operation and in the cooling phase is plotted. Similar to the lamp temperature profile plot, the temperature of the fin region also showed three distinct regions (heating, saturation and cooling region) The fluctuations in the temperature (rise and fall of temperature) at the saturation region can be attributed to the air flow.

Temperature profile of the fin region for different flow rates revealed that the maximum temperature attained was above 80°C for 800lpm, whereas the temperature rise was 70°C and less than 70 °C for 1000lpm and 1200 lpm respectively.

The temperature difference on the cooling phase for a time laps of 50s for 1000lpm and 1200lpm is given below in the table and this data clearly indicates that the cooling is more efficient with a higher flow rate.

	Drop in temperature during cooling phase for the time of 50 s
1000 lpm	21.7 C
1200 lpm	2.8 C

A separate graph (Fig: 9) is plotted for the cooling phase to get a clear picture of thermal decay of the Fin Region at different flow rates. The comparison between the three decay curves for 800lpm, 1000lpm and 1200lpm indicates that the thermal decay happens faster for 1200lpm and then 1000lpm and comparatively slower for 800lpm.

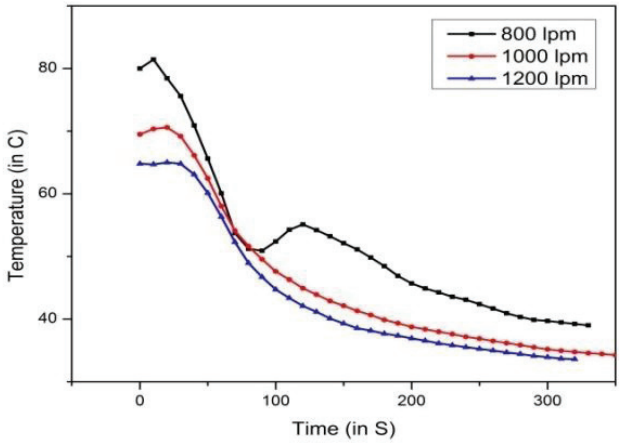


Fig. 9: Plot of Thermal decay of Fin Region for different flow rates- 800lpm, 1000lpm and 1200lpm.

4. Conclusion:

Infrared Thermography was carried out on the lamp assembly of the periscope for the validation of design modifications and ensuring better heat transfer efficiency. Mapping of temperature profiles of periscope lamp and Fin Region through the non contact temperature measurement was done successfully. The temperature measurement revealed that the maximum temperature recorded was on the lamp region and uniform distribution of temperature was exhibited in the Fin Region with no significant hot spot. The effect of flow rate in the heat dissipation of the Fin Region by forced convection was also clearly indicated by the comparison of surface temperature mapping of the Fin Region in all three flow rates- 800lpm, 1000lpm and 1200lpm. Cooling is more efficient for 1200lpm and 1000lpm and comparatively less for 800lpm. Trend in temperature profile recorded during the operation and lamp assembly and cooling phase has been clearly brought by the study.

Acknowledgement

The authors would like to thank Director IGCAR, Kalpakkam for his immense and constant support. They are also thankful to Smt Anagha C H and Shri. Gnanamoorthi. D for their valuable work and contribution. The authors are also thankful to staffs of RHID, IGCAR for their kind cooperation.

References:

1. "Development of Periscope for Prototype Fast Breeder Reactor", M. Singh, R. V. Sakrikar, A. M. Kadu, D. V. Udupa and S. Kumar Presented in "Technical Meeting on Fast Reactors In-service Inspection and Repair: Status and Innovative Solutions" at IAEA, Vienna, Austria during 19-20 December 2011
2. D.V. Udupa, Sanjiva K. and N.K. Sahoo, R.V. Sakrikar, A. Kadu and M. Singh, SS Bhavsar and R.K Garg, V. Rajan Babu and V. Balasubramanian, R.L. Suthar, G.P. Kothiyal. "Indigenous Development Of A 10 Meter Optical Periscope For Prototype Fast Breeder Reactor (PFBR)"
3. Library and Information services, IGCAR, Kalpakkam "Design of Prototype Fast Breeder Reactor"
4. P. Visweswaran, S. Sakthivel, "Design Enhancement for Efficient Cooling of Periscope Xenon Lamp Housing", PFBR/35340/DN/1004/Rev-A
5. B.Venkatraman, M.Menaka, P.Kalyanasundram and BaldevRaj "InfraredImaging-an Over view on its Multifarious Possibilities and applications in IGCAR"

Thermal Non-Destructive Testing with Effective Biomaterial for Bone Density Diagnosis: A Numerical Study

Sanchita Dass[1], Juned A Siddiqui[2]

[1,2] Department of Electronics, Medi-Caps University Indore, (M.P.), India

[2]Email: juned.siddiqui@medicaps.ac.in

Abstract: **Nanoscale biomaterials play an active role in the medical field. These materials are used for different applications, such as biological system repair, replacement, stimulation, and interaction. This encourages us to seek out bio-materials that can be helpful to enhance the detection capabilities of active thermography. This non-destructive testing technique (NDT) yields such promising results that it can be used as a screening tool for the early detection of bone diseases. Hence, in this work, we used modulated active thermography with iron oxide nanoscale biomaterial to detect bone density. Normally, modulated active thermography uses a post-processing scheme to improve depth penetration; hence, this work utilized a pulse compression-based technique. This study focuses on the effect of biomaterial coating on bone with varying densities when using active thermography. We are using a three-dimensional FEM bone model with different density variations for this. We also compare the coated and non-coated resolutions using the signal-to-noise ratio (SNR). Furthermore, we discovered that the iron oxide coating can improve the current thermal NDT technique.**

KEYWORDS: NDT; SNR, Biomaterial, Bone density

1. Introduction

Active infrared thermography (IRT) is a non-destructive technique for diagnosing that uses external heat simulation and records surface temperature variation. Because of its safe, non-contact, non-invasive, and wide-area inspection characteristics, it has gained critical importance in the field of non-destructive testing and evaluation for biomedical applications in recent years. This thermal wave imaging, which has a wide range of applications in the diagnosis of various diseases based on thermal contrast analysis, can also be used to determine variations in bone density. A controlled stimulus is applied to the subject, and the resulting response is recorded. To diagnose density variation, additional processing techniques are used to study the thermal map over skin[3]. The most commonly used active TNDT approaches, depending on the object to be inspected and the external stimulus, are pulse thermography (PT), lock-in thermography (LT), and pulse phase thermography (PPT) [5]. However, these conventional methods of pulse and pulse phase necessitate high peak power [6], and lock-in necessitates repetitive injection of mono-frequency sinusoidal heat flux to locate defects at different depths. To overcome the limitations of traditional thermal wave imaging techniques (depth resolution peak power), linear-frequency modulated thermal wave imaging [7] (LFMTWI) is proposed, which can be performed with moderate peak power heat sources in a shorter time span than conventional pulse and lock-in based thermographic methods [8]. This study shows how to use the FMTWI technique for bone diagnostics [11], specifically by considering the bone with tissue, skin, and muscle over layers. To test the efficacy of the proposed method, LFMTW is applied to a modelled bone sample along with a bio-material coating [9]. A bone sample with different stages of osteoporosis and a bio-material coating is modelled using finite element analysis and simulated with a frequency modulated stimulus in this paper [10]. Further, pulse compression and Fourier analysis techniques are used as post-processing schemes for better detection, and their performance with signal-to-noise ratios is compared with coated and non-coated bone models.

2. Heat simulation and postprocessing

As shown in fig 1, we used LFMWI heat stimuli with frequencies ranging from 0.01 to 0.5 Hz and lasting 100 seconds. In this technique, modulated thermal waves with a suitable frequency band and equal energies are probed into the test sample to detect defects at various depths. It can be expressed as

$$f(t) = A\, ej^{2\pi}((f1 + Rt)t) \qquad (1)$$

'A' is the flux amplitude, 'f1' is the modulated frequency, R is th sweep rate, and 't' is the time.

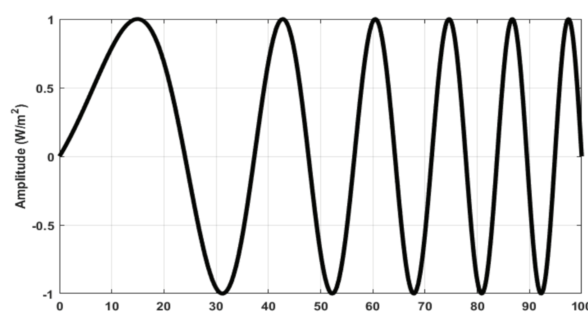


Fig. 1: Schematic of Linear Frequency Modulated Signal imposed on bone sample.

In this paper, we use a postprocessing technique based on pulse compression. Each pixel temperature profile is assumed to be a time sequence in the IRT. These patterns include a temporal thermal response and an active response that correspond to the offset in excitation. Crosscorrelation is perormed between the temperature time sequence distributionof the selected reference pixel and the time delayed version of the pixel over the sample to obtain an active response. The difference in temporal temperature responses provides information about defective and nondefective regions that are dependent on the thermal properties of the material. This captured temperature time sequence distribution can be recaptured using the following formula:

$$\text{Correlation - Coefficient(CC)} = \text{IFFT}\ \{\text{RT}\ (\omega)*.\text{OT}\ (\omega)\} \quad (2)$$

Here, The Fourier transforms of the chosen reference response and temporal temperature response at a given location are denoted by RT $(\omega)*$ and OT (ω).

3. Experimentation and Simulation

A 3D Finite Element Analysis (FEA) of a human bone sample was performed to test the proposed model. The modelled bone sample is made up of different layers with varying thicknesses, including skin (0.5 mm), fat (0.5 mm), muscle (0.5 mm), and bone (2.5 mm). In order to visualise the different stages of osteoporosis, the bone region was further comprised of four artificial abnormalities, each with a diameter of 20 mm and different thermal properties such as Density, Thermal Conductivity, and Specific Heat. Table 1 shows the sample thermal properties of the holes on bone region.

Table 1: Thermal Properties [27]

Region	Density (ρ) (Kgm^{-3})	Thermal Conductivity (k) ($Wm^{-1}\ K^{-1}$)	Specific Heat (c) ($J\ Kg^{-1}\ K^{-1}$)
Skin	1109	0.37	3391
Fat	911	0.21	2348
Muscle	1090	0.49	3421
Bone	2420	0.616	1430
D1	1480	0.25	1200
D2	1200	0.34	2000
D3	2090	0.532	1235
D4	2310	0.588	1365

Table 2: Iron oxide thermal Properties [28]

Nanoparticles	Density (ρ) ($Kg\ m^{-3}$)	Thermal Conductivity (k) ($W\ m^{-1}\ K^{-1}$)	Specific Heat (c) ($J\ Kg^{-1}\ K^{-1}$)
Iron oxide	5240	0.3	103.9

The front end (skin surface) of modeled sample is excited by imposing a Linear Frequency Modulation with a 500 Wm^{-2} heat flux during active heating, the corresponding temporal temperature response over the skin surface was recorded at a frame rate of 33 frames per second. The simulations were run under non-isothermal boundary conditions, with the sample at 310.15 K normal body temperature. The simulated data recorded over the skin is then analysed in the frequency domain. As shown in Fig. 2, FEA is performed on a modelled specimen coated with a thermo-active biomaterial. Furthermore, AWGN with an SNR of 60 dB is artificially inserted into the simulated data so that the proposed method can be used in real-time situations.

The front end (skin surface) of modeled sample is excited by imposing a Linear Frequency Modulation with a 500 Wm^{-2} heat flux during active heating, the corresponding temporal temperature response over the skin surface was recorded at a frame rate of 33 frames per second. The simulations were run under non-isothermal boundary conditions, with the sample at 310.15 K normal body temperature. The simulated data recorded over the skin is then analysed in the frequency domain. As shown in Fig.2, FEA is performed on a modelled specimen coated with a thermo-active biomaterial. Furthermore, AWGN with an SNR of 60 dB is artificially inserted into the simulated data so that the proposed method can be used in real-time situations.

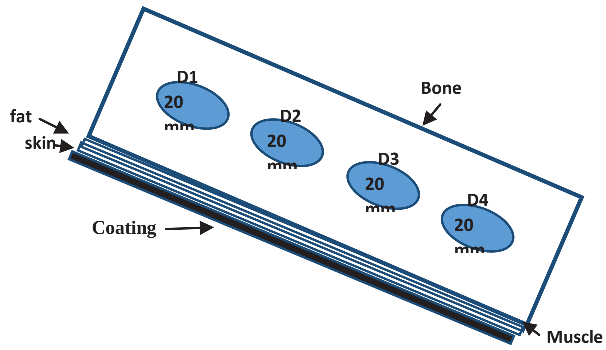


Fig. 2: Layout of the bone sample with biomaterial coating.

4. Results and discussion

This study demonstrates the efficacy of the bio-material (Iron-oxide) in conjunction with the linear frequency modulated thermal wave imaging technique. The results show that the contrast achieved in Correlation – Coefficient (CC) image with the bio-material coating on the bone is superior to that achieved in conventional Correlation – Coefficient (CC) image without any coating. This could be because the Iron oxide nano-particles have improved thermal properties. Figs. 3 and 4 depicts the measured SNR values for circular shaped bone defects with and without biomaterial coating. The results show that images with biomaterial coating have higher SNR values than images without coating.

Fig. 3. Simulation results of (a) non-coated and (b) coated bone sample

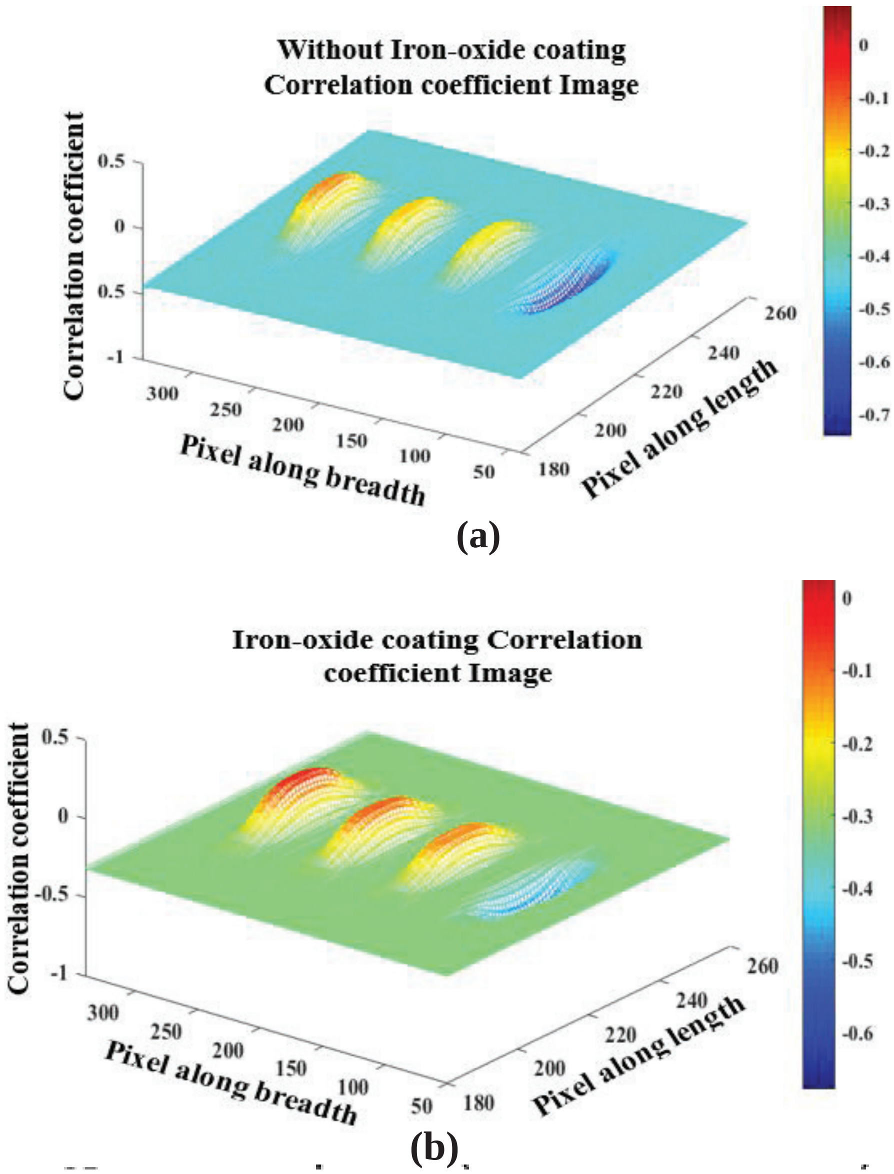


Fig. 3: Simulation results of (a) non-coated and (b) coated bone sample

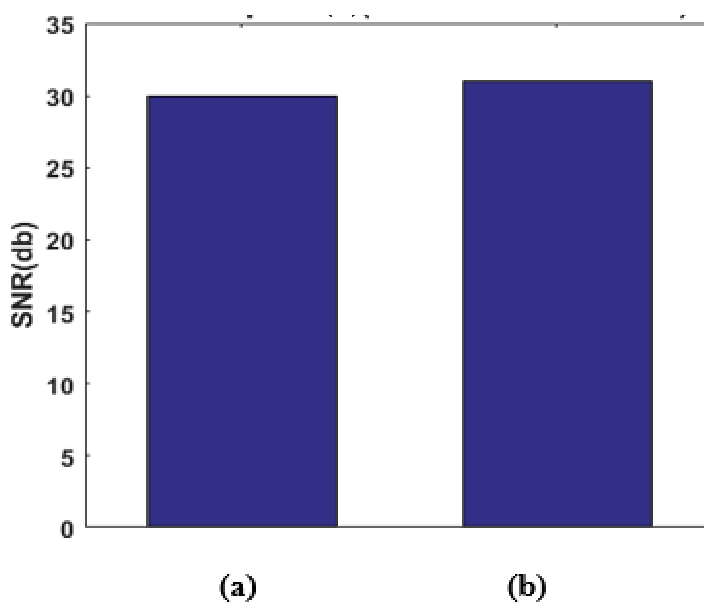


Fig. 4: SNR Comparison (a) non-coated and (b) coated bone sample

5. Conclusions

The frequency modulated thermal wave imaging technique is used in this paper to detect bone density variation with a Iron oxide nanoparticle coated sample using a finite element modelling approach. The proposed schemes' bone density detection capabilities are further quantified by taking SNR into account. The results clearly show that the bio-material Correlation images have a much higher contrast of visibility of defects when compared to the same images without bio-material LFM.

6. References

1. L. S. Nair and C. T. Laurencin, "Polymers as biomaterials for tissue engineering and controlled drug delivery," Adv. Biochem. Eng. Biotechnol., vol. 102, pp. 47- 90, 2006, doi:10.1007/b137240.
2. L. L. Hench, "Biomaterials: A forecast for the future," Biomaterials, vol. 19, no. 16,]2[, pp. 1419-1423, 1998, doi:10.1016/s0142-9612(98)00133-1.
3. E. J. Nassar et al., * Biomaterials and Sol–Gel Process: A Methodology for the Preparation of Functional Materials.
4. C. M. Agrawal, "Reconstructing the human body using biomaterials," JOM, vol. 50, no. 1, pp. 31-35, 1998, doi:10.1007/s11837-998-0064-5.
5. J.D. Bronzino, The Biomedical Engineering Handbook, 2nd ed, vol. 2, 2000.
6. A.B.H. Yoruc and B.C. Sener, "Biomaterials" in Prof. Kara S, editor. A roadmap of biomedical engineers and milestones, ISBN: 978-953-51-0609-8, 2012.
7. D. Campoccia et al., "A review of the biomaterials technologies for infection-resistant surfaces," Biomaterials, vol. 34, no. 34, pp. 8533-8554, 2013, doi:10.1016/j.biomaterials.2013.07.089.
8. K. Chaloupka et al., "Nanosilver as a new generation of nanoproduct in biomedical applications," Trends Biotechnol., vol. 28, no. 11, pp. 580-588, 2010, doi:10.1016/j.tibtech.2010.07.006.
9. A.A. Adedoyin and A. K. Ekenseair, "Biomedical applications of magnetoresponsive scaffolds," Nano Res., vol. 11, no. 10, pp. 5049-5064, 2018, doi:10.1007/s12274- 018-2198-2.
10. X.P.V. Maldague, Theory and Practice of Infrared Technology for Non Destructive Testing. New York: Wiley, 2001.
11. H.I. Ringermacher et al., "Flashquenching for high resolution thermal depth imaging," Proc. AIP, vol. 700, pp.477-481, 2004.
12. F.B.D. Djupkep et al., "Analysis of a new method of measurement and visualization ofindoor conditions by infrared thermography," Rev. Sci. Instrum., vol. 84, no. 8, p. 084906, 2013, doi:10.1063/1.4818919.
13. S. Nayak et al., "Systematic review and metaanalysis of the performance of clinical risk assessment (a) (b)Journal XX (XXXX) XXXXXX Author et al 7 instruments for screening for osteoporosis or low bone density," Osteoporos. Int., vol. 26, no. 5, pp. 1543-1554, 2015, doi:10.1007/s00198-015-3025-1.
14. G. Dua and R. Mulaveesala, "Infrared thermography for detection and evaluation of bone density variations by non-stationary thermal wave imaging," Biomed. Phys. Eng. Express, vol. 3, no. 1, p. 017006, 2017, doi:10.1088/2057-1976/aa5b4d.
15. A. Sharma et al., "Linear frequency modulated thermal wave imaging for estimation of osteoporosis: An analytical approach," Electron. Lett., vol. 56, no. 19, 1007- 1010, 2020, doi:10.1049/el.2020.0671.
16. L. Feng et al., "Lock-in thermography and its application in nondestructive evaluation," Infrared Laser Eng., vol. 39, pp. 1121-1123, 2010.
17. D.P. Almond and S.G. Pickering, "An analytical study of the pulsed thermograpy defect detection limit," J. Appl. Phys., vol. 1, p. 093510, 2012.
18. A. Levy et al., "A new thermography-based approach to early detection of cancer utilizing magnetic nanoparticles theory simulation and in vitro validation,", Nanomedicine, vol. 6, no. 6, pp. 786-796, 2010, doi:10.1016/j.nano.2010.06.007.
19. Y. Ohashi and I. Uchida, "Applying dynamic thermography in the diagnosis of breast cancer," IEEE Eng. Med. Biol. Mag., vol. 19, no. 3, pp. 42-51, 2000, doi:10.1109/51.844379.
20. P. Raverkar, J.A. Siddiqui, A. Kulkarni and R. Mulaveesala, "Corrosion detection in mild steel using effective post processing technique for modulated thermal imaging: A numerical study," 2021 IEEE International Conference on Technology, Research, and Innovation for Betterment of Society (TRIBES), 2021, pp. 1-4, doi: 10.1109/TRIBES52498.2021.9751651.
21. R. Mulaveesala and V.S. Ghali, "Cross-correlation based approach for thermal nondestructive characterization of carbon fiber reinforced plastics," Insight, vol. 53, no. 1, pp. 34-36, 2011, doi:10.1784/insi.2011.53.1.34.

22. V.S. Ghali et al., "Three dimensional pulse compression for infrared nondestructive testing," IEEE Sens. J., vol. 9, no. 7, pp. 832-833, 2009, doi:10.1109/JSEN.2009.2024042.
23. J.A. Siddiqui et al., "Modelling of the frequency modulated thermal wave imaging process through the finite element method for non-destructive testing of a mild steel sample Insight, Non- Destruct," Test. Cond. Monit., vol. 57, pp. 266-268, 2015.
24. R. Mulaveesala et al., "Pulse compression approach to infrared nondestructive characterization," Rev. Sci. Instrum., vol. 79, no. 9, p. 094901, 2008, doi:10.1063/1.2976673.
25. G. Dua et al., "Effect of spectral shaping on defect detection in frequency modulated thermal wave imaging," J. Opt., vol. 17, no. 2, pp. 1-5, 2015, doi:10.1088/2040- 8978/17/2/025604.
26. A. Sharma et al., "Novel analytical approach for estimation of thermal diffusivity and effusivity for detection of osteoporosis," IEEE Sens. J., vol. 20, no. 11, 6046-6054, 2020, doi:10.1109/JSEN.2020.2973233.
27. S.R.H. Davidson, Heat transfer in bone during drilling Master of Applied [Science thesis. University of Toronto, 1999.
28. L. Zhang et al., "Enhanced thermal conductivity for nanofluids containing silver nanowires with different shapes," J. Nanomater., vol. 2017, 1-6, 2017, doi:10.1155/2017/5802016.
29. R. Mulaveesala and S. Tuli, "Theory of frequency modulated thermal wave imaging for non-destructive subsurface defect detection," Appl. Phys. Lett., vol. 89, no.19, p. 191913, 2006, doi:10.1063/1.2382738.
30. V. Arora and R. Mulaveesala, "Pulse compression with Gaussian weighted chirp modulated excitation for infrared thermal wave imaging," Prog. Electromagn. Res.Lett., vol. 44, pp. 133-137, 2014,doi:10.2528/PIERL13111301

Super Resolution Imaging using Off-the-Shelf Ultrasonic Probes

Gorthy Sai Shashank, Mohamed Subair Syed Akbar Ali and Prabhu Rajagopal
Centre for Non-Destructive Evaluation and Department of Mechanical Engineering,
Indian Institute of Technology Madras, Chennai-600036.
E-mail: zubair.musam@gmail.com

Abstract:

High resolution ultrasonic imaging systems are of much interest in non-invasive diagnostics and non-destructive evaluation. By harnessing the evanescent wavefield, recent developments in metamaterials offer the promise of sub-wavelength and super-resolution imaging, but such advances require sophisticated reception making practical realization challenging. Set in this context, this paper presents the development of a portable device for achieving super resolution ultrasonic imaging using conventional transducers. A prototype of the device has been built and practical super resolution ultrasonic imaging down to one-fifth of the operating wavelength is demonstrated using commercial probes.

KEYWORDS: Ultrasonic imaging, Sub-wavelength imaging, Super resolution, Metamaterials, Holey lens, Fabry-Perot resonance, Evanescent waves, Conical baffle, Commercial Transducers.

1. Introduction

Super resolution imaging systems are of much interest in fields such as non-invasive diagnostics and non-destructive evaluation. Although Ultrasonic Imaging (UI) is attractive for offering safe, cost-effective and portable inspections with good penetration [1], conventionally, this modality suffers from poor resolution. Improving the resolution requires beating the diffraction limit [2], and for this, high frequency evanescent waves which decay quickly within the near-field must be captured. However, near-field imaging [3,4] approaches typically involve complex post-processing that is sensitive to noise, making hampering practical realization. An alternative is to harness the information carried by the evanescent waves by successfully transferring them to the far-field. This approach has attracted much interest in recent years with concepts such as negative indexed media, super-lenses and hyperlenses in the electromagnetic [5-11] and acoustic domains [12-15]. Holey metamaterial lenses (or 'metalenses') are simple in design, easy to fabricate, and can be used to achieve super resolution beyond diffraction limit [16,17]. Metalenses employ Fabry-Perot resonances to amplify evanescent waves scattered by defects in the sample and transfer them to the far-field. The dimensions and arrangement of the holes in such metalens must be subwavelength compared to the incident waves used for the imaging [16]. Recent demonstrations from our research group, the Center for Nondestructive Evaluation (CNDE), IIT Madras, have shown the application of periodic [18-20] and non-periodic [21] metalenses for super resolution imaging in the ultrasonic domain.

Although the potential of metalenses in super resolution imaging is remarkable, they have only been demonstrated in laboratory experiments using heavy, sensitive and expensive equipment such as the Laser Doppler Vibrometer (LDV). This is due to the fact that for successful imaging, waves passing through the holey lenses must be captured discretely at fine spatial intervals. Capturing waves at fine intervals under water immersion is a significant further challenge. This makes the practical field implementation or widespread deployment of metalens based imaging challenging. In view of this, the work reported here focuses on developing a portable and scalable device for super resolution ultrasonic imaging (SUI) that can be used in the field without requiring special instruments for wave reception. This work also incorporates an effective signal reception technique using commercial transducers attached with a conical hollow horn [22, 23].

The paper is organized as follows. The underlying physics of the holey metalens is first described, followed by a discussion of the problem studied. The design of a super resolution imaging device is then presented, followed by the description of the prototype and experiments. Results so obtained are then presented and discussed, after which the paper concludes with consideration of implications and further work.

2. Background

Periodic holey metalenses harness Fabry-Perot resonances when the hole length L satisfies the condition:

$$L = m\lambda/2n \qquad (1)$$

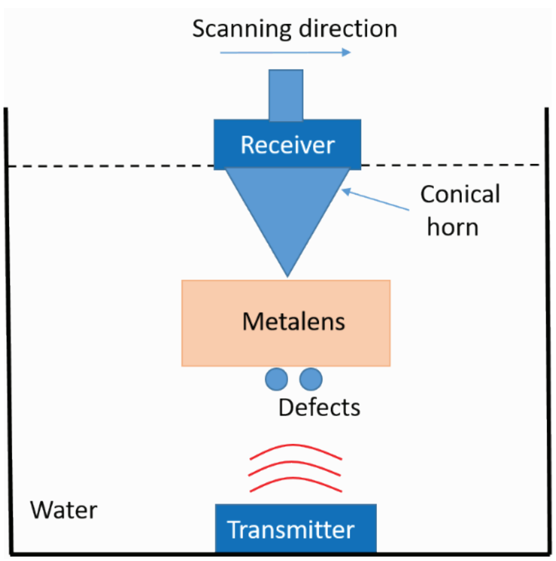
where m is an integer, λ is the wavelength of the wave used for imaging, and n is the refractive index. Consider the example of a plane ultrasonic wave with normal incidence on a defective sample. Waves scattered by the defects in the sample pass through a metalens immersed in water before being picked up by a receiver. Assuming that the features of the sample act as the perturbation to the plane wavefield, the transmission coefficient T can be expressed as [24],

$$T = 4(d/\Lambda)^2 Y e^{-ikL} / ((1+y(d/\Lambda)^2)2 - (1-Y(d/\Lambda)^2)^2 e^{2ikL})) \quad (2)$$

where d is the diameter of the hole, Λ is the periodicity of the hole array of metalens, k is the wavenumber, Y is the admittance of the waveguide mode within the holes, and L is the length of the holes. At resonance, the metalens transfers all the waves from the input side to the receiver-side without any loss. For better resolution, the geometry of the metalens should satisfy the following guidelines [19]: The diameter of the holes should be λ/n, where n is an integer of value $> = 10$. The length of the hole should be an integer multiple of half the wavelength $m\lambda/2$ and the periodicity should be $2p\lambda/n$, where m and p are integers.

3. Problem Considered

To experimentally demonstrate super resolution ultrasonic imaging using the proposed device and signal reception technique, two thin metallic rods/wires separated by sub-wavelength distance were considered as objects for imaging. Two aluminium rods of 2.5 mm diameter were used with a center-to-center distance of 5 mm, corresponding to $\lambda/5$ for a frequency of 100 kHz. The rods were placed in front of the metalens in a water bath as illustrated in Fig.1a. A 'through-transmission' configuration was considered for imaging whereby the transmitter and receiver probes were placed at either side of the assembly of metalens and rods. A 1D metalens made of stainless steel (see Figure 1b) with periodic channels/grooves of 1 mm which is much sub-wavelength to the operating frequency, was used for imaging. The length and periodicity of the channels were 45 mm and 2 mm, respectively.



(a)

(b)

Fig. 1: (a) Schematic illustration of the problem considered and (b) Photograph of the 1D metalens used for imaging.

4. Super Resolution Ultrasonic Imaging (SUI) Device

The device proposed here aims to simplify the practical super resolution ultrasonic imaging for the end user by avoiding the complex experimental setup used in laboratory demonstrations. The proposed device is a stand-alone component that allows for the easy placement of a probe, a sample specimen, a metamaterial, and a receiver. It comprises several parts, namely (a) Immersion container, (b) Positioning system, (c) Specimen holding platform, and (d) Metalens and receiver holding platform, which are described below

4.1 Immersion Container

The container is used to hold water for immersion ultrasonic scans. Also, it serves as a base for the other parts of the device. At the bottom of the container, there is a provision for placing the ultrasonic probe. It also has a pipe and drainage system for filling and emptying water. The sidewalls of the container are provided with a see-through glass window to position the specimen and metalens properly. One of the side walls has a door to enable the user to place the specimen and metalens in their respective platforms. The areas corresponding to the door and the probe are sealed with rubber gaskets to arrest water leakage. The top of the container is kept open to allow manual or automatic scanning. There is no restriction on the material of the container except that it should hold water and support the other parts of the device, so it should be rigid and rust-free.

4.2 Positioning System

The positioning system is one of the crucial aspects of the SUI device. The vertical movements of the sub-assemblies (c) and (d) are designed to be controlled by a positioning system. There are four columns designed inside the container to support the sub-assemblies (b), (c) and (d). Actions are guided along the diagonal columns for the vertical motion of the platforms used in (c) and (d). A hand-controlled knob is used to manoeuvre the positioning. For the work reported here, a positioning system based on bevel gears as shown in fig. 2 was considered. For demonstration purposes, only the vertical movement of the metalens holding platform was considered. Nevertheless, the positioning system can also be designed to allow independent motion to all the platforms holding the specimen, metalens and receiver.

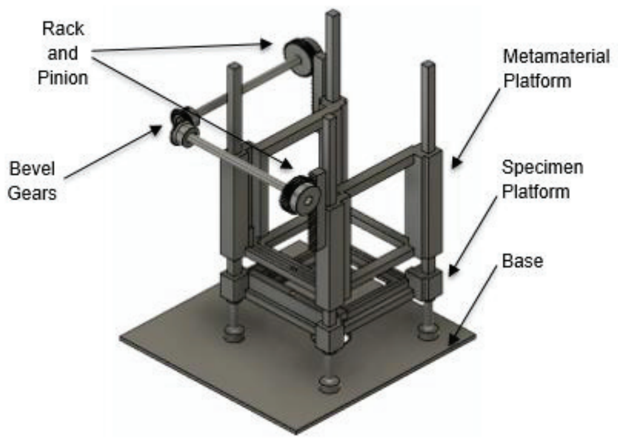


Fig. 2: Snapshot of 3D model of the bevel gear based design of the SUI device.

4.3 Specimen Holding Platform

The primary purpose of the platform is to hold the specimen in the water at a specific elevation from the probe to achieve plane wave incidence. Typically, the specimen should be kept farther ($>>\lambda$) from the transmitter to ensure a plane wave incidence, where λ is the wavelength. The rectangular holes in the platform are for guiding along the supporting columns during the vertical movements. The platform is designed to have a plug-in mechanism, where the tray as shown in fig. 3 can be pulled out through the door provided in the immersion container and plugged back after placing the specimen. A lock provided with the platform ensures that the tray does not move once placed inside. It is essential to ensure the flatness of the specimen holding platform, for which level measuring scales were given at the columns. These scales were placed next to the glass window to be seen outside. Similar scales are also provided on the platform to help center the specimen. Diagonal columns can be used to change the vertical location of the specimen after it has been placed on the platform.

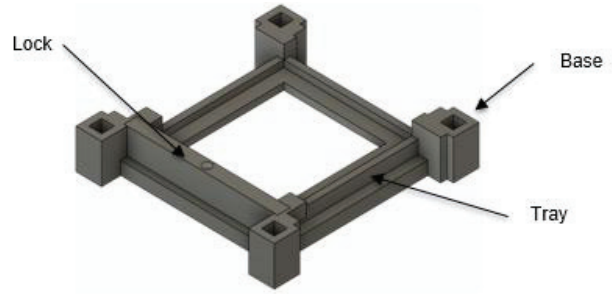


Fig. 3: Snapshot of 3D model of the specimen holding platform.

4.4 Metalens and Receiver Holding Platform

The SUI device also has the platform to place the metalens and receiver. Similar to the specimen holding platform, this platform is also designed with a plug-in/out mechanism such that the metalens can be placed by pulling the tray out through the door provided on the container. Level measuring scales are also given on the platform to position the metalens. Racks are attached on the diagonal sides of the platform to couple with the positioning system. The receiver can be positioned on top of the platform using additional supports. The receiver must be able to freely slide in both X and Y directions to facilitate the scanning. The 3D model of the metalens platform is shown in fig. 4.

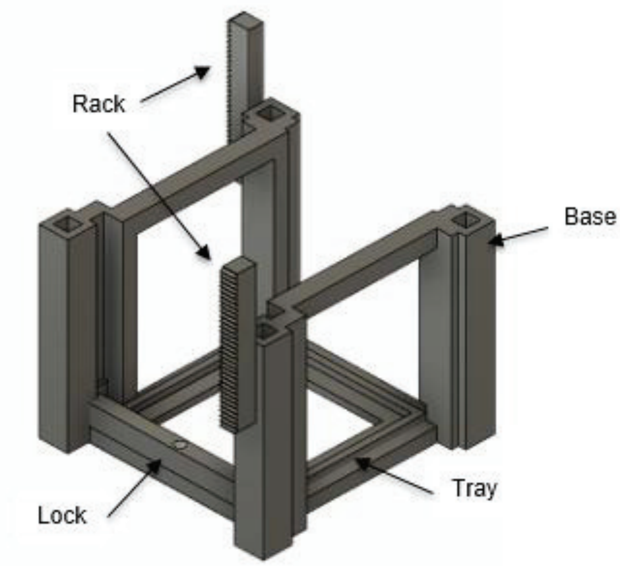


Fig. 4: Snapshot of 3D model of the metalens and receiver holding platform.

4.4.1 *Holding Mechanisms*

In practice, the samples or the imaging objects and metalenses can be of different sizes. To accommodate the various sizes of objects, the platforms need to be designed with an adjustable holding mechanism. One design can be a screw mechanism, as shown in fig. 5, which allows the two ends of the tray to move with respect to each other, allowing them to hold objects of different sizes.

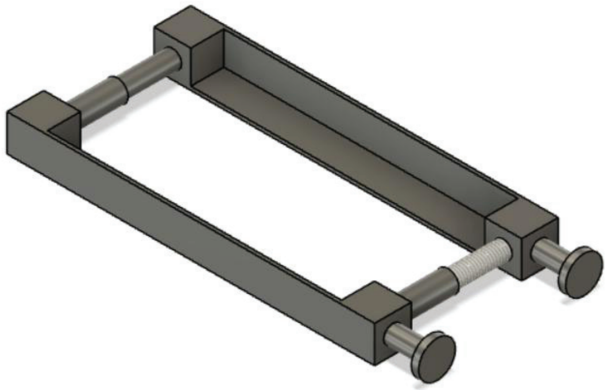
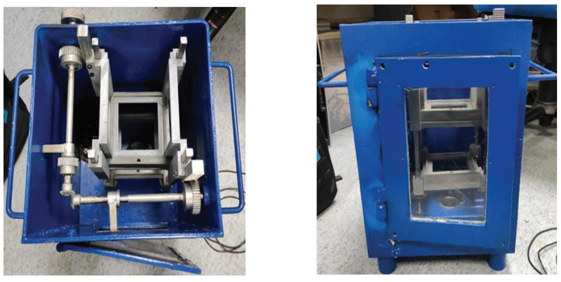


Fig. 5: Snapshot of 3D model of specimen/metalens holding platform to hold objects of various sizes.

5. Prototype of the SUI device

A prototype of the bevel gear based design of the SUI device was fabricated. The immersion container was made using stainless steel. To be cost-effective and rust-free, the steel grade 304 was used along with a coating. The prototype was made for a 100 kHz frequency imaging application where the wavelength in water is about 15 mm, and a standard probe for the given frequency has an average diameter of 40 mm. These are the main factors deciding the device dimensions, and the current rectangular container with an open top is about 250 mm x 255 mm x 350 mm. The base of the container has four circular cylinders with inner threading to fix the supporting columns in the container. A circular opening was provided at the bottom of the container to fix the probe (transmitter) from the bottom. The probe can be plugged in/out with the help of a gasket placed on the circular opening. Also, to ensure that the container's weight does not fall on the probe, four legs are provided at the bottom of the container. A door made of Plexiglass is provided on one side of the container using hinges to provide visibility during the experiment and ease of access for placing the metalens, specimen, and the receiver. To prevent water leakage, gaskets were attached to the door and provided multiple locks using the screw and nut mechanism. Figures 6a and b show the photograph of the fabricated porotype of the SUI device. Metallic racks were attached to the metalens platform with the help of screws.

In contrast, the specimen platform is stationary at a sufficient distance from the transmitter probe with the help of stoppers on the supporting columns. The positioning system, including the gears and the shafts, was also made using steel grade 304 and provided with a rust-free coating. Bearings were provided on the walls of the container to facilitate the rotation of shafts connected with gears.



(a) (b)

Fig. 6: Photographs showing the fabricated prototype of the SUI device. (a) top view, and (b) front view.

6. Signal Reception Technique

To capture the waves from each hole of the metalens discretely, a conical hollow horn attachment to a commercial probe [23] was considered. The conical add-on acts as a mechanical filter and enables a spatially narrowband or 'point' reception. The cone has a fine opening at its apex whose size is comparable to that of the hole/channel width in metalens. Thus the conical baffle serves as a bridge between each channel of the metalens with the commercial transducer and helps to capture the waves discretely. The cone was made using a 1 mm thick copper sheet with a narrow hole of less than 1 mm on its apex. The height of the cone was 15 mm, corresponding to the operating wavelength. Figure 7 shows the photograph of the receiver probe attached with the conical horn. Copper was chosen because of its higher impedance mismatch with water compared to other similar materials and ease of availability.

Fig. 7: Photograph showing the conical horn attached to the transducer.

7. Experiments

Experiments were conducted in a through transmission configuration. The probe was plugged-in into the bottom of the SUI device. The two aluminium rods with sub-wavelength separation and the metalens were placed on the respective platforms of the device. The distance between the rods and the transmitter probe was adjusted by moving the platforms using the positioning system and maintained a sufficient distance to ensure plane wave incidence on the rods. A RITEC 4000 pulser-receiver (Ritec Inc., USA) was used to give a 3 cycle Hanning windowed toneburst excitation to the transmitter probe (100 kHz, Panametrics). On the receiver side a higher frequency transducer (500 kHz, Panametrics) was used with a conical horn attachment as described in the previous section. The receiver was mounted on a moving arm of a raster scanning machine to facilitate automatic scanning. The signal received by the receiver probe was fed into a computer through a data acquisition card. The photograph of the experimental setup is shown in fig. 8. The length and step size of the line scan was chosen as 20 and 0.2 mm respectively.

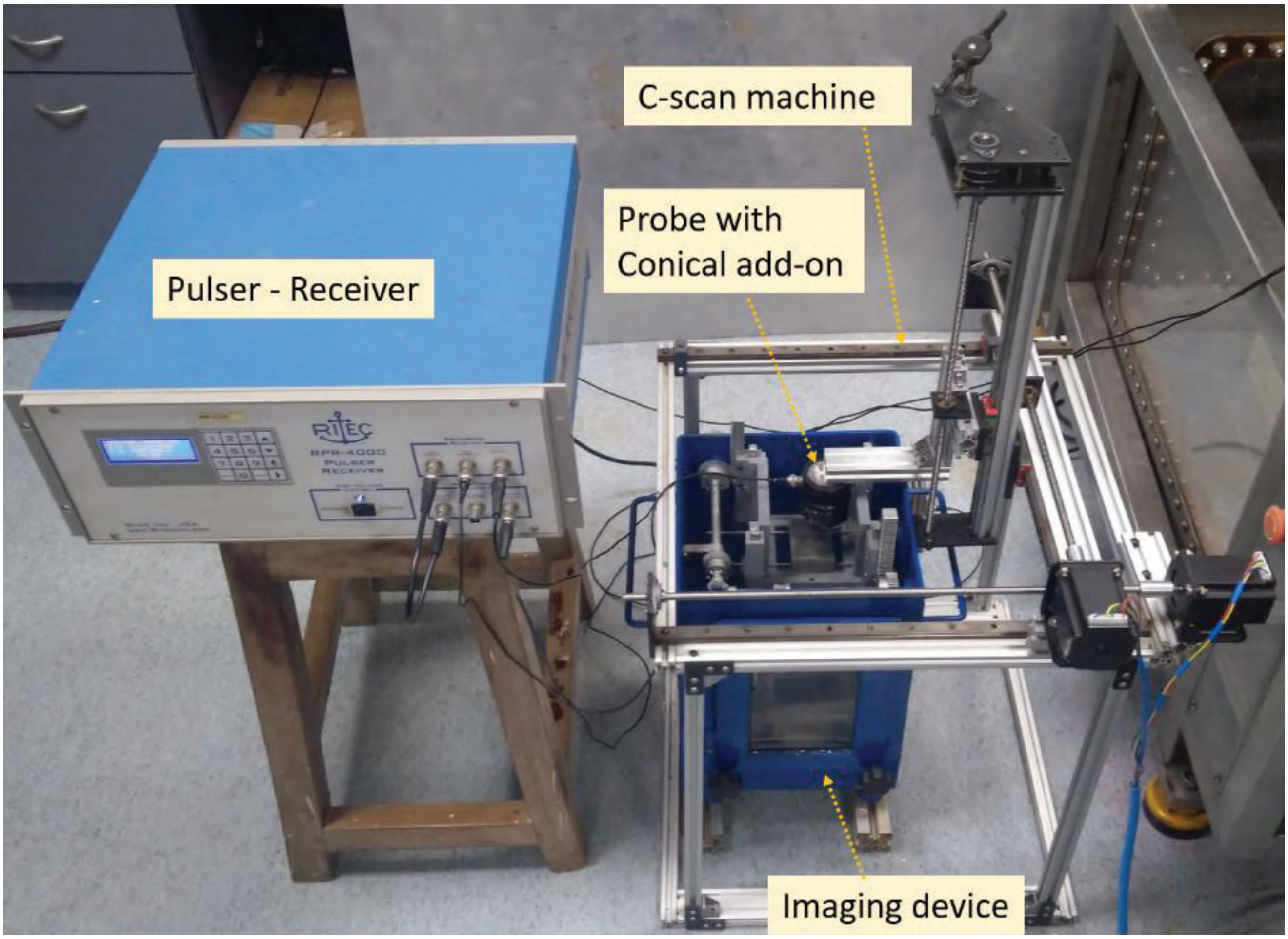


Fig. 8: Photograph showing the experimental setup for demonstrating the SUI device.

8. Results and Discussion

Experiments were performed with and without defects for comparison purposes. A line scan was conducted by acquiring the signals along the scanning direction using the conical add-on attached with the commercial transducer. The maximum amplitudes of the time-gated signals obtained from the line scan were plotted against the measurement position. The envelope of the maximum signals was plotted for the cases with and without defect, as shown in fig. 9. It can be observed that the peaks corresponding to the defects appeared when the prospective defects were placed in front of metalens, and the distance between the peaks also closely matches the sub-wavelength ($\lambda/5$) spacing between them. The deviation of the peak positions can be attributed to the wave scattering that arises from the defects and corresponds to the gap between the metalens and the tip of the conical add-on. Also, the formation of peak amplitudes corresponding to the defects is due to the scattering phenomena within the near-field, where the wave fields passing around the circular periphery of the defect meet again in the shadow region of the defect and interfere constructively.

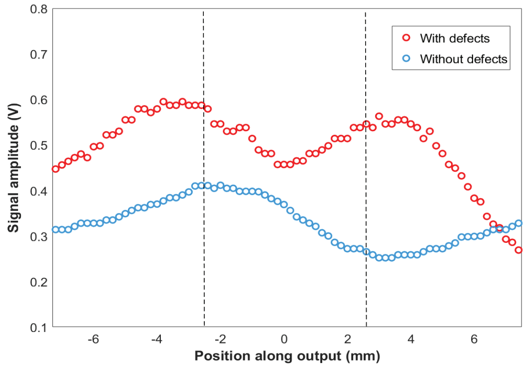


Fig. 9: Experimental results showing the envelope of maximum signal amplitude along the scan axis. Dotted lines represent the actual position of defects/scatterers.

9. Conclusion

Research reported here discusses the development of a device for practical sub-wavelength ultrasonic imaging. Imaging of defects separated by one-fifth of the operating wavelength was demonstrated successfully using a prototype of the device. The proposed device, along with the conical add-on based signal reception technique, offers a cost-effective alternative for super resolution imaging at low frequencies and can be easily implemented in industrial and biomedical fields. Further improvement and optimization of the device and the signal reception technique are expected to yield more robust and scalable practical solutions.

References

1. Gan, W. S. Acoustical Imaging: Techniques and Applications for Engineers. Chichester, UK: John Wiley & Sons, Ltd, 2012.
2. Zhang, X. and Z. Liu (2008b) Super lens to overcome the diffraction limit. Nature Materials, 7(6), 435–441.
3. Shekhawat, Gajendra S., Dravid, Vinayak P (2005) Nanoscale Imaging of Buried Structures via Scanning Near-Field Ultrasound Holography, Science, 310 (5745), 89–92.
4. Serge Mensaha and Emilie Franceschini (2007) Near-field ultrasound tomography, The Journal of the Acoustical Society of America 121, 1423.
5. Pendry, J. B. (2000) Negative refraction makes a perfect lens. Physical Review Letters, 85(18), 3966–3969.
6. Veselago, V. G. (1968) The electrodynamics of substances with simultaneously negative values of μ and ε. Sovient Physics Uspekhi, 10, 509-519.
7. Smith, D. R., J.B. Pendry and M.C.K. Wiltshire (2004) Metamaterials and negative refractive index. Science, 305, 788-792.
8. Cubukcu, E., K. Aydin, E. Ozbay, S. Foteinopoulou and C. M. Soukoulis (2003) Subwavelength Resolution in a Two-Dimensional Photonic-Crystal Based Superlens. Physical Review Letters, 91, 2074
9. Liu, Z., S. Durant, H. Lee, Y. Pikus, N. Fang, Y. Xiong, C. Sun and X. Zhang (2007b) Far-Field Optical Superlens. Nano Letters, 7, 403–408
10. Liu, Z., H. Lee, Y. Xiong, C. Sun and X. Zhang (2007a) Development of optical hyperlens for imaging below the diffraction limit. Science, 315, 1686
11. Cummer, S. A., J. Christensen and A. Alu (2016) Controlling Sound with Acoustic Metamaterials. Nature Review Material, 1, 16001, 1-13.
12. Ke, M. Z., Z. Liu, C. Qiu, W. Wang, J. Shi, W. Wen and P. Sheng (2005) Negative-refraction imaging with two-dimensional phononic crystal. Physical Review B, 72, 064306.
13. Cheng, Y., C. Zhou, Q. Wei, D. Wu and X. Liu (2013) Subwavelength acoustic focusing by surface-wave-resonance enhanced transmission in doubly negative acoustic metamaterials. Applied Physics Letters, 103, 224104.
14. He, Z., F. Cai, Y. Ding and Z. Liua (2008) Subwavelength imaging of acoustic waves by a canalization mechanism in a two-dimensional phononic crystal. Applied Physics Letters, 93, 233503.
15. Li, J., L. Fok, X. Yin, G. Bartal and X. Zhang (2009) Experimental demonstration of an acoustic magnifying hyperlens. Nature Materials, 8, 931– 934.
16. Zhu, J., J. Christensen, J. Jung, L. Martin-Moreno, X. Yin, L. Fok, X. Zhang and F. J. Garcia-Vidal (2011) A Holey-Structured Metamaterial for Acoustic Deep-Subwavelength Imaging. Nature Physics, 7(1), 52–55
17. Estrada, H., P. Candelas, A. Uris, F. Belmar, F. J. Garcia de Abajo and F. Meseguer (2010) Sound transmission through perforated plates with subwavelength hole arrays: A rigid solid model. Wave Motion, 48, 235-242.
18. Amireddy, K.K., Balasubramaniam, K., and Rajagopal, P (2016) Holey-structured metamaterial lens for subwavelength resolution in ultrasonic characterization of metallic components, Appl. Phys. Lett., 108, (22), pp. 1–6.

19. Amireddy, K.K., Balasubramaniam, K., and Rajagopal, P. (2017) Deep subwavelength ultrasonic imaging using optimized holey structured metamaterials, Sci. Rep., 7, (1), pp. 1–8.
20. Syed Akbar Ali, M.S., Amireddy, K.K., Balasubramaniam, K., et al. (2019) Characterization of deep sub-wavelength sized horizontal cracks using holey-structured metamaterials, Trans. Indian. Inst. Met., 72, pp. 2917–2921.
21. Amireddy, K.K., Balasubramaniam, K., and Rajagopal, P. (2018) Porous metamaterials for deep sub-wavelength ultrasonic imaging, Appl. Phys. Lett., 113, (12), pp. 1–61.
22. Sasaki, K., Nishihira, M., and Imano, K. (2006) Low-frequency air-coupled ultrasonic system beyond diffraction limit using pinhole, Japanese J. Appl. Physics, Part 1 Regul. Pap. Short Notes Rev. Pap., 45, (5B), pp. 4560–4564.
23. Maheswari, H., Syed Akbar Ali, M.S., Rajagopal,P. Ultrasonic imaging beyond diffraction limit using conventional transducers with conical baffles, Electronics Letters, Vol. 56 No. 19 pp. 1019–1022.
24. Taubner, T., D. Korobkin, Y. Urzhumov, G. Shvets and R. Hillenbrand (2006) Near-field microscopy through a SiC superlens. Science, 313, 1595.

NDE PATENTS

Dr. Shyamsunder Mandayam

We restarted this feature from the June 2022 issue of JNDE.

Through this feature every quarter, we intend to provide you a snapshot of some latest and important patents in the world of NDE. We also intend to use this feature to encourage the Indian NDE community to file more patents based on your innovations. We will be happy to provide guidance and assistance in different ways – Answering queries, Conducting Tutorials and webinars, One-on-one discussions, Networking with Intellectual property experts, etc.

Need help understanding, What are Patents? Why to Patent? When to Patent? What is the Patenting Process? …… Please feel free to reach out to me by email at mandayam.shyamsunder@gmail.com

Here we list below a few interesting patents related to NDE and Inspection using Infrared Imaging / Thermography.

United States Patent 10,728,426

Contrast based imaging and analysis computer-implemented method to analyze pulse thermography data for nondestructive evaluation

Inventors: Koshti; Ajay M.

Assignee: United States of America as represented by the Administrator of the National Aeronautics and Space Administration (Washington, DC)

Methods and systems for analyzing and processing digital data comprising a plurality of infra-red (IR) video images acquired by a pulse thermography system are used to compute video data from the raw and smoothed video data acquired for the performance of non-destructive evaluation. New video data types computed may include but are not limited to contrast evolution data such as normalized contrast, converted contrast and normalized temperature contrast. Additionally, video data types computed comprise surface temperature, surface temperature rise and temperature simple contrast.

United States Patent 11,249,039

Method of measuring depth of defects in large-scale wind turbine blade using infrared thermography

Inventors: Zhou Bo

Assignee: Shenyang University of Technology (Liaoning, CN) Shenyang Daxingcheng Energy Technology Co., Ltd (Liaoning, CN)

The invention relates to the technical field of operation and maintenance of wind turbines, and is also applicable to non-destructive measurement of a depth of a defect of other resin-based composite materials. It is aimed at the problem that the depth of the defect cannot be determined by an intuitive infrared thermal image in the measurement of a depth of a defect of a large wind turbine blade. This method not only ensures accuracy of the measurement, but can also be widely applied. The method comprises the following steps: S1: continuously heating a surface of a wind turbine blade with an irradiation heat source; S2: collecting and storing a real-time heat map sequence of a surface of the blade with an NEC R300 infrared thermal imaging camera; S3: extracting a surface temperature rise curve at a defect location and organizing the results into a temperature rise curve family of the layers in a depth direction at the defect location; S4: extracting a surface temperature rise curve at a non-defect location, and calculating the similarity between the two temperature rise curve families; S5-S7: obtaining a reference depth value of the defect; and S8: determining whether the depth value is in a characteristic interval.

PATENTS

United States Patent 11,218,112

Silicon photovoltaic cell scanning eddy current thermography detection platform and defect classification method

Inventors: Inventors: He Yigang, Du Bolun , Zhang Yaru, Duan Jiajun, He Liulu

Assignee: WUHAN UNIVERSITY (Hubei, CN)

The disclosure provides a silicon photovoltaic cell scanning eddy current thermography detection platform and a defect classification method. The technical solution adopted by the disclosure is: firstly, fixing the position of the electromagnetic inductive coil and the thermal imager, and using the main conveyor belt to carry the silicon photovoltaic cell to move forward on the production line to form a scanning eddy current heating of the silicon photovoltaic cell. Secondly, the defect temperature information is obtained through the thermal imager in terms of thermal image sequences. Thirdly, the feature extraction algorithms are used to extract the silicon photovoltaic cell defect features. Finally, the image classification algorithms are used to classify the silicon photovoltaic cell defects, and the sorting conveyor belts are used to realize the automatic sorting of silicon photovoltaic cells with different types of defects on the production line.

United States Patent 11,054,376

Method for inspecting composite structures using quantitative infra-red thermography

Inventors: Villette Thibault, Traidia Abderrazak

Assignee: Saudi Arabian Oil Company (Dhahran, SA)

A system and method for inspecting a surface of a structure for defects includes an inspection apparatus having a heating device for heating a section of the surface of the structure, an infrared camera for receiving infrared radiation from the surface in response to heating, a controller configured to generate thermographs from the received infrared radiation, and a communication device. A training system includes an expert system module configured to determine correlations between a set of thermographs generated by a thermal simulation of modeled structural elements with defects, and parameters of the modeled structural elements. A computer system communicatively coupled to the training system and the inspection apparatus, is adapted to receive thermographs received from the inspection apparatus and to detect quantitative parameters of defects in the structure using the correlations obtained from the training system.

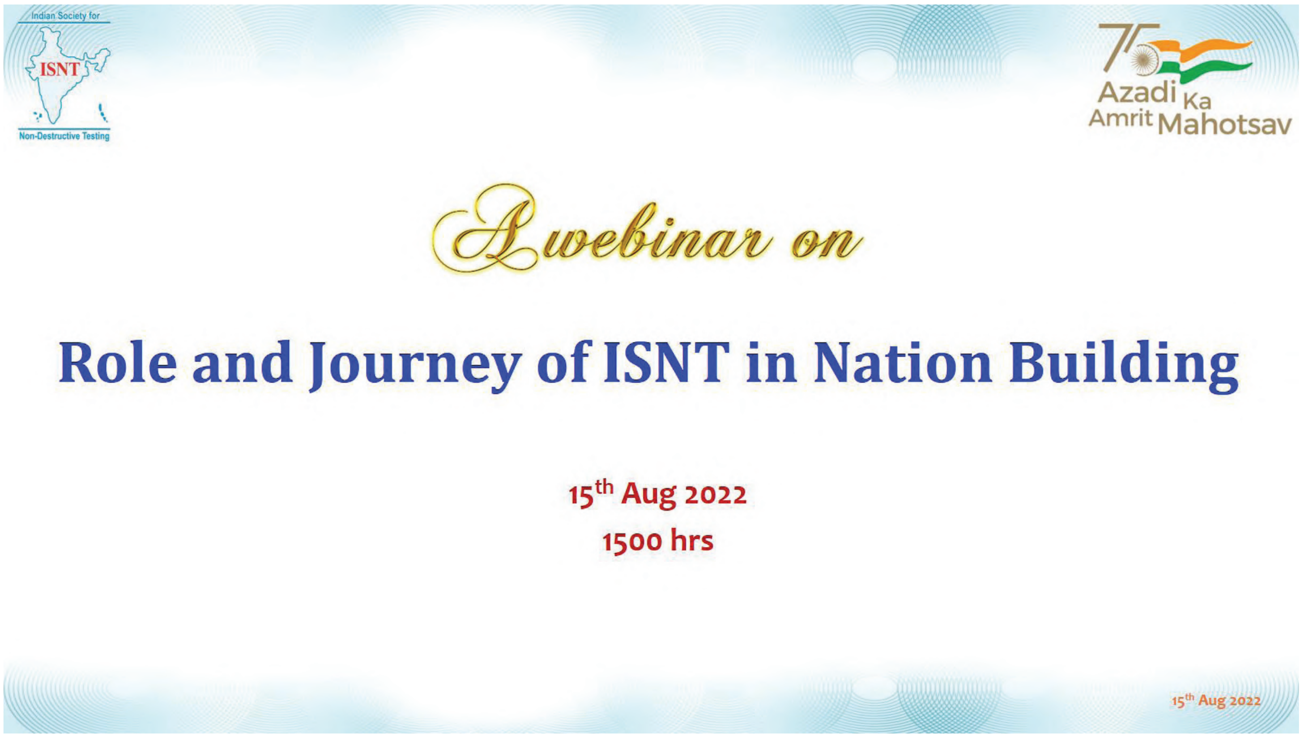
United States Patent 10,908,068

Thermography image processing with neural networks to identify corrosion under insulation (CUI)

Inventors: Amer Ayman, Al Shehri Ali, Parrott Brian, Sarraj Mohammed

Assignee: Saudi Arabian Oil Company (Dhahran, SA)

A method for identifying corrosion under insulation (CUI) in a structure comprises receiving thermographs from the structure using an infrared camera, applying filters to the thermograph using a first machine learning system, initially determining a CUI classification based on output from the filters, and validating the initial CUI classification by an inspection of the structure. The first machine learning system is trained using results of the validation. Outputs of the first machine learning system and additional structural and environmental data are fed into a second machine learning system that incorporates information from earlier states into current states. The second machine learning system is trained to identify CUI according to changes in the outputs of the first machine learning system and the additional data over time until a second threshold for CUI classification accuracy is reached. CUI is thereafter identified using the first and second machine learning systems in coordination.



A webinar on "Role & Journey of ISNT in Nation Building" to Celebrate Azadi Ka Amrit Mahotsav

- Bikash Ghose, Hon Gen Secretary

To commemorate 75 years of independence of India, the glorious history of its people, culture and achievements, the country is celebrating the "Azadi Ka Amrit Mahotsav" in a grand manner.

*To synergize the celebration, ISNT had organised a webinar on **"Role and Journey of ISNT in Nation Building"** which brought out the genesis, glorious years and the way forward for ISNT and its role and contributions in the Nation Building along with the way ahead for NDE. More than 25 Speakers have delivered their Talk.*
*The webinar of five-hour duration was conducted **at 1500 hrs on 15th Aug 2022**, the 76th independence day of India.*
Members of ISNT joined in large numbers, celebrated & cherished the unique occasion and celebrated together the occasion of Azadi Ka Amrit Mahostav.
The webinar brought out the Genesis & Glorious years of ISNT, ISNT as the organization and enabler for HR & skill development. The webinar also highlighted the role ISNT played and contributed during all these years of its existence in the Nation building in various sectors. It covered the aspects of career opportunity in NDE & role of ISNT, the role of ISNT in NDE 4.0, AI & ML. The webinar has discussed the innovation in NDE, Startup ecosystems and the way forward for ISNT for synergetic contributions to the growth of the Nation.

The program was befitting to the occasion and was a grand success. It was well appreciated by the participants.

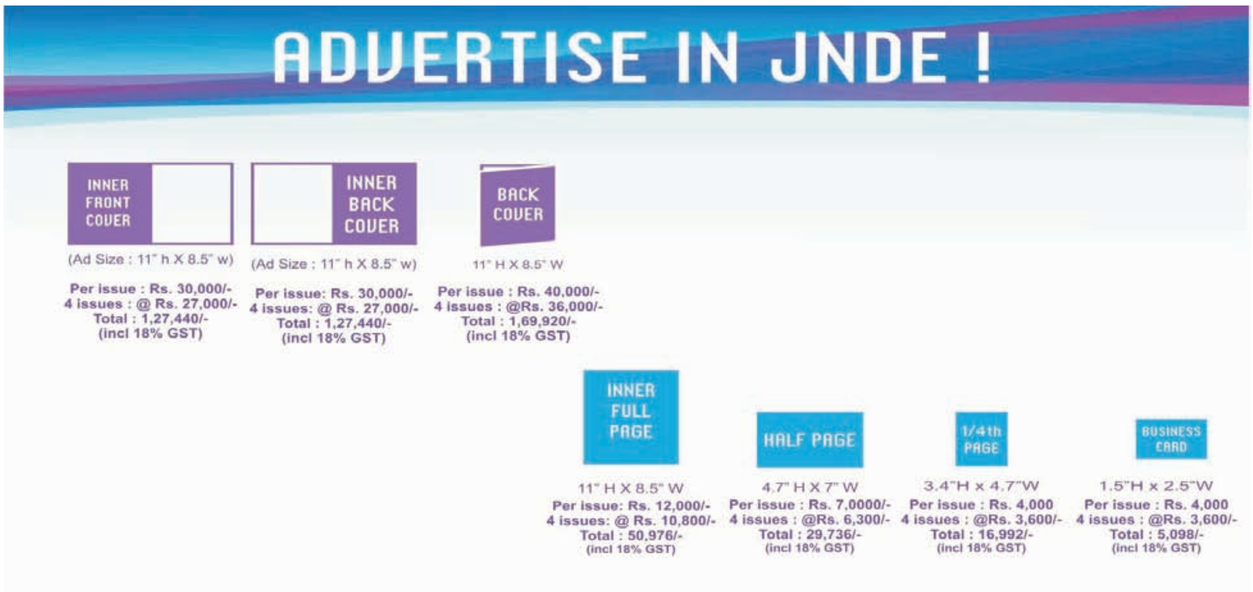
The program details are as follows

A webinar on Role & Journey of ISNT in Nation Building

Details	Speakers
Virtual Lighting of Lamp	
Welcome Address	Shri Bikash Ghose
Presidential Address	Shri Diwakar D. Joshi
Genesis of ISNT	Shri K. Vishwanathan
Glorious journey of ISNT	Dr. B Venkatraman
ISNT: The organization, its wings, their roles and the reckoning force in NDE. Role of ISNTfor a safer and better quality of life	Shri V Pari
ISNT : Enabler for human Resources development, skill development and a force multiplier	Dr. R J Pardikar
Role of NDE & ISNT in Nation building in the area of	
Power	Shri A K Das
Defence	Shri G V Sivarao
Space	Dr. M Arumugam
Nuclear & Atomic Energy	Dr. Anish Kumar
Oil & Gas	Shri UmakanthanAnand
Aeronautics	Shri P Vijayraghavan
Manufacturing	Shri AnandBagdare
Manufacturing of NDE equipment	Shri Rajul Parikh
NDT training	Ms. Navita Gupta
NDT service	Shri ChintamaniKhade
Civil Infrastructure & Railways	Shri S G S Murthy
Synergy for NDE with Atmanirbhar	Lt. Gen. V J Sundaram
NDE : Opportunity for career prospective and the role of ISNT	Shri V Manoharan
NDE: Enabler for Sensing and Decision making through Data Analytics, AI & ML in NDE and role of ISNT	Shri Krishna M Reddy
NDE in Startup Ecosystems of India and the success stories. Role of ISNT	Prof. PrabhuRajagopal
Role of ISNT in NDE 4.0	Dr. M T Shyamsunder
Innovations, Current trends & future of R&D in NDE, Asset integrity Management through NDE and the role of ISNT	Prof. Krishnan Balasubramaniam
Challenges and Way forward – NDE & ISNT	Dr P Nanekar
Vote of Thanks	Shri Kalesh Nerurkar
National Anthem	


Indian Society for
ISNT
Non-Destructive Testing
Speakers
Azadi Ka Amrit Mahotsav
Diwakar D Joshi
K Vishwanathan
Dr B Venkatraman
V Pari
Lt Gen V J Sundaram
K M Reddy
Rajul Parikh
G V Sivarao
V Manoharan
Dr Anish Kumar
Prof Krishnan Balasubramaniam
P Vijayraghavan
Dr Shyamsunder M
Dr R J Pardikar
A K Das
U Anand
Dr M Arumugam
SGN Murthy
Anand Bagdare
Navita Gupta
Chintamani Khade
Prabhu Rajagopal
Paritosh Nanekar
Bikash Ghose
Indian Society for Non-destructive Testing (ISNT)
Enriching Lives through NDE
A webinar on
Role & Journey of ISNT in Nation Building
15th Aug 2022

Journal of Jnde
Non Destructive Testing and Evaluation



10% discount for 4 issues with full advance payment
Advertisement material should be sent in PDF format with high resolution

Telephone: 044 22500412
Email: isnt.jnde@isnt.in


bsi.
ISO
9001:2015
Quality
Management