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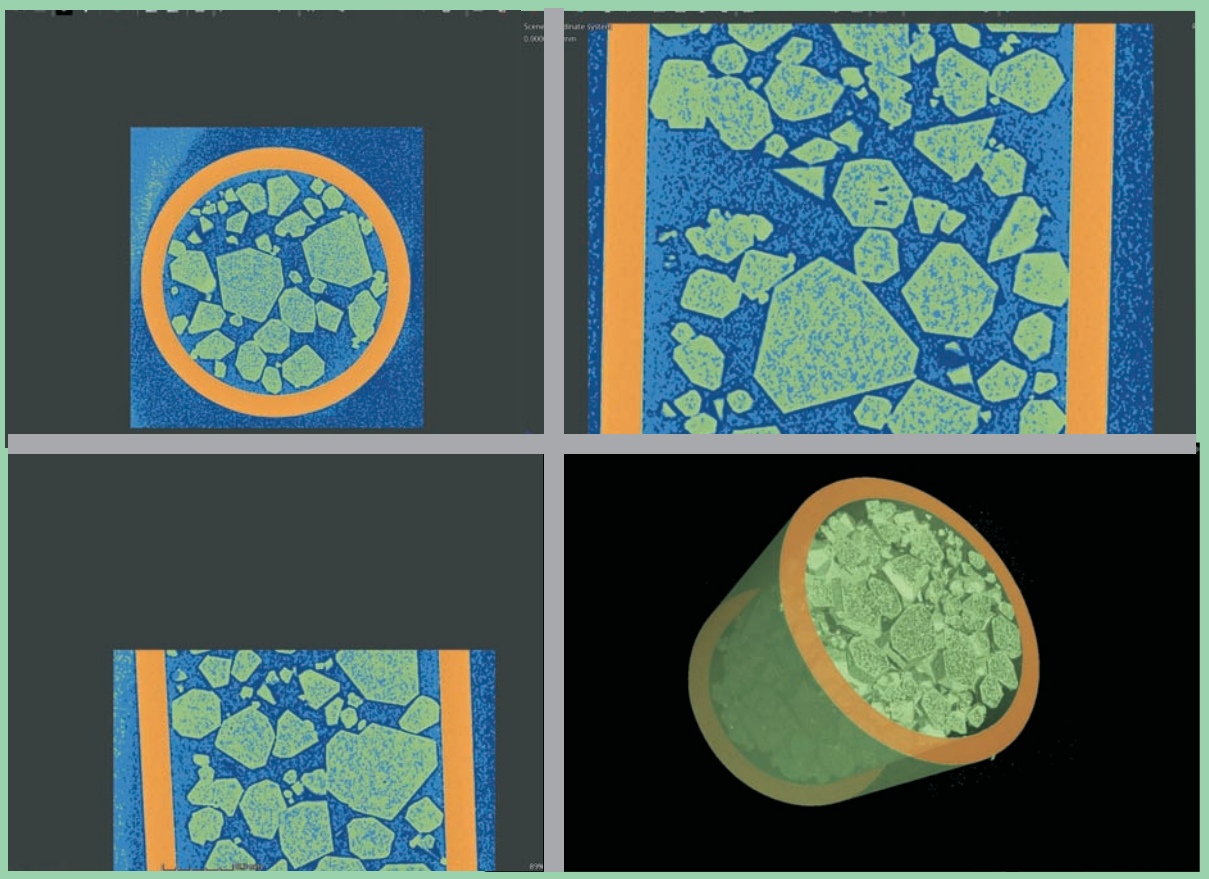
# Journal of Indian Society for Non Destructive Testing and Evaluation

**An Official Journal of the Indian Society for Non Destructive Testing**



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Guindy, Chennai-600032.
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An ISNT Publication

www.isnt.in

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

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Journal of JNDE Non Destructive Testing and Evaluation "Connecting NDT Professionals" AN ISNT PUBLICATION

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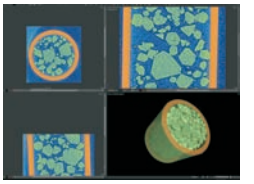

3D Nano CT image of organic salt in powder form kept in a cylindrical tube of outer diameter 1.2 mm. The cross sectional view in 3 orthogonal axes are also shown.
Courtesy HEMRL, Pune


**OBJECTIVE** – This Journal of Non Destructive Testing & 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 Memebership Contact**

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LETTERS

# PRESIDENT Talk

**Diwakar Joshi**
**President – ISNT**
**president@isnt.in**

Greetings to all of you!

It is good to see that the JNDE issue is back on track! You may have already gone through the March issue. Thanks to all authors, editorial board, advertisers and the whole team to get it back on track.

A lot of things happened in the past three months. The Training Management Board, the youngest body of ISNT, is already fully active. Training authorization schemes for IS 13805 certification and ICN certification are already prepared by the team of experts and it will go for implementation very soon. I am sure that training being the backbone of the certification scheme this is going to show excellent results in the coming days.

The NCB exams too are in an upward trend. In the past 3 months, more than 150 candidates have appeared for the NCB examination. This shows the confidence of the stakeholders in the ISNT certification scheme.

NCB is gearing up to improve the examination material. A set of new specimens, question banks etc. were acquired to enrich the examination material and keep up with the requirements.

Our online application forms system is already implemented and well appreciated by the stakeholders

It is heartening to note that the chapter activities have also accelerated with the number of courses and webinars going up.

Our next challenge is NDE 2022. Not having the seminar offline for the past two years creates a bigger challenge, as if we are restarting. But I am sure with the efforts that all of you are willing to put in, this too shall be a cakewalk for all of us. You will of course be continuously communicated what is happening and where we need you.

The issue in hand is dealing with relevant practical NDE applications and covering Structural Integrity area and Evaluation of Fitness for Service.

I am sure you will enjoy this issue, just as you enjoyed all our past issues!

# MANAGING EDITOR

**Bikash Ghose**
**Managing Editor, JNDE**
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I am excited to share that NDE-2022 will be organised at an exciting venue, Mahatma Mandir Convention and Exhibition Center (MMCEC), Gandhinagar, Gujarat, INDIA, from 24th -26th November 2022. This annual flagship program is back in Physical form after three years. We are eagerly looking forward to meeting you at the conference venue. I request each of you to support this landmark event and urge you to get the update on the event on the conference website www.isntnde.in.

The newly formed board of ISNT, "Training Management Board (TMB)", is working in full swing and now geared up to launch the mandatory authorisation process of training bodies/institutes for undertaking training and examination under IS13805 and ICN. With this authorisation process, the National Certification Board (NCB) will now take a leapfrog and will certify personnel as per International Certification on NDT (ICN) scheme of ISNT in accordance with ISO 9712.

The current issue of JNDE has glanced at the activities conducted by various chapters of ISNT across the country from March-May 2022. This issue also presents four interesting technical papers on different topics of interest. I hope this issue will be quite engaging for all. Thanks to all stakeholders for helping these issues be released on time.

The online version of the JNDE is now launched andis available at http://jnde.isnt.in. This online issue contains four technical papers and related contents, starting from this June 2022 issue. This will ensureexcellent visibility of the papers published in JNDE. Google Scholar now indexes the papers published on the online platform of JNDE.

Happy reading!!

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- Portable Ultrasonic Flaw Detector
- Phased Array
- Thickness Gauges
- Reference Blocks
- Probes & Accessories
- Rail & Axle Tester



## Magnetic Particle

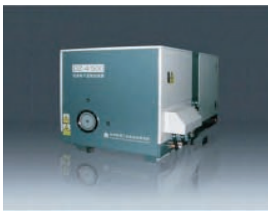
- Prod Units
- Yokes
- Bench Units
- Ultraviolet Black Light
- Consumables & Essentials



## Radiography

- Gamma Ray Projectors
- IR-192,Se-75, Co-60 Sources
- Linear Accelerator
- Digital Radiography
- Radiation Detection & Monitoring Devices



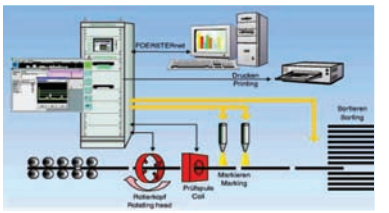



## Ultrasonic Systems

- On Line / Off Line Systems
- Bar Testing
- Pipe Testing
- Piston Testing
- Component Testing


## Eddy Current

- Sorting Equipments
- Component Testing Equipments
- Material Testing Equipments
- Portable Instruments





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Nov 2021/ TP

CHAPTER SPACE

# CHAPTER News FOR THE PERIOD FROM APRIL 2022 TO JUNE 2022

## CHENNAI CHAPTER

Surface NDT (MT & PT) Level-II course and examination was held on 21st April 2022 to 30th April 2022. Number of candidates attended the course were 23 and examination was 24.

RT Film Interpretation Level-II course and examination was conducted from 9th May 2022 to 14th May 2022. Number of candidates attended the course and examination was 6.

Ultrasonic Testing Level-II course and examination was held on 24th May 2022 to 04.06.2022. Number of candidates attended the course and examination was 15.

ISNT Chennai Chapter and CNDE of IIT Madras jointly conducted the 1st talk on "Artificial Intelligence (AI) in NDE" by Prof. Krishnan Balasubramanian, Institute Professor – IITM Chennai on 11.05.2022 at 5.30 PM through MS teams.

One day Workshop on NDE was conducted to college students of Society of Materials Science Engineers, College of Engineering, Anna University, Guindy, Chennai on 27th April 2022.

ISNT Day function was conducted in a grand manner at Hotel Quality Inn Sabari on 21.04.2022. A total of around 128 personnel (members and their family) attended the function.

Mr. R. Vivek was the Convener of the meeting. Mr. S. Subramanian Chairman presided over the meeting Chief Guest of the day was Mr. H. Shankar, Director - Technical, CPCL, Chennai and Guest Speaker was Rtn. Dr. S. Sushithrra Raajh.

The faculties, the examiners and the laboratories associated with the Chapter were honoured and mementos were presented.

The Best Member Award "Thambidurai Award" sponsored by M/s. Electro-Magfield Controls & Services was awarded to Shri S. Velumani.

The Best Technical Talk Award "Rajamani Award" sponsored by M/s. Electro-Magfield Controls & Services was awarded to Dr. Debasish Mishra, GE, Bangalore for the year 2020.

The Best Technical Talk Award "Rajamani Award" sponsored by M/s. Electro-Magfield Controls & Services was awarded to Prof. Balaji Srinivasan, IIT, Chennai for the year 2021

The Best Participation in courses Award "Pari Award" sponsored by M/s. QTECH was awarded to Ms. R. Gayatri, Naga Engineering, Chennai for the year 2020.

The Best Participation in courses Award "Pari Award" sponsored by M/s. QTECH was awarded to Mr. Akash Singh, EIL, Chennai for the year 2021.

EC Meeting was held on 20th March 2022

EC Meeting was held on 15th May 2022.

Opening student chapter at Eswari Engineering college on 19.04.2022.

## 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 |
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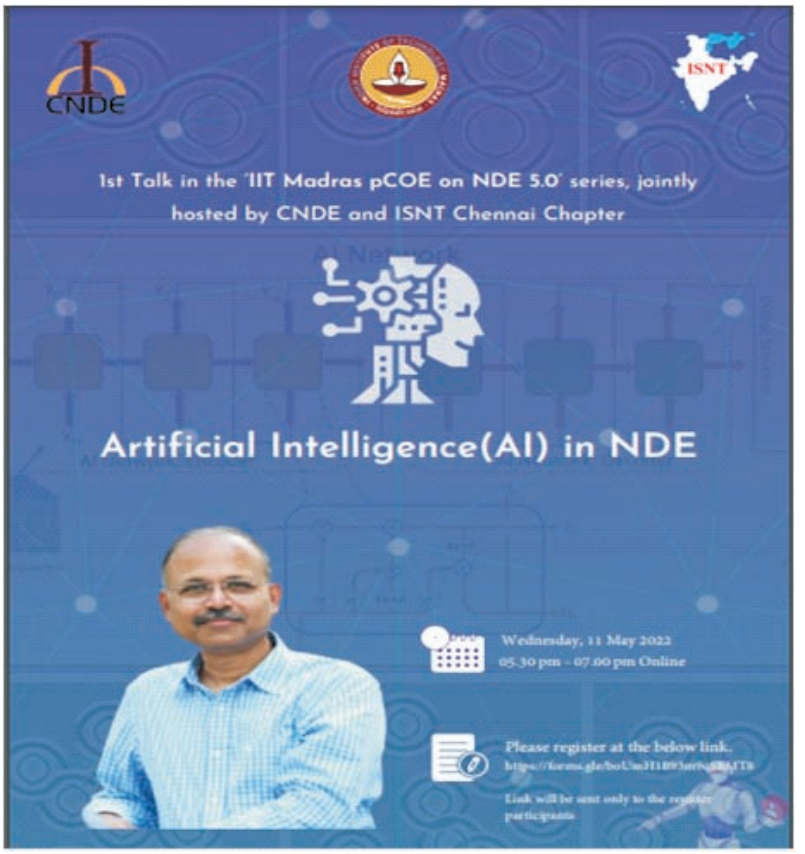
ISNT CHENNAI STUDENT CHAPTER INAGURATED ON 19-04-2022 AT EASWARI ENGINEERING COLLEGE




Technical talk on "Artificial Intelligence (AI) in NDE" by Prof.Krishnan Balasubramanian, Institute Professor – IITM Chennai on 11.05.2022 at 5.30 PM

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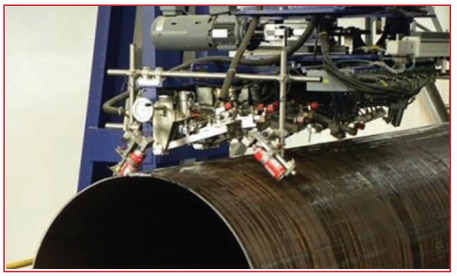

Ultrasonic Systems

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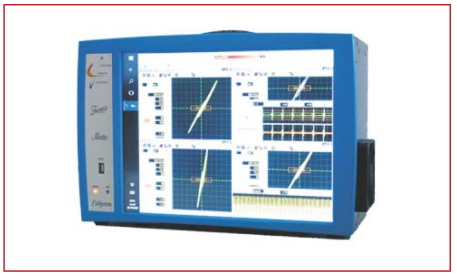

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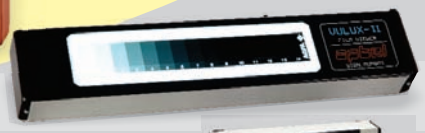

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## CHAPTER News FOR THE PERIOD FROM DECEMBER 2021 TO MARCH 2022

THE FACULTIES, THE EXAMINERS AND THE LABORATORIES ASSOCIATED WITH THE CHAPTER WERE HONOURED AND MEMENTOS WERE PRESENTED


DURING ISNT DAY CELEBRATION, A TOTAL OF AROUND 128 PERSONNEL (MEMBERS AND THEIR FAMILY) ATTENDED THE FUNCTION

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CHAPTER SPACE

# CHAPTER News FOR THE PERIOD FROM DECEMBER 2021 TO MARCH 2022

## JAMSHEDPUR CHAPTER

Ultrasonic (UT) Level-II Course conducted during the period 21st Feb to 5th March 2022. The examinations for practical and theory were held.

Venue: CSIR-National Metallurgical Laboratory, Jamshedpur.

There were overall 17 participants in the UT level-II training course.

## KOLKATA CHAPTER

Ultrasonic level II conducted 21st March 2022.

EC meeting -8th April 2022

## KOTA CHAPTER

Ultrasonic Testing level-I & II (From 25.04.2022 to 01.05.2022)

Leak testing Level -I &II (From 06.05.2022 to 13.05.2022)

Executive Body Meeting on 31.03.2022

General Body Meeting for EB election on 11.04.2022

## MUMBAI CHAPTER

PT III & UT III Online Training program was conducted virtually from 7th Mar – 10th Mar & 14th Mar – 20th Mar. Candidates – 10nos.

Technical Lecture :

1. NDT Requirements in shipbuilding by Mr. U. S. Kalghatgi was conducted virtually on 26th Mar, 2022

2. NDT Aerospace Industry by Mr. Shakti Singh was conducted virtually on 24th April, 2022

AGM was held on 25th Mar, 2022 virtually on MS Teams.

## PUNE CHAPTER

EC meeting No. 5 Conducted on dated 26.03.2022.

Program of New version of Website opening Ceremony of Pune Chapter conducted on dated 02nd of April 2022. There were 32 nos. of members present during online ceremony.

## TRIVANDRUM CHAPTER

ISNT DAY LECTURE-by Shri. Sridhar S, Group Head, CCQG/CMSE, VSSC/ ISRO on 20.04.2022

Student Chapter Activities:

Lecture on Ultrasonic Testing- Theory and Practice at Sri Chithira Tirunal College of Engineering, Thiruvananthapuram on 07.05.2022.

## TARAPUR CHAPTER

1. Two nos. EC meeting is conducted.
2. Life membership nos. was allotted to 11 members after continuous follow up with HQ.
3. Account Audit for the year 2021-22 draft is under review.

Examination for Revalidation of CWI NDT certificates is planned in the month of May 2022

## TRICHY CHAPTER

Surface NDT (PT) Level-II course completed during 12-05-2022 to 17-05-2022. Number of candidates attended the course were 11.

UT Level II course is under progress from 18-05-2022. Number of candidates attending the course 11.

EC Meeting was held on 11th-May-2022

## VADODARA CHAPTER

On 06-May-2022, Hon. President Shri Diwakar Joshi visited ISNT Vadodara Chapter office.

Hon. President also met with EC members of ISNT Vadodara Chapter at Hotel Suba Elite. He shared his vision for ISNT with EC Members of ISNT Vadodara Chapter.

On behalf of EC Members of ISNT Vaddodara Chapter, Hon. Chairman Shri R. Venkatasubramanian assured him all support from ISNT Vadodara Chapter for all activities of ISNT. The meeting was followed with Dinner.

**FOR THE PERIOD FROM DECEMBER 2021 TO MARCH 2022**

## Meeting Schedules

The proposed dates for Meetings for the year 2022

| Date | Meeting | From | Time |
|---|---|---|---|
| 18th June 2022 (Saturday) | TMB | 11:00 hrs | 13:00 hrs |
| | NCB | 14:30 hrs | 16:30 hrs |
| | Steering Committee | 16:45 hrs | 17:45 hrs |
| 19th June 2022 (Sunday) | NGC | 09:30 hrs | 14:00 hrs |

| Date | Meeting | From | Time |
|---|---|---|---|
| 10th September 2022 (Saturday) | Chapter Chairmen's Meeting | 10:00 hrs | 12:00 hrs |
| | TMB | 12:00 hrs | 14:00 hrs |
| | NCB | 15:30 hrs | 17:30 hrs |
| | Steering Committee | 17:45 hrs | 18:45 hrs |
| 11thSeptember 2022 (Sunday) | NGC | 09:30 hrs | 14:00 hrs |

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Mr. S. Harikrishna, Hon. Secretary
Mr. Partha Pratim Brahma, Controller of Authorisation

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## 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

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# Investigation of Structural Integrity and Stability Evaluation of Fire Affected Building by Non-Destructive Testing

K. N. Lakshmikandhan*,1 J. Prabhakar* and K. Sivasubramanian*
* Scientists, CSIR-Structural Engineering Research Centre, Tharamani, Chennai.600113
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## Abstract

**The structural integrity evaluation of building is an important concern in any post disastrous situations like earthquakes, fires, and etc. Fire hazard is probably initiated by the small electrical leakages or unnoticed straining in the building premises. However, such situations are controlled by manual or automatic surveillance. In Covid-19 scenario, many industrial buildings were under lock down and the monitoring of fire accidents became difficult. Such an event occurred in a Chennai industrial estate and the fire has caused huge structural and non-structural damages. A detailed visual inspection study is carried out. The structural beams, columns and slabs have been affected with micro to macro cracks and spalling of cover concretes. Reinforcements are exposed fire and some members are severely deformed. The extent of fire has been investigated using neutralisation test, relative geometrical variation measures. The structural integrity of structural elements are assessed using Non Destructive Testing (NDT) and Partial Destructive Testing (PDT). Using cores, the neutralization test and compressive strength tests are carried out. From the visualisation study, it has been observed that about 60 to 70 % of the structure is severely affected by fire. The NDT and PDT results indicated that the surface hardness, strength and integrity of concrete are severely affected due to fire. The neutralisation test indicates that about 50 mm depth of the concrete become acidic nature. The relative dimensional measures agreed with NDT and PDT findings and indicated that, the structural components are excessively deformed and it is not fit to usage without rehabilitation and structural restoration.**

**Keywords: NDT; Condition assessment; Structural Stability; PDT**

## 1. Introduction

In general belief in common is that the concrete is a non-combustible nature and it has an ability to preventing heat and the spreading of fire. Even the engineers and researchers are finding difficulties to clearly understand the nature of fire and its influence of different concrete materials. Based on the preambles of research, the design criteria are arrived and usually recommends adequate concrete cover to the reinforcement [4]. In reality, at a distinct point of heat, it is hard to believe that the concrete is also vulnerable for the safety. The problems appear to be equally severe for concrete columns and beams. When the concrete heated to a prolonged higher temperature undergoes explosive thermal spalling, thermal fracture, and disintegration due to dehydration [12]. The concrete structures are need to be designed with higher precautions on fire incidences.

### 1.1 Performance of concrete during fire

The reinforced concrete structures are normally good in fire resistance compared to the steel and other metal structures and they are found slightly inferior compared to the solid wooden structures. Due to the lower thermal conductivity and non-flammability, the concrete structures are performing well under fire of up to 300°C. It develops micro cracks on the concrete surface without any major loss to its strength and functionality. When the temperature increases beyond 300°C affects the concrete integrity due to the volumetric expansion of aggregates and, the moisture filled micro and macro voids present in the concrete [5]. The micro cracks affect the surface integrity of concrete and it reduces the compression strength of concrete and it affects the tensile strength of concrete. The incompatibility of thermal strains leads to the straining of the heterogeneous composite system and forms numerous micro and macro cracks in the interfacial transition zone, and result in degradation of the mechanical and physical properties [3,10]. The reduction in mechanical properties are also influenced by the method of cooling or breaking the fire [1,2]. The further increase in temperature fracture the surface cover concrete and heat up the inner concrete portions. During fire, many factors are affects the changes in the strength characteristic of concrete including size, source and position of aggregates, cement, duration and intensity of heating, the mix design and etc. [9]. The functionality of reinforced concrete structural system has been affected when the structure is exposed to temperature between 600°C and 1,400°C. The higher exposure of temperature modifies the chemical characterisation of concrete and weakens the physical properties. The concrete colour changes and the colour variation is depending on the duration and the intensity of heat exposure. For higher exposure conditions, the concrete's normal light grey becomes dark pink or red [11].

The moisture present in the inner pores are heated up and escalates the pore pressure and forms micro cracks on the surface and it allows the fire to directly contact to the inner surfaces of cover concrete and it leads to the further widening of cracks which leads to the falling cover concrete. Irrespective of the concrete mix proportions, the microstructure of normal and high strength concretes exhibits an analogous trend against the contact temperature [3]. The increase it temperature affects the performance of steel. The physical and mechanical characteristic steel is drastically affected during the prolonged temperature greater than 800°C. The steel conducts the heat at a higher rate to the entire portion of structures and it significantly reduces the strength of steel and lead to the failure of entire structure in catastrophically.

## 2 General Observation on Post Fire Study of Reinforced concrete – A Case Study

### 2.1 A Visual Observation Study

The structure is primarily constructed and used for the research and development activities on polymerisation process and a development of adhesive components. The structure has been used for storing highly inflammable components. The fire safety systems are installed in the entire building premises ad due to the COVID19, the entire industrial estate have been closed and the fire incident was unnoticed at the initial stage. The post fire analysis is started with investigating the structure with visual observation. In general, visual inspection can partly decide on the quality and integrity of fire affected building for taking a decision on the possibility of further operation of the facility. The typical view of fire affected building is shown in figure.1. The fire affected building is of G+2 story with RCC framed structure and partially loading brick masonry. RCC columns are placed in three rows along the length directions. These columns are spaced at 3.0 m intervals along the longer directions.

In the ground floor area, there rooms for administration, meeting Chamber, Instrumentation & Testing, Main entrance & reception area, Record Storage, Staircase area, Conference Hall, Raw materials Storage, EB room and Materials Processing area. All these areas were visually inspected and documented. The fire is probably started by electrical short-circuiting. The cables, panels and supporting systems are completely burned and it has spread into the adjacent rooms which are meant for conference and for storage of raw materials. The

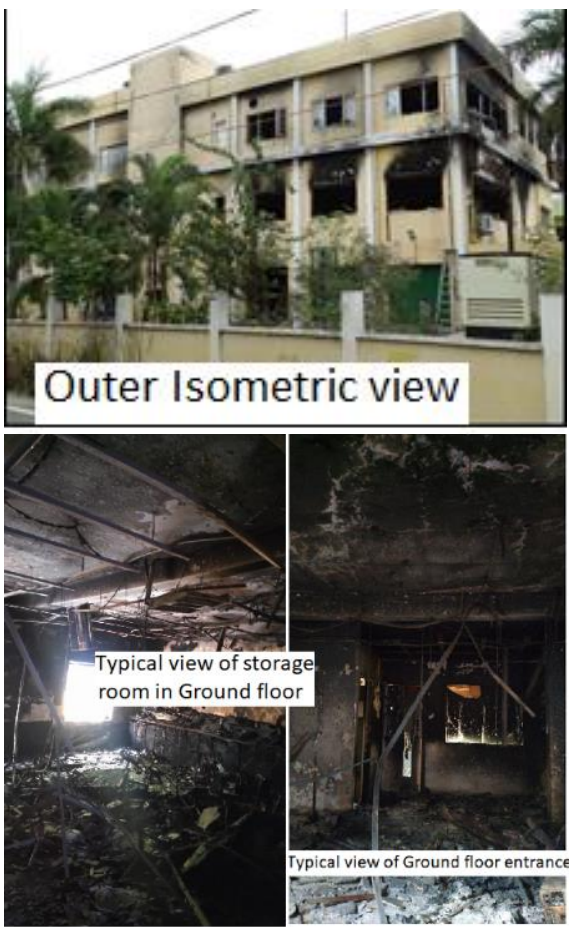


Fig.1 : Typical view of fire affected building – Outer and ground floor

Fig.2 : Typical view of fire damage in first floor of fire affected Building

wooden furniture and other ignitable items fuelled the initial spread of fire. The floor partitioned with brick infill has showed minimum damage compared to the floors partitioned with wooden reapers and plywood. The wooden furniture and partition walls have fuelled the fire and made the structure to exposed in high temperature. The brick infills have lost the mortar cover and cracked severely, but the brick infills have protected the beams and columns during fire. Unlike the ground floor, the first floor is seeming to be worst affected by the fire incident as shown in figure.2. This floor doesn't have a partition walls around the interior columns and beams. A full height wooden cabinets as partitions with chairs and wooden tables are provided in this floor. Inflammable chemicals and resigns are stacked in few cabins. The official paper and patent

documents, computer CPU's and monitors are kept in the cabins. During fire, the inflammables kept in the first floor is fuelled the fire heavily. The cabinets to carry out different research activities.

In a similar way, the second floor is visually inspected and seen that the concrete has damaged with numerous micro cracks and the cover concrete is removed off partially at few locations. The roof slab is found damped and some seepage of water from the terrace is observed. From the visual observations, the ground floor is very minimally affected and the second floor is moderately affected, and the 1st floor is seeming to be damaged extremely. The stability studies and the non-destructive and partial destructive studies are carried out to understand the actual integrity of concrete and the expediency of structure.

## 2.2 Non-Destructive Testing (NDT) on fire affected building components

Non-destructive testing (NDT) is carried out to assess the condition of fire affected structures using the Rebound Hammer Method (RHM), Ultrasonic Pulse Velocity (UPV) on some selected members. The surface hardness and integrity of the structural components are measured.

### *Ultrasonic Pulse Velocity (UPV) Test*

Ultrasonic Pulse Velocity test is basically a wave propagation test and consists of transmitting ultrasonic pulses of 50 – 60 kHz frequency through a concrete medium and measuring the travel time of ultrasonic pulses and arrive the velocity and from which the concrete quality is assed indirectly. With reference to Indian Standard code of practice [7], UPV values can suitably interpreted to assess qualitatively the condition of concrete with regard to homogeneity, uniformity, integrity. The presence of cracks, voids, and other imperfections, Changes in the structure of the concrete which occur with time, Quality of the concrete and etc. The beams and columns are tested in direct method to assess the presence of flaws along the sections and the in-direct method is used to measure the integrity along a plane, specifically the cracks. The semi-direct method is used to assess the concrete quality, where there is a minimal access on the side of section as shown in fig.3.

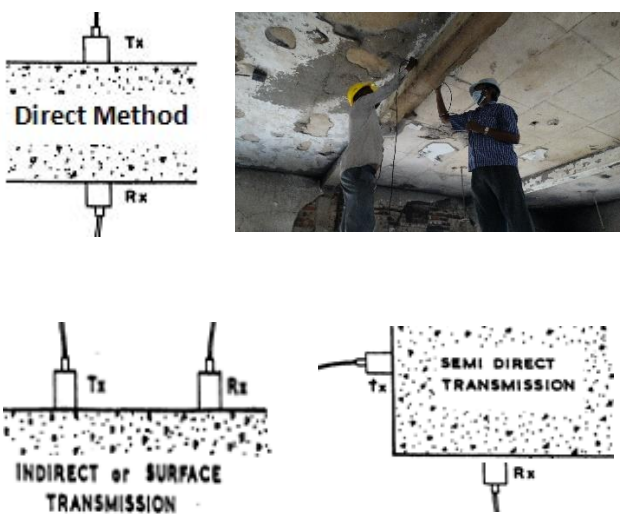


Fig.3 : Typical procedures of different methods for measuring UPV values

### *Rebound Hammer Test*

Rebound hammer test is performed to evaluate the surface hardness of concrete as typically shown in figure.4a, by essentially of impacting the concrete surface in a standard manner. The test method consists of a spring controlled mass that slides on a plunger within a tubular housing. The rebound values quantitatively reflect the quality of concrete within a depth of 50 mm from the surface. The rebound hammer method provides a convenient and rapid indication of the compressive strength of concrete by means of establishing a suitable correlation between the rebound index and the compressive strength of concrete [8] is shown in figure.4b.

Fig.4a : Typical view of Rebound Hammer Test in ground floor

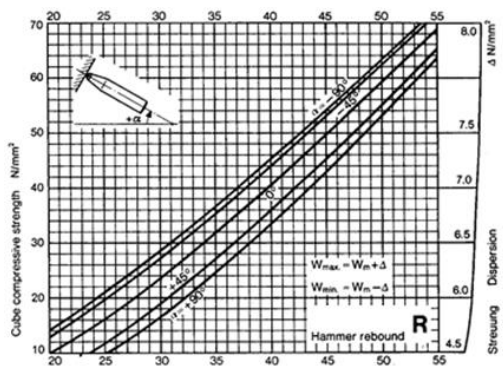


Fig.4b : Correlation graph between Rebound Hammer Number and Strength

### *Cover Meter test*

The cover meter test is performed to locate the steel reinforcement present inside the reinforced concrete and to measure their concrete cover. From the test, cover thickness and the profile of the re-bar is displayed on the screen and from that the location are chosen for core sampling and powder sampling. The cover meter works on eddy current pulse induction principle and this is a best imaging technology not influenced by concrete composition and humidity. Further. This test essential to understand the bar spacing and their placement in existing structures.

### 2.2 Partial destructive tests (PDT) – Core sampling ad powder sampling

The rebound Hammer and ultrasonic pulse velocity tests can give indirect evidence of concrete quality. During fire, the raise in temperature alters the original chemical composition of constituent materials. More realistic assessment on concrete can be made by core and powder sampling and testing. The PDT can give a quantitative measurement of actual concrete strength exists in the structure, Carbonation attack, pH and Chloride Level present in the actual site condition. The core samples are used to arrive the compressive strength, chemical analysis, petrography examination etc. the typical view of core sampling in floor slab is shown in figure.5.

Fig.5 : Concrete Core Extraction on Slab in Progress

### *Neutralization Test of Concrete*

Concrete is of alkaline in nature and its pH value about 13.0. When the concrete is exposed to fire, the pH value of concrete falls below 7 and it properties changes from alkaline to acidic. The core samples taken out from the structural elements are used to assess it pH condition with respect to depth and from that the depth of concrete affected by fire. For this, phenolphthalein solution is used as an indicator on the affected concrete portions. The Phenolphthalein solution remains colourless in acids/neutral substances, but turns bright reddish/ pink in base substances. From that, the present study is inferred the temperature history and depth of heat penetration.

### 2.3 Deformation measurements and stability checks on Flexural Members

Due to thermal effects, some of the beams and slabs deflected. The extent of deformation was measured typically. Levelling was done with water tube and a rope was tied between two points. The level difference was noted by measuring. Typical measurement of deformation of beam is given in figure.6.

## 3 RESULTS AND DISCUSSIONS

### 3.1 Visual Inspection

At the ground floor level, several cracks were noticed in brick infilled walls. Roof false ceiling was completely fallen. Several micro cracks and few macro cracks were observed on beams and the roofs. The infills have protected the ground floor columns. A portion of building is isolated from the region of fire where the Liquid Nitrogen Cylinder, Raw Materials for developing resigns, packing materials, Silicon containers, Epoxy storage tins, Oil Storage tins and other Hazards Waste Storage bins is avoided the major blast during fire. The brick infills covered the columns and beams by acting as a barrier between the heat and the reinforced concrete. concrete beams and columns are seen in block colour due to the deposit of fumes. In most of the columns and beams is in grey colour after swiping with cotton. In very few locations, the concrete colour is observed in pink to red colour,

Fig.6 : typical view of levelling and the measurement of sectional deflection

specifically where the reinforced concrete section is exposed to fire, due to lack of brick infill. This colour changes indicates that the temperature load is less than the 600°C and probably between 200°C and 400°C. In contrary, the first floor is visually found to be worst affected during the fire. The reinforced concrete beams and columns are directly contacted with fire and the most of the reinforced concrete sections have lost their cover concrete and the steel has got is exposed to fire. Due to the abnormal fire load, the column, beams and slabs have lost its stiffness and deformed. The exposed steel in few columns are buckled and this is happened due to the loss steel strength during the heat and failed to transfer the compression load. The concrete colour in the columns, beams and slabs are in whitish grey in many locations and few locations are in brown and blockiest Buff colour. This concrete colour change indicates that the entire floor is fire loaded with a temperature between 600°C and 1,400°C [5,11]. The second floor has moderately damaged due to fire. The second floor area covered with brick infills are showing undamaged with natural grey colour and the floor areas with wooden partitions and chemical stacking are affected in fire. Several crack have been seen in the columns, beams and roofs. The concrete colour is in light red colour in many locations and it is in grey colour in few locations. it indicates that the part of floor is fire loaded with a temperature above 600°C. The structural elements are found slightly deformed and it needs to be verified with a deflection checks. In overall, the ground floor concrete is not much affected due to fire and the non-structural damages can be repaired and it can be used for its regular activities. The 1st floor cannot be used and further study is required for rehabilitation and strength and serviceability condition restoration. Further, the usefulness of second floor can be decided after the detailed NDT and stability check investigations.

### 3.2 Ultrasonic Pulse Velocity (UPV) Test

Ultrasonic Pulse Velocity (UPV) was carried out using with 54 kHz frequency transducers. UPV test has been carried out on selected RC structural members in a systematic way by marking grid points. Measurement of transmit time is made at each grid point and the velocity is calculated by dividing the distance between the transducer and the receiver. The Ultrasonic Pulse Velocity (UPV) data generated from the structure is reported in Annexure-IV and the statistical parameters such as maximum, minimum, average, standard deviation, co-efficient of variation and characteristic values of velocity are reported in table-1, for the affected members of different floors.

**Table 1 : Statistical Parameters of UPV Values**

| Floor | Member ID | No.of Grids | Max. | Min. | Avg. | S.D | C.O.V. | VcK |
|---|---|---|---|---|---|---|---|---|
| Ground | B5 ,Column | 9 | 2.20 | 0.00 | 0.90 | 0.90 | 95.30 | -0.50 |
| | B6, Column | 9 | 1.90 | 0.10 | 0.60 | 0.50 | 89.10 | -0.30 |
| | B7, Column | 8 | 4.20 | 1.10 | 2.50 | 1.30 | 53.10 | 0.30 |
| First | A3-B3, Beam | 24 | 3.00 | 0.40 | 1.50 | 1.00 | 63.80 | -0.10 |
| | B2, Column | 20 | 3.60 | 0.30 | 1.70 | 1.10 | 65.40 | -0.10 |
| | B3, Column | 10 | 3.80 | 0.30 | 1.90 | 1.40 | 73.50 | -0.40 |
| | B4, Column | 20 | 2.90 | 0.00 | 1.20 | 1.10 | 92.20 | -0.60 |
| | B5, Column | 20 | 3.20 | 0.50 | 1.70 | 0.80 | 46.20 | 0.40 |
| | B6, Column | 20 | 1.70 | 0.40 | 1.00 | 0.40 | 40.70 | 0.30 |
| | B7, Column | 20 | 0.50 | 0.00 | 0.00 | 0.10 | 447.20 | -0.20 |
| | B8, Column | 10 | 3.20 | 0.00 | 1.50 | 1.00 | 64.10 | -0.10 |
| | B4-C4, Beam | 26 | 3.50 | 0.00 | 1.40 | 1.40 | 97.80 | -0.90 |
| | B3-A3, Beam | 30 | 3.30 | 0.00 | 1.10 | 1.10 | 95.50 | -0.60 |
| | A4,A5 & B4,B5, Slab | 12 | 1.90 | 0.50 | 1.00 | 0.50 | 43.30 | 0.30 |
| | A3,A4 & B3,B4, Slab | 10 | 1.70 | 0.60 | 1.20 | 0.30 | 24.00 | 0.70 |
| Second | B7, Column | 35 | 3.30 | 0.10 | 1.80 | 0.80 | 44.90 | 0.50 |
| | B8, Column | 23 | 2.80 | 0.40 | 1.80 | 0.60 | 34.20 | 0.80 |
| | B2-C2, Beam | 42 | 3.50 | 0.30 | 1.60 | 0.90 | 59.00 | 0.00 |
| | B5-C5, Beam | 14 | 1.03 | 0.00 | 0.26 | 0.38 | 142.94 | -0.36 |
| | B6-C6, Beam | 14 | 3.20 | 0.40 | 2.30 | 0.80 | 36.50 | 0.90 |
| | B5C5-B6C6, Slab | 12 | 3.41 | 2.08 | 2.65 | 0.41 | 15.64 | 1.97 |
| | B6C6-B7C7, Slab | 55 | 3.06 | 0.60 | 2.16 | 0.52 | 23.98 | 1.30 |

The UPV data collected from the identified RCC beams both from affected and un-affected beams. From the results, it is observed that the characteristics UPV values in affected beams was found ranging from 0 and 0.90 km/sec. and the corresponding co-efficient of variation was found to ranging from 59.00 to 36.50. The co-efficient of variation in un-affected members was found to be 3.90 and its corresponding characteristics UPV value found to be 3.70 km/sec. The UPV results shows that the beams the fire affected area are lost its concrete integrity and it is indirectly indicating that the composite action between the steel and concrete lost and it is susceptible for further damage to corrosion and loss of flexural strength. In similar way the UPV data collected from the identified RCC Columns both from affected and un-affected beams and compared. The results indicate that the characteristics values of UPV values in affected columns was found ranging from -0.90 and 0.80 km/sec. and the corresponding co-efficient of variation was found to ranging from 34.20 to 97.80. The co-efficient of variation in un-affected members was found ranging from 2.90 to 9.62 and its corresponding characteristics UPV values found to be 4.30 and 3.51 km/sec. The results clearly show that the structural beams and columns present in the firer affected area are not fit to usage with the present condition. The slab in fire affected area is also showed a similar trend with UPV values are in a ranging from 0.30 and 1.97 km/sec. and the corresponding co-efficient of variation was found to ranging from 43.30 to 15.64. The co-efficient of variation in un-affected member was found to be 2.30 km/sec. and its corresponding characteristics UPV values found to be 20.95. In overall the slab concrete is found to be inferior and not satisfying the design criteria.

### 3.3 Rebound Hammer Test

Rebound hammer test was carried out in the identified locations where the Ultrasonic test also carried out. The Rebound Hammer Number data generated from the structure and the statistical parameters such as maximum, minimum, average, standard deviation, co-efficient of variation and characteristic values of velocity are assessed and compared. The Rebound Hammer data collected from the RCC Beams are observed that the unaffected members, the co-efficient of variation of affected members was found to be 22.40 and its corresponding characteristics Rck values was found to be 12.00. The results indicate that these beam members become dis-stressed with a very low reserved strength. The columns in the firer affected building regions, co-efficient of variation of affected members was found to be 34.40 and its corresponding characteristics Rck values was found to be 5.40. The results indicate that these columns are in dis=stressed condition and it lost its strength and need to be supported with temporary supports, extended from the firm ground floor and needs to be repaired for carrying out other repair works or installation of other regular activities. The slabs are also showed that the slabs are in dis-stressed condition and needs to be strengthened.

### 3.4 Deflection measurement and stability Checks

The deformation of beams and slabs were measured on selected portions and the maximum level difference is presented in table.2. The measured deflections are checked for the flexural stability checks as per prescribed in the Indian code of practice [6]. The deflection measured in the beams and slabs are exceeds the limiting deflection at first floor level. In second floor level, the beams and slabs in affected area partly fulfils the design criteria and partly exceeds the design criteria for the stability checks.

**Table.2 : Maximum deflection measured in selected members**

| Floor | Location | Member | Maximum deflection, mm |
|---|---|---|---|
| First Floor | B2 – C2 | Beam | 46 |
| | B3 - C3 | Beam | 58 |
| | B4 – C4 | Beam | 57 |
| | B5 – C5 | Beam | 50 |
| | B7 – C7 | Beam, | 58 |
| | A7 – B7 | Beam | 50 |
| | B6 – B7 | Beam | 54 |
| | A3 – B3 | Beam | 38 |
| | A2 – B2 | Beam | 45 |
| | B3,C3 - B4,C4 | Slab | 54 |
| Second Floor | A3,A4 and B3,B4 | Slab | 22 |
| | A3 – B3 | Beam | 40 |
| | B5 – C5 | Beam | 16 |

### 3.5 Neutralization Test

During the test on the structural members and extracted concrete core samples, 1% phenolphthalein solution was first applied to their side surfaces that were affected by the fire without treating the surfaces. As shown in figure.7. the colour did not change in cover region up to 40 mm and with a purple area where the alkaline concrete reacted to the indicator for the sample extracted in fire affected zone. Whereas the test was conducted for the core samples extracted from un-affected area indicates fully change in colour which shows that the concrete is of fully alkaline in nature. Therefore, the concrete cover of 40-50 mm have experienced a maximum temperature of more than 600°C.

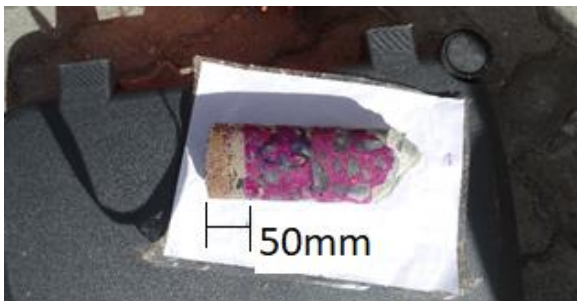


Fig.7 : Neutralization Test on Extracted Concrete Core Sample

### 3.6 Core Sampling and Testing

Concrete core samples of 69 mm dia. were collected from the RCC columns and slabs both from affected and unaffected areas. These samples were extracted from the identified locations and marking was done on the samples for proper identifications as shown in figure.8a. The extracted cores are cleaned and dressing of the core is carried out in the laboratory. The dressed samples are placed under CTM and levelled with capping material, and tested for its actual compressive strength as shown in figure 8b. The compressive strength values were corrected for its h/d ratio and later the equivalent cube strength was obtained. The equivalent cube compressive strength values of core samples are reported in table.3.

(a) (b)

Fig.8 : (a) Extracted Concrete Samples
(b) Concrete Core under Compressive Load

**Table 3 : Compression test results of core samples**

| Core Details | l/d, Ratio | Load, kN | Compressive Strength, MPa | | Equivalent Cube Strength, MPa |
|---|---|---|---|---|---|
| A1 Column, Ground Floor* | 2 | 80 | 18.60 | 18.60 | 23.25 |
| B5 Column, Ground Floor | 2 | 45 | 10.46 | 10.46 | 13.08 |
| Passage Lintel Beam Between A3-B3, Ground Floor | 2 | 40 | 9.30 | 9.30 | 11.62 |
| First Floor Slab Between B3C3 & B4C4 | 1.3 | 50 | 11.62 | 10.64 | 13.30 |
| First Floor Slab Between B2C2 & B3C3 | 1.2 | 48 | 11.16 | 10.27 | 12.83 |
| Roof Beam near First Floor to Second Floor Staircase Landing area, A4-B4 | 2 | 38 | 8.83 | 8.83 | 11.04 |
| B3 Column, Second Floor | 2 | 36 | 8.37 | 8.37 | 10.46 |
| Second Floor Slab Between B3C3 & B4C4 | 1.4 | 48 | 11.16 | 10.32 | 12.90 |
| B6 Column, Second Floor | 2 | 30 | 6.97 | 6.97 | 8.72 |

* - Core Extracted from un-affected area

The acceptance criteria with respect to cube strength obtained by testing concrete core i.e. individual specimen shall be at least 75% and average strength shall be at least 85% of the concrete strength considered in design. From the test results, it is observed that the concrete strength in unaffected areas was about 23.25 MPa and at the affected areas is ranging from 8.72 MPa to 13.30 MPa, which 60 % reduction lesser strength compared to unaffected areas. The strength of concrete is fails to satisfy the design criteria and needs to restored with appropriate strengthening measures.

## 4 Conclusions

Based on the visual observations, geometrical stability analysis measurement of the structure, Non Destructive Tests and Partially Destructive Tests are carried out on the fire affected building structure, the following major observations and inferences were arrived.

- From the visual observations and deflection criteria of the RC structural members indicate that 60 to 70 % of the area is severely affected by fire. The fire fightening systems installed in the building has failed due to COVID19 and longer lock down, which lacked the support from the human maintenance around the in-and-around the building premises.
- The floor partitioned with brick infill has showed minimum damage compared to the floors partitioned with wooden reapers and plywood. The wooden furniture and partition walls have fuelled the fire and made the structure to exposed in high temperature.
- The brick infills have lost the mortar cover and cracked severely. The brick infills have protected the beams and columns during fire in the ground floor area.
- In second floor, the portion walls are made-up of wood reapers and ply boards, and many inflammable chemicals and resigns have fuelled the fire. Lack of brick infill, the columns, beams and slabs are directly exposed to fire and its colour changed red and buff. From the colour change, it inferred that the floor is exposed to the temperature about 800 to 1400 degree centigrade.
- Cross-sectional loss in the beams, columns and slabs have been observed due to concrete cracking and spalling.
- The rebound hammer and UPV test results have confirmed the damages observed during the visual observation. The loss of concrete bond, integrity and strength have been inferred from the results. About 60% of loss concrete strength is estimated from the NDT tests.
- The cylinder core samples have confirmed the loss of strength due to the fire.
- The neutralisation test have shown that the concrete section has lost its alkali character and become acidic to a depth 50mm from the concrete surface.
- Due to the loss of cover, bared reinforcement was observed in columns, beams and slab. Due to loss of concrete strength, integrity and softening of steel during fire have resulted in excessive deformation and steel buckling.
- The deformation measures and the stability checks have confirmed the findings of NDT and PDT tests. The NDT and PDT methods have clearly indicated that the structure is not fit for the use with the present condition, requires extensive investigation for rehabilitation and restoration of structural strength and serviceability requirements.

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# Properties of GMR based sensor for Magnetic field measurement atincreasing Temperature Conditions

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## Abstract

**This paper presents investigations and associated results for characterization of a giant magneto resistance (GMR) sensor at varying temperature conditions. The approach constitutes an experimental setup using a commercial GMR sensor for measurement of the magnetic field response of the system. The work aims to act as a fully-operational evidence of the application, with an emphasis on the standard mode of operation and to improve the sensitivity of the measurement system. The system provides high flexibility in design applications where local magnetic fields must be detected. The measurement setup can be modified and redesigned for a wide variety of applications, thus allowing path for future research, for better accuracy and extended operation range.**

**Keywords: GMR effect, Magnetic field, Magnetic Flux Leakage testing, Condition monitoring.**

## 1 Introduction

In industries like nuclear, solar thermal and oil & gas, bound parts and components ought to operate in hostile conditions. Pipelines, tanks, pressure vessels and absorbent tubes carrying flammable liquids suffer from defects like creep, thermomechanical fatigue and hot corrosion due to high temperatures [1-5]. This could lead to the collapse of the internal or external structure of the parts and components that might result in the closing of the plant, economic harm and in some cases to severe hazard for human life. The structural assessment of these parts and components is of immense importance, as early detection of defects will prevent , an irreversible failure of the structure and reduce the probabilities and possibilities of the structures being drained and in that case, NDT techniques will be used for structural observance or monitoring of structures operating at high temperature conditions [5].The challenging factors for the use of NDT techniques in such environments include the operational conditions

, access, size of the structure, and structural complexity of the component under observation and previously certain NDT techniques such as Acoustic Emission (AE), Eddy Current (EC), Laser Ultrasonic, Interferometry, Thermography and Guided Wave Testing (GWT) have been used at increasing temperature conditions. The performance of the sensors or transducers at high temperatures may degrade, and this will limit the potency of the technique being implemented [13-18].

Magnetic sensors provide a more rugged, reliable and maintenance-free technology compared to other sensor technologies [6-7]. Different sensor types such as; fluxgate sensors, the giant magneto resistive (GMR) sensors, anisotropic magneto resistive (AMR) sensors or hall effect

sensors can be used for the magnetic field measurements. However, a major disadvantage of these sensors is its inability to be used for sensing large areas of a specimen [6].

Rochaz et al. [7,8] introduced a Wheatstone bridge circuit with GMR sensor consisting of about 21 magnetic layers composed of Nickel-iron (NiFe) separated by a nonmagnetic material silver (Ag) in between. The NiFe magnetic layer thickness measured was 2 nanometers and that of Ag spacer was 1.1 nanometers. The advantage of this GMR structure is its stability when exposed to high temperatures compared with other GMR sensor structure designs that have a Cu layer spacer. Moreover, these sensors have a better output linearity, the hysteresis signal is low (less than 1 Oersteds) and the effect of magnetic resistance decreases by a temperature factor between 1.5 to 3 at a temperature between 4 K and room temperature [7]. The increase in temperature increases the number of electrons scattered in NM, which is said to be nano layers, causing the number of electrons to move between the layers of GMR structure, and this reduces the efficiency of the GMR mechanism at increasing temperatures. Although power transducers based on Hall sensors act as multiplying elements, and can be used for direct

power measurement, their insufficient sensitivity usually results in the need for ferromagnetic cores to concentrate the magnetic flux into the sensor area. Thus the high sensitivity of GMR based sensors can be used as potential substitutes of Hall sensors as in this application at room temperature, magneto resistive sensors are, generally, more sensitive than Hall effect based ones, so avoiding the need for major amplification signals [7].

Achuta [9] presents an enumeration and discussion of the physical, thermal, mechanical and magnetic properties of AlNiCo permanent magnet materials and sheds light on their different grades. The article shows AlNiCo as a mature product in the industry and the data obtained includes comparison of maximum temperature of the AlNiCo grades and the changes occurred below the room temperature conditions.

## 2 Methodology for High Temperature Testing

The measurement system used includes the components described below. Table 1 shows specifications of the GMR sensor [10] used:

**Table 1 : Specifications of the GMR sensor.**

| | |
|---|---|
| Analog Series | NVE AA002-02 |
| Maximum operating temperature | 150° C |
| Magnetic field range | >400 milli Tesla |

### 2.1 Permanent Magnet

Alnico5 grade type of dimensions 54×83×70 mm [11] was chosen as it has some excellent characteristics at varying temperature conditions. Its maximum operating temperature is 500° C, which makes it easy to test at increasing temperature conditions. AlNiCo magnet has a pull force of 47 kg, which indicates the maximum magnetic force the magnet can hold on a steel surface to be tested with respect to the magnetic sensor.

### 2.2 GMR sensor

This system is set up to generate a magnetic field in the direction that is sensitive to the axis of the GMR sensor. The GMR sensor is positioned exactly between the two poles of the magnet in a direction i.e. perpendicular to the magnetic field (see Figure 1). The permanent magnet is placed such that the magnetic field measured for every sensor is higher and precise and is necessary for obtaining the required output.

### 2.3 Measurement system

The measurement system includes two

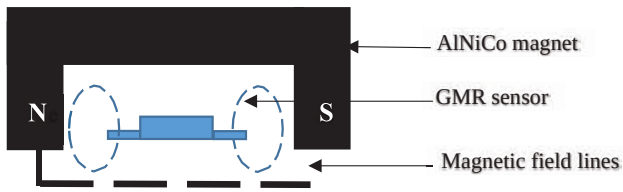


**Figure 1 : (Side view of GMR sensor) indicating the flow of magnetic field lines**

separate environments, a harsh high temperature environment where the whole magnetic circuit needs to be placed. The magnetic circuit: an AlNiCo magnet, a holder and the GMR sensor, which is placed inside an oven. DC power supply and oscilloscope are placed at room temperature environment. The DC power supply is used for supplying voltage to the circuit and oscilloscope for detecting the change in voltage. A holder was designed using Autodesk Inventor and printed using 3D printer and this is used for placing and positioning the sensor. The holder is made of a polymer material which has a maximum operating temperature of 90° C. In order to measure the temperature stability, a thermocouple is connected to the magnetic circuit inside the oven. The thermocouple readings are recorded using Picologger software placed in the room temperature environment.

## 3 Results

The results presented in this section are a summary of six tests done for every increment in temperature. Ranging from room temperature with a progressive step of 10°Celsius, the data was

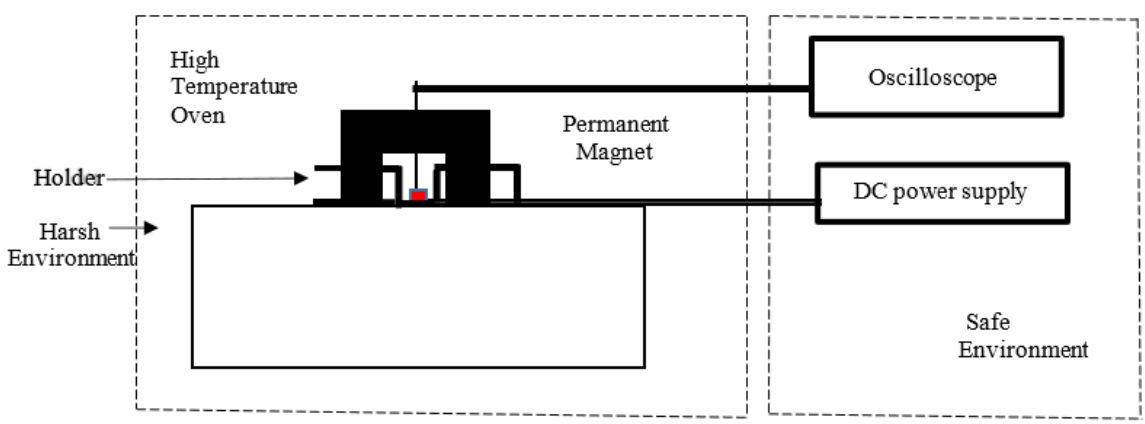


**Figure 2 : Measurement system using GMR sensor**

recorded up to 80°Celsius, as the holder material had a maximum operational temperature of 90°Celsius.

Figure 3 shows the measurement system including the corroded pipe sample of 8 mm thickness with the magnetic circuit placed inside the oven.

Figure 3 : Measurement system using GMR sensor Temperature vs Time

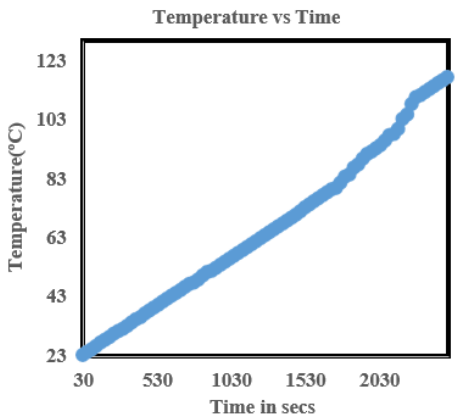


Figure 4 : Thermocouple temperature measurements over time

Figure 4 shows the measurements obtained from the thermocouple at different temperatures plotted accordingly with respect to time. With time intervals of 30 seconds the temperature increase is shown on the y-axis, exhibiting an almost linear curve of temperature as a function of time.

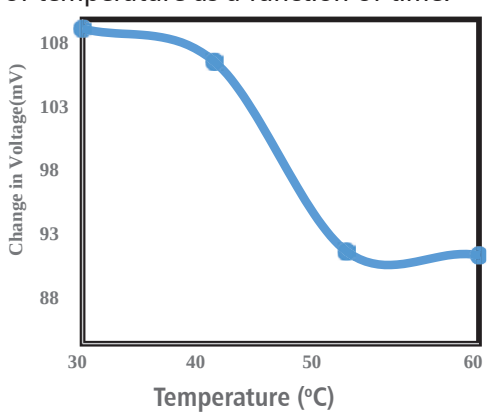


Figure 5 : Measurement system response for change in voltage vs temperature

Figure 5 shows the change if voltage as a function of temperature. It is observed that with increase in temperature, the sensor output is decreased. Further sensor output measurements with relation to time were taken consideration over a range of temperatures from 30°C till 60°C as shown below in Figure 6.

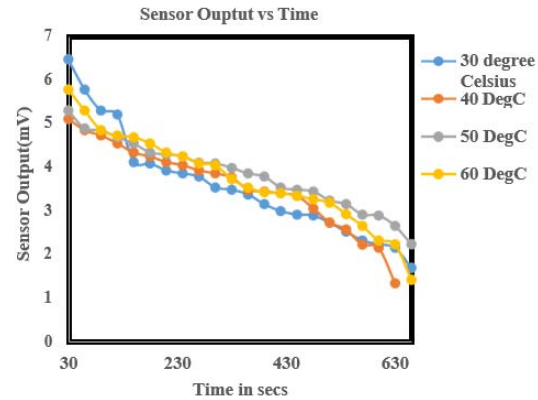


Figure 6 : Variation in sensor output with respect to time for varying temperatures

It can be seen in Figure 6 that as the temperature increased, the voltage tended to decrease. Furthermore, the voltage decreased over time from 30 to 630 secs. There was a voltage drop by a factor of 0.5 V for every 30 secs time. There were variations observed in readings and this was due to measurement noise. The lift off between the pipe sample and the sensor caused the decrease in the sensor output.

## 4 Conclusion

A magnetic field measurement system and methodology have been presented for high temperature environments. The measurement set up developed has been found to be suitable for high temperature conditions with suitable holder for positioning of the magnetic sensor. Metallic samples up to 8 mm can be tested effectively with the developed system for high temperature conditions. It can also be concluded that the effect of temperature on the sensor does not cause changes in voltage within the range of temperature tested. GMR sensor had a maximum operating temperature of 150°C, but the polymer holder can sustain heat only up to 80 °C. Thus, the tests were performed up to 60 °C. Realization of a non-magnetic metal holder, will allow for temperatures above 60 °C, and such tests will be done for increasing temperatures above 60°C, and such tests will be done in future work with varying pipe sample thicknesses.

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Declaration of Interest

The authors declare no conflicts of interest.

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# NDT OF DIELECTRIC MATERIAL USING CPW FED UWB RECEIVER ANTENNA AND SINGLE BAND SENSOR ANTENNA

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Abstract

**This document presents a simulation model for carrying out non destructive evaluation of relative permittivity for dielectric materials using dual antenna setup. The proposed model involves coplanar waveguide fed single band sensor antenna and an ultra wideband receiver antenna. The sensor antenna consists of a single resonating band and is mounted on the surface of the test material. An ultra wideband antenna is placed in the far field region of the sensor antenna inorder to capture the frequencies radiated by the sensor antenna. The working principle of the proposed concept lies in the fact that the resonating frequency of the sensor antenna is a function of relative permittivity of the dielectric material under test. The designed sensor antenna radiates at a particular known frequency when mounted on the surface of the test material of known permittivity. This frequency radiated by sensor antenna is captured by ultra wideband antenna and any shift in the resonating band of the sensor antenna can easily be detected. Thus any shift in resonating band for sensor antenna will directly reflect the change in the permittivity value of the test material. The proposed sensor antenna has resonating band with center frequency at 5 GHz, while the ultra wideband antenna covers the entire frequency sweep from 3 - 12 GHz.**

**Keywords : CPW, dielectric, non destructive testing, patch antenna, sensor antenna, UWB antenna**

## I. Introduction

The use of microwave spectrum for non destructive testing (NDT) of materials has become quite prominent since last two decades. Mechanism for detection of surface cracks and air voids have been readily implemented using microwave frequency. In [1] a leaky wave antenna is studied which is operating in X band, in [2] mechanical scanner is integrated with vector network analyzer in order to detect the change in frequency due to variation in permittivity of test material, in [3] subsurface radar is implemented, in [4] antenna array of multiple dipole antennas for microwave imaging is studied, in [5] open ended waveguide is studied for evaluating dielectric properties.

In this document a dual antenna setup is modelled using CST Microwave Studio for non destructive evaluation of relative permittivity of dielectric material. The proposed antenna setup comprises of two coplanar waveguide (CPW) fed patch antennas, namely, sensor antenna and receiver antenna. The sensor antenna is a single band planar antenna which can be mounted on the surface of the test material of known permittivity. An ultra wideband (UWB) antenna is placed in the far field of the sensor antenna for capturing the frequencies radiated by the sensor antenna. Since, the sensor antenna is modelled with respect to the permittivity of the test material, hence, it will be resonating at a particular known frequency. This frequency radiated by the sensor antenna will be intercepted by the ultra wideband antenna and will be displayed on Vector Network Analyzer (VNA). Since, the resonating band of the sensor antenna is a function of relative permittivity of the test material, hence, any shift in the resonating band of sensor antenna will directly reflect a change in the permittivity value of the test material.

## II. Antenna Design And Analysis

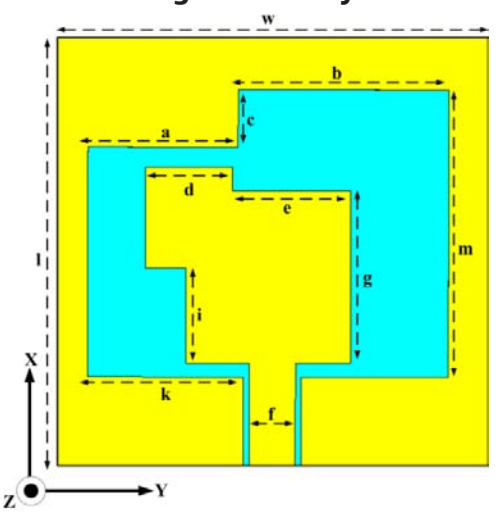


Fig. 1 : Geometrical view of proposed sensor antenna

**Table 1 : Geometrical Dimensions Of Sensor Antenna**

| a | b | c | d | e | f |
|---|---|---|---|---|---|
| 10.4 | 14.6 | 4 | 6 | 8.2 | 3.2 |
| g | l | w | ii | k | m |
| 12 | 30 | 30 | 6.6 | 10.8 | 20 |

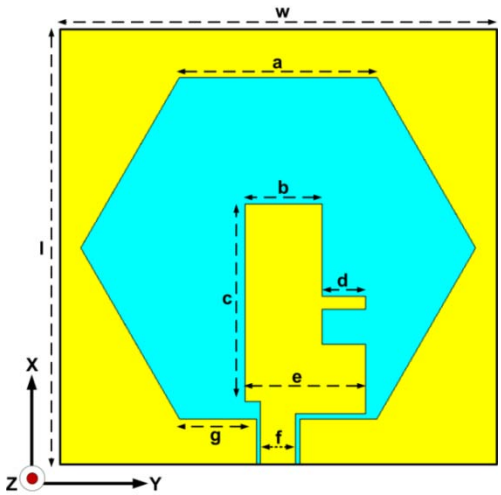


Fig. 2 : Geometrical view of proposed UWB receiver antenna

**Table 2 : Geometrical Dimensions Of UWB Receiver Antenna**

| a | b | c | d | e | f | g | l | w |
|---|---|---|---|---|---|---|---|---|
| 18 | 7 | 18 | 4 | 11 | 3.2 | 7 | 40 | 40 |

The geometrical view of the proposed sensor antenna is depicted in fig. 1 along with its physical dimensions illustrated in Table I. Fig. 2 depicts the geometrical view of the proposed ultra wideband antenna whose physical dimensions are displayed by Table II. Both antennas are modelled on CST Microwave Studio with FR4 as substrate.

### *A. Input Impedance Matching Analysis*

Impedance matching at the input feed port of antenna is the most crucial factor for achieving resonant band. The impedance matching analysis is carried out by studying Smith chart plot and voltage standing wave ratio (VSWR) plot. Smith chart for sensor antenna is depicted in fig. 3, while Smith chart for ultra wideband antenna is depicted in fig. 4. VSWR for sensor antenna is illustrated in fig. 5, while for ultra wideband antenna it is illustrated in fig. 6. VSWR value for a resonating band must be less than two. For both the antennas, VSWR value lies below two for the resonating band.

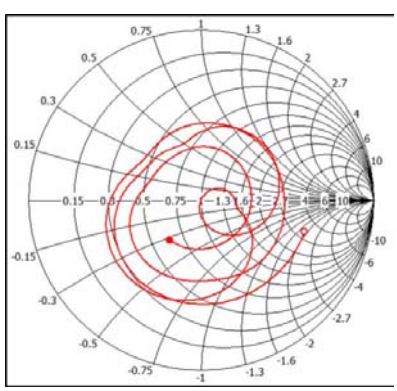

Fig. 3 : Smith chart plot for sensor antenna

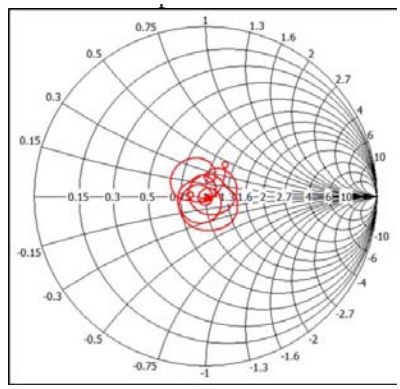

Fig. 4 : Smith chart plot for UWB receiver antenna

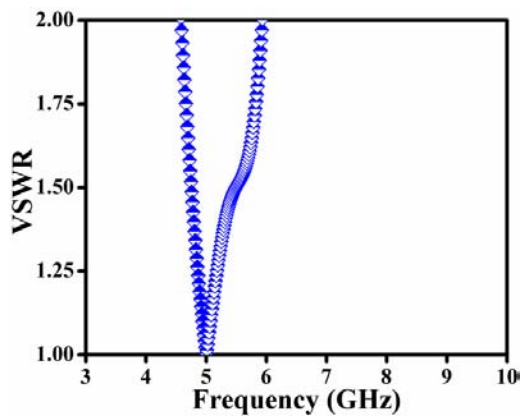


Fig. 5 : VSWR of proposed sensor antenna

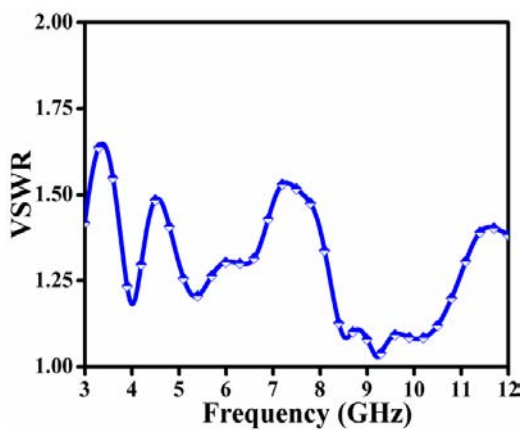


Fig. 6 : VSWR of proposed UWB receiver antenna

### *B. Proposed Antenna Setup Analysis*

The dual antenna model for non destructive evaluation of dielectric constant of the test material is analyzed in this section. The side view of the sensor antenna mounted on the test material is depicted in fig. 7. The sensor antenna mounted on the test material has three layers, namely, copper (yellow

layer), FR4 substrate (blue layer) and test material (red layer). The schematic diagram for the proposed antenna setup is illustrated in fig. 8.

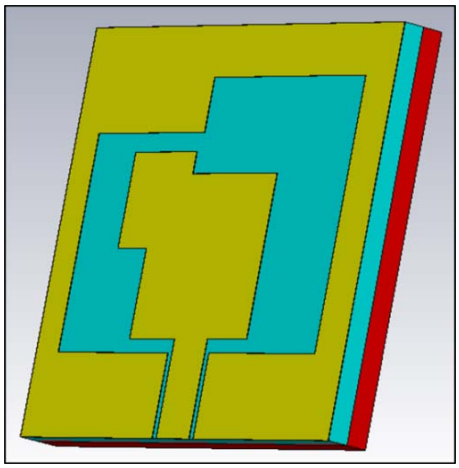

Fig. 7 : Sensor antenna mounted on the surface of test material

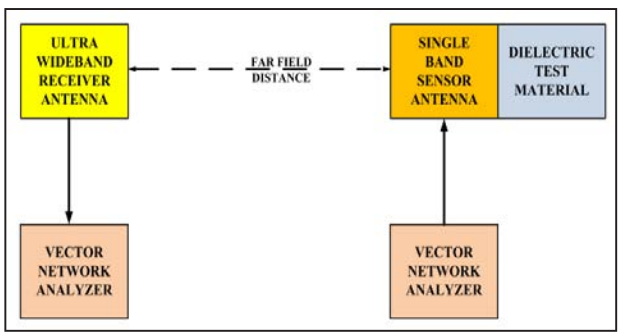


Fig. 8 : Schematic view of proposed antenna setup

### C. *Surface Current And Mode Analysis*

Surface current distribution for antenna with advancing time illustrates the antenna regions responsible for major radiation. Surface current distribution for sensor antenna is shown in fig. 9, which confirms that the patch as well as ground plane are contributing to radiation. Fig. 10 depicts surface current distribution for ultra wideband antenna which illustrates that the active patch is the major contributor for the radiation. Subsequently, fig. 11 and fig. 12 shows the modes generated in the coplanar waveguide antenna with respect to advancing time.

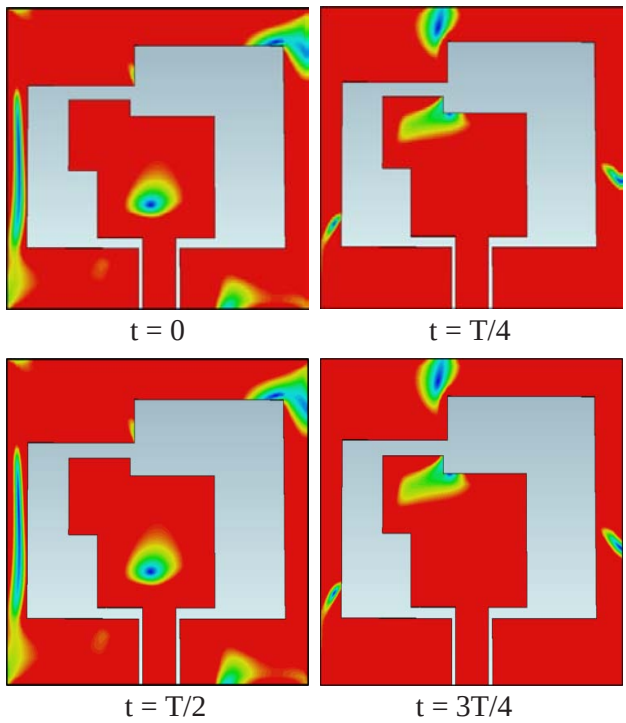


Fig. 9 : Surface current distribution for sensor antenna at 5 GHz

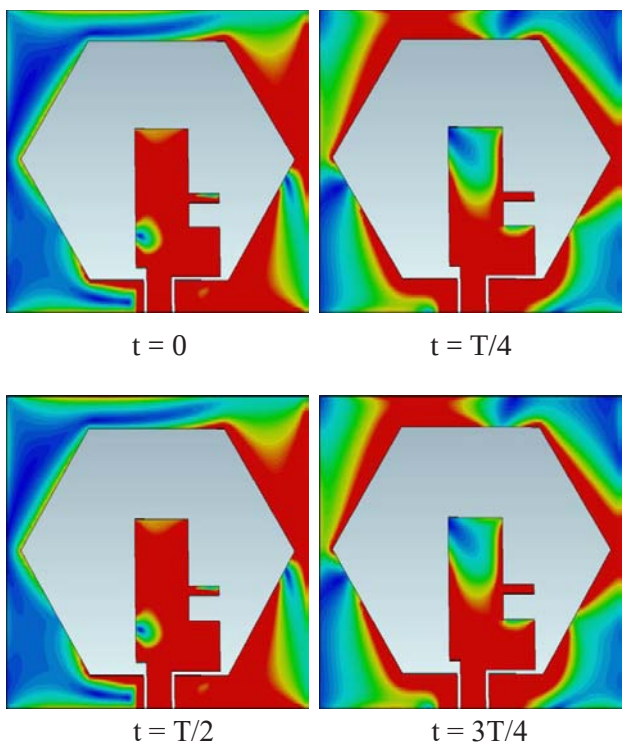


Fig. 10 : Surface current distribution for UWB receiver antenna at 5 GHz

It can be inferred from fig. 9 and fig. 10 that only even mode [6] is generated in both the antennas. Hence, both the antennas are linear polarized and are subjected to the orientation and alignment.

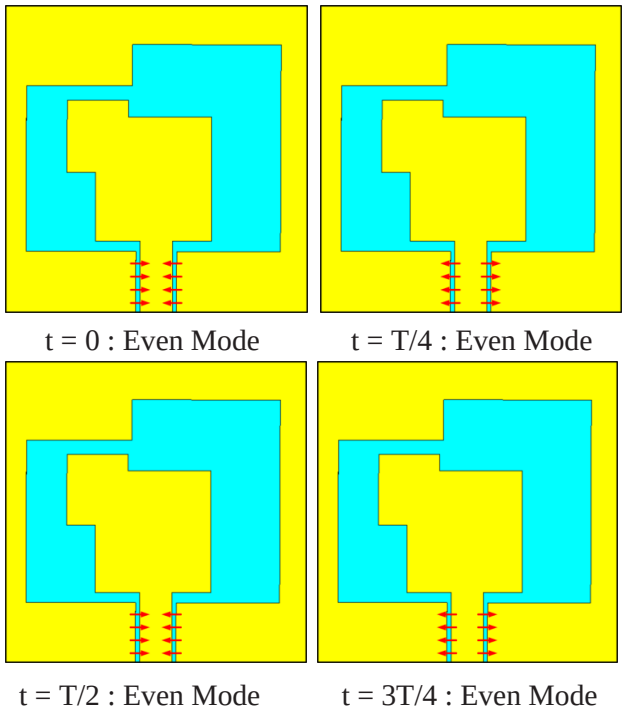


Fig. 11 : Mode distribution for sensor antenna at 5 GHz

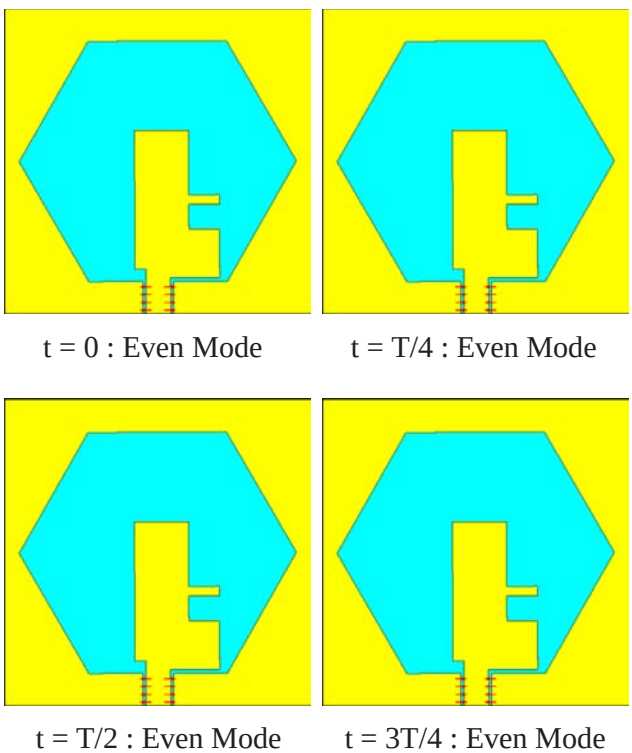


Fig. 12 : Mode distribution for UWB receiver antenna at 5 GHz

## III. Results And Discussion

### *A. Far Field Parameters analysis*

$S_{11}$ of the proposed sensor antenna is depicted in fig. 13, which confirms the single resonating band with center frequency at 5 GHz. Fig. 14 depicts the 10 dB impedance bandwidth of the ultra wideband antenna , which confirms that the resonating band sweeps the entire 3–12 GHz spectrum. As aforementioned, the sensor antenna resonates at 5 GHz when mounted on the surface of the test material with permittivity equals to one. Now as per the proposed concept, with the increment in the value of permittivity of the test material, the resonating band of sensor antenna must shift. This is verified in fig. 15, which illustrates that the resonating band for sensor antenna shifts towards left side with the increment in dielectric constant value of the test material. Hence, non destructive testing of the dielectric material can be carried out by this method for evaluating the healthiness of the permittivity value. Simulated average gain of the sensor antenna is shown in fig. 16, while for ultra wideband antenna it is depicted in fig. 17. 3D radiation pattern for sensor antenna is plotted in fig. 18, while radiation pattern for ultra wideband antenna is depicted in fig. 19. Radiation patterns of both the antennas confirm their directive nature.

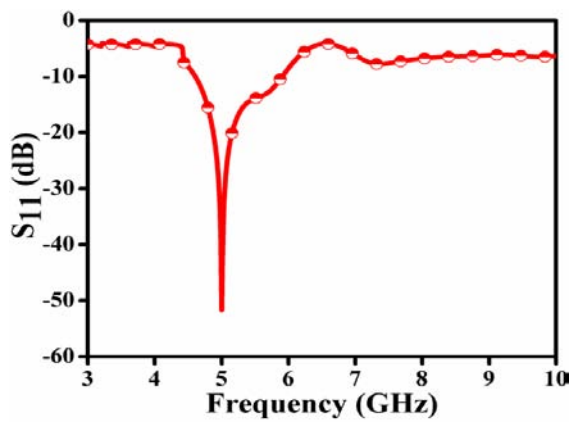


Fig. 13 : $S_{11}$ of proposed sensor antenna

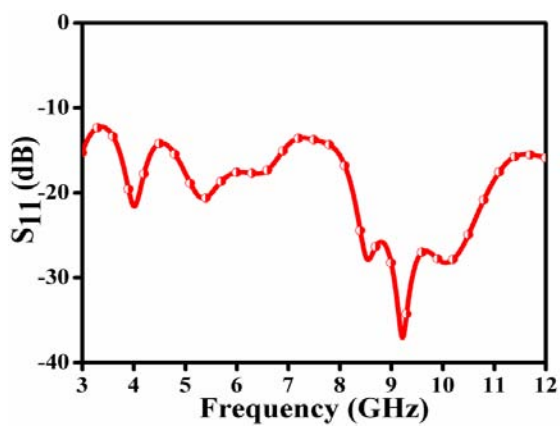


Fig. 14 : $S_{11}$ of proposed UWB receiver antenna

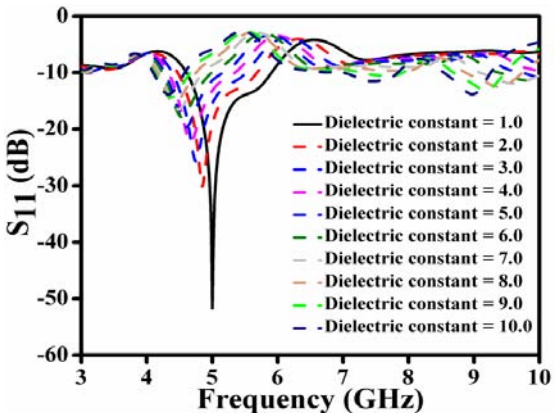


Fig. 15 : Shift in resonating band of sensor antenna with increment in permittivity value of test material

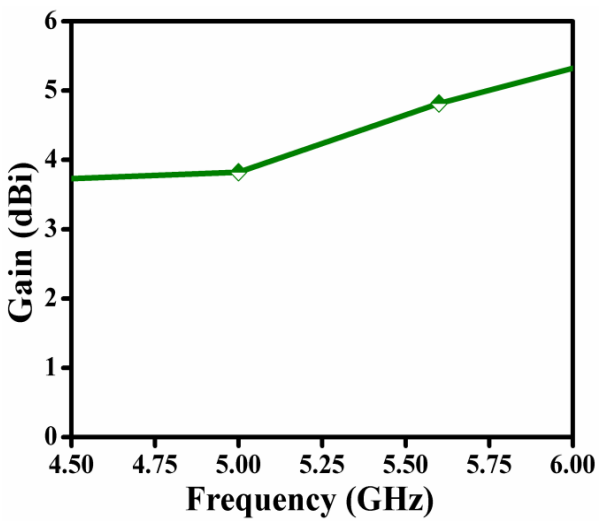


Fig. 16 : Gain of proposed sensor antenna

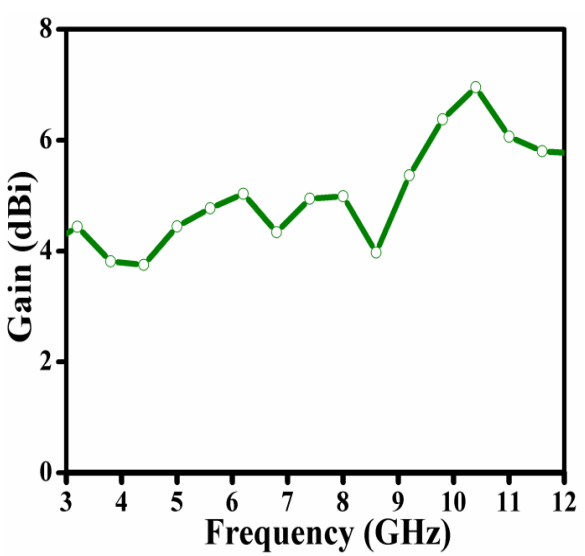


Fig. 17 : Gain of proposed UWB receiver antenna

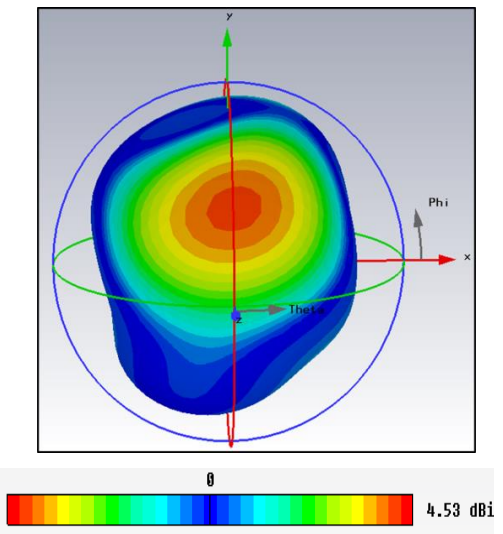


Fig. 18 : 3D radiation pattern of proposed sensor antenna at 5 GHz

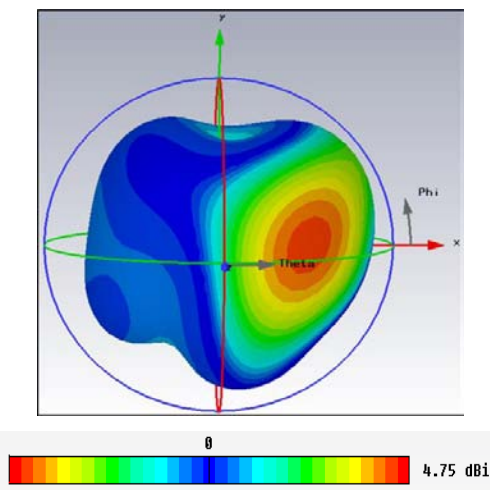


Fig. 19 : 3D radiation pattern of proposed UWB receiver antenna at 5 GHz

### *B. Friis Equation Analysis*

Friis equation analysis for the proposed antenna setup is carried out in this section in order to calculate the power received by the ultra wideband receiver antenna. It must be noted that the received power is calculated by considering 1dBm reference power transmitted by the sensor antenna. Friis equation for a dual antenna setup is illustrated as equation (1), operating wavelength of the antenna setup is calculated using equation (2), while the Far field range for the proposed setup is obtained from equation (3). $P_t$ = 1 dBm = 1.25 mW, $G_t$ = 3.8 dB = 2.40, $G_r$ = 4.4 dB = 2.75, $\varepsilon_r$ = 4.2 for FR4 substrate.

$$P_r = (Pt\ Gt\ Gr) / Path\ Loss \quad (1)$$

$$\Rightarrow P_r = (Pt\ Gt\ Gr\ \lambda^2) / (4\pi R)^2$$

$$\Rightarrow P_r = -26\ dBm$$

$$\lambda = (3 \times 10^8) / \sqrt{\varepsilon_r} \quad (2)$$

$\Rightarrow \quad \lambda = 0.0293$ m

$$R = 2 \times d^2 / \lambda \qquad (3)$$

$\Rightarrow \quad R = 0.06$ m

$P_t$ is the power transmitted by the sensor antenna, $G_t$ is the gain of the sensor antenna, $G_r$ is the gain of the ultra wideband reciever antenna, $\lambda$ is the operating wavelength of the setup, R is the minimum Farfield distance for the proposed setup, d is the largest dimension of the sensor antenna. From equation (1) it can be inferred that for 1 dBm transmitted power by the sensor antenna, -26 dBm is the power received by the ultra wideband antenna.

## IV. Conclusion

A dual antenna setup simulation model for non destructive evaluation of relative permittivity of dielectric material has been studied in this paper. Two antennas, namely, sensor antenna and ultra wideband receiver antenna have been proposed. The sensor antenna has a single resonating band operating at 5 GHz and is mounted on the surface of the test material. Shift in the resonating band of the sensor antenna is captured by the ultra wideband receiver antenna which reflects variations in the value of dielectric constant of the test material. The proposed simulation model can be further extended to tera hertz frequency range with adequate setup for achieving high measurement accuracy and to analyze presence of air voids along with permittivity value and its status.

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# Comparison of Side Drilled Holes and Surface Notch response for Phased Array Sectorial Beams calibration process.

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## Abstract

**In this work, Phased array ultrasonic testing (PAUT) is calibrated for sound velocity, wedge delay, sensitivity and time corrected gain using side drilled holes and notches as reflectors. The responses of the reflectors for various angles (40 – 70°) are studied and standardised. The significant use of these reflectors and the cause of non-uniformity in notches, are analysed by comparing the reflection property of side drilled holes and surface notches for useful range of sectorial beam sets. Results are validated with the simulation studies.**

**Keyword: Phased array UT; Side drilled hole vs flat bottom hole; PAUT calibration for pipe welds**

## Introduction:

Phased array ultrasonic testing (PAUT) is a significantly growing advanced ultrasonic testing technique and is replacing other conventional techniques in several applications [1] The phased array probe could generate multiple angles sequentially to identify the volumetric defects present in the components. The use of multiple beam angles would increase the probability of finding the mis-oriented defects [2]. Equipment and Probe selection play a vital role in inspection. The effects of probe and equipment parameters on inspection results are well known to PAUT users [3]. Similar to conventional ultrasonic testing, the probability of the reflected sound reaching back the probe depends on the defect orientation and the sound beam orientation. The beam angle range is selected based on weld bevel details and the probable defect orientation that could occur in the welding process. The beam incident angle could be selected as optimum angle +/- 10 degree for most of the testing [4]. The inspection coverage and effectiveness of focal law depend on the scan plan [5] prepared for the inspection zone. In addition to this, calibration plays a vital role similar to any other NDT techniques.

Standardisation/Calibration of equipment to suite the job requirement is comparatively simple in conventional ultrasonic testing. Distance amplitude correction curve (DAC) is widely used for conventional UT standardisation. While performing DAC calibration in conventional UT, calibration is to be performed for only one beam angle. Whereas, in phased array sectorial scanning, multiple angles will be generated and all the angles have to be calibrated within a same calibration set up. Performing the calibration, manually, in phased array, is cumbersome as it involves multiple angles. Therefore, the calibration process is supported by the equipment to bring to the range calibration (velocity calibration and Wedge delay calibration) and gain calibration (Sensitivity and TCG) [6]. The Velocity calibration is used to determine the actual sound velocity in the material, Wedge delay calibration is for compensation of variation in the travel distance within the wedge for different angles [6]. Sensitivity calibration is for compensation of energy loss within the wedge for all angles and Time corrected gain calibration- TCG is for compensation of energy loss for different angles and various depth, due to attenuation in material).

During the phased array calibration process, a reflector is detected by all the beams sequentially and the system will provide corrections to bring the indication to a uniform standard level [6]. This is performed for all waveforms (i.e. focal laws/ angles) present in the beam sets/group. The detection and the severity of defects depend on the type and size of the reference reflector used during the calibration. Hence, reference reflectors are essential for standardising the ultrasonic equipment and achieve a reference sensitivity level. The selection of type and size of the reflector are followed in accordance with the applicable code. Among the various reference reflectors used in ultrasonic testing, side drilled hole and notches are most commonly used. As per ASME Section V [7] code recommendation, ultrasonic testing operator selects Side Drilled Holes (SDH) for flat components and surface notches for curved structures like pipes and tubes. This is due to the difficulty in drilling SDH in curved components. This is practically possible for relatively bigger diameter and thicker jobs. For smaller diameter tubes, notch is used, because of variation in SDH depth from the surface of the tube when the measurement is made along the length of the SDH.

The sensitivity of inspection depends on the reflecting area of the reflector, that sends a portion of ultrasonic energy back to the probe. In general, the reflecting area of a side drilled hole is stringent than a notch, therefore they are preferred more than a notch. During the standardisation of equipment

set up (Sensitivity calibration), the amount of energy reflected from a known sized reflector is set to a fixed height (typically 80% FSH) by adjusting the individual beam gain (gain offset) for each angle. For a good reflector, the reflected energy has to be proportionate to the beam path. Increase in beam path from lower angle to higher angle would have decreased in amplitude [6]. This decrease is due to increase in the travel path for higher angles which in turn causes increased attenuation in wedge and material.

Since Phased array sectorial beam sets produce multiple angles, the response of reflector to useful range of angles need to be studied to understand the uniformity in sensitivity. The various calibration processes involved in phased array inspection are Velocity calibration), Wedge delay calibration) Sensitivity calibration and Time corrected gain calibration- TCG. Therefore, it is decided to study the response of the reflectors for the range of beam angles, typically used for weld inspections.

**Experimental:**

To have a practical comparison of UT response between side drilled holes and surface notches, two samples are prepared from carbon steel material. Sample 1 is a 70 mm thick block that consists of 1.5 mm diameter side drilled hole at a depth of 25 mm (Figure 1). Sample 2 consists of four notches having various depths such as 0.5 mm, 1 mm, 2mm and 3 mm (Figure 2). The width of the notch is 5 mm and length of the notch is 25 mm. It is ensured that the SDH and surface notches are at same depth from the surface to have same beam travel in the material, which avoids need of performing TCG for this comparative study. Omni scan MX2 (32:128) equipment is used for the inspection trial. Phased array probe (5L64A12) of 5 MHz frequency with total elements of 64 and pitch of 0.6 mm is used. Shear wave wedge (SA12N55S-IHC) that has nominal refracted angle of 55 degrees (in steel) is used for the trial. Grease is used as a Couplant between the probe and wedge. Water is used as Couplant between the wedge and test samples. Sectorial group with active aperture of 16 is generated by using elements from 49 to 64. Shear wave beam set with angles ranging from 40 to 70 degrees is generated at 1-degree angle step.

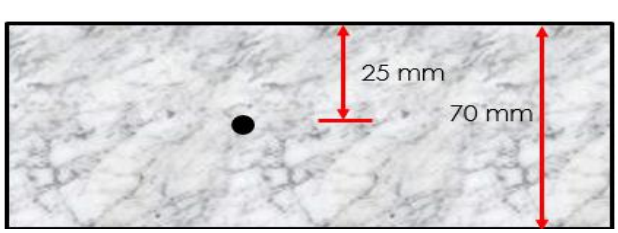


Figure 1 : Sample 1 with SDH reflector


Figure 2 : Sample 2 with surface notch

Velocity calibration is performed to determine the actual shear wave velocity in the material. Wedge delay and sensitivity calibrations are performed with side drilled holes present in the sample 1. After wedge delay calibration, the change in the beam delay for each angle is noted and after sensitivity calibration, the change in the gain offset for each angle is noted. The change in the beam delay and the gain offset for each angle are plotted (Figure 3 and Figure 4 ). Similarly, the wedge delay and sensitivity calibrations are performed for the sample 2 containing notches (0.5mm, 1mm, 2mm and 3mm depths).

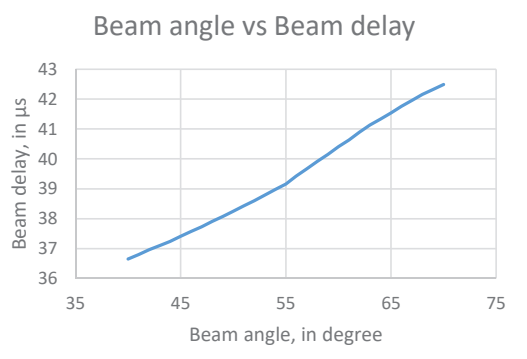


Figure 3 : SDH response for Wedge delay calibration

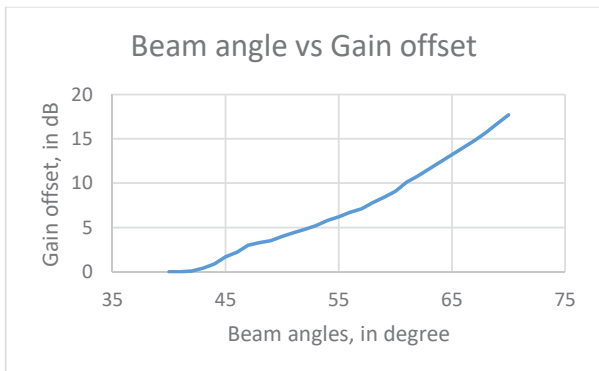


Figure 4 : SDH response for sensitivity calibration

## Results and discussion

### Beam delay and gain offset changes with the beam angles:

Figures 5 and 6 give plots between beam delay & beam angle and gain offset & beam angle, respectively. It is seen that the beam delay and gain offset increases almost linearly with the increase in the beam angle for the side drilled hole. The beam delay and gain offset responses for a change in the

beam angle for the notches are shown in the Figure 5 and Figure 6, respectively. It is observed that the beam delay exhibits linearity with the change in the beam angle, whereas gain offset shows linearity only up to certain angle (63°).

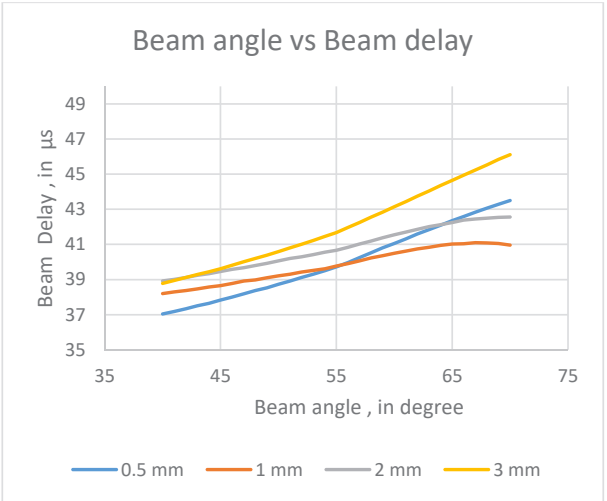


Figure 5 : Notch response for wedge delay calibration

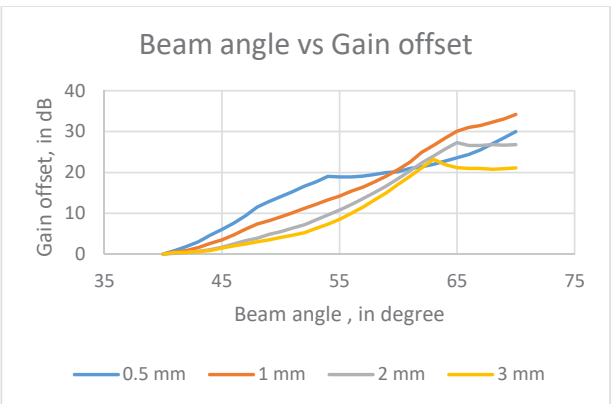


Figure 6 : Notch response for sensitivity calibration

**Calibration of gain offset for side drilled holes:**

While detecting a side drilled hole, higher angle takes longer path than the lower angles. This causes increased energy loss (due to attenuation and beam spread). The calibration process involves applying of increased gain offset to higher angles to bring all the angles to equal sensitivity level. For a side drilled hole calibration the loss of energy is uniform whereas for notch there is a variation in energy loss and subsequently variation in gain offset (particularly in the angles between 60 to 65 degrees).

To have a better understanding on the energy variation, the reflectors (SDH and notches) are scanned after making calibration. Since side drilled hole produces uniform sensitivity, it is used for calibrating the system and analyse the energy variation. The data acquired for 1.5 mm SDH is shown in Figure 7. It shows the different PAUT displays such as A, B and C scans.

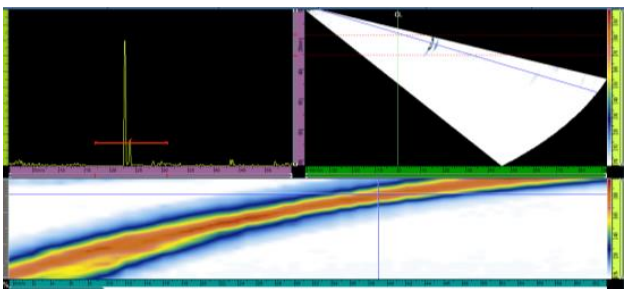

Figure 7 : Inspection of 1.5mm diameter SDH using SDH calibration

The maximum amplitude obtained for each angle is observed and it is noted that all angles are getting reflected within the acceptable limit of 80% (uniform red colour shown in C scan). Since side drilled hole gives uniform sensitivity, same calibration is used to analyse the energy drop in notches. The notches of dimension 0.5 mm, 1 mm, 2 mm and 3 mm, are scanned perpendicular to the notch such that all the angles are getting reflected by the notch. The data acquired for the notches 0.5 mm and 1 mm is shown as Figure 8 and Figure 9. It is observed that the amplitude drops for the higher angles compared with the amplitude received for lower angles.

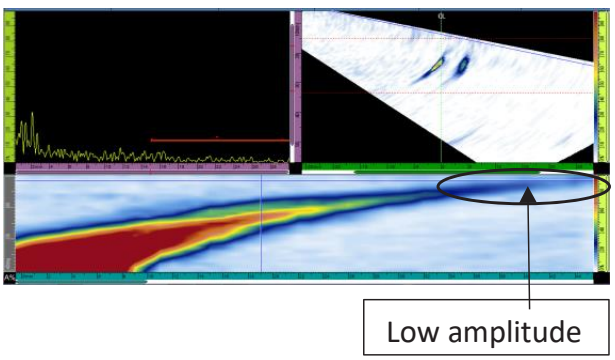


Figure 8 : Inspection of 0.5mm depth notch with SDH calibration

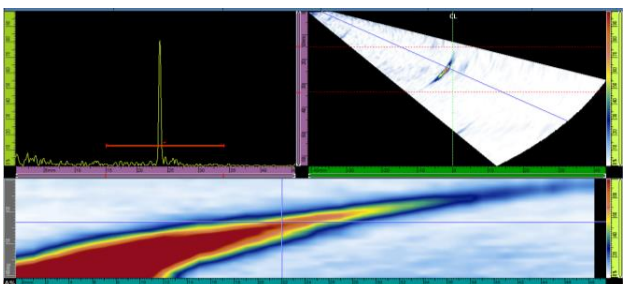

Figure 9 : Inspection of 1 mm depth notch with SDH calibration

The data acquired for the notches 2 mm and 3 mm is shown in Figure 10 and Figure 11. It is noticed that the amplitude drops in the middle and it rises as the angle increases. To avoid saturation of signals, general gain is adjusted which applies the changes in all the angles.

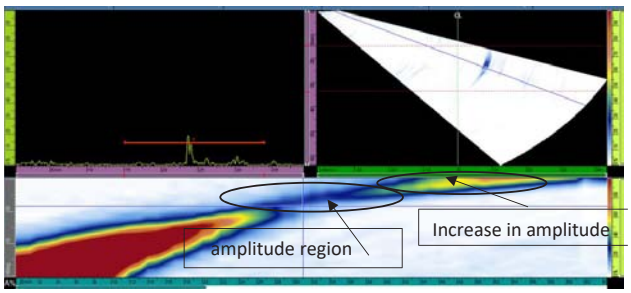


**Figure 10** : Inspection of 2 mm depth notch with SDH calibration

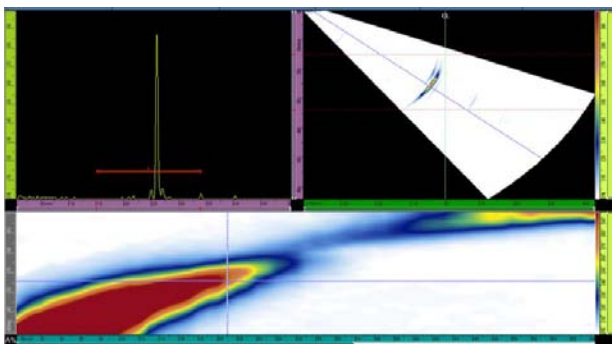

**Figure 11** : Inspection of 3 mm depth notch with SDH calibration

The maximum amplitudes obtained for all the angles for a 3 mm depth notch is detected and plotted (Figure 12). The amplitude decreases with the increase in the beam angles up to 63° and then increases with further increase in the beam angles.

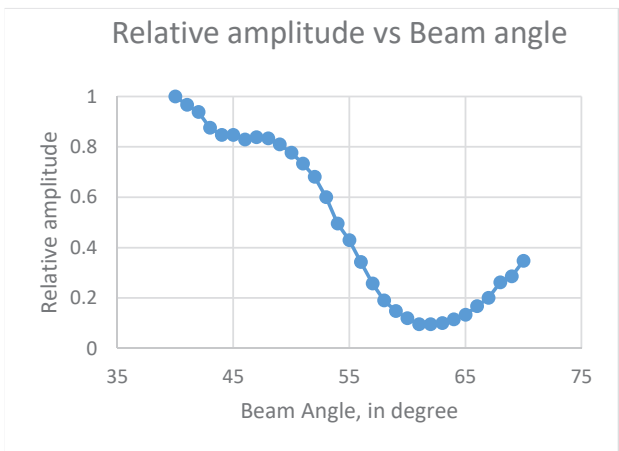


**Figure 12** : Response of notch for SDH calibration sectorial beams

## Simulation of notch response

To validate the results, the inspection is simulated using CIVA simulation software. The experimental set up is modelled and an In-line scanning is done across a notch (Figure 13) such that all the angles will hit the notch reflector sequentially. It is observed that sound beam gets reflected by various portions of the notch. The similar responses are also evident during the practical trials as shown in the Figures 15, 16 and 17.

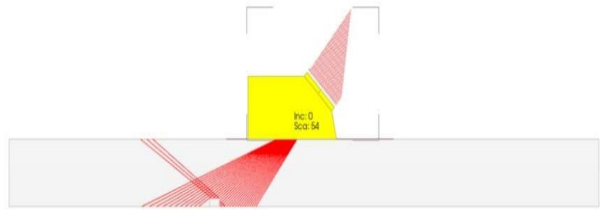

**Figure 13** : In line scanning of notch in CIVA

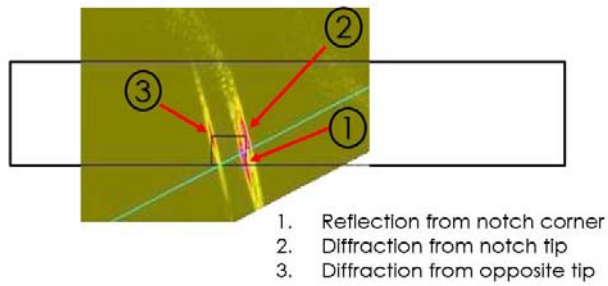


**Figure 14** : CIVA Simulation for a notch reflecting surface

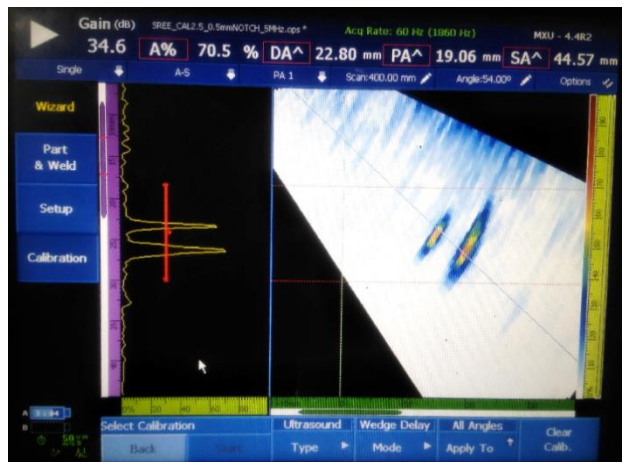


**Figure 15** : Multiple reflections from notch

It is noticed from the above results that the SDH gives uniform reflections, while the notch response is irregular between the angle 60 to 65 degrees. When the SDH is used for calibration purpose, the sensitivity obtained for all the angles looks uniform (Figure 4 and 9). The variation of gain offset for notches shows that energy reflected back to the probe is lesser for the beam angles between 60 to 65 degrees. This is because of reasons like mode conversion and multiple reflecting surfaces present in notch. The mode conversion takes place in the vertical wall of the notch for the angles between 60 to 65 degrees, causing reduction in the reflected energy. Multiple points such as bottom corner, top

tip and opposite tip of the notches are causing reflection/diffraction from the notch. This is evident in CIVA simulation results and also in the practical trials (Figure 14 and 17).

The drop in energy from lower angles towards higher angles, for notch reflector (Figure 8 to Figure 12) reveal that the sensitivity is not uniform for all the angles when compared with uniform reflection of SDH (Figure 7). Figure 10 and 13 show that there is a drop in amplitude from 40 to 60 degree and it rises after 65 degree towards 70 degree. This shows that the loss of energy due to mode conversion is from 60 to 65 degrees. The drop in amplitude (relative to the maximum amplitude) of the reflected energy is up to 20 dB from 45 to 60 degree and it rises to around 11 dB for 70-degree beam angle.

## Conclusion:

The study shows that side drilled hole is a good reference reflector for phased array inspection and notch will have irregular sensitivity. The variation in amplitude from the angle 45 to 60° is around 20 dB and the amplitude increase after 60 to 70° is around 11 dB. When a defect is detected by the angles between 60 to 65° (using notch as reference reflector), the sensitivity would be high for these angles compared with the lower angles.

The error in sensitivity is very high to an extent of 20 dB. This will cause a side wall lack of fusion or elongated slag to be sized with high sensitivity if detected in these angles range. This variation in sensitivity throughout the angles has to be taken care of during the interpretation, if notch is used as reference reflector where making a side drilled hole reflector is practically difficult. Such situations would arise while inspecting smaller diameter tubes/pipes where making a side drilled hole is difficult, the depth of the reflector from the surface will vary when measured at different lengths of the SDH.

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# NDE PATENTS

Compiled by Dr. Shyamsunder Mandayam, Vice President, ISNT

After a break of nearly 3 years, we are restarting this feature in the Journal. In today's world of fast paced technology innovations, Patents are an important facet and provide different types of information and value addition to Academia, Industry, Research or Business. Keeping oneself updated with the latest patents in their respective domains can help gain some great insights and perspectives into what are the technologists around the world working on and in addition help to trigger ideas and solutions!

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Here we list below a few interesting patents related to NDE and Inspection for Additive Manufacturing.

**United States Patent 11,027,332**

**System and method for in-situ characterization and inspection of additive manufacturing deposits using transient infrared thermography**

Inventors : ZalamedJoseph N, Burke Eric R, Hafley Robert A, Domack Christopher S
Assignee: United States of America as represented by the admiistrator of NASA (Washington, DC)

Systems and methods are provided for the real time inspection of additive manufacturing deposits using infrared thermography. Various embodiments may enable the measurement of material properties and the detection of defects during the additive manufacturing process. Various embodiments may enable the characterization of deposition quality, as well as the detection of deposition defects, such as voids, cracks, disbonds, etc., as a structure is manufactured layer by layer in an additive manufacturing process. Various embodiments may enable quantitative inspection images to be archived and associated with the manufactured structure to document the manufactured structure's structural integrity.

**United States Patent 11,105,754**

Multi-parameter inspection apparatus for monitoring of manufacturing parts
Inventors : Yacoubian Araz

Additive manufacturing, such as laser sintering or melting of additive layers, can produce parts rapidly at small volume and in a factory setting. To ensure the additive manufactured parts are of high quality, a real-time non-destructive evaluation (NDE) technique is required to detect defects while they are being manufactured. The present invention describes an in-situ (real-time) inspection unit that can be added to an existing additive manufacturing (AM) tool, such as an FDM (fused deposition modeling) machine, or a direct metal laser sintering (DMLS) machine, providing real-time information about the part quality, and detecting flaws as they occur. The information provided by this unit is used to a) qualify the part as it is being made, and b) to provide feedback to the AM tool for correction, or to stop the process if the part will not meet the quality, thus saving time, energy and reduce material loss

**United States Patent10,926,328**

**System and method for in-situ inspection of additive manufacturing materials and builds**
Inventors : Ralls John W, SoghomonianZareh, Hebert Daniel John, Wade Kyle A
Assignee : Huntington Ingalls Incorporated

An inspection system for in situ evaluation of an additive manufacturing (AM) build part is provided. The inspection system comprises a build plane induction coil sensor configured and positionable so that during construction of the build part, the sensor's magnetization and sensor coils surround at least the last-produced layer of the AM build part in the build plane. The inspection system further comprises an energization circuit and a central processing system. The central processing system comprises a communication processor configured for sending command signals to the energization circuit and receiving impedance data from the build plane induction coil sensor, and energization controller configured for determining energization commands for transmission to the energization circuit, and an induction data analyzer configured for processing build part impedance data using complex impedance plane analysis and for identifying anomalies in the AM build part.

**United States Patent 10,919,285**

**Method and system for x-ray backscatter inspection of additive manufactured parts**
Inventors : DehghanNiriEhsan, KottilingamSrikanth Chandrudu, Going Jr.Claude Leonard
Assignee : General Electric Company (Schenectady, NY)

A method for inspection of additive manufactured parts and monitoring operational performance of an additive manufacturing apparatus is provided. The method includes a step of obtaining, in real-time during an additively manufactured build process, a backscatter x-ray scan of an area of a build platform. The build platform is configured for supporting at least one part during the build process. An evaluating step evaluates, by a processor, the backscatter x-ray scan. A determining step determines, based on the evaluating, whether an operational flaw with the additive manufacturing apparatus has occurred or a defect in the at least one part has occurred. A backscatter x-ray system has an emitter that emits x-rays and a detector that receives backscattered x-rays. The emitter and detector are located on a movable support located above the build platform, and the movable support raises and lowers the emitter and detector with respect to the build platform.

**United States Patent 10,773,458**

**Terahertz inspection for additively manufactured materials**
Inventors : Lou TaisiaTsukruk, Palmer Jr. Donald Duane, Smith Nathan Rylan,
Dorrell Shayne Andrew
Assignee : The Boeing Company (Chicago, IL)

Apparatuses and systems comprising an additive manufacturing device and an associated terahertz inspection device for inspecting additively deposited layers in real time during or immediately following material deposition and parts made and inspected by the apparatuses and systems and their associated methods are disclosed herein.

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