Indian Society for
Non-Destructive Testing
Hyderabad Chapter

Proc. National Seminar on
Non-Destructive Evaluation
Dec. 7 - 9, 2006, Hyderabad

A Gamma Scattering Technique for Inspecting Concrete Structures

Shivaramu
Radiological Safety Division, Safety Group, Indira Gandhi Centre for Atomic Research,
Kalpakkam-603 102
e-mail: shiv@igcar.gov.in

Abstract

The present paper deals with a feasibility study of Compton scattering technique for inspection of concrete structures for the detection of local defects and the discrimination between materials of different density and composition, such as concrete, void and steel. The experimental set- up consists of a ^{137}Cs radioactive source and a HPGe planar detector providing high resolution energy dispersive analysis of the scattered spectrum. Reinforced concrete was represented by the insertion of two mild steel rods, 125 mm in length and diameter 9 mm into concrete slab of dimension 170 mm x 150 mm x 55 mm. An air cavity was created by inserting two cylindrical plastic voids each of size18.5 mm^3 into concrete slab. Scanning of the object was achieved by lateral movement of the concrete slab across the source and detector collimators in steps of 5 mm. The results show that the scattering method is highly sensitive to changes in electronic and physical densities of the volume element under study. The cylindrical voids and mild steel rods have been detected in the present study with a statistical accuracy of better than 0.1%**.** The density contrast is estimated to be 0.5 % and spatial resolution for detecting steel and void is estimated to be roughly 5 and 10 mm, respectively. The presence of steel and void can be clearly distinguished. As the steel bar intersects the sensitive volume, there is an increase in the total electron density of the material comprising of the sensitive volume, hence an increase in detector response. As the sensitive volume intersects the void cavity, there is a reduction in the total electron density and, therefore, a decrease in the detector response

Keywords: *Compton scattering, Inspection of concrete structures, Density contrast, Voids*

1. Introduction

In nondestructive testing (NDT) with radiation, the transmission modality is usually employed, where a source and a detector (e.g., a radiography film) are placed on opposite sides of the object, and the attenuation of the source photons through the object is measured. However, transmission measurements may not always be possible due to surrounding space constraints and for if the object is too bulky to produce sufficient radiation penetration. Transmission provides line-integrated information along the path of radiation from the source to the detector, which masks the position of an anomaly present along the transmission line. Therefore, it is difficult to determine the position of an anomaly directly from transmission measurements. The scattering modality provides an alternative. In scattering, the detector is positioned so that it is located outside the direct field of view of the source, and thus it measures radiation deflected from the object. Moreover, in scattering, point-wise information can be obtained by focusing the field of view of the source and detector so that they interact around a point. Scattering also eliminates the need of accessing two opposing sides of the target object. Scanning of the object can be achieved by moving the source and detector and changing their relative positioning such that the area of interest is covered. Since both the source and detector are located on one side of the object, examination of extended structures becomes possible

The Compton scattering method is a viable tool for inspecting material since it is an interaction which is strongly dependent on the electron density of the scattering medium, and in turn, its mass density. Therefore the information obtained by this technique is strongly related to the material density, thus allowing changes in the material uniformity to be monitored**.** The Compton scattering method is a powerful technique with a growing list of applications and the evaluation of concrete is a good place to examine the principles of density measurement [1]. Gamma or X-rays scattered from a well-defined volume element (VOXEL) are detected by a well-collimated detector placed at an angle which could vary from forward scattering angles to the back-scattering configuration. The X-rays are not as penetrating as gamma-radiation since X-rays typically have lower photon energies than gamma rays. On the other hand, the gamma-rays from radioactive isotopes produce an energy spectrum that has distinct emission energy peaks, thus providing well-defined photon energies that enable easier analysis of the measured signal. Moreover, gamma-ray isotopic sources are readily portable, self-contained, self-energizing and useable in hostile environments. The choice of scattering angle used is then dictated by the energy of the incident photons. The reflected signal provides a measure of the electron density ρ_e of the material comprising the inspected volume. By scanning a well-defined volume element through a plane of interest in an object, using a raster motion, it is possible to obtain density distribution in this plane. Moreover, in NDT, the nature of the inspected object is usually known and the purpose is to determine any disturbance in the measured signal that can indicate the presence of an anomaly. Hence, Compton scattering enables the detection of local defects and the discrimination between materials of different density and composition, such as concrete, void and steel

Non Destructive Evaluation (NDE) has potential applications in three key areas in the management of safety related concrete structures: i) Determination of as-built (or current) structural details, ii) detection of flaws and iii) characterization and quantification of flaws. The latter include the use of NDE technique as a means for monitoring concrete ageing. Nondestructive test methods can be used to indicate the strength, density and quality of concrete; locate voids or cracks in concrete; and locate steel reinforcement and its corrosion if any and indicate depth of concrete cover. Development of NDE techniques to meet the following needs would bring high benefit: Detection of corrosion in steel liners that are buried (covered by concrete) and detection of voids > 20 mm diameter in concrete. Detection of flaws before they propagate to the point of causing failure is essential. Therefore an urgent need exists to develop diversified effective non-destructive technologies to detect flaws in concrete structures.

A gamma scattering method of determining the moisture content in limestone concrete and hidden corrosion in mild steel reinforcement of concrete structures has been previously reported by us [2, 3]. In this paper, the feasibility of a Compton scattering technique for the inspection of extended concrete structures for the presence of steel rebar and void enclosures is demonstrated experimentally.

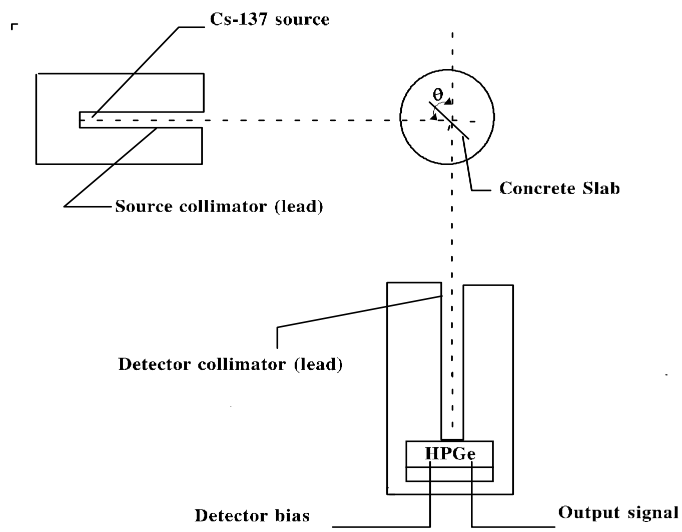

Fig. 1: Experimental setup

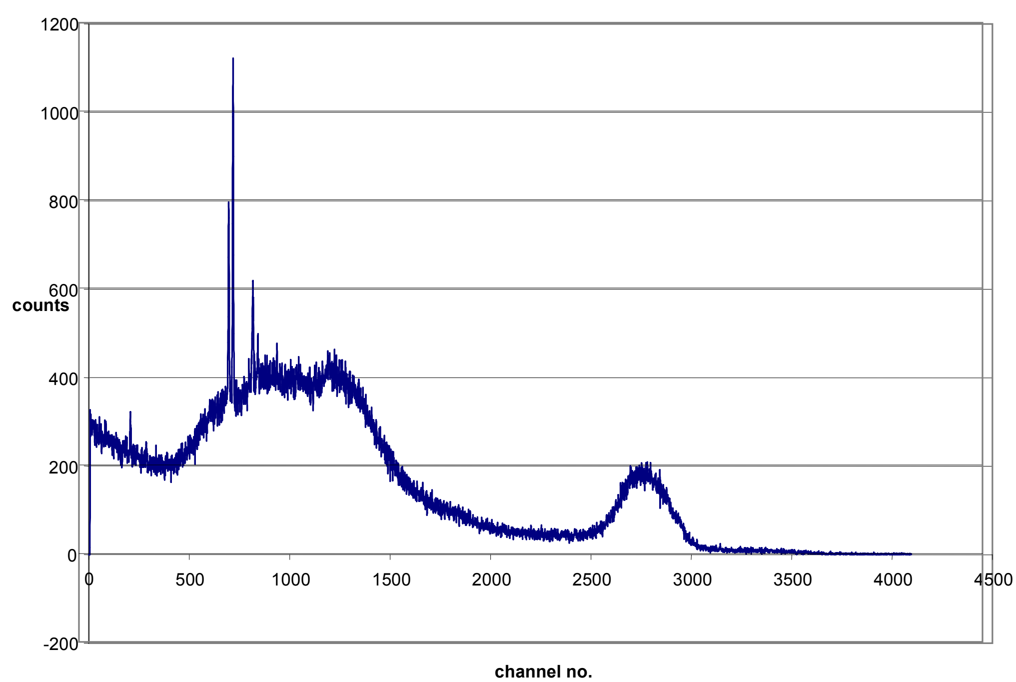

Fig. 2: A typical pulse height spectrum of the scattered intensity from the concrete slab

2. Experimental method

The experimental set- up, shown in Fig. 1 consists of a collimated ^{137}Cs radioactive source with a lead shielding mounted on a fixed arm of about 100 cm length, which could be rotated around the target centre and a collimated detector providing energy dispersive analysis of the scattered spectrum. The scattering angle can be varied from 0^o (for transmission measurements) to 140^o although for all scattering studies 90^o was chosen to minimize the scattering volume and to increase the positional sensitivity. The intersection of a collimated beam of photons with a collimated field of view of a detector defines the inspection (scattering) volume. The voxel to be analysed or sample volume V is geometrically established by the intersection of the incident and scattered beams, as defined by the input and output collimators of source and detector respectively and depends on source- structure, detector-structure distances and size of the collimators and can be easily chosen.

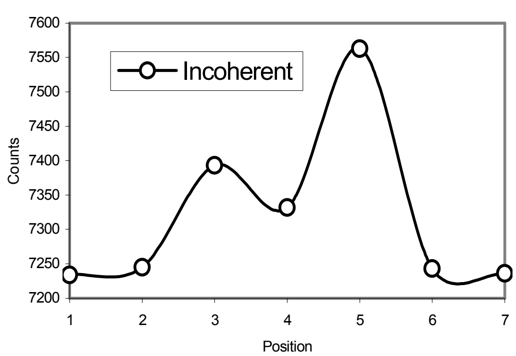

Fig. 3: Incoherent scattering intensity from concrete slab with two steel rods at 3 and 5 positions

Reinforced concrete was represented by the insertion of two mild steel rods, 125 mm in length and diameter 9 mm into concrete slab of dimension 170 mm x 150 mm x 55 mm. An air cavity was created by inserting two cylindrical plastic voids each of size18.5 mm^3 into concrete slab. The sample holder was mounted on a mild steel target frame. The source and detector were equipped with solid lead cylindrical collimators. The horizontal and vertical scanning of the concrete slab was achieved by lateral movement across the source and detector collimators in steps of 5.0 mm. The scattered beam was detected using a high-purity germanium planar detector. The pulse height spectrum of the detector was displayed using a multichannel analyzer which was interfaced with a PC for data storage and analysis

3. Results and discussions

A typical pulse height spectrum of the scattered intensity from the concrete slab is shown in the Fig. 2. The experimental scattered intensity at different positions of the sample representing the reinforced concrete slab for scattering angle $\theta = 90°$ is shown in Fig. 3. As the steel bar intersects the sensitive volume, there is an increase in the total electron density of the material comprising of the sensitive volume, hence an increase in detector response. Here a positive count rate was observed since the inclusions are denser than the material of the reference target, hence producing more scattering. a steel inclusion results in an increase in scattering for a gain in density of about 5500 Kg/ m3 (the difference in density between steel and concrete)

The experimental scattered intensity at different positions of the sample containing the two cylindrical plastic voids for scattering angle $\theta = 90°$ is shown in Fig. 4. As the sensitive volume intersects the void cavity, there is a reduction in the total electron density and, therefore, a decrease in the detector response. The higher sensitivity to the void can be explained by the large decrease in electron density caused by the removal of concrete from the inspection volume, as compared to the less drastic increase introduced by replacing concrete with steel. The abrupt change in the detector counting rate very clearly identifies the position and size of voids. The decrease in the counting rate is proportional to the volume of the defect, estimated as 18.5 mm^3 in the case shown. The bottom of the counting-rate valley estimates the defect position.

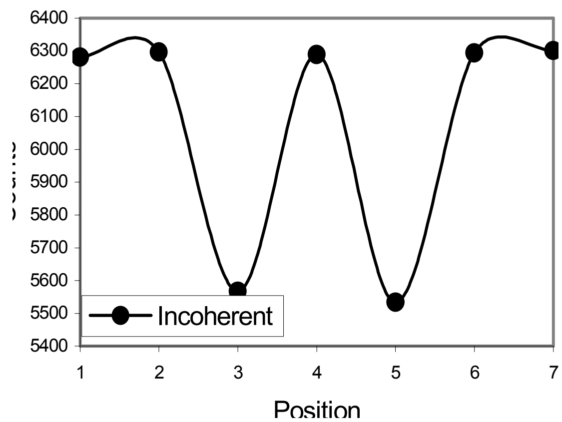

Fig. 4: Incoherent scattering intensity from concrete slab with two voids at positions 3 and 5

The cylindrical voids and the rebars of size given above have been detected in the present study with a statistical accuracy of better than 0.1%. The density contrast is estimated to be 0.5 % and spatial resolution for detecting steel and void is estimated to be roughly 5 and 10 mm, respectively. From the shape of the distinct peak, or dip, in the indication spectrum, one can deduce the size (by the width of the peak) or density of the defect (from the peak's height)

The effectiveness of this inspection technique can be defined by the spatial resolution and the density contrast achievable. Good resolution requires a small sensitive volume, while high contrast demands large sensitivity to changes in composition. The size of the inspection volume defines the spatial resolution. Reducing the collimator aperture to improve the spatial resolution leads, however, to a decrease in the count rate. This can be compensated for by increasing the source strength and the counting period. A practical compromise is therefore necessary to achieve a reasonable resolution within an appropriate counting period and without exposure to a high dose of radiation. In order to increase the contrast, the contribution to the detector from the material contained within the sensitive volume should be enhanced while that of the surrounding media should be reduced. This can be achieved by reducing the attenuation of the radiation as it travels to and from the sensitive volume, and/ or by increasing the probability of scattering within the volume. The attenuation and scattering probability, however, depend on the radiation energy and the angle of scattering. The incident angle, defined in fig. 1. determines the photon path length and in turn affects the attenuation probability. The source energy and the scattering angle are, however, the two most important design parameters as they directly affect the detector response

4. Conclusions

The above results demonstrate the ability of the Compton scattering technique to distinguish between steel and void enclosures in concrete. The fluctuations within the concrete medium are seen in the recorded signal and are attributed to the inhomogeneity of the concrete medium. The presence of steel and void can, however, be clearly distinguished. The main advantage of this method as compared to other techniques is the ability to detect rebars and voids with out the need for all- round access to the concrete structures under investigation and the method is relatively simple and results are of direct nature

The photon scattering preferable to other forms of NDE in certain cases: high contrast even for thick samples, good spatial resolution, 3-dimensional capability, and the ability to make direct real-time density measurements of only the volume of interest within the sample. Finally, the technique is quite promising for NDT, becoming very helpful when one of the sides of the body is inaccessible and transmission techniques cannot be used

5. References

1. Lawson, L., "Backscatter Imaging", Materials Evaluation, 60 (11), 1295-1316, 2002
2. Shivaramu, Vijayakumar, R., Rajasekaran, L., and Ramamurthy, N., "Determining the moisture content in limestone concrete by gamma scattering method: a feasibility study", National Seminar NDE 2002, Chennai
3. Shivaramu, "NDE of corrosion of MS reinforcing in concrete structures by gamma scattering method", National Seminar NDE 2004, Pune