ONE SIDED RADIOGRAPHIC INSPECTION USING BACKSCATTER IMAGING

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INTRODUCTION

Radiographic inspection, where access is limited to one side of the part, can be performed by the use of backscatter imaging techniques. Compton scattering is the primary source of the backscattered signal strength with some contribution from x-ray fluorescence. A variety of approaches have been used in both medicine and industry to create the images [1-25]. The flying spot technique which uses a collimated beam of x-rays, and a large area detector has been used in the work reported here. The backscatter imaging is particular useful in the inspection of low-density, composite materials.

RADIATION BACKSCATTER

The attenuation of photons of the energies less than 1 MeV (a range of most industrial inspections) is composed of Compton scattering, photoelectric effect and to a small degree coherent scattering. Figure 1 shows the contribution of Compton scattering to the total attenuation for several elements as a function of energy. Low atomic number elements, such as carbon, attenuate predominately by scattering even at relatively low energies. Composite materials are therefore good subjects for backscatter imaging.

The backscatter signal will be dependent upon the atomic number, density and thickness of the material under test and the incident energy spectrum of the photons. Calculations have been run using the FSCATT [26] slab geometry radiation transport code. Figure 2 shows the total backscatter as a function of thickness of acrylic and aluminum for two incident spectra. The spectra are bremsstrahlung at 55 kVp and 110 kVp. The results indicate that at 110kVp, an infinite thick acrylic layer would

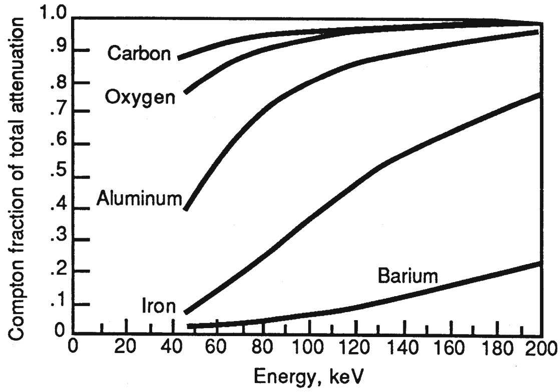

Fig. 1. Fraction of Compton scatter in the total x-ray attenuation as a function of energy for selected elements.

backscatter approximately 25% of the incident energy and an aluminum layer about 7%. From the figure, the depths where 75% of the maximum backscatter is reached is 5 cm in acrylic and 1 cm in aluminum.

Figure 3 shows the effect of changing the atomic number of the scatterer. The relative scatter is calculated to be high at low atomic number, decreases, and then increases again before decreasing at high atomic number. The curve shapes are a function of the kVp used in the calculations. (Note, a limited number of elements are available in FSCATT). The increase in scatter at intermediate atomic numbers is due to fluorescence yields. These results indicate that x-ray fluorescence can be a large contributor to the scatter depending upon the incident energy spectra. This leads to the possibility of atomic number discrimination with x-ray backscatter imaging.

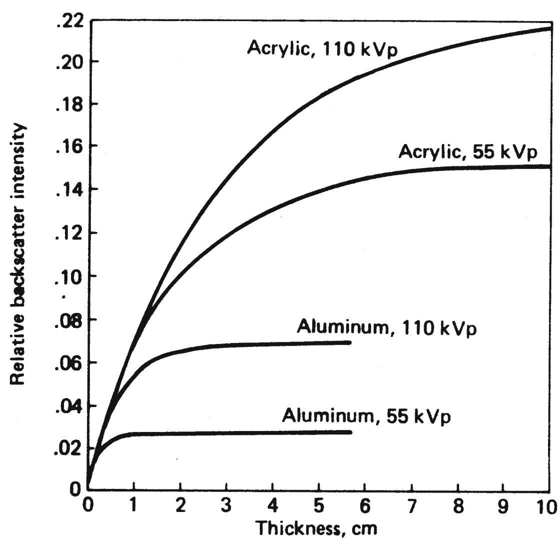

Fig. 2. Calculated backscatter as a function of acrylic and aluminum thickness as 55 kVp and 110 kVp.

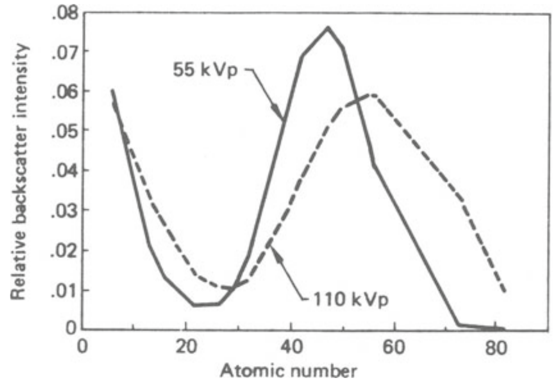

Fig. 3. Backscatter intensity as a function of atomic number from FSCATT code calculations.

Conventional radiography images the transmitted photon beam, with the transmitted signal given by

$$I = I_o e^{-\mu x} \tag{1}$$

where I is the transmitted intensity, I_o is the incident intensity, μ is the linear attenuation coefficient and x is the material thickness. The contrast sensitivity to a change in material, dx, is then

$$\frac{dI}{I} = -\mu \, dx \tag{2}$$

which shows that the change in signal is a function of the attenuation coefficient and thickness change.

In backscatter imaging, the scatter signal(I_b) from a volume element is given by

$$I_b = I_o e^{-\mu x} \quad \mu w e^{-\mu_2 x} \tag{3}$$

where I_o is the initial intensity $e^{-\mu x}$ is the attenuation of entering the material $e^{-\mu_2 x}$ is the attenuation of the scattered beam leaving the material and μw is the probability of scatter at location x by a material with scattering coefficient μ and thickness w. If the material is changed then the contrast is

$$\frac{I_b - I_b'}{I_b} = \frac{\mu - \mu'}{\mu} \tag{4}$$

where μ' is the scattering coefficient for the new material at location x. The contrast in this backscatter case is due only to the change in coefficients. [18, 25]. This is an advantage in the inspection of thin materials. Backscatter imaging is usually superior to through transmission imaging for thicknesses that are radiologically thin, where the product of the linear attenuation coefficient and material thickness is less than one [18].

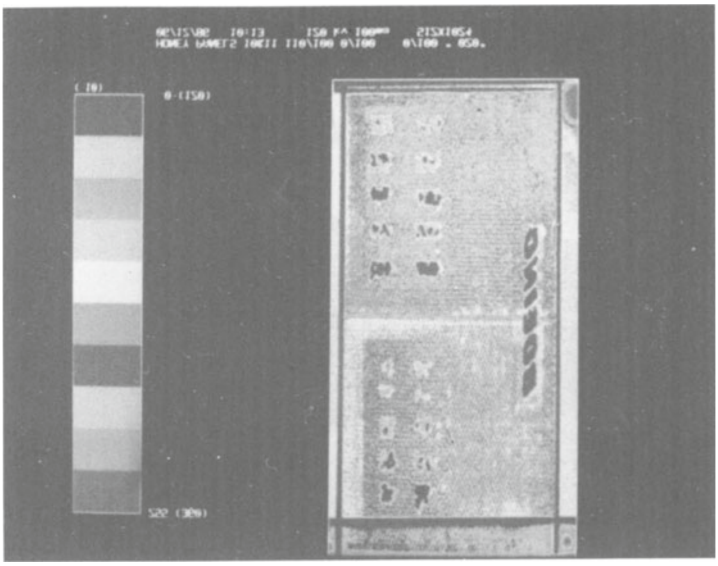

Fig. 4. Backscatter image of water injected in a graphite honeycomb panel. (B&W print is obtained from a color original).

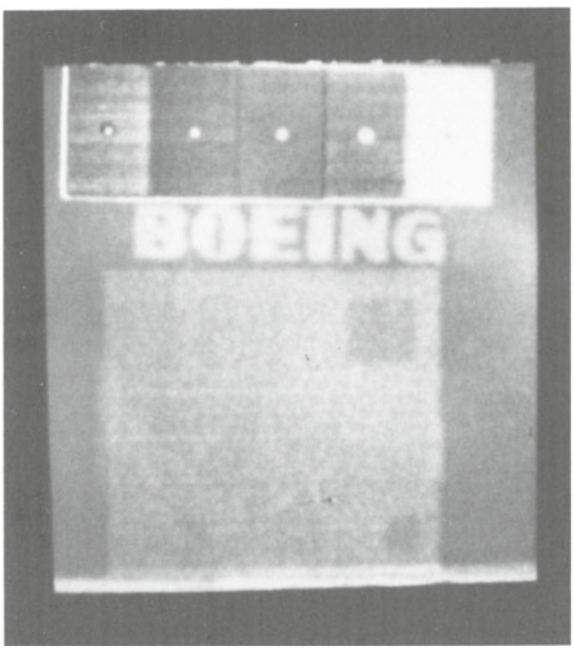

Fig. 5. Composite honeycomb part, 12 cm x 12 cm x 1 cm thick with large front surface skin cut out and small back surface skin cut out, and graphite step block (approx. 4 mm steps with 3 mm holes). (B&W print is produced from a color original).

EXPERIMENTS

Backscatter images have been obtained by using flying spot imaging approaches. A collimated beam of radiation is made to move over a part by means of mechanical apertures and part positioning. Detectors placed on the source side of the object detect the backscatter radiation.

Figure 4 shows the image of water in honeycomb. The scanning technique used for this image acquisition was the American Science and Engineering flying spot device [28, 29]. Figure 5 shows the backscatter image of a graphite step block (steps of approximately 4 mm with 3 mm holes) and a composite honeycomb part with removal of small patches of front and back skins. This image was obtained with a prototype Boeing experimental device. The part was moved in a rastor scan motion relative to a pencil beam of radiation. A large (76cm O.D., 38cm I.D.) annular ring detector was used to detect the radiation.

The Boeing system is being modified to incorporate a spiral scanning aperture located in the center of the large annular ring detector. With this approach, images may be obtained without requiring motion of the object or scanner. Figure 6 shows how this system is conceived for field implementation.

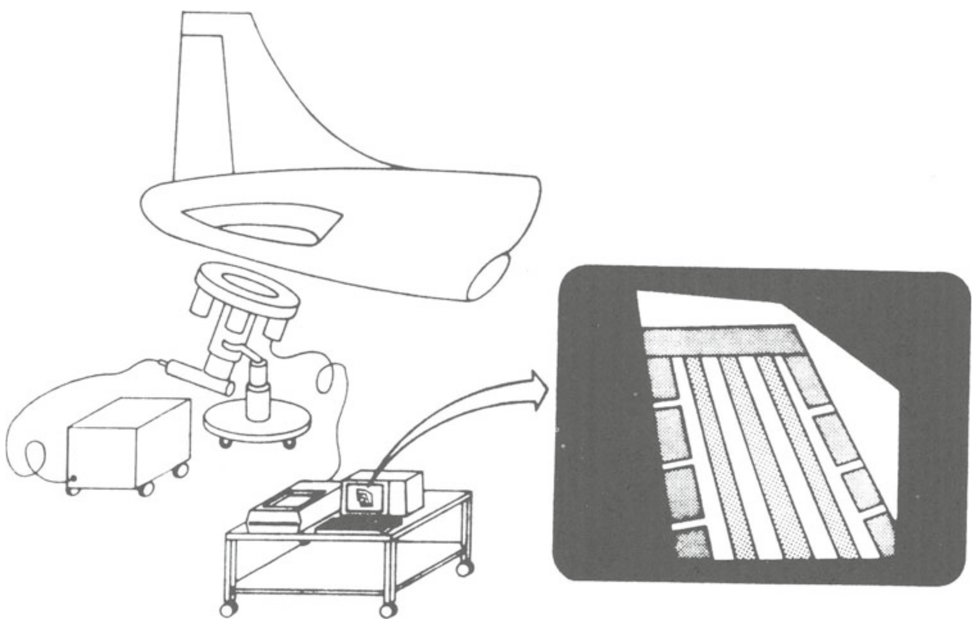

Fig. 6. Spiral scanning backscatter imaging device for field inspection.

REFERENCES

1. Karl-Hans Reiss and W. Schuster, "Quantitative Measurements of Lung Function in Children by Means of Compton Backscatter", Pediatric Radiology, Vol. 102, March,1972.
2. Leon Kaufman, Gordon Gamsu, Charles Savoca, Sybil Swann, Louis Murphey, Bernard Hruska, David Palmer and John Ullman, "Measurement of Absolute Lung Density of Compton-scatter Densitometry", IEEE Transaction on Nuclear Science, Vol. NS-23, February, 1976.
3. P. G. Lale, "The Examination of Internal Tissues, using Gamma-ray Scatter with a Possible Extension to Megavoltage Radiography", Physics in Medicine and Biology, Vol. 4, 1959.
4. R. L. Clarke, E. N. C. Milne, and G. van Dyk, "The Use of Compton Scattered Gamma Rays for Tomography", Investigative Radiology, Vol. 11, 1976.
5. F. T. Farmer and Margaret P. Collins, "A New Approach to the Determination of Anatomical Cross-sections of the Body by Compton Scattering of Gamma-Rays", Physics in Medicine and Biology, Vol. 16, 1971.
6. F. T. Farmer and Margaret P. Collins, "A Further Appraisal of the Compton Scattering Method for Determining Anatomical Cross-sections of the Body", Physics in Medicine and Biology, Vol. 19, 1974.
7. Bruce C. Towe and Alan M. Jacobs, "X-ray Backscatter Imaging", IEEE Transactions on Biomedical Engineering, Vol. BME-26, September, 1981.
8. Bruce C. Towe and Alan M. Jacobs, "X-ray Compton Scatter Imaging Using a High Speed Flying Spot X-ray Tube", IEEE Transactions on Biomedical Engineering, Vol. BME-28, October, 1981.
9. J. J. Battista and M. J. Brinskill, "Compton-scatter Tissue Densitometry: Calculation of Single and Multiple Scatter Photon Fluences", Physics in Medicine and Biology, Vol. 23, No. 1, 1978.
10. Peter R. Duke and James A. Hansen, "Compton Scatter Densitometry with Polychromatic Sources", Medical Physics, Vol. 11, No. 5, 1984.
11. Alan L. Huddleston and Jay P. Sacklerh, "The Determination of Electron Density by the Dual Energy Compton Scatter Method", Medical Physics, Vol. 12, No. 1, 1985.
12. G. Harding and R. Tischler, "Dual-energy Compton Scatter Tomography", Physics in Medicine and Biology, Vol. 31, May, 1986.
13. L. Brateman, A. M. Jacobs and L. T. Fitzgerald, "Compton Scatter Axial Tomography with X-rays: Scat-Cat", Physics in Medicine and Biology, Vol. 29, November, 1984.
14. S. Bukshpan, Dan Kedem and Drora Kedem, "Detection of Imperfections by Means of Narrow Beam Gamma Scattering", Materials Evaluation, Vol. 33, October, 1975.
15. G. A. Arkhipov, E. G. Golukov, B. L. Dvinyaninov, P. P. Zol'nikov, Yu. A. Kovyazin, and K. A. Sukhanova, "Using Scattered Gamma *Radiation for Detecting Subsurface Defects in Metal", translated from Defektoskopia, No. 3, May-June, 1976.

16. B. Bridge, "A Theoretical Feasibility Study of the use of Compton Backscatter Gamma-Ray Tomography (CBGT) for Underwater Offshore NDT", British Journal of NDT, November, 1985.
17. D. G. Costello, J. A. Stokes, and A. P. Trippe, "Theory and Applications of Collimated Photon Scattering", 14th Symposium on Nondestructive Evaluation, San Antonio, TX, 1983.
18. G. Harding, "On the Sensitivity and Application Possibilities of a Novel Compton Scatter Imaging System", IEEE Transactions on Nuclear Science, Vol. NS-29, No.3, June 1982.
19. H. Strecker, "Scatter Imaging of Aluminum Castings Using an X-ray Fan Beam and a Pinhole Camera", Materials Evaluation, Vol. 40, September 1982.
20. H. Berger, Y. T. Cheng, and E. L. Criscuolo, "High Sensitivity, One-Sided X-ray Inspection System", NSWC TR 85-292, July 1985.
21. A. Ashley, "Airport X-ray Spots Invisible Weapons", Popular Science, May 1986.
22. J. H. Stanley and J. J. LePage, "Development of a Prototype Backscatter Tomograph" AFWAL-TR-85-4140, February 1986.
23. Marin Annic, Paul Bjorkholm and Tichard Mastonardi, "ZT: A Tomographic Backscatter Technique for Nondestructive Evaluation", 16th Symposium on Nondestructive Evaluation, San Antonio, TX, April 1987.
24. N. K. Gupta, R. F. Rodenbaugh, M. D. Silver, and E. A. Sivers, "Backscatter Imaging Tomography with High Efficiency Detectors: Work in Progress", Review of Progress in Quantitative NDE, Williamsburg, VA, June 1987.
25. J. Kosanetzky, G. Harding, K. H. Fischer, and A. Meyer, "COMSCAN X-ray Imaging", Philips GmbH, Hamburg, W. Germany.
26. R. H. Fisher and R. A. Kruger, " A Numerical Treatment of Scattering and Fluorescence in Plane Geometry", DASA 2418, May 1971.
27. R. H. Fisher and J. W. Wiehe, "A User's Guide to the FSCATT Code", DASA 2618, November 1970.
28. American Science and Engineering, Fort Washington, Cambridge, MA.
29. R. Bossi, K. Friddell and J. Nelson, "Backscatter X-ray Imaging", Materials Evaluation - to be published.