COMPUTED TOMOGRAPHY IMAGING FOR NONDESTRUCTIVE EVALUATION

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INTRODUCTION

X-ray Computed Tomography (CT) is a relatively new Nondestructive Evaluation (NDE) technique in industry. Traditional Radiography or Digital Radiography is a data acquisition technique where the full volume information is superimposed in an overlapping fashion on a two-dimensional image. In contrast, CT gathers full volume data at a specified plane in the object and, in software, 'reconstructs' the cross-sectional image of the object, removing all superpositioning of overlapping information.

CT has been proven as an invaluable technique in the inspection and evaluation of a variety of materials and components. Application areas for CT cover a broad spectrum of objects, for both the Air Force and industry. This paper will present examples of CT imaging as an NDE tool in some aerospace and industrial application areas. It will also show some research efforts that insert CT into the in-process evaluation of new materials, and some experimental work to evaluate the optimum performance of the CT machine.

The system used for all the CT imaging contained in this paper was the LAMDE CT System located at Wright Laboratory, Wright-Patterson AFB, Ohio. The LAMDE CT System is a translate-rotate type CT machine with a 420 keV X-ray tube source. The system can examine components up to 600 mm in diameter and 500 pounds.

INDUSTRIAL APPLICATIONS

In terms of product design and costs to build, casting is one of the less expensive methods of production. However, castings are generally never made for critical usage/areas. CT inserted in the in-process design development, as well as an inspection tool, can bring information to the design engineers that has the potential to open up castings for more complex parts with less manufacturing costs.

Figure 1 is a CT image of a first run aluminum casting that shows voids present near the center of the left element. From this information, the design engineer was able to evaluate the design and structural performance of the part using finite element analysis. The detailed information provided by CT was required to determine if any degradation to performance would occur as a result of the voiding.

To illustrate CT capability on a more familiar object, a defective 24 mm socket was inspected. When visually examined, the inner surface showed severe cracks. The CT

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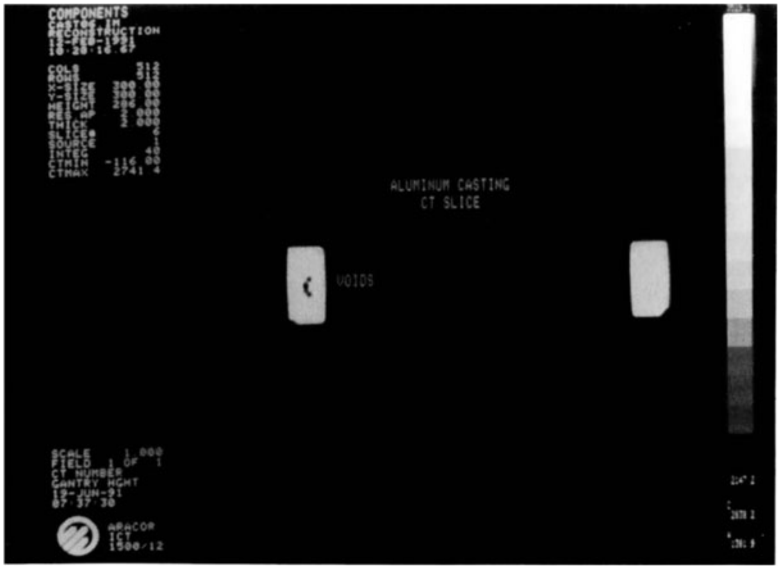

Figure 1. CT Image of Aluminum Casting

inspection revealed severe voids present behind the surface cracks. Figure 2 is the CT image. The socket was then dissected and as shown in the photo in Figure 3, the CT data is validated.

AEROSPACE APPLICATIONS

CT images generate a great deal of information that is not available with other NDE methods. Figure 4. is a CT image that was generated to determine the internal structure of an inconel fan blade. This fan blade was manufactured by casting two halves and diffusion bonding the halves together. Of importance in this area of the fan blade, is the alignment of the ribs between the two halves. Quality control inspection, that included film radiography, had been performed on this fan blade and it had been deemed an acceptable, no flaw, part. CT shows that the ribs are significantly misaligned and this part may not acceptable. Due to the superpositioning limitations of film radiography, the rib misalignment could not be detected by any method other than CT.

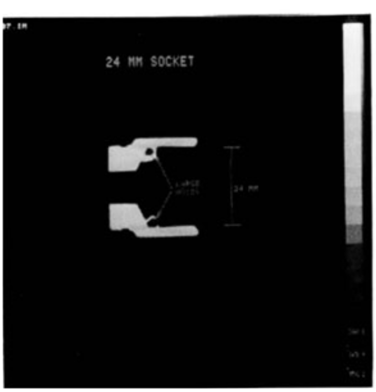

Figure 2. CT Image of Forged Socket

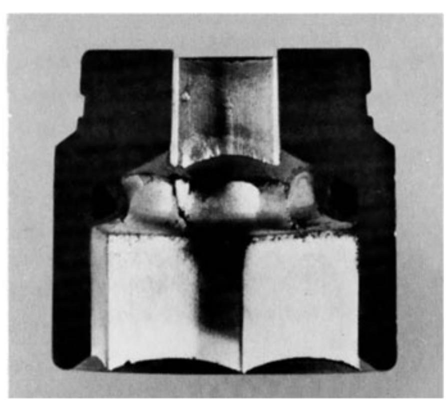

Figure 3. Photo of Dissected Socket

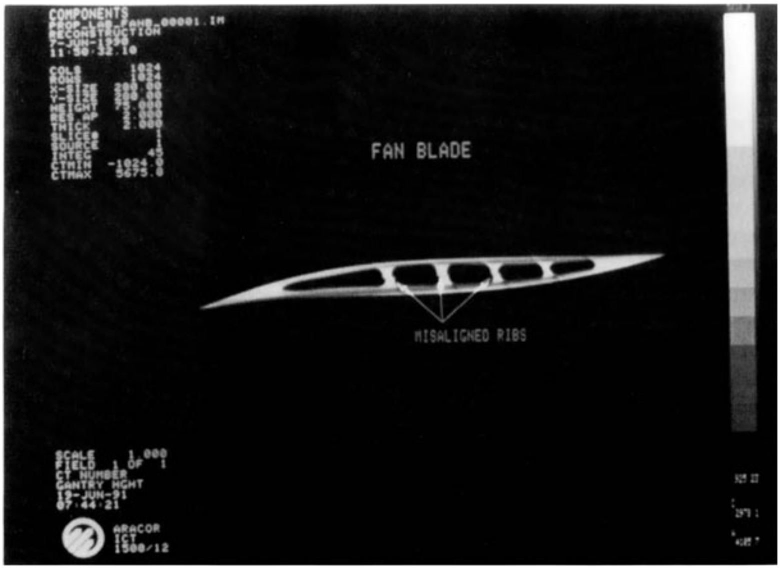

Figure 4. CT Image of a Fan Blade

PROCESS EVALUATION

CT can be an invaluable tool in the examination of new materials and processing. Figure 5 is a CT image of six (6) carbon-carbon material specimens. The two larger specimens in the center are standard specimens that were made as a comparison for the new material specimens. The smaller four specimens at the outer edges were each produced by slightly different processes. Each process produced a sample of slightly different density. The CT examination was to determine if an inspection method is available to register the small variations in density of the four different processes.

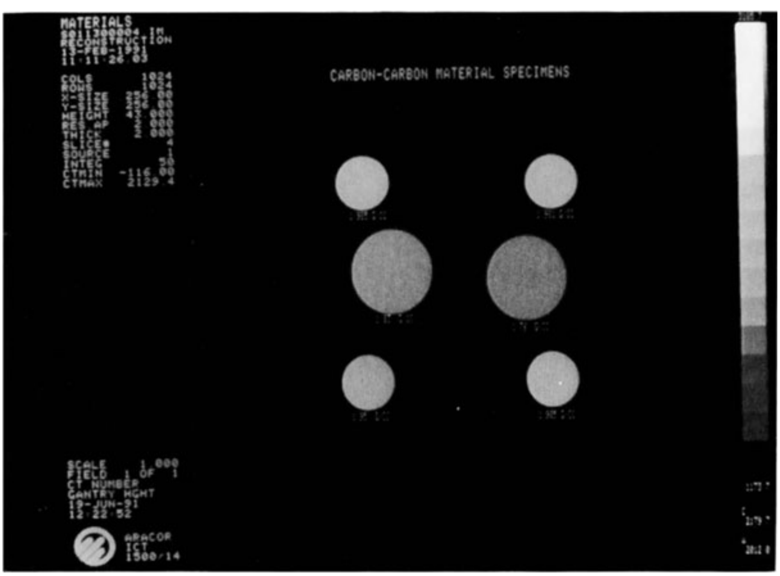

Figure 5. CT Image of Carbon Specimens

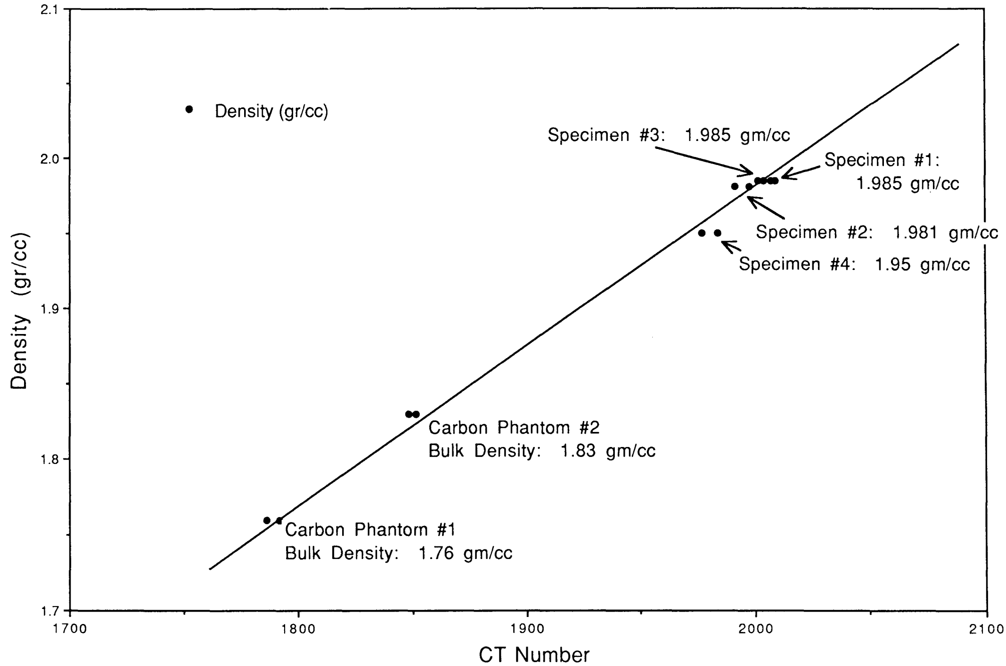

Figure 6. Graph of CT Number versus Bulk Density Measurements

Two CT scans were taken at different heights in the set-up as shown in Figure 5. A graph of the mean CT numbers of each specimen versus that specimens bulk density measurement is presented in Figure 6. There are two data points for each specimen. In Figure 6, each data pair per specimen is distinctly separated from the other specimen data pairs. This demonstrates that CT is extremely sensitive to small variations in density. CT is also a repeatable inspection, as the data points from the two slices pair up well.

CT SYSTEM PERFORMANCE

DUAL ENERGY CT

Dual Energy refers to gathering data at two different energy ranges and through computational analysis, reconstructing two images, one that is proportional to the electron density of the material under inspection, and one that is sensitive to the atomic number of the material. [1]

Dual energy CT is possible due to the interactions that X-rays have with matter. Figure 7 shows a graph of X-ray energy versus the photon-matter interaction that occurs. At low X-ray energies, the photoelectric effect dominates in the photon-matter interactions. The frequency of occurrence of the photoelectric effect is directly associated with the atomic number of the material with which the X-ray photon interacts. At slightly higher X-ray energies, the Compton effect will dominate. The frequency of occurrence of the Compton effect is directly proportional to the electron density of the material under inspection.

To study the effectiveness of the dual energy capability on the system, a standard or phantom was used. Figure 8 is a drawing of the CT density phantom, a disk 14 cm in diameter and 5 cm tall with ten 13 mm diameter inserts extending from the top surface to halfway through the disk. One insert is air and the remaining nine inserts are, counterclockwise, materials that are monotonically increasing in density, from air to titanium. This disk was CT scanned using the dual energy capabilities.

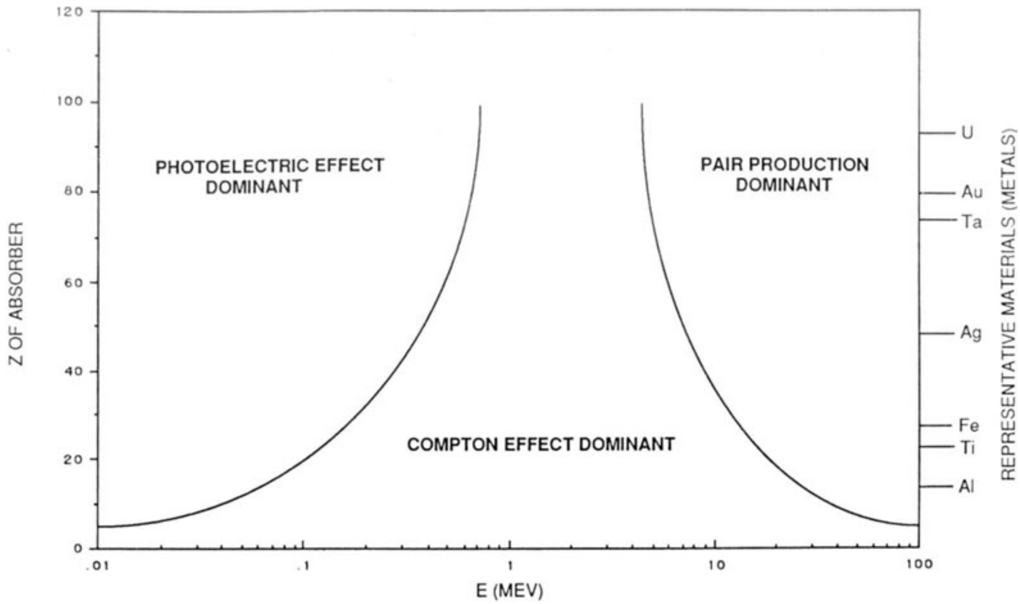

Figure 7. Graph of X-ray Photons to Matter Interactions

Figure 9 is the CT image of both the pseudo-photoelectric effect image (upper left) and the pseudo-Compton effect image (lower right). The pseudo-Compton image is directly proportional to the electron density of the material density phantom. The lower right image shows the gradually increasing CT numbers that represent the monotonically increasing density in the various plugs.

The upper left image, the pseudo-photoelectric effect image, is a representation of the atomic number sensitivity of the X-ray photons to the different material inserts. In this image, insert #4 is now imaging as a higher CT number than the surrounding host material. Insert #4 is a compound called Nylatron ®, which contains less than 10% MoS_2, a high atomic number material used to adjust the material bulk density to the required value. [2]

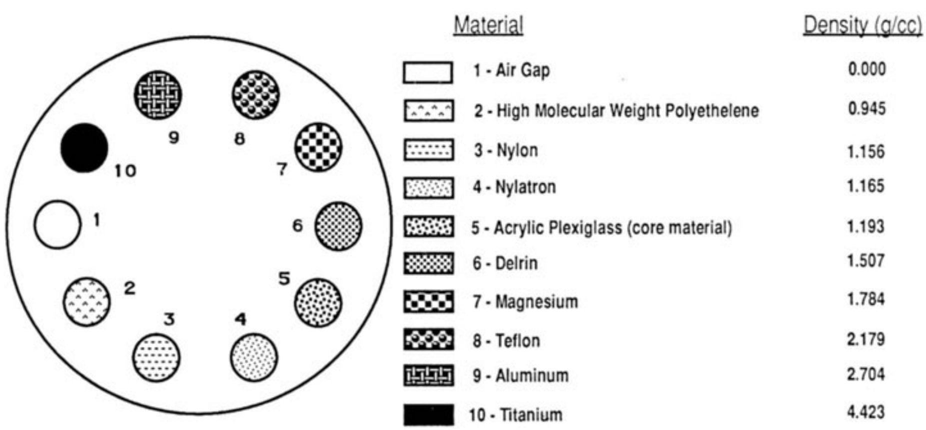

Figure 8. Schematic of CT Density Phantom

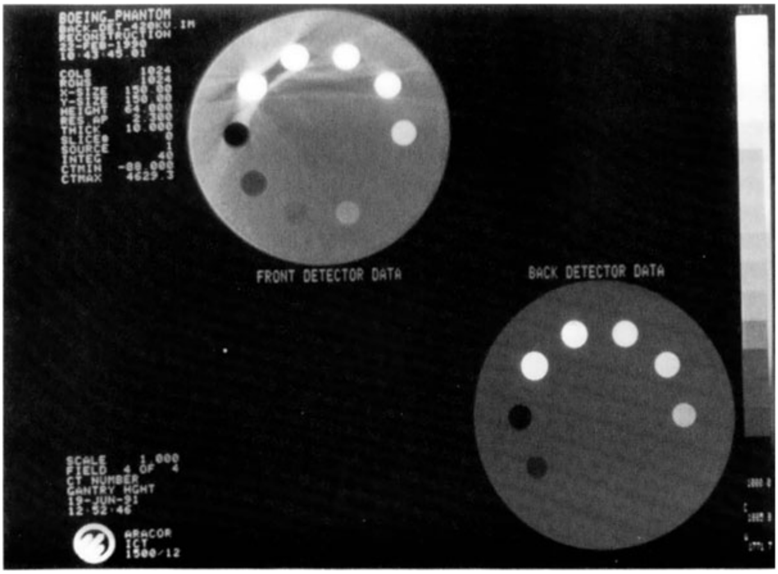

Figure 9. Dual Energy CT Images of the Density Phantom

NOISE PHANTOM

It is important to monitor the performance of any inspection device to ensure that the system is performing identically over time. There are many such checks on any given system. One such check is the periodic scanning of the same part and comparing the data. On this system, a 150 mm aluminum disk, called a noise phantom, is scanned every week. This effort allows monitoring of X-ray source and electronics stability.

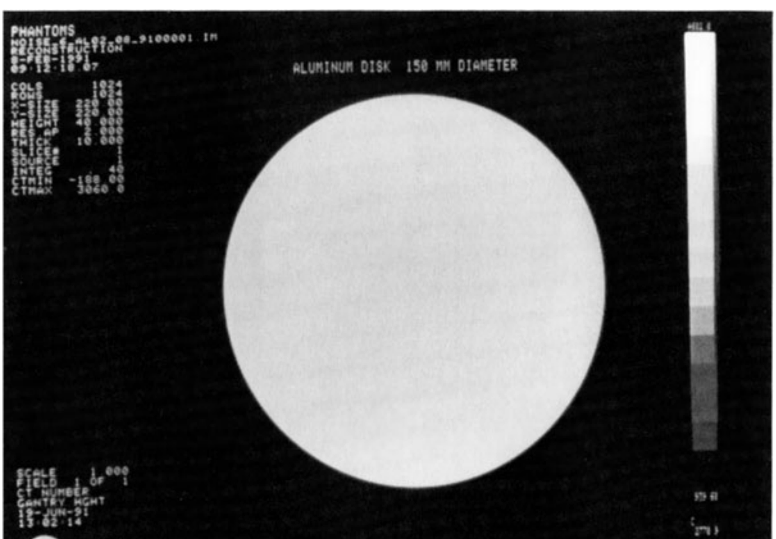

Figure 10. CT Image of Noise Phantom

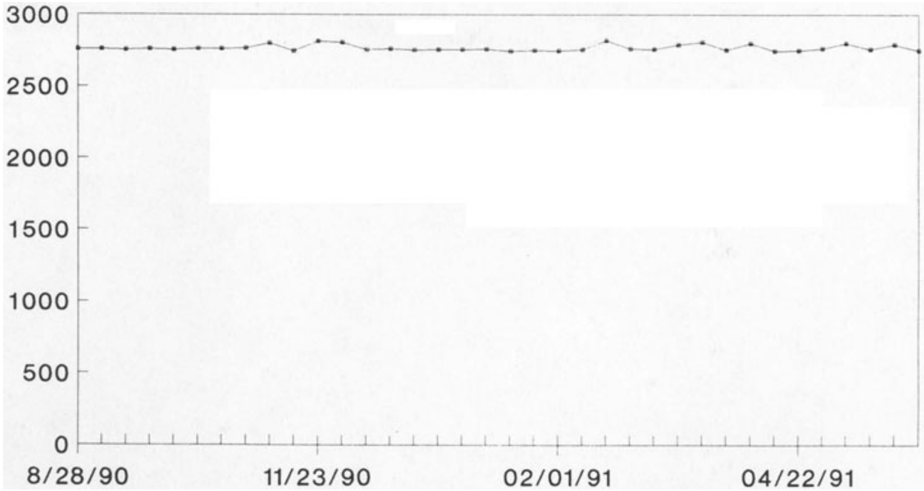

Figure 11. Graph of Noise Phantom Data

Figure 10. is a CT image of the aluminum noise phantom. Figure 11. is a graph of the mean CT number at the center of the disk over several months time. The smoothness of the graph would indicate a stable system performance over the time of the scans, specifically, stability in the X-ray source, as well as the overall electronics that could adversely effect the system performance.

SUMMARY

In this paper we have shown only a small fraction of the CT capabilities available to aerospace and industry for their NDE needs. In addition we have provided some insight into one of the performance parameters which must be monitored on a continuing basis.

ACKNOWLEDGEMENTS

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REFERENCES

1. Kropas, C.V., Moran, T.J., and Yancey, R.N., ASNT Journal: Materials Evaluation, Volume 49/Number 4, April, 1991.

2. Gardner, W., Cooke, E.I., and Cooke, R.W.I., *CRC Handbook of Chemical Synonyms and Trade Names, 8th Edition*, 1978, CRC Press, Cleveland, Ohio.