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Study on Synthetic Aperture Focusing Technique (SAFT)

[1]Mr. Geo Francis, [2]Dr. Arun K, [3]Mr. Akash Paul Savio

[1,2,3]Viswajyothi College of Engineering and Technology, Vazhakulam P.O, Muvattupuzha 686670, India

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A B S T R A C T

The Synthetic Aperture Focussing Technique (SAFT) restores ultrasonic images obtained from either B or C scans having focusing distortion. With the help of SAFT, improvement in image resolution was obtained without the use of traditional ultrasonic lenses. The images from both the B and the C scans have a lateral resolution limited by the focus of ultrasonic transducers. The techniques commonly used to improve the lateral resolution include using additional lenses or by using synthetic focus. The use of lenses makes the beams more collimated but introduces a considerable loss in transmitted signals. The use of the SAFT is efficient since it does not introduce any additional losses, but it can only be used in a digital signal acquisition system.

The use of SAFT brings significant benefits to mechanized ultrasonic testing. In addition to the more precise defect localization and the better separation of neighbouring defect indications, the improvement of the structure-related signal-to-noise ratio (SNR) is an important reason for the use of SAFT. It can be used for defect analysis and offers a high degree of robustness when configured correctly. Sufficient computing power is required to carry out the SAFT analysis. In order to reduce the computing effort, the data from an ultrasonic test can be evaluated separately for each layer using 2D-SAFT. Although these results are volume related and can be displayed in three dimensions (and are therefore sometimes misleadingly referred to as 3D SAFT), some of the benefits of SAFT remain untapped.

Keywords: *B Scan, C Scan, Synthetic Aperture, Signal-to-noise ratio (SNR)*

1. Introduction

Synthetic Aperture Focussing Technique (SAFT) is used in order to restore ultrasonic images obtained either from B or C scans having focussing distortion. With the help of this technique an improvement in image resolution can be obtained, without the use of the traditional ultrasonic lenses. The use of the Synthetic Aperture Focussing Technique (SAFT) brings significant benefits to mechanized ultrasonic testing. In addition to the more precise defect localization and the better separation of neighbouring defect indications, the improvement of the structure-related signal-to-noise ratio (SNR) is an important reason for the use of SAFT. Synthetic Aperture Focussing Technique (SAFT) has been used in non-destructive testing mainly in its simplest form which mimics acoustic lenses used for focussing ultrasonic beams on a solid object or structure. There are two setups that are normally used in NDE for ultrasonic inspection of solid objects: contact and immersion mode.

- In contact mode ultrasonic transducer is directly coupled to the surface of the inspected object using a thin layer of contact agent.
- In the immersion mode object and transducer are immersed in a liquid medium (commonly water) and ultrasonic waves propagate towards the inspected object through a thick water layer.

Most SAFT implementations are based on a very simplified model of the imaging system used for developing radar and sonar applications. Such implementations can perform relatively well provided that the theoretical assumptions, generally valid for Synthetic Aperture Radar (SAR) and Synthetic Aperture Sonar (SAS), are fulfilled in the particular application. The principal assumption, which is usually correct in radar and sonar, is that the region of interest (ROI) is located in the far field of the transducer (antenna) is used for creating synthetic array, where its specific diffraction effects are neglected (point-like source assumption). At least two kinds of problems may be encountered in such setup, firstly, transducer's diffraction effects may impair image quality, and secondly, sparse spatial sampling used for gathering ultrasonic data may yield aliasing artifacts in the resulting image.

Non-Destructive testing

Non-Destructive Testing (NDT) refers to a set of inspection methods that allow inspectors to evaluate and collect data about a material, system, or component without permanently altering it. Today modern non-destructive tests which are used in manufacturing, fabrication, and in-service inspections to ensure product integrity and reliability, to control manufacturing processes, lower production costs, and to maintain a uniform quality level.

The six most frequently used test methods are:

- Ultrasonic Testing (UT)

- Liquid Penetrant Testing (PT)
- Magnetic Particle Testing (MT)
- Eddy Current Testing (ET)
- Radiographic Testing (RT)
- Visual Testing (VT)

Non-Destructive Testing (NDT) plays a vital role in industries such as aerospace, pipelines, bridges, refineries and oil platforms as well as power stations as it can help prevent failures that could have an adverse impact on safety, reliability, and the environment.

Ultrasonic Testing

Ultrasonic Testing (UT) uses high frequency sound waves (typically within the range 0.5 and 15 MHz) to conduct examinations and make measurements. Ultrasonic testing is mainly based on the capturing and quantification of either the reflected waves (pulse-echo) or the transmitted waves (through-transmission). A simple inspection method using ultrasonic sound is shown in figure 4.1. Ultrasonic testing is mainly performed on steel and other metals or alloys, though it can also be used on concrete, wood and composites with less resolution. It's used in many industries including steel and aluminum construction, metallurgy, manufacturing, aerospace, automotive and also in transportation sectors. The depth of penetration for flaw detection or measurement is superior for ultrasonic testing compared to other NDT methods.

Modes of display

A Scan or Amplitude mode display: Amplitude mode display gives only one-dimensional information about the given specimen. A single transducer transmits and receives the pulses from the specimen. This scanning mode is most widely used for inspection of material. The height of the signal helps to identify the size of the defect and the location of the signal helps to identify the location of the defect or discontinuity.

B Scan or Brightness Mode Scan: B-scans are two-dimensional, cross-sectional views of the inspected material depicting material thickness measured at different positions over time. The principle of the B-Scan is same as that of A-Scan except with a small difference, in B-Scan the transducer is moved rather than keeping it in a fixed position.

C Scan or Motion Mode: C-scan uses a projection of the ultrasonic data onto a plan view of the component being tested to create an image. This technique is usually used for corrosion or thickness mapping, also visualizing of cracks and inclusions in the component. C-scan is one of the most sophisticated modes to view ultrasonic testing data. It is a 3D representation of the material thickness plotted over position both horizontally and vertically. In essence, C-scans are visual maps that reveal patterns of degradation in the object.

Synthetic Aperture Focusing Technique

Synthetic Aperture Focussing Technique (SAFT) has been used in non-destructive testing mainly in its simplest form which mimics acoustic lenses used for focussing ultrasonic beams on a solid object or structure. There are two setups that are normally used in NDE for ultrasonic inspection of solid objects: contact and immersion mode.

- In contact mode ultrasonic transducer is directly coupled to the surface of the inspected object using a thin layer of contact agent.
- In the immersion mode object and transducer are immersed in a liquid medium (commonly water) and ultrasonic waves propagate towards the inspected object through a thick water layer.

Some experiments were performed to verify the performance of the SAFT algorithms in terms of resolution and suppression of the backscattering from material structure.

For example: consider a cast austenitic steel cube, subjected to contact mode SAFT.

Three side drilled holes (SDHs) with different diameters are drilled at the depth of approx. 40 mm under the cube's upper surface are used as targets, as shown in Fig.1. The original B-scan data and the SAFT results are plotted in Fig. 2 and the respective profile plots (max amplitude in each A-scan plotted vs the scanning distance) are shown in Fig.3. It can be seen that the resolution of the raw B-scan is poor and a high level of material noise due to the backscattering from the coarse steel structure is shown. After SAFT processing, the resolution is considerably improved and the noise level due to the backscattering is considerably reduced. Note, that the holes have relatively large diameter, which has an apparent effect on the time of flight at the B-scan responses; the response of the largest hole (the right one) appears at the shorter range than the smallest one.

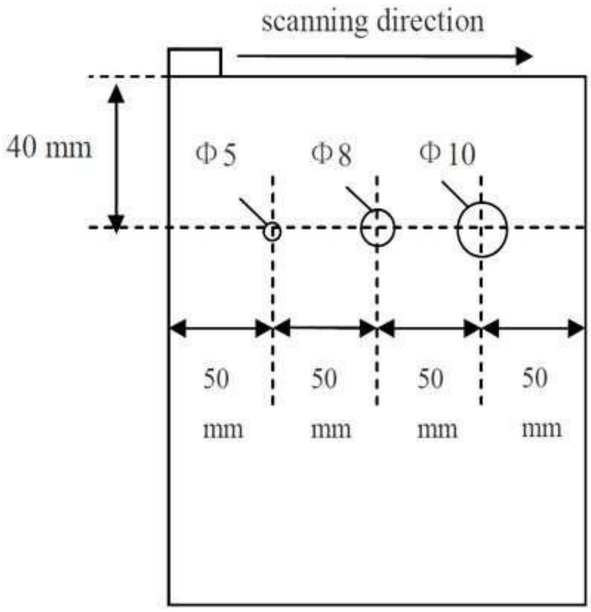

Fig 1. Austenitic steel block used in the experiment.

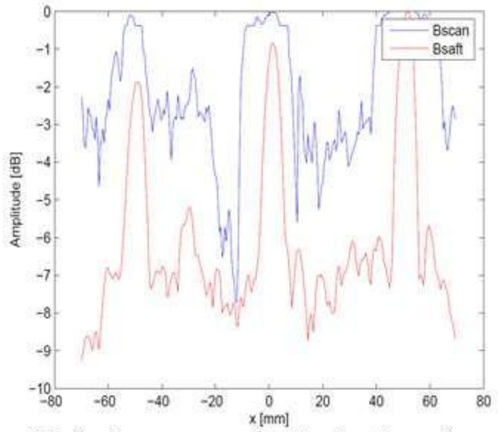

Fig 3. Cross-range profiles showing the maximum width of the hole responses calculated for the B-scans presented in Fig 2.

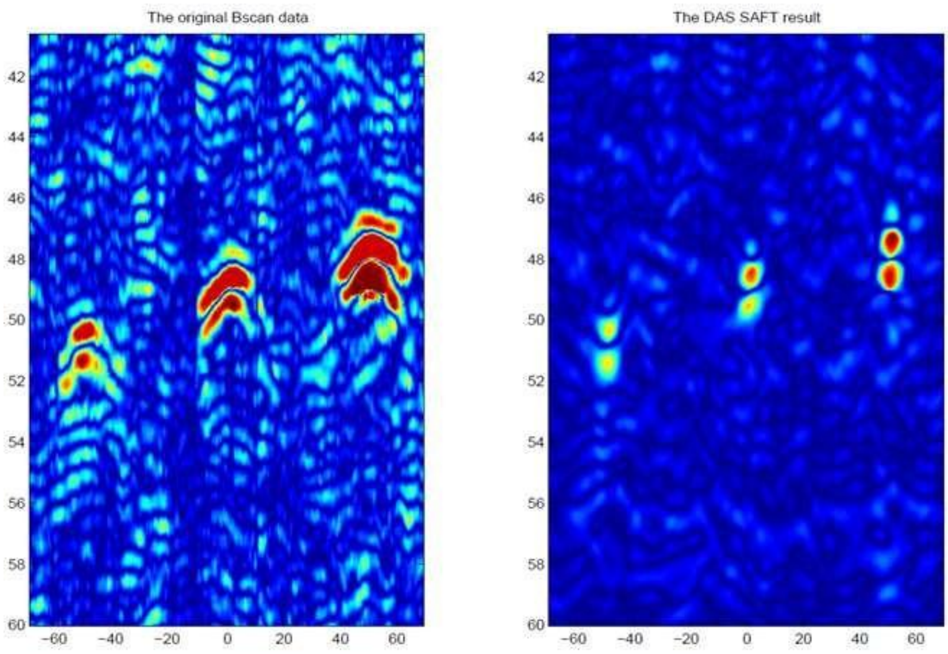

Fig 2. B-scans acquired in the experiment: raw data (left) and SAFT processed data (right).

Consider another example of cylindrical rotor forgings, subjected to contact mode SAFT:

The probe locations while scanning for a defect and the shape of the defect obtained in a typical B-scan (Crescent shape, having the main defect point indicated in red color) are shown in Fig 4. The defects shown by scanning a cylindrical rotor forging were obtained by a B-scan image which had a lot of external noise, which is reduce shape of the defect by eliminating noise (unwanted signals) as shown in Fig 5.

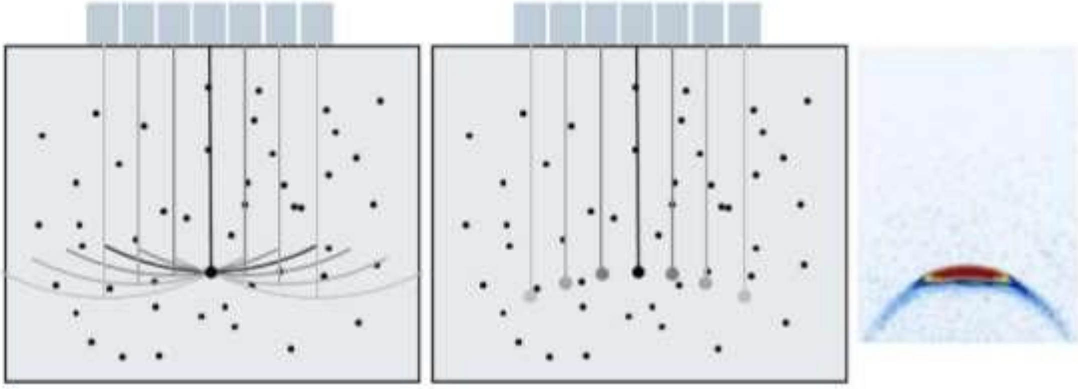

Fig 4. One indication (big black dot) is found by 7 probe locations, for each probe location the distance is known but not the angle (left); in typical B-scans indications are plotted at the location of the probe using the known distance; this leads to crescent shaped indications (center); B-Scan of a real indication (right).

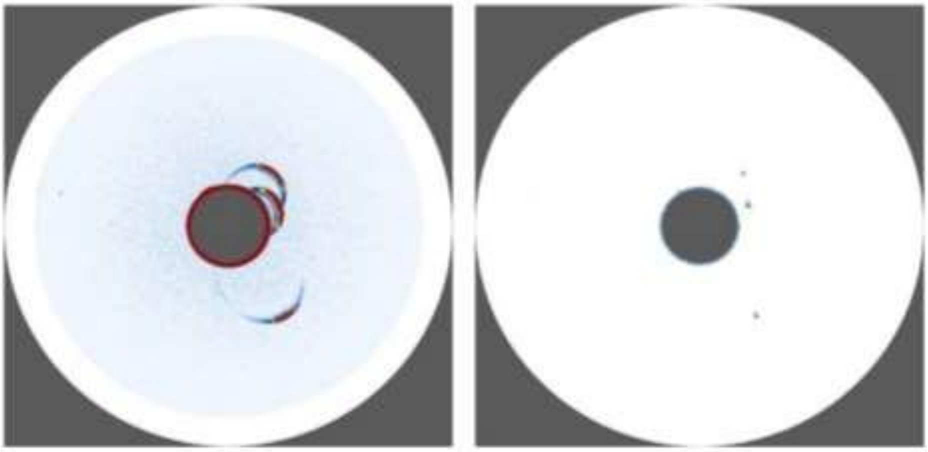

Fig 5. Classical result of the ultrasonic inspection (left) of a rotor forging in comparison to the SAFT reconstruction (right).

Signal-to-Noise Ratio

Signal-to-Noise Ratio (SNR), is one parameter that has significant effect on quality of ultrasound images. The SAFT analysis improves the structure-related signal-to-noise ratio (SNR). Signal-to-Noise Ratio is the ratio of the amplitude of a signal of interest to the amplitude of noise signals. In ultrasonics, it is the amplitude of a signal generated by a defect divided by the amplitude of the surrounding background noise and expressed in decibels (dB). For the above examples, the noise can be the electronic noise of the instrument or it can be ultrasonic signals scattered by the structure of the material. Higher the SNR value means better is the output. The reason for that is there's more useful information (signal) than unwanted data (noise) in a high SNR output.

Applications of SAFT

- Improving the lateral resolution of airborne radar systems.
- Photo-acoustic endoscopy.
- Radio Detection and Ranging (RADAR)
- Sound Navigation and Ranging (SONAR)

Other field of applications,

- Topography
- Oceanography
- Glaciology
- Geology (for example, terrain discrimination and subsurface imaging)

Conclusion

Synthetic aperture focusing technique (SAFT) is used in non-destructive testing mainly in its simplest form that mimics the use of acoustic lenses for focusing ultrasonic beams at a point of a solid object or structure. SAFT processing is an effective tool improving spatial resolution and contrast in ultrasonic images, it drastically improves the signal-to-noise ratio and the lateral resolution. The first production inspections using SAFT show a sensitivity improvement of up to one order of magnitude compared to classical ultrasonic inspections.

In conclusion, it is clear that the state of the art of SAFT-UT has progressed a great deal over the past years. Many laboratories around the world have adopted this technique for inspection and are gaining confidence in the results of SAFT-UT. With the understanding that has been developed and the continued support of the nuclear industry, a real-time, high-resolution tool for inspection of reactor components appears to be both practical and feasible.

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