Kirchhoff migration of ultrasonic images

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Abstract

The object of an ultrasonic nondestructive evaluation (NDE) is to find anomalies using nondestructive methods. Block filtering and deconvolution are the most commonly used digital signal processing methods for improving the resolution of the ultrasonic image. However, the anomaly is not a horizontal plane anomaly, these methods can not correct the distortion and mislocation of the anomaly image.

The Kirchhoff migration is an image processing method, currently used as the most basic and important procedure for data processing of seismic exploration. It is also the simplest, non-limited migration method. This method can improve the image resolution and recover the true shape and location of an anomaly image. This research used the Kirchhoff migration method to process ultrasonic images. The experimental results show that the Kirchhoff migration method can be used successfully to process both 2-D and 3-D ultrasonic image. This method clearly improves the image resolution and represents the anomaly’s shape, size and location more accurately.

Key word : ultrasonic nondestructive evaluation, digital signal processing, Kirchhoff migration
**Introduction**

Nondestructive evaluation (NDE) techniques are used to detect anomalies or evaluate qualities of an object. After testing, the properties and performance of the tested object are not reduced. Due to the deep penetration and high resolution of ultrasound, ultrasonic NDE is widely used for nondestructive testing. A simple ultrasonic NDE detector operated in the artificial mode is usually used to locate a single anomaly. The pitch-catch method is commonly used to estimate the depth of a vertical surface opening crack by measuring the travel time of echoes (Krautkramer and Krautkramer, 1977, Blitz and Simpson 1996). Due to advances in electronics technology, an automatic or semi-automatic system can now be used to scan anomalies and exhibit the results of the scan as images. Therefore, the anomalies in an object can be more easily estimated.

There are numerous methods that can be used to improve the resolution of an ultrasonic image. Block filtering and deconvolution are the most commonly used digital signal processing methods. The block filtering method acquires a useful signal in the frequency domain and the signal to noise ratio (S/N) can be increased (Zhao et al., 1995). The deconvolution method can reduce the spread of a sound beam and compress the wavelet of the echoes reflected from the anomaly (Vollmann, 1983, Cheng and Chao, 1996). If the echoes are diffracted from a discontinuous boundary or reflected from the oblique plane, then the anomaly image will be shown as an apparent shape and located at the apparent position. Although the above methods may increase the resolution of the image, however the distortion and mislocation of the anomaly image can not be corrected. Consequently, a digital signal processing (migration method) is proposed to process an ultrasonic image, which can improve the resolution of the image and migrate the anomaly image from its apparent position.
The migration method is image processing method in seismic data processing of reflection seismology used to improve the resolution of the seismic section in order to accurately estimate the structure and strata of the earth (Dobrin and Savit, 1988, Yilmaz, 1987). A similar theory used in ultrasonic NDE is the array transducer method (Simaan et al., 1987). This technique assumes that the signals are coherent and the noises are random. After distance correction from the anomaly to each transducer, the output of the transducer array is summed, then the signals will be enhanced and the noises will be decreased. The amplitudes and traveling times of the echoes diffracted from the tip of the surface opening crack in concrete were used to image the crack by the migration method (Liu et al., 1996, Kuo et al., 1998). A similar migration method was used to map a 3-D image of the surface opening crack in concrete (Chang and Wang, 1997). Frequency-wavenumber migration was used to migrate the regular and large data coverage 2-D ultrasonic data for improving the image resolution (Chang and Chern, 2000). The quality in both size and location for the anomaly image can be improved after migration.

Kirchoff migration is the simplest, non-limited migration method (Chun and Jacewitz, 1981). This method can be used to process the echoes reflected from a steep dip reflector, but its performance will be reduced if the S/N ratio is low (Dobrin and
Savit, 1988). Because there are numerous possible arrangements of the transducers in scanning, the data coverage is commonly limited and the S/N ratio of the signal is usually high in the ultrasonic NDE. Thus, Kirchhoff migration is the optimum method used to process 2-D and 3-D ultrasonic images, successfully used in seismic data processing.

**Theory of the Kirchhoff migration**

The time history of an echo is the ultrasonic pressure variation with time and detected by probe. If the velocity of the object is known, then the formula “depth = time \times velocity” can be used to transform the time axis into the depth axis and the depth of anomalies in the object can be determined. Since the sound beam is not infinitely small, an anomaly exhibited in the image will be distorted after the transformation from the time axis to the depth axis, if the anomaly is not a horizontal plane anomaly.

A point anomaly in the B-scan image will be shown as a hyperbola, and Figure 1 shows the synthetic B-scan image of two point anomalies. In this figure, the hyperbola of shallow anomaly is smaller and clearer than the deep one even though the anomalies are the same size (point). If an oblique plane crack located at $CD$ is scanned (Figure 2), the B-scan image will show the crack at the apparent position ($C'D'$). The apparent length is longer than the true length; the apparent dip angle ($\theta'$) is less than the true dip angle ($\theta$); and the apparent position is shallower than the true position of the crack. The contrast between the apparent position and true position of the crack will be enlarged when the dip angle is increased. In order to improve the resolution and correct the distortion of the image, the migration method must be used.
to process the ultrasonic image.

If the scan is operated using the single-probe pulse-echo technique, the possible positions which reflect or diffract the echoes are located on a circle with the center as the point where the probe is located, and the radius as the distance for the time it took the echo to reach the probe. The Kirchhoff migration (or great circle method) uses this theory and redistributes all of the echoes into space and then sums the energies in the same positions within the space (Dobrin and Savit, 1988, Yilmaz, 1987). If the position is the “origin” where the echoes are reflected or diffracted then the echoes in this position will be reconstructed after summation. If not, the echoes will be deconstructed after summation. Figure 3 demonstrates the procedures of the Kirchhoff migration. If a point anomaly, A, in the object is scanned, then when the transducer is located at position B, the apparent position of the point anomaly will be at position $B'$. The echo will then be redistributed on the circle using B as the center and $BB'$ as the radius. For a transducer located at position D, the echo recorded at D is redistributed on another circle. The cross point of the two circles will be at A. Therefore, the echoes located at A will be enhanced after summation. Since the signals are coherent and noises are random after echo redistribution and summation, the true location of the “origin” will be enhanced.

The 3-D Kirchhoff migration is like the 2-D Kirchhoff migration except that the echoes are redistributed on a spheroid.

**Apparatus**

Since no expensive or automatic tools were used in this research, the measurements were carried out artificially. The single-probe pulse-echo method was used to scan the anomaly and the space sampling interval of the scan was 1 mm. The pulser/receiver (Panametrics 5058PR) emits high pulse voltage to excite the
transducer, and also receives and amplifies the weak signals. A 20 MHz longitudinal contact transducer (Panametrics V116) with diameter 2.5 mm (0.1 in.) was used to produce and receive the ultrasound. The transducer contacts on the top surface of the specimens uses honey as the couplant to improve the coupling conditions. The oscilloscope (Tektronix 11402A) surveyed the signals and converted the analogic signals into digital signals. A personal computer was used to read the digital signals from the oscilloscope and processes the signals. The configuration of the apparatus is shown in Figure 4.

**Experimental results**

In order to verify the possibility of using Kirchhoff migration to process the ultrasonic image, four anomaly models were made and scanned.

1. **15° Oblique crack**

   A duralumin block 3cm in height, 3 cm in wide and 15 cm in length, with a 15° oblique crack at the center, shown in Figure 5a, was scanned. The longitudinal wave velocity of the duralumin is 6623 m/s. The B-scan image is shown in Figure 5b. The dashed line in the figure is the true position of the crack. The apparent position of the crack, shown in the B-scan image, is above the true position. The multi-reflections (MR), pointed out by the arrow, are the echoes multi-reflected between the top surface and crack. The image after performing the Kirchhoff migration is shown in Figure 5c. In the migrated image, the position of the crack has moved to its true position. Since the velocity of the specimen used to migrate the ultrasonic image and the apparent velocity of the multi-reflections are different, the multi-reflections in the migrated image were decreased.
2. **30° Oblique crack**

A 30° plane crack was cut at the center of the duralumin block, as shown in Figure 6a, and the B-scan image is shown in Figure 6b. Since the size of the transducer is finite and the sound beam is narrow, it is not easy for the echo reflected from a steep oblique crack to return to the transducer. The amplitude of the echo reflected from the crack and detected by the transducer will decrease if the oblique angle is increased. Therefore, the B-scan image of Figure 6b is more blurred than Figure 5b. The migrated image is shown in Figure 6c and the position of the crack has moved to its true position. Because the S/N ratio is not high in the B-scan image, the migrated image is more blurred than the B-scan image.

3. **One blind anomaly**

A duralumin block 3cm in height, 5 cm in wide and 5 cm in length, drilled with a blind cylindrical 3 mm diameter hole at the center of the block, is shown in Figure 7. The C-scan image of the model is shown in Figure 8a. The blind hole shown in the C-scan image is 5 mm in diameter and its shape has some distortion. The migrated image is shown in Figure 8b. The resolution of the migrated image has been improved greatly. So that the diameter of the hole is 3 mm and its shape is circular.

4. **16 blind anomalies**

16 blind 3 mm cylindrical holes were drilled at the center of the duralumin block, as shown in Figure 9. In order to evaluate the resolution of the images, the distances between the holes are different. The C-scan image of the model is shown in Figure 10a. Since the image is blurred, it is difficult to resolve all of the holes in the image. The diameters of the holes exhibited in the C-scan image are greater than 3 mm. The migrated image is shown in Figure 10b. The resolution of the migrated image has
been improved and the diameter of the holes is 3 mm, and the hole located at the right-bottom of the migrated image can be seen clearest, because the interference in the echoes reflected from this hole is less. The holes located in the left-column of the specimen can not be resolved in the C-scan image, but they can be resolved in the migrated image although the two holes at left-bottom are not very clear. The echoes reflected or diffracted from the anomaly may never come back to the probe. Therefore, it is difficult to completely construct the image of the anomaly in both shape and location from finite shooting and receiving-positions and viewing-angles.

**Conclusion**

From the results of this research using the Kirchhoff migration to process 2-D and 3-D ultrasonic images, some conclusions can be made.

The Kirchhoff migration method can migrate the image of an oblique plane anomaly from its apparent position to its true position. The image after Kirchhoff migration will be more blurred than the original image if the S/N ratio is low in the original image. The multi-reflections will be reduced in the migrated image if the velocity of the specimen is used to perform the migration process. The blind anomalies in the C-scan image are not easily distinguishable but can be resolved in the migrated image, where the size and shape of these anomalies can be more correctly exhibited.

We have shown that Kirchhoff migration can be successfully applied to process the ultrasonic images. The position, size and shape of the anomaly can be more correctly shown in the migrated image.

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References


**Figure captions**

Figure 1 Two point anomalies shown in the B-scan image. “T” is the transducer.

Figure 2 Oblique plane anomaly (CD) shown in the B-scan image, will locate at the apparent position (C'D').

Figure 3 Theory of performing Kirchhoff migration.

Figure 4 Apparatus used in the experiments.

Figure 5 The 15° oblique plane anomaly, (a) configuration of the model, (b) B-scan image, where “MR” are the multi-reflections, (c) migrated image.

Figure 6 The 30° oblique plane anomaly, (a) configuration of the model, (b) B-scan image, (c) migrated image.

Figure 7 Configuration of one blind anomaly, (a) top view, (b) side view.

Figure 8 One blind anomaly, (a) B-scan image, (b) migrated image.

Figure 9 Configuration of 16 blind anomalies, (a) top view, (b) side view.

Figure 10 16 blind anomalies, (a) B-scan image, (b) migrated image.
Pulser/Receiver

PC

Digital signals

Oscilloscope

Synchronized signal to trigger the oscilloscope

RF signals

Pulser/Receiver

Synchronized signal to trigger the oscilloscope

Transducer

Object
Top view

4.5 5.5 6.5

 blind holes

Unit: mm

Side view

30

4.5 5.5 6.5