Ultrasonic Radar and Its Applications

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Abstract: - A rangefinder is a device that measures distance from the observer to a target, for the purposes of surveying, determining focus in photography, or accurately aiming a weapon. Some devices use active methods to measure (such as sonar, laser, or radar); others, available since the nineteenth century, measure distance using trigonometry (stadia metric rangefinders and parallax, or coincidence rangefinders). They usually use a set of known distances or target sizes to make the measurement [2].

Key-Words: - RANGEFINDER, WEAPON, TARGET, SURVEYING, RADAR, ULTRASONIC, PIC.

1 Introduction

NARRO is currently developing an ultrasonic system for tracking people and objects as a way of observing activity in living spaces while keeping invasion of privacy to a minimum. Aim is to create a system that improves quality of life (QOL). By tracking people and objects, System would allow the observation of activities of daily living (ADL). Data from these observations could then be used to construct behaviour models, which could in turn facilitate the provision of evidence-based care. We suppose an ultrasonic radar based system that can comply with the following: 1) unconstraint measurement of location for the human, 2) minimally privacy-violation, which are compounding this human activities observing system [1] [2].

Fig.1: Ultrasonic Radar System [6]

2 Ultrasonic Radar System

Ultrasonic radar detects human location by determining time-of-flight among human head and ultrasonic sensors [6]. Figure 1 and figure 2 show the ultrasonic radar system for observing human daily activities. The system is composed of 117 transmitters, 117 receivers, transmitter-controllers, receiver-controllers, network device and a host computer. The transmitters and receivers are embedded in a ceiling, and other devices are set on an attic [7].
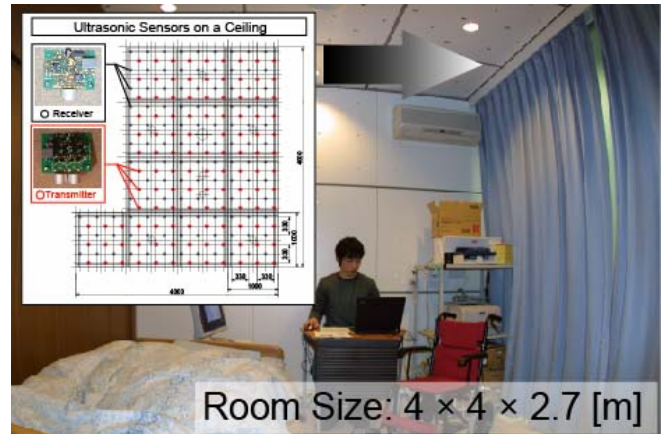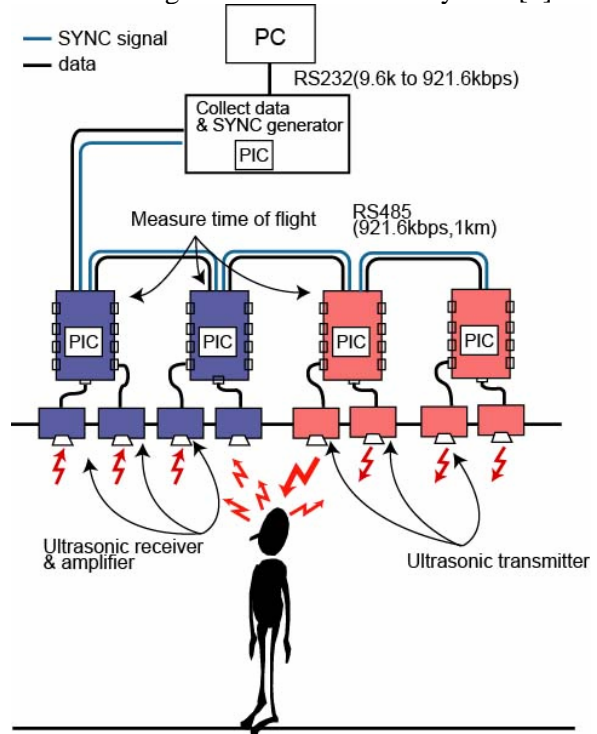

Fig.2: System Configuration [7]

2.1 Principle of measurement in ultrasonic radar system

In the ultrasonic radar system developed by the authors, it is assumed that the human head is an object moving at a relatively high vertical position in a living area, and emitting ultrasonic sounds and receiving them back as they are reflected from the head can detect the position of the head. This section explains the principle used to measure and calculate, that is, to locate, the position of a human head with unconstraint. If the positions of the i-th transmitter, j-th receiver and head are $\mathbf{P_{ti}} : (x_{ti}, y_{ti}, z_{ti})$) B C $\mathbf{P_{ri}} : (x_{rj}, y_{rj}, z_{rj})$) B C $\mathbf{P} : (x, y, z)$, respectively, and the propagation distance is L_{ij}, as shown in Figure 3, then the following equation of a spheroid can be obtained.

$$L_{ti, rj} = |\mathbf{P_{ti}} - \mathbf{P}| + |\mathbf{P_{rj}} - \mathbf{P}|$$ If $\mathbf{P_{ti}} : (x_{ti}, y_{ti}, z_{ti})$) B C and $\mathbf{P_{ri}} : (x_{rj}, y_{rj}, z_{rj})$ are known, then the head position $\mathbf{P} : (x, y, z)$ can be calculated from the three equations of a spheroid [6].
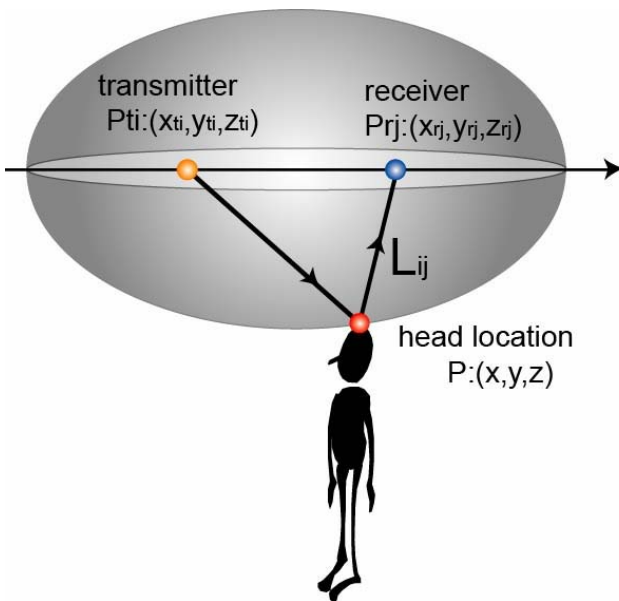

Fig.3: Principle of measurement [6]

2.2 Resolution and measuring error

The resolution in the x, y, and z directions is illustrated in figure, which shows the probability density distribution for 1000 locations of head calculated by the system. The resolution in x and y directions is about 34 mm, while that in the z direction is about 10 mm. The average of measuring error is 43 mm [3] [4].

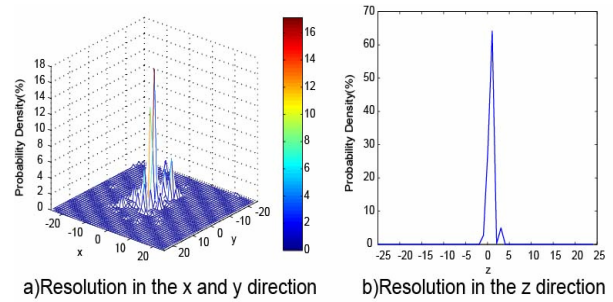a)Resolution in the x and y direction   b)Resolution in the z direction

Fig.4: Probability distributions for human head detection [3, 4]

2.3 Tracking result

The upper part of the Fig.shows the measured trajectory of the human head when the test subject moves as shown in the lower part of the figure. The Fig.shows that the system can detect the positions of the head at a frequency of 1 Hz [4] [7].
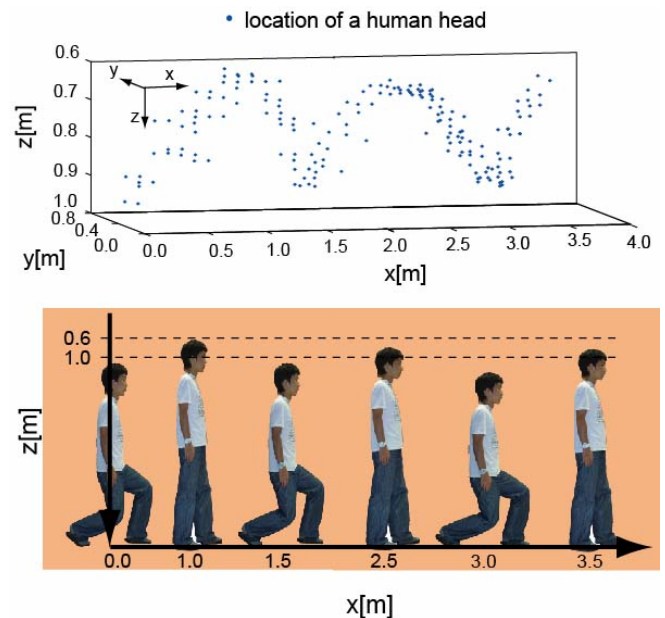

Fig.5: Tracking position of a human head [4]

2.4 Experiment for discrimination based on the height difference among objects

The system can distinguish the detected objects by their height difference. For example, there is the difference between the head and a desk [3]. The Fig.shows a result of experiment for discrimination [5]. In the figure, red squares show the highest position of an object and green squares that of another. The Fig.indicates that the system can distinguish the detected objects band trace.
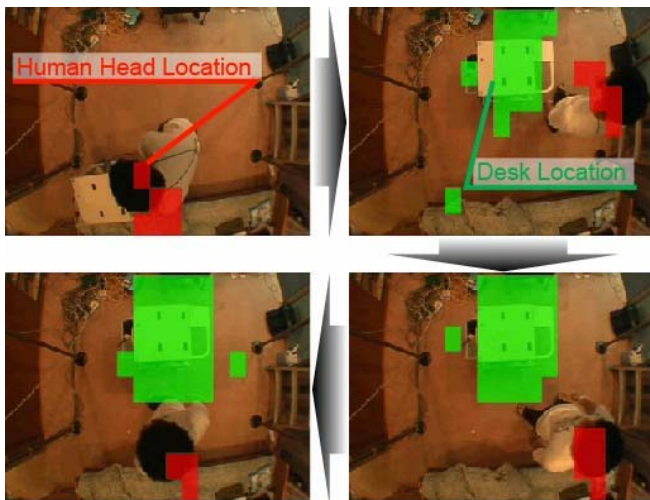
Fig.6: Result of experiment for discrimination [7]

2.5 Ultrasonic Phased Array

Ultrasonic phased arrays are a relatively new method of generating and receiving ultrasound. Phased array testing is a specialized type of ultrasonic testing that uses sophisticated multi element array probes and powerful software to steer high frequency sound beams through the test piece and map returning echoes, producing detailed images of internal structures similar to medical ultrasound images [1].

3 Advantages

As such, phased arrays offer significant technical advantages over conventional single-probe ultrasonic; such as:

- Electronic scanning (E-scans) which permits very rapid coverage of the components, typically an order of magnitude faster than a single-probe mechanical system.

- Beam forming which permits the selected beam angles to be optimized ultrasonically by orienting them perpendicularly to the predicted defects; for example, lack of fusion in welds.

- Beam steering (usually referred to as S-scans for sectors scanning) which permits the mapping of components at appropriate angles to optimize probability of detection. S-scans are also useful for inspections where only a minimal footprint is possible.

- Electronic focusing which permits optimizing the beam shape and size at the expected defect location, as well as optimizing probability of detection. Focusing significantly improves signal-to-noise

ratio, which, in turn, permits operating at lower pulse voltages.

4 How does it work?

Ultrasonic phased arrays are similar in principle to phased array radar, sonar, and other wave physics applications. However, ultrasonic development is behind the other applications due to a smaller market, shorter wavelengths, mode conversions, and more complex components [6].

Phased arrays use a collection of elements, all individually wired, pulsed and time-shifted. These elements can be a linear array, a 2-D matrix array, a circular array, or some more complex forms (see Fig.1). Most applications use linear arrays, since they are the easiest to program, and are significantly less expensive than the more complex arrays. However, as costs decline and experience increases, greater use of the more complex arrays is predicted [2].
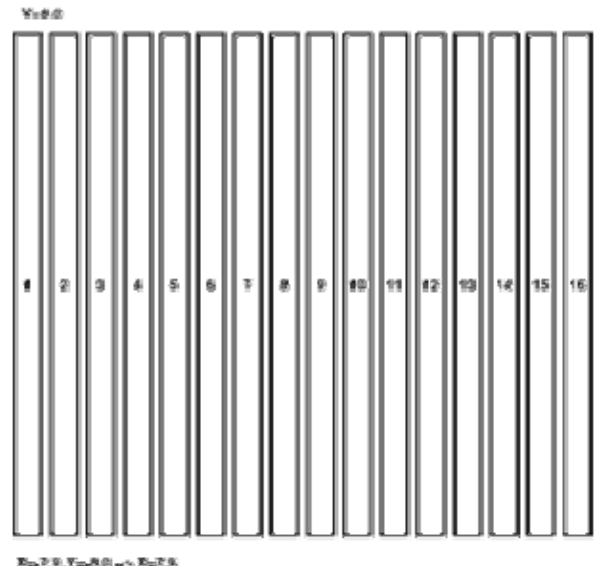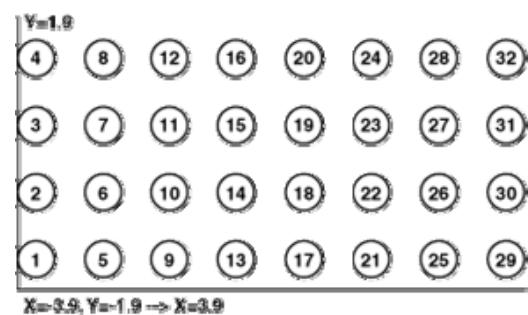

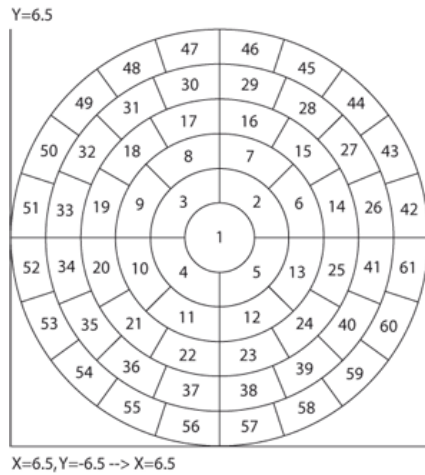Fig.7a: See Notes [2]

Fig.7b: See Notes [2]

Fig.7c: See Notes [3, 4]

As with all ultrasonic testing, elements are used to collect data. Within the phased array application the elements are ultrasonically isolated from each other, and packaged in normal probe housings. The cabling usually consists of a bundle of well-shielded micro co-axial cables. Commercial multichannel connectors are used with the instrument cabling [3] [4].

Elements are normally pulsed in groups from 4 to 32. The acquisition and analysis software calculates the time delays for a setup from operator input on inspection angle, focal distance, scan pattern, etc. The operator could also use pre-prepared files (see Fig.2) [3]. The time delays are back-calculated using time-of-flight from the focal spot, and the scan assembled from individual "Focal Laws." Time-delay circuits should be near 2-nanosecond accuracy to provide the phasing accuracy required [1].
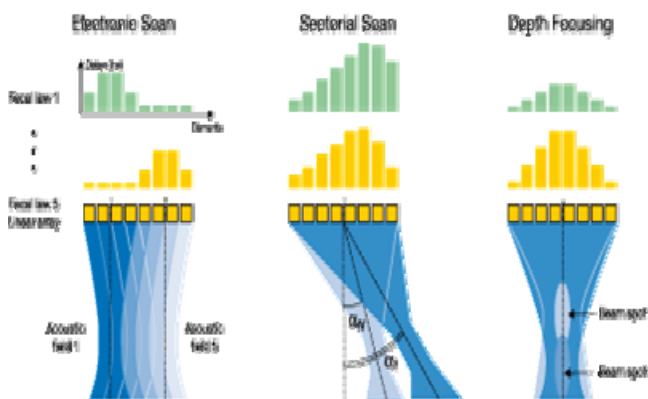

Fig.8: See Notes [1]

Each element generates a beam when pulsed. These beams constructively and destructively interfere to form a wave front. The phased array instrumentation pulses

the individual channels with time delays as specified to form a pre-calculated wave front. For receiving, the instrumentation effectively performs the reverse [7]. For example, the instrumentation receives signals with pre-calculated time delays, sums the time-shifted signal, and then displays it (See Fig.9).
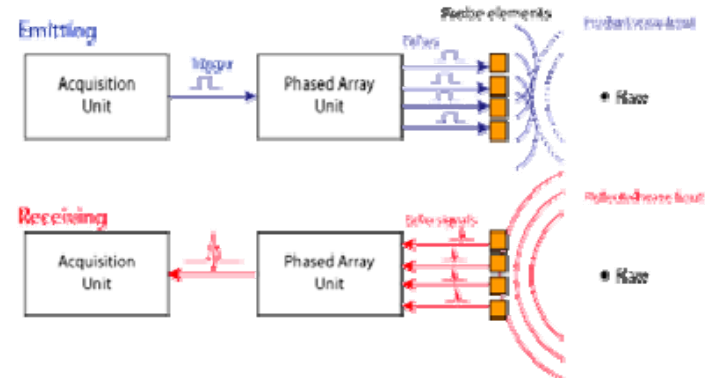

Fig.9: See Notes [7]

The summed waveform is effectively identical to a single-channel flaw detector using a probe with the same angle, frequency, focusing aperture, etc. Fig.3 shows typical time delays for a focused normal beam and shear wave. Fig.4 shows sample scan patterns, which are discussed later.
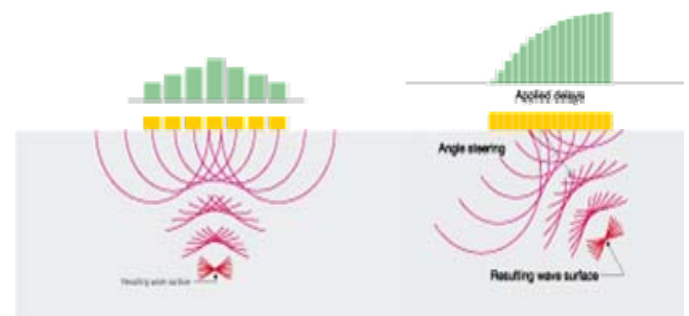

Fig.10: See Notes [6]

4.1 Software

While phased arrays require well-developed instrumentation, one of the key requirements is good, user-friendly software. As phased arrays offer considerable application flexibility, software versatility is highly desirable. The application software needs to be powerful to manage the acquisition of UT (ultrasonic testing) signals. Besides calculating the Focal Laws, the software saves and displays the results; therefore, good data manipulation capabilities are essential. Phased array inspections can be manual, semi-automated (for example, encoded), or fully automated. These options depend on the application, speed, budget, etc [6].

It is safe to say that encoder capability and full data storage are usually required [6].

As an added benefit, the software saves the user both time and energy. For example, though it can be somewhat time-consuming to prepare the first setup, the information is recorded in a file and takes seconds to reload. Also, modifying a prepared setup is quick in comparison with physically adjusting conventional probes [3].

4.2 Operating with phased arrays

From a practical viewpoint, ultrasonic phased arrays are merely a method of generating and receiving ultrasound. Once the ultrasound is in the material, it is independent of generation method, whether generated by piezoelectric, electromagnetic, laser, or phased arrays. Consequently, many of the details of ultrasonic inspection remain unchanged. For example, if 5MHz is the optimum inspection frequency with conventional ultrasonic, then phased arrays also typically start by using the same frequency, aperture size, focal length, and incident angle [3].

4.3 Typical Scans

As with conventional ultrasound, phased arrays use scans to collect the data. Electronic pulsing and receiving provide significant opportunities for a variety of scan patterns [4].

4.4 Electronic Linear Scans

Electronic linear scans (E-scans) are performed by multiplexing the same Focal Law (time delays) along an array (see Fig.11). Typical arrays have up to 128 elements. E-scans permit rapid coverage with a tight focal spot. If the array is flat and linear, then the scan pattern is a simple B-scan. If the array is curved, then the scan pattern will be curved. E-scans are straightforward to program. For example, a phased array can be readily programmed to perform corrosion mapping, or to inspect a weld using 45 $^\circ$ and 60 $^\circ$ shear waves, which mimics conventional ASME manual inspections.
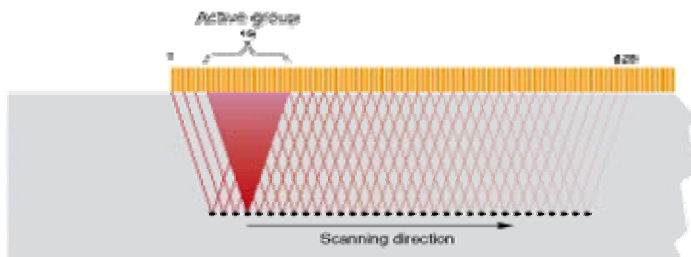

Fig.11: See Notes

Manual ultrasonic weld inspections are performed using a single probe, which the operator "raster" back and forth to cover the weld area. Many automated weld inspection systems use a similar approach (see Fig.12a), with a single probe scanned back and forth over the weld area. This is time consuming because the system has dead zones at the start and finish of the raster [8].
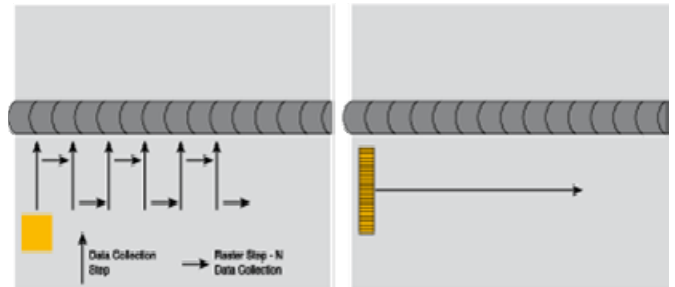

Fig.12a and Fig.12b [8]

In contrast, phased arrays use a linear scanning approach (see Fig.12b). Here the probe is scanned linearly around or along the weld, while each probe sweeps out a specific area of the weld. Often it is possible to use many more beams (equivalent to individual conventional probes) with phased arrays. The simplest approach to linear scanning is found in pipe mills, where a limited number of probes inspect ERW pipe welds.

4.5 Sectorial Scans (S-Scans) Beam Steering

Sector scans (S-scans) are unique to phased arrays. Sector scans use the same set of elements, but alter the time delays to sweep the beam through a series of angles. Again, this is a straightforward scan to program. Applications for S-scans typically involve a stationary array, sweeping across a relatively inaccessible component like a turbine blade rotor, to map out the features and defects (see Fig.13). S-scans can also be used for inspection welds, but there are some limitations [8]. Depending primarily on the array frequency and element spacing, the sweep angles can vary from $\pm$ 20 $^\circ$ up to $\pm$ 80 $^\circ$.
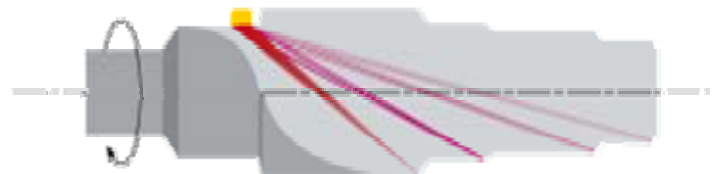

Fig.13: See Notes [8]

4.6 Combined Scans

Combining linear scanning, sectorial scanning and precision focusing leads to a practical combination of displays (see Fig.8). Optimum angles can be selected for welds and other components, while electronic scanning permits fast and functional inspections. For example, combining linear and L-wave sectorial scanning permits full ultrasonic inspection of components over a given angle range; for example, ± 20 °. This type of inspection is useful when simple normal beam inspections are inadequate. A related approach applies to weld inspections, where specific angles are often required for given weld geometries. For these applications, precise beam angles are programmed for certain weld bevel angles at designated locations [8].
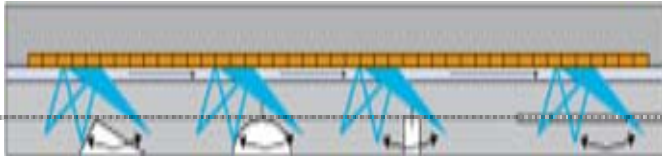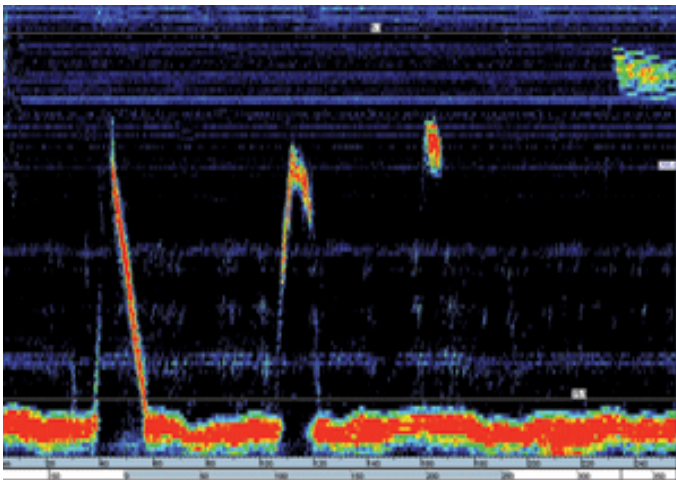

Fig.14a: See Notes [8]

Fig.14b: See Notes [8]

5 Applications

Phased arrays are usually used for the inspection of critical structural metals, pipeline welds, aerospace components, and similar applications where the additional information supplied by phased array inspection is valuable. However, realistically, there is no "typical application" for phased arrays. Phased arrays are very flexible and can address many types of problems. Consequently, ultrasonic phased arrays are being used in a wide variety of industries, where the technology has inherent advantages. These industries include: aerospace, automotive, nuclear power, steel mills, pipe mills, petrochemical, pipeline construction, general manufacturing, construction, and a selection of special applications. All these applications take advantage of one or more of the dominant features of phased arrays:

- **Speed**: scanning with phased arrays is much faster than single-probe conventional mechanical systems, at the same time offering better coverage.

- **Flexibility**: setups can be changed in a few minutes, and typically a lot more component-dimension flexibility is available.

- **Inspection angles**: a wide variety of inspection angles can be used, depending on the requirements and the array.

- **Small footprint**: small matrix arrays can give significantly more flexibility than conventional probes for inspecting restricted areas.

- **Imaging**: showing a "true depth" image of defects is much easier to interpret than a waveform. The data can be saved and redisplayed as required.

Each of these features generates its own applications. For example, **speed** is important for pipe mills and pipelines, and some high-volume applications. **Flexibility** is important in pressure vessels and pipeline welds due to geometry changes. **Inspection angles** are key for pipelines, some pressure vessels, and nuclear applications. **Small footprint** is invaluable to some turbine and turbine blade applications. **Imaging** is useful for weld inspections, particularly for defect sizing [7].

Phased array technology is relatively novel to NDT and continues to progress within its setup configuration, especially for complex 3-D applications. Nevertheless, 2-D setups are generally straightforward. At this stage of development, phased array systems are often more costly than single-channel systems. However, higher speed, data storage and display, smaller footprint, and greater flexibility offset the higher costs, especially with the newer portable instruments [8].

6 Conclusion

Phased array is a vital tool for the non-destructive testing industry. Its flexibility and capabilities are being welcomed by all industries.

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