ULTRASONIC EXAMINATION OF TYPE IV CRACKING IN HIGH ENERGY STEAM PIPING USING TOFD AND PHASE ARRAY TECHNIQUES

H. Fukutomi [1], S. Lin [1], and A. Nitta [1]
[1] Central Research Institute of Electric Power Industry, Tokyo, Japan

Abstract: Type IV creep damage in welded high energy piping has been an industry problem over the years. Ultrasonic examination is one technique that helps detect creep damage at early stages. Current ultrasonic methods range from traditional pulse echo techniques, that requires a traditional raster scan, to the time of flight Diffraction (TOFD) technique, that requires a traditional pulse echo technique performing traditional raster scans. Although generally viewed as a higher-cost inspection method, ultrasonic imaging methods continue to improve, both in terms of cost and the amount of quality information they provide. With recent technological improvements, an advanced phased array system has been developed for detection of cracking occurred in the heat affected zone (HAZ), outside of the weld metal. This paper will discuss the investigation of TOFD and phase array techniques for the inspection of type IV cracking, and the development of advanced seam weld inspection system.

Introduction: Although the safety and remaining life of high energy steam piping in fossil power plants has been a concern, the frequency of leaks and catastrophic failures of main steam and hot reheat piping systems in United States[1,2] continue to support the need for developing improved methods of evaluating and monitoring the condition of these piping systems. With the increasing nuclear base load capacity, older fossil plants have been relegated to peaking or cycling duty, raising even more the concern by utilities for the acceleration of degradation in high energy steam piping systems. Recent experience of plants with seam welded hot reheat piping continues to confirm the high risk associated with seam welded pipes.

The high energy piping systems operate at temperatures and pressures that are sufficient to initiate creep damage after extended periods of operation. Creep damage generally occurs at and near welds, typically in the weld metal itself or, more prevalently, at the fusion line or in the HAZ of the base metal. In seam welded pipe, damage typically initiates and grows fairly uniformly along appreciable length of a given weld seam because stresses are primarily hoop and fairly uniform along the length of the pipe. Once the damage has progressed to macro-cracking and a crack such as type IV cracking grows to the critical depth and becomes unstable at some point along the length of the weld, it grows into degraded material and therefore tends to cause sudden, catastrophic failure of the entire length of the seam. Therefore the increasing awareness of cracking as well as the potential for uniform fusion line cavitation in a uniform through-wall stress field has driven the need increasingly towards incipient creep damage detection.

Ultrasonic examination is one technique that helps detect malignant creep damage at stages early enough to implement corrective measures. The application of conventional ultrasonic techniques is difficulties that associated with interpreting the examination data often result in an undesirable variability among NDE examiners. Current ultrasonic methods range from the TOFD technique to the phase array techniques.

Investigations into the use of TOFD and phase array techniques for examining high energy ping seam welds have been conducted, and modelling effort based on finite-element approaches has been made to predict wave propagations and examination data under the test at Central Research Institute of Electric Power Industry[3-6]. The investigations included evaluating the use of TOFD and phased array data for detecting discontinuities associated with longitudinal seam welds and for estimating their corresponding size. This paper describes the activities performed during these investigations and presents the results of laboratory experiments performed on seam welded specimens designed to contain known discontinuities. In addition the paper includes the development of advanced ultrasonic seam weld inspection system.

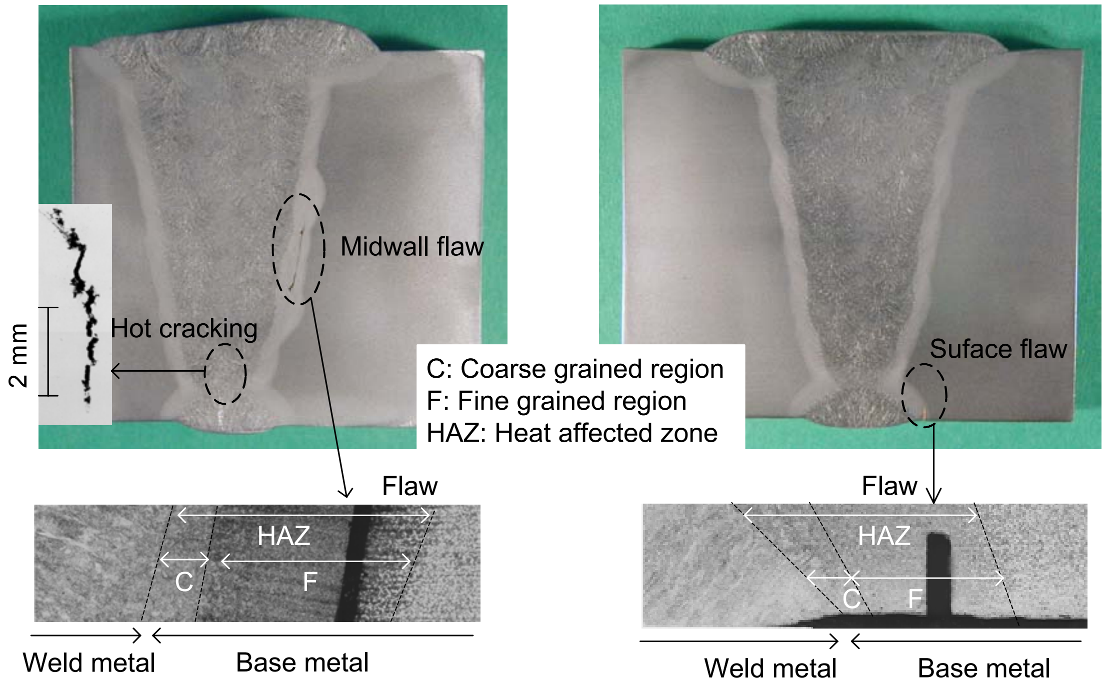


Figure 1 Cross sectional views of seam weld specimens

Laboratory Investigation: To evaluate the benefits of applying TOFD and phased array techniques to seam welded high energy piping examinations, a series of experiments were conducted using plate specimens containing known flaw-like rectangular slits/gaps. The flawed specimens were made from 2.25Cr-1Mo steel used in the hot reheat piping system in aged fossil plants. The specimens were designed to contain a range of various flaw types including: slits connected to the plate surface and gaps lying at a depth of approximately 1/2 wall in the HAZs; hot cracking located within the weld material. Figure 1 shows cross sectional views of the specimens. The thickness of the specimens was 50 mm. The slits/gaps ranged in height from 1 mm to 10 mm. They had lengths of 2 mm and 10 mm, and had widths of less than 0.3mm. The inspection setup includes a TOFD instrument and a phased array instrument, an automated scanning device and an associated control unit. Seam weld investigations were performed using 5MHz/10MHz single element transducers for TOFD inspection and a 5MHz phased array transducer containing 64 elements. Probe center spacing was set to 110 mm and 140 mm.

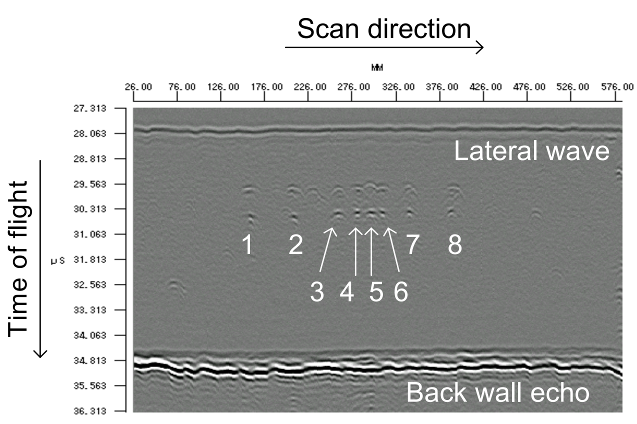


Figure 2 TOFD image

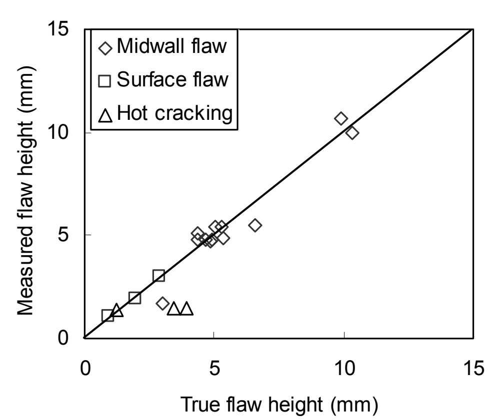


Figure 3 Plot of measured versus true heights

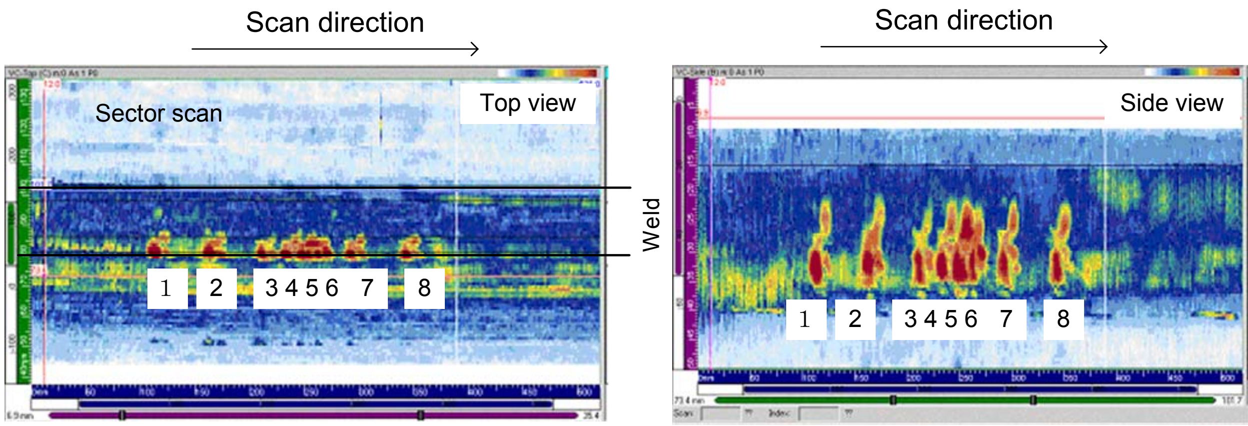


Figure 4 Top and side view images from sector scan

The heights and lengths of the various flaws in the seam welded specimens were evaluated using the TOFD technique. Figure 2 shows examples of the various flaws, as detected by TOFD and displayed in the typical TOFD image format. As these images show, eight flaws were very easy to detect properly. The Root Mean Square (RMS) error for height sizing was 0.42 mm as shown in Figure 3, and that for length sizing was 0.28 mm. From these results, it was evident that TOFD data provide the excellent measurement accuracy of flaw height. A primary difficulty in the inspection of seam welds lies in the need to positively discriminate between inherent weld and base metal flaws, such as lack of fusion, slag, base metal laminations, etc. and true type IV damage. Run/repair/replace decisions based on false calls, i.e., related to benign inherent flaws rather than active creep, can lead to extremely expensive and most likely unnecessary actions. Conversely, any undetected creep damage results directly in nonconservative condition assessment. Traditional pulse echo ultrasonic techniques consisting of single or dual element probes with a fixed angle, or TOFD B scans might be useful. However, inspections become costly because the pulse echo ultrasonic technique requires a two-dimensional or raster scan in order for the angle to interrogate the entire weld volume, and the TOFD B scan requires the motion perpendicular to the weld. Phased array technology offers a means to reduce the scanning time by using an array probe to replace many different conventional probes and by simplifying the scan pattern. Figure 4 provides examples of top and side view presentations from a sector scan of flaws at the HAZs. From these results, although eight flaws with which the specimen was used in Figure 2 were very easy to discriminate the flaw location properly, it was difficult to find the corresponding tip echoes and then size them. This situation presumedly arose from that the inspection system itself was not optimized.

The TOFD technique provided the excellent measurement accuracy of heights of surface/ midwall flaws in the HAZs of welds. The phased array technique provided their locations and distributions which are indispensable in discriminating between inherent benign flaws and active creep damage. Both techniques have an advantage over implementing in a uni-axial scan along the weld length. The automated, combined TOFD/phased array approach can be expected to be economical and reliable because it can be implemented relatively quickly and can detect flaws with accurate size and location measurements.

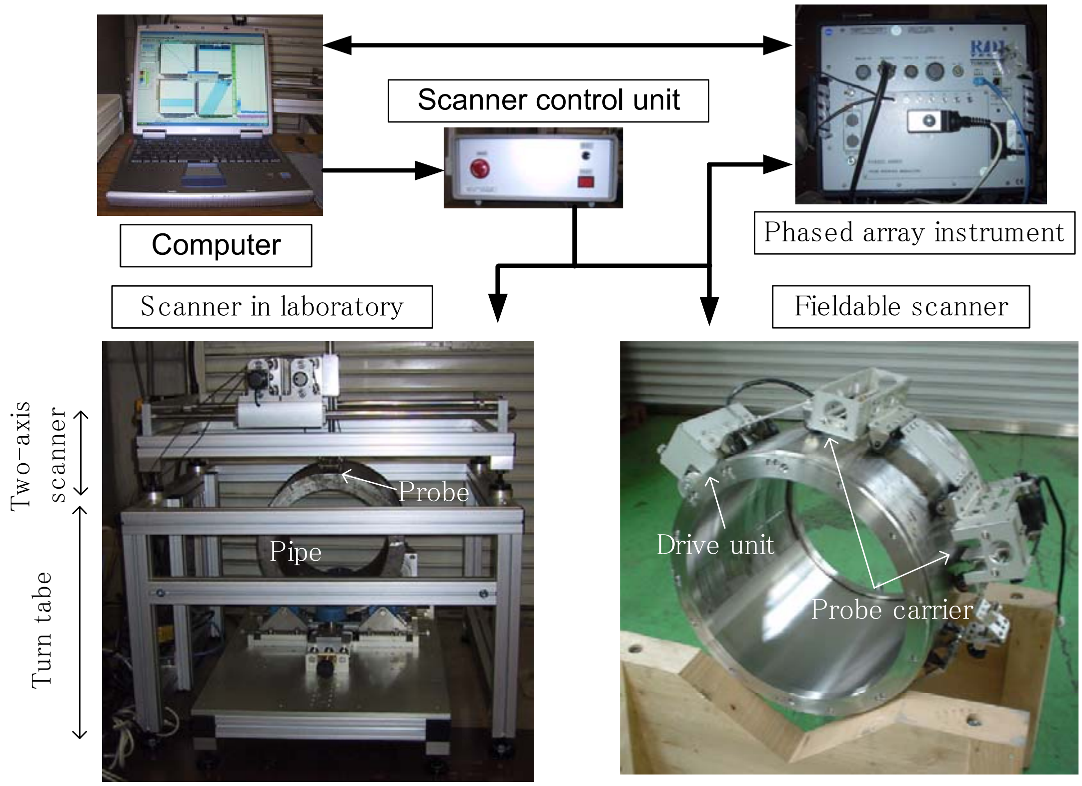


Figure 5 Advanced phased array system

Advanced seam weld inspection system: As stated previously, the TOFD techniques were useful in sizing flaw heights while the phased array techniques were convenient to estimate the flaw location which is of importance to positively decide whether or not indications relate to creep damage. An advanced phased array system was developed that results in faster and lower cost examinations that would be better than existing technologies, without compromising on probability of detection and false call rate, as shown in Figure 5. A typical setup includes a phased array instrument, two types of automated scanners, an associated control unit and a computer to control the system, and acquire and analyze TOFD and phased array data. A portable phased array instrument was upgraded to include 128 channels and use more than one phased array transducer together with many different conventional probes and acquire data, i.e., from phased array and TOFD inspections at the same time. The console portion of the instrument is used during analysis and acquisition and displays various image presentations such as top, side and end views. For laboratory and field uses, the scanners were designed to use a phased array probe simultaneously with different conventional probes. The scanner used in laboratory is composed of a 2-axis scanner and a turn table which are separable. The fieldable scanner is capable of accurately manipulating the probe carriers in circumferential and axial directions on pipe surfaces. This scanner has variable speed controls and precise incrementing controls in circumferential and axial directions. Another benefit of this fieldable scanner is that two workers can easily fix it on a pipe within less than five minutes.

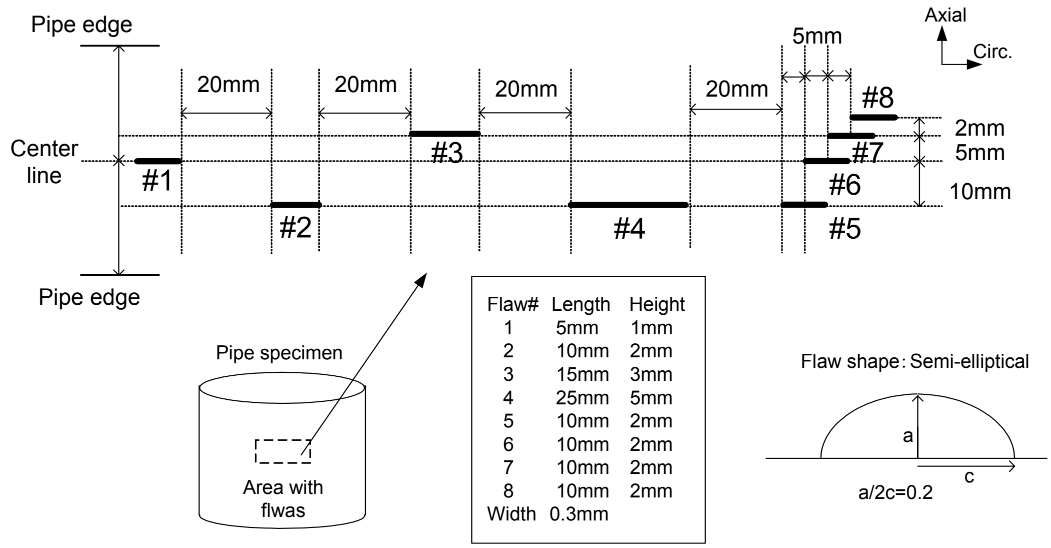
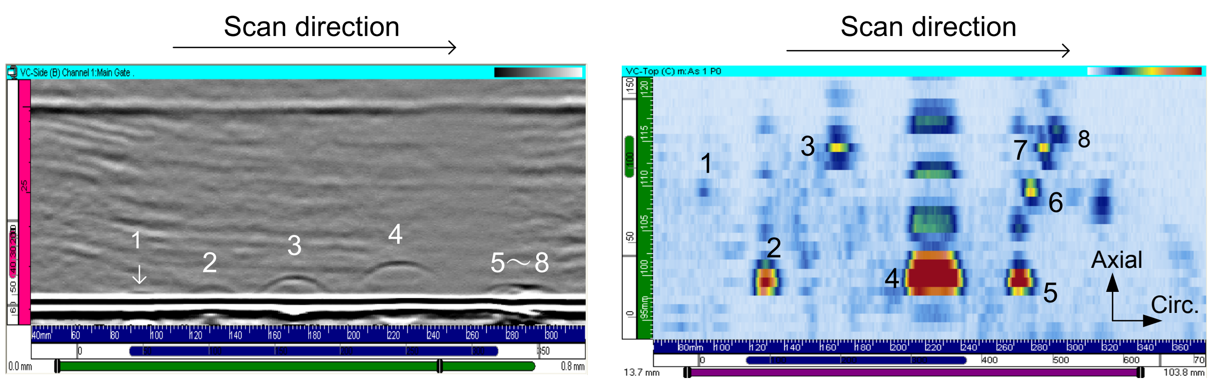


Figure 6 Overview of pip specimen



(a) TOFD image

(b) Top view image from sector scan

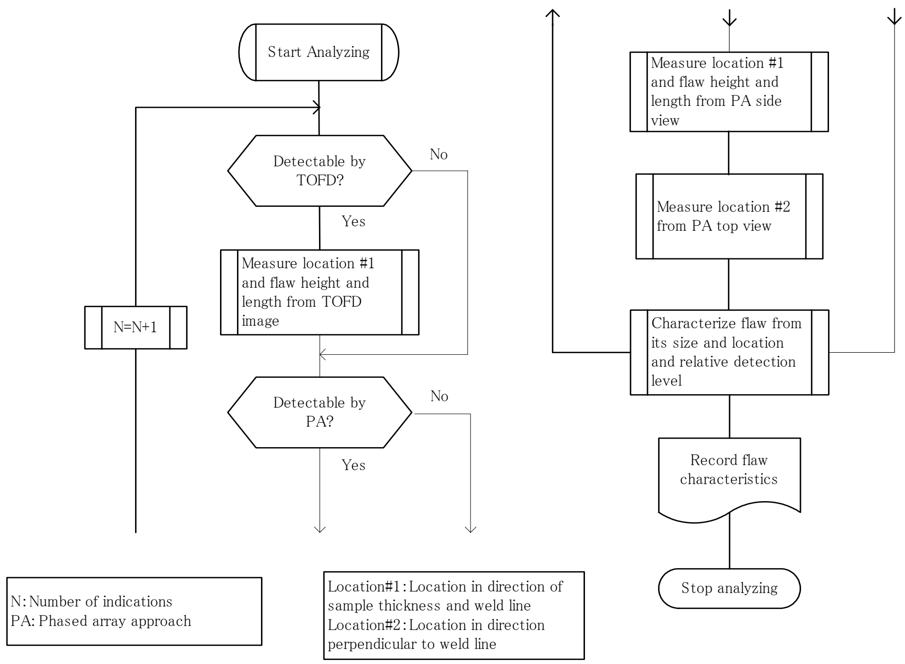
Figure 7 Test results of pipe specimen

Table 1 Root mean square errors in flaw size

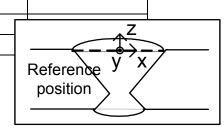
Height (mm)		Length (mm)		
TOFD	Phased Array	TOFD	Phased Array	
			6 dB drop	12 dB drop
0.30	0.36	3.42	1.41	4.76

Phased array data from sector scan

In order to verify the system developed, the previous plate seam welded specimen with surface flaws and a pipe specimen were inspected. Figure 6 shows the overview of the pipe specimen made from 2.25Cr-1Mo steel with semi-elliptical flaws. The thickness of the pipe specimens was 40 mm. The slits ranged in height from 1 mm to 5 mm and in length from 5 mm and 25 mm. They had a width of 0.3mm. Figure 7 shows TOFD and phased array images of the various flaws connected to the surface in the pipe specimen. These images were obtained from only one unidirectional scan at the same time. The RMS errors for height and length sizing are listed in Table 1. It can be seen that the TOFD technique provided excellent height measurements, while the phased array technique provided excellent length measurements. However, one can not discriminate each of the flaws #5 through #8 lining up in the direction of beam from the TOFD image. Once again, it is very important to positively discriminate between inherent flaws and malignant flaws. Thus we are developing examination and analysis procedures using this advanced seam welded inspection system with faster examination and accurate sizing capabilities, for discriminating between inherent fabrication flaws and type IV cracking. In achieving the same coverage using conventional automated pulse echo techniques requiring comprehensive, two-dimensional raster scanning, the use of phased array techniques makes it possible the scanning time is reduced by a factor of more than fifty. An analysis procedure after data acquisition utilizing TOFD and phased array inspections is under development and its concept is shown in Figure 8. An example of characterizing flaws in the seam weld specimen by this analysis procedure is given in Figure 9. This analysis procedure based on the automated, combined TOFD/phased array approach can be expected to be useful to discriminate from inherent weld flaw and Type IV cracking without compromising on probability of detection and false call rate.

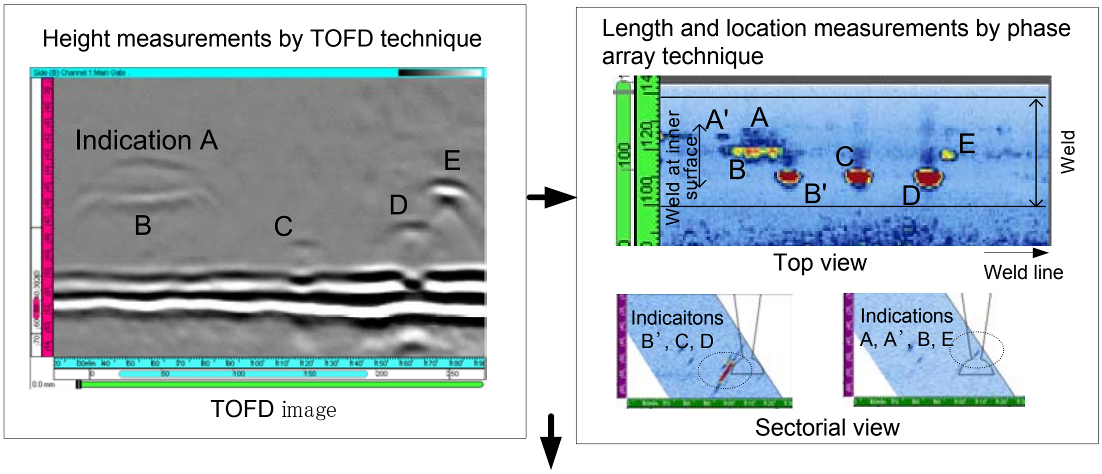


Indication ID	Size (mm)		Laction [*1] (mm)			Detection Level[*2]	Flaw type
	Height	Length	x	y	z		
a	1	5	•••	•••	•••	B-a	
b	10	20	•••	•••	•••	A	
•							
•							



[*1] Reference position: the center line of weld at outer surface for example
[*2] Detected by both TOFD and PA: A,
Detected by TOFD only: A-a, Detected by PA only: A-b,
Measured height by both methods: B, Measured height by TOFD only: B-a
Measured height by PA only: B-b, Not measured height by both methods: B-c
Measured Length by both methods: C, Measured Length by TOFD only: C-a
Measured Length by PA only :C-b, Not measured Length by both methods: C-c

Figure 8 Concept of analysis procedure



Inspection results

Indication	Size (mm)		Location		Flaw characterization
	Height	Length			
A	1.0	23.0	Weld near first pass	A, B-c, C	Hot cracking
B	1.0	29.0	Weld near first pass	A, B-c, C	Hot cracking
C	1.8	10.0	HAZ on Inner surface	A, B, C	Surface flaw
D	2.7	10.0	HAZ on Inner surface	A, B, C	Surface flaw
E	1.0	9.0	Weld near first pass	A, B-c, C	Hot cracking
A'	1.0	10.0	Weld near first pass	A-b, B-b, C-b	Hot cracking
B'	1.5	10.0	HAZ on Inner surface	A-b, B-b, C-b	Surface flaw

Figure 9 Example of flaw characterization

Conclusions: TOFD and phased array techniques were evaluated to address seam welded high energy piping with emphasis on defects simulating type IV cracking in the HAZ, and an advanced seam weld inspection system was developed using the automated, combined TOFD/phased array approach. Key conclusions include the following.

1. The TOFD technique provided the excellent measurement accuracy of heights of surface/midwall flaws in the HAZs of welds, the phased array technique provided their locations and distributions which are indispensable in discriminating between inherent weld and base metal flaws, such as lack of fusion, slag, base metal laminations, etc. and true type IV damage
2. Because the TOFD and phased array techniques are implemented in a uni-axial scan along the weld length, they can be implemented as rapidly as the equipment can be transported over the weld. The automated, combined TOFD/phased array approach can be implemented economically because it can be implemented relatively quickly, and is much more reliable to discriminate from benign inherent flaws and active creep damage.
3. An advanced seam weld inspection system using combined TOFD and phased array techniques have been developed. The combined approach is much more rapid and effective in discriminating between benign and malignant flaws, such as fabrication flaws and type IV cracking, than a TOFD approach combined with pulse echo techniques.

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