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# Visualization of weld defects in water by laser-ultrasonics

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**Abstract**

We present a new method of visualized weld defects in water by laser-ultrasonics. To detect and visualize a surface of weld metal with welding bead, the authors have developed a new detection method by leaky wave induced by interaction with surface acoustic waves and defects. Furthermore, developing Synthetic Aperture Focus Technique (SAFT) for visualized inspection surface 2-dementionally, we achieve the inspection result alike Penetrant Testing (PT) despite underwater environment. The proposed method can visualize weld defect of pit with around ϕ0.16mm and weld cracks with opening of a few μm and around 0.24mm in length.

**Keywords:** Laser-ultrasonics, leaky wave, weld defect, penetrant testing, SAFT

## 1. Introduction

Recently, a technique of welding metal structure in water has been developing. One of its applications is welding reactor internal components of nuclear power plants in water [1].

Surface inspection technique after welding is generally applying liquid Penetrant Testing (PT). However, PT is difficult to adapt underwater inspection due to using liquid as penetrant and developer. Conventional Ultrasonic Testing (UT) or Eddy Current Testing (ECT) is suitable to underwater inspection, though it is difficult to visualize inspection result of asperity bead surface with defects like PT due to low spatial resolution. Therefore, we propose a new inspection technique using Laser-ultrasonics having feature of high spatial resolution and develop a new signal analysis method for 2-dimensional visualization capability, comparable to the performance of PT in air.

## 2. Principle and measurement method

Irradiating pulsed laser with a few ns pulse duration to inspection surface induces ablation plasma. The plasma generates Shock Wave (SW) in water and Surface Acoustic Wave (SAW) on inspection surface by counteraction of plasma. Propagating SAW concentrically, Leaky Surface Acoustic Wave (LSAW) is generated by leaking a part of SAW's energy in water by critical angle derived from Snell's law. When there are cracks on propagating path of SAW, interaction between SAW and cracks generates a Leaky Waves (LW). Sound pressure of LW is identified as dilatational change, therefore change of index of refraction is occurred [2]. As refraction index change is equivalent to optical path length change, laser interferometer can detect LW.

Laser-ultrasonics is using two lasers for generating and detecting ultrasonic waves [3]. It is known as a distinctive technology having high spatial resolution, so it has a potential to be used as surface inspection substitute for PT. However conventional Laser-ultrasonics is that detection laser irradiates inspection surface directly, and thus sensitivity of detection is highly depend on surface condition of asperity, roughness and reflectivity. Therefore we propose a new robust detection method, which detection laser doesn't irradiate inspection surface directly.

Put a reflector with mirror finished surface on in water, and detection laser irradiates to surface of reflector. When LW generated by defects pass through laser beam path, laser interferometer detects LW signals as the changing of laser path length. As a result, proposed method can detect ultrasonic in water without effect of inspection surface conditions.

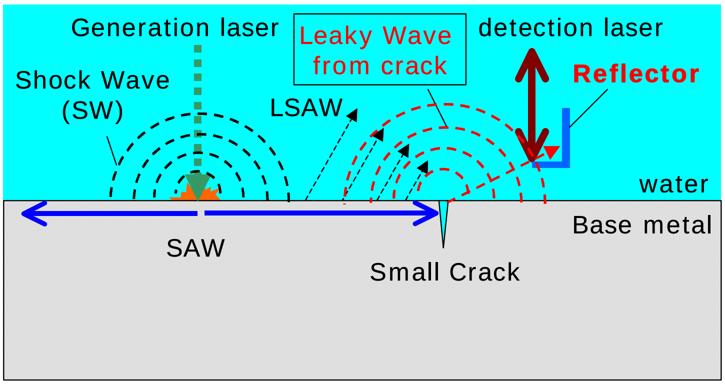



Figure 1. Principle and proposed detection method

## 4. Experimental setup

An experimental setup is shown in Fig.2. A pulsed Q-switched Nd: YAG laser induced SAW, which wavelength, pulse energy and pulse duration were 532nm, 30mJ/pulse and around 10ns, respectively. The laser is delivered with optical fiber and focused on around $\phi$1.0mm of spot diameter. To detect LW, the other Q-switched Nd: YAG laser irradiates surface of reflector, which wavelength and pulse duration were 1064nm and around 100μs, respectively. Signal of LW is detected with Fabry-Perot interferometer having frequency response from 0.5MHz to 50MHz. Both two lasers were irradiated with waterproof probes set on scanning stage in order to inspect surface 2-dimentionaly. Ultrasonic signal data was acquired with A/D converter which sampling frequency is 200MHz.

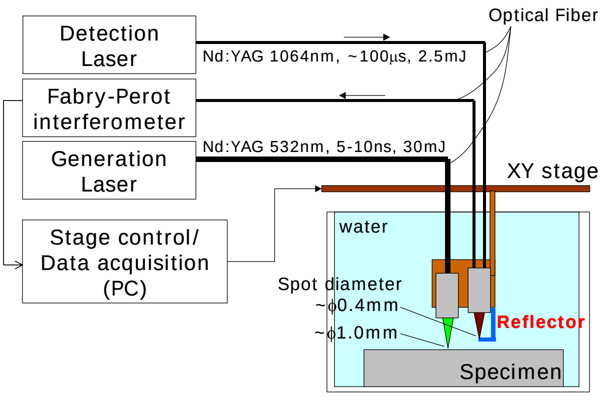
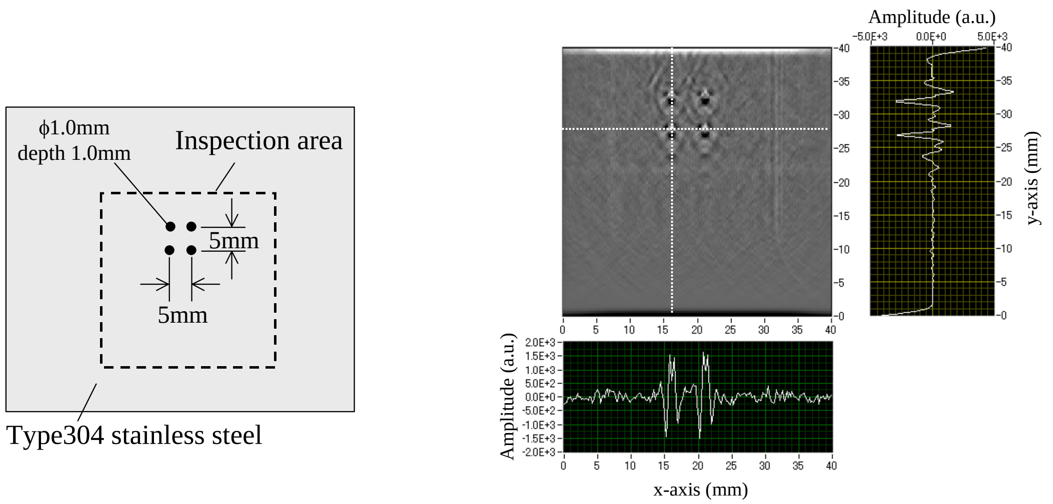



Figure 2. Experimental setup for proposed method

## 6. Detectability of artificial cracks

To confirm detectability of proposed method, we tested visualized performance by using artificial holes having diameter of φ1.0mm and depth of 1.0mm. Four holes were drilled on type304 stainless steel apart from 5mm each other (shown in Fig. 3(a)). Inspection area (40x40mm) was scanned at 0.2mm intervals. In order to visualize inspection result as similar as PT, acquired ultrasonic data should transform to 2-dimentional surface information by signal processing. SAW generated by generation laser is nondirectional ultrasonic source, therefore it is suitable to adapt SAFT algorism. So as to reconstruct objects images from ultrasonic signals, SAFT is common technique [4] and uses in many fields. Several studies were applying to laser-ultrasonics [5]. However SAFT for 2-dimentional surface reconstruction technique is not common, therefore we developed SAFT for 2-dimentional surface working under combining SAW and water velocity.

The result is shown in Fig. 3(b). It visualizes four indications caused by holes. Therefore proposed method and SAFT for 2-dimentional are applicable to visualize surface inspection substitute for PT.



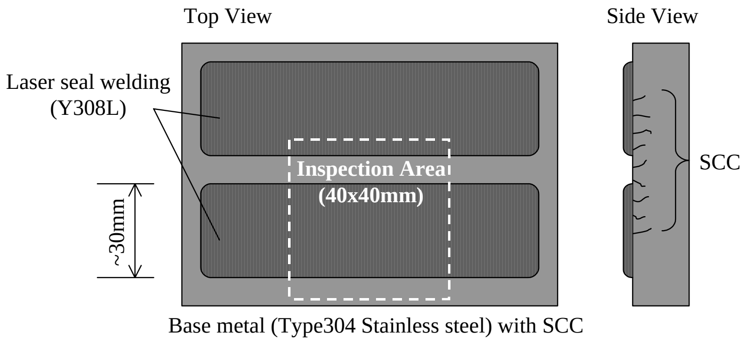

(a) Top view of specimen (b) Visualized result

Figure 3. Result of feasibility study by drill holes

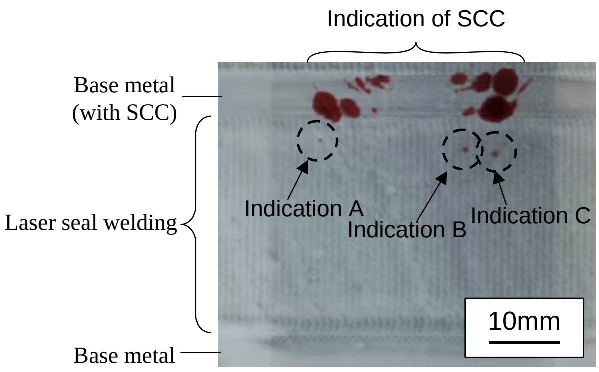
### 7. Detectability of actual weld defects

To confirm detectability for actual weld defects, specimen of laser welding with defects was prepared (Fig. 4(a)). Base metal of specimen is type304 stainless steel with Stress Corrosion Cracking (SCC) on surface. Laser seal welding is on surface in order to isolate the crack tip from corrosive water environment. This welding was performed to not appropriate conditions due to making weld defects intentionally. A result of PT is shown in Fig. 4(b). There are three indications cause of weld defects and SCC indications on base metal. Indication A and C are pits of around ϕ1.6mm and ϕ0.23mm, respectively. Indication B is a crack having opening of a few μm and length of around 0.2mm.

Scanning area was 40x40mm by 0.2mm pitch, and ultrasonic signals detected by proposed method were calculated by 2-dimentional SAFT. Result of visualized surface inspection is shown in Fig. 5. We can observe 4 indications on weld metal. Three indications are match with result of PT. The other is effect of geometry like a crack on weld, which doesn't indicate by PT. Moreover, indications of SCC can also observe on base metal. The shapes of indications are similar with result of PT. As a result, the proposed and developed method has performance of visualizing inspection surface in underwater environment and has possibilities of substitute for PT.



(a) Illustration of specimen



(b) Result of PT

Figure 4. Specimen of laser seal welding

### 8. Conclusion

In order to inspect weld metals in water substitute for PT, the new inspection method using modified laser-ultrasonics and SAFT for 2-dimentinal was developed. The technique can

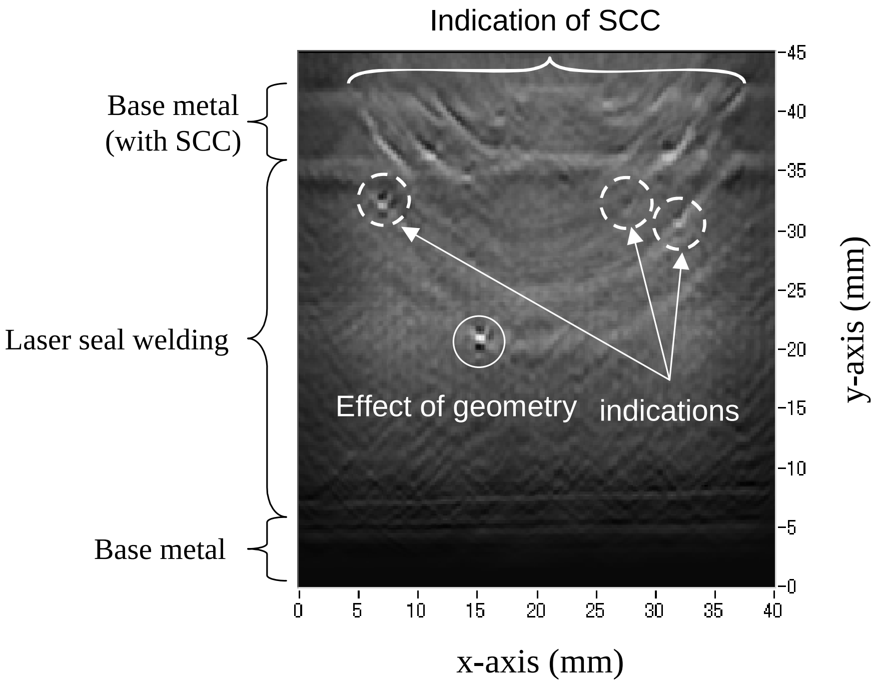



Figure 5. Visualized result of surface inspection

detect and visualize inspection surface of weld bead. Moreover, the spatial resolution is very high comparing conventional other methods, so it has the performance of substitute for PT in water. In future work, practical inspection methods and devices will be developed.

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