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Application of Holography in Subsea Pipeline Corrosion Control

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Abstract
Oil leak caused by pipeline corrosion has always be a seriously problem in oil industry. Not only the economic loss happens in oil company, but also sever damages to the environment around the pipe line. Due to the problems caused by oil leak, lots of technologies have been developed to monitoring and controlling pipeline corrosion.In the age of technology, holography is a very advanced and popular optical technology in the world, and has been used in the industry engineering area. This paper is going to clearly and simply clarify the working concept of holography, and some applications of this optical method in oil and gas industry.

Key words: Holography; Laser; Pipeline corrosion; Subsea

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INTRODUCTION

Holography has been developed for a long time since 947. In 947, Dennis Gabor[1] is the first physicist in the world exploited the theory of holography. He was also honored by the award of the 971 Noble Prize in Physics for his invention of the holographic method[1]. However, due to the technology and equipment are not completed, the holograms had a less visibility. Hence, the utilization of holography theory was incomplete. The usage of this theory expanded after the discovery of laser technology in the early 960s. Theodore Maiman[1] recognized as the person who invented ruby laser in 960, and this type of laser was the first successful light laser in the world. Actually, Leith and Upatnieks began the actual development of holography in 970s. Their research brought about the development from two-dimensional piece of film to three-dimensional images[1]. Moreover, blessed by the modern optical development, the holography method made rapid progress in the 11st century. This paper is going to be divided into two parts. The first one is the introduction of basic working theory of holography. Some applications are going to be provided in the second part as a demonstration to prove the holography technology could be used for measuring corrosion problem of alloys.

1. THE WORKING PROCESS OF HOLOGRAPHY

1.1 Creating a Hologram of Holography

Holography is a technology of recording the lights waves of lasers reflected off, or passing through a substance. Two processes are involved in holography: recording an interference pattern and reconstructing an image from the interference pattern[2]. The recording process involves two basic components, first of which is creating holograms. The occurrence of holography theory and the formation of holograms cannot be successful without laser. A useful facility to provide assistance for the creation of hologram is a beam splitter. The function of a splitter is that it divides one beam into two identical beams, with different effects. One beam is called an illuminating beam. It is expanded by a lens and directly shines on the object with mirrors. Then the recording medium will record part of the light scattered from the object. The other beam is the reference beam expanded by a lens as well, but it spreads to the recording medium directly without any touch with the object after leaving the lens[3]. Because the light of first beam intersects and interferes with the second one, interference pattern of beams forms, and the interference pattern could be considered as the fingerprints of the two beams, which also means the interference pattern is the information will imprint on the recording medium and also can be called holograms[1]. This complete process of hologram formation can be shown briefly in Figure 1[1].

The next process of hologram is a reconstruction from the interference pattern to an image. A laser similarly to the reference beam that is used in the recording process is illuminating the hologram plate. The original object's wave front will be exactly reconstructed by this illumination. In other words, the produced image is a replicate of the original subject. Obviously, this image includes the depth and perspective of the three-dimensional object. This reconstruction process can be understood easily with the process diagrams, which are Figure 2.

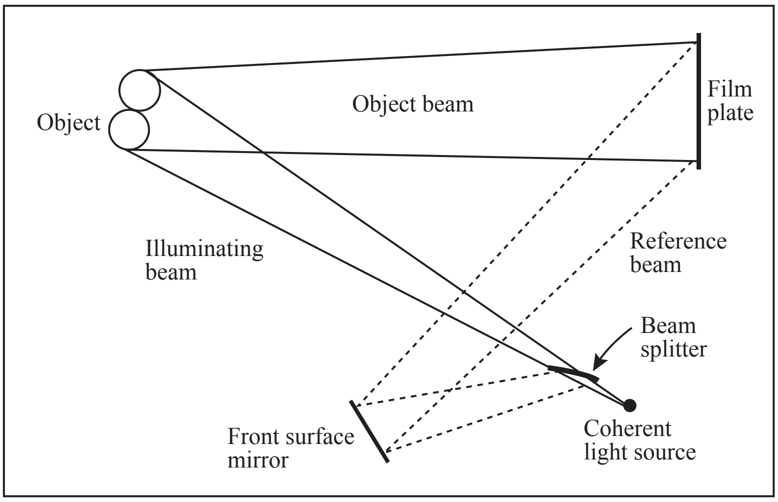


Figure 1
Creation of One Hologram[2]

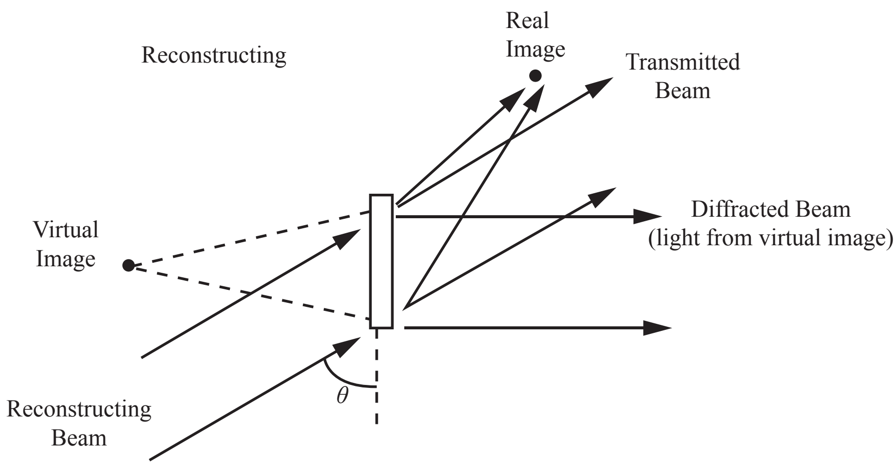


Figure 2
A Reconstruction of A Hologram[2]

In summary, there are four main factors influencing the success of holography process.

(a) Suitable objects (at least one subject),

(b) A Suitable laser beam,

(c) A recording medium,

(d) A suitable working environment.

Observing objects and laser beams are important to holography, and it is necessary to pay attention to the working environment. A suitable working environment can contribute to the stability, needed by interference pattern during the production process[4]. In addition, a suitable recording medium has a significant influence on the resolution of real images, which means choosing a recording medium with good recording characteristics could lead to the production of a qualified recording result.

1.2 Recording Medium in Recording Process

Recording medium is fundamental to the success of holography process. The purpose of recording medium is to convert the interference patterns produced by the wave action of two beams into an optical element. Because the recording medium takes an important position in holography, a recording medium must meet the basic requirements. Basically, the medium is required to have good spectral sensitivity, corresponding to other characteristics, such as the available laser wavelengths, linear transfer characteristics, high resolution and low noise[5].

Until now, many materials have been investigated to get the above properties. Scientists have studied silver halide photographic emulsion, dichromated gelatin, photoresists, photo thermoplastics, photopolymers and so on[5]. According to the requirement for recording medium, Table 1 shows the basic characteristics that are used to select the material of recording medium and some possible materials could be used as recording medium. Table 1 also illustrates the result of Hariharan's comparison of those materials, photographic emulsions is the most common recording material[4].

Table 1
General Properties of Recording Medium[5]

Material	Reusable	Processing	Hologram type	Theoretical maximum efficiency	Required exposure (mJ/cm^2)	Resolution limit (mm^{-1})
Photographic emulsions	No	Wet	Amplitude	6%	1.5	5,000
			Phase	60%		
Dichromated gelatin	No	Wet	Phase	100%	100	10,000
Photoresists	No	Wet	Phase	30%	100	3,000
Photo thermoplastics	Yes	Charge and heat	Phase	33%	0.1	500-1,100
Photopolymers	No	Post exposure	Phase	100%	10,000	5,000
Photorefractives	Yes	None	Phase	100%	10	10,000

Although there is no material satisfying all the demands for recording medium, silver halide photographic emulsions is most commonly used in conventional of holography. The common usage of silver halide photographic emulsions is due to the high relative sensitivity and easy availability[5].

In the early development of holography, films are used as a storage media. Because of the rapid growth of techniques, photopolymers are used as a storage media as well. Besides photopolymers, holograms can be generated electronically and seen with a computer. Using computer in reconstruction process of holography technology leads to the convenience for inspector to analyze data.

However, due to the hazard condition and environment of transport pipelines, until now, holography has not been used in monitoring the corrosion of oil and gas pipelines. To apply this technique to monitor oil pipelines it will require further researches.

Holography has many of potential applications, such as general archiving, examination and measurement of damage sites, examination of marine growth, and even measurement of the corrosion pitting and cracking of hydrocarbon pipelines[6]. It is well known that quality inspection of corrosion inside hydrocarbon pipelines has to be monitored under poor visibility condition. Therefore, since the investigations of holography, people have been trying to use holography technique to inspect alloy corrosion. In the exploration of holography, how to apply those advanced optical methods to monitoring and measuring corrosion successfully is a major concern. Four main applications are investigated based on holography, which are holographic interference, optical corrosion meter, digital holography and underwater hologrammetry. Almost all of them have been used for measuring corrosion of metals experimentally.

2. APPLICATIONS OF HOLOGRAPHY THEORY

2.1 Holographic Interference

The first technique to be introduced is holographic interference based on the holography theory. Holographic interferometry is one application of holography to measure the static and dynamic displacement of objects to optical interferometric precision, as well as to visualize and analyze fluid flow. Nowadays, due to the visibility of this technique, this method is adopted to monitor corrosion phenomena in oil pipelines[8]. It is well known that the corrosion phenomenon inside pipelines is difficult to substantiate, and engineers cannot see what happens in the pipeline with their eyes. Since the discovery of holography theory, images are produced to let engineers see if corrosion occurs inside pipes through this technology. With the exploration of holographic interference, optical corrosion meter was invented to measure the corrosion current density of metals.

2.2 Optical Corrosion Meter

As a further application of optical holography, optical corrosion meter has been developed to measure corrosion problem of alloys several years ago. An investigation of using the optical corrosion meter to monitor corrosion current density of different alloys in aqueous solutions by Habib and his colleagues is shown as follows[8]. The working mechanism of optical corrosion meter is based on holographic interferometry and electrochemical technique[8]. Micro-surface alterations can be measured by holographic interferometry, and electrochemistry is used for measuring the current density. Furthermore, the experiment of using optical corrosion meter to monitor current corrosion density of different metals in solution was established with a mathematical model, which has a relationship with the thickness of cathodic deposition. The model is described as bellows[8]:

$$J = \frac{F\,|\,Z\,|\,du}{MT}. \tag{1}$$

Where J is metal's corrosion current density, F is Faraday's constant, $|Z|$ is the absolute number of electron charge, the atomic weight of the sample material is M. The time of the anodic current is T, d is the density of the metal, u is the orthogonal displacement of the metal surface, and this parameter can be measured by the holographic interferometry technology[8].

In this experiment, aluminum, stainless steel, and low-carbon steel were used as the experimental metallic samples, and each sample was put in the solution for measurement[8]. The solutions used for this experiment are sodium chloride, potassium chloride and sodium hydroxide. Corrosion began to occur when the sample stayed in the solution for long time, and the corrosion current density of each metal can be calculated through Equation 1. However, before measuring the corrosion current density of metals, the optical corrosion meter can be used to measure orthogonal displacement of the metal surface. An off axis holography was used to record a hologram of each sample in this experiment. For each of the samples, the holographic interferograms were recorded lasted for 60 minutes. Because of the interpretation between interferograms and the orthogonal displacement of the metal surface, the recordings of holographic interferometry can be used in Equation 1 to calculate the corrosion current density of each alloy. Figure 3 demonstrates the recording process of the sample's hologram[8]. It is clearly known from the process diagram that camera was applied in this study to promote achieving the recordings of the interferograms of those samples[8].

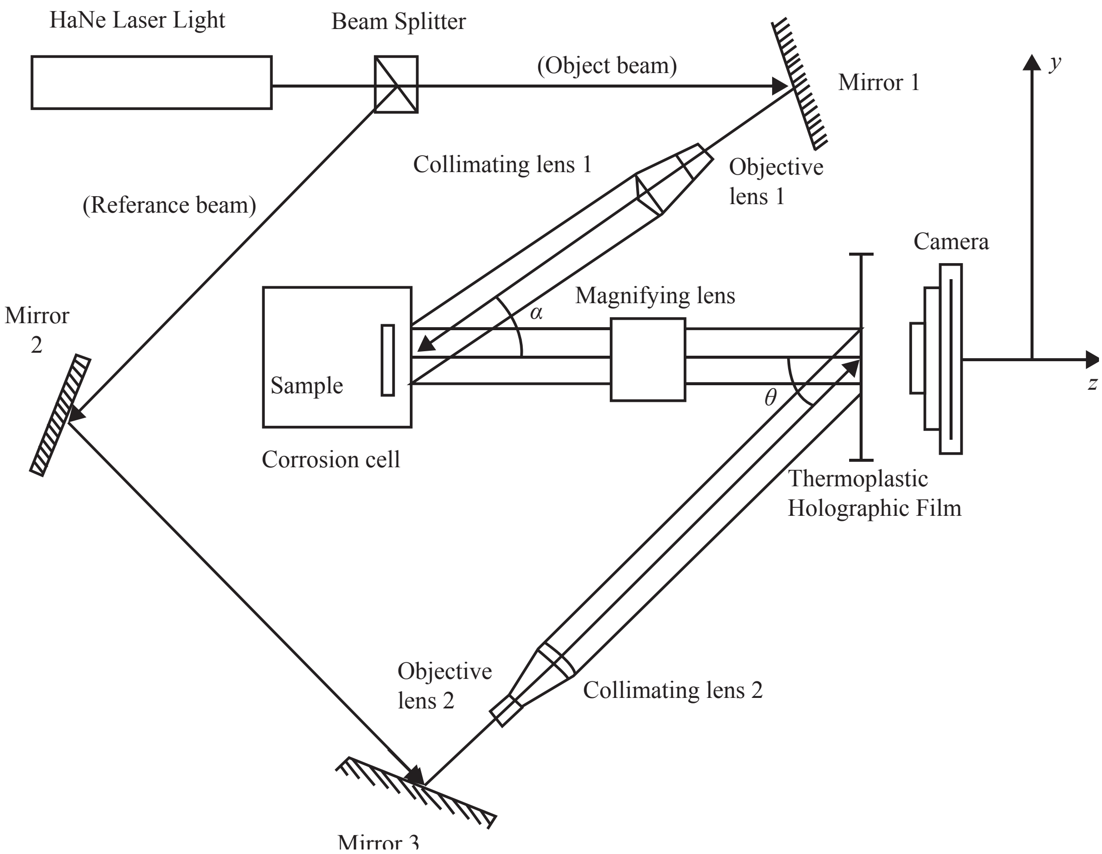


Figure 3
The Design of Using Holography in Optical Corrosion Meter[7]

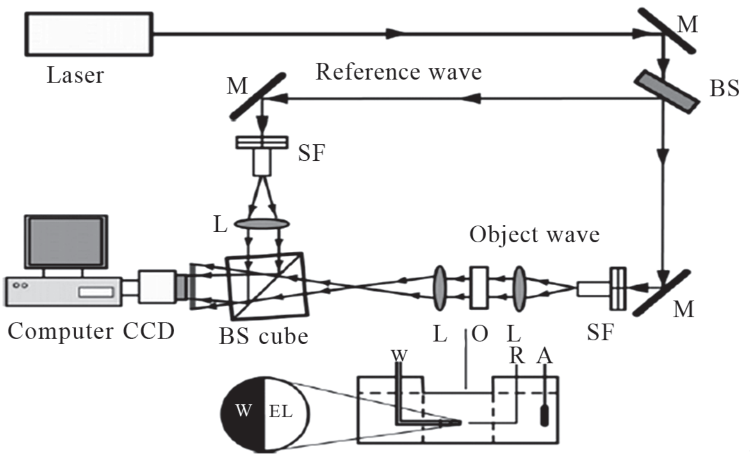
The operator got a detailed result of this experiment by using optical corrosion meter. The result of this experiment illustrates that the corrosion current density of the stainless steel in 1 M NaCl is about triple times higher than the corrosion current density of the aluminum in 1 M KCl, and it is also triple higher than the corrosion current density of the low-carbon steel in 1 M NaOH[8].

The success of this investigation demonstrates that holographic interferometry is a useful method in monitoring corrosion of metals in aqueous solution. Although, this experiment only detected the alloys in aqueous solutions instead of in the hydrocarbon fluids, it is still a strong demonstration to prove that the holography technology is of use in monitoring and measuring alloy's corrosion process.

2.3 Digital Holography

There is another application of holography theory: digital holography. Digital holography is an improvement of holographic interference. The overwhelming advantage of digital holography over the original one is that the measurement data can be transmitted and processed via a Charge Coupled Device (CCD) camera with super-resolution[10]. A CCD can capture the hologram directly, and then go through reconstruction process conducted by a computer, saving the annoyance to wait for the images in a laboratory. Besides the convenience of reconstruction procedure, high-resolution is possible to be obtained in digital holography. The dynamic phase diffraction can be grated to cause the aperture improvement of the Charge Coupled Device array[9]. Therefore, the trouble of photographic processing in the traditional holography is avoided in digital holography[11].

According to an investigation operated by Chao Wang and so forth, digital holography can be used to measure the chloride-induced pitting process of iron in the H_2SO_4 solution. In the working process of their investigation, an electrochemical cell with the in-line digital holography recording system is used. The working electrode and reference electrode changed with a controlled injection speed at different moment, those changes, recorded by the digital holography system, and the information of recording could be read through the computer. The working procedure can be clearly understood in Figure 4.



M, Mirror; BS, Beam Splitter; SF, Spatial Filter; L, Lenses; O, Object; BS Cube, Beam Splitter Cube; W, Working Electrode; R, Reference Electrode; A, Counter Electrode

Figure 4
A Process of Digital Holography Recording System[11]

Wang and so forth successfully obtained the result and proved the feasibility of applying digital holography in monitoring the dynamic processes of alloy local corrosion through their direct observation of the dynamic processes[12]. This achievement not only proves the capability of using holography technique, but also provides the evidence to show the correct developing application of using digital holography technology.

2.4 Underwater Hologrammetry

Watson and Foster[8] briefly summarized the current work about the potential application of holography to subsea inspection and measurement. In their overview of underwater inspection work, it is clearly shown that underwater holography is developed for measuring holograms from underwater. The underlying theory of underwater holography depends on holography. The process includes recording a hologram from underwater, and then replaying the real image in air to obtain the positional and dimensional information from underwater[6]. However, the reconstruction of producing virtual image takes place by using micro-scopy or TV-videography. This change makes the usage of holography more akin to photogrammetry[6]. Due to changes in the process, there is a new name of this technique, hologrammetry[6]. Usually, off-axis recording and in-line recording are present to be used for recording underwater holograms in the work result of John Watson and E. Foster[6]. In the process of in-line recording, the object and the holographic film are illuminated by only one beam. Off-axis recording is a little complicated, compared with in-line recording. It is easier to understand with an experimental recording set-up, in Figure 5 below[6]. As it is found that the holographic plate illumined by a paralleled reference beam, as water in the tank lit with two beams, which come from the front of the tank, and the differences of in-line recording and off-axis recording can be saw in Figures 5 and 6[7].

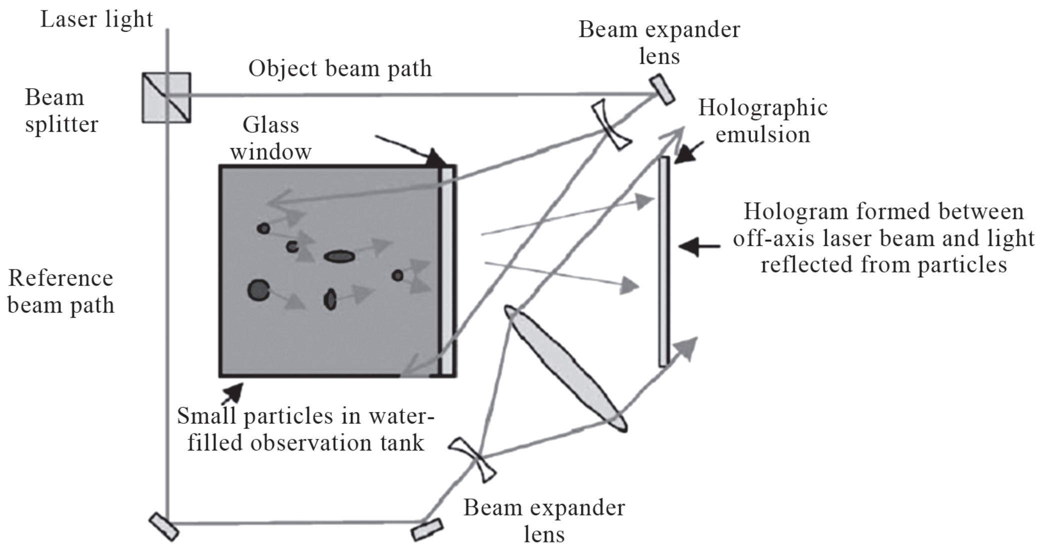


Figure 5
An Experiment Set-up of Recording an off-Axis Underwater Hologram[7]

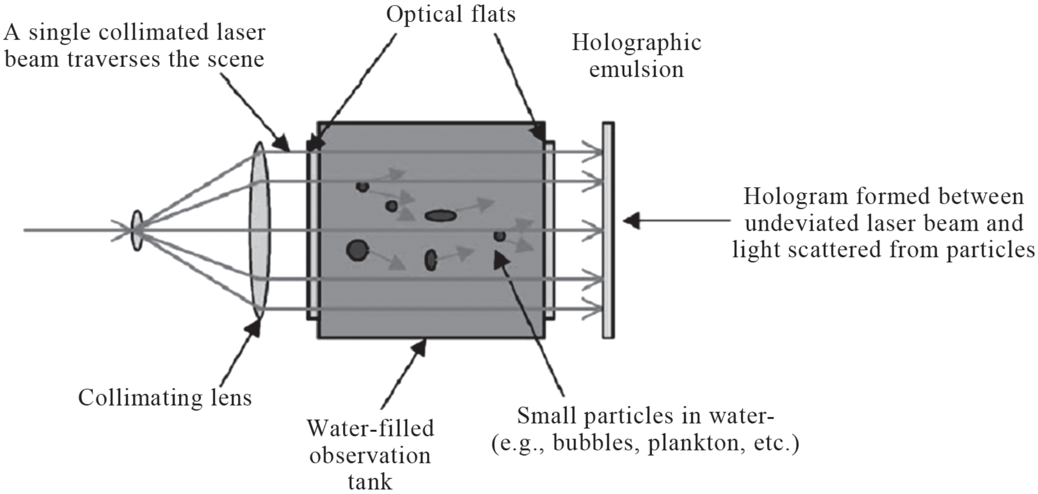


Figure 6
An Experiment Set-up of Recording an in-Line Underwater Holography[7]

The investigation result of underwater hologrammetry illustrates the potential of measuring holograms in underwater conditions. This possibility could make great contributions to the growth of visibility in underwater monitoring and measurement. Furthermore, observing the subsea structure and components in a 3-D dimensional image could bring humorous benefits for inspection engineers. The possibility of applying this measurement to detect the corrosion pitting and cracking also exist[6].

According to the introductions of holography theory and its developments, laser is a key factor in this technology. Hologram could be produced with the application of laser and could lead to the successful recordings by the recording medium. Contributing to the increasing visibility of inspection technique, and brings many benefits for inspection operators. Additionally, it could be obviously known that if there is a possibility to employ holography technique in measuring corrosions of hydrocarbon pipelines, it could provide huge benefits for the monitoring engineers. The visibility and none-destructive characteristics of holography and its applications are the most important elements to resolve the poor observing conditions of oil pipelines' monitoring[6]. Especially, the new development of reconstruction process makes it possible to observe the corrosion degree inside pipelines by removing the recording medium instead of CCD. Using Charged Coupled Device create a potential of viewing corrosion phenomena on a computer screen. Furthermore, underwater hologrammetry can be used for quality inspection underwater. The success of measuring holograms from underwater is a strong support for the increased potential of using underwater hologrammetry to inspect the corrosion issue of subsea oil pipelines.

3. ADVANTAGES OF HOLOGRAPHY TO ASCERTAIN CORROSION ISSUE OF SUBSEA PIPELINE

Due to the application of holography, we know that its applications have a lot ofadvantages for detecting corrosion of subsea pipelines[6]. Those successful experiments mentioned could be used as evidences to prove that holography theory can be used for monitoring and measuring varied parameters of metal corrosion.

There are five advantages for holography technology in corrosion inspection:

(a)The operation of holography is easy. The operating process ofholography is simple and easy, using a suitable laser beam to illuminatethe surface of pipelines, holograms could be produced. Then, usingrecording medium to storage the information carried by the reference beam[2]. Lots of experiments have used holography to study metalsamples and the recorded data was useful in the measurement of corrosion of samples[2].

(b)Holography technique is none-destructive and none-contact. Because this technique is an optical method, there will be no contact between the detection equipment and subsea pipeline. Hence, holography technique would not cause damage to the structure of pipelines.

(c)3D images are the result of the holography technique. It could increase the visual inspection condition of subsea pipelines [5]. Holography could increase the ease of inspecting the condition of pipeline corrosiondue to better visibility than none optical methods as the user can view a 3D copy of the surveys on a computer at a remote location.

(d)The detected information obtained by holography could be interpreted tomeasure metal corrosion[8]. This is because holography can be used to measure the corrosion of metal samples and seeing as iron is the main component of hydrocarbon pipelines, it increases the potential of utilizing holography to record the information of metals with the offshore industry. The physical characteristics of oil pipeline could be changed by pipeline corrosion, leading to changes of the pipeline metals' features aswell. These changes to the surface of the metals could be seen byholography. Using object beam illuminates the surface of pipelines toproduce holograms, and the reference beam could illustrate the changes of the metal, such as the orthogonal displacement of the metal surface[8], the thickness of the anodic dissolved layer of carbon steel[10] or electrode interface of iron[12].

(e)It is possible to measure holograms underwater[13]. The success of measuring underwater increases the possibility of using holography tomonitor corrosion of subsea oil pipelines. Once the hologram of subsea pipeline surface is recorded, the images of the recording could be produced in the laboratory. It could help inspectors detect corrosion of underwater pipelines much more conveniently.

CONCLUSION

Based on the discussion of holography methods, it clarifies that the advanced characteristics of optical methods make itself possible to measure pipeline corrosion. What is more, in terms of the evaluation of holography technique, it is adaptable to detect the pipeline corrosion in marine environment.

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