出國報告（出國類別：會議）

參加 2015 法國巴黎非破壞檢測及評估國際研討會並發表論文

服務機關：行政院勞動部勞動及職業安全衛生研究所

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派赴國家：法國（France）

出國期間：**104 年 05 月 14 至 05 月 22 日**

報告日期：**104 年 09 月 10 日**

摘要

本次出國案依勞動部及所屬機關 104 年公務預算派員出國計畫，參加 2015 非破壞檢測及評估國際研討會(ICNTE 2015 : International Conference on Nondestructive Testing and Evaluation) ，並發表研究成果論文「Study of Electro Magnetic Acoustic Transducer to detect flaw in pipeline」。本研討會是由 WASET (World Academy of Science, Engineering and Technology)國際組織主辦，本次 2015 ICNTE 是第 17 屆於 5 月 18 日至 5 月 19 日在法國巴黎舉辦。透過參加本次研討會議及論文發表，獲得目前非破壞檢測技術最新趨勢及應用現況，提供我國產業在設備事故預防及安全檢查技術應用之參考，並藉由論文發表及與國外相關專家學者之實務經驗交流，推展國內研究成果。

本次研討會共分兩天進行，論文發表之議題含蓋：化學工程、機械工程、材料科學、結構工程應用等方面。參與發表的專家學者包含歐、美、印度、中國大陸等來自世界各地的國家，透過分段主題發表的方式，提供與會專家學者一個知識交流平台，在有限時間內瞭解目前國際在非破壞檢測技術的發展現況。

本次研討會的議題較廣泛，所發表的工程應用成果包含種類相當多，包含災害控制、材料微觀破損分析、綠能環保、智能機械等，各國學者專家出席率非常踴躍，帶來的近年研究成果也相當豐富，多探討非破壞檢測技術在目前多元工程應用的情形，未來對我國設備完整性現況問題的解決對策，或相關安全檢測的技術研究，應有相當程度助益。

關鍵字：非破壞檢測、研討會、論文發表

目 次

壹、目的

鑑於國內近年來因石化產業之部分設備趨於老舊，設備或管線洩漏等工安事故頻傳，如何有效利用非破壞檢測技術來提升設備之可靠度，以降低危害風險有需求上之迫切性。本次參加在法國巴黎舉行之 ICNTE 2015 非破壞檢測及評估國際研討會是由 WASET 主辦，該研討會每年舉行 1 次，會議有來自世界各國對非破壞檢測技術在各產業應用的專家學者參加，發表近年的研究成果，提供解決石化設備完整性及危害預防等之相關議題上的技術管道。

藉由參與本次國際非破壞檢測技術及應用研討會，收集會議討論主題相關資料及最新趨勢及問題解決對策，做為未來國內設備完整性、事故預防及安全檢查技術應用等方向之參考借鏡。且藉由研討會之論文發表及與國外相關專家學者之研討等進行實務經驗交流，提升本所能見度。

貳、時程

一、　概述

本次行程以參加研討會為主，因此配合大會舉辦研討會時間及飛機票時程於 05/14（週四）23：50 出發，於 05/15（週五） 07 : 35 抵達法國戴高樂國際機場（時差慢 8 小時）；次日 05/16（週六）～05/17（週日）為例假日，05/18（週一）～05/19（週二）二天參加本次出國主要活動「非破壞檢測及評估國際研討會」及論文發表；05/20（週三）整理相關資料；05/21（週四） 11 : 20 搭機返國，於 05/22（週五） 06:30 抵達台灣桃園國際機場。

二、　研討會

第 17 屆 ICNTE 2015 非破壞檢測及評估國際研討會，成立宗旨在匯集國際先進技術的學術科學家、研究人員和研究學者，對非破壞檢測及評估技術提供一個平台，交流和分享他們的經驗和研究成果。它還提供了一流的跨學科論壇，研究人員、從業人員和教育工作者可以介紹和討論最新的創新技術及發展趨勢，對於實務上遇到的實際挑戰和非破壞檢測領域採用的解決方案提出看法。

圖 1 研討會場入口

圖 2 與本次研討會主席 Dr. James A. Nelson 合影

圖 3 各國學者依議程報告論文內容(一)

圖 3 各國學者依議程報告論文內容(二)

圖 5 研討會報到處

圖 6 研討會假日飯店會場外景

三、 論文發表

本次研討會發表的論文題目為「Study of Electro Magnetic Acoustic Transducer to detect flaw in pipeline」電磁超音波在管線缺陷檢測之探討。為使製程管線運轉中檢測更快速、方便、經濟與可靠的目的，完成電磁超音波實體檢測(EMAT)技術探討，該技術可在運轉狀態下實施非破壞性檢查，減少準確性受表面高溫的影響，或是檢查前需要將表面的防蝕層刮除，增加準備工作的耗時。本研究完成傳統超音波與電磁超音波之檢測差異性分析、數位 RT 檢測管線 CUI 缺陷之可行性評估、實驗管線架設、管線腐蝕實體測試(如圖 2, 3)、建立電磁超音波準確度分析等。經實驗瞭解管線缺陷與訊號之

間的關係，經由量測振幅訊號找出缺陷振幅和缺陷長度的變化；缺陷深度與振幅衰減的變化關係；管線的平底圓孔面積增大則振幅信號衰減的變化關聯性等。本研究得到下列結果：

1. 電磁超音波檢測可以克服傳統超音波檢測前的繁瑣準備作業，並且適用於高低溫環境下之管線檢測。
2. 電磁超音波檢測可以做管線缺陷之定性、半定量檢測，且可以依據示波器波形形狀，判斷管線缺陷是屬於層狀缺陷或是氣孔，所以可以快速判斷缺陷位置、數量、形狀等。
3. 電磁超音波找出缺陷位置後亦可用數位 RT 做定量分析，判斷缺陷尺寸。

電磁超音波檢測對於管線焊道、彎管、法蘭與夾持式支撐架等管線特徵，會阻礙 EMAT 掃描機拖曳，唯獨當焊冠很小時才不會損壞線圈。

四、 假日市街參觀及路邊工地防護小集

利用 5/16 及 5/17 兩天的例假日隨機參觀巴黎市街名勝、文化及路邊工地假日停工時的安全防護措施。

	
圖 7 移動式起重機路邊停放時，以圍籬作適當人員隔離及防護	圖 8 高空工作車路邊停放時，也作好適當人員隔離及防護

圖 9 人行道上的施工架，在與人體有接觸之處的高度，包套塑膠軟墊

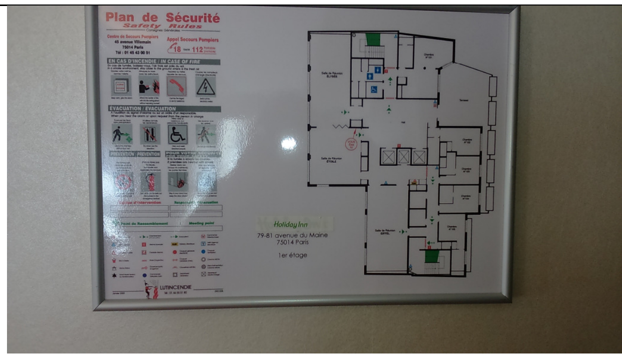

圖 10 緊急逃生路線標示看板

圖 11 羅浮宮

圖 12 巴黎塞納河

參、心得

(一)　老劣化鋼纜放射線檢測技術

鋼纜在使用過程中會逐漸發生腐蝕、磨蝕及斷絲等情形，該論文提供鋼纜之放射線檢測，作為評估鋼纜缺陷之初步依據，可有效協助工程人員評定老劣化鋼纜之品質，以提高整體結構安全。

(二)　風機防蝕塗層性質監測技之應用

使用 CHM(Coating Health Monitor)腐蝕監測儀器進行探討，利用恆電位儀所測得的交流阻抗數據，確認 CHM 監測腐蝕的準確性，本系統可監測損壞距離、不同濕度溫度環境下的影響等。

(三)　應用電磁超音波於管線支撐座腐蝕定量

使用導波在管線上傳遞之特性對管腐蝕進行定量研究，中長距離導波適用在管線上激振出 SH0 模態，使用激振頻率 100kHz 下，在實驗管上量取支撐座腐訊號，藉由反射訊號強弱來進一步量腐蝕深度。

(四)　壓載水艙腐蝕檢測方法

壓載水艙常因結構形狀多樣，塗裝不易、光進不去、暗中不易檢查、非常潮濕，而讓腐蝕狀況往往相當嚴重。本研究提出了船在塢修前便可以探知壓水艙腐蝕狀況的檢測及評估方法，並提出如何設計壓水艙的陰極防蝕系統。

(五)　常溫乾燥型耐高溫塗料

本研究開發，主要改良純有機矽樹酯，使其具有大氣乾燥性，作為常溫乾燥型耐高溫塗料之主體，以期改善熱處理前，塗膜容易沾黏灰塵或擦撞堆疊破壞之缺陷產生。研究中，主要觀察乾燥性、耐高溫性與堅韌性重點，由結果顯示，開發出之常溫乾燥型耐高塗料可於大氣環境中乾燥，並在高溫理境中，未有熱劣化情況發生，使塗膜保持一定熱穩定性能。

(六)　含釩高強度鋼材之氫誘發破裂敏感性評估

利用對開槽圓棒試棒預充氫及般拉伸試驗法，探討釩的添加與回火處理溫度對高強度鋼簧鋼材氫誘發破裂敏感性之影響。預充氫含量－破壞之臨界氫含量值，當氫含量大於該臨界值後，其破斷應力隨著鋼材內之可擴散氫含量增加，而呈現冪次法則關係遞減。

(七)　高爐管線膨脹接頭破損分析

膨脹接頭為連接高爐爐頂氣及粉塵洗滌區之氣體輸送管線，主要功能乃經由冷加工成形類似波浪狀，藉以調節管線因熱脹冷縮誘發之體積變化。管線內部溫度屬溫濕度較高之腐蝕性環境，於波浪形之管壁填入岩棉以隔絕環境與不锈鋼之接觸。原本用為阻隔環境與材料直接接觸之岩棉，因其於潮濕環境中易發生水氣吸附之現象，反而成為腐蝕因子與材料接觸之載體，進而加速孔蝕生成。

肆、建議

有幸參與本次第 17 屆 ICNTE 2015 非破壞檢測及評估國際研討會，深刻體認到國際產學界在非破壞檢測技術方面成長的日新月異，除增加視野與見聞外，也帶給自己在推動業務上甚多的啟發及省思。

一、 本研討會發表內容相當廣泛，包括設備檢測技術、環境綠化、機械設備安全、健康促進、採礦管理、交通安全管理等議題，對提昇本所相關安全研究能量有很大幫助。在研究主題上，能參採與國際趨勢與國際接軌，吸收國外優良之專業改善案例，擴展技術視野。

二、 面對日益複雜之設備安全及職災降災目標之挑戰，除加強勞動檢查的方式外，藉由擴大專業研討會方式或類似推廣平台的作法，彙整全國產業、學界及官方對改善安全衛生專業技術的具體成果及改善實例，有系統的加強防災教育宣導，也是很重要的一環。若能結合各方經驗，協助事業單位強化安全衛生技術，進而消彌危害，才能保障勞工工作之安全與健康，進而提升整體職場安全水準，以期達成減災目標。

三、 為提高產業整體的設備安全檢測水準及防災效能，以國內中小企業為主的企業型態，除藉由勞動檢查外，應能適時提供適切的解方案是很重要的，藉由國外

安全改善技術的成功案例及經驗，有助於事業單位改善本身安全衛生缺失並推動自主管理工作。

伍、附錄

一、 論文發表之投影片

Study of Electro Magnetic Acoustic Transducer to detect flaw in pipeline

Yu-Lin Shen[1], Ming-Kuen Chang

May 19, 2015

[1]Institute of Labor, Occupational Safety and Health, Ministry of Labor, Taiwan, R.O.C.

IOSH 勞工安全衛生研究所 1

INTRODUCTION

- Chemical substance and gases easily lead to pipeline corrosion
- pipeline corrosion may lead to thinning and rupture, causing serious safety concerns
- To find an effective detection method

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Electromagnetic Acoustic Transducer Testing (EMAT)

- Advantage
  - quickly scan
  - work at high temperature environment
  - non-contact to objects
  - ……

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Compare four different defects

- In this study, we compare four different type defects:
  - The same defect length, but has different defect depth.
  - The same defect depth, but has different defect length.
  - The detect signal affect by the defect location.

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Experiment principle

- EMAT is composed of a set of permanent magnets and the receiving coil.
- EMATs generate ultrasonic power :
  - for non-ferromagnetic material, EMAT generated ultrasonic by Lorentz force
  - for ferromagnetic materials, EMAT generated ultrasonic by magnetostrictive force.
  - The EMATs generated wave mode type was affect by direction of applied magnetic field, coil geometry and electromagnetic frequency.
- This study applied magnetostrictive force to generate Lamb wave on carbon steel pipe

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Experimental Materials Processing

- prepared four steel pipe
  - ASTM A106
  - diameter 114 mm
  - wall thickness 6.5 mm
  - defects depth are 1/2T and 1/4T respectively. (T is wall thickness)
  - five defect length is 4cm and 15cm respectively.
  - Defect circumferential angle are 90°、180°、270° and 360° respectively, shown in Figure 3. The tube defect depth is 1/2T.

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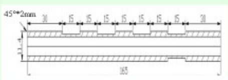
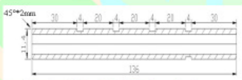
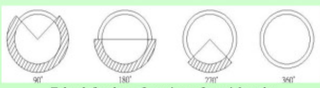


Testing tube with defect length 15cm



Testing tube with defect length 4cm



Tube defect have four circumferential angle

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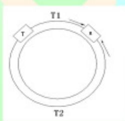
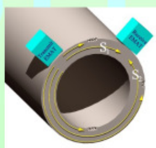
Detection method

- Used EMAT Scans software 'Do Runs mode'
- The excitation coil T1 and T2 with Lamb waves transmission to the receiving coil
- T1 is around the tube top, T2 is around the tube from bottom to top.





EMAT wave delivery route

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Results and discussion

- ✶Defects
  - ✚ **Same defect length ：15 cm,**
  - ✚ **different defect depth ：1/2T and 1/4T**
- ✶Compared the signal amplitudes

EMAT measuring

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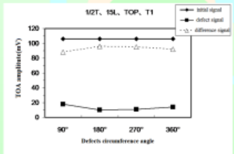
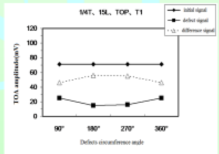
Results and discussion

T1 route experiment



T1 signal amplitude of defect depth 1/2T, length 15cm



T1 signal amplitude of defect depth 1/4T, defect length 15cm

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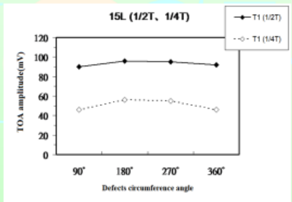
Results and discussion



Comparative of T1 signal amplitude of length 15cm

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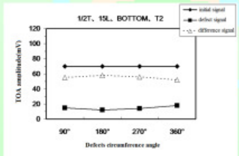
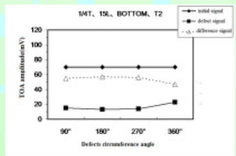
Results and discussion

T2 route experiment



T2 signal amplitude of defect depth 1/2T, length 15cm



T2 signal amplitude of defect depth 1/4T, defect length 15cm

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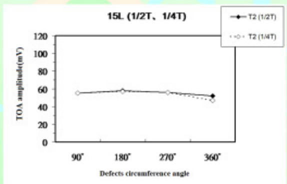
Results and discussion



Comparative of T2 signal amplitude of length 15cm

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Results and discussion

- ✶Defects
  - ✚ **Same defect depth ：1/2T,**
  - ✚ **different defect length ：4 cm and 15 cm**
- ✶Compared the signal amplitudes with T1 route

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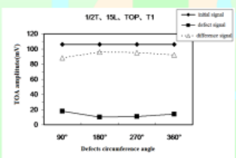
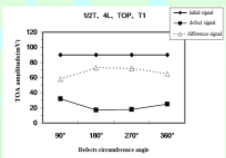
Results and discussion

T1 route experiment



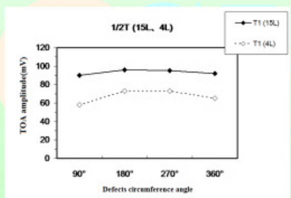
T1 signal amplitude of defect depth 1/2T, length 15cm



T1 signal amplitude of defect depth 1/2T, defect length 4cm

15

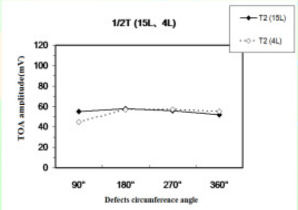
Results and discussion



comparative of T1 signal amplitude of length 15cm, 4cm (1/2T)

16

Results and discussion



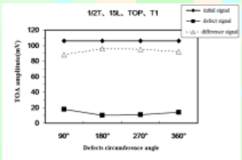
comparative of T2 signal amplitude of length 1/2T (4cm, 15cm)

Conclusion

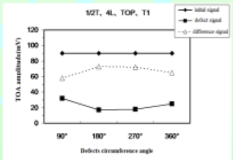
* For the same defect length, the signal amplitude gap between with defect-free location is greater in the 1/2T defect depth than 1/4T defect depth, so we can confirm that signal amplitude increases with defect depth.
* For the same defect depth, the signal amplitude gap between with defect-free location is greater in the 15cm defect length than that in 4cm defect length, so we can confirm that signal amplitude increases with defect length.
* If tube has circumferential 270° and 360° defects, the wave propagation velocity will be affected and the above relationship will be reversed.

Results and discussion

T1 route experiment

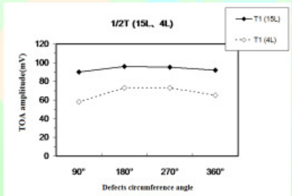


T1 signal amplitude of defect depth 1/2T, length 15cm



T1 signal amplitude of defect depth 1/2T, defect length 4cm

Results and discussion



comparative of T1 signal amplitude of length 15cm, 4cm (1/2T)

二、 本次法國研討會投稿論文(全文)

Study of Electro Magnetic Acoustic Transducer to detect flaw in pipeline

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Abstract

In addition to a considerable amount of machinery and equipment, intricacies of the transmission pipeline exist in Petrochemical plants. Long term corrosion may lead to pipeline thinning and rupture, causing serious safety concerns. With the advances in non-destructive testing technology, more rapid and long-range ultrasonic detection techniques are often used for pipeline inspection, EMAT without coupling to detect, it is a non-contact ultrasonic, suitable for detecting elevated temperature or roughened e surface of line. In this study, we prepared artificial defects in pipeline for Electro Magnetic Acoustic Transducer Testing (EMAT) to survey the relationship between the defect location, sizing and the EMAT signal. It was found that the signal amplitude of EMAT exhibited greater signal attenuation with larger defect depth and length.. In addition, with bigger flat hole diameter, greater amplitude attenuation was obtained. In summary, signal amplitude attenuation of EMAT was affected by the defect depth, defect length and the hole diameter and size.

Keywords: EMAT, Artificial Defect, NDT, Ultrasonic Testing.

I. Introduction

In the oil, gas, chemical transporting process, pipeline plays an important role, it transports many dangerous substances. Pipeline damages account for the highest proportion of mechanical failures in the petrochemical industry[1-7]. Chemical substance and gases easily lead to pipeline corrosion; defect or holes on the pipeline may lead to leakage ,fire, or even explosion. Pipeline has many corrosion types, such as void or cavity is the most serious defect of pipeline.,Iit will increase the risk of leakage. For this reason, we must find an effective detection method, such as electromagnetic acoustic transducer testing (EMAT) technology has been developed to detect outside surface corrosion of steel wire. EMAT have many advantage, such as it can quickly scan, work at high temperature environment, and scan non-contact to objects. In order to survey EMAT sensitivity on flaw size detection, we prepared many different flaw sizes in sample pipelines, investigate their effects on the EMAT detection results.

In this study, we compare four different type detects:

(1) The same defect length, but has different defect depth.
(2) The same defect depth, but has different defect length.
(3) The detect signal affect by the defect location.

II. Experiment principle

Generate electromagnetic ultrasonic principle

Electro Magnetic Acoustic Transducer is composed of a set of permanent magnets and the receiving coil [8]. EMATs can generate ultrasonic power in two different ways: for non-ferromagnetic material, EMAT generated ultrasonic by Lorentz force; for ferromagnetic materials, EMAT generated ultrasonic by magnetostrictive force [3, 6]. EMATs can also generate Lamb wave, Shear Horizontal Polarization (SH), Shear Vertical Polarization (SV) [4]. The EMATs generated wave mode type was affect by direction of applied magnetic field, coil geometry and electromagnetic frequency. This study applied magnetostrictive force to generate Lamb wave on carbon steel pipe [9-11].

III. Experimental Methods

1. Materials Processing

In this study, we prepared four steel pipe (ASTM A106), tube diameter is 114 mm, wall thickness is 6.5 mm, circumference is 360 mm. Defects was made by milling machine, tube defects depth are 1/2T and 1/4T respectively, T is wall thickness. There are five defect length is 15cm, tube defects depth of 1/2T, shown in Figure 1. The defect length is 4 cm, shown in Figure 2. Defect circumferential angle are 90°、180°、270° and 360° respectively, shown in Figure 3. The tube defect depth is 1/2T.

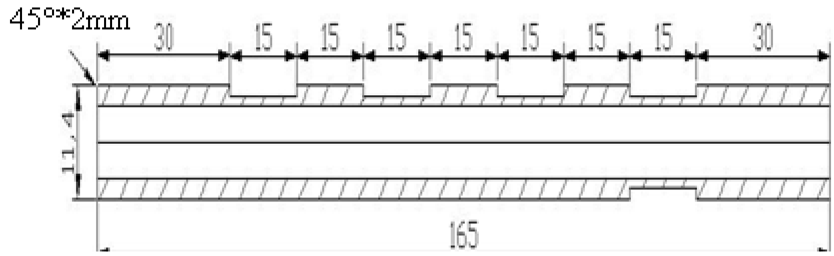

Figure 1 testing tube with defect length 15cm

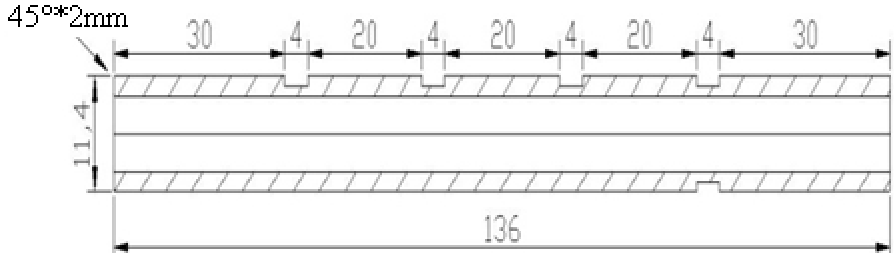

Figure 2 testing tube with defect length 4cm

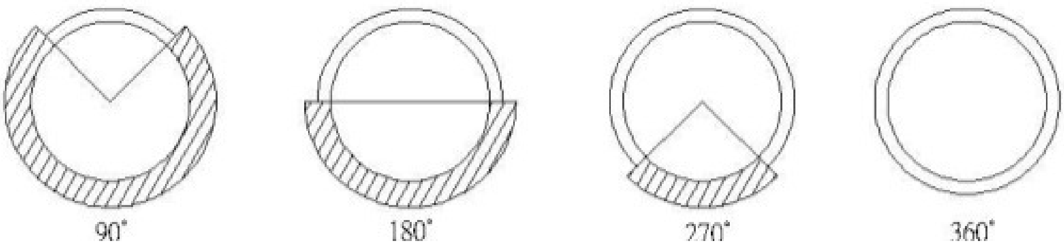

Figure 3 tube defect have four circumferential angle

2. Detection method

In this study, we used EMAT Scans software 'Do Runs mode' to show the defect signal, the 'Do Runs mode' apply the phase, amplitude scan recording pattern, shown in Figure 4. The excitation coil T1 and T2 with two kinds of Lamb wave transmission to the receiving coil, T1 is around the tube top, T2 is around the tube from bottom to top.

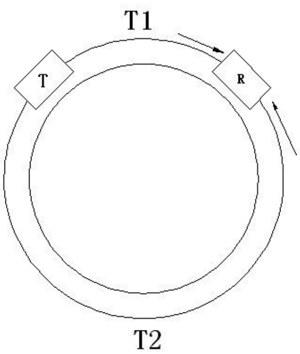

Figure 4 EMAT wave delivery route

IV. Results and discussion

1. Same defect length, different defect depth

Tube defects depth are 1/2T and 1/4T, defect length is 15 cm, compared the signal amplitude of 1/2T and 1/4T defect depth each other.

(1) T1 route experiment

Table 1 and Table 2 is data sheet of 1/2T and 1/4T defect depth, 15cm defect length respectively, T1 measure defects from the tube top. Figure 5 shows the T1 signal amplitude of 1/2T defect depth, defect length is 15 cm. Figure 7 shown the T1 signal amplitude of defect depth 1/4T, defect length 15 cm.

Table 1 Data sheet of tube defect depth 1/2T, length 15cm, top, T1(unit: mV)

Defect angle	90°	180°	270°	360°
Defect signal amplitude	16	10	11	14
Signal amplitude difference	90	96	95	92

Note: tube without defect initial amplitude: 106 mV

Table 2 Data sheet of tube defect depth 1/4T, defect length 15cm, top, T1 (unit: mV)

Defect angle	90°	180°	270°	360°
Defect signal amplitude	25	15	16	25
Signal amplitude difference	45	56	55	46

Note: tube without defect initial amplitude: 71 mV

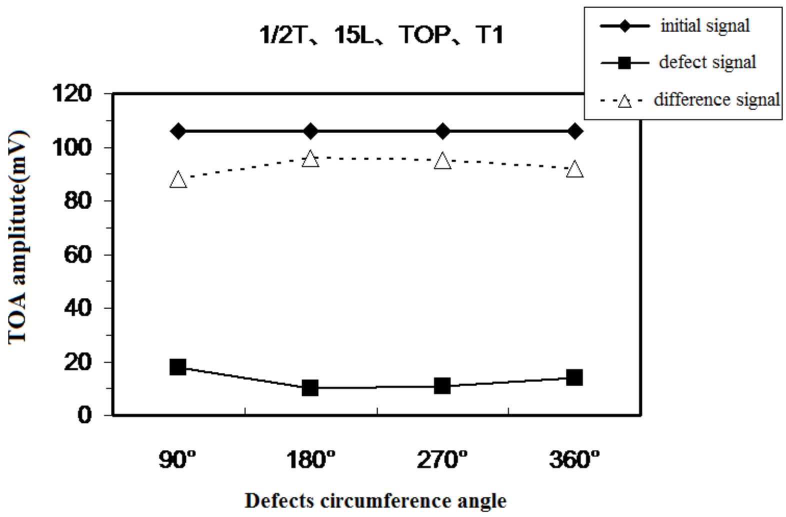

Figure 5 T1 signal amplitude of defect depth 1/2T, length 15cm

From Figure 6 and Figure 7, we found that at 90° and 180° defect angle, the amplitude of the defect signal decline, but at 270° and 360° defect angle, the amplitude of the defect signal rise may be affect by wave propagation velocity changes. Figure 8 shows the signal amplitude difference of 1/2T defect depth is greater than 1/4 T, it can be confident, that the signal amplitude affect by defect depth by T1 mode.

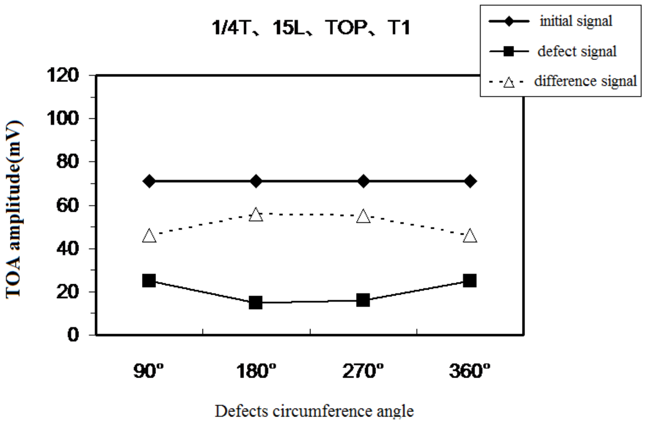

Figure 6 T1 signal amplitude of defect depth 1/4T, defect length 15cm

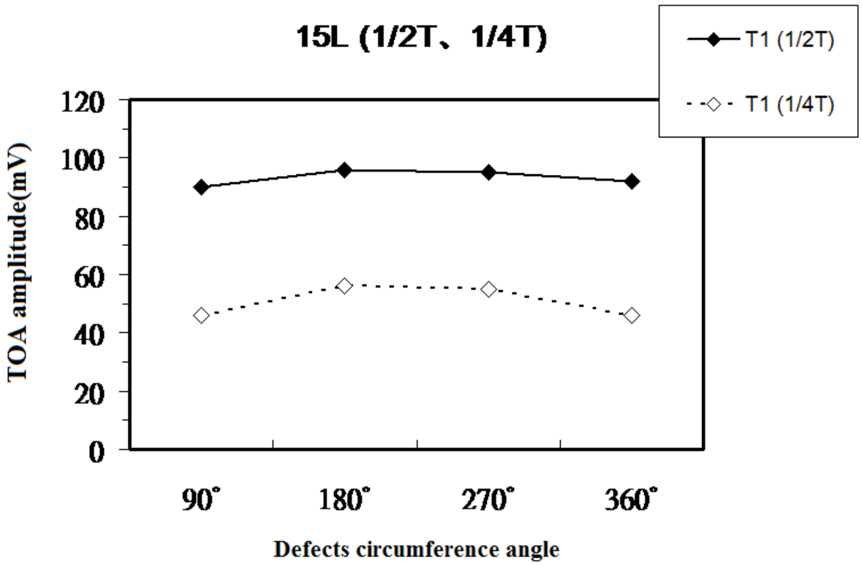

Figure 7 comparative of T1 signal amplitude of length 15cm (1/2T, 1/4T)

(2) T2 route experiment

Table 3 and Table 4 is data sheet of 1/2T and 1/4T, T2 measure defects from the tube bottom. Figure 9 shows the T2 signal amplitude 1/2T defect depth, defect length 15 cm. Figure 10 shows the T2 signal amplitude of 1/4T defect depth, defect length 15 cm.

Table 3 Data sheet of tube defect depth 1/2T, length 15cm, bottom, T2 (unit: mV)

Defect angle	90°	180°	270°	360°
Defect signal amplitude	15	12	14	18
Signal amplitude difference	55	58	56	52

Note: tube without defect initial amplitude: 70 mV

Table 4 defect depth 1 / 4T, defect length 15cm, bottom, T2 (unit: mV)

Defect angle	90°	180°	270°	360°
Defect signal amplitude	15	13	14	23
Signal amplitude difference	55	57	56	47

Note: tube without defect initial amplitude: 70 mV

From Figures 8 and 9, we a found that at 90° and 180° defect angle, the amplitude of the defect signal decline, bur at 270° and 360° defect angle, the amplitude of the defect signal rise may be affect by wave propagation velocity changes. Figure 11 shows the signal amplitude difference of 1/2T defect depth is very close to 1/4 T, but at 360° circumferential, 1/2T amplitude signal slightly higher than 1/4T defect depth. It can be confident, that the signal amplitude affect by defect depth by T2 mode.

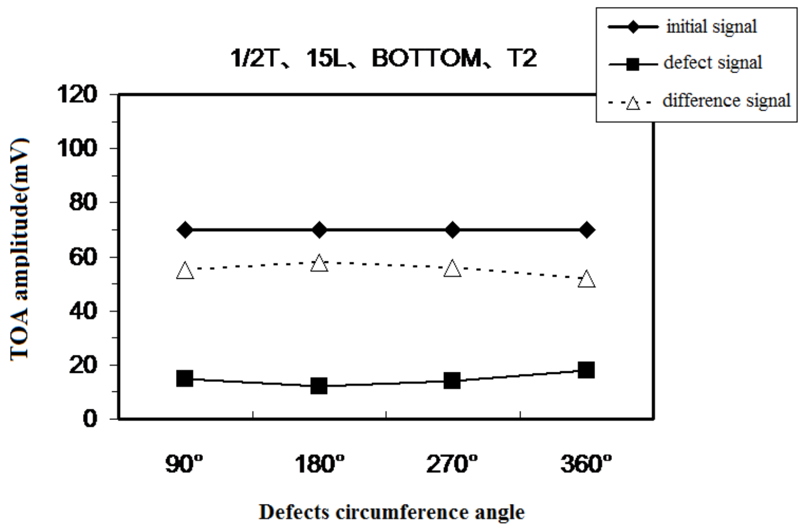

Figure 8 T2 signal amplitude of defect depth 1/2T, length 15cm

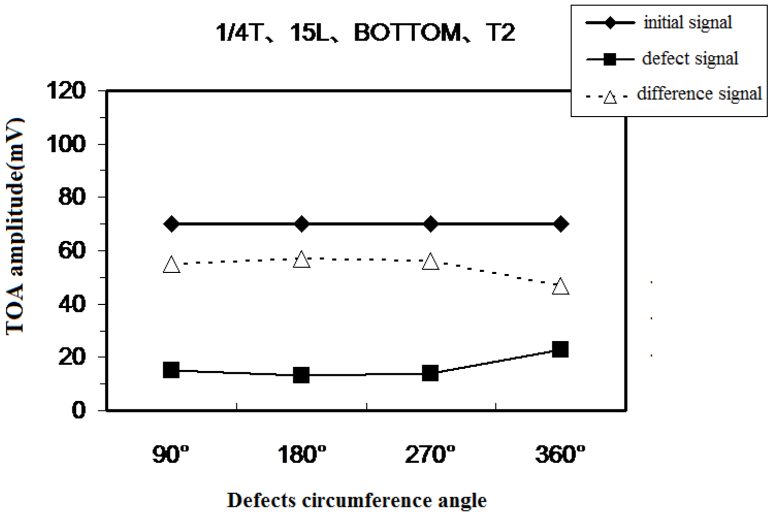

Figure 9 T2 signal amplitude of defect depth 1/4T, length 15cm

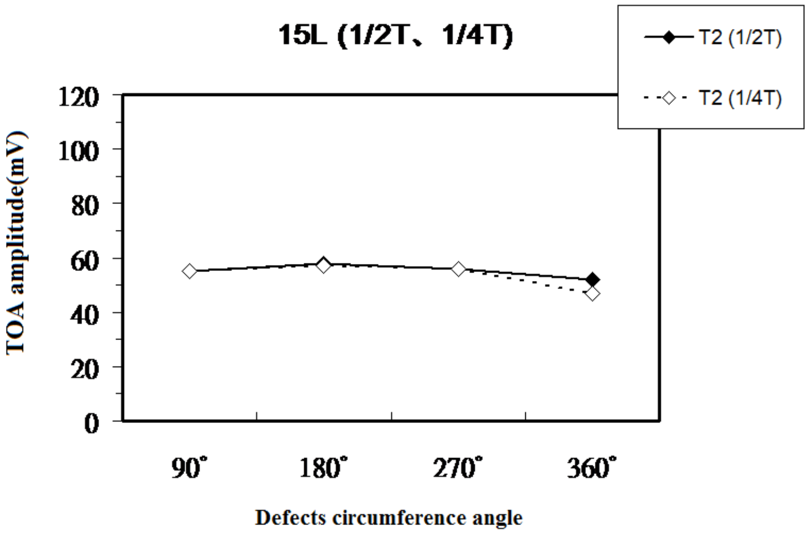

Figure 10 comparative of l T2 signal amplitude of length 15cm (1/2T, 1/4T)

2. Same defect depth, different defect length

(1) T1 route experiment

Table 1 and Table 5 is data sheet of 15 cm and 4 cm defect length, 1/2T defect depth respectively, T1 measurements for defects in the tube top. Figure 5 shows the T1 signal amplitude of 1/2T, defect length 15 cm. Figure 11 shown the T1 signal amplitude of defect depth 1/2T, defect length 4 cm.

Table 1 Data sheet of tube defect depth 1/2T, length 15cm, top, T1(unit: mV)

Defect angle	90°	180°	270°	360°
Defect signal amplitude	16	10	11	14

Signal amplitude difference	90	96	95	92

Note: tube without defect initial amplitude: 106 mV

Table 5 Data sheet of tube defect depth 1/4T, defect length 4cm, top, T1 (unit: mV)

Defect angle	90°	180°	270°	360°
Defect signal amplitude	32	17	18	25
Signal amplitude difference	58	73	73	65

Note: tube without defect initial amplitude: 90 mV

From Figure 5 and Figure 11, we found that the amplitude at 180°, 270°, 360° defect angle is very close. Figure 11 shows defect signal amplitude of 90° than the 180°, 270°, 360°. Figure 12 shows that the signal amplitude difference between without defect and 15 defect length, greater than 4 cm defect length. It can be s confident, that the signal amplitude affect by defect length by T1 mode..

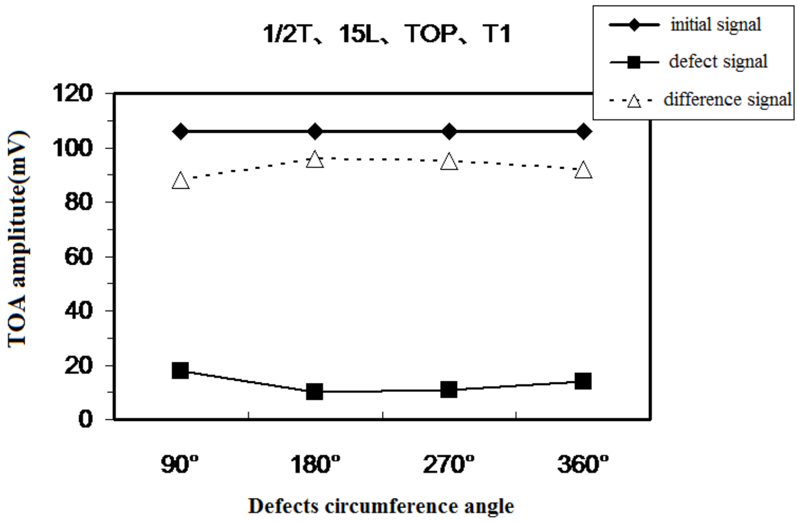

Figure 5 T1 signal amplitude of defect depth 1/2T, length 15cm

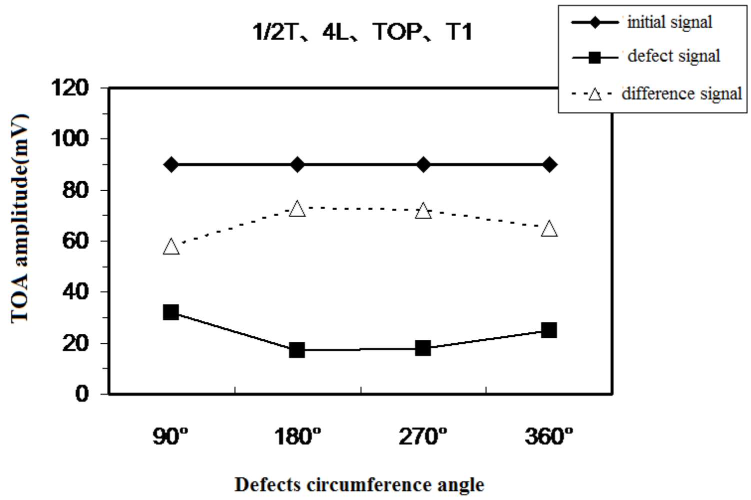

Figure 11 T1 signal amplitude of defect depth 1/2T, defect length 4cm

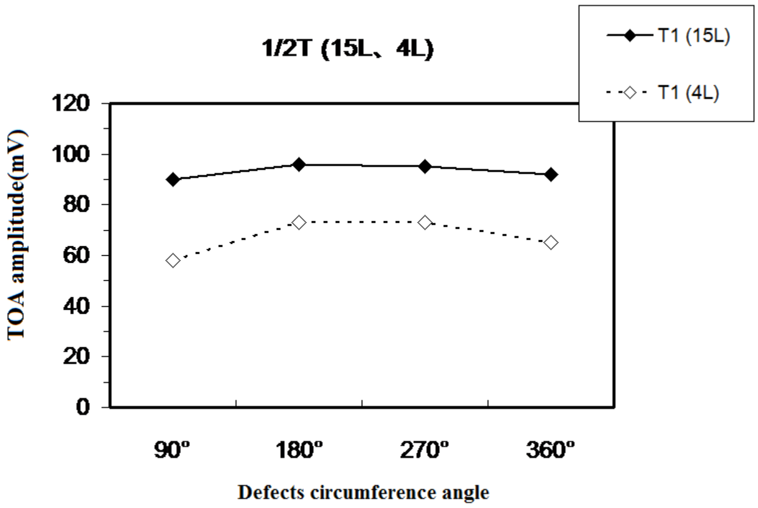

Figure 12 comparative of l T1 signal amplitude of length 15cm, 4cm (1/2T)

(2) T2 route experiment

Table 3 and Table 6 is data sheet of 15 cm and 4 cm, T2 measurements defects from tube bottom. Figure 8 shows the T2 signal amplitude 1/2T defect depth, defect length 15 cm. Figure 13 shows the T2 signal amplitude of 1/2T defect depth, defect length 4 cm.

Table 3 Data sheet of tube defect depth 1/2T, length 15cm, bottom, T2 (unit: mV)

Defect angle	90°	180°	270°	360°
Defect signal amplitude	15	12	14	18
Signal amplitude difference	55	58	56	52

Note: tube without defect initial amplitude: 71 mV

Table 6 Data sheet of tube defect depth 1/2T, length 4cm, bottom, T2 (unit: mV)

Defect angle	90°	180°	270°	360°

Defect signal amplitude	30	18	18	20
Signal amplitude difference	45	57	57	55

Note: tube without defect initial amplitude: 75 mV

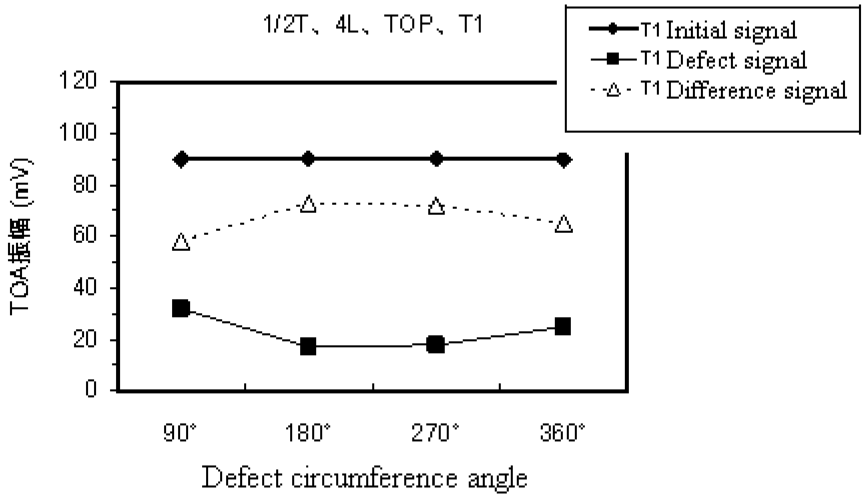

Figure 12 T1 signal amplitude of defect depth 1/2T, defect length 4cm

From Figure 13, we found that signal amplitude of 4cm defect length at 90° defect angle is higher than 180°, 270°, 360° angle, the defect length of 4 cm, 180°, 270°, 360°the defect signal amplitude is very close. Figure 14 defects angle of 90° , 15 cm signal amplitude difference higher than 4 cm, but the amplitude of the other three angles are very close to the difference signal. It can be confident, that the signal amplitude affect by defect length.

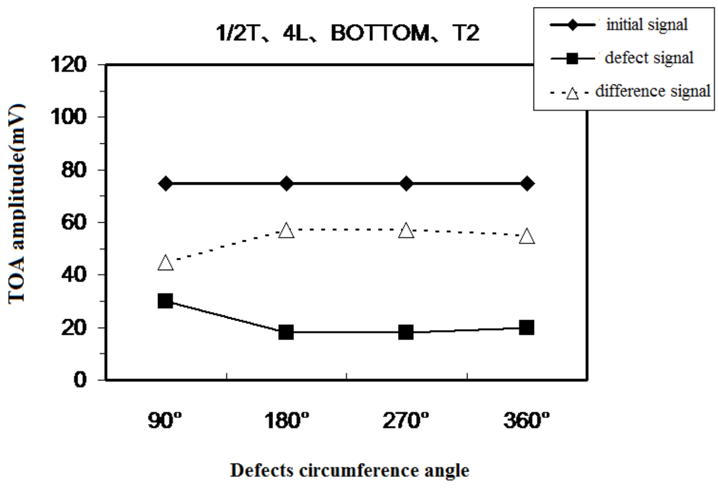

Figure 13 T2 signal amplitude of defect depth 1/2T, defect length 4cm

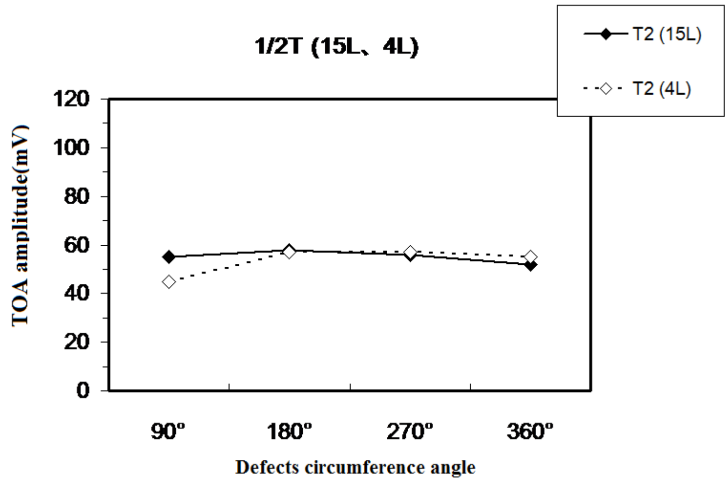

Figure 14 comparative of l T2 signal amplitude of length 1/2T (4cm, 15cm)

Comparing detect defect T1 and T2 signal amplitude from top or from bottom
Table 7 and Table 8 is data sheet of the defect depth1/2T, defect length 15cm. Table 9 and Table 10 for defect depth 1/4T, defect length 15cm. Tables 11 and Tables 12 for the defect depth 1/2T, defect length 4cm, top and bottom measure defect amplitude signal data shown in Figure 15 to Figure 20.
Because the EMAT sensor scanned to the defect-free place, so that the Tables 7 to 11 cannot be show part angle. Because T1 and T2 distance is very close, so resulting in T1 and T2 defects signal amplitude is similar in Figure 16 to Figure 20.

Table 7 Data sheet of tube defect depth 1/2T, length 15cm, top (unit: mV)

	Defect angle	90°	180°	270°	360°
T1		16	10	11	14
T2		X	13	15	20

X: unable to measure

Table 8 Data sheet of tube defect depth 1/2T, length 15cm, bottom (unit: mV)

	Defect angle	90°	180°	270°	360°
T1		X	X	15	19
T2		15	12	14	18

Table 9 Data sheet of tube defect depth 1/4T, length 15cm, top (unit: mV)

Defect angle	90°	180°	270°	360°
T1	25	15	16	25
T2	X	15	16	25

Table 10 Data sheet of tube defect depth 1/4T, length 15cm, bottom (unit: mV)

Defect angle	90°	180°	270°	360°
T1	X	X	18	25
T2	15	13	14	23

Table 11 Data sheet of tube defect depth 1/2T, length 4cm, top (unit: mV)

Defect angle	90°	180°	270°	360°
T1	32	17	18	25
T2	X	17	18	25

Table 12 Data sheet of tube defect depth 1/2T, length 4cm, bottom (unit: mV)

Defect angle	90°	180°	270°	360°
T1	X	X	20	25
T2	30	12	18	20

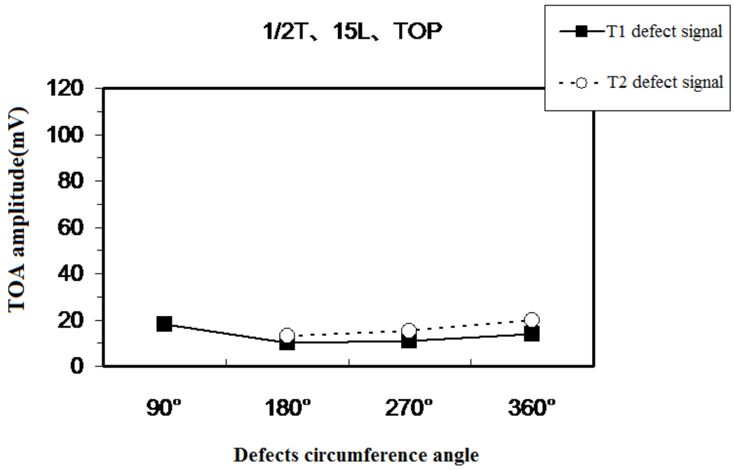

Figure 15 T1 and T2 signal amplitude defects1/2T, defect length 15cm

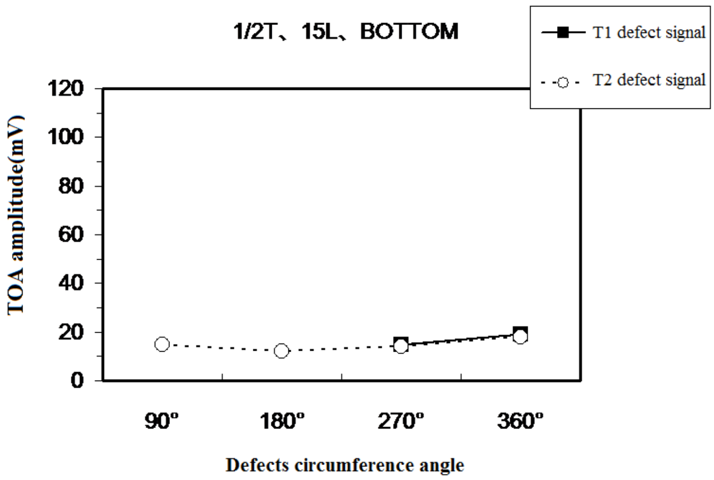

Figure 16 T1 and T2 signal amplitude defects1/2T, defect length 15cm

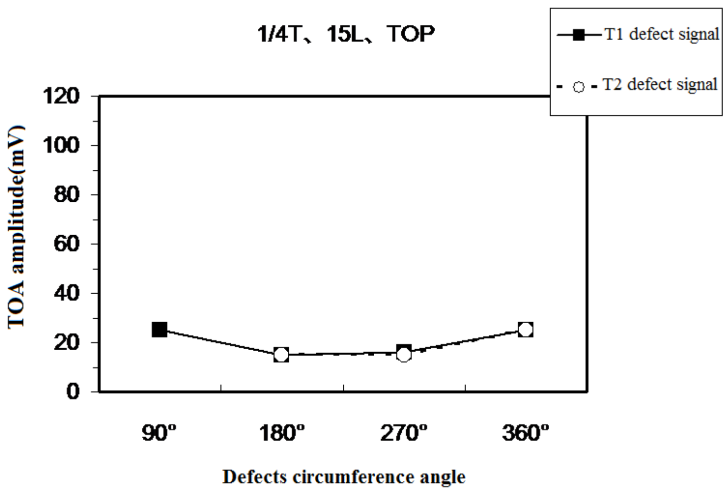

Figure 17 T1 and T2 signal amplitude defects1/4T, defect length 15cm

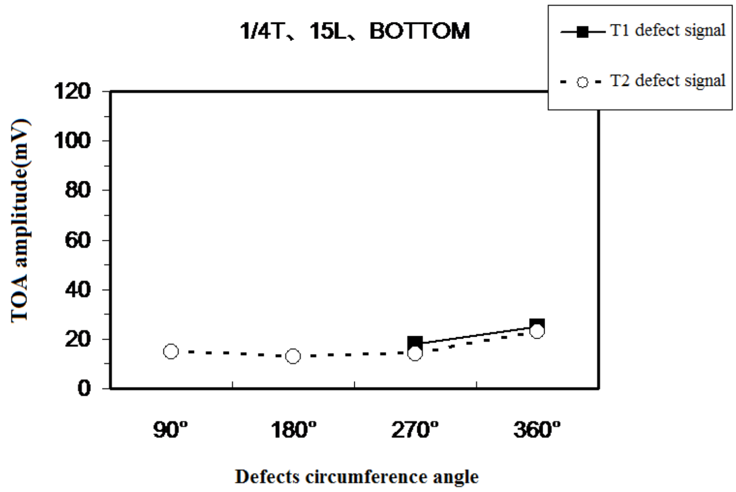

Figure 18 T1 and T2 signal amplitude defects1/4T, defect length 15cm

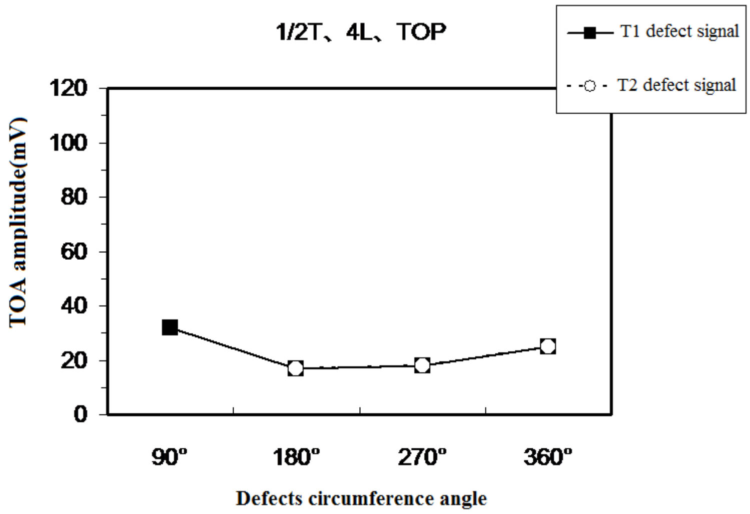

Figure 19 T1 and T2 signal amplitude defects1/2T, defect length 4cm

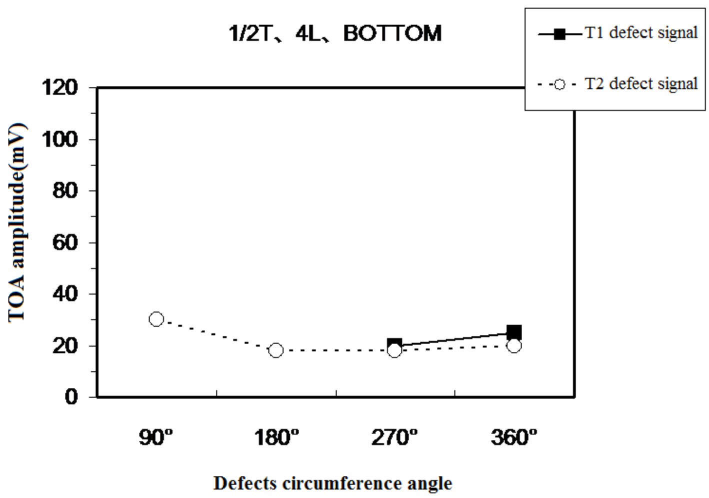

Figure 20 T1 and T2 signal amplitude defects1/2T, defect length 4cm,

V. Conclusion

In this study, we applied EMAT to investigated pipeline defect detection. the following conclusions are obtained

1. For the same defect length, the signal amplitude gap between with defect-free location is greater in the 1/2T defect depth than 1/4T defect depth, so we can confirm that signal amplitude increases with defect depth.
2. For the same defect depth, the signal amplitude gap between with defect-free location is greater in the 15cm defect length than that in 4cm defect length, so we can confirm that signal amplitude increases with defect length.
3. If tube has circumferential 270° and 360° defects, the wave propagation velocity will be affected and the above relationship will be reversed.

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