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CAPABILITY OF EMAT SYSTEM FOR STEEL CYLINDER FLAW DETECTION

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by

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16. Abstract

An electromagnetic acoustic transducer (EMAT)-ultrasonic guided wave inspection system, developed by Tektrend Inc. of Montreal, is currently being used for scanning the sidewall portions of industrial high-pressure gas cylinders. Unlike conventional ultrasonic scanning, the ultrasonic guided waves allow inspection of bends and hidden parts of cylindrical structures. The technology may therefore be adaptable to the inspection of cylinder ends, an area that cannot be easily inspected using ultrasonic scanning.

The ability of the EMAT-ultrasonic guided waves to detect crack-like defects in the sidewalls and ends of cylinders was investigated. Fatigue cracks were generated in the sidewalls of cylinders by hydraulic pressure cycling. The study included flaws in necks of cylinders that had been removed from service. These flaws had been detected by manual ultrasonic inspection.

The EMAT-ultrasonic guided wave method had limited success in detecting fatigue cracks in the sidewalls of the cylinders, and could not detect the neck flaw in another cylinder. The detection problem can likely be attributed to the transducer orientation used for the introduction of the guided waves.

The research team recommended further development of the inspection technique before it could be applied to the detection of longitudinally oriented flaws in the ends of cylinders.

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16. Résumé

Un système d'inspection par transduction électromagnéto-acoustique (EMAT) à faisceau ultrasonore focalisé, étudié par la société Tektrend Inc., de Montréal, est mis à l'essai pour l'auscultation du corps des bouteilles de gaz sous pression industrielles. Contrairement à l'auscultation ultrasonore classique, cette nouvelle technique permet d'examiner les bouteilles cylindriques aux angles et dans les parties jusqu'ici inaccessibles. En d'autres termes, elle pourra servir à inspecter les bouts des bouteilles, un endroit difficile à ausculter par la technique ultrasonore classique.

Les chercheurs ont étudié l'aptitude du nouveau système EMAT à faisceau ultrasonore focalisé à détecter les fissures dans le corps et les bouts des bouteilles. Le corps des bouteilles auscultées comportait des fissures de fatigue engendrées par variation cyclique d'une charge hydraulique. Les essais de détection ont également visé le col de bouteilles retirées du service dont on savait qu'elles comportaient des fissures grâce à une auscultation ultrasonore classique.

La technique EMAT à faisceau ultrasonore focalisé a affiché un faible taux de réussite quant à la détection des fissures de fatigue dans le corps des bouteilles et elle s'est avérée incapable de détecter le défaut que présentait le col d'une autre bouteille. Les difficultés de détection sont sans doute attribuables à l'orientation du transducteur utilisé pour l'émission du faisceau ultrasonore focalisé.

L'équipe de recherche a recommandé de pousser plus avant le développement de la technique avant de vérifier son aptitude à détecter les fissures longitudinales dans les bouts des bouteilles.

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EXECUTIVE SUMMARY

High-pressure steel gas cylinders used for the storage of compressed natural gas (CNG) as a vehicle fuel are currently being non-destructively inspected using conventional ultrasonic scanning techniques. The cylinder sidewalls are scanned using an automated system, while the changing contours of the cylinder ends require the use of manual ultrasonic inspection. The manual portion of the inspection increases the time and cost of inspection, and relies on human skills of observation and interpretation of indications.

Tektrend Inc. of Montreal has developed a method of ultrasonic guided wave inspection using electromagnetic acoustic transducer (EMAT) technology for the inspection of steel high-pressure cylinders used for industrial gas service. Automated systems for the inspection of cylinder sidewalls are commercially available. Unlike conventional ultrasonic scanning, the guided waves allow inspection of bends and hidden parts of cylindrical structures. It may therefore be possible to adapt this technology for the automated inspection of CNG cylinder ends.

A program to evaluate the ability of the EMAT-ultrasonic guided waves to detect crack-like defects was initiated. Testing was performed on cylinders with marked service pressures of either 3,600 psi or 4,000 psi, used for the ground storage of CNG at filling stations. Powertech Labs used conventional ultrasonic inspection methods to identify ground storage cylinders with flaws in either the sidewall or end regions. Typically, the flaws oriented in the longitudinal (axial) direction along the length of the cylinder, as a result of the cylinder manufacturing process.

Several of the flawed cylinders were hydraulically pressure cycled in the approximate range of 10 percent to 125 percent of service pressure in an attempt to increase the size of the flaws by initiating the growth of fatigue cracks. The pressure cycling had limited success in increasing the initial flaw size, since a fatigue crack would often initiate elsewhere on the internal sidewall surface and grow through-wall. The flawed cylinders, along with several calibration samples containing machined flaws, were supplied to Tektrend Inc. for evaluation using the EMAT-ultrasonic guided wave system.

As reported by Tektrend, the EMAT-ultrasonic guided wave method apparently had only limited success in detecting the longitudinally oriented fatigue cracks in the sidewalls of the cylinders. The method also could not detect the longitudinally oriented flaws in the neck ends of cylinders. It was suspected that the EMAT transducer orientation (longitudinal versus transverse) contributed to the detection problem.

Further development would be required before the inspection technique could be applied to the detection of longitudinally oriented flaws in the ends of cylinders.

SOMMAIRE

L'inspection des bouteilles en acier servant au stockage haute pression de gaz naturel comprimé à bord de véhicules mus par ce combustible se fait à l'heure actuelle selon une technique éprouvée de contrôle non destructif aux ultrasons. L'auscultation ultrasonore des bouteilles se fait au moyen d'un dispositif automatisé, mais le contrôle des bouts à courbure variable n'est possible qu'à l'aide d'un système manuel. La partie manuelle de l'inspection est onéreuse en temps et en argent et ses résultats sont largement tributaires de la compétence sur le plan de l'observation et de l'interprétation des lectures.

La société Tektrend Inc., de Montréal, a étudié une technique d'auscultation ultrasonore à faisceau focalisé dérivée de la technologie de la transduction électromagnéto-acoustique (EMAT pour electromagnetic acoustic transducer) et applicable à l'inspection des bouteilles en acier servant au stockage haute pression de gaz industriels. Il existe déjà sur le marché des systèmes automatisés d'inspection du corps des bouteilles, mais la technique à faisceau focalisé présente par rapport à la méthode classique d'auscultation ultrasonore l'avantage de permettre l'inspection des bouteilles aux angles et dans les endroits jusqu'ici inaccessibles. Et il est peut-être possible d'adapter cette technologie à l'inspection automatisée des bouts des bouteilles de GNC.

Aussi a-t-on entrepris un programme visant à évaluer l'aptitude de la technique d'inspection par transduction électromagnéto-acoustique (EMAT) à faisceau ultrasonore focalisé à détecter les fissures dans les bouteilles de gaz naturel. Les essais ont été réalisés sur des bouteilles à pression de service nominale de 3 600 lb/po^2 ou de 4 000 lb/po^2, utilisées pour le stockage de GNC dans les stations-service. Powertech Labs s'est servie de techniques classiques d'auscultation ultrasonore pour repérer des bouteilles dont le corps ou les bouts comportaient des fissures. De façon générale, les fissures détectées avaient une orientation longitudinale, c'est-à-dire généralement parallèle à l'axe longitudinal de la bouteille, qui peut être reliée au procédé de fabrication des bouteilles.

Powertech Labs a soumis plusieurs de ces bouteilles à une variation cyclique de charge hydraulique entre environ 10 et 125 pour cent de la pression de service afin d'agrandir les défauts existants par amorce de fissures de fatigue. Cette méthode n'a pas donné les résultats escomptés puisque, plutôt que d'agrandir le défaut existant, elle donnait souvent lieu à une fissuration par fatigue ailleurs sur la face intérieure du corps, la fissure de fatigue se propageant sur toute l'épaisseur de la paroi. Les bouteilles affaiblies ainsi que plusieurs éprouvettes d'étalonnage comportant des défauts usinés ont été remises à Tektrend Inc. pour les fins de l'évaluation de la technique de détection électromagnéto-acoustique (EMAT) à faisceau ultrasonore focalisé.

Selon le rapport fourni par Tektrend, la technique EMAT à faisceau ultrasonore focalisé a affiché un faible taux de réussite quant à la détection des fissures de fatigue longitudinales dans le corps des bouteilles et elle s'est avérée incapable de détecter les fissures longitudinales dans le col des bouteilles. Les chercheurs pensent que les difficultés de

détection peuvent être liées à l'orientation (longitudinale plutôt que transversale) du transducteur utilisé pour l'émission du faisceau ultrasonore focalisé.

D'autres travaux de recherche seraient nécessaires avant que cette technique d'inspection puisse servir à la détection des fissures longitudinales dans les bouts des bouteilles.

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1. BACKGROUND

High pressure cylinders used for the transportation of compressed gas typically require a periodic retest using hydrostatic pressure. For steel and aluminum cylinders, ultrasonic scanning has recently been introduced in several countries as an alternative retest method. While hydrostatic testing can provide an indication of gross defects in cylinders, ultrasonic inspection has the ability to detect defects at an earlier stage of development. Many standards now require ultrasonic scanning of cylinder sidewalls during production, to ensure the absence of defects that could result in premature failure.

A limitation associated with the conventional ultrasonic C-scan inspection method is the difficulty in performing automated scanning of the cylinder ends. Automation is prevented by the difficulty in orienting the transducers to match the non-parallel contours of the inside and outside surfaces of cylinder ends. As a result, cylinder ends must be ultrasonically inspected manually, requiring considerable labour and time.

2. EMAT TECHNOLOGY

Electromagnetic Acoustic Transducers (EMATs) are ideal for the on-line inspection of steel structures, because they provide a noncontacting means for generating and detecting ultrasound in metals. EMAT technology has been adapted by Tektrend International Inc. to inspect the sidewalls of cylinders in a manner similar to that used by ultrasonic scanning systems. While not as accurate as ultrasonic measurements for defining relatively small defects, the guided waves generated by an EMAT system offer the capability of inspecting around bends in structures, such as the ends of cylinders. A description of the system is provided in Appendix A.

3. RESEARCH APPROACH

The ability of Tektrend's EMAT system to detect flaws in steel cylinders was evaluated by providing steel cylinders containing flaws in the sidewalls and the head region. The high pressure cylinders were of TC-3AAM design, measuring approximately 228 mm (9 inches) in diameter and 158 mm (62 inches) in length, with a water volume of 50 L.

In one cylinder, a neck flaw measuring about 5 percent of the wall thickness and 25 mm long was detected using manual ultrasonic inspection. The cylinder was then hydraulically pressure cycled from 10 percent of the service pressure up to 125 percent of the service pressure in an attempt to enlarge the pre-existing neck flaw. It was found that instead of enlarging the neck flaw, the pressure cycling caused a fatigue crack to develop in the cylinder sidewall.

Pressure cycling typically causes fatigue cracks to initiate on the internal surface of cylinders in the sidewall region. This happens because the hoop stresses in the sidewall of cylinder designs are significantly greater than the stresses existing in the dome ends of cylinders. The greater hoop stresses also result in the fatigue cracks being oriented in the axial (longitudinal) direction. Fatigue cracks only initiate in the neck or base portion of cylinders if there is a pre-existing flaw of significant size. The pre-existing neck flaw detected in the cylinder could not have been a fatigue crack initiated in service, otherwise it would have continued to grow during hydraulic pressure cycling. Instead, the flaw must have been caused by pre-existing folds introduced during cylinder manufacture.

Several other cylinders were hydraulically pressure cycled to generate fatigue cracks. The following cylinders were then supplied to Tektrend for evaluation:

Serial Number	Service Pressure (psi)	Nature of Flaw
5848407	3,600	neck flaw of 5% depth and 25 mm length, also through-wall fatigue crack in sidewall
5980810	3,600	pressure cycled, but no leak occurred
6001583	4,000	through-wall fatigue crack in sidewall
6001607	4,000	no flaws

In addition, a cylinder neck end, containing machined neck flaws oriented in the axial direction, and a cylinder base end, containing machined flaws oriented in the circumferential direction, were provided for calibration purposes. The locations and types of flaws, if any, were not marked on the cylinders.

4. RESULTS

The results of inspecting the four cylinders using guided waves and EMAT are detailed in the TISEC/Tektrend report in Appendix B.

5. DISCUSSION

The report in Appendix B indicates that the EMAT probe unit was used to scan the cylinders in the longitudinal direction only. The EMAT system detected a sidewall flaw in cylinder s/n 5980810. This cylinder had been pressure cycled, but a through-wall fatigue crack had not been developed. The pressure cycling had possibly created a smaller fatigue crack in the sidewall, but the exact nature of the defect detected by the EMAT system requires verification.

The EMAT system did not detect the through-wall fatigue cracks in the sidewalls of the other cylinders (cylinder s/n 6001583 and s/n 5848407). Since the through-wall fatigue cracks were oriented in the axial direction, it was likely that the cracks would avoid detection if the guided waves were only applied in the same direction during the scanning of the cylinders.

The EMAT system was also unable to detect the neck flaw on either the calibration standard (10% depth and 25 mm length), or on cylinder s/n 5848407. Again, this is probably because the neck flaws occur oriented in the axial direction, which is parallel to the direction of the guided waves used for scanning. Detection would probably require the EMAT transducers to be oriented to generate guided waves in the circumferential direction over the neck end of the cylinder.

6. CONCLUSIONS

Using the EMAT-ultrasonic guided wave method to scan in the circumferential direction such that the guided waves travel longitudinally along the cylinder limited its ability to detect the longitudinally oriented fatigue cracks in the sidewalls and necks of cylinders.

Further development of the inspection technique is required for it to be applied to the detection of flaws oriented longitudinally in the ends of cylinders.

7. RECOMMENDATIONS

Verify the nature of defects (if any) existing in cylinder s/n 5980810 by ultrasonic inspection.

Adapt the EMAT equipment to scan in the transverse direction on the ends of cylinders, and repeat the inspections.

APPENDIX A

Description of the EMAT System of Guided Waves

(Electronic format not available/
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APPENDIX B

Non-Destructive Evaluation of Compressed Gas Cylinders Using Guided Waves and EMATs

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