Reliability of Manual Ultrasonic Testing

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Abstract Since the introduction of carbon reinforced fibre polymer (CRFP) into primary aircraft structure, there has been a renewed interest in portable devices for in-service inspection. It is foreseen that with less skilled NDT personnel, airlines need to perform more often unscheduled inspections (Bennecer, 2011). Such scanner devices are required to detect and characterise damage which may not be visible on the surface. This motivation can be attributed in part to the success of laboratory based ultrasonic immersion scanning systems for characterising defects in CRFP during material development and production. The extension of these methods to manual ultrasonic testing would offer immense advantages over incumbent methods where information available to the operator will be greatly enhanced by the production of multi-dimensional surface scans.

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Keywords: Reliability, Manual Ultrasonic Testing.

1. Introduction

Manual ultrasonic non destructive testing (MUT) generally provides cost-effective and high sensitivity to flaw detection whenever short distances and/or practical access to pieces under inspection are involved. For example, MUT represents more than 70% of inspections for lengths of 1 m or less (Dau, 1986) (Passi, et al., 1998) (Hands, 1996). Nevertheless, MUT remains dependent on the actual performance of operators in the testing field from calibration of ultrasonic equipment through adhering to inspection procedures to interpretation of results (Stephens, 2000) (Dymkin & Konshina, 2000) (Rummel, 2004) (Fucsok, 1998). Indeed, an extensive inspection programme known as Programme for Inspection for Steel Components (PISC) (Crutzen, et al., 1998) (Crutzen & Nichols, 1996) was initiated in 1974 in order evaluate the inspection procedures applied at that period. It was the first world large scale work of this kind and was split into three parts (Lemaitre & Koblé, 1996) (Lemaitre & Koblé, 1996) (Lemaitre & Koblé, 1996). Motivated by the success of PISC, similar programmes were launched, predominantly to evaluate the reliability of different NDT techniques, notably in the nuclear, aerospace and offshore sectors. Manual inspection almost always occupied a central part. Among the most important works are: NORDTEST, carried out in Scandinavia; NIL of the Dutch Welding Institute (Nederlands Instituut voor Lasterchniek); ICON (Inter

Calibration of Offshore Non-destructive examination), USAF (US Air Force), TIP (Topside Inspection Project) and Sandia trials. In general, these programmes showed the superiority of automatic inspection over manual inspection, mainly when computerised processing techniques such as SAFT (Synthetic Aperture Focusing Technique) are added to the system. More recently Programme for the Assessment of NDT Industry (PANI 3) (McGrath, 2008) for the Health and Safety Executive in the UK, report focusing on the influence of human factors still shows that MUT reliability is sub-optimal.

The NIL study showed a drop in the plateau from 80% for a fully automated UT weld inspection procedure to 50% for the same procedure applied manually. The reliability of MUT inspection, as reported in PANI 3 for instance, established the probability of a given inspector finding a given fault at only 52% +/- 17% under typical test conditions. The UK Health and Safety Executive attributed this poor performance to the complex nature of ultrasonic inspection task. They have explained that human errors arise from poor technique producing scanning errors and errors in interpretation of the echoes on the flaw detector; random measurement errors for example in the measurement of range and probe position; lapses in vigilance; isolated inexplicable errors or blunders. All these sources of error are affected by the motivation of the operator, the difficulty of the inspection and external factors such as time pressure or uncomfortable environments. In addition, the inspection may impose technical demands which are beyond those for which the operator has been trained or qualified. Likewise, a review of research (Jesús Domech Moré, et al., 2007) in this area presented a qualitative evaluation of human reliability on MUT, and identified the complex interaction between 59 Factors that shape Human Performance in MUT. Of these, 12 key ‘Performance Shaping Factors’ represent 80% of the human performance weighting. Consequently, the simple task of manual inspection, as it may appear, encompasses many complex issues affecting the performance of operators during in-service inspection and may become an overwhelmingly daunting task to analyse and redress rationally. Moreover, simple real time systems become tedious when utilised to inspect large pieces such in the aerospace industry which perhaps in some ways explains why the application of MUT is confined and more economically viable in small space applications. There are some potential applications which are still dominated by other non-destructive testing (NDT) techniques such as radiography, often perceived to be expensive and even sometimes hazardous, that MUT is expected to enter should cost-effective high reliability MUT successors exist (ICARUS Consortium, n.d.).

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2. Paradigm Shift

From a human factor perspective it is useful to differentiate between NDT techniques involving hand-to-eye coordination, such as manual UT, and methods relying on image interpretation, such as radiography and automated ultrasonics. To simultaneously move a probe on a surface, whilst ensuring coupling, and observing data in real time on a screen is intrinsically a more difficult process than simply interpreting a data set. This leads to considering a different approach that may bring the problem at hand into a new perspective with those attributes of simple, natural and intuitive human experience. It is generally the case that human factors influencing the reliability of MUT manifest themselves in three main symptoms:

1. Missing the trajectory of the scanning path as described in the required procedure
2. Poor coupling of the ultrasonic transducer probe with the test piece
3. Lapses of vigilance or misinterpretation of scanning results

Some studies (Passi, et al., 1995) have estimated that failure to correctly follow the path of inspection as stated in the procedure reduces the reliability of flaw detection using MUT by 56% whilst 34% of reduction comes from lack of acoustic coupling.

In contrast to the earlier evolution of improving the reliability of MUT consisting of training operators to adhere to written procedures to minimise the effects of human factors, the emerging line of development puts more emphasis on additional devices based on information technology and intelligent inference engines. The ideas for possible aids to increase the probability of defect detection using manual ultrasonic inspections are those which are able to heal its aforementioned ailing symptoms. The devices should be aimed at assisting operators in those areas where they are least well adapted to controlling the quality of the test. It is assumed that the flaw detector is controlled by a computer. Therefore, in order for these ideas to function the probe position must be recorded, either by encoders or other means. Complementary aids envisaged are additional displays such as B-scans and projection into 3 views, plotting a moving probe, complex modelling and a series of interpretation aids. The latter range from monitoring acoustic coupling to estimating defects locations and sizes. Here, artificial neural networks (ANN), which are essentially dynamic pattern recognition systems, enable an architecture well-suited to a decision support and inspection qualification component. The modelling of test pieces is useful and is aimed at either helping to design the inspection procedure or as aids in analysing the recorded signals.

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3. Spatial Positioning Systems

The implementation aspects of such systems (including its physical dimensions, power consumption, cost, packaging, complexity and reliability) are the most critical parameters. In fact, mobility and portability are regarded very important for in-service inspection in the aerospace industry (Bennecer, 2011). There is a range of technologies that can potentially meet these requirements. For example, portable manual scanner arms such as ANDSCAN (Smith, 1995) (Smith, 1995), RapidScan (Sonatest Plc, n.d.) and P-Scan (FORCE Technology, n.d.) (see Figure 1) are highly accurate using encoders with less than 0.1 mm error tolerance in positional information. Acoustic coupling can be monitored by saturating the gain to obtain a fully coloured scan area even at noise level. This ensures whole coverage and defects will become systematically apparent once the gain level is lowered. In addition, storage of scans permits verification that the inspection was performed correctly. However, physical size and particularly cost remain prohibitive to MUT applications. It also comes at a time when the market trend is more towards low-cost devices amid the current global financial crisis. Furthermore, many of these arms are often limited in applications to flat or large surface or require additional information about the geometry of the piece under inspection.

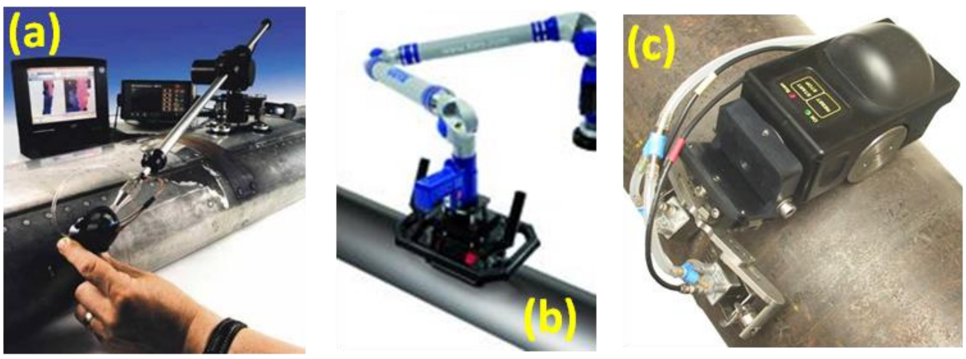

Figure 1: Portable scanners for non-destructive testing applications: (a) R-Theta ANDSCAN (Smith, 1995) (Smith, 1995) (b) RapidScan 3D from Sonatest (Sonatest Plc, n.d.) (c) MWS-5 P-Scan from FORCE Technology (FORCE Technology, n.d.)

Other designs of portable scanners have been reported which use a range of novel positioning systems from acoustic-pulse triangulation (Passi, et al., 1995) (Passi, et al., 1999) to imaging of a probe mounted light using a video camera (NDT Consultants, n.d.) (see Figure 2). The first attempt to realise a measurement universe where receivers sensitive to acoustic emitters was proposed by Lund and Jensen in 1976 in the well-known P-Scan system. Stable working version have been created by D. Sirota in 1981 in USSR and Chang *et al* in 1982 in the USA. Here, the receivers are placed at right angles to one another to create a coordinate reference frame. However, it is fair to say that both systems did not leave the research laboratories. This is due in part to impracticalities of its realisation for in-service inspection. In 1996, Passi *et al* published some work on their I-Sonic system. It is able to track the position of the ultrasonic probe while monitoring the acoustic coupling. This is alongside its capability to determine the probe swivelling to 1° resolution in the -90° to +90° range. Optical tracking systems can also be applied in the same manner. Sensors (e.g. cameras) are mounted at fixed locations. ultrasonic probes to be tracked are marked with passive or active landmarks. Such techniques are known to be susceptible to occlusion problems, albeit, this is overcome by using additional landmarks which incidentally improve the accuracy of pose estimation. These types of position tracking systems nowadays offer highly portable solutions which scale well on any surface geometry although many are prohibitively expensive due to high development costs of relatively complex technologies.

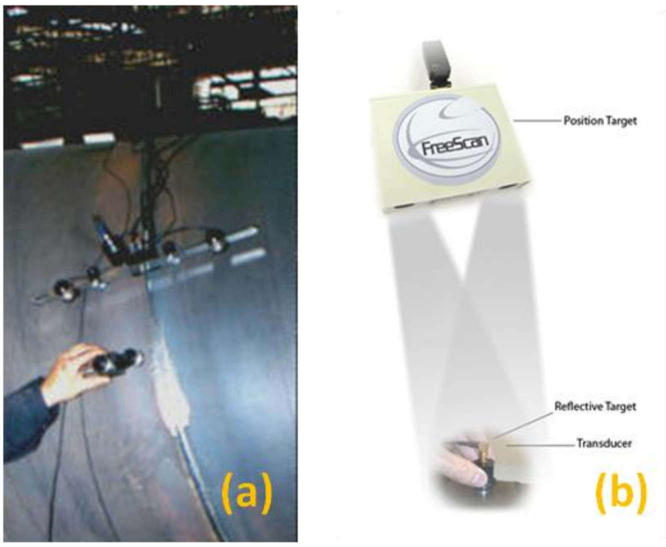

Figure 2: Example of triangulation based positioning systems for non-destructive testing: (a) I-Sonic from Sonotron (Passi, et al., 1999) (b) FreeScan from NDT Consultants (NDT Consultants, n.d.)

4. Discussion and Concluding Remarks

In this paper, I attempt to present a novel approach to circumvent the shortcomings of MUT by adopting an information and communication technology to optimise the reliability of manual non-destructive testing. The motivation in this work is how to offer an appealing path to gradually upgrade MUT operators performance by increasing the probability of defect detection (PoD) whilst keeping the virtues of low cost, simplicity, low power consumption and smaller size. Benefits which will be gained from this approach project are manifold:

- Improved confidence in inspection performance
- Improved safety and quality assurance
- Improved quality of training
- Reduced overall inspection time
- Reduced risk of human errors
- Reduced operating and maintenance costs
- Support inspector training, decision making and procedure compliance
- Provides more natural and intuitive human-machine interaction

The proposed approach must, however, meet some technical as well as commercial requirements. This deliverable, therefore, describes these specifications of its operating environment. *There is still scope for human error, for example in set-up, sensitivity setting, initial calibration of the equipment.*

Some basic components can be easily defined which will then be detailed in the talk:

- Ultrasonic data acquisition system
- Positional data acquisition system
- Graphical user interface
- Storage file
- Bayesian inference engine

While incumbent non-destructive scanners currently available on the market and aimed at increasing the reliability of MUT contain more or less similar components, incorporating the last component (Bayesian inference engine) remains a novelty to the best of our knowledge. The flexibility of this engine being implemented in software will pave the way towards improving the confidence when inspecting more complex and sometimes even challenging test pieces. In addition, it opens new avenues for research to monitor acoustic coupling of the probe with the component under inspection in cases of the back-wall echo becomes completely scattered. During the talk, I will show test blocks used for our case studies, specifications for the hardware and software will be described before the outcomes of test beds are summarised and recommendations are made at the end of this talk.

Finally, a virtual NDT operator training environment is presented. It is aimed to provide additional information to manual operators like surface coverage, acoustic coupling, speed of inspection, defect detection and false indication scores. It is anticipated that similar successes to flight and medical simulators can be achieved in training NDT operators. Also, the advantages and limitations of synthetic environments, including their architecture and key components, are discussed.

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