



How NDT Companies Can Benefit From Human Factors Knowledge

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Abstract. Ultrasonic phased array is, currently, the technology which is being applied as the solution to a lot of inspection problems. The perceived benefits are seen to be worth the outlay on equipment and specialised personnel. Yet, there is a source of knowledge, freely available, which can also deliver immediate benefits, through more reliable inspection results, and consequently increased client confidence, but which is largely ignored by the greater part of the NDT community. This talk will review the latest Human Factors knowledge and provide practical illustrations of how companies can use it to improve their competitive edge.

Introduction

A market forecast for NDT equipment in 2013 [1] highlighted that phased array flaw detectors represent the highest growing segment in the ultrasonic equipment market in terms of revenue and volume. Contributory factors are the trend in replacing radiography with advanced ultrasonics, a better understanding of phased arrays and the work towards the production of standards. The application of phased arrays demands greater knowledge and skills than for conventional ultrasonics and the shortage of certified and skilled operators is leading equipment manufacturers to make the devices easier to use. Despite the outlay on equipment and the cost inherent in training and retaining specialised personnel, the outlay is deemed to be worthwhile to achieve the benefits of a faster and accurate volumetric inspection that provides an image of the object under test.

In QA terms, NDT is a special process. The results of a special process are highly dependent on the control of the process and / or the skill of the operator. Operators, being human, are prone to error, but there is a body of knowledge on Human Factors, built up over the years, which provides information on how to minimise such errors, improve the reliability of the inspection results and hence increase client confidence. The majority of this information is freely available but a large part of the NDT community ignores this resource. This paper will provide a summary of information available and highlight how NDT vendors can take benefit from it.



Why Bother?

In February 2012, during a refuelling outage, a qualified manual ultrasonic inspection of a safe-end dissimilar metal weld was performed at North Anna Nuclear Power Station (NPS). Following the inspection the weld was machined, ready for a modification, and two through-wall leaking cracks were exposed, one was over an inch long on the surface and the other about a quarter of an inch. The cracks were within a couple of inches of each other. A subsequent ultrasonic inspection identified a further 3 cracks, between 50% to 70% throughwall, that had been missed by the first inspection. A Root Cause Analysis of the incident identified inadequate training and oversight [2] [3].

The response to human error in NDT has often been to reduce the role of the operator by automating the inspection. However, operators are still required and Human Factors is still important as discovered at Shearon Harris NPS when a defect indication in a time of flight inspection was found to have been missed [4]. Root cause analysis in this case stated that the analysts' working conditions of tight quarters, noise and other distractions could have been a contributing factor. In addition, the two analysts involved had worked 24 days and 17 days respectively without a day off. Anyone who has done any work requiring concentration knows that noise, tiredness and distractions will impact on the quality of the work, without the benefit of a human factors study, so it is an indication of how little the NDT community heeds Human Factors, to know that the analysts were not concerned with the working conditions and viewed it as typical [4]. As James Reason [5], (p. 173) said:

“Rather than being the main instigators of an accident, operators tend to be the inheritors of system defects created by poor design, incorrect installation, faulty maintenance and bad management decisions. Their part is usually that of adding the final garnish to a lethal brew whose ingredients have already been long in the cooking.”

What is Human Factors?

The HSE [Ref. 6] define Human Factors as:

“The environmental, organisational and job factors, and human and individual characteristics which influence behaviour at work”.

The 2nd American-European Workshop on NDE Reliability held in Boulder, Colorado in 1999 [7], agreed the following definition of Human Factors:

"the mental and physical make up of the individual, the individual's training and experience, and the conditions under which the individual must operate that influence the ability of the NDE system to achieve its intended purpose."

So it is does not all lie with the individual, but also with the environment and the organisation, which the operator is not necessarily able to influence.

The Operator

As mentioned above the operator is important to the correct application of any NDT. The operator can influence the reliability of an inspection through their personal condition and attitude, their competence and their personality.

Vigilance

As NDT is primarily a signal detection task, UT requires the operator to be vigilant, i.e. to concentrate on the flaw detector screen, which is affected by operator fatigue and

motivation. As part of the PISC programme in the early 1990s Murgatroyd et al [8] measured Flaw Detection Frequency (fdf) and compared the capability of operators between laboratory-type conditions and the simulated industrial environment.

The results indicated substantial differences in detection capability from day to day, and even from morning to afternoon. However; these differences were often identified as being mainly due to variations in maintaining overlapping scan lines and good coupling – see Figure 1 and Figure 2. Loss of attention caused an indication to be missed or the inspector lost their place during scanning. Inspector fatigue was considered to be a contributory cause of these errors. In order to mitigate against the deterioration in coupling, Murgatroyd et al recommended that, where higher detection reliability is required, the sensitivity specified in the initial scanning stage should be substantially greater than the reporting sensitivity – an addition of 10 dB.

In 1943 Cambridge University psychologists identified that having a break after 30 minutes improved the detection rate of radar operators. More recently, in 2000, the same university came to the same conclusion for radiologists looking at mammograms: after 30 minutes there is not a conscious lack of concentration but visual weariness occurs which may not be noticed by the operator. Whilst it is not always expedient to take a break every 30 minutes and each individual is different, it is important that a system of regular breaks is planned and implemented to ensure the reliability of the inspection.

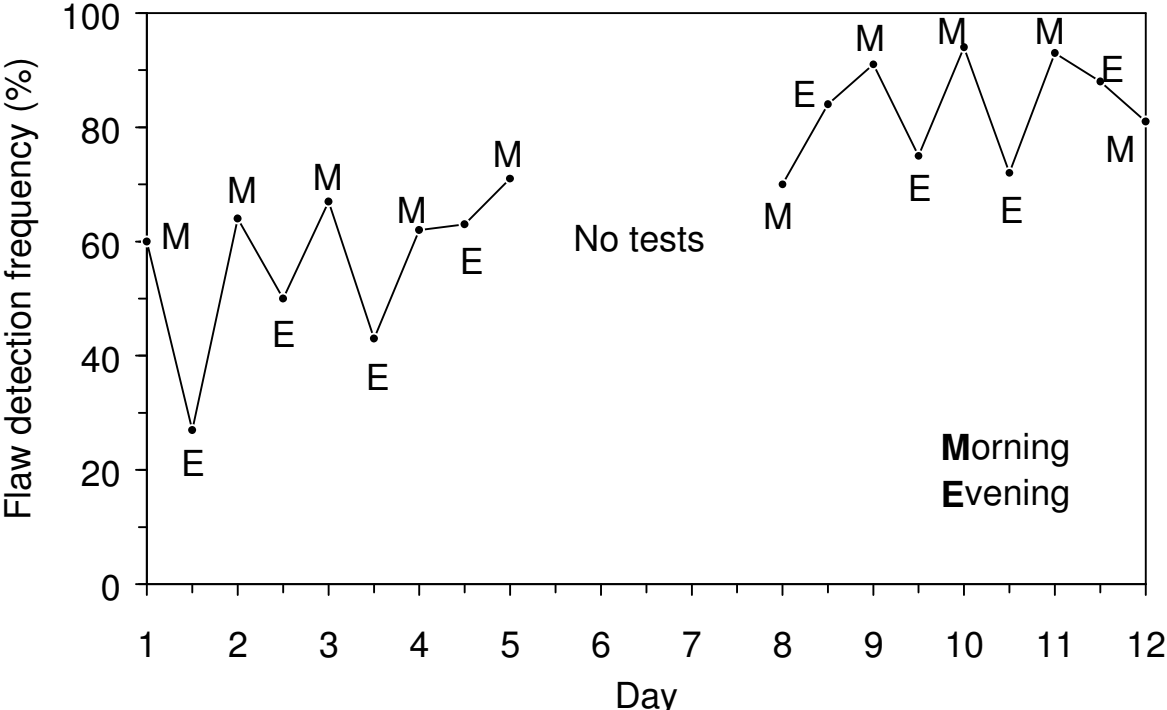


Figure 1 Performance change during the day

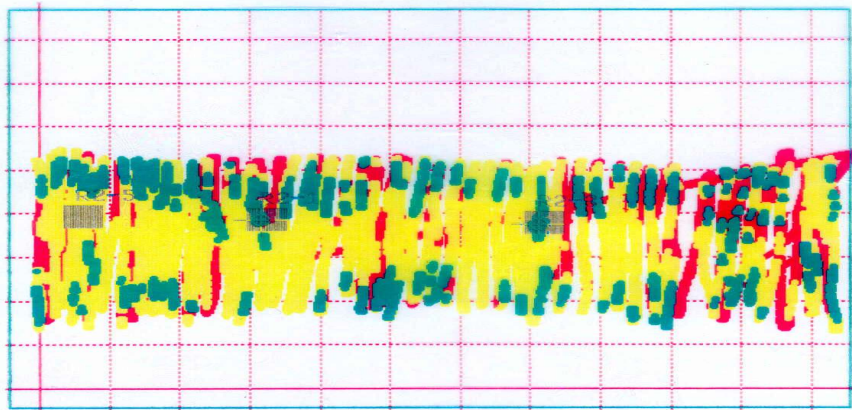


FIG 6.13 INSPECTOR R
MORNING OF DAY 1

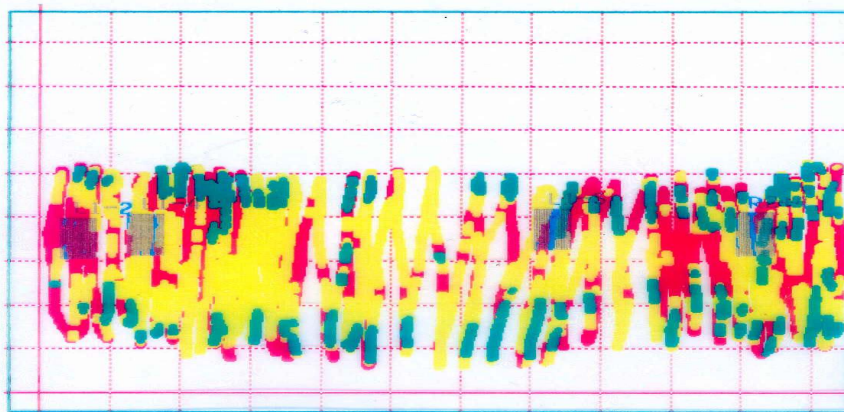


FIG 6.14 INSPECTOR R
EVENING OF DAY 1

Figure 2 Plots showing the difference in scanning coverage and couplant efficiency between the morning and the afternoon.

Competence

There have been many round robin exercises over the years in many of the common NDT methods and a common aspect of the results is that operators qualified to the same national standards show a difference in detection performance, especially when the inspection is not simple. This was shown in both the PANI 1 and PANI 2 projects. The way to address this factor is to provide the operators with job and operator specific training.

Murgatroyd et al stated that several of the basic causes of non-detection in their study could be rectified by specifically oriented training aimed at faults identified by the simulator. PANI 2 showed that the use of training and application of improved procedures produced significant improvements, more than doubling the flaw detection frequency in some cases when the defect or the geometry was complex. For simpler defects and geometries, the improvement was less.

Dury [9], looking at fluorescent dye penetrant inspection of aircraft broke the task down in to steps: Initiate; Access; Search; Decision; Response. He reports that using these generic inspection functions as the basis of improved training has had considerable success. He cites other papers which show that such training must cover search strategy and decision making if it is to be effective.

The observations from PANI 3 [10] give clues to how to improve performance by training:

Operators must be able to understand the ultrasonic implications of the geometry

Methodology:

Review procedure and obtain clarification

Once decided on methodology –stick to it

All recordable indications evaluated

Comprehensive report produced

By methodical approach weld can be split into zones to simplify

Having shown that better operator performance was associated with a higher score on the test of Mechanical Comprehension, the PANI 3 report recommended that in relation to selection and training, there should be a focus on identifying and developing (respectively) mechanical comprehension in NDT operators.

Personality

Informed by previous published work, the PANI 3 project conducted tests which showed that better operator performance was associated with lower scores on the personality scales measuring Cautiousness and Original Thinking. It is not easy to change personality but it is possible to mitigate any consequential impact on the reliability of an inspection by developing self awareness. The report recommended that NDT vendors should develop self-awareness in operators so that they might recognise when they are behaving in an over-cautious manner and also develop self-awareness in operators so that they might recognise when they, as individuals, are applying procedures which are not compatible with those prescribed for the (NDT) assessments being undertaken.

The Task

In practice, NDT is often performed under “highly stressful” conditions, which include high temperature and humidity, poor lighting and high noise levels, poor access and difficult workspaces, extensive shifts, time pressures, and exposure to factors such as extreme weather conditions and radiation. Dickens and Bray [11] suggest that as a task becomes increasingly more complex, environmental factors degrade performance. Murgatroyd et al [8] concluded working long shifts in a typical industrial environment can cause tiredness and demotivation for some inspectors which in turn can significantly reduce reliability. This was also supported by Dury [9] for dye penetrant inspection, who wrote that human performance decreases in adverse noise and thermal environments. Drury also states that because the search function is resource-limited, overall probability of detection is very sensitive to time limitations. In particular, external pacing of inspection tasks increases errors. Furthermore, the nature of the defect, the mix of defects requiring detection and the probability of a defect occurring all impact on the detection performance.

If humans are involved, things are never simple and two subsequent studies [12], [13] were unable to confirm the hypothesis that increased stress due to environment or time pressures led to poorer performance with the inspection task. The SKI study [12] explained their results by the adaptation of the task by the operator to the conditions. In this case the task was complicated and if the operator had too much time to consider all the information it could lead to confusion and indecision. The operators who simplified the task, just made the decision on the important information. Bertovic et al. [13] were also unable to find significant effects of time pressure on the quality of the performance except in situations when the operators perceived they felt time pressure. This perceived time pressure does not

just come from actual limitations in time but also from other factors such as organisational pressure, heat, noise etc.

When it comes to writing and reading procedures the NDT profession is particularly poor. Procedures have been written without any consideration of how best to communicate necessary information to the operator or without assisting the operator to apply the inspection in a reliable way. Dury [9] cites a paper which showed that poor wording and layout of workcards, manuals and service bulletin, and their computer equivalents, can have a major effect on error rates. PANI 3 [10] showed that operators do not fully read the procedure and may only apply a part of it. Yet, it also showed the importance of applying the inspection in a methodical way and gave a possible example of how to present a procedure. Building on suggestions for the optimisation of the procedures from PANI 3, researchers at the BAM Federal institute for Materials Research and Testing in Berlin used eye tracking technology and a user-centred design to study how operators examine a procedure, to identify shortcomings in the procedure and to optimise its content and format [14].

Even mechanised NDT, e.g. mechanised phased array, is at risk of human error, as operators are still actively involved in the preparation and the data evaluation. The Failure Modes and Effects Analysis (FMEA) - conducted to identify potential risks in mechanised NDT and derive measures against them - showed potential for failure throughout both the acquisition and evaluation of data [15]. The recommended practices to avoid those errors include improvements of the procedures, hardware and software solutions, further automation (e.g. alarms), human redundancy etc. The study of Bertovic [15] furthermore indicated that an automated software – designed to detect and size indications – may be misused and disused by the operators, both of which can degrade the performance in the task, especially in terms of sizing. Misuse occurs when operators uncritically rely on the correct functioning of an automated system even when it is wrong due to a belief in its high reliability (automation bias). E.g. one may agree with the automated defect detection and sizing software even when it is wrong. On the other hand, disuse occurs when people distrust the automated software and hence underutilise it, even when it is correct [16]. E.g. the operator changes the already correctly identified size of the defect. These examples illustrate that automation, in spite of its numerous benefits, may carry risks previously not considered by the designers. Decreasing the bias in automation (safety risk) can be achieved by acknowledging its existence, by experiencing automation failures and building appropriate trust towards the aid, by understanding why aids may fail, and by organisations encouraging their employees to openly speak up about problems and discuss potential risks, among others.

The Organisation

It has been reported through discussions with NDT operators that there are additional activities incumbent on them when undertaking NDT inspections. Operators are often required not only to complete the inspection and provide a report, but often to plan the inspection, write the inspection procedure, selecting the appropriate equipment and technique, and ensure that precursors for the inspection such as access and surface preparation are performed. These situations result from a lack of client awareness of NDT requirements and best practice and simply add to the list of pressures associated with the completion of NDT in the field. Behravesh et al [17] discuss the importance of organisational support and pre-planning in the successful completion of NDT. Koens [Ref. 18] gives a comprehensive description of how to manage NDE services to improve effectiveness and reliability. He describes how, by working together, the NDT Vendor and

end user can manage the NDE operator resource to increase the skills of the operator, reduce the direct cost of NDT services by 40% and avoid the even greater indirect costs that result from misleading results.

Holstein et al [19] also looked at the interaction of the NDT Vendor and the end user and developed a model of the processes governing the organisation of NDT Services, which helps companies to visualise the interactions and identify the process owners, the involved parties and the documentation requirements. As part of this work, Holstein [20] also conducted a questionnaire of NDT Vendor companies. The answers illustrate a number of issues that impact on the organisational context of the operator. 21% of the respondents cited ISO9001 as the main quality management system. This standard has a process based approach and, the latest 2015 edition [21], now has a specific section, 7.1.4, on the “Environment for the operation of processes”, which covers social, psychological and physical factors. Working more closely in accordance with ISO 9001, or other similar standards, could assist in improving the reliability of NDT.

Summary

In 2012, the Rail Safety and Standards Board published a scoping study report [22] which proposed a research plan in to how best to optimise the human element of rail axle inspections. The report states that significant human factors research has taken place regarding the application of NDT in various industries and so the gap is not in the knowledge but in how best to apply this knowledge in the most cost effective way to ensure rail axle inspection is fit for purpose.

This is the persistent problem for the NDT profession: the justification of applying human factors knowledge in monetary terms is not as easy as justifying the purchase of phased array kit to deliver the benefits of a faster and accurate volumetric inspection that provides an image of the object under test. And yet without control of the human factors we don't know if the image produced is accurate or not.

By helping the operator to avoid fatigue, assisting in developing their competence by job and operator specific training, improving their self awareness, mitigating environmental factors, managing their perception of time pressure, optimising the inspection procedure, optimising the interaction with automated systems, adopting better planning and management of the NDT process, there are many small steps that can be taken, one at a time, to incrementally improve the reliability of NDT. The benefits of each step can then be evaluated before committing to the next improvement, ultimately giving you that competitive edge.

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