Inspection Replacement in Heavy Construction: New Regulations and Old NDT Methods

Casper WASSINK, RTD bv, Rotterdam and Delft University of Technology, Delft, The Netherlands
Danny FREDERICKX, RTD nv, Kapellen, Belgium

Abstract. Over the last decades a large number of new NDT techniques have emerged. They have again and again proven to be very cost effective, more reliable in detection probability and reproducibility and a big improvement on the side of total efficiency of the construction process. Still their acceptance in the market has so far been reluctantly. The reluctance is best represented by the fact that the majority of construction projects, where replacement was successfully executed, is still or again being done with radiography. This despite the inherent difficulties of radiation and a photographic process.
This article explores three cases of replacing radiography with ultrasonic inspection. The examples are the construction of pipelines, heavy pressure vessels and LNG storage tanks. For each case, the regulatory background, drivers for technology change, technical challenges in the implementation and benefits and concerns in retrospect will be addressed. Also the reasons for the reluctant market reception will be explored and those areas where new regulations reveal the promise of innovation will be pointed out.

1. Introduction

It is a startling idea, that non-destructive testing, in the construction phase in the heavy industry, in the 21st century is in most cases done in exactly the same way it was done right after the second world war. When asking older Non Destructive Testing (NDT) experts for the major innovation in Radiography of welds, the only thing they can come up with is the fact that high voltage generators are smaller, and that film material has become higher quality, processing equipment has been automated and more isotopes are used. Nothing changed however in the way the basic work process of sticking the film to the weld and making an exposure with sufficient resolution and density.

From the point of view of the NDT specialist, new and improved techniques have been developed. The era of the building of nuclear reactors saw the development of new automated inspection techniques and ultrasonic probes all aimed at being absolutely sure that not a single defect was missed in the reactor vessel. The history of these developments is described in the article by Frits Dijkstra and Jan de Raad in this conference [1]. These methods have been transferred to some other areas where similar high reliability is needed, but in heavy construction, radiography is still the standard. The standard is in this case meant literally, as the codes and standards in most cases used to prescribe radiography as the first and mandatory method to be used.

2. The functional source of innovation

In his book ‘The Source of Innovation”, Eric von Hippel [2] argues that the success of an innovation is highly correlated to the functional source of the innovation. Some of these functions are: to be the innovations manufacturer, user or supplier. He proceeds to show that user driven innovation is often much more successful than the more traditional manufacturer’s innovation. The driver of the innovation however is in most cases the function that receives the biggest economic reward from this innovation. In NDT in the construction phase in heavy industry, the value chain is built up out of several stages as depicted in figure 1.

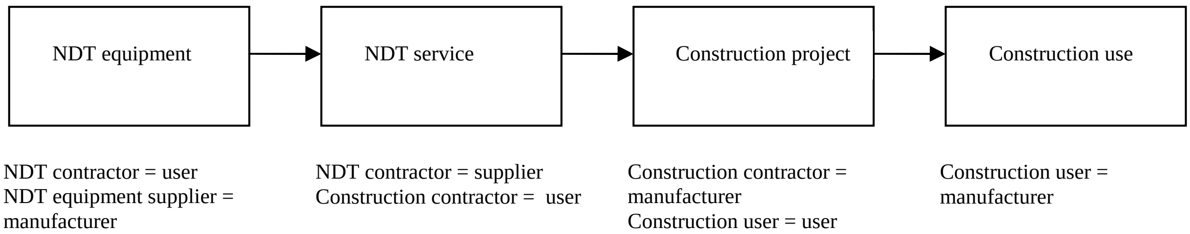

Figure 1. The value chain of an NDT service for Heavy Construction

An inspection company like RTD is the user of the NDT equipment and serves as a supplier of the NDT service to the company doing the actual heavy construction. Following the argument above it would be logical for RTD to be successful in innovating the use and application of NDT equipment and indeed this is the area where RTD is renowned as a lead user of new technologies.

In the heavy construction cases addressed in this article, i.e. transmission pipelines, pressure vessels and LNG storage tanks, the biggest rent of any innovation in the value chain is made in the use stage of the construction. This can be easily realised when considering that the turnover per e.g. reactor vessel for the NDT contractor is measured in tens of thousands of euros, of the construction contractor in millions and of the use of the construction in tens of millions.

Innovation literature suggests that most innovation would then be driven from the stage of construction use and that this innovation would be targeted at the use of this equipment e.g. better processes and more transmission. Only in very limited cases will this have impact on the way the construction is done. In even fewer cases will this have an impact on the way the NDT on the construction is done. The point here is that by the economic reality of heavy construction, innovation in the way NDT is performed is unlikely to happen. This deduction is counter to the popular proposition that the main problem of NDT replacement is getting the authorities to accept the new NDT techniques.

The most likely way for innovation of NDT for heavy construction to happen is for the users of the equipment to realise the economic potential of using innovative NDT solutions. Indeed, in most cases it was the construction users e.g. the big oil and gas companies, that funded the research of RTD into new NDT solutions. This will be further illustrated in the cases in this article

3. Risk and payoff of better inspection

Especially in maintenance, NDT people are very aware of the definition of risk. Risk in de context of methodologies like Risk Based Inspection (RBI) is defined as the probability of an event taking place multiplied by the impact of the event.

Risk = Probability x Impact

In NDT probability is most often captured in figures like POD (Probability of Detection), POM (Probability of Miss) and FCR (False Call Rate). In logic, POM would be called the probability of an error of the first kind. FCR would be called the probability of an error of the second kind.

The impact of POD and POM is a relatively straight forward issue. If a defect is missed, the POD curve tells us the maximum size of a flaw missed. Fracture mechanics then will tell us about the probability of failure of the resulting construction. Because the impact of the failure of a construction is easy to imagine and calculate, a lot of attention goes to achieving near-perfect POD and marginal POM unless the flaw falls well into the conservative margin taken into the construction design. Who bears the risk of failure and thus of missing a defect is described in laws. In some laws the authority is responsible, in some others the construction operator. In areas where safety is considered probabilistic, the acceptable probability of a failure of one of the construction cases treated in this article is in the order of 10^{-4} to 10^{-7} (occurrences per year). Although the consequence of failure could be catastrophic, the risk is low, because of the low probability. Work on a well kept chemical plant or refinery is safer than almost any other human activity [3].

The impact of FCR is a lot less obvious. When a defect is detected but in reality this defect is not there, the impact of this error is fully borne by the equipment constructor. He will have to perform a repair whether there is a defect or not. When faced with penalties for not getting the construction finished in time, this risk can be significant compared to the size of the company involved. Although the impact of one weld repair is small, the risk to the construction contractor can be substantial. It is my believe that it is not uncommon for a new (experimental) NDT technique to have FCR up to 50%, leading to the possibility of tens of unnecessary repairs.

From this it can be realised that construction user funded research will be aimed at maximizing POD. When this is not balanced by at least keeping FCR at the same level it will cause a very threatening situation to the construction contractor where he will start bearing more of the risk involved in the whole value chain. It is only likely that a new technology will be used when the innovation rent is bigger than the increased risk of higher FCR and the cost of introduction of new technology combined. It will not surprise anyone that a construction company would rather avoid the risk of being late and incurring associated penalties.

4. Radiography versus Ultrasound

Traditionally many welded components in heavy construction are required to be tested with the Radiography method. Radiographic testing was permitted as a method for testing fusion welded components since 1931 in the ASME Boiler and Pressure-vessel Code [4]. This was 9 years after 1922 when the first 200.000 Volt X-ray generator provided the possibility for testing thick steel plates. Radiography has been one of the important factors in getting the quality of welding to a level where welding became a reliable construction method, taking over from riveted construction. The need for fast building in and after the second world war further pushed welded construction, and with it radiographic testing as the primary method in heavy construction. The main role of non-destructive testing in this case is to close the quality loop, and provide a feedback to the welding crew. In this period of growth, the reliability of testing was not a big issue. Testing was to workmanship criteria, in other words, checking if the worker delivered proper work i.e. testing the welder. In modern NDT, more and more the checking of the quality of the work piece itself is important.

Table 1. History of Radiography vs. Ultrasonic Testing

	Radiography	**Ultrasonic Testing**
Method invented	1898	1930s
First use by RTD	1937	1948
Capability for heavy construction	1922	1952
Allowed under ASME VIII	1931	1999
POD according to PISC II	~50%	~80% with a good procedure

As can be seen in table 1, ultrasonic inspection in comparison is a much newer method. It was mainly developed from sonar and radar equipment used in the second world war. RTD started ultrasonic testing in 1948 with the purchase of systems based on Sonar technology. The main driver was to improve the detection capabilities. Ultrasonic testing proved to be a method capable of detecting very small flaws, although the probability of detection did not necessarily get better. This also posed a problem, as more and more components started to be rejected for smaller detectable flaws.

Automated Ultrasonic Testing (AUT) was first allowed under de ASME Boiler and Pressure-vessel Code with the adaptation of the code case 2235 in 1999 [5]. (For some specific components it was allowed before). This was 47 years after the publication of the patent for the zonal ultrasonic inspection philosophy in 1952 which has all the components needed to do a successful inspection. Inclusion of a new method took this long even though several round robin type joint industry projects showed that AUT has an excellent Probability of Detection compared to radiography [6][7]. Another difference between Radiography and AUT is the way in which AUT is qualified. For Radiography, in most cases a personnel certification is sufficient to qualify. For AUT extensive POD and sizing trials are often required for every job.

5. The problem of 2D measurement

Part of the problem of replacing Radiography with AUT is that for legal (i.e. liability) reasons it is often required that on replacement of one NDE method for another, at least the equivalence (the same of better) is proven. In the case of replacing Radiography with AUT this is fundamentally impossible. Both techniques present their result as 2 dimensional projection, but do so on different projection plane. Radiography in its basic form is a top down through view. AUT in it’s raw form is a side view along the weld bevel design.

This difference can be clearly seen in the sensitivities and insensitivities of both techniques. Radiography is sensitive to volumetric flaws like porosity and inclusions while it is insensitive to planar flaws like cracks and lack-of-fusion defect. This is reflected in acceptance criteria for indications that reject any planar defect because it could be a crack. Ultrasonic testing is sensitive to planar defects in those places where you expect them, e.g. the weld bevel for lack-of-fusion defects, and less sensitive to volumetric defects, especially when they have irregular shapes.

Since Radiography was the first and is the standard, the first way in which the problem of translating the acceptance criteria was tackled was by trying to directly project the Radiography criteria on Ultrasonic Testing. It is however very hard to make the ultrasonic device sensitive to the flaws that Radiography will typically detect well, without being over-sensitive to the flaws that Ultrasonic testing typically detects well. The top-down view of an object is typically very different from the side view.

The basis for acceptance of AUT as a replacement method came when the capabilities of AUT to size planar defects were used in ECA (Engineering Critical Assessment) type calculations. This for the first time gave the opportunity to accept components with a planar flaw that was determined to be non-critical in the calculations. With Radiography this determination would never have been possible, and all planar flaws are rejected.

6. Case 1: Pipelines

Since this case is extensively covered in another article in this conference, this case will be treated very briefly. As described in the article by Dijkstra and De Raad [1] the first prototype of AUT on pipeline welds was used in 1959 (figure 2). This system was named Rotoscan which is still RTD's trade name for AUT on pipeline girth welds. It took until 1978 until pipeline owners became interested in pushing this technology into use. The reason for this was that to maximise the benefit of high strength steel (X65 and better) in pipeline construction, flaw detection and sizing had to be improved over the level achievable with Radiography.

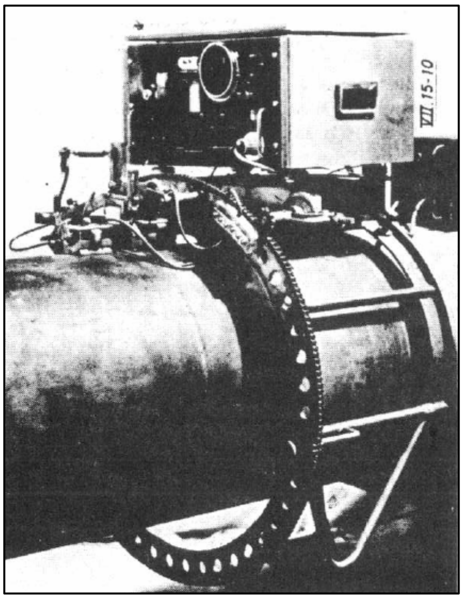

Figure 2. First Rotoscan system in 1959

The primary reason for innovation was the cost reduction achieved by the pipeline owners if the pipeline could be constructed with thinner walls. To be able to construct thinner walls, smaller defects had to be accurately classified. In the process of qualifying the technology, the authorities where heavily involved and put further requirement on the detection capabilities.

The commercial success of Rotoscan came only when also the False Call Rate was brought to an acceptable level and thus also the interests of the pipeline construction contractor where sufficiently covered. This was achieved by two innovations. Firstly implementing acceptance criteria suitable for AUT and backed by ECA calculations. Secondly the implementation of root mapping to eliminated geometry based false calls.

At present when asking pipeline contractors why they prefer AUT over radiography they point to the increased productivity of AUT over Radiography and the reduction in construction project risk that is achieved by real time inspection results. It is interesting to notice that these reasons were not the ones that pushed the technology into use.

7. Case 2: Pressure Vessels

Most of the component innovations used in the Pressure Vessel inspection technique of RTD were developed in nuclear research. The two most important ones are the Time of Flight Diffraction technique and Phased Array ultrasonics [8]. Most of the research into these techniques was performed in (semi-)governmental institutions. Institutes like AEA of the United Kingdom, BAM and IZFP of Germany and FORCE Institute of Denmark were involved in the development and instrumentation of the methods for safe construction of nuclear reactors.

ToFD was invented by Maurice Silk of AEA in the late 1970s. It was based on earlier observations made by RTD [9] describing the flaw tip reflection phenomenon and some ways of using it for flaw sizing. Although extensively used in the nuclear environment, ToFD was long (and partly still is) viewed with suspicion. There are two main reasons for this. One of the reasons is that interpretation of the inspection result needs a lot of skill with the NDT technician. The other is that ToFD has a dead zone near the metal surface. For the nuclear (research) world these were not a major problems as ToFD was backed up by other methods and the overall objective was to gather as much information as possible. They were a big problem for a commercial roll-out however.

An important stage in getting ToFD accepted was formulating acceptance criteria. These were developed in a Dutch joined industry project where construction owners, NDT contractors and the authority worked together. Special care was taken to ensure that repair rates for welds inspected with radiography and ToFD were in the same order of magnitude. The result of the effort was a Dutch standard [10]. ToFD is now an accepted method in The Netherlands and the United Kingdom and gains acceptance in the rest of Europe.

The first use of Phased Array ultrasonic equipment occurred in the same nuclear environment as ToFD. In the 1980s BAM and KWU (now IntelligeNDT) did the first experiments with Phased Array systems. The price of Phased Array equipment was long prohibitive to commercial use, until companies like R/Dtech brought PA equipment into the range where it was an economic alternative. The reason for RTD to start using Phased Array was that the decreased time needed for setting up equipment for complex inspection task made up for the extras cost of equipment.

Pressure Vessel inspection using these techniques was not considered for a long time. The basic reason was that it was not in the construction standard, which prescribe Radiography. Although some codes and standards allow some inspection replacement, the process for doing this is long and expensive. The length would be longer than the construction time of the vessel, and the cost would be tens of thousands of euros. In other words, although technically possible in reality it was not an option.

One of the important drivers for change is new government radiation regulation that practically makes radiography just as hard as getting ultrasonic testing accepted. Heavy walled pressure vessels are tested with a Cobalt 60 isotope. In many cases a whole worksite needs to be evacuated to make the exposure. The only practical way to do this by doing the radiography in the night time. Construction companies more and more also do normal work at this time however.

Since the standards have responded to these condition by allowing ultrasonic testing, under strict conditions, we now see that once construction companies have experienced the other benefits of ultrasonic testing (i.e. real time feedback and increased inspection speed) they often opt to replace all radiography where possible.

8. Case 3: LNG storage tanks

RTD first did a feasibility project for inspection of the welds of an LNG Storage tank in 1980 [11]. Based on the findings out of these measurement, new NDT procedures and ultrasonic probes were developed to detect the typical flaws that occur in welds of LNG tanks. LNG storage tanks are build of 9% Nickel steel, which is a ferritic material and welded with high nickel content welding consumables, which is an austenitic material. In the case that was studied this gave rise to lack-of-fusion flaws and solidification cracking. Also at this time it was concluded that Radiography was a badly unsuccessful method because the boundary of base metal and weld metal could be confused with flaws, and because the grain of the austenitic material gave rise to interference of the X-rays causing ghost indications. The recommendation of RTD and it's technology partners were very clear: inspection with ultrasonic testing was far superior to radiography.

The materials used to construct LNG storage tanks are difficult to inspect with ultrasonic testing. New probes and inspection procedures had to be invented (figure 3.). This research was funded by a major oil company. The reason for funding this research was very simple: the collapse and explosion of an LNG storage tank would be major catastrophe of the type that puts major companies out of business. (one such incident happened and further pushed the research).

Figure 3. Scanning of a 9% Ni LNG storage tank

When LNG started to emerge as a growing market in the late 90s, RTD was approached by several tank construction companies to assist with new developments. The background for these construction companies was strategic as they wanted to be ready and able to provide competitive solutions in the emerging LNG market. The same techniques already developed for the construction owners, in the nuclear and oil industry, were presented to these companies and accepted as the way to go. Lessons learned from the pipeline case about reducing FCR and using acceptance criteria that do not cause excessive repairs were also accepted easily by both the construction contractors and the construction users. Commercial use still took several years (roughly from 1998 to 2005), where all parties involved worked on new issues of the construction standard API 620, governing the building of these tanks.

By now it was clear to the construction companies, from examples in the other cases, that mayor saving and risk reduction could be attained by replacing Radiography with Ultrasonic Testing, and they used their influence in the codes and standards community to get these new methods accepted. CB&I was one of the companies that took the lead in bringing about this change.

9. The promises of new regulations

From the cases above it can be seen that the order of actions in replacing Radiography with AUT in these 3 cases was:

1. New technology gets developed, mostly with the construction user as the driver of the research
2. The technology gets modified to reduce the risk to the construction contractor
3. Regulations get modified in a collaborative effort by construction contractor, construction user and NDT contractor

With the lessons learned in previous case, 1. and 2. are now well understood and cared for in the commercial processes of RTD. 3. is the one which traditionally takes most time. New regulations now promise an avenue for achieving this more easily. In the nuclear energy sector ENIQ (European Network of Inspection Qualification) qualification is now an accepted method in most European countries, leading to a situation where it is no longer needed to do extensive POD and sizing trials in every country and for every authority. The new PED regulations give more opportunities to propose new risk reduction methodologies, opening more doors for new NDT techniques.

One of the promises of these new regulations is that clear, well understood processes for inspection replacement will be available.

10. Conclusions

In the article, the issues of replacing Radiography with Ultrasonic Testing in heavy construction were considered in the framework of innovation management research. It was shown that the construction user is in most cases the driver for research into new NDT methods but that commercial success and adaptation into codes and standards will not be pursued by all parties involved until the interests of all parties are met. The interests were expressed in the associated risk of the NDT technique for the parties involved.

The assessment of the innovation issue from the theoretical framework was illustrated in 3 cases that all confirmed the suppositions out of innovation management research. In all cases new NDT technology was first researched in projects funded by the construction user, i.e. the pipeline operator, LNG tank operator and (Nuclear Reactor) Pressure Vessel operator. Acceptance and commercial success followed years later when new minor innovations covered the needs of the construction contractor. Acceptance in standards then follows slowly but surely.

New regulation offer the promise of being able to shorten the time needed for inspection replacement in the near future.

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