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Technical Paper

A fresh initiative on the use of daylight magnetic particle inspection for the inspection of underwater steel structures

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Abstract

Underwater magnetic particle inspection (MPI) was a common non-destructive testing (NDT) method in the early days of North Sea oil and gas development (in the 1970s/early 1980s). It was primarily used to find cracks in nodal welds on offshore structures.

Underwater MPI was carried out using fluorescent inks, which were visible under ultraviolet (UV) light and had to be carried out in the hours of darkness. This led to lengthy and costly inspection programmes, as the inspection work was generally done during the summer months, with perhaps only 4 h of darkness in the northern North Sea.

The use of underwater MPI declined from the late 1980s for about 25 years but is now making a comeback. As offshore structures age and exceed their original design lives, the spectre of fatigue cracks has led to the need for detailed node weld inspection.

During the last 25 years, MPI inks have changed. Although they conform to the relevant international standards, these standards are for topsides use and thus not necessarily applicable to underwater conditions.

Recent trials have been conducted to determine the suitability of available inks to increasing white light levels underwater. This paper presents the work and discusses the findings, which have application worldwide.

Keywords: MPI, ink, NDT, magnetic particle inspection, non-destructive testing, MPI ink, offshore structure inspection, ultraviolet light

1. Introduction

Detailed inspection of offshore structures is carried out by divers using a variety of non-destructive testing (NDT) methods to assure the continued integrity of the facilities. Divers detecting surface-breaking cracks in welded steel structures have commonly used magnetic particle inspection (MPI). This technique is particularly used on welds and comprises energising the piece with a magnetic field, then applying ink containing ferrous iron particles. If there is a surface-breaking crack or other discontinuity, the magnetic flux created in the steel 'leaks' or jumps across the crack or discontinuity.

When fluorescent ink containing ferrous iron particles is applied to the test area, the fluorescent-coated ferrous iron particles are attracted to the escaping magnetic flux, thus making the defect detectable. The fluorescent ink is viewed under ultraviolet (UV) light, and so there are limits on the amount of white light that may be present. The maximum permissible white light according to international standards (British Standards Institution (BSI), 2012) is 20 lux. However, some fluorescent inks are more tolerable to white light levels than others.

1.1. Historic use

In the early days of oil and gas development in the North Sea (and elsewhere), all diver MPI work had to be done at night (to accord with the maximum 20 lux light levels given by BSI). This was sometimes a logistical nightmare, keeping the qualified MPI divers for nightshift work with perhaps only about 4 h of darkness in a 24 h period in the northern North Sea during the summer. However, in the 1980s with the advent of daylight MPI inks (and permitted light levels up to 500 lux), the requirement to only carry out MPI at night was relaxed.

Then, in 1986 the oil price plummeted from around US $30 to below US $10 a barrel, which led

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to the significant rationalising of expenditure, particularly expensive diving programmes. With changing economics coupled with new technology, the use of diver MPI declined. The technical innovations, which incurred less cost to deploy, included the use of remote operated vehicles (ROVs) to carry out flooded member detection (FMD) on steel bracings and eddy current inspection (ECI), as well as alternating current field measurement (ACFM) techniques to find cracks on welded components. All these NDT techniques required less cleaning of the steel surface prior to weld inspection, thus saving both time and money.

1.2. Current requirements

Fast-forwarding into the 21st century, underwater MPI is now making a comeback. As offshore structures age and exceed their original design lives, there is the increased risk of fatigue cracks occurring and the need for detailed node weld inspection – partly as a means of confirming crack-like indications detected by ECI. With technological advances, it is now possible to clean and fully remove any steel surface coatings to bare shiny metal (Sa 2.5) in minimal time, thus making diver MPI more economical to use.

Given the intervening period of around 25 years since the daylight MPI inks were last used, very few of these earlier inks remain, and those that do, lack any scientific basis for their use beyond the 20 lux ambient light levels stipulated in the relevant standards.

2. Previous work

Before the current underwater MPI trials were started, a literature search was carried out to identify and possibly build on previous work carried out by others. However, this proved to be quite limited regarding the use of daylight MPI for the inspection of underwater structures. Moncaster (1982) undertook MPI diver tank trials using samples with weld crack lengths ranging from 5 mm to 480 mm with mixed results. Isolated cracks 'of perhaps 30 mm in length could be found with almost certainty, using MPI, but below this size the probability of detecting an isolated crack reduces sharply and is perhaps only 10% for a 5 mm isolated crack'. Those trials focused on the comparison of diver inspector qualifications, the relative reliability between visual inspection and MPI, and the reporting of results. Cognitive factors were researched by Leach and Morris (1998), who focused on the divers' ability to report known defects. Further trials were conducted by Visser et al (1996) assessing the probability of a diver reporting crack indications on nodal welds, but not specifically about the use of daylight MPI techniques.

The earlier published work has shown that there are a number of variable test parameters when conducting MPI trials. These include size of defect, probability of detection and types of ink. The current work acknowledges these factors, but its sole focus is on determining the range of the white light lux levels at which each daylight MPI ink can be used to reliably detect surface-breaking cracks. It then aims to recommend the most suitable ink going forwards.

3. Standards

There are currently no UK standards covering daylight MPI (other than dry powder), and there are no standards for the use of underwater MPI regardless of technique. All the current standards are for topsides use only, though a number are relevant and can be adapted (in part) to the application of MPI underwater. The UK current standards are given in Table 1.

MPI viewing conditions are specified (topsides) in BS EN ISO 3059:2012, which stipulates a maximum white light of 20 lux when viewing fluorescent indications. Theoretically, most MPI inks should be capable of being seen at increasing white light levels.

4. Selected MPI inks

In order to verify the use of daylight MPI ink underwater, a set of trials was conducted in 2014. The trials

Table 1: UK standards

Current standard	Former standard	Content
BS EN ISO 3059:2012	BS EN ISO 3059:2001 BS 4489:1984	MPI viewing conditions
BS EN ISO 9934-1:2001	BS 6072:1981	MPI general principles
BS EN ISO 9934-2:2002	BS 4069:1982	Specifications for MPI inks and powders
BS EN ISO 9934-3:2002	–	MPI equipment
BS EN ISO 17638:2015	BS EN 1290:1998	Weld MPI
BS EN 1330-7:2005	BS 3683-2:1985	MPI terminology
BS 667:2005	BS 667:1996	Lux meters
BS EN ISO 23278:2009	BS EN 1291:1998	Weld MPI acceptance levels

Fig 1: Containerised MPI inks

broadly followed the methodology given in the UK standards (listed in Table 1) adapted for underwater use. The exception was the introduction of increasing white light levels to determine the fluorescent ink sensitivity. Four commercially available inks were selected for the trials, identified in Fig 1 and Table 2.

Three of the inks used were specifically designed for underwater use (marked by an asterisk in Table 2). The Ardrox 8544 ink was not, but was included in the trials as historically Ardrox 8560 was commonly used for underwater daylight MPI but is no longer available. It was noted that Moncaster (1982) used Ardrox 8560 and Mi-Glow UW 1 in earlier work.

Dilution of the ink concentrates followed the manufacturers recommendations. Where dilution was only given for topsides (i.e. Ardrox 8544) the rule of thumb for underwater concentrations is typically three to four times the concentration used topsides. Thus Ardrox 8544 was therefore diluted 1:10 for the underwater trials.

The NeoAstra ink was similarly diluted 1:10 as per the manufacturers' recommendations. The Circle products were powder-based and were diluted according to manufacturers' recommendations using 15 g of powder to 1 L of water. All four inks were diluted using fresh water.

Historically a Sutherland flask would have been used to test the amount of suspended solids in the inks. This was a requirement of the relevant standard of the time (BS4069:1982). However, this criterion has been superseded by BS EN ISO 9934-2:2002, its replacement, where the onus for ink suitability now lies with the ink manufacturers to carry out appropriate testing of their inks and to recommend the level of concentration. Thus, a Sutherland flask is no longer used for testing the inks onsite (unless specifically required by a client).

5. Equipment calibration

The test equipment was calibrated against the various applicable standards. This included testing the pull of the electromagnet (BS EN ISO 9934-3:2002), confirming the intensity of the UV light (BS EN ISO 3059:2012) and function testing the safety earth leakage circuit breakers (ELCBs) on the power and light circuits. The inks were confirmed to be less than three years old; a fine non-magnetic strainer was used to fill the ink reservoir on the MPI unit, and the ink was agitated prior to use.

The front face of the UV-A lamp was cleaned before use and prior to the necessary intensity checks.

Table 2: MPI ink specifications

Product	Colour	Manufacturer and UK supplier	Format/dilution
Ardrox 8544	Green/yellow	Chemetall, Germany UK supplier: www.chemetall.co.uk	Water-based liquid concentrate; recommended dilution 1:40 in water (topsides) (1:10 underwater)
NeoAstra DGCUW*	Green	Johnson & Allen, UK UK supplier: www.johnsonandallen.co.uk	Water-based liquid concentrate; recommended dilution 1:10 in water
Mi-Glow UW 1*	Orange/red	Circle Systems, USA UK supplier: www.searchwise.co.uk	Powder; use 2 oz powder/US gallon of water (equivalent to 15 g powder to 1 L of water)
Mi-Glow UW 528*	Orange/red	Circle Systems, USA UK supplier: www.searchwise.co.uk	Powder; use 2 oz powder/US gallon of water (equivalent to 15 g powder to 1 L of water)

6. Underwater MPI trials

The trials were carried out at the Validation Centre (TVC) in Great Yarmouth, UK, on 28 August 2014 and was project managed by HiKen Ltd. It was not considered necessary to use a diver in a wet tank, as the purpose of the trials was to test the sensitivity of the MPI inks underwater in varying light conditions. Accordingly, the trials were carried out examining the four inks against standard test pieces with known defects in a shallow water bath. The test tank setup is shown in Figs 2 and 3.

DC electromagnetic yokes were used to induce the magnetic field in the test plates. A continuous water flow was necessary to flush out excess ink in the test tank in order to view the crack defects in the test plate. This was achieved by installing a submersible pump into the tank and maintaining an open circuit (as shown in Fig 3).

The test tank was in a windowless, darkened room with light introduced through two floodlights powered through a rheostat. The actual lux level was measured using a white light meter encased in a waterproof housing and positioned by the test plate (see Fig 4).

Two separate butt-welded steel test plates with certified artificial defects were used. One plate contained six surface breaking non-visible cracks varying in length, between 5 mm and 15 mm on a 600 mm × 300 mm test piece. The other plate contained three surface-breaking non-visible cracks that were 30 mm to 40 mm in length on a 300 mm × 200 mm test plate. Two plates were used to determine whether the size of plate or length of defect (over 5 mm) had any bearing on the test results. None were reported.

Fig 3: Test tank with submersible pump

The component parts of the ASAMS System 3 Underwater MPI unit were used, with a DC electromagnet providing the magnetic flux in the test piece. The standard ASAMS UV light was employed with ink dispensed through a nozzle in the lamp head.

Photographs were taken using a digital camera at different lux levels to provide evidence of the work. It was noted that sometimes the defects appeared brighter, or conversely less distinct, on the photograph (due to the camera electronics) than they did to the human eye during the trials. This aberration was ignored; observation by the human eye was the ultimate reference for these trials, as they essentially replicated what a diver would see underwater.

Field Flux (Burmah Castrol) Strips Type 1 were specified to confirm adequate magnetic flux adjacent to the defects in the test plate. The indicator strips contain three milled slots and are manufactured from permeable magnetic steel sandwiched

Fig 2: Test facilities

Fig 4: Measuring ambient light prior to MPI

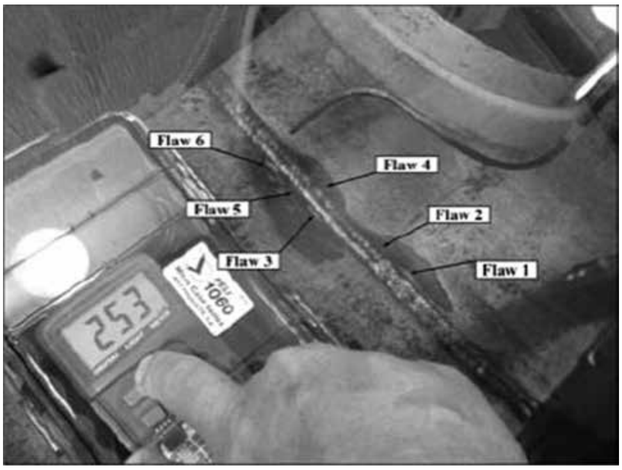

Fig 5: MPI of test plate at 253 lux

between two brass plates. For reasons unknown, the field flux strips did not work during the trials. The strips were tested on the surface and worked fine using an aerosol-applied black magnetic ink, but refused to work underwater. Chedister (2003) had reported similar findings that the field flux may not be effective in a water bath, but no specific reasons were given.

This did not affect the tests, as BS EN ISO 9934-1:2001, clause 8.2a, specified 'the adequacy of the surface flux density shall be established by testing a component containing fine natural or artificial discontinuities', which is precisely what was achieved during the trials by using the test plates provided.

The trials team comprised two personnel, both with an NDT background though not specifically in underwater MPI. The lead technician had been tested for colour-blindness as part of the offshore medical certificate.

7. Ink performance

The trials were conducted in a single day with all four inks tested over a range of light conditions. Each ink was tested starting at light levels of around 20 lux, then increasing the level of white light in approximately 50 lux steps until the defects were no longer discernible to the human eye. Lux levels were measured using a digital lux meter enclosed in an underwater housing (see Fig 5).

There was a concern that the UV lamp might contain a portion of white light and thus sway the lux meter readings, but it was determined by testing that the UV lamp had virtually nil effect on the lux meter readings during the trials.

Ink colour was also deemed important. The orange/red inks were more pronounced (and easier to detect with the UV lamp/naked eye) than the green/yellow inks. This was particularly noticeable when viewed in comparison to the grey surface of the steel test plate.

8. Trials results

The ink trials results are summarised in Table 3. The visible limit of the test was when the remaining defects became indistinct or no longer visible. The clear winner was the Circle Systems UW 528, followed by the Chemetall Ardrox 8544 and then the Johnson & Allen NeoAstra ink.

It is interesting to note that Circle Systems promote UW 1 for larger cracks and UW 528 for finer cracks, with the former ink comprising (larger) pure iron particles whilst the latter ink is made from (finer) iron oxide-based material. Moncaster (1982) used Mi-Glow UW 1 MPI ink but on cracks up to 480 mm length. No breakdown of results was given or which MPI inks were trialled against which defects in this 1982 work. The use of UW 1 MPI ink in 1982 might explain why there was a lower percentage rate for the detection of smaller defects in the 5 mm to 32 mm crack length range.

The smallest defect (5 mm length) on one test plate in the current trials was often the first to be lost, but not with every ink. The 5 mm length defect was poorly defined but just visible using UW 1 at 10 lux. The low level of sensitivity for UW 1 ink was a key factor in rejecting it as a preferred ink.

9. Conclusions

The top three inks (i.e. Mi-Glow UW 528, Ardrox 8544 and NeoAstra DGCUW) in Table 3 are recommended for underwater use based on the trials conducted in this study.

It is crucial that a lux meter is used for any diver MPI to determine the light levels, which will likely

Table 3: Summarised results

Ink	**Colour**	**Maximum lux level**	
		Full clarity (all defects)	**Visible limit of test**
Mi-Glow UW 528	Orange/Red	250 lux	720 lux
Ardrox 8544	Green/Yellow	200 lux	560 lux
NeoAstra DGCUW	Green	150 lux	500 lux
Mi-Glow UW 1	Orange/Red	100 lux	300–500 lux

change during the duration of an underwater MPI test. It might be prudent to limit underwater MPI to a maximum of 150 lux to 250 lux, depending on the ink used, and to take into account any inherent inaccuracies of the test procedure.

Ink colour is also important. In clear water and shallow depths, inks that fluoresce red or orange-red are likely to be more sensitive to detection by the human eye, whereas in turbid or otherwise dark water, the ink particles that fluoresce greenish-yellow are likely to give a better contrast.

Further trials against specific offshore site conditions are recommended based on geographic location and depth. The preferred ink could be specified for use in the MPI ink dispenser with the alternative ink(s) carried to site and deployed using a squeegee bottle as a comparator.

Finally, the expiry date of the ink is significant. According to specifications (BS EN ISO 9934-2:2002) the 'expiry date shall be given by the producer and shall be marked on each original container'. Typically, this is three years from date of manufacture.

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