

The Global Marine Systems Digital Xray Camera (DXr1)

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Abstract: From the early days of submarine cables, moulded joints have been X-rayed using conventional film technology. This paper describes the Global Marine Systems Limited Digital X-Ray Camera, DXr1, a major innovation in joint radiography which will reduce repair times, eliminate wet film processing and enable radiographical images to be emailed and archived electronically.

1. INTRODUCTION



Figure 1: Digital X-Ray Camera DXr1

Ever since the inception of polyethylene moulded, powered submarine cable joints - it has been recognised that the existence of air voids and metallic inclusions in the polyethylene could be a cause of high voltage breakdowns of the joints. To

detect and quantify these inclusions, a radiographical examination of the moulded polyethylene is required. Bespoke X-ray cameras such as the Mk7 and Mk9 were developed for analogue use and during the early days of fibre optic jointing, the Barr and Rusty Blue Cameras were manufactured as prototypes. As Universal Jointing progressed, so did the X-ray camera development leading to the Type 13 cameras that are in use today. The Type 13 Mk3 was the most sophisticated design employing a robust mechanical construction, fail safe safety features and the ability to detect the smallest inclusions in the moulded polyethylene. This paper describes the very latest innovation in joint radiography, the new Digital X-ray camera, DXr1.

2. WHY DIGITAL?

Like conventional cameras, all X-ray cameras including the Type 13 Mk3 use standard film technology and wet chemical processing. In a maritime environment, this means dispatching large quantities of chemicals around the world to vessels and then for the vessels to safely dispose of all

used chemicals. For a busy repair vessel and in a world with increased safety and environmental consciousness, the quantities can be considerable and there are frequent export/import problems. The films used are A4 size and as thirty X-ray exposures are required for every joint, the film cost can be high. For digital, as no films have to be changed, valuable time is saved in not walking around the camera to change the film for every shot or to and from the darkroom. As the planned maximum operational life of a system is typically 25 years, all repair information, including the films, have to be retained and archived for this period of time, requiring ever-enlarging storage facilities.

For radiography, there are great similarities between the medical and submarine cable repair industry; both require the use of radiography (the radiation attenuation levels of polyethylene and human tissue is similar), both need to assess the films and both need to securely archive images for 25 years or more. For some years the medical industry has been moving towards fully digital X-ray facilities in hospitals and clinics and Global Marine Systems recognised the need for a similar requirement for the submarine cable industry. The DXr1 Digital X-ray Camera together with the appropriate assessor software was duly developed in conjunction with the leading UK radiography company, JME Limited. While this is described below, it has the immediate advantages of no chemical film processing, no X-ray films, no physical film archiving and the ability to email radiographical images as soon as they are taken.

3. DXr1 – GENERAL DESCRIPTION

The DXr1 looks physically similar to the Type 13 Mk3 but is slightly larger and heavier at 145kg with the same marine-

compatible, easily manoeuvrable and self-contained construction. The DXr1 is also wider than the Type 13 thus allowing the inspection of longer joints or lengths of cable. When X-raying a joint mounted centrally in the camera, there is a smaller chance of leakage through collets from radiation passing through the cable screening due to the greater spacing between the joint and camera sides. Externally, the main physical difference is the introduction of the interactive touch screen in place of the control panel. Ionising radiation is generated in the normal way for X-raying joints and the leakage levels are equivalent to the high standards of the Type 13 Mk3, providing that correct cable collets are used. Although radiation barrier distances are similar to previous, the shape of the boundary has changed to help operate the camera from the back. The electrical requirements are a 96 – 240V AC mains supply at a current of 5 Amperes with a frequency of 50-60Hz. The same low energy 35kV X-ray generator is used to help capture fine detail and air voids in the low density polyethylene mouldings. The software is compatible with most versions of WINDOWS with testing to be completed on the recently released WINDOWS 8.

The camera head can be rotated to achieve the requisite angular positions but the lateral inspection positions can be set on the control screen.

Instead of using a film, the X-ray image is captured on a digital panel mounted on motorised horizontal sliders. The motors only operate when the camera door and interlocks are closed so there is no danger of trapping hands. The very compact digital panel and X-Ray tube horizontal drives operate on a closed loop control system. Every time the machine is switched on the motors drive out to a fixed end stop to create a known datum. From then on all programmed in movements are

checked via the on board encoders to ensure more accurate positioning. The digital panel has a sensor suited to the low energy generator and to help improve the quality further, has a reduced amount of internal screening allowing more of the less damaging low energy beams through to give finer detail in a shorter shot time. This very fast image capture has allowed a single X-ray tube and digital panel to be used (The Type 13 uses two tubes) and get faster results than the film based Type 13. An advantage of the traversable single tube and panel is that the whole length of the cabinet can be scanned.

Apart from the obvious financial savings (X-ray tubes and digital panels are very expensive) the advantage of using one X-ray tube is to considerably reduce the amount of scatter inside the cabinet and to eliminate cross talk interference caused by the beam from one x-ray head affecting the image of the opposite end of the joint.

Scatter is produced all the time the X-ray beam is on. The primary beam travels in a straight line from the focal spot through the joint and on to a particular pixel on the digital panel while secondary radiation is produced by the primary beam hitting the joint and cabinet. This secondary radiation then hits the digital panel randomly from all directions. On the DXr1, five images are actually taken in very quick succession and these are averaged to produce one final image with extremely low noise. All the images have scatter on them but there are differing amounts on any particular pixel in each image captured. If one image displays a random pattern of noise or scatter, it will not be exactly repeated on the other four shots at the same position so the resultant noise will only be approx. 20% of the single image.

Figure 2 clearly shows the advantages in noise reduction and image clarity between a single image (on the right) compared with an averaged image (on the left). The

image is then exported as a file that can be viewed and assessed. X-Ray film at most contains 100 – 150 levels of greyscale but the DXr1 system captures and identifies approximately 16,000 levels of greyscale thus providing more information to the assessor after intelligent image processing. The imaging system has high sensitivity, small pixel size, low noise levels, and a very fast data transfer and has facilities for light and dark calibration correction and high dynamic range imaging, none of which are available with film. Slightly under/over exposed images can be corrected with brightness/contrast adjustments rather than re-taking and processing film plates.

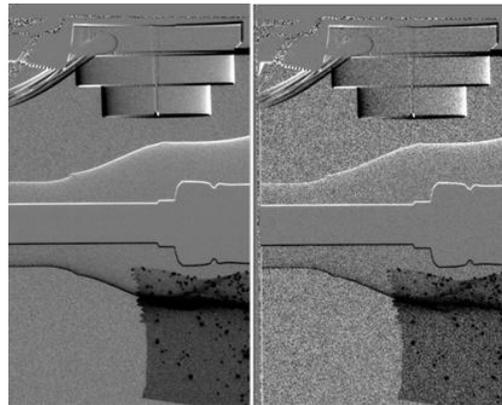


Figure 2: Averaging (Averaged imaged on left & non-averaged image on right)

One of the design considerations in using a digital flat panel instead of a diode line detector system is that the panel employs specialised materials and manufacturing methods that offer optimum sensitivity, pixel size and low noise. Figure 3 (centre and right) show a 0.5mm ball occupying one pixel for 0.4mm and 0.8mm diode line detectors. Figure 3 (left) shows it as a true circle occupying approximately 28 pixels for the 75 micron pixel size flat digital panel.

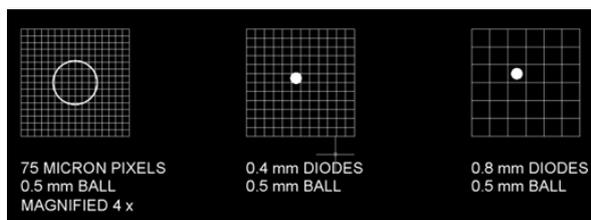


Figure 3: Digital Panel v Diode Detector

The time to take one image is reduced from 15 seconds with film to 0.5 seconds on the DXr1 not including the film processing time. For a complete joint, the time from commencement of radiography to start of assessment is 2–2½ hours with conventional film and approximately 20 minutes for the DXr1 but with the DXr1, assessment can start as soon as the first image is available thus further reducing the overall time.

As soon as the first image is captured, it is stored in a dedicated folder on a local network. The assessor can be located anywhere providing they are connected to the network. The image(s) could then be emailed anywhere in the world from a vessel with Internet connections. Typical single image size would be 13MB. The machine can run a complete repertoire of images for one joint or single shot images. Standard warnings are displayed audibly and visually but for a complete joint with full automatic cycle selected, only one 10 second warning is used at the start of the cycle thus further reducing the overall time.

Standard film processing necessitated a delay while the films were processed chemically and were then examined individually on a lightbox using a graticule viewer. With the DXr1 system, the assessor uses specially designed software that enables tools to be selected from a menu to determine the size and magnitude of any voids and inclusions found on the image and also wall thicknesses. The images can be marked-up showing the

features and comments included in a dialogue box. Each image is classified as Pass, Fail or Pass with Features and finally a Summary Sheet produced giving the overall result of the assessment. The assessed images are saved on the server and can be emailed from the vessel if required; perhaps for a further opinion or for archiving.

4. ASSESSOR SOFTWARE

Having a high sensitivity panel to capture high quality images is a good starting point but this is only a part of the overall package of the inspection process. So developed alongside the DXr1 camera is a simple user interface ‘assessor’ software. There are three main stages in the assessment part of the process: 1. Loading and processing the original image, 2. The actual assessment of the image including visually looking for defects and taking measurements and 3. Producing the archivable report once the assessment is completed.

First Stage: The assessor software works with and displays the 16 bit TIF images correctly. The first thing to select is the image set; these images are then loaded into their correct place in the initial image matrix screen. Once the images are in the table there is an option to process them to make them more suitable for the assessment that is to follow. Selecting the process button starts an automatic software enhancement of the image using algorithms and settings optimised for this application. As the images contain approximately 16,000 levels of greyscale and the human eye can only detect approximately 150 levels at any one time, some information that is available within the image can be difficult to see on the screen. So the software makes this fine detail more visible to the assessor. The settings chosen for the enhancement

produce screen images that are a close match to the appearance of D7 film used in the Type 13 camera. A good example of what the enhancement does is the before and after images of the IQI (Image Quality Indicator). The IQI image below includes a 0.25mm ball and a 0.7mm central hole. The image on the left is without enhancement and the ball is just visible while the hole cannot be seen. In the enhanced image on the right, the ball can be clearly seen and the central hole is quite visible without sacrificing the overall appearance of the image as usually happens with normal brightness/contrast adjustments.

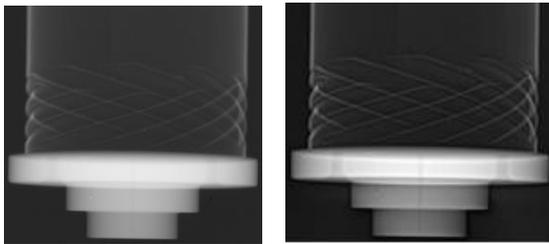


Figure 4: Image Enhancement

Second Stage: Once the image is displayed in the matrix and the enhancement has finished, the actual assessment can start. Other images will be added in as they become available. In the assessment screen there are several tools for taking measurements and adding comments. But there are also tools that can aid with the visibility of features of the image such as inverting greyscale (flipping between the two states by using the scroll wheel on the mouse) and holding down the right mouse button and dragging the cursor across or up and down on the screen to change brightness and contrast. Another useful feature is holding down *alt* and drawing a rectangle around part of the image to stretch the greyscale within the rectangle to cover all values between black and white. Zoom and magnification tools are also available.

Third Stage: Creating the report. Once all the images have been assessed, the software has a button that creates a report according to a pre-defined template. It will store copies of the marked-up images as well as information such as date, joint serial number, assessors name, jointer's name, etc. During the assessment process, the original captured image is not lost or modified but remains 'as captured' for security and legal reasons so that it is available in the future as an un-tampered record. All results from the assessment process are saved separately to the original images, so there is no danger of corrupting the original images.

5. CAMERA OPERATION, IMAGE ACQUISITION & STORAGE

Without detailing every step and option, the following gives a summary of a typical Joint X-ray sequence:

The Joint is placed centrally in the camera and clamped. The camera is then closed and the power switched on.



Figure 5: Joint Located in Camera

The User Type is then selected with the option of using a PIN for security. The Radiographer level is used for normal radiographic inspection of moulded joints, and to review previous exposures. The Supervisor level allows for normal radiography, but also to set up new

inspection definitions. The Engineer level allows access to system settings.



Figure 6: Select User Type

The Job Type is selected, in this case 'Standard UJ'. By scrolling left or right, other joint types or options can be selected.

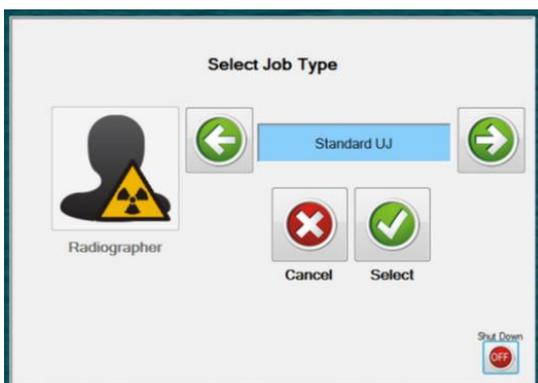


Figure 7: Select Job Type

The Radiographic Screen is divided into Image Capture Area, System Status Area, Job Details Area, System & Controls Area and Clock.

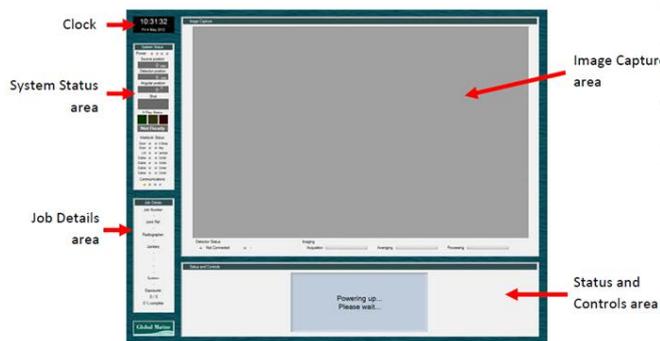


Figure 8: Radiographic Screen Areas

The Job Details are entered using the on-screen keyboard. After entering details, they are displayed and a confirmation is required to continue.

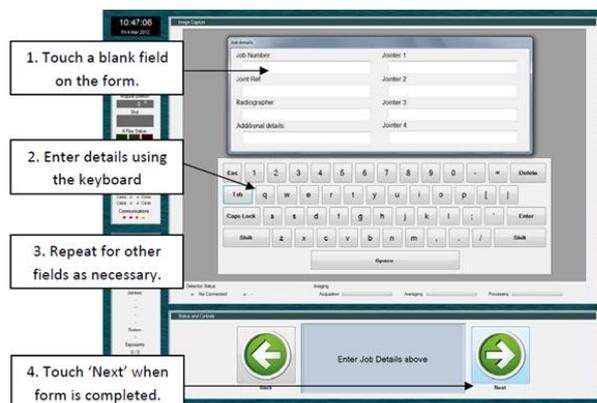


Figure 9: Entering Job Details

Once the job details have been entered, the x-ray source and detector panel will move to their first position ready for inspection. The display will prompt the user to ensure that the inspection cabinet is set to the first inspection angle, usually 0°. Once the cabinet is locked into the correct position, the user should touch the button to continue. Once the correct angle has been confirmed, and if all of the interlocks are in place, the system is ready for the first exposure. If any interlocks are not in their safe condition, a pop-up window will identify which interlocks need to be closed before the system will continue. Touching the START button will initiate a 10 second pre-x-ray delay. During this period, the amber beacons on the cabinet will flash and an internal sounder will emit a beeping tone during which no X-rays are emitted. This is the final warning before X-rays are produced.

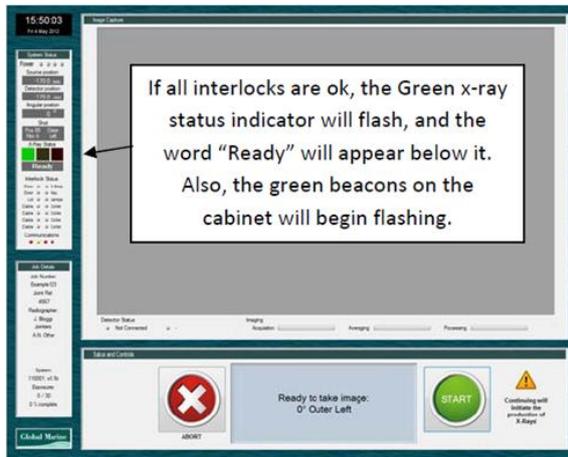


Figure 10: X-Ray Camera Ready

After the x-ray tube is energized, there is a delay of 3 seconds during which the output radiation from the x-ray tube stabilizes, then the detector panel will begin to acquire the image. The progress of the acquisition can be seen at the bottom of the Image Capture area. There are three stages to acquiring an image: Firstly, a sequence of images is obtained from the panel and then an average image is assembled, based on the acquired images. Finally, calibration factors are applied to give a 'flat' image. Once an image has been acquired, it will be displayed in the main window of the Image Capture area. The image will have the job details digitally encoded into it, and be automatically stored in the job folder. Image Assessment can now start.

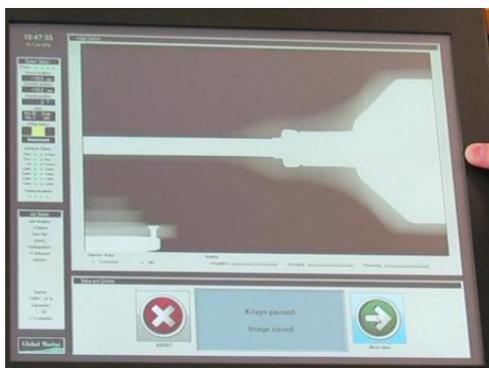


Figure 11: The Image is Displayed

The on-screen instructions will then state what the next camera position should be and the camera is rotated accordingly. The next image is then captured and the procedures repeated until the repertoire of images is complete for the joint. The radiographer has the option of repeating any of the shots if the images are defective in any way. All the images for the joint are now stored in the appropriate network folder and the assessment process can be completed.



Figure 12: Angular Rotation

6. IMAGE ASSESSMENT

The X-Ray Assessor can be located anywhere provided that they are connected to the network where the images are stored. The images are displayed on a matrix indicating their angular position. When viewed initially, all image borders are blue which indicates 'Un-assessed' but as each image is assessed, the borders will change to green for Pass, red for Fail, yellow for Pass with Features and purple for a re-take of the image. A single shot X-ray will be shown in its appropriate angular position on the matrix. The illustration shows un-assessed images for one half of a joint.

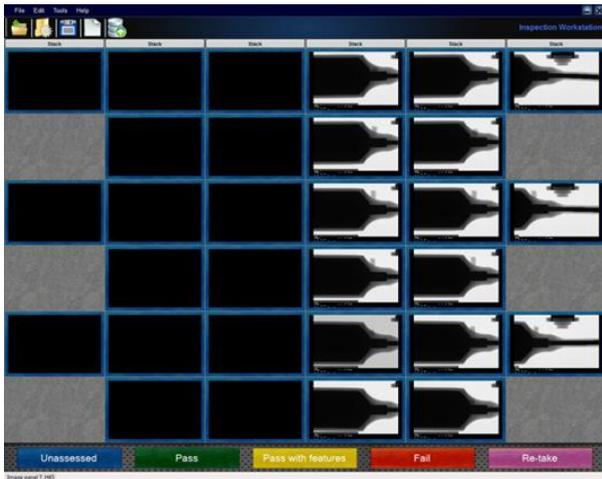


Figure 13: Assessment Screen

Each image is selected in turn and assessed using the Image Inspection Tools in the menu, if required. If an image has no rejectable features, it can be marked Green. If an image has a rejectable feature, it will be marked Red and the joint can be re-moulded immediately. If the image shows allowable defects, it will be marked Yellow.

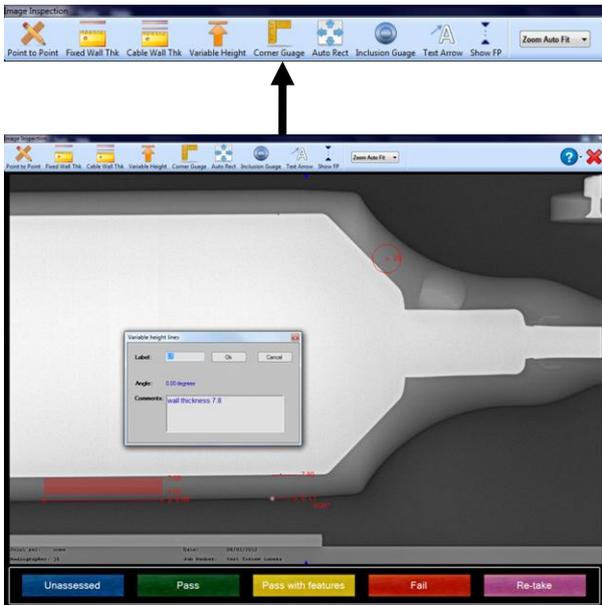


Figure 14: Assessment Tools

The Image Inspection Menu contains all tools necessary to assess the image and no graticule viewing is required. Figure 15,

shows a sleeve wall thickness measurement. The measurement will be entered in the Comments Box with a label. The annotations and comments will be saved with the image and can be retrieved. This does not affect the raw data image which is saved separately.



Figure 15: Measuring Wall Thickness

Figure 16 shows an Inclusion Gauge which comprises inner and outer circles in point sizes equivalent to those on a T13 graticule. Initially the smallest sizes appear on the screen and are placed over the inclusion. Using the mouse scroll wheel then increases the circle size until it matches the inclusion size. Multiple circles can be drawn and linked in the case of inclusion chains. Other pull-down tools are the Cable Wall Thickness Gauge, the Corner Gauge for PEEK Seals, the Auto Rectangle for Void Heights and a focal point indicator.

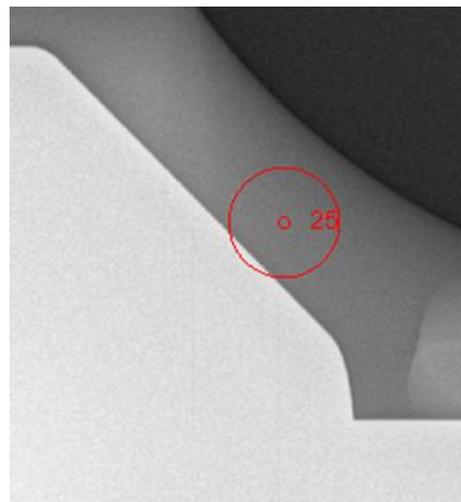


Figure 16: Inclusion Gauge

When all images have been assessed, a Summary Sheet is produced giving the overall result, Pass or Fail. If a result is marginal and a second opinion is required,

the image(s) can be emailed for adjudication.

7. SEA TRIALS

Sea Trials of the DXr1 were carried out on the Global Marine Systems vessel, Wave Sentinel, in late 2012. The camera was found to be robust, not affected by vibration in the jointing space and worked equally well from vessel or shore power.

8. AVAILABILITY

The DXr1 will be available from Global Marine Systems Limited in 2013.

9. FUTURE DEVELOPMENTS

A commonly asked question is can the angular rotation be mechanised? Although this is possible, large motors would be needed and for safety reasons, a large enclosure would have to be added to ensure that operators would not be endangered by the rotating mechanism. So this aspect will stay manually operated for the foreseeable future.

Automatic defect recognition is already being developed for the medical industry and will eventually be available for the submarine cable industry. When this happens, all subjectivity from assessment will be removed and further time savings achieved.