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HIGH END INSPECTION BY FILMLESS RADIOGRAPHY ON LSAW LARGE DIAMETER PIPES FROM EUROPIPE

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ABSTRACT

Pipes for transportation of combustible media are subject to the most severe safety requirements. In order to guarantee best performance during construction and long term services the level of quality and the productivity are continuously increased.

After many years of experience with the Filmless-Radiography (FLORAD) for internal process control (detection of typical weld seam defects like slag and pores), EUROPIPE has eventually invested in the digital X-ray inspection technology for the final release. Therewith the classic X-ray film has been replaced, the environmental impact due to chemicals reduced and the complete NDT process enhanced. By the availability of safe digital images via computer network it became in addition much easier for third party inspectors to monitor the release process. Furthermore the use of a professional data storage system guarantees a safe and traceable long term archival storage with a quick access to all data within minutes. The new installation consists of two separate X-ray chambers. In each chamber two digital detector arrays (DDA) and two X-ray tubes are installed to inspect the weld seam at the pipe ends and areas having indications from the automated ultrasonic testing. EUROPIPE is the first company which has implemented this technology in a highly automated serial production of large diameter pipes.

Keywords: Filmless-Radiography, large diameter pipes, digital detector array, DDA, automated X-ray testing.

NOMENCLATURE

AXION: Automatic X-Ray Image Evaluation
DOKAS: Document Archiving System
DDA: Digital Detector Array
FLORAD: Filmless radiograpy
E-FLORAD: Filmless radiography after Expansion
NDT: Non destructive testing
PRODIS: Production Control and Information System

INTRODUCTION

The first thoughts and activities in the field of digital radiography reach back nearly 40 years. As a result of sustained research and development with numerous trials, in 1998 the time was ripe for EUROPIPE to install an image intensifier based system for the internal quality control [1,2].

The FLORAD system provides a lot of advantages compared to the classical X-ray film (Table 1):

X-ray film	FLORAD
Film costs	No film costs
Costs for film storage	Low costs for electronic storage only
Disposal costs for chemistry	No chemistry
Processing time 10 minutes	No processing required
Very high image quality	Comparable image quality
Available only at one place	Available throughout the mill and beyond
Only manual evaluation possible	Computer aided evaluation possible

Table 1: Advantages of filmless radiography (FLORAD) compared to conventional X-ray film

Of course, the fundamental question is if the image quality of the FLORAD system is sufficient to detect all relevant defects which can be detected with X-ray film. This question was examined independently by the inspection and certification authority RWTÜV, by Shell Global Solutions and by DNV, Norway. All reports concluded that (in the wording of DNV) “the EUROPIPE Filmless Radiographic System (FLORAD) has been found to give at least the same detectability of weld defects as conventional film radiography, and is suitable to replace film radiography”.

After years of experience with FLORAD for the inhouse quality control, EUROPIPE has invested in this upgraded technology for the final inspection after mechanical pipe expansion. With this step the conventional X-ray film was replaced in the UOE pipe mill in Muelheim. The conceptual design of the installation with the name E-FLORAD (Filmless Radiography after Expansion) was developed by EUROPIPE together with the research institute Salzgitter Mannesmann Forschung (SZMF). Beside the introduction of modern technology the main challenge was the integration into a serial production flow (up to 40 pipes/hour) with automated monitoring of traceability and quality assurance.

REQUIREMENTS FOR X-RAY TESTING IN A LSAW PIPE MILL

General Requirements

Since LSAW pipes are typically used for the transport of combustible media the requirements on the NDT process are very high and are continuously increasing. The complete weld seam is tested with an automated ultrasonic testing (UT) system. Each indication of the UT system has to be re-checked and sized by X-ray testing. In addition, it is mandatory to inspect the longitudinal weld seam at both pipe ends with X-ray. Not confirmed indications will be again re-checked by manual ultrasonic testing.

Due to the highest quality requirements, high standards must be applied for the X-ray testing process and a high probability of detection is required. The large throughput in the mill with a cycle time of 90 s per pipe calls for a quick, safe and reliable testing process. In addition, all X-ray images must be archived for at least 12 years. 500000 X-ray images recorded each year enforces a professional and safe solution with low costs of operation.

The pipes produced in the Muelheim works of EUROPIPE cover the following range of dimensions:

Length:	9.0 m ..... 18.3 m
Outside diameter:	610 mm ... 1524 mm (24” ... 60”)
Wall thickness:	8 mm .... 45 mm

It was a major challenge to devise a mechanical set-up by which the digital detector arrays (DDA) could be positioned inside the pipe with the required speed and precision.

Targets to move from film to digital radiography

The following main targets were defined for the transition from film to a digital system:

- Full traceability and data integrity (e.g. use of checksums for digital images)
- Increased reliability of evaluation by optimised viewing conditions and automated evaluation assistant
- Quick access to the NDT Data for third party inspectors
- General improvement of the NDT process by digital administration of all documents in the release process of the pipe
- All documents of the pipe should be digital documents available anywhere in the mill
- Automated long-term archival of all documents including X-ray images
- Avoid chemistry for film processing and costs for proper disposal
- Reduced maintenance by reduced number of X-ray tubes (4 tubes in 2 chambers instead of 12 tubes in 3 chambers)

The complexity of these targets makes it obvious that it was impossible to reach them by just re-fitting the X-ray chambers. The whole NDT process had to be reconsidered and adapted.

TECHNICAL DESCRIPTION OF THE E-FLORAD SYSTEM

Detector and X-ray tube

EUROPIPE started the application of filmless radiography in 1998 within its internal quality control in front of the expansion process. The detector used at that time was an image converter the heart of which is a rather bulky image intensifier tube. Because of its size it was not possible to use the detector inside the pipe. Instead, it had to be mounted on a carriage above the pipe and the X-ray tube had to be mounted inside the long spar within the pipe. This set-up is mechanically complex and reduces the choice of X-ray tubes.

Since then the next generation of detectors (flat panel detector or digital detector array DDA) appeared on the market.

The detector type used now is a Varian Paxscan 2520 system together with a GE ISOVOLT 320/7 X-ray tube. The small detector size of 267mm x 328 mm makes it possible to use it inside even the 20” pipes. The pixel area is 194 mm x 244 mm with a pixel pitch of 127 µm and a grey level resolution of 12 Bit (4096 grey level). This configuration forms the optimum between detector size, sensitivity and spatial resolution for the weld seam testing of large diameter pipes within the existing dimension range.

An example of the installed flat panel is shown in Figure 1 with the main technical data for this detector given in table 2:

Detector size	267 mm x 318 mm (10.5 in. x 12.5 in.)
Detector thickness	51 mm (2 in.)
Pixel area	195 mm x 244 mm (7.68 in. x 9.6 in.)
Pixel pitch	127 µm
Number of pixels	1920 x 1536
Dynamic range	12 Bit (4096 grey levels)

Table 2: Technical data of flat panel detector

Figure 1: Flat panel detector (left) with command processor and power supply (right)

Layout of X-ray chambers and testing procedure

The layout of the X-ray chamber is sketched in figure 2. The pipe is moved over a cantilever type spar into the chamber via rollers. The chamber gate (not shown) is closed and the spar is supported at the free end to avoid vibrations. The pipe is turned to the 12 o'clock position. The detectors mounted inside the spar and the X-ray tubes are automatically moved to the testing positions and the images are recorded. When the testing process is finished, the pipe is moved out of the chamber. The whole process is completely automated. For each image recorded, an associated parameter file is created which completely documents the whole testing process including all X-ray parameters and pipe data.

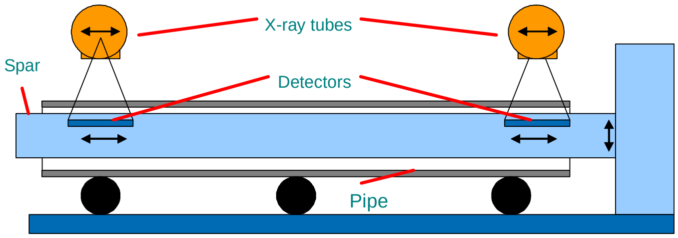

Figure 2: Layout of X-ray arrangement

Figure 3 shows the X-ray chamber with a pipe, the spar and the two carriages above the pipe containing the X-ray tubes. When the pipe ends are tested, lead plates are pneumatically attached to the pipe ends in order to protect the detectors.

To capture all data obtained during the various steps of production and testing and to control these data within close tolerances, an integrated IT-system covering all production stages - from the steel mill to the pipe coating - is indispensable to ensure a precise traceability of data and products [3]. The core of data acquisition and control is the Production Control and Information System under the name of PRODIS, where all information and measuring data required for the pipe production are collected /2/. Therefore, with the change from film to digital detectors, the new possibilities of digital document administration had to be incorporated into PRODIS.

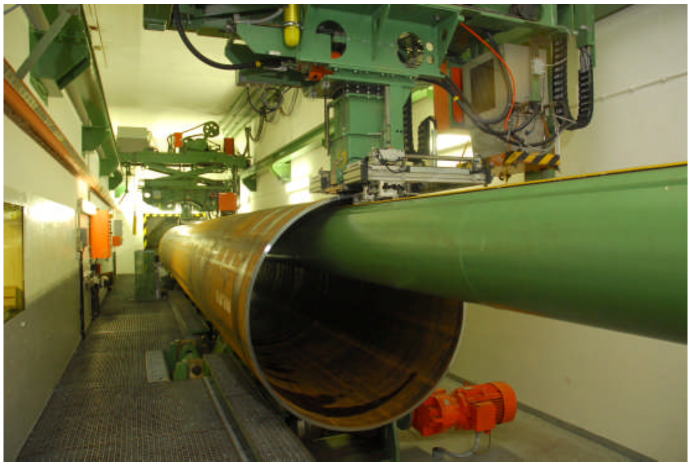

Figure 3: Photo of X-ray chamber

When the pipe now arrives in front of the X-ray chamber, PRODIS transmits all data required for the testing process to the E-FLORAD system which automatically carries out the tests with the help of a PLC. The images themselves and the parameter files are stored on the storage system of the E-FLORAD computer cluster.

Image evaluation process

PRODIS continuously keeps a list of all images recorded. The image evaluators select a pipe at their PRODIS terminal and immediately see the list of images ready for evaluation. They select an image at the PRODIS terminal and the image is automatically displayed on a high resolution monitor at the associated E-FLORAD image evaluation station. The E-FLORAD image viewer provides all the tools necessary to evaluate the image, including the usual brightness and contrast adaptations, filters, geometrical measurement tools to determine the size of defects (the calibration is automatically determined by the geometrical data stored in the parameter file) and to measure the signal to noise ratio of the image. The result of the evaluation is stored in the PRODIS system.

Digital systems have the great advantage of image processing like contrast adaptation, filtering etc. Based on the high amount of radiographs an automated x-ray image evaluation system (AXION) was developed to support the evaluator in order to increase the reliability of detection. This system works on the basis of an intelligent expert system and is also linked to the UT evaluation system to achieve best performance.

Currently the evaluation software AXION examines each image recorded with FLORAD and checks it for possible defects. In the current development phase, AXION is invoked after the evaluator has made his assessment. While the evaluator draws a red rectangle around the defects he has found, suspicious areas found by AXION are marked with a green rectangle and the defect is classified using a database (see Figure 4). This procedure gives the possibility to verify the operation of AXION against the evaluator with a large number of images taken in the regular mill production. The main goal is to increase reliability of detection.

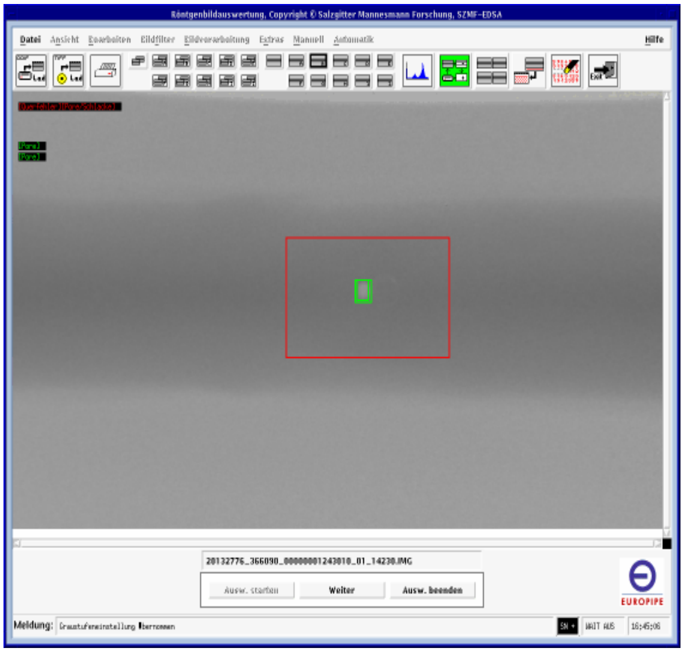

Figure 4: Example of a FLORAD X-ray image assessed by human evaluator (red) and by AXION (green)

PRODIS manages the data access of all orders by login and password for the third party inspectors. It assists the release process by an interactive release list. Herewith it guarantees a quick access to all relevant inspection reports and X-ray images. Through online connection with the NDT department additional activities like re-shots can easily be initiated by inspectors. PRODIS assures the highest amount of traceability and integrated quality management.

E-FLORAD computer and archival system

X-ray films and images are important documents which must be preserved for at least 12 years. X-ray film can easily fulfil this requirement when stored properly. Furthermore, X-ray film testing is a proven and reliable technique for decades. The same level of security and availability is mandatory for any filmless system. With the digital technique it is possible for third party inspectors to have the images rapidly at any place without danger of scratches on the film which would make the film invalid as document. All digital X-ray images will be stored in the same way as the X-ray films for at least 12 years. The retrieval and the handling will be facilitated by use of a digital image data bank.

For the FLORAD system, these features are reached by a redundant cluster of OpenVMS computers with shadowed disks attached to a shared SCSI bus. Long term storage of the images is performed on ISO 9660 formatted CD-ROM disks. In this configuration, the cluster gives the required availability while through the shadowed disks the images are preserved also in case of a hardware failure.

E-FLORAD is also a redundant cluster of OpenVMS computers, but with a multi path FIBRE CHANNEL RAID 1 storage system. It is connected via TCP/IP to PRODIS, the PLCs for the control of the mechanics of the X-ray chambers and to the long-term archival system DOKAS described in following paragraph. Furthermore, an unlimited number of image evaluation stations may be attached to the E-FLORAD system via TCP/IP. Thus, the image evaluators, the responsible NDT engineer, the third party inspector or whoever in the mill authorised to review the X-ray images may inspect them, with the access rights administered by PRODIS.

E-FLORAD has the capacity to store all images locally for several months. Due to the redundant design, absolute data safety and integrity is guaranteed. However, for the long term storage the images are transferred to a redundant archival system called DOKAS. It consists of 2 identical systems equipped with high-capacity tape storage robots located in different buildings on the Muelheim premises in order to provide a high degree of disaster tolerance. The whole archival process also works completely automatically. Data integrity is guaranteed by use of a checksum stored independently on PRODIS and DOKAS. In case off-line images are required they are automatically restored to E-FLORAD from DOKAS.

As PRODIS controls all manufacturing and inspection steps it is possible to collect the relevant inspection reports like for hydrotesting, UT inspection and X-ray in one electronic directory for each single pipe (see Figure 5). These reports are accessible for third party inspectors via network.

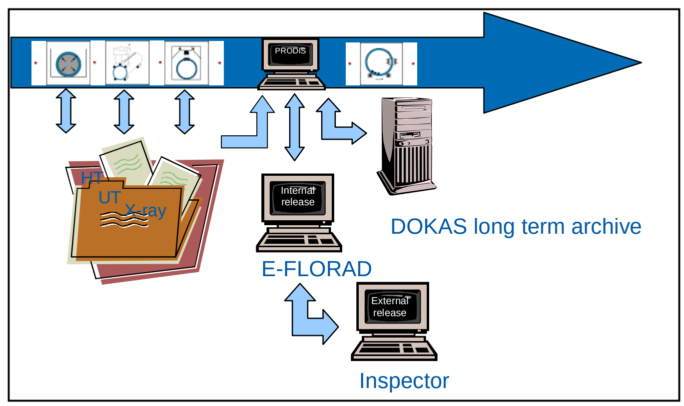

Figure 5: PRODIS and the release process

IMAGE QUALITY AND STANDARDISATION

For film radiography a comprehensive set of standards exists which describe every aspect from the films themselves over exposure geometries, film processing required optical density up to the film viewing conditions. By adhering to the standards sufficient image quality is guaranteed.

Currently there are several activities for developing standards for the use of digital detector arrays like ISO/WD 10893-7 [4]. But it will last another several years to reach the same level of standards like it is available for film technique. Nevertheless, the knowledge about the properties of DDAs has increased considerably in the recent years, which makes it possible to define rules for the proper use of DDAs for a special application.

One of the most renowned institutions in the field of DDAs is the Federal Institute for Materials Research and Testing (BAM) in Berlin. Therefore EUROPIPE and SZMF have asked BAM for a qualification of the E-FLORAD components and procedures before the system was installed in the mill. The required trials were carried out in the X-ray laboratory of

SZMF.

In the qualification statement, BAM has defined guidelines to prove image quality by

- Single wire IQI for contrast resolution (as with film)
- Double wire IQI for spatial resolution (additional requirement)
- Measurement of S/N ratio (equivalent to film density and class)

Currently the single wire IQI is used for radiography as a reference body to check the required contrast sensitivity (contrast resolution in % of wall thickness under inspection). Commonly X-ray films are used as radiographs. The X-ray films have to be processed after exposure by a chemical process (comparable to black and white photography). As the chemical process parameters (e.g. temperature, concentration, etc) have a strong influence on the contrast of the film, each single film has to be checked by a wire IQI to guarantee constant process sensitivity. The draw back that this area on the film is "disturbed" by the wires has to be accepted.

By the use of modern filmless radiography with digital detector arrays the situation has changed completely (it is comparable with the change from black and white photography to digital photography). No chemical process parameters can influence the image quality. For a fixed installation it is necessary to define the right parameters like distances, energy, intensity etc. only once. One check with the IQI will be sufficient then to guarantee the required sensitivity. The long term stability will be guaranteed by monitoring these parameters and keeping them in narrow tolerances. Accordingly the reference of ISO 19232-1:2004 [5] Para. 6 can be applied:

[…If steps have been taken to guarantee that radiographs of similar test objects and regions are produced with identical exposure (…), the image quality need not be verified for every radiograph…]

The advantage not to have an IQI on each image is that the evaluator has an undisturbed image (no area is disturbed by the wires of the IQI); this will improve the probability of defect detection. The additional application of an automated-evaluation-system like AXION is possible which will increase the reliability and the probability of defect detection by compensation of human factor (see Figure 4).

In the hypothetical case that the image quality would not meet the requirements, all pipes have to be re-tested from the last successful quality check. This procedure is analogous to the ultrasonic testing.

Figure 6 gives an example of the image quality check that is performed once per shift by

1. Single wire IQI (hard to see as print out)
2. Double wire IQI
3. Signal-to-Noise value with the help of a software tool (applicable for every image)

For digital radiography in a fixed installation it can be guaranteed that all exposure conditions are identical and no image quality differences are likely. A check with the IQI once per shift is sufficient. Furthermore the digital technique enables the use of additional image quality criteria like the Signal/Noise value which can be measured on every image at any time which is more suitable for the quality check of digital images than the traditional IQI only.

Following these guidelines the E-FLORAD system fulfils all applicable standards (e.g. API 5L, DNV–OS-F101, EN 10246-10, EN 13068-3, ISO 12096). Of course, these guidelines are fully implemented in the work instructions for the operation of the system in the mill.

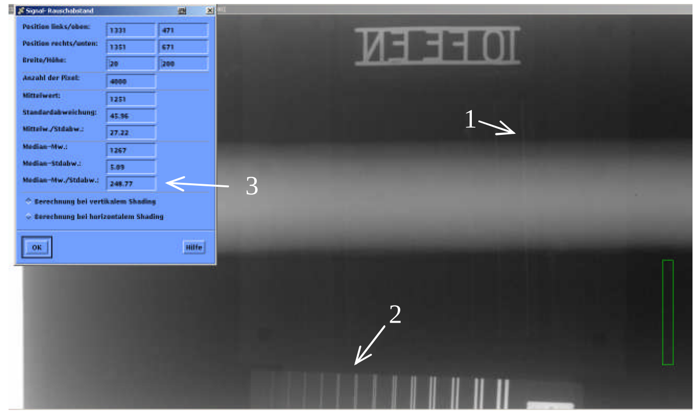

Figure 6: Check of image quality by wire indicator and control of signal-to-noise ratio

CONCLUSION

As a result of longterm research and development EUROPIPE replaced the conventional X-ray film technique by digital X-ray technology. The defined targets like avoidance of chemicals, full traceability and data integration were achieved and lead to an overall enhancement of the NDT process.

The digital system gives at least the same detectability of weld defects as conventional film technique. By the image integration technique a signal-to-noise ratio which is at least twice as good as a conventional C4 X-ray film is achieved. Combined with an enlarged display on a high resolution monitor and a contrast improvement of the 12 bit images the probability of detection of weld seam defects is even better than with conventional film technique. As a matter of course this set-up fulfils all requirements defined for X-ray films. With the benefit of directly available digital images, E-FLORAD improves the complete NDT process. All inspection reports issued during manufacturing like hydrostatic report, UT-report, X-ray images are directly accessible via network, which enables easy communication between third party inspectors and the NDT department. All data are stored for at least 12 years and are accessible within minutes.

Existing standards are describing the relevant requirements for conventional film technology and cannot be endorsed for this new technology due to the deviating physical basis. It is therefore necessary to adapt the existing standards or to develop new ones. This work has started but will need some years to be completed.

For EUROPIPE, the investment into the filmless radiography has been a great success in terms of quality monitoring, process stability and costs.

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