X-Ray Non-Destructive Testing
Example Application: Inspection of High Voltage Cables

Application Note

The University of Southampton, with financial support from National Grid Transco, have developed an X-ray imaging technique that allows non-destructive investigation of high voltage cable joints [1-3]. Defects such as thinning of the semiconducting sheaths, or of the bulk insulation, can be accidentally introduced into the cable joints during manufacture and X-ray imaging allows their inspection. The interfaces between the respective insulation components can be found by differentiating the X-ray image surface profile, which in turn allows the measurement of the thickness of each insulation component. The recorded thicknesses can then be used as a quality measure for a given high voltage cable joint.

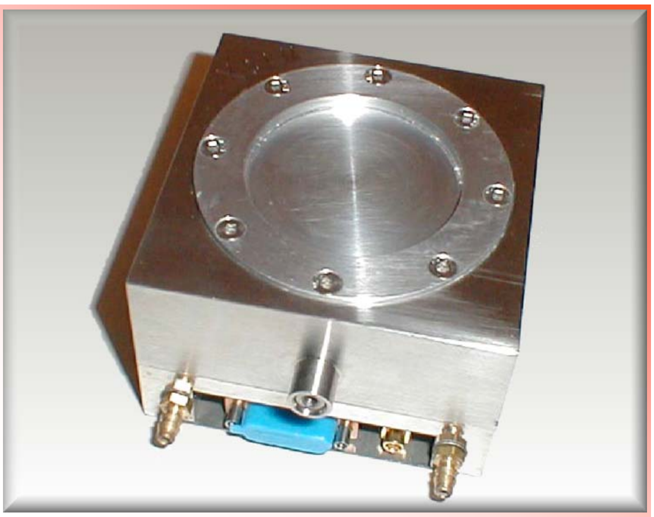

Fig. 1 The CCD camera head housing a CCD bonded to a scintillating fibre optic plate (SFO), supplied by Xcam Ltd.

Non-destructive cable inspection

High voltage cable manufacture is an automated process that ensures the cable insulation is manufactured to a required specification. However, only cables of finite length are manufactured due to transport restrictions, requiring longer cables to be produced by joining sections of cable together. Due to its complexity, the joining of two cables is a manual procedure, and requires a non-destructive testing method to determine if any voids, inclusions, mechanical damage, or reductions in thickness of the joint insulation and semiconducting sheaths have been created. Such defects reduce the dielectric properties of the insulation and have a detrimental effect on the working lifetime of the cable. One method of non-destructively looking for joint defects is to use X-rays and photographic film. This process however, suffers from problems associated with processing and storage of the film; problems that can be removed by replacing the photographic plate with a charge coupled device (CCD) coupled to a scintillating screen [4]. The resulting CCD images can then be analysed using digital image processing algorithms [5, 6], removing the problems associated with the processing and inspection of photographic film.

The work carried out by the University of Southampton has used an X-Tex microfocus X-ray source to generate X-rays and an X-ray CCD camera supplied by Xcam Ltd and shown in Figure 1. The CCD has 2048 $\times$ 2048 13 μm pixels and is connected to a scintillating fibre optic plate with a 1:1 ratio providing a 27.6 $\times$ 27.6 mm field of view, and X-ray efficiency up to 200 keV. The CCD made it possible to produce digital images of small sections of the cable down to feature sizes of 20 μm, with relatively low noise.

Image capture and analysis

The joint used for inspection was a section of 90 kV submarine cable. A CCD image of the joint was then accumulated during 90 second exposures, the median pixel intensity of 10 such images was used to obtain the final image for analysis. The central conductor of the joint was radiologically dense and not easily imaged, but the thickness of the insulation and semiconductive layers were imaged within the 27 mm field of view. The small field of view also required the cable joint to be imaged in 27 mm sections along its length, including some overlap in each image for recombination into the final 61 mm cross section of the cable joint. Tungsten needle markers were positioned just above the surface of the cable in regular intervals to improve the accuracy of this montaging. Figure 2 shows a final montaged image of the cable joint. The tungsten needle markers are clearly visible and labelled in the figure.

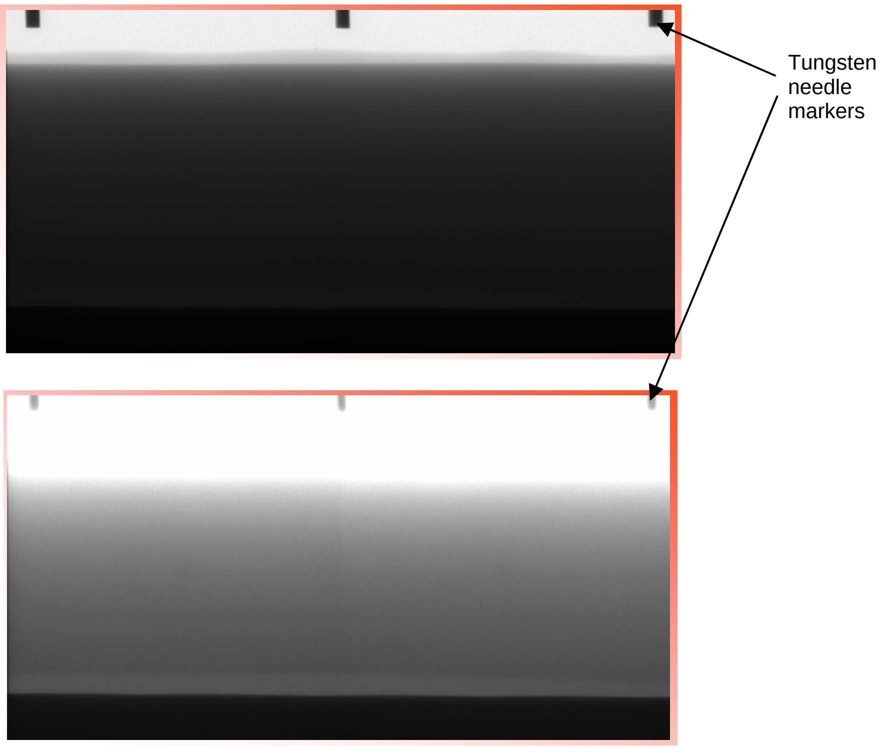

Fig. 2 Two montaged CCD images of the studied cable joint using a different contrast setting in each case to highlight the various layers in the cable

Taking vertical sections through the cable joint image reveals the change in measured pixel intensity through the different layers in the cable. Differentiating these intensity profiles for each column in the image allows the position of the various interfaces to be found: air/outer semiconducting sheath (A/IS), outer semiconducting sheath/insulation (IS/I), insulation/inner semiconducting sheath (I/CS), inner semiconducting sheath/conductor (CS/C). The thickness of each cable layer can then be obtained by counting the number of CCD pixels between each measured interface location and multiplying by the CCD pixel size. The minimum, maximum and average thickness of each layer can then be calculated, providing a qualitative assessment of the cable joint.

Every interface point is then stored in a binary image of the cable joint, the interfaces marked as ones, the rest of the image as zeros. After smoothing to reduce the effects of noise, quantisation and pixelation, the binary images can be superimposed onto the original image of the cable joint to clearly show the interface lines. Figure 3 shows a montaged CCD image of the cable joint, combined with the binary interface image. All four interfaces were found and are labelled in the figure. The measured thicknesses of each layer in the studied cable joint are given in Table 1 and were verified by using a digital vernier at the end of the joint.

Cable Layer	Min (mm)	Max (mm)	Average (mm)
Outer semiconducting sheath	0.94	1.51	1.28
Insulation	14.27	14.69	14.49
Inner semiconducting sheath	1.38	1.56	1.51

Table 1 Measured cable layer thicknesses

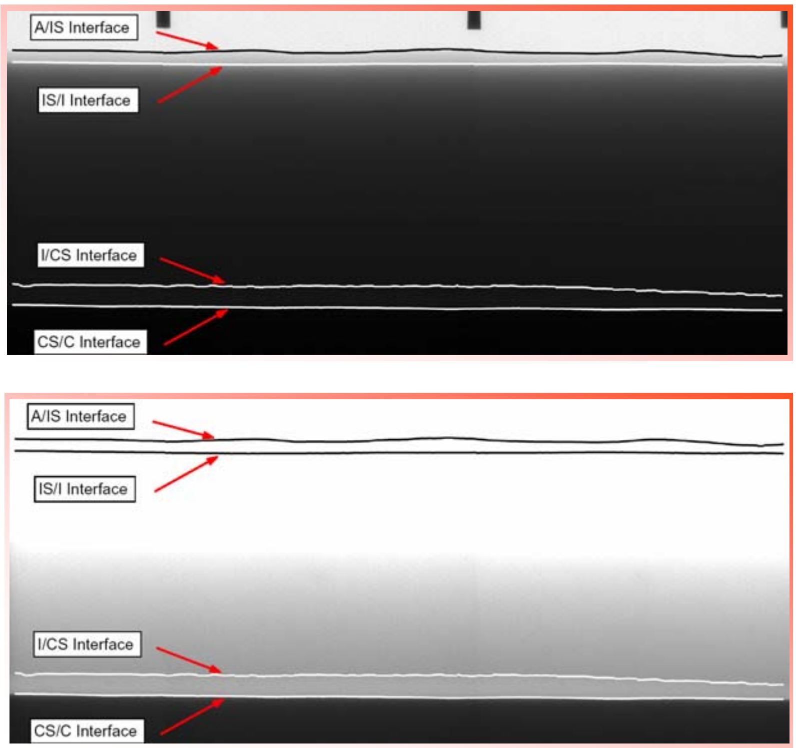

Fig. 3 Two montaged CCD images, using different contrast settings, of the studied cable joint combined with the binary interface image. The different layers in the cable are labelled for clarity

Future developments

This X-ray imaging and processing technique developed has shown that non-destructive imaging of high voltage cable joints is possible using a CCD imaging detector. The boundaries of the various layers in the cable were clearly resolved and measured layer thicknesses were obtained providing data that can be used as a quantitative assessment of cable joint quality. Further improvement to the image processing algorithms should make it possible to convert the new CCD based inspection process to a fully automated process. Development of the process to provide 3D imaging capability is also under investigation. The principle involves imaging the sample cable from 8 angles, each separated by 45 degrees. The interface lines from each of the 8 montaged CCD images are then plotted in 3D space and extra lines added by interpolation before the final solid object is rendered. An example 3D reconstruction of a cable joint is shown in Figure 4.

Further information about the CCD used for this work can be obtained from Xcam.

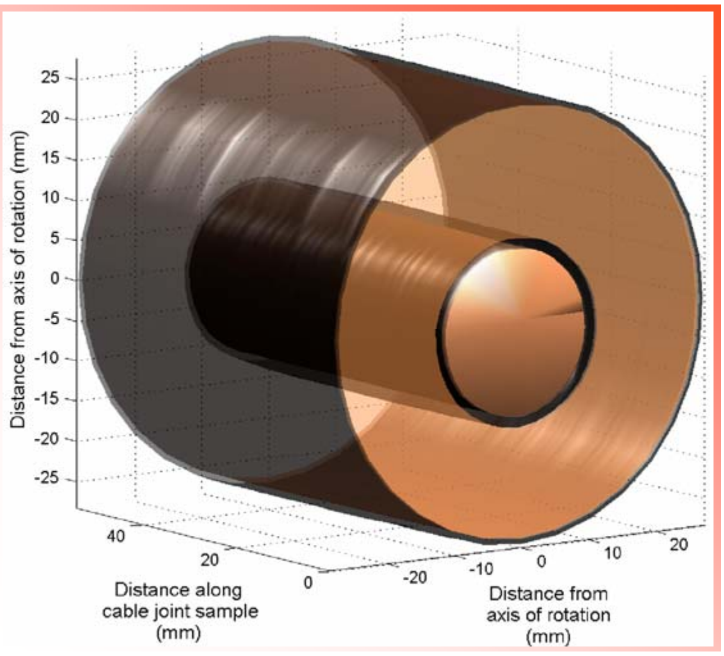

Fig. 4 A reconstructed 3D image of a cable joint, produced by digital image processing of several montaged CCD images

References

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