BACK-SCATTER X-RAY TECHNOLOGY FOR DETECTION OF SUB-SURFACE DEFECTS ACCESSIBLE FROM ONE SIDE

By Jørgen Rheinländer
InnospeXion ApS, www.innospexion.dk

NOTE: This work has in part been accomplished as part of the EU-funded RTD (IP) project "FILMFREE".

Advantages of Back-Scatter imaging

Traditional X-ray inspection requires access from both sides of a structure, i.e., the X-ray source on one side and the detector on the other side. The traditional X-ray image is a shadow-like picture where the contrast depends on the differences in density and the radiation path length through the different structures of the sample. This is usually a very cost-effective way to image structures in real-time, for example on a production line.
However, there are situations where access to two sides of a structure is not possible. In addition, the type of damage or defects searched for may be of dimensions that are not readily visible by ordinary X-ray imaging. In practice, this is often the case for damage of several tens or even thousands of square centimetres, for example on structures such as large panels, air crafts, vessels and many others.
The advantages of back-scatter imaging is indeed the ability to "image" the interior of a structure to depths of 10-30 cm with a good sensitivity for many common defects, including detection of armouring and foreign bodies. Our focus has been to explore the capabilities of the technology while emphasising the need of an affordable and cost-effective methodology.

The Technology

The system that has been developed consists of an X-ray source, 40-60 kV with 25W max. power, a digital X-ray source controller (with RS232 interface) a scintillation detector (complete with MCA and power supply), a set of collimation devices (optionally a remote control collimator can be supplied), a set of linear guides with step motors and step motor control, fixtures and mounting supports. The system price is aimed around 40000 EURO, excluding options.

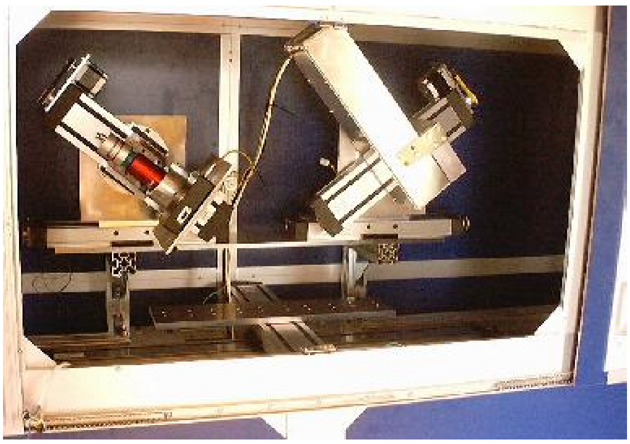


Fig. 1 (left) and 2. The backscatter assembly mounted in a cabinet (object moving) or on a linear guide with stationary object (right).

The system has been developed with particular reference to being deployed for field applications, hence weight and overall dimensions have been of primary concern. The X-ray source and detector assembly is mounted on a C-arm which in turn is mounted onto a linear guide. The length and other characteristics of the linear guide may vary with the application.

Applications

Sandwich panels and similar structures

The technology is aimed for inspection of large structures e.g. for detection of damage in composite sandwich structures. These may involve skin layers of glass fibre reinforced plastics (GFRP) or of carbon fibre reinforced plastics (CFRP). The core is a low density (usually < 0.1 kg/l) material such as PVC foam or balsa. Such materials are intensively used for large panels used e.g. in ship, train and aircraft constructions.

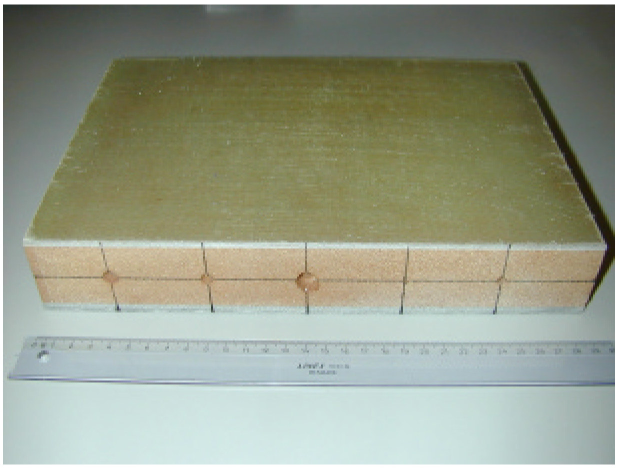


Fig. 3 and 4: Example (left) of a sandwich structure used for laboratory tests. The sample have holes with a diameter from 5 to 15 mm drilled into the central part of the core, cf. Fig. 5. This type of materials have many applications for light and strong structures, e.g. for naval vessels (right).

For the considered structures, the main interest is in the detection of even deeply located defects, caused by manufacturing irregularities, excessive loads and impacts. Backscatter imaging is particularly suited for this kind of defect detection, concerning e.g. voids, agglomerates, density differences etc. Defects in these materials that have a critical impact on the strength of the structure tend to be fairly large, often in the tens of centimetre size.

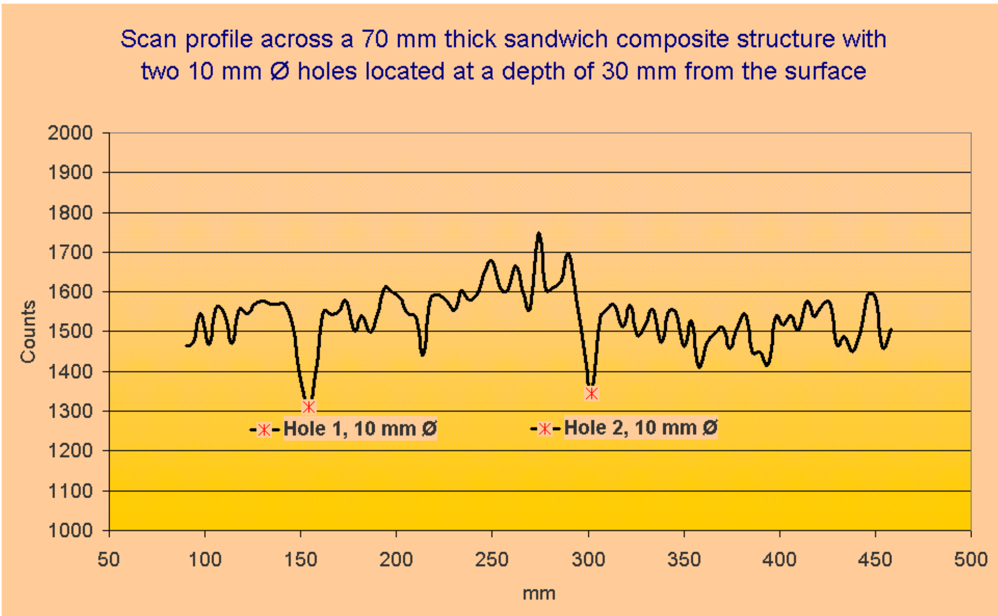
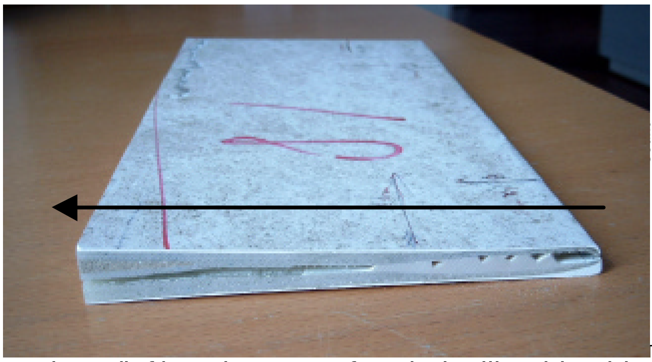


Fig. 5. A backscatter scan through a sandwich sample with drilled holes in the middle of the structure (cf. Fig. 3).

However, the detection capability can be optimised considerably dependent on the material to be inspected. With backscatter imaging the sample is scanned, and it is the scanning resolution that to a large extent determines the spatial resolution. As a rule of thumb, defects smaller than a few tens of a mm are not usually detectable. Also some types of defects can be difficult to detect, this concerns for example very thin de-laminations, lenticular and thin voids, etc.

Glass and carbon fibre reinforced panels

GFRP and CFRP constitute a very important set of construction materials for light constructions, such as e.g. fan blades of wind turbines.
The specific strength requirement is steadily increasing as a result of increasing fan blade length. Hence, defects become increasingly critical relative to the properties of the fan blade and towards safeguarding its quality and fit-for-the-purpose.



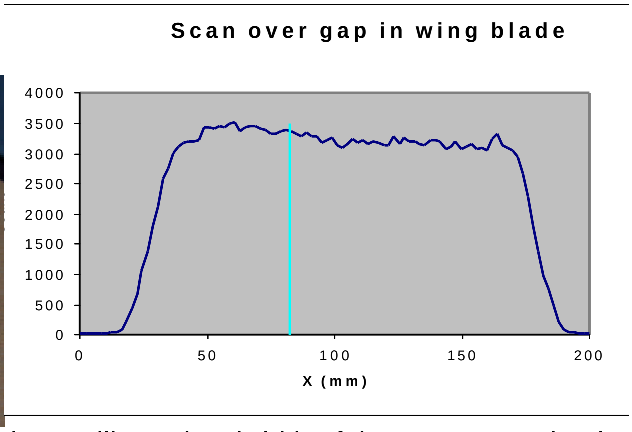


Fig. 6 (left) and 7. Part of a wind mill turbine blade's trailing edge (width of the cut out section is about 20 cm). The gap and the small caves in the glue are considered as manufacturing defects. The arrowed line indicates the position and direction of the backscatter scan, displayed to the right (Fig. 7). The vertical line within the profile indicates the (known) position of the start of the gap.

Fig. 6 and 7 displays the data from a scan over a section from the rear edge of a windmill turbine blade. The defect is a 2mm thick gap approximately 4mm below the surface. This may be compared to a volume de-bond. It is clear from the data that the scattered X-ray at the defect (the gap) becomes less compared to the "normal" area to the left of the "mark" line that indicates the edge of the gap.

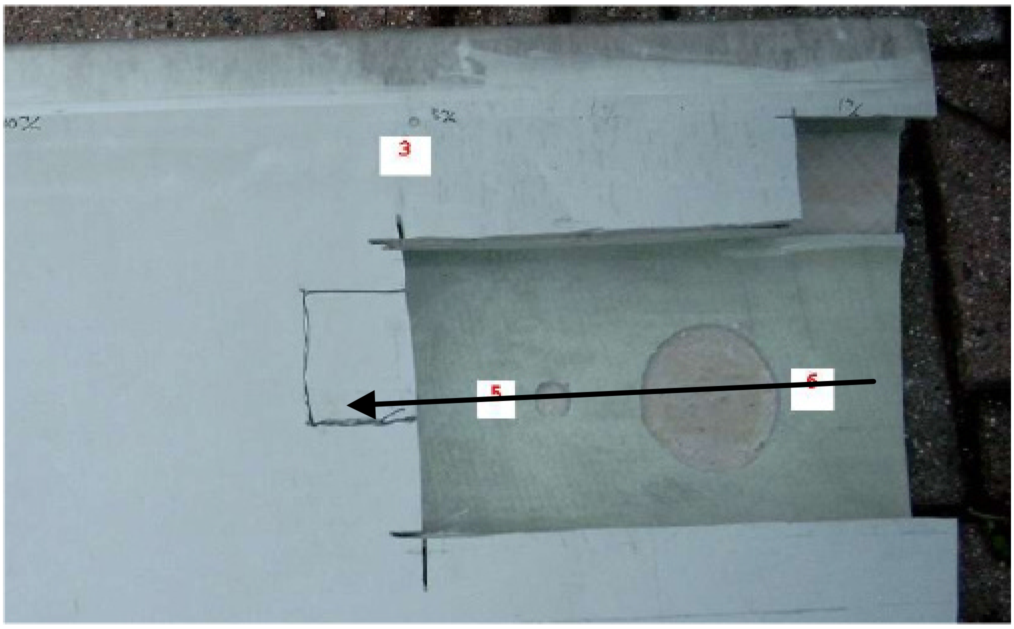


Fig. 8. Part of a wind mill turbine blade specially prepared for inspection studies. Defects made on the sample are labeled with numbers. Defects 5 and 6 were scanned along the arrow line above the surface to the other side of the blade.

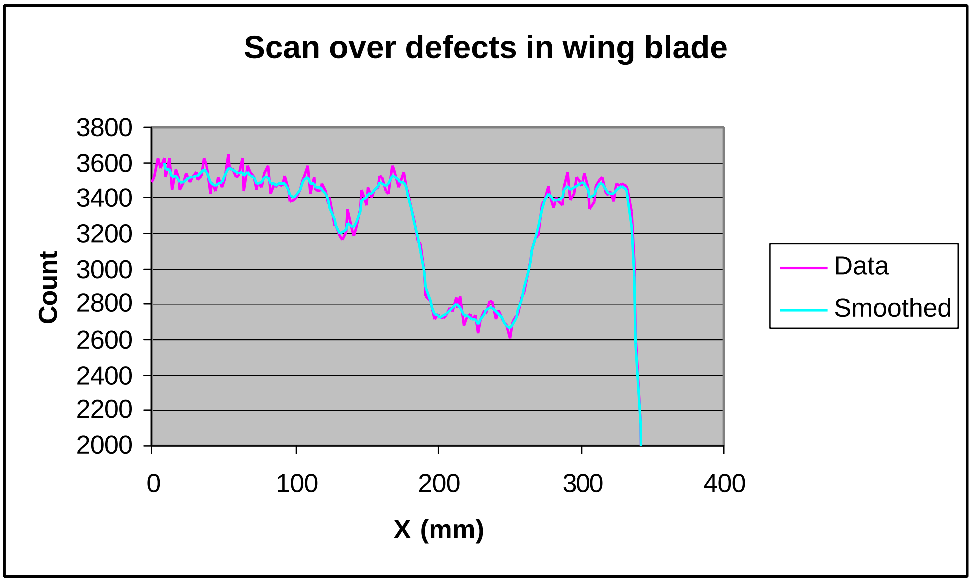


Fig. 9. Backscatter profile across the artificial defects of the sample shown above.The presence of the two defects is clearly unveiled in both cases.

The defects considered can be compared to indents on the inner side surface of the GFRP turbine blade section. One of these is 80mm in diameter (a large defect) and the other is 20mm. The indent thickness of both is about 5mm and about 5mm from the surface. Scans were performed from the out surface of the sample. Both defects are clearly detected.

Metal structures

The methodology has been developed for light structures and hence the X-ray energy is relatively limited. In its present configuration, the technology is not suitable for e.g. inspection of metals such as steel. However, light alloys, such as aluminium, may be inspected. Below are shown examples on the capability of detecting larger volumetric flaws in an aluminium turbine blade.

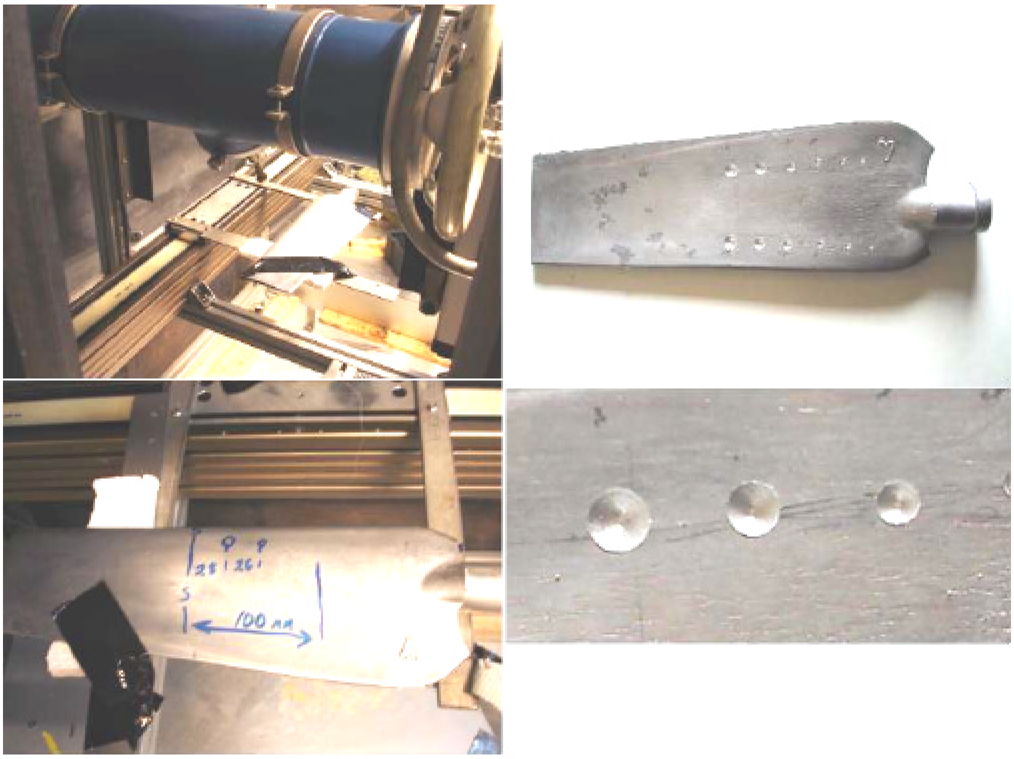


Fig. 10. Image series showing an aluminium turbine blade (approx. 40 cm long) into which a series of holes (round bottom) have been drilled from one side, to a depth of 4 mm from the drill side surface. At the left side is shown the positioning of the sample onto a heavy duty linear guide.

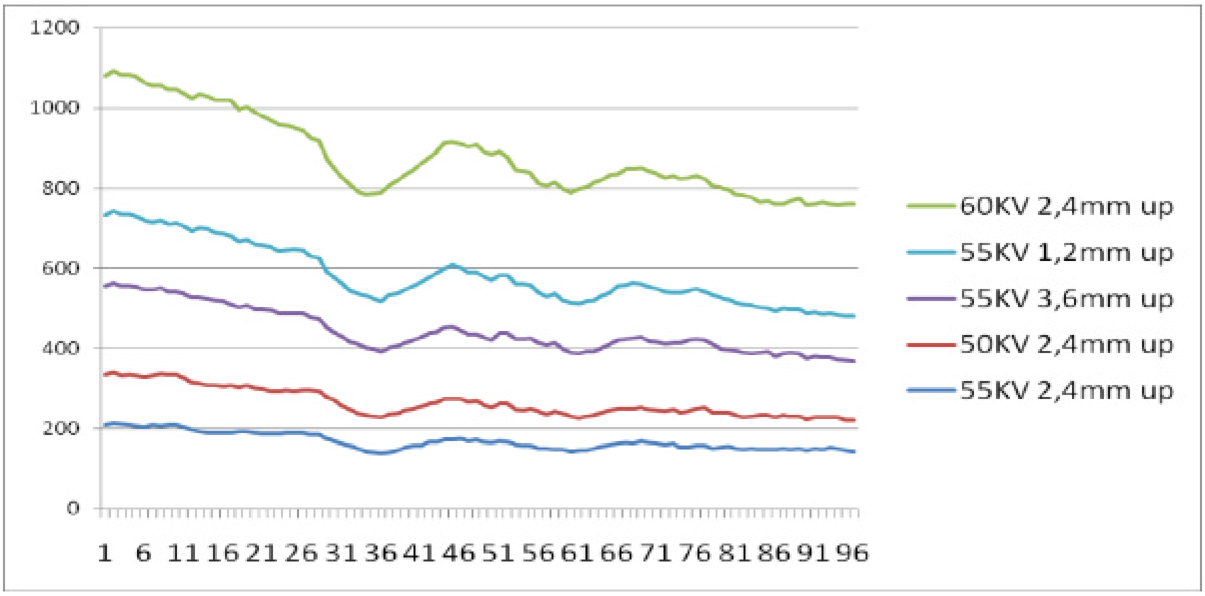


Fig. 11. The set of curves are backscatter profiles across the aluminium fan blade sample seen above. It is apparent, that it is possible to find defects in aluminium. The hole size is Ø12mm, Ø10mm and Ø 8mm, located at X-position 36, 61 and 82, respectively. The depth is 4mm in all cases.

Discussion and Conclusions

The study has unveiled the capability of backscatter X-ray measurement to unveil defects and damage of volumetric nature in a range of light element structures, with access only from one side.

The defects detected with a certain high probability of detection are in all cases relatively large, however they are not likely to be detected by other methods when considering price-performance ratio and the variability of the defects. Candidate methods are ultrasound, shearography and thermography, however, there are concerns on using them all.

The detection capability by X-ray backscatter depends on many factors, mainly of two origins.

The first is set-up related. Two important factors are the X-ray energy and the size of interaction volume.
The number of detected X-ray photon depends on both scatter and total attenuation. In order to obtain high contrast in an inspection, a high scatter to attenuation ratio is favorable. Usually the scattering coefficient is a slowly varying function of X-ray energy while attenuation increase rapidly with decreasing X-ray energy. At sufficiently high energy, materials become “transparent” to X-rays. The number of scattered photons will then only depend on the local density. Data fluctuation caused by variation of the sample, especially those having a rough or/and curved surface, can be reduced in those cases. It is therefore a good advantage, from detection point of view, to use higher energy X-ray than what would be applied for a high contrast “ordinary” X-ray imaging. However the safety considerations may constrain the energy that is practical.

The interaction volume is another important factor. It determines the resolution of a set-up regarding the detection of a defect. A smaller volume is always a better choice provided the counting rate of the scattered photon is sufficient for obtaining good data.

For a certain set-up with chosen X-ray energy and certain detection volume the detection ability depends further on the physical property of the defect, its size and location in the sample, and the physical property of the materials around it.

Further information:

InnospeXion ApS – Horseager 14 – DK 4330 Hvalsø
tw@innospexion.dk - www.innospexion.dk - (+45) 4640 9070