NPL National Physical Laboratory

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Ensuring safety and reliability through non-destructive testing and condition monitoring

Identifying damage and irregularities to avoid failures in safety-critical components and large structures

Evaluate materials in the lab and out in the field

Lab-based non-destructive testing (NDT) can provide in-depth knowledge of the behaviour of a material or component, helping to highlight variations in processes or product quality. NDT is complemented by condition monitoring, which allows potential defects in large structures – such as railway tunnels – to be identified at the earliest opportunity, enabling corrective action before a problem progresses. The Advanced Engineering Materials (AEM) group at the National Physical Laboratory (NPL) offers both lab-based NDT – to identify potential defects in the internal structure of materials – and on-site condition monitoring services to determine the health and integrity of structures, helping to extend the lifetime of critical components and infrastructure in even the harshest environments.

What is non-destructive testing?

The importance of identifying defects and irregularities in the materials of safety-critical infrastructure components cannot be underestimated. Left undetected, they can compromise structural integrity, reduce lifetimes and increase the likelihood of failure. Any such failure could seriously threaten staff or public safety, not to mention the potential for long-term environmental consequences.

This is equally important in materials used for applications that are not safety critical, as minor defects can cause catastrophic failure of parts if they are allowed to propagate undetected. The challenge is to test and monitor materials, components and structures for defects without damaging them. NDT provides a solution to this problem, and encompasses a wide range of analytical techniques that can be used to detect and quantify manufacturing and in-service defects, from on-line production quality control through to operational inspection and life management. It is often the only means of obtaining information about the current 'health' of a material, and is therefore used to evaluate materials and components across a wide range of sectors, including rail, nuclear, automotive, aerospace, marine and many other engineering applications.

What is condition monitoring?

Condition – or structural health – monitoring is vital to ensure that large structures such as bridges, tunnels and power plants are safe and stable throughout their lifespans. These crucial structures are systematically monitored over time, measuring and recording any changes in position, shape or performance to track and assess their condition. This enables early detection of any potential problems, which can then be addressed promptly to avoid further issues. Condition monitoring applications undertaken by NPL include railway tunnels, nuclear power plants, roads, bridges, waterways, power distribution networks and buildings.

Lab-based NDT of internal structures

NPL uses a variety of NDT techniques to investigate the internal condition of materials and identify any defects without the need for destructive sectioning. Our services cover a wide choice of established NDT techniques, including conventional ultrasonics at a range of frequencies, high resolution scanning acoustic microscopy, thermography, X-ray radiography, laser shearography, microwave imaging, eddy current testing and coating thickness evaluation using eddy currents or magnetic induction. Our bespoke service includes simulating in situ conditions for each investigation, for example, performing NDT on one or both sides of a material according to the access available when the component is in position.

Ultrasonic NDT

NPL's ultrasound capabilities encompass everything from the simplest application of contact probes at varying frequencies to C-scan immersion testing of larger samples to high resolution scanning acoustic microscopy. The method chosen is dependent on the specific customer needs and the level of resolution required to determine the characteristics of interest, from evaluation of material or layer thickness, to ultrasonic velocity measurement and the detection of voids, porosity, wall thinning, delamination or cracking.

NPL uses a suite of ultrasound equipment to perform these investigations, including:

Contact probes

Handheld contact probes – ranging in frequency from 1 to 30 MHz, for both longitudinal and shear modes – can be used to assess material properties or locate defects in a component. The probes are coupled to the sample using a water-based couplant, and used to either manually scan every point of interest or to determine the speed of sound within a material using a through transmission method. While this approach is suitable for any type of material, it is important to consider the surface condition of the item, and whether a couplant can be used. Lower frequency 54 kHz probes can be similarly used to assess ultrasonic pulse velocity and cracking in concrete.

These probes are ideal when the samples of interest cannot be immersed in water, or when it is necessary to mimic in situ inspection conditions in the laboratory.

Ultrasonic C-scan immersion testing

Ultrasonic C-scan immersion testing is used to detect, measure and characterise a wide range of manufacturing and in-service defects in materials that can be immersed in water – particularly composites – and is routinely used in the aerospace industry.

Large parts are immersed in a water tank and scanned with 1 mm resolution over a 650 x 650 mm area. Probes ranging from 0.5 to 50 MHz in frequency are used to enable flat, rotational and custom surface-following scans that accommodate difficult geometries.

Scanning acoustic microscopy

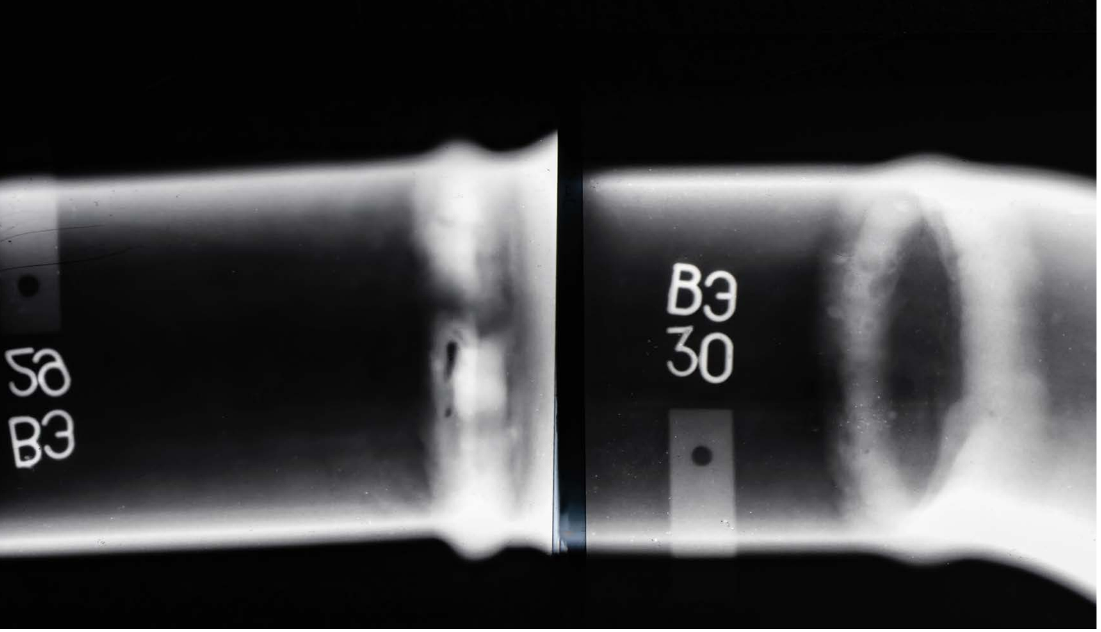
Scanning acoustic microscopy (SAM) also uses water immersion to provide coupling, and can scan at much higher temporal and spatial resolutions than C-scan equipment. It uses focused probes with a much smaller active area, allowing the detection of smaller defects than in conventional ultrasonics. However, SAM is limited in terms of both overall sample size – due to the scanning bed size – and thickness, due to the penetration power of the probes.

NPL's scanning acoustic microscope offers minimum spatial sampling of 5 µm, a 120 µm beamwidth, and can perform scans at frequencies up to 75 MHz. The system can perform tomographic acoustic microscopy imaging, providing the opportunity to 'slice' through the imaging data in a manner akin to X-ray CT – albeit not in 3D – to visualise the position of defects in a sample. This is suitable for identifying porosity and other hard to detect defects in any type of material.

Thermography

Active thermographic NDT is a non-contact technique that involves heating a sample, then looking for variations in the infrared radiation emitted from its surface using an infrared camera. Heating can be achieved in a variety of ways, and variations in the thermal images of the surface can tell the operator about defects that hinder the propagation of heat through the sample. Thermographic techniques can be used to identify near-surface defects, and work best in materials with low thermal conductivity, such as composites. They are less effective in metallic materials.

NPL offers flash, long pulse and lock-in thermography services, which are typically used to investigate voids, delamination and layer thicknesses in composites and other materials where heat propagation occurs at a rate that can be captured. The choice of method depends on the specific testing scenario, with initial flash thermographic testing – to check for detectability of defects – often followed by further investigations using long pulse tests and cameras that retail at a more accessible price point for customers wishing to implement testing themselves.



X-ray radiography

X-ray analysis allows the investigation of both surface topography and internal features without the need to disassemble a component. Exposure to X-ray irradiation generates a cross-sectional image of the density of a component and local variations in radiation attenuation, helping to assess voids, cracking, porosity and wall thickness. X-ray techniques are suitable for most materials, and are particularly effective for assessing metals and other dense materials due to the improved contrast, although very dense metals can pose challenges. This approach is useful for the analysis of complex components where other techniques might prove difficult, although there can be limitations regarding resolution and penetration depending on the material being analysed. The AEM facility has a 2D X-ray cabinet with a 110 kV source and digital scanning bed, providing 83 µm resolution for samples up to approximately 200 x 200 mm.

Laser shearography

There are several types of laser shearography systems available, which vary in their complexity and capabilities. The equipment at NPL measures the rate of change of the out-of-plane surface displacement caused by applied stress without damaging the material, either by direct loading of the specimen or through controlled methods such as heating lamps or a vacuum hood. This non-contact method uses a camera and an applied laser speckle pattern to compare the changes. It is effective for detecting delamination, voids and disbonds in both sandwich and honeycomb structures, but depth penetration can be limited in simple composite panels, and it is less effective for metallic samples.

Microwave imaging

Microwave imaging exploits the dielectric properties of materials, as only those that are not electrically conductive can be penetrated by microwaves. It can provide information on the internal structures of samples, as well as to check for voids, delamination and water ingress. Microwave scanning can also be used to locate conductive materials within a sample as they reflect microwaves, creating detectable signal variations. An XY scanning table enables indexed recording of point measurements that can be used to build an image of the sample, highlighting any anomalous areas. Microwave scanning is most effective at a wavelength of a similar scale to the feature of interest; 10.5 GHz (λ ~3 cm), 24.1 GHz (λ ~1.3 cm) and 34.0 GHz (λ ~0.9 cm) probes are available at NPL, to cater for a range of defect sizes.

Eddy current and magnetic induction testing

Eddy current testing uses electromagnetic induction to detect surface and near-surface defects in conductive materials by measuring changes in induced electrical currents. Eddy current testing and other magnetic induction principles can be used to assess the thickness of non-conductive layers on conductive or ferromagnetic substrates. This approach can measure very thin layers, and is commonly used for applications such as the determination of paint thickness. NPL offers a choice of probes to assess the quality of coating thicknesses across different ranges, as well as for duplex coating measurements.

Eddy current testing can also be used to detect surface cracks in high conductivity, usually metallic, materials. NPL's capabilities include 0.5-1 and 4-6 MHz pencil probes – similar to those used in the aerospace industry – for the detection of small cracks in electrically conductive samples, as well as 60 kHz probes for conductivity testing.

Large-scale digital image correlation for condition monitoring in the field

Digital image correlation (DIC) is an innovative non-contact optical technique used for measuring strain and displacement of micro – and macrostructures in civil engineering projects. This typically includes condition (structural health) monitoring of tunnels, roads and bridges, plus applications for nuclear industries – where access is limited – and energy grids. The objects monitored can range in size from micrometres – measured by scanning electron microscopy – to kilometres, using panoramic image capture techniques at resolutions of >250 gigapixels. Images are compared to assess external surface deformation, in-plane displacements (height, if using 3D DIC), and in-plane strain and shear, which are often caused by thermal or mechanical changes to an object, surface corrosion, weathering or damage. These observations can then be used to derive field displacement and strain parameters.

NPL offers both short- and long-term DIC monitoring techniques that enable feature recognition and detection of common structural defects, including scoping options to reduce the risk to individual organisations. No two environments are the same, and bespoke solutions are frequently required. These must be compliant with relevant regulations and meet all health and safety requirements. Following a site risk assessment, large-scale DIC services can be devised to quantitatively monitor structures and track changes over time. This may involve prototype design and development, and/or bespoke machinery design and build. Algorithms have also been developed that, in some cases, can automatically detect defect signatures in a single pass, avoiding the need for multiple images.

Digital image correlation (DIC) is used to highlight and quantify changes over time. White areas in the lower half of the image show areas of low correlation in the brickwork above, and hence the changes that have happened since the area was last imaged.

Typical DIC applications include, but are not limited to, measurement and monitoring of:

- in situ structural measurements of nuclear facilities and decommissioning structures;
- condition monitoring of the interior of tunnels;
- detection of surface and sub-surface structural faults in brickwork and concrete structures;
- the effect of loading on road bridges;
- vibration and movement in oil and gas processing;
- fire damage to piers;
- residual stress measurement at the micrometre scale;
- crack propagation during mechanical testing; and
- large-scale mechanical testing in the laboratory.

Case studies

Improved understanding of stored nuclear materials

DIFCAM automated tunnel examination

Data handling, combination and integration

DIC generates enormous quantities of data. A tunnel inspection, for example, can produce up to 10 terabytes of data, which must be efficiently and securely processed and managed. NPL has extensive experience in data processing and management, including handling datasets larger than 10 terabytes, and data integration into common asset management software, such as geographic information systems (GIS). DIC can also be integrated with data from other NDT methods, for example, ground penetrating radar, thermal imaging, and any of the techniques discussed above.

Ultra-high-resolution imagery can be collected using conventional digital cameras, off-the-shelf DIC systems or with a bespoke system designed and built by NPL such as Network Rail's DIFCAM trolley (pictured) or Sellafield's HAIS system.

The National Physical Laboratory – giving you confidence in NDT and condition monitoring

NPL is the UK's National Metrology Institute, and aims to promote advances in metrology, underpinning non-destructive testing, condition monitoring and diagnostic engineering – including structural health monitoring – for design and quality assurance purposes. With state-of-the-art facilities and expertise in NDT – complemented by non-destructive evaluation (NDE) services – NPL is ideally placed to serve industry and academia by providing measurements, data analysis, consultancy and research.

The AEM group at NPL has extensive expertise in assessing the quality and condition of materials, components and structures using numerous sensing, imaging and other surface analysis techniques. The team's combination of in-depth knowledge and advanced instrumentation supports materials characterisation, product development, long-term performance assessment and damage monitoring across numerous industries. Our technology-agnostic approach means that customers are assured of impartial information, giving them confidence when designing, building and maintaining structures.

Get in touch with us for more information about our NDT and NDE services, or to discuss bespoke solutions for your unique application.

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