Improving passenger train maintenance efficiency

Shift2Rail's Gearbodies project seeks to reduce passenger train maintenance costs. **Celestino Sánchez Martín**, project manager with Eurnex, **Alkiviadis Tromaras**, research associate with the Centre for Technology Hellas/Hellenic Institute of Transport (Certh/Hit), and **Stefanos Gogos**, technical affairs manager with Unife, outline the objectives and present their initial findings.

THE impact of rolling stock maintenance on operating costs is significant for rail's competitiveness, compared with other transport modes. Rolling stock maintenance is estimated to account for approximately 25-30% of train operation costs and up to 20% of the vehicle's total life cycle cost (LCC). A key challenge for developing new rail technologies is the tendency to increase up-front costs, emphasising the importance of assessing the cost implications of different technologies over the whole life of the asset.

Gearbodies, a Shift2Rail project, is aimed at reducing costs by improving the maintenance efficiency of passenger trains in two critical areas: running gear and the car bodyshell. For the former, long lifetime elastomer components and innovative concepts for low LCC journal bearings are being explored. Regarding the bodyshell, new NDT inspection methods for composite materials are being developed. We will now focus on the latter and present the initial project findings.

The use of composite materials, mainly carbon-fibre-reinforced plastic (CFRP) and glassfibre reinforced plastic (GFRP), for car bodyshell manufacturing has increased in recent years as they offer several advantages not found with aluminium or steel. One benefit is achieving a significant vehicle weight reduction while maintaining or even improving the mechanical structural properties. Additionally, composites have a lower electrical conductivity and higher resistance to corrosion than metal car bodies experience.

Regarding maintenance, the inspection of car bodyshells is usually performed manually and requires inspectors to examine the asset from both the exterior and the interior, which very often requires the disassembly of the interiors. The use of composite materials in car bodies will require new inspection methods during maintenance which could be existing or new non-destructive testing (NDT) techniques.

As an initial step for the design and prototyping of an inspection platform for the automated inspection and assessment of defects in composite car bodies, Gearbodies has analysed the potential of infrared thermography (IRT) and ultrasonic testing (UT) to detect defects in two different composite configurations: monolithic CFRP and sandwich panels composed of a CFRP skin and foam core. The two methods are well established in the NDT industry and are effective in detecting defects or damage on large composite structures such as aircraft and wind turbines. However, the challenge was that the potential material for the new rail vehicle bodyshells would be both thick and inhibit thermal insulating properties. The validation of these NDT techniques therefore began in a risk-free environment using modelling and simulation software. The dimensions and materials considered for the simulations are illustrated in Table 1.

> "The use of composite materials in car bodies will require new inspection methods.

The detection of defects analysis using IRT has been carried out using ThermoCalc 3D modelling and simulation software. Two different techniques have been researched: optical lock-in and pulsed thermography.

Properties	Monolithic	Sandwich
Composition	CFRP	CFRP skins + PET foam core
Overall thickness	20mm	40mm
CF layer direction top skin	Unidirectional 0/90, +/-45	Unidirectional 0/90, +/-45
CF layer direction bottom skin	Unidirectional 0/90, +/-45	Unidirectional 0/90, +/-45
CF skin thickness	-	5mm (front and back)
PET core	-	30mm

Table 1: Properties and dimensions of composites used in the simulation.

To model the monolithic and sandwich samples, the following thermal and material properties were used (Table 2). These properties were extracted from literature and based on materials for potential rail application. All defects were modelled as air gaps in the materials to replicate delaminations and disbonds that could potentially occur from impact damage on the car body's side walls from flying ballast or general delaminations in the CFRP sections from mechanical loading of the train.

To test the ability of lock-in and pulsed thermography on the monolithic material, a series of disbond defects with different dimensions were introduced in the sample at various depths and locations. Table 3 shows the characteristics of the modelled defects.

The results from the monolithic sample showed that both optical lock-in and pulsed thermography simulations were able to detect defects, although both had their limitations. Regarding the lock-in method, the most important factors for detecting deep defects in the 20mm monolithic CRFP sample were that shorter heating wave periods worked better, although a longer heating time was required in the region of 60 seconds up to 120 seconds. Also, retaining high heating power was shown to increase the overall sample's temperature.

The pulsed thermography simulations on the monolithic sample also generated interesting results. First, pulsed thermography proved more reliable for defects up to 5-10mm with good temperature signals as it is intended to be used in real life. However, simulations using realistic heating times did not provide adequate results in the 20mm CFRP sample, probably due to its extreme thickness. Subsequently, heating times of 0.1 seconds were used

Material	Density ρ, kg/m³	Heat capacity Cp, J/ (kg·K)	Thermal conductivity λ, W/ (m·K)
Air (in thin gaps)	1.2	1005	0.070
Carbon fibre reinforced plastic (CFRP)	1600	1200	0.8 (^) 7 (‖)
PET foam	250	524	0.047

Table 2: Additional material properties defined for IRT.

Row	Depth	Location	Defect size
1	2.5mm	Top skin surface	3mm, 5mm,7mm (length and width), 1mm thickness
2	5mm	Top front	9mm,11mm,13mm (length and width), 1mm thickness
3	10mm	Middle	15mm, 17mm, 19mm (length and width), 1mm thickness
4	15mm	Middle back	21mm, 23mm, 25mm (length and width), 1mm thickness

Table 3: Modelled defects in the sandwich sample.

mostly with a heating pulse that was equivalent to 3-6kJ on the sample area 0.09m. Typically, pulsed thermography is very fast and does not include such long observation. However, long observation times lasting between 40 and 60 seconds were used to see how many rows of defects were detectable.

Similar defects were modelled in the sandwich component. Additional disbond defects were added between the two CFRP skins and the foam core.

The sandwich sample proved to be the most challenging of the two components. Following the optical lock-in simulations, Gearbodies concluded that most of the settings, even those with low levels of heating power density, were able to detect defects of at least 3.75mm.

When tracking disbonds, those occurring at 5mm were mainly being detected through their temperature signal. Disbonds that manifested between the foam core and the back wall skin went undetected by every available setting. It remains unclear whether they can be detected in reflection thermography mode due to the PET core being a heat resistant material that probably reflects the heat back towards the source.

Regarding the pulsed thermography simulations on the sandwich component, the consortium found that simulations using realistic heating times provided adequate results in the 40mm CFRP-PET-CFRP sandwich component. However, any defects below the 5mm skin depth and behind the core were invisible. Consequently, additional image processing of short observation time simulations did not provide better defect detectability. Practically, pulsed thermography would only be adequate for inspecting the front skin of the sandwich sample.

Analysis of defect detection using UT was conducted using Comsol FEM-based software with the Discontinuous Galerkin Method to describe the pulse propagation in orthotropic materials. Overall, the UT simulations were aimed at exploring the use of lamb waves and the air coupled ultrasonic method. An additional simulation of the pulse echo technique was conducted for the monolithic component using SimNDT software.

A 10x1mm defect of 1mm thickness was introduced at a 17mm depth in the monolithic sample. The results from the pulse echo simulation show that the defect is detectable. However, its location and size causes energy to reflect back and forth between the transducer and the defect. This can be seen in Figure 1, which shows the C scans of the monolithic component taken from the simulations with and without defects. Figure 1e depicts the initial pulse energy reaching the defect, causing the energy to be reflected back to the transducer (Figure 1f and 1g) while a portion passes through it.

For the sandwich material, lamb waves with frequencies ranging from 100kHz to 200kHz were used in the simulation. It is important to note that 200kHz is preferred according to the air transducers that could be used in experimental testing.

The IRT simulations have proven that both thermography techniques can detect defects up to a certain depth. However, there are limitations with both techniques. With pulsed thermography, the technique has proven to be more effective for defects at a depth of 5-10mm for both samples. Deeper defects, such as 15mm, on the monolithic component, were mostly detectable using the optical lock-in method when heat was applied to the specimen for up to 2 minutes. Hence, defects beneath the foam core of the sandwich component were not detectable with any IRT technique.

UT simulations showed the predominant propagation of antisymmetric lamb wave modes. During the sandwich component experiments, a leakage from the top CFRP skin to the PET core material was observed under the 200kHz simulations. Overall, the simulations have proven that lamb waves can be used for NDT testing of the monolithic and sandwich components. Pulse echo simulations were also conducted on the monolithic component where the use of this technique proved to be a viable option for deeper defects not previously detected by IRT.

The findings provided by the simulations will be contrasted with the findings from the experiments on the CFRP monolithic and foam sandwich to be conducted on material samples. This is part of the second phase of the Gearbodies project and will be carried out during the first half of 2022. **IRJ**

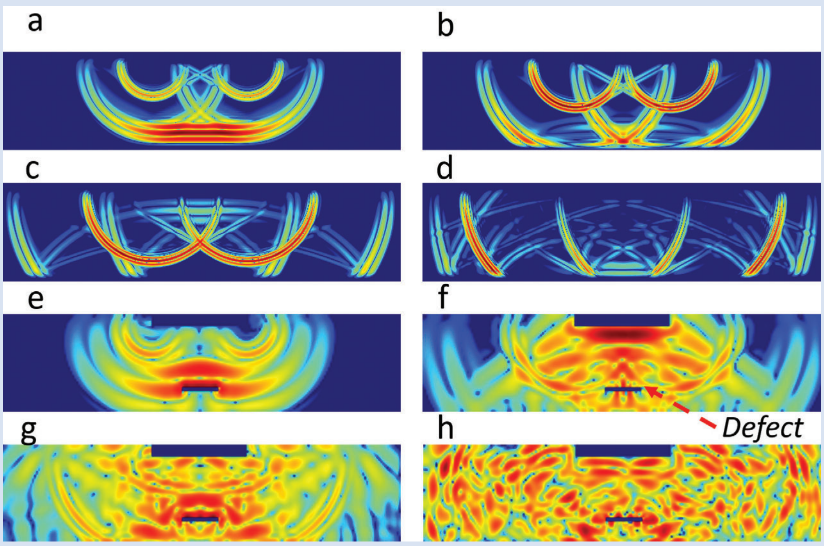

Figure 1: Pulse echo C scans during different moments of the simulation on the CFRP monolithic component. A-D C scans without defect, E-H with defect.