The PanMon pantograph monitoring system has been developed by Ricardo Rail to improve the reliability of electrified routes and protect critical infrastructure. It is already approved by Network Rail in the UK and under evaluation by InfraBel in Belgium, as Anthony Smith reports.
Electrification has been fundamental both to new railway development and the improvement of existing lines across the UK and continental Europe for many decades. With significant benefits in both operational efficiency and environmental impact over the alternative of diesel traction (see panel), this trend is entirely understandable.

The favoured electrification solution, especially where higher speeds and longer distances are involved, is via high-voltage overhead line equipment (OLE), where trains pick up their power through roof-mounted pantographs with contacts that slide along the underside of an overhead contact wire. The crucial interface in this system is that between the pantograph and contact wire. Poorly maintained or damaged pantographs are a significant cause of so-called ‘dewirement’ incidents, in which
Anatomy of overhead electrification

At the heart of the OLE system – which also comprises the supporting steelwork masts and gantries, and tensioning wires known as the catenary – is the ‘contact wire’, which provides the continuous power supply to the rolling stock. This critical component is tensioned in lengths of around 1.5 km, and follows a zig-zag pattern or ‘stagger’ between the support masts which are spaced at around 50 m intervals.

Power is collected by pantographs by means of a series of carbon strip inserts that slide along the underside of the contact wire. These are consumable items, which need to be replaced on a planned inspection and maintenance cycle. The wire’s stagger ensures that the contact patch on the pantograph moves from side to side as the train moves forward, thus ensuring that the wear is an even as possible across the contact strips.

As well as providing the physical contact between the train and its electrical supply, the pantograph also transfers considerable power across this contact patch. To put some numbers to this, in the UK the standard operating voltage of the contact wire is 25 kV AC. At this voltage, the pantographs of an electrical multiple unit commuter train might each draw up to 2 MW, while that of a high-speed train such as a Pendolino – where just a single pantograph is typically deployed for each service – could typically draw up to 6 MW.

Snagging can cause extensive damage to the electrification infrastructure; although comparatively infrequent, these incidents can lead to extensive and costly disruption to rail services.

To help tackle this issue, Ricardo engineers have developed PanMon, an innovative system that uses highway enforcement (speed-camera) technology to continually monitor the pantographs of passing trains, automatically identifying incipient problems and providing real-time warnings to enable immediate corrective action and targeted maintenance. In this way, pantograph problems can be resolved before they cause serious and costly consequential damage to the electrification infrastructure.

Pantographs: the critical interface

The interface between the pantograph and the high-voltage contact wire is thus crucially important, not just for the individual train but for the reliability of the complete OLE system. Pantograph faults are a major cause of dewirements, where snagging of the sliding carbon strip or supporting structure can lead to catastrophic damage to sections of the OLE. While robust and resilient against extremes of weather and normal service operation, OLE systems are necessarily slender and light in their construction, such that the momentum of a speeding train can do a significant amount of damage over a lengthy section of track – in the worst cases, tearing down almost the entire system other than the steel masts.

The financial consequences of this type of damage can be extremely costly, as Ricardo Rail’s business manager for intelligent rail, David Bishop, explains: “In the Netherlands we see around ten dewirement incidents per year, and on the UK’s Network Rail system, around one per month. Each of these costs the industry around £1m on average, but on high speed lines or at major bottlenecks, the situation can be much worse.”

In particular, Bishop cites the examples of a dewirement on the mainline spur tunnel at Heathrow airport in 2016 which was attributed as costing over £1m, while one at Retford on the UK East Coast Main Line earlier in 2017 reportedly incurred £2.5m costs in ‘performance regime’ payments alone (the rebate paid to train operators in lieu of infrastructure-related delays).

For this reason, a system that can provide early warning of the conditions that lead up to dewirement will be of major value to the rail industry worldwide.
technologies, together with smart analysis software, and real-time processing and reporting. “One of my colleagues came across Sensys as a company that had a camera system to capture high speed images of pantographs,” continues Arjan Rodenburg. “The problem was, that while these provide an instantaneous shot of the condition of a given pantograph at a given location, detailed visual inspection of each image would be excessively time consuming. As such, there would be only a very remote chance of being able to identify a failing and potentially damaging pantograph with sufficient speed and efficiency to be able to take preventative action.”

The Sensys camera system is fitted to a gantry immediately above the running rails and contact wire, and takes high speed digital images of each pantograph from above as it passes. The concept of PanMon is based on the use of smart software to very rapidly capture and process the images and, based on continuous learning, to characterize the condition of each passing pantograph.

In addition to its Sensys camera, the PanMon system also uses a high-speed video camera provided by DMA of Italy. This is mounted at pantograph height on a mast alongside the rails, and captures the uplift of the contact wire as each pantograph passes, using LED lights to illuminate the video sequence. Finally, in terms of PanMon’s sensing systems, a tag reader identifies each carriage of each train passing, such that any fault can be immediately traced back to a given vehicle and individual pantograph.

Automatic analysis

As a PanMon installation captures its high-speed photography and video of each passing pantograph, the first automatic processing task carried out by the system is to correct for the perspective and view angle of the camera, so that an orthogonal representation of the pantograph can be constructed from the image. This is then compared by the software against a library of types and designs of pantograph that are known to pass the location. The system then assesses the image for physical damage such as broken or bent structural components which might pose a risk of snagging the contact wire or catenary. Damage such as this can occur as a result of acts of vandalism where foreign objects become lodged in the OLE system, or where maintenance equipment has been erroneously left in place. While such initial damage to the pantograph may have been isolated, PanMon can identify immediately if there is a risk of consequential dewirement – for example, at a junction or points switch location where the train crosses between lines.

In addition, PanMon automatically assesses the wear on the carbon strip inserts of the pantograph. Here the system looks both for the general level of wear – for example, whether replacement should be considered at the next planned depot inspection. More importantly, however, it identifies whether any localized damage has occurred in the form of chipping, which might risk snagging the contact wire as the contact patch moves from side to side as a result of the stagger pattern, or at junctions.

Finally, the video captured is analysed for the uplift of the contact wire as the pantograph passes and for its dynamics as the wire settles following this. Pantographs generally apply upward force either through a spring-loaded or pneumatic system, or a combination of both. In addition, some are equipped with aerofoil sections that add to the contact

Advantages of electric versus diesel traction

According to the Community of European Railway and Infrastructure Companies, around 80-90 percent of the energy consumed by rail operations is used for traction. With their higher efficiency and lower costs – particularly for busier, high traffic routes – electrified routes represent around 60 percent of the European rail network and 80 percent of traffic carried.

According to the UK rail infrastructure authority, Network Rail, electric trains provide the following typical advantages over diesel traction:

- 45 percent lower fuel costs
- 20 percent lower rolling stock leasing costs
- 33 percent lower maintenance costs
- 13 percent less wear to the tracks, with consequent long-term savings in permanent way maintenance costs
- Reduced effective carbon dioxide emissions resulting from superior fuel efficiency
- Quieter and zero emissions at point of use – particularly advantageous in the urban environment
- Superior performance as a result of higher power-to-weight ratios, which allows them to accelerate and brake more quickly

While low-voltage DC third-rail systems (typically operating at 600-750V) offer advantages for some underground, metro and suburban networks, this form of electrification is restricted both in the efficiency of electrical supply, and a maximum operating speed of around 110 mph. As a result, almost all new mainline electrification is provided via high-voltage AC overhead systems, in the UK operating at the standard voltage of 25 kV.
force. Contact wire uplift might be as high as 120 mm and will depend upon train speed and prevailing wind conditions as well as the condition of the pantograph. PanMon can be programmed to take account of such local conditions, and provide warnings if the uplift exceeds the design limit of the OLE.

**Advance warnings**

Fault notification from a PanMon installation can be provided in almost real time, with some installations using the mobile 4G data networks while others communicate directly with the customer railway’s wired communications networks. In either case, PanMon's warnings can be set to specific levels depending upon the damage identified. In extreme cases where there is an imminent risk of dewirement occurring, the network control centre might be alerted to halt a train showing a fault at the next opportunity, either withdrawing it from service, lowering the offending pantograph of a multiple unit train, or switching pantographs for a high-speed train.

Conversely, less severe damage or excessive wear might instead merely be flagged for that pantograph on the next scheduled maintenance operation for the train in question.

**Customer interest**

The UK rail infrastructure operator Network Rail was the first customer to recognize the potential of PanMon to deliver reliability improvements and cost savings, as David Bishop explains. “With the financially-driven nature of a privatized railway, the business case for an innovation such as PanMon is comparatively easy to demonstrate. Each delayed or cancelled service accrues significant financial cost to the infrastructure manager, and dewirements are typically very costly due to the large number of services affected by each incident, and the time taken to fix the OLE and restore normal service.”

Following an initial installation at Cheddington on the West Coast Main Line (WCML), Network Rail formally approved the use of PanMon for use across the whole UK national rail system – a highly significant step as PanMon remains the only such system certified for use by a major network operator.

Orders have already been placed for two PanMon systems to protect the Heathrow airport spur at the entrance and exit tunnel portals, underscoring the particular attraction of using a system such as this to protect critical infrastructure where service disruption would be particularly costly.

Beyond the Cheddington installation, where a further three units are earmarked for the three tracks not currently instrumented, a further pair of four-track installations have been identified for the WCML route, with potential further applications on many other UK electrified mainlines.

In Brussels, the Belgian state railway operator, Infrabel, is in the process of evaluating a system with a view to its eventual certification of PanMon for the national network. Current work is ongoing in developing the software-based library of pantograph types and fault analysis to capture the requirements of the Belgian rail system.

“PanMon is effective for all vehicles using pantographs, from international high-speed trains travelling at 340 km/h to city centre trams,” explains Bishop. “Damage to pantographs and contact wire is most likely to be serious for trains travelling at speeds above 80 km/h, and the consequences are most costly on the busiest of routes. As such, the optimum locations for PanMon installations are likely to be in the protection of ‘golden assets’ such as major junctions and system bottlenecks, or key locations. The order already received for the tunnel portals into and out of Heathrow airport demonstrates just that.”

**Future OLE monitoring technology**

If PanMon provides an instantaneous health check and emergency warnings regarding the state of every pantograph passing a given location, a further Ricardo Rail smart monitoring innovation is under development aimed at assessing the condition of the OLE. The CatMon system comprises a range of sensors fitted to an individual pantograph, which continuously feeds back data regarding the contact wire. Chipping of the carbon strips of pantographs is thought to occur most frequently at so-called ‘hard spots’ where the flexibility of the contact wire changes sharply. This can be, for example, at insulator sections, or at junctions.

Rolling stock equipped with CatMon will thus be able to report back, in real time, the location of hard spots or excessive contact wire flexibility, enabling OLE maintenance to be more proactive in targeting locations that might be either at risk of failure themselves, or having the potential to damage pantographs and hence lead to dewirements in other parts of the network.

“Ricardo has something of a unique position in the international rail sector in that our engineers have detailed asset knowledge of both rail rolling stock and infrastructure systems as well as railway operations,” concludes David Bishop. “PanMon and CatMon are just two among a range of innovations that we are developing and making available to customers, based on the generation of real-time condition monitoring and analysis.”

“Collectively, these intelligent railway systems can help rail infrastructure and operations businesses to manage safety-related risks in real time, and to develop improved asset management and cost-effective maintenance processes. In this way, we are able to make a significant contribution in improving railway performance while driving down costs.”