Keeping Crossrail cool and smoke-free

London's £14.8bn Crossrail project will use a sophisticated ventilation control system to cool trains and to extract smoke if there is a fire. The developers used real hardware to simulate the system, which includes 48 fans and 160 dampers, and the set-up is now being used to train operators.

The £14.8bn Crossrail project, now nearing completion in London, is one of the largest infrastructure projects of its kind in Europe. Intended to carry more than 200m passengers every year, it involves building 42km of twin-bore tunnels and ten new stations, as well as improving 30 more. The finished railway, which will be named the Elizabeth Line when it opens in late 2018, will take in 40 stations and stretch around 100km from Reading and Heathrow to the West of London, to Shenfield and Abbey Wood to the East.

The project will increase the passenger capacity in central London by 10% and is predicted to add £42bn to the UK economy. It will bring an extra 1.5 million people to within 45 minutes of central London, and cut journey times from Heathrow Airport to the City of London from 55 to 34 minutes.

A critical element of the project is the ventilation system consisting of 18 tunnel-to-surface shafts containing 48 fans rated at 350–500kW, and more than 160 dampers. The system will both cool trains and stations during normal operations, and extract smoke to help passengers to evacuate safely in an emergency. Hundreds of ventilation and back-up modes have been devised to cope with almost any potential scenario.

All modern metro systems include a tunnel ventilation and control system (the VCS) to ensure that the required mode of ventilation can be selected quickly and easily by operators. Given the number of variables that determine the required ventilation mode – including train positions, the location of any fire, and the availability of ventilation equipment – the control systems have to process a complex set of logic, and yet keep the user interface as simple as possible. The system has to ensure that, in an emergency, delays are minimised – and that any actions that need to be performed by operators are simple and obvious.

The £3.9m contract for the Crossrail ventilation control system (VCS) was awarded to a Siemens-led team that includes a London-based system integrator called Applied Industrial Systems (AIS), which specialises in tunnel control systems. The contract was awarded by ATC (a joint venture between Alstom, TSO and Costain), which is responsible for fitting out the tunnels, including mechanical and electrical systems.

The VCS is integrated with the signalling system and a site-wide Scada system. The system has been designed to SIL2 safety levels. It uses custom-designed software based on SIL-rated Siemens S7-400FH PLCs and WinCC OA (Open Architecture) Scada software. Siemens has also supplied 18 motor control centres for the fans and dampers. Touchscreen HMIs display all of the data that operators need to initiate emergency modes quickly and reliably. ABB has supplied the variable-speed drives that control the fans.

The VCS interface uses information on train locations from the signalling system to control the ventilation system for normal and emergency ventilation. The signalling system, in turn, uses the status of the ventilation system to limit train movements in the event of a ventilation shaft not being available.

Designed to deliver 99.96% availability, the ventilation control system is operated from a regional control centre (RCC) via colour touchscreen HMIs integrated with local WinCC OA servers to provide system-wide control. If the RCC is unavailable, a backup control facility provides full redundancy.

Multi-mode

The Crossrail VCS has to perform a complex logical functions to set up the ventilation modes for both normal operations and emergencies.

As trains move through the tunnels, they create air pressure due to the piston effect – the sensation of a breeze that usually precedes a train arriving at an underground station. This is dissipated through dampers that allow the forced air to escape up relief shafts.

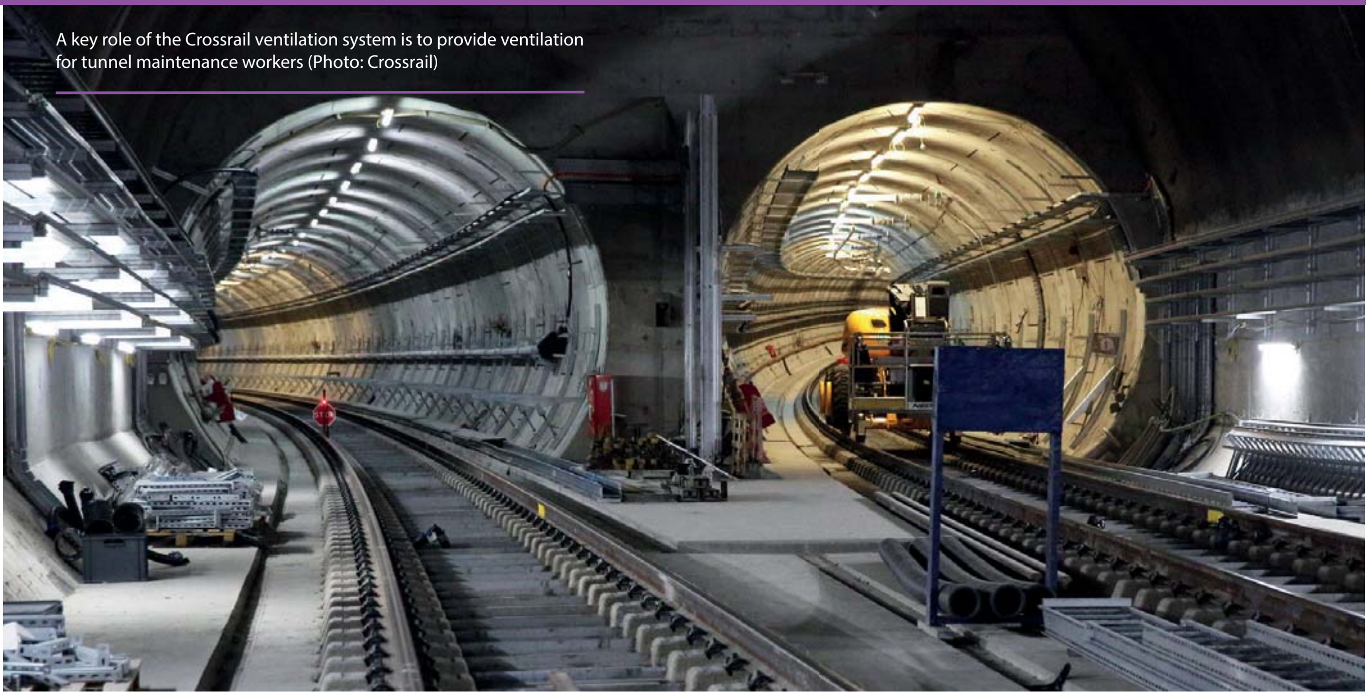
Forced ventilation – provided by the shaft-mounted fans – has four roles:

- to remove heat from trains in stations, via under-platform extract ventilation that can be scheduled to run in warm weather;
- to provide a cooling airflow to maintain air-conditioning on trains when they are stopped in tunnels;
- to provide fresh air and extraction for workers in a tunnel when it is closed for maintenance; and
- to control smoke if there is a fire in a tunnel, allowing passengers to be evacuated via an escape route with a fresh air supply – smoke is extracted in one direction, and the passengers escape in the other.

The £14.8bn Crossrail project will boost central London's passenger capacity by about 10% when it opens later this year (Photo: Crossrail)

Some of the operating modes are triggered automatically – for example, ventilation to cool trains that are stopped in tunnels. Others are initiated manually – for example, ventilation during tunnel maintenance, and ventilation to control smoke in the event of a fire. The reason that smoke extraction is not triggered automatically in the event of a fire is that any tunnel fire is likely to be on the train rather than in the tunnel (which contains no flammable materials). Personnel on board any affected train will therefore be in the best position to assess the situation and how to react to it, rather than relying on "dumb" sensors.

The ventilation system has been programmed to respond the a variety of circumstances, such as directing cooling air when several trains are stopped simultaneously in a section of tunnel between stations. Similarly, in the event of a fire, the way the ventilation system behaves depends on the number of trains in the tunnel and their locations. ■



A key role of the Crossrail ventilation system is to provide ventilation for tunnel maintenance workers (Photo: Crossrail)

Simulation and training

The critical and complex Crossrail ventilation control system was developed and tested at AIS' offices in West London, using a test suite that simulates the VCS input and output equipment.

A team of software engineers has been testing every operating mode that could feasibly be required of the VCS. The test system uses Siemens' Simba Pro simulation devices to mimic the action of the fans, dampers and more than 500 actuators that control the airflow in and out of the 18 ventilation shafts.

The simulator can test the operational modes of each shaft sub-system, as well as master modes for system-wide ventilation. It includes all of the display screens and operates as it will when installed on site.

The aim is to test the logic controlling all of the operating sequences fully, including back-up modes that are needed if one or more ventilation shafts are unavailable. This has taken a considerable amount of time because there are thousands of permutations of possible equipment failures. The system is designed to be fault-tolerant, and testing has had to prove this as part of the validation and verification activities to comply with SIL2.

Installing hardware to simulate the operation of the PLC I/Os was crucial because it allowed the test team to write scripts that simulate all of the various I/O responses. Faults, such as damper failures, can be simulated to enable testing of all the back-up modes.

Although it would have been possible to test the software without simulation, this would have taken longer and been less accurate. Each scenario would need to be simulated by connecting the I/O to switches, lamps and potentiometers to simulate the operation of the field equipment. Several people would have been needed to operate the test equipment for each scenario.

The test system is connected to an example of each item of the field equipment. This not only tests the interface, but also ensures that the field equipment operates as expected and that the simulation is accurate.

The philosophy adopted for Crossrail testing had one aim – to ensure that by the time the system arrives on-site for commissioning, no logic or software changes will be needed.

Using the simulation approach, the developers say they are as near to 100% confident of achieving this aim as it is possible to be.

The simulation set-up has also been used to train Crossrail operators.

When operated manually, the ventilation control system needs an operator – usually the traffic controller – to initiate the required ventilation mode. Because most manual interventions will be in response to emergencies, training personnel to use the system is vital.

The operator of the new Elizabeth Line, Transport for London (TfL), was keen to engage its operating staff early on in the project – especially with regard to the design of the HMIs through which they will interact with the tunnel ventilation system.

When designing HMIs, getting the right combination of detail and complexity is a balancing act. Too little detail on control screens, and the operators will lack the information needed to make informed decisions. But too much detail can bring unnecessary complexity, leading to muddled or slow decision-making. In an emergency, operators need to decide how to apply the tunnel ventilation within seconds. One of the best ways to achieve this is by involving them in the design process from an early stage.

Although people are not always good at specifying exactly what they want, they can quickly pinpoint what's missing or wrong. AIS allowed the operators to influence the design and development of the HMIs by suggesting changes and enhancements before these became too costly.

The control staff have thus become embedded in the design process and have much greater ownership of the delivered system.

For instance, when developing the HMI screens, it became apparent that in areas where the Crossrail lines split to take passengers either North East or East, the screens were too complex to monitor. Based on feedback from the operators, AIS simplified the displays, making it easier for them to respond rapidly to a potential incident.

The simulator has two user interfaces – one for trainers, the other for trainees. The trainer can set up operating scenarios – with the trainee's screen looking as it would for the live railway. The trainer can then introduce emergencies – such as a fire on a train – and the operator has to respond appropriately. The system monitors the operator's response and reports whether it was appropriate. This is used to correct their actions interactively and to provide further scenarios.

Apart from making training much more relevant, this approach also means that training sessions can be repeated over time. Operators can maintain their skills and become more confident about operating the ventilation control system in an emergency.

A simulation suite containing examples of the hardware used in the ventilation control system has been used to develop the system and to train operators.