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Integration of a Water Mist System for the critical Life Safety Control System: The Example Dartford Crossing, UK

This paper describes how a watermist system was fire tested and installed in the Dartford Tunnel, a focus being the integration of the watermist system into the Life Safety Control System (LSCS). As this tunnel has a cast iron lining in some parts and is also part of one of the most important traffic routes in the UK, the overall process faced some considerable challenges, including especially fire testing, integration into the overall control system and mechanical installation. Even though watermist systems in tunnels have been extensively tested and proven in full-scale fire tests, this tunnel with cast iron lining posed special requirements in terms of temperature tolerances, which had to be proven in tunnel fire tests. Secondly, the integration of the fixed fire fighting system (FFFS) into a highly available Safety Integrity Level (SIL) 2 rated control system has never been implemented in a tunnel before, leading to a challenging task. Last but not least, the installation of the FFFS into a tunnel being refurbished with continued operation requires an extremely well organized project management and installation team. These issues will be described in the following chapters.

Einsatz eines Wassernebelsystems für kritische Steuersysteme beim Personenschutz: Das Beispiel Dartford Crossing

Dieser Beitrag beschreibt, wie ein Wassernebelsystem im Dartford Tunnel im Brandversuch getestet und installiert wurde. Ein Schwerpunkt des Beitrags liegt auf der Integration des Wassernebelsystems in das Personenschutzsystem. Da dieser Tunnel in einigen Teilen über eine Auskleidung aus Gusseisen verfügt und zudem auf einer der am stärksten genutzten Verkehrsrouten in Großbritannien liegt, war der gesamte Prozess mit erheblichen Herausforderungen, u. a. spezielle Brandversuche, die Integration in das Gesamtsteuerungssystem und die mechanische Installation, verbunden. Obwohl Wassernebelsysteme in Tunneln umfassend getestet und sich in Brandversuchen im 1 : 1-Maßstab bewährt haben, stellte dieser Tunnel mit seiner Auskleidung aus Gusseisen besondere Anforderungen an die Temperaturtoleranzen, für die die Zuverlässigkeit im Tunnelbrandversuch nachgewiesen werden musste. Hinzu kommt, dass die Integration eines ortsfesten Brandbekämpfungssystems in ein hochverfügbares Steuersystem der Sicherheitsintegritätsstufe (SIL) 2 zuvor noch nie in einem Tunnel umgesetzt worden war, so dass dieser Aspekt eine anspruchsvolle Aufgabe darstellte. Und nicht zuletzt erfordert die Installation eines ortsfesten Brandbekämpfungssystems in einen Tunnel während der Sanierungsarbeiten bei Fortsetzung des Betriebs ein extrem gut organisiertes Team für das Projektmanagement und die Installation. Diese Punkte werden in den folgenden Kapiteln behandelt.

1 High pressure watermist systems for tunnels

Following several fire catastrophes in road tunnels, safety standards and especially design fires have changed. A new EU directive with significantly higher safety requirements including minimum standards for the trans-European road network has been introduced followed by national standards in most countries [1].

Several major research projects have been carried out to investigate new potential measures for tunnel safety. High pressure watermist systems in particular have been extensively tested in full-scale fire tests in various government supported projects such as FiT (Fires in Tunnels), UPTUN (Upgrading of Existing Tunnels), SOLIT and SOLIT2 (Safety of Life in Tunnels). As a result, it can be summarized that watermist systems not only improve safety for people in tunnels and support firefighters reaching the fire source, but in particular are also very effective in cooling the tunnel structure [2].

The technology has consequently been improved and designed for the use in the harsh tunnel environment. As watermist systems fight fires directly at an early stage and control the heat release rate (HRR), reducing temperatures and smoke volume, they can lead to major cost savings, e.g. in reducing ventilation capacities and replacing passive fire protection measures. Short downtimes due to minimal damage, even after severe fires, help to ensure business continuity for the operators. In many cases, insurance costs could also be significantly reduced.

Fig. 1 *Activated watermist system in the Dartford Tunnel*

2 Life safety control systems

Life safety control systems (LSCS) have been developed in response to the increased safety requirements being demanded by tunnel operators. The latest European Union directives require enhanced measures to protect tunnel users in the event of fire or other life threatening incidents [1]. The requirement is for systems that in the first instance support self rescue – so that users can be safely evacuated – and then provide a more tolerable environment for firefighting and other emergency services to enable them to enter the tunnel and deal with the incident in order to protect the infrastructure if possible.

The systems used to provide these life safety functions typically include ventilation fans, incident detection systems and FFFS. The role of the LSCS is to integrate the control of various systems into a single system with a single user interface, combining decision support with automated control.

During an incident, these usually disparate systems need to be operated as an integrated overall life safety system by the tunnel operations staff. The systems need to be deployed correctly and their deployment maintained in order to provide the best tunnel environment for evacuation and protection of the infrastructure.

3 Example case – Dartford Tunnel

The Highways Agency, which operates major roads for the British Ministry of Transport, decided in 2010 to upgrade the Dartford Tunnels to meet the European Union directive. The upgrading process including the related challenges is described in this chapter.

3.1 Dartford-Thurrock Crossing

The Dartford Crossing comprises a bridge and two tunnel bores connecting Grays in Essex on the north side with Kent on the south side of the Thames. The Dartford Crossing is part of the M25 motorway ring round London and is one of the busiest and most important traffic routes in England and the UK. Around 150,000 vehicles use the Crossing on an average day. Both tunnels are approximately 1,430 m long and have two traffic lanes each. The older of the two tunnels, which was opened in 1963, is lined with cast iron and thus represents a particular risk, especially in case of fire.

3.2 Fire safety upgrade

Tunnel safety experts at the operator Highways Agency analysed various possibilities for the refurbishment of the tunnels. The main objective was the protection of the structure and thus the availability of the tunnel, the safety of human lives and conditions for fire services.

After evaluating different upgrade possibilities it was decided to install a high pressure watermist system FFFS. Passive protection panels were not considered as an appropriate upgrade since the tunnel lining has to be visible for frequent inspections.

The contract for the design, fire testing, installation, commissioning and service of the FFFS was given to Fogtec Fire Protection. Fogtec has previously installed high pressure watermist systems in various road tunnels and has broad expertise in this field including various research projects.

3.3 Watermist system

Very stringent and demanding targets were set by the Highways Agency for the performance of the watermist system. As the cast iron structure of the older tunnel bore is critical if exposed to high temperatures over a long period of time, the requirements for the FFFS were set to a high level. Important reasons why this technology was chosen were limitation of fire extent, prevention of fire spread and the cooling effects of the watermist system, especially at the tunnel crown where maximum temperatures are specified for the tunnel structure.

The fire tests were subcontracted to IFAB (Institute for Applied Fire Safety Research). IFAB has long term experience in carrying out full scale fire tests in tunnels and was seen as the best partner for this challenge. The tests were carried out in the test tunnel of TST (Tunnel Safety Testing S.A.) in northern Spain; the tunnel geometry of the test tunnel is similar to the Dartford tunnel and was seen as the ideal location.

The performance of the system was to be proven in full scale fire tests. As worst case scenario, a severe class A HGV fire of minimum 100 MW HRR was chosen, represented by a mockup of wooden Euro pallets. In addition, the FFFS should prevent spill over to adjacent vehicles.

One of the demanding requirements was not to activate the system until 30 MW HRR were reached. Additionally, 40 MW HRR should not be exceeded during the entire activation period and the HRR should be reduced to maximum 25 MW HRR after 15 minutes.

Engineers from both Fogtec and IFAB took into account these specifications in the design of the exact layout and nozzle type. A wide range of measurement equipment was set up including devices to record temperatures, heat flux, gas concentration, air velocity. Some measurement equipment had to be well

Fig. 2 *Full scale fire test*

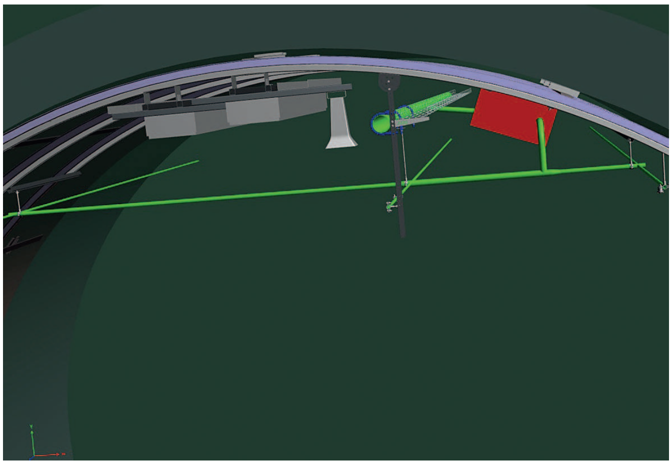

Fig. 3 *3D-model of the FFFS architecture*

protected to withstand the high temperatures before system activation, especially taking into account a long pre-burn time to reach 30 MW HRR, which already represents a severe fire.

Six full scale fire tests were carried out. The fire load was ignited in the lower part of the mockup, representing a fire source in the engine of a truck. Approximately seven minutes after ignition, the required heat release rate was reached and the watermist system was activated.

The results of the fire tests were analysed and compared to the requirements of the Highways Agency. After activating the watermist system the HRR did not exceed 40 MW and was able to suppress the fire well below 25 MW after 15 minutes of operation.

As a result, the demanding specifications were met by the watermist system. The set-up of the watermist system in the full scale fire tests was transferred and installed similarly into the tunnels [3].

As both tunnels are in continuous operation and traffic volumes are among the highest in the UK, the short time for installation was extremely challenging. The works in the tunnel bores could only been carried out during night shifts while one of the tunnel bores was closed. Other works in the tunnel were carried out at the same time and had to be coordinated. All equipment had to be transported and installed in the tunnel after the tunnel had been closed and also had to be dismounted before tunnel opening, leaving a short time for installation work.

The short time available for the works in the tunnel posed a significant challenge, even for experienced installation teams. Fogtec had previously installed FFFS as part of a refurbishment process into highly frequented road and rail tunnels with even more demanding time restrictions. One of the key success factors was an efficient prefabrication process already in the workshop to minimize working hours inside the tunnel. The entire watermist system in the tunnel was simulated in a 3D model to optimize material requirements and the prefabrication process. Last but not least, an efficient procurement process ensured the successful installation of the watermist system.

3.4 Life safety control system

All new safety systems installed in the Dartford Crossing have to fulfil SIL2 (Safety Integrity Level 2 according to EN 61508) requirements. This includes the watermist system, which has to be integrated into the overall tunnel control system. Such high requirements had never been applied previously for a FFFS in a

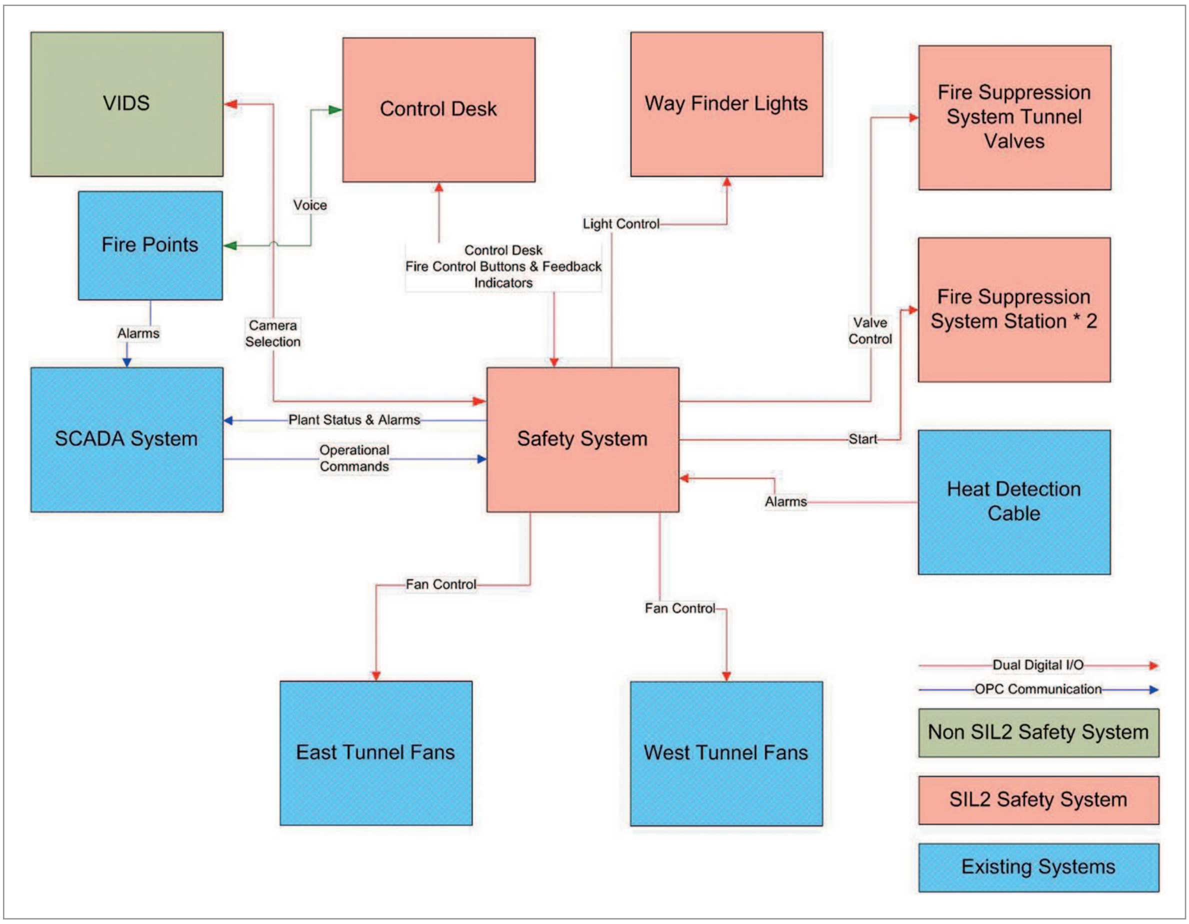

Fig. 4 *LSCS System overview*

road tunnel. The Fogtec watermist system installed in the Eurotunnel has reached a very high availability rate of 99.983 % according to RAMS (Reliability, Availability, Maintainability, Safety) studies, but a SIL2 rated system was not required in that case.

An important reason for the demanding requirements to be met in the Dartford Crossing is the fact that the watermist system is also being installed to compensate other safety measures in the tunnel. One example is the compensation of omitted passive fire protection panels to protect the tunnel structure; as the watermist system cools the structure very efficiently, further structure protection measures were not necessary.

Various safety systems, e.g. the SCADA system, the fire detection system, the tunnel ventilation jet fans and the FFFS, are included in the LSCS of the Dartford tunnel. The following illustration gives an overview of the Safety System Control Philosophy including the corresponding sub-systems [4].

Fogtec developed the entire Control System (including actuators, sensors and other FFFS equipment) of the FFFS to be executed to a SIL2 rated level. The interface to the overall LSCS was developed jointly with AIS (Applied Industrial Systems Ltd) who executed the LSCS at the Dartford Tunnels.

3.5 Integration of a watermist system into a SIL2 certified LSCS

Meeting the SIL2 requirements of the client led to several challenges, not only in terms of integration of the FFFS into the LSCS. As a first step, a risk analysis is usually carried out to evaluate the existing safety equipment. This is especially important as the FFFS is intended to interact with existing safety measures in the tunnel and to partly compensate omitted or insufficient ones. As part of the risk analysis, safety measures such as ventilation systems, detection systems, evacuation systems etc. are taken into account. As a result the existing safety level of the tunnel safety systems is evaluated. On the other hand, probability values are determined for incidents such as fires in tunnels and the corresponding hazard rates are derived.

The tunnel operator defines the safety level which has to be achieved as part of the upgrade process. The difference between the existing safety level (outcome of the risk analysis) and the desired safety level has to be overcome with additional safety measures in the tunnel, e.g. a FFFS.

In case of the Dartford Tunnel, a watermist system was integrated into the SIL2 rated control system. Several challenges came up during the integration process, especially as this was the first time a FFFS in a tunnel has been integrated to such a sophisticated tunnel control system. Moreover, the FFFS used is a so-called On-Demand system, meaning a system which is at standstill most of the time and is only turned in certain events. At these moments it must be ensured that the system works without faults.

There are several ways of reaching these demanding values. One important parameter is the maintenance activity and frequency. Shortening the maintenance intervals of systems with limited operating periods will usually lead to lower susceptibility to errors and thus to a higher availability. In case of ordinary FFFS, this correlation is not appropriate in any case. Many FFFS are not available during the time when maintenance works are carried out since this means doing test runs with the pump systems leading to lower overall availability values.

FOGTEC's specialized RAMS Engineers carried out calculations for Probability of Failure-On-Demand values for the FFFS. These values are important to achieve the required specifications. The Failure-On-Demand value for a SIL2 certification is in the range of $\geq 10^{-3}$ to $< 10^{-2}$ which had to be achieved by the FFFS controls.

Fig. 5 Pump house of the watermist system

Fogtec customized a generic system architecture. For this purpose, theoretical analyses based on assumptions and experiences from other projects regarding Failure-On-Demand values were carried out followed by calculations of hazard rates and availabilities for different possible system architectures.

Various intelligent solutions were developed, including a highly sophisticated maintenance plan. To overcome non-availability times of the FFFS during maintenance, a bypass solution was included for testing the pumps. Two completely redundant pump rooms were installed, each of them with two pumps for duty and one redundant pump unit. It was chosen to use diesel powered pumps as these are deemed to be highly available and have already been used for the same reason in other tunnel projects.

Another example of how the demanding SIL2 requirements were met is the case of the section valves. The section valves are the only active components of the system in the tunnel tube itself and thus represent a critical component in the entire system. Each section valve is connected by two independent power supply cables to ensure its function even in case of one power supply failure. To ensure high availability of each valve itself, frequent testing is essential as can also be seen from RAMS studies. Fogtec has developed and patented a section valve with a remote testing function, allowing the operator to test the valve from the control system without the need to physically access the valve and without discharging water into the tunnel. Section valves with remote testing function have already been installed into other high pressure watermist systems in tunnels and have demonstrated their efficiency, also with very low maintenance costs.

The entire pipework in the tunnel consists of highly corrosion resistant stainless steel pipes, suitable for the rough conditions in the tunnel. The pipes are connected by welding, ensuring a robust connection, long lifetime and maintenance free pipework.

Finally, the entire FFFS including the SIL2 rated controls were approved and validated by TÜV Rheinland as an independent 3rd party checker.

4 Conclusions

High pressure watermist systems can improve both life safety and asset protection in tunnels. The asset protection was the primary reason for the investment in the Dartford tunnels as the tunnel lining is particularly sensitive to heat exposure, which could lead to long traffic interruptions. The full scale fire tests have proved that even tunnels with cast iron linings can be protected against modern 100MW HGV design fires.

The life safety control system that operates and controls the watermist system and other safety equipment is of major importance. The case study shows that these can be built for very high demand and availability values. The LSCS in the Dartford tunnels is SIL2 rated; this is the first project in the world where a watermist is integrated to such a control system.

The motivation for designing and implementing such a reliable control and watermist system is not only ensuring a proper and reliable operation in case of fire incident, but having lower LCCs and ensuring business continuity.

The presented Dartford Tunnel project shows that it is possible to install a watermist system and LSCS in old tunnels while keeping them open for traffic almost continuously. The installation slots were limited to night shifts when one tunnel bore could be closed for traffic. The tunnel has now been in successful operation for more than two years since the implementation of the watermist and LSCS system.

References

[1] Directive 2004/54/EC of the European Parliament: Minimum safety requirements for tunnels in the Trans-European Road Network, 2004

[2] SOLIT Engineering Guidance for a Comprehensive Evaluation of Tunnels with Fixed Fire Fighting Systems – Main Report, 2012

[3] IFAB: Test Report: Full Scale Fire Tests – Dartford Thurrock River Crossing, 2010

[4] Connect Plus Services / Applied Industrial Systems Ltd.: Life Safety Systems – Control Philosophy, 2012