REMOTELY OPERATED TRAIN FOR INSPECTION AND MEASUREMENT IN CERN'S LHC TUNNEL

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Abstract

Personnel access to the LHC tunnel will be restricted to varying extents during the life of the machine due to radiation and cryogenic hazards. For this reason a remotely operated modular inspection train, (TIM) running on the LHC tunnel's overhead monorail has been developed. In order to be compatible with the LHC personnel access system, a small section train that can pass through small openings at the top of sector doors has now been produced. The basic train can be used for remote visual inspection; additional modules give the capability of carrying out remote measurement of radiation levels, environmental conditions around the tunnel, and even remote measurement of the precise position of machine elements such as collimators. The paper outlines the design, development and operation of the equipment including preparation of the infrastructure. Key features of the trains are described along with future developments and intervention scenarios.

INTRODUCTION

CERN's Large Hadron Collider (LHC) is installed in a 27 km circumference main ring tunnel and associated service galleries. Personnel access restrictions mean that the possibility of carrying out inspection, measurement and handling tasks remotely offers advantages in terms of safety and accelerator down time.

For this reason the development of a remotely operated vehicle using the existing infrastructure was launched [1]. The vehicle produced was battery powered, running on the existing I section monorail anchored to the tunnel ceiling in the transport zone of the tunnel. The vehicle, called TIM (Train Inspection Monorail), demonstrated the feasibility of controlling a vehicle in the tunnel from a control console at the surface, as well as obtaining inspection images, via the mobile telephone network in the tunnel. The TIM uses industrial electronics such as programmable logic controllers (PLCs) and is not intended for operation in the LHC with beam. The basic concept of TIM is to provide a remotely operated train and then to develop wagons to carry out specific tasks.

TYPES OF INTERVENTION

It was realised that interventions could be split into two main types:

- Rapid intervention for visual inspection and measurements when the machine is closed.
- Longer interventions where more complicated operations would be carried out – for example remote precise measurements of collimator alignment or exchange of collimators.

For the longer duration interventions, carried out during long shutdowns, it will be possible to open access doors so the main dimensional constraints are compatibility with the zone reserved for transport. For the rapid interventions however, there will be several additional constraints – a major one being the need to be able to enter the tunnel and pass through sector and ventilation doors installed along the tunnel without opening them. In order to achieve this, the concept of a "small TIM" was proposed and discussions started to agree passages through ventilation and sector doors.

INFRASTRUCTURE PREPARATION

Sector Doors

A key safety feature of the LHC is the personnel access system; the system has to guarantee that personnel cannot be present in the LHC underground areas when beam is circulating and during certain commissioning tests. To make sure that the tunnel is clear of personnel before starting the machine, the underground areas are searched by a "patrol." The underground areas are divided up into sectors for the purposes of patrolling. The sectors are separated by fences or interlocked doors so that once a sector has been patrolled and found to have no one in it it is not possible for people to access it without opening the interlocked doors. Sector doors are installed in the LHC tunnel and without special provisions would block the passage of the TIM train. It was therefore necessary to determine dimensions for openings that would be compatible with the passage of a useful train and would meet access safety requirements. A train cross section of 30 x 30cm (TIM 30-30) and openings of 32 x 33cm below the monorail were agreed for the sector doors (see Fig. 1).

Figure 1: TIM 30-30 train passing through sector door .

Ventilation Doors

The 27 km of LHC ring tunnel is split into eight sections with access points numbered from 1 to 8. The

LHC main ring ventilation system uses the tunnel as a ventilation duct and relies on the tunnel being partitioned so that air is pumped into the tunnel at the even-numbered access points and extracted at the odd-numbered access points. For this to work correctly the tunnel is blocked at certain positions by steel panels. These panels are equipped with doors that are closed when the LHC is operating but can be opened to allow passage of transport and personnel when necessary. A solution to meet ventilation requirements and allow passage of the TIM 30-30 was proposed by the CERN Cooling and Ventilation Group – the use of brush seals to close openings around the monorail that are big enough to allow the passage of a 30 x 30 cm section TIM train.

Shielding Doors / Access to Tunnel

The transport zone passes around the four LHC experimental areas through special by-pass galleries. The by-pass galleries around the ALICE, ATLAS and LHCb experimental areas (points 2, 1 and 8) are blocked by shielding doors or walls during operation of the LHC, whereas the by-pass around CMS at Point 5 is open to the ring tunnel. This means that six out of eight sectors have a continuous overhead monorail track that is not blocked by shielding doors when the LHC is closed.

After discussion with CERN Radioprotection and considering radiation effects on electronics it was agreed that the TIM could be safely parked in the by-pass at Point 5 during LHC operation. From Point 5 it could then be driven ~10 km in either clockwise or anticlockwise directions to cover the six accessible sectors, not blocked by shielding. This coverage could be extended in the future, for example, by modifying the shielding at point 1.

Shielding at Point 7

The collimation region at point 7 will be one of the most radioactive areas of LHC. For this reason shielding chicane walls are built across the tunnel to prevent radiation damage to equipment outside the region. For the small TIM to access this area it was therefore necessary to ensure that openings could be left below the monorail. Simulations by the radiation protection group showed that this would be acceptable and suitable openings have been included in the shielding design to allow passage of the TIM 30-30.

Positioning

In order to be able to operate autonomously the TIM needs to know its position as it drives around the LHC. It measures the distance travelled using an encoder fitted to the traction wheel; in addition, position bar codes have been installed next to the monorail every ~100m around the ring tunnel to avoid accumulative errors.

Mock-Up

To allow testing of the TIM and specialised modules before use under radioactive conditions, a 30m long mock up of the LHC tunnel with load-bearing monorail has been built.

SMALL SECTION TIM DEVELOPMENT

Train Layout

To fit the equipment from the prototype TIM into the space for the TIM 30-30 it was necessary to extend the basic train to three wagons (control, motor and battery). Each wagon was made as long as possible whilst remaining compatible with the space around the monorail in the tightest curves and also with the space in the access lifts and equipment access locks. It was necessary to install a much smaller battery charger that reduced the net charging rate to 11A. A pan-tilt zoom surveillance camera, spotlight, anti-collision detector and emergency stop button are fitted to each end of the train (see Fig. 1). The control wagon includes the motorised power and earth connections for battery charging. The driving speed was increased from 3km/h for the prototype TIM to 10km/h for the TIM 30-30.

Safety

Although TIM is meant for operation when personnel are not present in the tunnel and the transport passage is clear of obstacles, there is always the possibility that TIM could be required to drive when it is not possible to guarantee the absence of personnel or obstacles. The tunnel mobile telephone network used for control and image communication has a relatively low data transmission rate (240kbps) and a transmission delay (600ms) so that video signals from the TIM arrive in the form of still images that are refreshed after a delay of several seconds. This means that the TIM cannot be safely driven, except at very low speed, by an operator relying on the images from the camera at the front of the TIM. A risk assessment was carried out and the main safety initiatives arising were the installation of high safety level anti collision systems, the use of safety PLCs and the installation of the control console in the CERN Control Centre (CCC) so that TIM operators could have direct communication with LHC operations staff.

Operator Control Arrangements

After discussions with the CCC Technical Infrastructure (TI) operators it was agreed that a PC, two monitors, a keyboard and a mouse would be made available for operation of the TIM from the CCC, and that the surface PLC and modems would be installed in the CCR (rack room) next to the CCC. The CCC TI operators specified a simple operator interface allowing, for example, the operator to enter a desired destination and for the TIM to drive there with zero (or minimum) operator intervention, advising the operator on arrival.

The requirement for minimum operator intervention combined with known "obstacles" in the tunnel that will trigger the anti-collision sensors, such as doors and relatively tight curves in the monorail meant that the TIM had to be programmed to automatically slow down and pass these obstacles without any input from the operator. In addition in the event of a telephone network communication fault the TIM is programmed to continue towards its requested destination unless the communication is cut for more than 2 minutes – in this case the TIM will drive back towards its pre-programmed "home" position. Note that the anti-collision system provides safety protection irrespective of the communication with the operator.

Energy Management

The TIM is battery operated, but can plug into the power rail next to the monorail when stationary in order to recharge. An energy management system is being developed so that the TIM shuts down functions that are not needed and automatically recharges whenever feasible in order to ensure that it is ready to return to its parking position as quickly as possible after an intervention.

ADDITIONAL APPLICATIONS

Radiation Level Measurements

In collaboration with CERN's Radiation Protection (RP) Group a TIM module for remote radiation surveys has been developed. The RP Group specified measurement of radiation levels at the height of the LHC beam all around the LHC. A radiation measurement probe suspended below the TIM on a retractable arm lifts automatically to pass through sector and ventilation doors. Safety inductive sensors will be used to detect steel strips installed next to the monorail at door positions in order to provide a fail-safe method of detecting doors. The TIM communicates its position in the tunnel to the RP module PLC which then transmits the data via the telephone network to the RP operator in the CCC so that a detailed record of dose rate vs. position can be built up.

Survey Measurements of Collimator Alignment

A system for remote precise measurement of collimator alignment has been developed jointly with the CERN Survey Service. The system is based on a TIM client wagon equipped with four digital photogrammetric cameras fixed on a frame and with two wire position detectors mounted on motorised telescopic pivoting arms. The train is driven to a position adjacent to the first collimator to be surveyed; the operator then drives the motorised arms, using camera views, in order to position the wire sensors around a reference stretched wire installed next to the collimators. WiFi communication is used to allow real-time viewing and arm control for this operation. The arms are programmed to automatically centre the detectors on the wire with a tolerance of ~2mm and also compensate as the system is moved, to allow for wire sag and non-parallel alignment of wire and monorail. The digital photogrammetric cameras are used to measure the relative positions in 3-D of targets installed on the collimators and on the wire sensors. When these measurements are combined with the measurements from the wire sensors, the mathematical model of the stretched wire and measurements taken with respect to adjacent reference magnets, the position of the collimators can be determined to within 0.2mm in two axes.

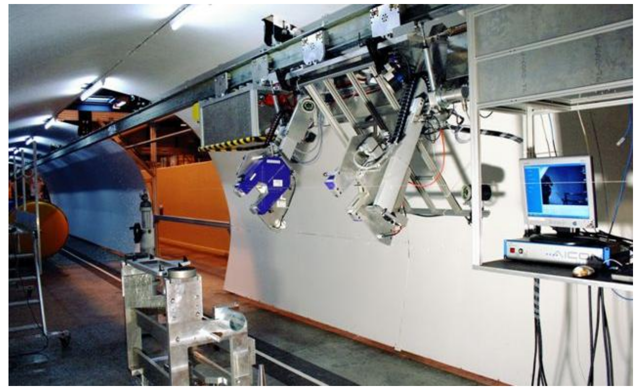

Figure 2: TIM with remote collimator alignment measurement module during testing in tunnel mock-up

Fire Service Interventions

CERN's fire service have asked to use the TIM to check conditions in the tunnel before fire-fighter intervention; their list of information required includes visual images, temperature, radiation levels, oxygen levels, and possibly thermal camera images. In the longer term they would like to use TIM to deploy CO_2 fire extinguishers. For such interventions, TIM needs to be able to function in the event of power failure, absence of lighting and telephone network failure in the affected part of the tunnel. In response to this, a "reconnaissance" wagon is being developed; the wagon will use an industrial PC to record images and measurements. If the telephone network is down in the intervention zone, TIM will be programmed to advance a distance set by the operator while recording data, then reverse back to transmit data to the operator via the mobile telephone network or via a WiFi hotspot in the tunnel.

Future Developments

A conceptual design based on TIM to handle and transport radioactive collimators is being reviewed in the light of developments of the collimators, infrastructure, and operational restrictions. Extension of TIM communication, control and safety techniques to floor-running vehicles is possible for non–LHC applications.

CONCLUSIONS

Following the proof of feasibility of remote operation of a monorail train via the LHC mobile telephone network, a reduced section TIM has been developed, and the tunnel infrastructure prepared to permit remote visual inspection and measurements. Additional developments are underway to improve autonomy and allow operation in the event of local telephone network failure in the LHC tunnel. A system for remote precise measurement of collimator alignment nears completion and extension of capabilities to include handling are being studied.

REFERENCES

[1] K. Kershaw et al., "Remote Inspection, Measurement and Handling for LHC", PAC'07, Albuquerque, June 2007.