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Remote Inspection, Measurement and Handling for LHC

K. Kershaw, F. Chapron, A. Coin, F. Delsaux, T. Feniet, J-L. Grenard, R. Valbuena
CERN, Geneva, Switzerland

Abstract

Personnel access to the LHC tunnel will be restricted to varying extents during the life of the machine due to radiation, cryogenic and pressure hazards. The ability to carry out visual inspection, measurement and handling activities remotely during periods when the LHC tunnel is potentially hazardous offers advantages in terms of safety, accelerator down time, and costs. The first applications identified were remote measurement of radiation levels at the start of shut-down, remote geometrical survey measurements in the collimation regions, and remote visual inspection during pressure testing and initial machine cool-down. In addition, for remote handling operations, it will be necessary to be able to transmit several real-time video images from the tunnel to the control room. The paper describes the design, development and use of a remotely controlled vehicle to demonstrate the feasibility of meeting the above requirements in the LHC tunnel. Design choices are explained along with operating experience to-date and future development plans.

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INTRODUCTION

The LHC tunnel - general layout

CERN's Large Hadron Collider (LHC) is installed in the existing 27 km circumference tunnel that previously housed the Large Electron Positron Collider (LEP).The main LHC ring tunnel has a nominal cross section diameter of 3.8 m. All around the tunnel, alongside the LHC beam equipment, there is a zone reserved for transport. The transport zone includes an I section monorail beam, suspended from the tunnel roof, with its associated sliding contact electrical power rail.

Collimation Regions

Collimators for the LHC machine are mainly concentrated in two regions adjacent to access points 7 and 3. Induced radioactivity in the collimators in these regions will lead to high radiation levels, so the collimators and their supports have been designed to allow exchange of failed collimators using remote handling techniques.

Initial LHC applications for a remotely controlled vehicle

Before allowing personnel access to collimation regions following LHC operation the CERN Radiation Protection (RP) Service need to carry out radiation level surveys; carrying out these surveys remotely reduces the doses to RP personnel, in addition the measurements can be taken earlier while radiation levels are higher. The CERN Survey Group wanted a remote method of precisely measuring collimator positions, in order to reduce the radiation doses to their personnel.

At certain stages of LHC commissioning personnel access is forbidden for safety reasons, the LHC Hardware Commissioning team were therefore keen to have the possibility of sending a remote controlled mobile camera to obtain images of potential problem areas.

For remote handling operations, such as collimator exchange, two or preferably three camera views are required to provide the necessary 3-D information to the operator. A method of communicating these video images from the tunnel to the surface will be needed.

THE MONORAIL INSPECTION TRAIN - BASIC CONCEPT CHOICES

To meet the needs of the above applications it was decided to develop and demonstrate a remotely controlled vehicle that would provide a capability for visual inspection, a mobile platform for various types of measurement equipment, and a basis for communication of real time video images from the tunnel to the surface.

Key requirements for a remotely controlled mobile device to be able to drive in a restricted space over distances of several kilometres are methods of guidance / steering; energy supply and control / communication. In addition, for the LHC tunnel, the implications of radiation have to be considered.

Guidance, energy

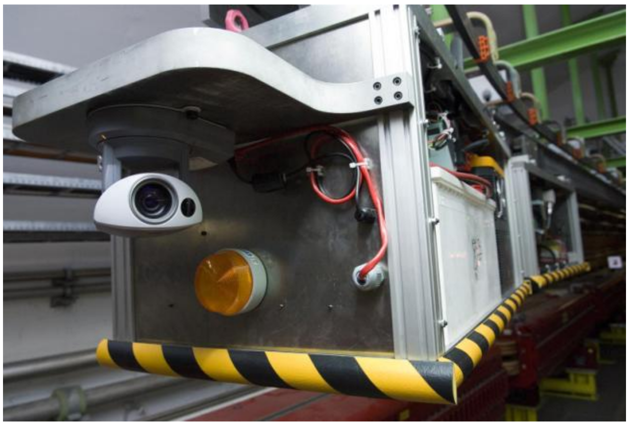

Figure 1: Remote inspection train on LHC monorail

By choosing to suspend the remotely controlled vehicle from the overhead monorail we avoid the need for a sophisticated automatic guidance system and can pass over obstacles on the floor. The vehicle was therefore named TIM (in French - Train Inspection Monorail).

The TIM is based on a modular approach in the form of a train; measurement equipment is installed on one or more "client" wagons. The rest of the train is made up of a traction and control wagon, an energy wagon and optional video communication wagons.

Although the monorail has a 400 V 100 A three-phase power supply rail next to it, the TIM is powered from traction batteries. This is to provide autonomy in the event of a problem with the supply to the power rail or the sliding contacts when operating remotely. The batteries give a range of over 20 km.

Control / Communication methods

The TIM is controlled remotely by an operator via a control console. The console is equipped with a touch screen and joystick. Two monitors are used to view the images from the cameras mounted on the TIM. The communication system between the TIM and the control console neatly fits the communication requirements (control, pictures and video transmissions) to the existing communication services in the LHC tunnel.

For LHC installation and commissioning, the tunnel was equipped with a leaky-feeder cable to transmit GSM (Global System for Mobile communications) signals for voice and data services. VDSL (Very High Speed Digital Subscriber Line) sockets are also available approximately every 100 m along the tunnel for applications requiring high network connectivity.

For real-time control of TIM movements, control signals are sent to the on-board PLC using CSD (Circuit Switch Data) over GSM. Still camera pictures are periodically sent to the control console via GRPS (General Packet Radio Service) allowing the operator to check the environment as TIM moves, or to carry out inspection tasks. For remote handling operation, at a specific location, the TIM connects a wireless base station to a VDSL socket enabling real-time video monitoring.

The modular design of the TIM’s communication system and the use of standard technologies make it easy to adapt to developments of the communication infrastructure. In particular, the next TIM generation will support EDGE (Enhanced Data rates for GSM Evolution) or UMTS (Universal Mobile Telecommunications System) for improved real-time control and video monitoring.

Radiation tolerance implications

When the beam is circulating, the LHC will give off high energy particles that can cause operation errors or even cause burnout when they hit electronic components. The initial uses identified for TIM were interventions soon after LHC beam is switched off, while radiation levels are sufficiently high to make personnel access a problem, but not so high as to rule out the use of standard electronic devices. For this reasons the TIM development is based on the use of standard industrial electronics, and its use will be limited to times when the beam is not circulating.

DESIGN FEATURES

Mechanical Design

The final dimensions of the prototype TIM were set to be compatible with the maximum curvature of the monorail and the space around the monorail, which varies around the tunnel, while leaving 1950 mm below in order to allow passage underneath by personnel walking in the tunnel. This gave a standard wagon size of 1000 mm long, 480 mm wide and 530 mm high.

The TIM prototype wagons are made up an aluminium box structure with top and bottom plates connected by extruded sections. The upper plates are fitted with two pivoting bogies, to allow passage of curves and the wheels have polyurethane tyres for smooth running. The bogies are guided laterally by wheels running on the vertical web of the monorail. To allow the TIM to be installed on the monorail anywhere in the LHC, the bogies open laterally so that the TIM can be lifted up from underneath the monorail and the bogies are then closed so that the support wheels run on the monorail lower flange.

The traction drive is dimensioned to allow a full TIM train weighing up to 1 tonne to go up the maximum tunnel slope of 1.5% at a speed of 3 km/h. The traction wheel is pushed against the underside of the monorail by a spring and motorised jack arrangement.

Electrical design

The electrical system uses industrial standard equipment in order to keep internal development costs to a minimum and to benefit from the high reliability associated with mass-produced components. The electrical control system is based on PLC (programmable logic controller) modules fitted to each wagon and in the surface control console.

A key requirement for the electrical design was a high degree of modularity to allow trains to be made up from different wagon combinations and changes to be made with minimum disruption.

The energy wagon includes two batteries and a charger. The traction and control wagon includes the master PLC, communication modem and motor drive. The client wagons are fitted with PLC remote I/O (input/output) and power supplies. The interface with the client equipment was defined so that the wagons can be given to the clients for them to install and test their measurement equipment independently of the rest of the train.

The VDSL wagon for high speed communication of video images is designed to plug into VDSL connectors positioned close to the monorail; the rest of the train will disconnect from the VDSL wagon and then communicate with it from up to 100 m away using wireless technology.

Position measuring and navigation

The operator needs to know the position of the TIM in the tunnel with varying degrees of precision depending on the application: TIM uses an existing reference system based on the cumulative distance (DCUM) around the

LHC ring from interaction point 1. TIM measures the distance moved using an encoder linked to the traction drive wheel and provides its DCUM position on the operator display screen. Barcodes will be fitted on the monorail around the LHC to give TIM its initial reference and to correct build-up of measurement errors.

The camera system

The camera system is used for navigation and for inspection. Both ends of the TIM train are fitted with surveillance video cameras with integrated pan-tilt supports. The camera software allows the camera to be connected to a network; images are viewed and the camera is controlled (pan, tilt, zoom) from a PC. The limited bandwidth of the GPRS means that images are received as still photos at a rate of one photo every ten seconds or so. The operator can select the image resolution; so that the images can be refreshed more quickly at the expense of detail when travelling. The image resolution can be increased when more detail is needed for inspection.

Collision detection

TIM is essentially destined for use in the tunnel when there are no personnel present. There was, however, a request from the Cryogenic Group for a relatively fast TIM that could be used to obtain images quickly in the event of equipment problems even when people are present in the tunnel. To allow this sort of operation a collision detection system is being implemented to detect obstacles for a distance of up to 20 m in front of the TIM.

OPERATIONAL EXPERIENCE

Figure 2: Functional testing of TIM in the LHC tunnel

Following successful functional tests, TIM was used in the LHC tunnel, at times when personnel access was not allowed, during pressure testing and cryogenic cool-down of the first sector to be commissioned. During the pressure test, at the request of Vacuum Group, TIM was driven to the positions of stand-alone measurement equipment; using the TIM’s camera it was possible to zoom-in and read the figures on the equipment’s display.

During the initial cool-down TIM was used at the request of the hardware commissioning team to provide images of the current leads of the DFBs (electrical distribution feed box) at both ends of the arc in order to check for the presence of condensation. TIM will be operating in the tunnel during cool-down of the remaining sectors.

FURTHER DEVELOPMENTS

To improve autonomy a battery charge monitoring system has been added, and a system to allow TIM to recharge by connecting to the power rail when stationary. Lighting has been added to improve picture quality with full zoom.

The communication system will be modified to use EDGE for control and image transmission to improve performance and remain compatible with the CERN network.

A client wagon has been delivered to Radiation Protection for installation of detectors.

The joint development with Survey Group of the system for precise measurement of collimator alignment is underway. A client wagon will be equipped with digital photogrammetry cameras fixed on a frame and with two wire position detectors mounted on motorised arms. The system will move the wire sensors to centre them on a reference taut wire installed next to the collimators, then check the alignment of collimators by measuring the relative positions of the collimators, the wire sensors, and adjacent reference magnets.

To allow full testing of the remote collimator alignment system and other equipment before use under radioactive conditions, a mock up of the LHC tunnel with 30 m of load-bearing monorail will be built.

Initial feasibility studies have been made for a smaller cross section TIM capable of passing through small openings in LHC sector doors for inspection tasks.

Design of equipment to exchange collimators remotely has started. This work concentrated initially on feasibility studies and ensuring that adequate space was reserved during the tunnel integration design. The system will use TIM communication and control techniques.

CONCLUSIONS

The use of TIM during LHC commissioning successfully demonstrated the feasibility of a mobile remote inspection device for LHC, built using standard industrial electronics without any modification to the existing tunnel communication infrastructure.

The system offers benefits such as reduction of radiation exposure to personnel and can provide information for intervention planning in the time before personnel access is allowed after LHC operation runs.

The TIM modules form a good basis for other remote applications; the development of remote measurement systems is underway, and TIM modules will be used as part of the proposed remote handling equipment for collimator exchange.