ON-LINE RADIATION TEST FACILITY FOR INDUSTRIAL EQUIPMENT NEEDED FOR THE LARGE HADRON COLLIDER AT CERN

Raymond Rausch and Marc Tavlet
CERN, Geneva, Switzerland

Abstract

The future Large Hadron Collider to be built at CERN will use superconducting magnets cooled down to 1.2 K. To preserve the superconductivity, the energy deposition dose levels in equipment located outside the cryostat, in the LHC tunnel, are calculated to be of the order of 1 to 10 Gy per year.

At such dose levels, no major radiation-damage problems are to be expected, and the possibility of installing Commercial Of The Shelf (COTS) electronic equipment in the LHC tunnel along the accelerator is considered. To this purpose, industrial electronic equipment and circuits have to be qualified and tested against radiation to insure their long term stability and reliability.

An on-line radiation test facility has been setup at the CERN Super Proton Synchrotron (SPS) and a program of on-line tests for electronic equipment is ongoing. Equipment tested includes Industrial Programmable Logic Controllers (PLCs) from several manufacturers, standard VME modules, Fieldbuses like Profibus, WorldFIP and CAN, various electronic cards, power converter equipment and cryogenic components.

The irradiation is taking place in one of the target areas of the CERN SPS. The radiation is typical of a proton accelerator; it includes mainly gammas and neutrons, plus some high-energy particles.

1 RADIATION QUALIFICATION

Before installation in the LHC tunnel, electronic equipment and systems must be fully tested and qualified for standing the radiation levels to which they will be exposed, depending on their position along the collider.

The absorbed dose levels have been calculated to be of the order of 1 Gy per year under the middle dipole of a regular half-cell and of 12 Gy per year under the Short Straight Section (SSS) quadrupole at a distance of 700 mm from the proton beams [1,2,3,4]. At such dose levels, no major radiation-damage problems are to be expected, and designers plan to use Commercial Off The Shelf (COTS) electronic components and systems.

2 ON-LINE RADIATION TEST FACILITY

In order to do systematic radiation tests on to qualify all electronic equipment to be installed in the LHC machine tunnel, CERN has decided in 1998 to create a radiation test zone in one of the Super Proton Synchrotron (SPS) north experimental areas. A test zone, was settled along a secondary beam line of the SPS accelerator, some 100m downstream of a particle-conversion target (T6).

This radiation test area, fully operational since the start-up of the SPS in March 1999, has been provided with all the required facilities: high power electrical supply for the test of power converters, compressed air for the test of pneumatic electro-valves, radio communication, video observation, CAN, Profibus and WorldFIP fieldbuses, connections to the accelerator control network and to the office LAN. In addition, numerous coaxial and twisted pair cables for analogue and digital signals have been laid between the radiation test zone and the local control room distant of some 200 m. In the local control room experimenters have installed their PCs, workstations and measurement instruments for the monitoring and if necessary the remote control of their experiment. Some systems have been connected from this local control room to the general CERN office LAN, thus providing the experimenter with all the facilities needed to monitor on-line his experiment from his office.

2.1 Irradiation Conditions

A 400 GeV-proton beam hits a metallic target (T6), muons are collected downstream and guided toward physics experiments. The radiation field around such target is typical of a proton accelerator; it includes mainly gammas and neutrons, plus some high-energy particles. The gamma spectrum extends from a few hundred keV to several hundred MeV, but is mainly between 1 MeV and a few MeV. The neutron spectrum is about the same, but it also includes a large quantity of low-energy neutrons thermalized by concrete shielding. The presence of other particles is very low, but it is not excluded that some hadrons (protons, neutrons, pions) and muons of high energy create particular effects in digital electronics. The radiation field is characterised by means of passive solid-state dosimeters and active semi-conductor dosimeters [14]. Measurements show that the radiation field is not homogeneous, neither in intensity, nor in nature; the weekly absorbed doses vary between 10 to more than 50 Gy, depending on the location, while the neutron fluences (1 MeV equ.-Si) vary from 10^{11} to 2 x 10^{12} $n.cm^{-2}$, moreover the neutron spectrum also changes.

CERN radiation experts recognise that these irradiation conditions are similar to those that will exist in the tunnel of the future LHC where the dose-rate and the neutron spectrum will also change from place to place.

2.2 Radiation Monitoring and Calibration

From 1999, on-line monitoring of the radiation doses, to which the equipment is exposed, is available in the local control room and on the Web. The test zone has a surface of some 8 square meters. The monitoring of the dose rate is done by four ionisation chambers (3 litres of air), located at each corner of the test zone at a height of 800 mm (= beam height). These monitors are connected to the CERN radiation monitoring system, "ARCON". The radiation data is stored in the central ORACLE Data-Base which can be consulted at leisure by the experimenters to retrieve historical data and to correlate it to the results obtained from his experiment. The doses are stored day after day, every hour and the data is kept at disposal for several years.

In addition, the absorbed doses are also integrated by passive solid-state dosimeters (polymer-alanine, radio-photo-luminescent glasses, and MOS dosimeters). The measurement of the neutron fluence uses the activation technique (radioactive isotopes are created in metals) and silicon PIN diodes. After exposure, these dosimeters are regularly exchanged and measured; the latter are measured in the laboratories of the French Atomic Energy Commission (CEA) in Valduc.

3 TESTED MATERIAL

The tests include industrial Programmable Logic Controllers (PLCs) from various manufacturers, electronic modules conforming to the VME and G64 Bus Standards, fieldbus interfaces for Profibus, WorldFIP and CAN, Components used for the LHC Cryogeny, digital positioners, quench protection equipment, power converters, optical fibres and data-transmission equipment, fire and gas detectors, etc... are included in the programme, [6],[7].

4 PRELIMINARY RESULTS

The test zone was fully equipped for on-line radiation tests and the irradiation campaign has started in May. The target doses are in the order of 10 to 30 Gy per week, the material remains permanently under irradiation unless a failure appears. In this case the sample is taken out, let cool-down and then is analysed to identify the defective component(s).

In 1999, after a few weeks of irradiation, having reached dose levels between 20 and 200 Gy, and neutron fluence of the order of a few 10^{12} $n.cm^{-2}$ (1MeV equ.-Si), the measurements show disquieting results for some components and promising results for other ones.

Some type of opto-coupler degraded progressively right from the beginning of the irradiation; the CTR dropped to less than 20% at 20 Gy. Another opto-coupler model still continues to work properly after a dose of 100 Gy showing a CTR derating of only 5%, [8].

Within the framework of the protection system for supra conducting elements of the LHC different kind of electronic devices have to be qualified with respect to radiation tolerance. The irradiation tests started with the main components of quench heater power supplies, aluminium electrolytic capacitors and phase control thyristors. The different type of thyristors passed the ongoing tests up to a received dose of about 55Gy (=5.5.e$10^{15}$$ncm^{-2}$) without any functional degradation, whereas some of the tested capacitors showed a significant increase of the leakage current. The measured DC capacitance remained constant for all tested specimens, [9].

For the cryogenics electro-pneumatic positioners valve are remotely controlled using compressed air to energise them; their movement can also be observed by means of a remote CCD camera and a video monitor situated in the local control room. The detailed analysis of the results has been published in a report, [10].

The PLCs and associated Profibus fieldbus equipment could not be effectively tested, because their operation was controlled and driven by a RAM memory which was corrupted after only a few hours in operation. A new experimental set-up has now been placed into the test zone ; it comprises only simple I/O modules and Profibus interfaces.

Good results were obtained from two experiments using a total of six WorldFIP Fieldbus interfaces with MicroFIP protocol chips. A continuous write/read/compare operation showed only one single error since the beginning of the irradiation campaign. All six interfaces still operate today with some 200 Gy total integrated dose.

Memory tests have been done with different types of memory chips mounted on a VME PowerPC board. Continuous write/read/compare operation showed no errors in DRAM and EEPROM memorieswhile NVRAM and SRAM showed an error rate proportionnal to the integrated dose.

Three standard VME power supplies, well known and used in large quantities since many years at CERN, broke down very rapidly. All three showed the same fault: a power MOSFET transistor breakdown, probably due to single event failures.

For the cryogenic system, the high-precision resistors and the associated capacitors used in the construction of conditioners for thermometry have undergone successfully the radiation tests; only a tiny fraction of a percent deviation has been noticed, [11].

No errors have been detected in the Actel antifuse-based FPGAs, an error rate of 2 to 10 bit-error per day has been measured in the HP G-link, which makes both of these components suitable for use at the dose rate and fluences of the LHC.

Tests on a 200 meter fibre cable, containing 12 mono-mode fibres and 12 multi-mode fibres, have been done. As expected the multi-mode fibres showed an attenuation of some 50db per km while the mono-mode only a loss of 8 dB per km at a dose of 80 Gy.

The CCD camera degraded progressively, the number of white spots increased continuously, at 25 Gy the picture was still visible but at 30 Gy the camera stopped working. This camera has been replaced by a new one.

The GSM repeater, used for mobile telephones, revealed a degraded operation at 20 Gy and went out of operation at 30 Gy.Analogue and digital telephone equipment went definitely faulty. An RNIS bus did not reply anymore after some 15 days operation having received a dose of some 30 Gy.

The fire and gas detectors which have been exposed went faulty at 20 Gy and 25 Gy, respectively.

5 CONCLUSIONS

At the time of publication we have several preliminary radiation results on electronic components and systems to be installed in the tunnel of the LHC machine.

More statistic is needed but experimenters can already draw some conclusions for their particular application. Identification and replacement of sensitive components will improve the radiation hardness of this electronic equipment.

These preliminary results demonstrate clearly that testing and qualification of all COTS electronic equipment for the machine will be necessary, despite the low level of radiation expected in LHC tunnel.

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7 REFERENCES

[1] K.M. Potter, H. Schönbacher, G. R. Stevenson, “Estimates of Dose to Components in the Arcs of the LHC due to Beam-Loss and Beam-Gas Interactions”, LHC Project Note 18, November 24, 1995.

[2] M. Tavlet, “Radiation Environment around High-Energy Particle Accelerators and in Physics Detectors”, Radecs'94, L'Onde Electrique, Vol.75, No 3, 1995.

[3] L. Coull, R. Schmidt, T. Spickermann, “Beam Losses, Radiation Dose and Electronic Equipment in the LHC Arcs”, LHC Project Note 109, September 26, 1997.

[4] K. Wittenburg, R. Schmidt, T. Spickermann, “Radiation Dose for Equipment in the LHC Arcs”, LHC Project Report 274, February 11, 1999.

[5] M. Tavlet and M. E. León Florián, “Dose and Neutron-Fluence Measurements in mixed Gamma-Neutron Fields by Means of Semi-Conductor Dosimeters”, Radecs'93, IEEE Cat. N° 93TH0616-3, pp 27-32,1994.

[6] R. Rausch and M. Tavlet, “Radiation Test Programme on COTS Components needed for the Large Hadron Collider at CERN”, Radecs'98.

[7] L. Adams, Brunel University, UK and P. Jarron, R. Rausch, M. Tavlet CERN, CH, “COTS Needs for the Large Hadron Collider and Detectors at CERN”, Los Angeles, February 7-10, 1999.

[8] H. Burkhart, B. Hallgreen, “Front-End I/O via CAN Bus of the ATLAS Detector Control System” LEB98 Workshop, Rome, Italy, 21-25 Sept. 1998.

[9] F. Rodriguez-Mateos, R. Denz et al., “The Protection System for the Superconducting Elements of the Large Hadron Collider at CERN”, LHC Project Report 283, PAC’99, New York, USA, March 29 – April 2, 1999.

[10] R. Trant and W. Hees, “Evaluation of Electro Pneumatic Valve Positioners for LHC Cryogenics”, LHC Project Note 100, May 17, 1999.

[11] J. Casas, “Preliminary Test for Radiation Tolerant Electronic Components for the LHC Cryogenic System”, LEB99 Workshop, Snowmass, Colorado, USA, 20-24th September, 1999.