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RADIATION TOLERANCE OF COMPONENTS USED IN THE PROTECTION SYSTEM OF LHC SUPERCONDUCTING ELEMENTS

R. Denz, F. Rodriguez-Mateos

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***Index Terms*-- LHC, COTS**

I. Introduction

A major part of the protection system [1] of superconducting elements of the Large Hadron Collider LHC [2] will be exposed to radiation during the exploitation of the accelerator. This part of the protection equipment will be installed underneath the LHC main bending magnets and includes the local quench detectors, the quench heater discharge power supplies and the acquisition and monitoring controllers. The required radiation tolerance was determined to 200 Gy corresponding to a fast neutron fluence of 2 x 10^{12} ncm^{-2}. In addition the devices must be single event upset free. During the development phase, tests on radiation tolerance of various electronic components formed an integral part of the design process [3]. Meanwhile the design phase of the protection system is almost completed and tests focus mainly on the verification of the developed designs and the qualification of pre-series devices.

A. TCC2 irradiation test area

All test were performed in the irradiation test zone in the North, fixed target area TCC2 of the CERN SPS accelerator [4], where secondary beams for physics experiments are produced with the help of proton induced nuclear reactions. Recent calculations [5], confirm that this area represents a radiation environment, which is very close to that expected for equipment installed in the LHC tunnel.

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II. Devices and components

A. Instrumentation Amplifiers

All electronic devices used for the detection of resistive transitions in superconducting elements [6], the so-called quench detectors, will be equipped with analog input stages, which are based on instrumentation amplifiers. The design of the quench detectors is such that any adjustment of these input stages is avoided. In consequence gain and offset of the instrumentation amplifiers must exhibit sufficient stability during operation and exposure to radiation. The performed tests show remarkable differences between various brands of instrumentation amplifiers, whereas the deviations within a batch rest rather small. The results presented in figure 1 to 3 for the tested AD620 and INA141 devices, show clear advantages for the INA141 device. In addition the offset voltage of all the INA141 amplifiers was found to increase in first approximation linearly with the dose. Linear fits give an average value of 0.20 mV/Gy (increase of the output offset at a gain of 10). As this value is regularly monitored during LHC operation, it can serve as a warning sign for a potential radiation damage of the device.

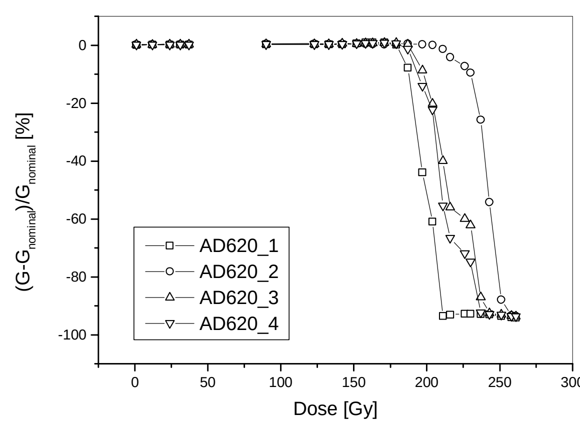

Figure 1. Gain stability of the AD620 instrumentation amplifier as a function of the total integrated dose.

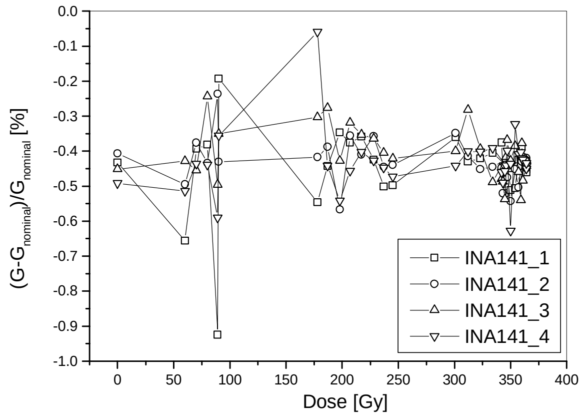

Figure 2. Gain stability of the INA141 instrumentation amplifier as a function of the total integrated dose.

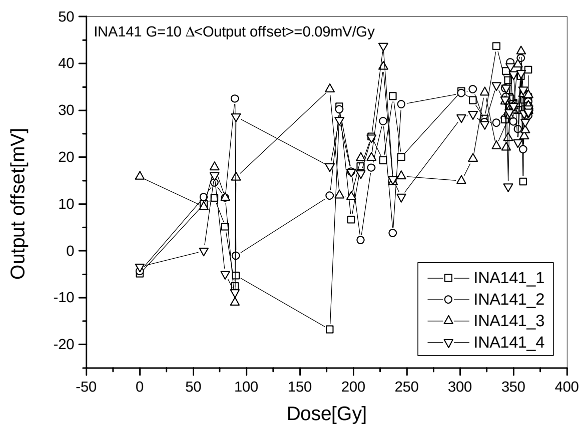

Figure 3. Output offset of the INA141 instrumentation amplifier at a fixed gain of 10 as function of the total integrated dose.

B. Quench Heater Power Supplies

This type of power supply will be used to energize in case of a quench the quench heater strips mounted on the coils of many LHC superconducting magnet. The function is based on a thyristor- triggered discharge of Aluminium electrolytic capacitors. As individual electronic components and sub-circuits of this equipment type have been extensively tested in previous radiation campaigns [3], this test should confirm the validity of the present design with respect to the required radiation tolerance of 200 Gy. Five quench heater power supplies, taken out of different pre-series production batches, were submitted to a functional test under radiation. The devices were operated under nominal conditions performing charge – discharge cycles. During the test the voltage across the capacitor bank was monitored.

As for the results previously referred to, the useful lifetime of the power supply under radiation is mainly limited by the two thyristors used for the discharge of the capacitor bank. In the tested pre-series devices three different brands of thyristors were installed, all of 1.8kV - 80A rating. All thyristors suffered from radiation-induced defects, which affected their proper function after exposure to doses between 50 and 400 Gy. Depending on the type of thyristor either the firing of the thyristor was inhibited or the thyristors were destroyed during the discharge (=short circuit). In the latter case the damage affects only the power supply unit itself, whereas an inhibited thyristor firing could cause severe damage to the protected superconducting magnet. The results are summarized in table 1. It is noteworthy that not irradiated specimen of thyristor type C require significantly less power delivered to the gate for triggering than the other two types [7].

Despite the problems with the thyristors no other radiation-induced failures were revealed by the tests.

TABLE I
IRRADIATION TESTS WITH QUENCH HEATER POWER SUPPLIES

Device ID	Thyristor type	Dose limit [Gy]	Failure type
1	A	160	Firing inhibited
1	B	140	Firing inhibited
1	C	380	Short after discharge
2	B	50	Firing inhibited
3	C	400	Short after discharge
4	C	150	Failure not radiation induced. Thyristors still intact.
5	C	420	Short after discharge

C. Switch-mode Power supplies

Switch mode power supplies with +5V and ±15V outputs are required for the powering of the local quench detectors. Three batches of five units each of industrial grade, switch mode power supplies from different manufacturers were submitted to test.

TABLE II
SWITCH MODE POWER SUPPLIES

Device ID	Dose [Gy]	Dose limit +5V stage [Gy]	Dose limit ±15V stage [Gy]	Failure mode
A1	820	800	820	+5V output voltage starts to decrease
A2	820	670	820	
A3	820	660	820	
A4	820	650	820	
A5	820	650	820	
B1	580	580	400	Regulation of ±15V stage fails; output voltage drifts to zero.
B2	580	580	200	
B3	580	580	190	
B4	580	580	190	
B5	580	580	190	
C1	160	160	160	No failures so far
C2	160	160	160	
C3	160	160	160	
C4	160	160	160	
C5	160	160	160	

In two of the three tested brands, the voltage rating of MOSFET transistors has been increased compared to the series model. In no case the device design makes use of opto-couplers.

All devices were connected to a resistive load and operated at about 60% of their nominal power. The results are summarized in table 2. Because of the limited test capacity the five devices of brand C could only be tested up to 160 Gy. In case of brand B, which also has been successfully tested by a different group at CERN [8], the manufacturer was able to trace down the failure to the component level (i.e. drift of a linear regulator in the ±15V stage) and proposed a modified design, which may be tested in the next radiation campaign.

D. Micro-Controllers

A simple data acquisition system consisting of a micro-controller and a field-bus coupler will be used for the supervision and control of quench protection equipment. The micro-controller is of the ADuC812 type and combines a 12Bit 8 channels ADC with an 80C51 core. The field-bus coupler is based on the MICROFIP VY27257 ASIC and implements the WorldFip protocol. The radiation tolerance of the VY27257 has already been verified in detail [9]. One of the main tasks of the data acquisition system will be the monitoring of different analog signals from quench detectors and quench heater power supplies. Therefore the first test was focusing on the acquisition of analog input signals. In the tested assembly, different test voltages were generated with the help of a REF102 type voltage reference, which is known to be sufficiently stable up to at least 1kGy. In addition the two DAC channels of the ADuC812 were wired to two analog input channels. The small application program was stored in the internal flash memory of the chip. In the experimental setup the micro-controller does not require any access to an external memory nor the field-bus coupler, which was operated in the stand-alone mode. All acquired data were transmitted via the field-bus to a protected local control room. The data were stored on a personal computer, which served also as bus arbiter for the WorldFip connection.

TABLE III
ADUC812 BASED DATA ACQUISITION SYSTEM

ADC input channel	Nominal voltage [V]	Initial values [V]	Last transmitted values [V] (Dose = 650Gy)
ADC 1	2.5	2.495	2.495
ADC 2	2.0	1.999	1.984
ADC 3	1.5	1.499	1.558
ADC 4	1.0	0.999	1.058
ADC 5	0.5	0.497	0.572
ADC 6 (DAC 0)	0.2	0.205	0.178
ADC 7 (DAC 1)	0.5	0.516	0.489

The device was transmitting properly data up to a total integrated dose of 650 Gy, when the power supply broke down. Some of the acquired analog data however show significant deviations from their initial values (see table 3), which are most probably caused by the amplifiers, namely OP491 and OP284 types, used for the buffering of the I/O channels of the ADuC812.

III. CONCLUSIONS

The outcome of the 2001 radiation test campaign on a variety of electronic components and devices, gives clear evidence that the COTS-based design of the protection system is valid. The success however can only be guaranteed if the technical specifications, based on these results, are strictly followed during the series production. The test program will be continued in 2002 with emphasis on devices not yet fully tested, like quench detectors and acquisition and monitoring controllers.

IV. ACKNOWLEDGEMENTS

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V. REFERENCES

[1] K. Dahlerup-Petersen et al., LHC Project Report 283, PAC'99, New York, USA, March 29 - April 2, 1999
[2] The LHC Study Group, The Large Hadron Collider Conceptual Design, CERN/AC/95-05, 1995
[3] R. Denz, F. Rodriguez-Mateos and A. Vergara, "Irradiation Tests on COTS used in the Protection System of LHC Superconducting Elements", RADECS 2000, Louvain-la-Neuve (Belgium), 2000
[4] Rausch R. and Tavlet M., CERN-TIS-TE/IR/98-11, 1998
[5] C. Fynbo and G. Stevenson, LHC Project Note 235, CERN, 2000
[6] R. Denz and F. Rodriguez-Mateos, "Detection of Resistive Transitions in LHC Superconducting Elements", LHC Project Report 482, PAC'2001, Chicago, USA, 18-22 June 2001
[7] F. Perisse, "Qualification des condensateurs et des thyristors pour des alimentations de chaufferette", UCB Lyon, 2001
[8] D. Hundzinger, private communication, CERN, 2001
[9] J. Casas-Cubillos, F. Faccio, P. Gomes, M.A. Martin, M.A. Rodriguez-Ruiz, "SEU Tests Performed on the Digital communication System for the LHC Cryogenic Instrumentation", LHC Project Report 503, CERN, 2001