Radiation Hardness of the Siemens SIPART intelligent valve positioner

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Abstract. About 1400 Siemens SIPART PS2 intelligent valve positioners are installed in the LHC accelerator. They were selected assuming that their non-electronic parts are intrinsically radiation hard. This positioner variant is a split design: the electronic board located in a radiation protected area and the electro-pneumatic unit on the valve stem. The next LHC upgrade will result in a significant increase of the radiation levels and the initial radiation hardness assumption may not hold.

A preliminary test on an electro-pneumatic unit was done with a cobalt 60 source. At the end of the test (99.8 kGy) one of the two miniature piezoelectric valves was damaged. After this result, the CERN CALLAB facility was used to irradiate 10 miniature piezoelectric valves while they were powered by an electrical signal. The first failures are observed after a dose of 137 kGy. The paper describes the test protocol and synthesizes the results.

1. Introduction

During the LHC accelerator design phase, various commercially available digital valve positioners were evaluated [1] in order to avoid using the analog I/P pneumatic control valve positioners. At that time, the main advantages of the new positioners’ generation were simpler installation thanks to a common communication cable, automatic calibration, remote configuration, diagnostic data for preventive maintenance and reduced pressurized air consumption. Unfortunately all of the tested digital (intelligent) valve positioners malfunctioned at Total Integrated radiation Dose (TID) levels as low as 50 Gy. These positioners were therefore not suitable for the radiation environment found in the LHC tunnel.

The observed failures are mainly related to the electronic components and therefore Siemens proposed a split design of the SIPART PS2 intelligent valve positioner. The main electronic components are separated from the electro-pneumatic unit, the former is installed in radiation protected areas and the latter on the valve stem. The split design requires long cables for reading the potentiometer that indicate the opening of the valve and for switching the two piezoelectric miniature valves, the longest cable length used is close to 900 m.

The electro-pneumatic unit was assumed to be intrinsically radiation hard as its main components are a rotary potentiometer and two piezoelectric miniature valves; so far this assumption is valid as no radiation induced failure has ever been reported on the 1400 split SIPART PS2 valve positioners operating continuously since at least 10 years in the LHC. However during 2016 it was estimated that some pneumatic units during the LHC high luminosity operation could be exposed to a TID exceeding 100 kGy [2]. Therefore a radiation qualification campaign was undertaken in order to understand the radiation effects on the electro-pneumatic unit. This paper present the main results.
2. SIPART PS2 intelligent valve positioner

The LHC-type Siemens SIPART PS2 electro-pneumatic unit uses two piezoelectric miniature valves [3] to regulate the pressure of a single acting spring loaded pneumatic valve actuator. The electro-pneumatic units are mounted on cryogenic valves (Figure 1) located around the LHC cryogenic distribution line (QRL) and are exposed to the tunnel radiation environment. For the LHC tunnel, the remote electronics is located in drawers compatible with 19” racks containing up to 3 clusters of five SIPART PS2 control electronics (five is the typical quantity of cryogenic valves clustered around a QRL jumper connection to the superconducting magnets) communicating through a profibus-PA network (Figure 2). The LHC detectors use a different remote electronic made of three SIPART PS2 control electronics using 4-20 mA communication housed in a 19” enclosure.

As there were no irradiation tests performed in the past, during 2015 a single SIPART PS2 electro-pneumatic unit was irradiated at the Fraunhofer Institute for Technological Trend Analysis (INT). The unit was installed in the radiation area without any electrical or pneumatic connections, the TID was 99.8 kGy and the pneumatic unit showed afterwards a malfunction in one of the two piezoelectric miniature valves. There were no intermediate checks and the data does not permit to assess the maximum TID level that this particular pneumatic unit can withstand. The 99.8 kGy TID level is relatively low within the scope of the future radiation environment of the LHC HiLumi upgrade. A radiation test campaign was therefore required to understand how to design a maintenance scenario to keep all the SIPART PS2 in good operation conditions in the future LHC environment.

Past SIPART PS2 failures in the CERN equipment, are mostly related with either the piezoelectric miniature valve releasing the air of the spring loaded valve actuator (as was the case after the irradiation test) or the rotary potentiometer. None of the failures could be attributed to the radiation level that was indeed low and the repair is performed by exchanging the complete pneumatic unit. The piezoelectric miniature valve is produced by Hoerbiger Origa [4] as Original Equipment Manufacturer (OEM), it is a 3/2 way valve made of a piezoelectric bending element actuated by a DC voltage switching the process port between the normally open and closed ports (Figure 3).
3. Test set-up

The piezoelectric miniature valves are not available commercially and 20 units were provided to CERN by Siemens in order to evaluate the influence of the radiation effects. On the SIPART PS2 the piezoelectric valves are actuated by a train of voltage pulses; under these conditions the valve functions as a purely ON/OFF valve. According to the data-sheet [4] the main operational specification are a 1.2 barg inlet pressure, 1.5 l/min nominal flow, a leakage through the closed port not exceeding 0.15 l/min and a 24 Vdc operating voltage. The pressure and flow ranges applied on the spring loaded pneumatic actuator are adjusted by a second set of valves operated through the piezoelectric miniature valves [4].

3.1. Functional test set-up

Typical damages on the SIPART PS2 pneumatic unit is a fault on either the rotary potentiometer or on the piezoelectric miniature valve that releases the air of the spring valve actuator.

Damage on the rotary potentiometer is observed as noise on the valve stem position feedback, the origin of the problem is probably due to dust or oxidation on the wiper track. Radiation damage would be expected to provoke a gradual change of the wiper track resistance. Such an effect is easily corrected by recalibrating the positioner and if it exists the change is less than 10% for a TID of 100 kGy.

The piezoelectric miniature valve is assumed to be the most sensitive element to radiation damage. To evaluate whether a fault is present, the volumetric flow is measured when the valve is either fully opened or closed, Figure 4. The pressurized air volumetric flow is measured with a thermal mass flowmeter (range 0.03 to 6 standard liter per minute) and the inlet pressure is regulated and measured in order to keep similar conditions for all the tests.

3.2. Irradiation test set-up

The irradiation test set-up can hold up to ten piezoelectric miniature valves and they are electrically powered in parallel by a standard SIPART PS2 electronic unit (4-20 mA interface), see Figure 5a. The electronic unit is located outside the irradiation area. The rotary potentiometer is kept at a constant value.

Figure 3. Miniature 3/2 way valve (a) Operational principle, bending element in normal (continuous line) and actuated (dashed line) positions, (b) Package, size is 30 mm x 19 mm and (c) opened package showing the bending piezoelectric cantilever.

Figure 4. Test set-up for measuring the flow with the air supply port in the (a) normally closed position, (b) opened position and (c) experimental set-up with pressure regulator, mass flowmeter and piezoelectric miniature valve.
in between the maximum and minimum values of the requested set-point and the valve position set-point is applied as a square pattern that send pulses sequentially to the five “release” valves and the five “supply” valves. This set-up do not foresee a pressurized air supply as this would add too much complexity to the experimental set-up.

The piezoelectric miniature valves were irradiated in the CC60 irradiation room of CERN’s CALLAB facility [5], Figure 5b. The irradiation is started by raising from the bottom of a shaft a Co-60 source, the radiation dose rate depends on the distance between the source and the sample. The piezoelectric miniature valves were placed as close as possible to the Co-60 source in order to get the maximum irradiation rate and be able to reach at least a TID of 100 kGy after a few weeks of test. During the irradiation several stops were foreseen in order to check, with the functional test set-up, each individual piezoelectric miniature valve (Table 1).

4. Irradiation Tests Results

Figure 6 shows, for ten activated piezoelectric miniature valves (Figure 4b), the air flow rate normalized by the gauge pressure (about 0.97 bar) versus the TID. The functional tests were performed between May and November 2017 with a relatively long non-irradiation cooling period between June 22 and October 11, Table 1. The first failures are observed after receiving 137 kGy, two valves self-healed and resulted in four operational valves till the end after reaching 280 kGy (see Figure 6).

Thermal annealing processes in electronic circuits often self-heal, at least partially, radiation damage during non-irradiation periods. Surprisingly, six miniature valves failed during the consecutive 111 days of non-irradiation (Figure 6). Radiation effects on the piezoelectric miniature valves are observed exclusively as complete failures on the opening of the normally closed port (Figure 3a).

To check whether the failures could be due to wearing of the piezoelectric miniature valves, nine “new” valves were used as in the radiation tests but without exposure to the gamma radiation. The duration of this test was about 1100 hour well above the irradiation duration corresponding to 130 kGy

| Date       | Duration [hr] | TID [kGy] | Date       | Duration [hr] | TID [kGy] |
|------------|--------------|-----------|------------|--------------|-----------|
| 02-May     | 02-Jun       | 10        | 11-May     | 631          | 10        |
| 11-May     | 12-Jun       | 10        | 15-May     | 793          | 10        |
| 17-May     | 19-Jun       | 25        | 19-May     | 863          | 25        |
| 22-May     | 22-Jun       | 34.6      | 24-May     | 863          | 34.6      |
| 24-May     | 11-Jul       | 44.2      | 29-May     | 863          | 44.2      |
| 29-May     | 02-Aug       | 58.9      | 31-May     | 863          | 58.9      |
| 31-May     | 11-Oct       | 68.5      | 02-Jun     | 836          | 68.5      |
| 02-Jun     | 13-Oct       | 92.7      | 01-Nov     | 863          | 92.7      |
| 01-Nov     | 17-Oct       | 102.4     | 17-Oct     | 1001         | 102.4     |
| 17-Oct     | 23-Oct       | 112.4     | 23-Oct     | 1120         | 112.4     |
where the first radiation induced failures are observed. All of the valves showed a variation of the activated flow (varies between 0.3 to 0.9 l/min) as the ones shown on Figure 6.

5. Conclusion

The radiation tests performed on the piezoelectric miniature valve permit to estimate a radiation hardness of about 130 kGy for the pneumatic unit of the SIPART PS2 valve positioner, this value is higher than 99.8 kGy as seen on the first test performed at the Fraunhofer Institute. These values are compatible with future LHC HiLumi operation that does not foresee a TID greater than 70 kGy. The tested piezoelectric miniature valves are radiation-hard COTS (Commercial Off The Shelf components) as they can operate well above 1 kGy.

For an environment like a particle accelerator that has a very large variation of the radiation dose over a few meters, the radiation hardness of the pneumatic unit can still be increased by splitting the rotary potentiometer and the piezoelectric miniature valves, appropriate operation has been checked when using a 30 m flexible pipe between the pneumatic block and the single acting spring loaded actuator.

The tests performed were done with a Co-60 source and it is not clear whether a mixed particle field as the one found in the LHC will provoke more damage at equivalent TID value. Unfortunately, qualifying equipment up to 100 kGy with a large spectrum of particles is difficult, which may be feasible but only if testing a single miniature valve at a time in the IRRAD facility [5].

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