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# Irradiation tests of 3/2-way piezo valves at CERN

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**Abstract.** Miniature 3/2-way piezoelectric valves are part of both the Siemens Sipart™ intelligent valve actuator and of ON/OFF valves manufactured by Hoerbiger™. The use of the miniature valves permits reducing either the pressurized air consumption or the electrical current, respectively; these are desirable properties when dealing with long distances as found in the Large Hadron Collider (LHC). Future deployment in the LHC High Luminosity (HL-LHC) upgrade require a better understanding of the effects of particle radiation on the operation of these 3/2-way piezo valves. When used in radiation environments, both the intelligent valve actuator or the ON/OFF valve require the removal from the radiation environment of any integrated commercial electronic circuit. This paper presents the test setup and examines the effects of hadron radiation and gamma rays on the performance of 3/2-way valves under various operating conditions, providing insights into their reliability in radiation environments.

## 1. Introduction

The LHC High Luminosity (HL-LHC) upgrade will result in a high level of radiation that is expected to reach up to 100 kGy for all the equipment that is located outside the cryostats but inside the tunnel. This includes the valves' ancillary components as well as all the instrumentation operating in ambient conditions. Such a high radiation level exceeds the radiation qualification campaigns for most of the equipment and its effects need to be better understood to select the equipment and design its maintenance procedures

In the LHC accelerator there are about 1'500 cryogenic control valves that use the Siemens Sipart™ intelligent valve actuator modified at CERN's request for installation in radiation areas. The actuator is split into two parts: the control module containing electronic circuits which is located in a radiation-free area and the pneumatic unit with both the miniature valves and the feedback position potentiometer mounted on the control valve stem, which is exposed to particle radiation. For the HL-LHC it is desirable to deploy this set-up; however, the radiation environment imposes a new qualification campaign. To date, all reported radiation tests were performed by using gamma rays [1] that may underestimate the effects if the devices are prone to radiation displacement damage. The radiation qualification reported in this paper, was carried out in CERN's IRRAD proton facility where the primary proton beam with a momentum of 24 GeV/c is extracted from the CERN PS accelerator ring [2]. Such heavy particle irradiation, apart from radiation damage, provokes the activation of materials complicating the handling of components that become radioactive. The radiation test was performed on the components that had previously failed in tests, specifically the 3/2-way piezo miniature valves.

Till present all cryogenic ON/OFF valves are operated via a solenoid pneumatic switch valve that require a significantly higher electrical current compared to new piezo based designs. For the

LHC the switch valves were operated by using currents above 70 mA along cables with lengths ranging from 30 to 700 m; such configuration required to adapt the supply voltage to take into account the voltage drop along the cable that could be as high as 5.6 V. Model P8 piezo pneumatic switch valves are available from Hoerbiger™. While their local electronics must be replaced, these valves offer significantly lower power consumption, eliminating the need to adjust the supply voltage for different cable lengths. These valves were tested in the CC60 irradiation facility [2] that used a cobalt gamma rays source.

This paper presents the irradiation tests set-ups as well as the results.

## 2. Valve actuator and switch valve

The same type of miniature 3/2 way piezo valves is used in pairs in the SIPART™ intelligent valve actuator and as a single unit in the Hoerbiger™ type-P8 piezo-pneumatic switch valve. Radiation environment operation requires that every single component needs to be qualified and for most cases it is preferable to avoid electronic integrated circuits because of the complex qualification procedure and associated obsolescence complicate long term maintenance. For the SIPART™ and type-P8 valve it is therefore required to have respectively a split design with the control electronics in a radiation protected area and a replacement of the active electronics with purely passive electronic components.

The miniature piezo valve is based on a slab made with a polycrystalline piezoelectric body. The tests described in this paper hold the piezo actuator position for a relatively long time and the powering/depowering cycle has to be designed to avoid creep or hysteresis [3]. The powering waveform (see Figure 1a) of the 3/2 way piezo electric valves is produced for the individual piezo valves according to a reference document [4]. For the type 8 switch valve, the embedded electronic circuit is replaced by a passive electronic circuit producing a very similar powering cycle as the commercial version, see Figure 1b.

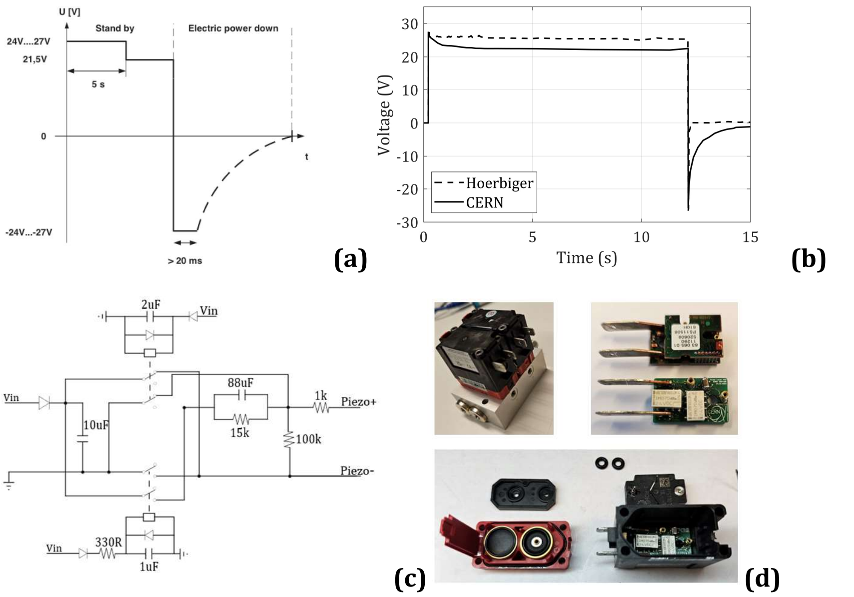



**Figure 1.** Powering of the 3/2 way valves. (a) According to [3] and applied during the PS IRRAD test, (b) local passive electronics in the modified type P8 switch valve, (c) type P8 switch powering waveforms measured by the commercial and passive electronics and (d) replacement process.

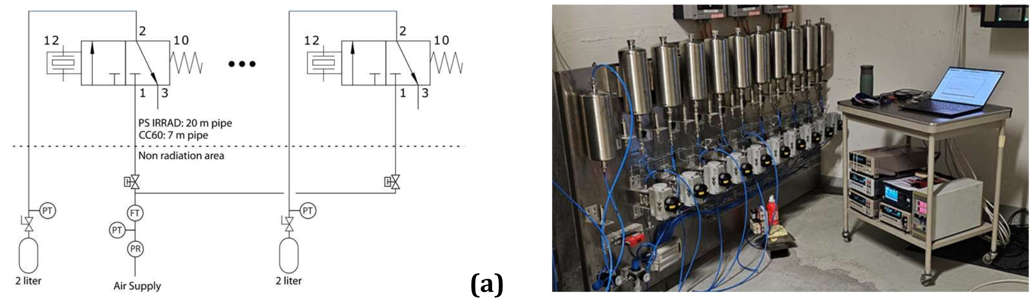



**Figure 2.** (a) The PS IRRAD and CC60 irradiated respectively 10 or 6 x 3/2 way valves. The piping connecting the radiation and non-radiation areas has a 4 mm internal diameter. PT, FT and PR are respectively a gauge pressure sensor, a mass flowmeter and a pressure regulator and (b) Setup.

**Table 1.** Main valve parameters in nominal conditions deduced from the data sheets.

| Valve type | Flow [ln/min] | Supply pressure [barg] | Leak rate [ln/min] |
|---|---|---|---|
| Miniature piezo | 1.5 | 1.4 | < 0.1 |
| Type P8 | > 50 | 6 | n.a. |

## 3. Test set-up

The test set-up (Figure 2), apart from the pipe length, is identical for both the individual piezo valves or the P8 piezo pneumatic switch. Up to ten 3/2 way valves can be tested sequentially, the control valves and measuring sensors are controlled by a LabView™ application. The apparatus is optimized to assess the leaks that may be present in the miniature piezo valve that has much lower operational pressure and nominal flow when comparing to the P8 switch valve (see Table 1). The control valves (rotating ball type), piping and piping fittings were selected and checked to have a leak rate well below the one expected for the miniature valve actuator.

**Table 2.** Test Sequence

| Step | Supply ball-valve | Piezo valve | Duration [s] | Purpose |
|---|---|---|---|---|
| 1 | OFF | OFF | 2 | Standby (check zeroing) |
| 2 | ON | OFF | 3 | Is there leakage through port 1? |
| 3 | ON | ON | 240 | Flow monitoring, is there leakage through port 3? |
| 4 | OFF | ON | 240 | Is there leakage through port 3? |
| 5 | OFF | OFF | 240 | Exhaust through open port 3 |

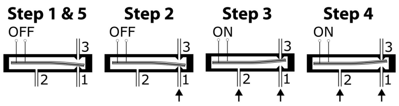



**Figure 3.** Miniature valve position according to the test sequence. The arrow indicates the presence of air above ambient pressure

During the irradiation, the valves were tested sequentially by the steps listed in Table 2, the 3/2 way valve corresponding valve position is shown in Figure 3.

The 3-2 way miniature valve leak can be measured directly via a mass flowmeter (0.06 to 3 ln/min span) during step 3 once the maximum pressure is reached and indirectly by measuring the pressure variation when the compressed air supply ball-valve is closed (step 4). The enclosed volumes connected to ports 1 and 2 are required to calculate the leaks. This volume can be evaluated by the sum of individual volumes and by integrating the compressed air mass flow ($\dot{m}$), calculating the compressed air density ($\rho$) that depends on the temperature ($T$) and pressure ($P$):

$$Volume = \frac{\int_o^{t_f} \dot{m}\, dt}{\left(\rho_{air}(P_f, T_f) - \rho_{air}(P_i, T_i)\right)}$$

Figure 4 shows, for a leak tight 3/2 way valve, the pressure, mass flow and accumulated mass for the set up used in the PS IRRAD facility. The enclosed volume is made by two 20 m long flexible pipes with an internal 4 mm diameter giving a volume of 0.0025 m$^3$ that corresponds well to the measured volume of 0.0026 m$^3$ (Figure 4).

The proton irradiation was performed in the PS IRRAD facility that provides a beam with a cross section of 12 mm x 12 mm FWHM (Full Width at Half Maximum). Ten miniature 3/2 way piezo valves and two dosimeters were aligned on a supporting frame installed on a movable table that permits whenever required to expose the valves to the beam track. This irradiation field permits to understand if the miniature valves are affected by displacement damage. Piezo electric devices contain mainly PZT (Lead zirconate titanate) material that is activated when exposed to the PS IRRAD irradiation field, therefore the miniature valves will require long cooling times before they can be manipulated by hand.

The gamma irradiation was performed in the Cobalt-60 irradiation facility. A maximum of six type P8 switch valves were located as close to the cobalt source in order to achieve 100 to 200 kGy within a reasonable time.

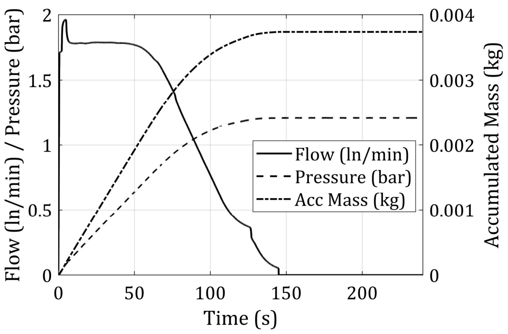



**Figure 4.** Accumulated mass in system set-up deduced from the mass flow and pressure measurements.

## 4. Irradiation test results

The purpose of the test is to qualify the operation of the devices in a 100 kGy radiation environment and the maximum irradiation targeted is about 200 to 400 kGy. The valves under test are depicted in Figure 5.

*4.1 miniature 2/3 way piezo valve*

The IRRAD facility has several users in parallel and furthermore feeds the CHARM irradiation area, it means that our request for a low dose rate was not satisfied and a dose exceeding 2.5 MGy was reached after very few days, see Figure 6. As shown in Table 2, the test sequence is relatively slow and the TID for a given step cannot be considered constant.


(a) (b)

**Figure 5.** (a) Piezo ceramic chips under test, on the left side chips tested at CC60, on the right chip tested at IRRAD. and (b) CC60 valves under test.

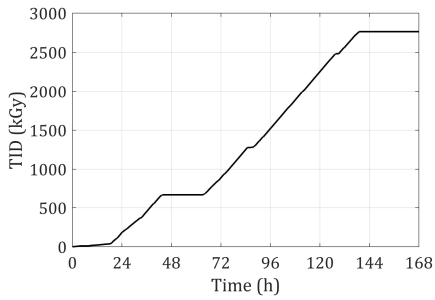
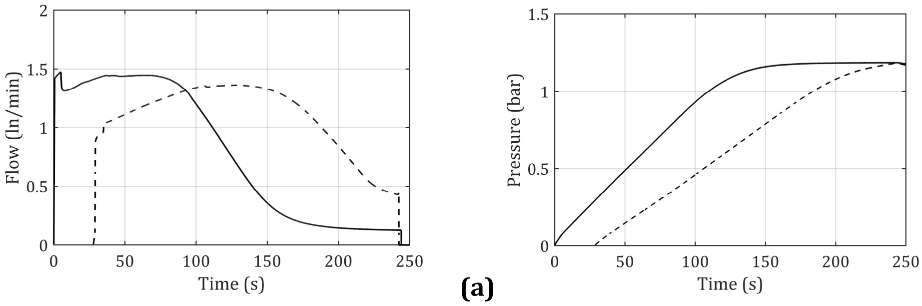



**Figure 6.** Accumulated dose during the test of the miniature piezo electric valves.




(a) (b)

**Figure 7.** Sample 5 dry run and after 175 kGy irradiation (a) variation of flow and (b) pressure of the enclosed volume for step 3.

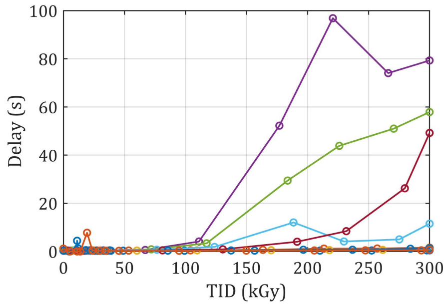



**Figure 8.** Turn ON delay versus TID.

When the piezo valve was closed and pressurized air was applied at port 1 (step 2), a leak is never observed all the way up to TID exceeding 1 MGy. This ensures the intrinsic safety of the Siemens Sipart™ intelligent valve actuator that will exhaust pressurized air through port 3 of both piezo valves when there is a power failure.

For step 3 a turn ON delay was observed and this phenomenon is not yet understood. The delay is different for each piezo valve and increases with increasing TID, see Figures 7 and 8. The flow rate also diminishes with increasing radiation dose suggesting a not completely open port 1 accompanied with a leak through port 3 that is the air exhaust. For step 4 a pressure reduction of the enclosed volume is observed and the flow that leaks through port 3 can be calculated.

Table 3 shows the radiation hardness on the turn ON delay and the maximum pressure at port 2 that is set arbitrarily to 80% of the nominal value. The turn ON delay is the most troubling radiation effect and it is difficult to predict what would be the behaviour for an oscillating drive condition as found in the SIPART™ valve controller. The overall results, delay < 1s and acceptable leakage through port 3, indicate that the maximum dose that can be withstood by the piezo valve is about 100 kGy; this value corresponds to the gamma irradiation tests performed in the past [1].

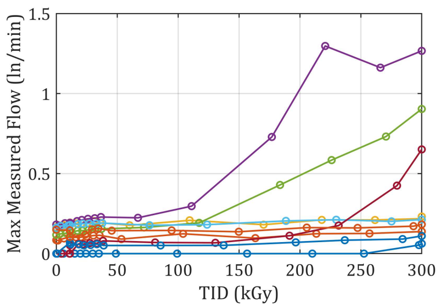



**Figure 9.** Leakage through port 3 versus radiation total integrated dose.

**Table 3.** TID versus acceptable delay and maximum output pressure

| Metric | TID [kGy] | | | |
|---|---|---|---|---|
| | Delay < 1 s | Delay < 5 s | Delay < 10 s | Max Pressure < 0.8 bar |
| Min | 90 | 177 | 177 | 289 |
| Median | 191 | 522 | 522 | 657 |
| Max | 1023 | 1070 | 1070 | 1033 |

*4.2 Type P8 piezo-pneumatic switch*

The Cobalt-60 (CC60) gamma-ray [2] facility is used to investigate the total ionizing dose effects on Hoerbiger™ piezo-pneumatic switch valves. An initial material-focused test was carried out, where individual components were exposed to a radiation dose of 56 kGy. The external valve housing became extremely fragile and the base turned brittle, although all the components remained operational.

Following this preliminary study, two sets of 3D-printed valve casings were produced using Accura 25™ and Ultem™ materials. The valve geometry was provided by Hoerbiger™, and the material selection was guided by existing literature data [5]. To establish a baseline for comparison, two unmodified switch valves with the original plastic casing were also included in the irradiation campaign. In total, six piezo valves were tested.

The most common failure mode observed during testing was the valve's inability to interrupt flow, essentially, a failure to close. The first such failure occurred at a dose of 20 kGy, with several others observed well before reaching 100 kGy. These malfunctions were primarily caused by embrittlement and cracking of structural materials. In such conditions it is probable that the piezo valve may be exposed to a far too high pressure or that there is a direct hydraulic path between the input and output ports. Furthermore, mechanical stress from the mounting of the miniature piezo valve on the CERN-designed passive circuit board also played a role in the observed failures, albeit to a lesser extent.

The P8 model switch valve was ultimately deemed unsuitable for deployment in the High Luminosity LHC project due to its inability to reliably withstand the expected radiation environment. However, it remains feasible to enhance the radiation tolerance of the valve by using alternative materials less prone to radiation-induced degradation. With these more resilient


**Figure 10.** P8 valves after CC60 campaign.

materials, the valve's radiation resistance could potentially be extended up to 100 kGy, by employing plastics less prone to radiation damage [5]. Figure 9 depicts the irradiated valves.

## 5. Conclusion

The radiation tests confirm that the maximum radiation dose that can be withstood by the SIPART™ intelligent valve controller is about 100 kGy independently of the radiation field. The deployment of these devices in the LHC HiLumi tunnel shall take into account maintenance and therefore good accessibility will reduce radiation exposure to maintenance crews. It shall be noted that the piezo-valves part can be located within 10-20 m of the valve stem resulting in a 3-split design with the electronics in a radiation protected area, the piezo valves in a moderate radiation field and the potentiometer at the moving stem of the cryogenic valve. The type P8 switch valve cannot be deployed in its present form in the LHC HiLumi but it can be installed in low radiation areas like the LHC circular arc.

## Acknowledgments
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## References

[1] Radiation Hardness of the Siemens SIPART intelligent valve, Juan Casas and Jean Marc Quetsch, IOP Conf. Ser. Mater. Sci. Eng. 502 (2019).
[2] Irradiation Facilities at CERN, Blerina Gkotse et al., Conference on Radiation and its Effects on Components and Systems, CERN, Geneva, Switzerland, 2 - 6 Oct 2017.
[3] Introduction to Piezoelectric Transducers, Rob Carter and Richard Kensley, Piezo.com
[4] Smart Positioner Modul, Technical Data, HOERBIGER Flow Control GmbH, PS31028A, 2023.
[5] Compilation of radiation damage test data, M. Tavlet, A. Fontaine and H. Schonbacher, CERN Yellow Reports: Monographs, 1998.