



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

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## Introduction

The LHC High Luminosity (HL-LHC) upgrade will increase the accelerator's luminosity by five to seven times. To accomplish this, approximately 150 meters of the accelerator on each side of the ATLAS and CMS detectors will be replaced with new components designed to handle more intense particle collisions.

This upgrade will expose equipment located outside the cryostats but inside the tunnel to radiation levels up to 100 kGy, which is beyond current qualification standards. Valves, ancillary components, and ambient instrumentation require radiation testing to ensure reliable operation.

About 1,500 cryogenic control valves use Siemens Sipart™ actuators, which separate electronics in radiation-free areas from pneumatic units exposed to radiation. The piezoceramic chip inside the Siemens Sipart™ actuator is tested with proton irradiation at CERN's IRRAD facility. Previous radiation campaigns mainly used gamma rays, which may underestimate hadron damage.

Cryogenic ON/OFF valves currently use solenoid pneumatic switch valves with high power consumption. Piezo valves, employing an identical piezoceramic chip to those in Siemens Sipart™ actuators, offer lower power use and improved performance. These piezo valves are tested under gamma irradiation at the CC60 facility.



Piezoceramic chips under test.

## Test set-up

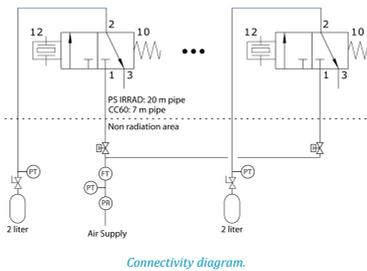
To evaluate the radiation tolerance and performance of miniature 3/2-way piezo valves and P8 piezo-pneumatic switch valves, a dedicated test setup was developed. The same configuration and testing method was used for both campaigns. The system allows up to ten valves to be tested sequentially, managed by a LabView™ application that controls all actuators and sensors. The apparatus is specifically optimized to detect leaks in the miniature valves, which operate at lower pressure and flow rates than the larger P8 switch valves. High-integrity ball valves, low-leak piping, and fittings were selected to ensure that any measured leak originates from the tested valves, not the infrastructure.

During irradiation, each valve was cycled through a defined test sequence consisting of:

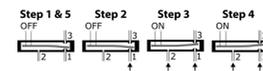
- Step 1 & 5: Valve in open position, system pressurization
- Step 2: Valve closed, input pressure applied
- Step 3: Valve opened, flow and leak measured
- Step 4: Ball valve closed, pressure decay measured

For proton irradiation, testing was conducted at CERN's PS IRRAD facility, which provides a high-energy proton beam ideal for simulating displacement damage. Ten miniature 3/2-way piezo valves and two radiation dosimeters were mounted on a movable support frame, precisely aligned within the irradiation field. The beam has a cross-sectional profile of 12 mm × 12 mm full width at half maximum, allowing uniform exposure of all tested components. Since the piezoceramic material, lead zirconate titanate (PZT), becomes radioactive under proton exposure, extended cooling periods were required before post-irradiation handling could take place.

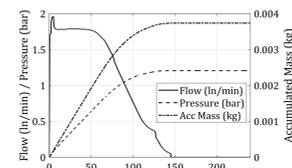
For gamma irradiation, the Cobalt-60 (CC60) facility was used to assess the total ionizing dose tolerance of the P8 piezo-pneumatic switch valves. Six valves were positioned near the cobalt source to reach total radiation levels between 100 and 200 kGy within a practical timeframe. Identical setups and test sequences were applied during both irradiation campaigns.



Connectivity diagram.



Test sequence.



Connectivity diagram.



Piezoceramic chips under test at IRRAD.



CC60 radiation source.



Testing setup CC60.

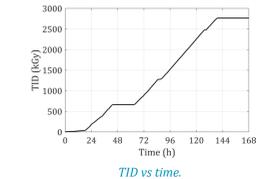
## Irradiation test results

### IRRAD – Proton beam

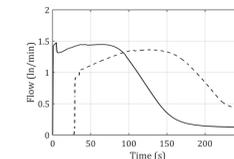
Tests at CERN's IRRAD facility exposed piezoceramic chips from Siemens Sipart™ actuators to high radiation doses, with dose rates exceeding expectations due to facility constraints. Despite this, integrity was maintained with no leaks up to 1 MGy total ionizing dose (TID).

- Nine piezoceramic chips tested with total dose exceeding 2.5 MGy.
- Turn ON delay increased noticeably after 100 kGy and varied between individual valves.
- No leaks were detected when valves were closed and pressurized at port 1, up to 1 MGy.
- Flow rate gradually decreased with increasing total ionizing dose, indicating partial valve opening and minor leaks through the exhaust port.
- Overall, piezoceramic chips performed reliably up to approximately 100 kGy, aligning with previous gamma irradiation results.

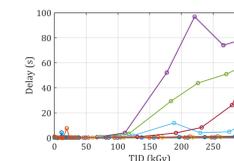
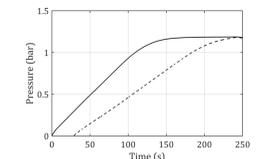
The piezoceramic chips inside Siemens Sipart™ actuators show strong resilience to proton irradiation up to 100 kGy, with no leakage and only a modest increase in turn ON delay. While higher doses cause increased delays and reduced flow, performance remains within acceptable limits for HL-LHC applications. Further studies are needed to understand behavior under dynamic operating conditions.



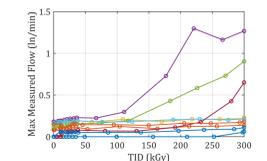
TID vs time.



Turn on delay variation of (a) flow and (b) of pressure.



Turn on delay vs TID.



Leakage vs TID.

## Valve actuator and switch valve

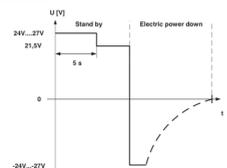
Two types of piezo valves that integrate identical piezoceramic chips were tested to assess their behavior under radiation, with different configurations and use cases:

➤ Piezoceramic chip used in Sipart™ intelligent valve actuator:

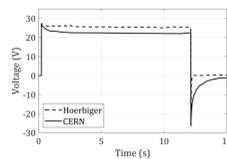
- Sipart™ contains two piezoceramic chips, with control electronics located to radiation-free areas.
- Tested under proton irradiation at CERN's IRRAD facility.

➤ Type P8 Hoerbiger™ valve:

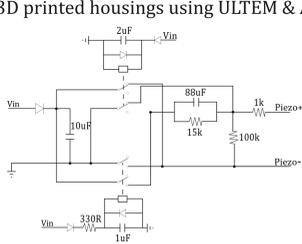
- Contains identical piezoceramic chip.
- Original embedded electronics replaced by custom radiation tolerant CERN electronics.
- 3D printed housings using ULTEM & Accura25.



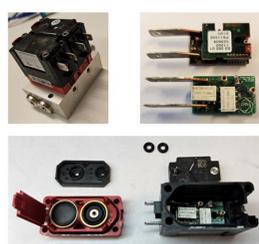
Control signal according to datasheet of P8 valve.



Experimental control signal.



CERN radiation tolerant electronics schematic.



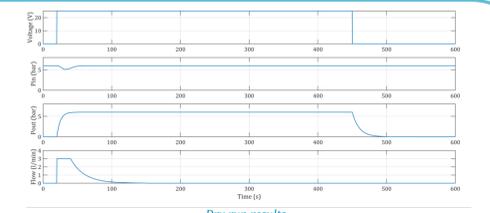
Industrial electronics replaced by CERN radiation tolerant electronics.

### CC60 – Gamma ray

To assess the radiation tolerance of Hoerbiger™ piezo-pneumatic switch valves, tests were carried out at CERN's CC60 gamma facility. Six valves, including original and modified units with 3D-printed housings and CERN passive electronics, were exposed to increasing radiation doses. Failures due to material degradation were observed below the 100 kGy HL-LHC target.

- Six valves: 2 original, 4 with 3D-printed housings using Accura 25™ and ULTEM™.
- Passive CERN circuits replaced embedded electronics.
- Most common failure: inability to close (flow not interrupted).
- First failure at 20 kGy, due to brittle housings and cracking.
- PCB mounting stress also contributed to malfunction.

The current P8 piezo switch valve cannot withstand HL-LHC radiation levels in its present form. However, using more radiation-resistant materials could significantly improve its performance.



Dry run results.



P8 valves under test.

Damaged P8 valves after CC60 campaign.

## Conclusions

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.