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Qualification of 0-60 mbar pressure transducers for the LHC HiLumi environment

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Abstract. The LHC HiLumi upgrade requires the procurement of 0-60 mbar absolute pressure sensors with an absolute accuracy of +/- 0.3 mbar and a radiation Total Integrated Dose (TID) that may reach 100 kGy. Such a low-pressure range is usually measured through the deformation of a relatively large diaphragm and the sole passive sensors commercially available use magnetic coupling for the measurement of the deformation. Additionally, ABB provided CERN with their low-pressure measuring cell that is based on a piezo resistive bridge measuring the diaphragm deformation. A radiation qualification test was performed with a gamma source targeting a 100 kGy TID. The sensors under test were a Valydine AP10 and an ABB passive pressure cell. The pressure sensors were attached to a leak-tight sealed cell, the cell temperature can be adjusted and therefore the pressure followed the law of ideal gases. The paper presents the radiation measurement set-up, the readout electronics located in a radiation-free location and the results of the irradiation.

1. Introduction

The LHC (Large Hadron Collider) upgrade (HL-LHC) at CERN, requires 0-60 mbar absolute pressure sensors with an absolute accuracy of +/- 0.3 mbar and a radiation Total Integrated Dose (TID) that may reach 100 kGy. Unfortunately, commercial sensors with embedded electronics cannot be used due to the effort required for validating standard commercial electronic components for radiation environments that, in this application, is extremely high. Such a low-pressure range is usually measured through the deformation of a relatively large diaphragm and, to our knowledge, the sole passive sensors available commercially use magnetic coupling for the measurement of the deformation. An industrial partner, ABB®, provided CERN with their low-pressure measuring cell that is based on a piezo resistive bridge measuring the diaphragm deformation. This cell is used in their commercial device that, apart of the radiation hardness, satisfies the HL-LHC accuracy requirements. In radiation environments, 0-60 mbar pressure sensors have been installed and operated successfully in CERN's accelerators complex (LHC and SPS), the sensors were manufactured respectively by NICHE® (not anymore available) and ABB®.

A radiation qualification test was performed with a gamma source targeting a 100 kGy TID. The sensors under test were a Valydine® AP10 and an ABB®, both passive devices. The pressure sensors were attached to a leak-tight sealed chamber, the chamber temperature can be adjusted and therefore the internal pressure followed the law of perfect gases.

The paper presents the radiation measurement set-up, the readout electronics located in a radiation-free area and the results of the irradiation.

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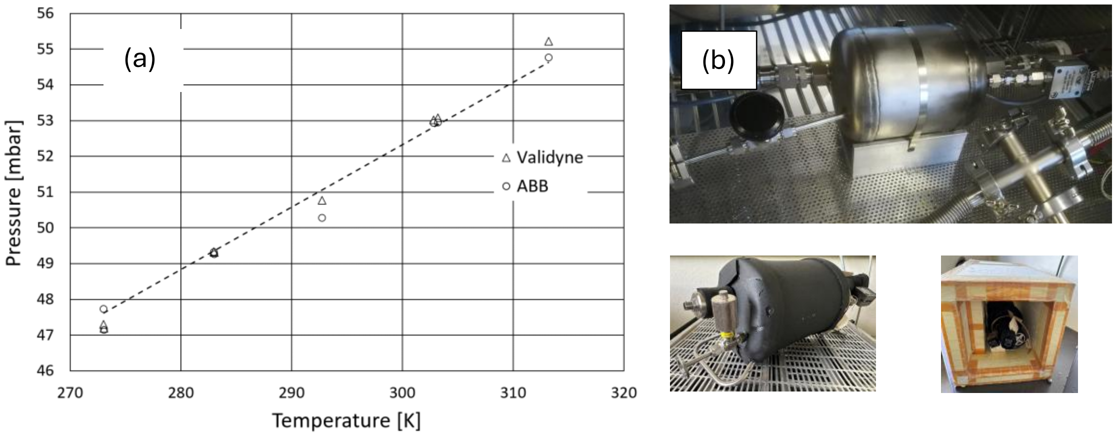

Figure 1. Test set-up. (a) Variation of pressure versus temperature. (b) Sealed chamber: bare, with insulation and inside the extruded polystyrene insulation chamber

2. Test set-up

The qualification of a device for operation in a radiation environment usually requires the comparison to a reference apparatus that is either non affected by the radiation or that is moved outside the radiation field. The reference pressure selected in this test is a closed and leak-tight chamber. Its internal pressure is varied by modifying the gas temperature, in such conditions the pressure can be expected to be changed by at least 10%, by assuming that the pressure is dictated by the law of ideal gases (pressure proportional to the absolute temperature) and the volume constant (thermal expansion is negligible and no correction is performed on the pressure), see Figure 1a. The temperature sensor is located inside the sealed chamber also exposed to the radiation field; it is a platinum 100 ohm sensor, this type of device was qualified for operation in radiation fields more hostile than the one to which the pressure sensors are exposed [1]. To avoid leaks due to synthetic material degradation, the pipes are joined by metallic compression fittings and the gas filling port uses a bellow sealed valve. The sealed chamber has a synthetic insulation, and it is placed inside a cubicle made with 50 mm thick extruded polystyrene insulation plates, see Figure 1b.

The measurement apparatus is controlled by using a LabView® application that monitors the ABB® bridge and that acquires the Validyne® sensor signal either through a Validyne® CD15 signal conditioner or by using a transformer coupling excited by a 5 kHz sinusoid.

3. Individual sensor calibration

The pressure sensors are calibrated inside a climate chamber to obtain an approximation function that is capable of compensating variations of the sensor temperature. For applications at CERN, this type of pressure sensors are typically used to measure the saturation pressure of superfluid helium baths. The accuracy target is selected to match or surpass the temperature measurements that show a reproducibility of ± 0.005 K, it means ± 0.3 mbar with respect to a saturated helium bath of 18 mbar with a corresponding temperature of 1.827 K. It can be noted that the sensors operate at ambient temperature and the measurement is done by using a sensing capillary.

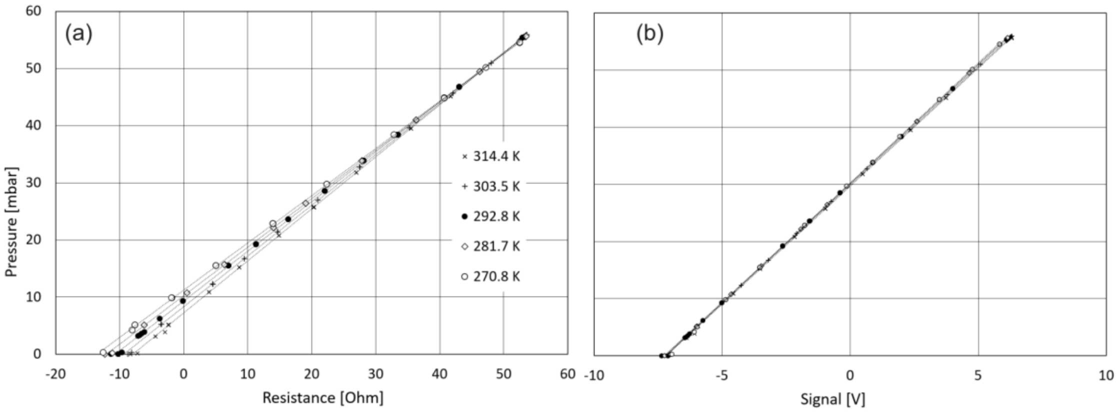

Figure 2. Pressure calibration in a climatic chamber, the chamber temperature is 270.8, 281.7, 292.8, 303.5 and 314.4 K. The sensors are (a) ABB® and (b) Validyne® AP10.

The ABB® sensor is made of a Wheatstone bridge engraved on a silicon substrate. When used in the commercial 266AST sensor series, it complies the HL-LHC accuracy requirements. The Wheatstone bridge has a parasitic diode and, for compensating any offset, it is excited with a square current waveform with 880 µA & 0 A values that is the standard configuration when using the radiation tolerant electronics [2]. The output signal is expressed in ohm and it is the ratio between the measured voltage bridge imbalance and the excitation current; it means a negative voltage imbalance will result in a negative resistance, see Figure 2a. The sensor has a good linearity with respect to the applied pressure, however the spread with respect to the sensor temperature increases when decreasing the pressure. The 0.3 mbar accuracy target requires a temperature correction even for an ambient temperature variation as small as 1 K.

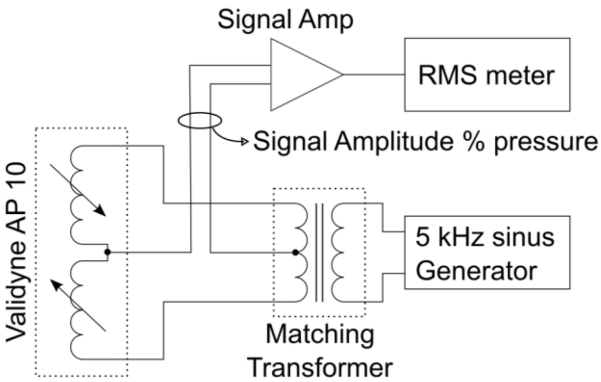

Figure 3. Test set-up for measuring a Validyne AP 10 pressure sensor. The insulated differential signal amplifier is a Tektronix AM502 and the matching transformer is a Triad magnetics TY-250P made to work in the audio range.

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The Valydine® AP10 sensor is either connected to a set of individual instruments (Figure 3) or to a Valydine® CD15 signal conditioner, this conditioner permits to change the amplification and span width of the pressure sensor signal. The AP 10 sensor response (Figure 2b) has a very good linearity and is insensitive to ambient temperature effects. The CD15 signal conditioner has two 10-turn rotary potentiometers to adjust gain and zero, over the long term (i.e. during irradiation tests) we have observed sudden zeroing permanent offsets that most probably are due to the electronic unit, therefore for some tests the conditioner was replaced with a set of individual instruments (Figure 3) and no sudden offset was observed. The connecting cable is part of the complex sensor impedance and therefore the signal amplitude depends on the cable impedance loading. The cable shield is grounded on both sides and both twisted pairs shields are grounded only on the electronics side. The CD15 gain and zeroing potentiometers are used to compensate for cable loading effects.

4. Radiation tests

The pressure sensors were irradiated in the CC60 irradiation room of CERN's CALLAB facility [4]. 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 test duration was about a month in order to reach the target Total Integrated Dose (TID) of 100 kGy that corresponds to the radiation that the sensor may reach at its location in the HL-LHC accelerator. Three pressure sensors were irradiated, they were one ABB® passive piezo-resistive and two Validyne® AP10. A platinum 100 ohm sensor was placed inside the low pressure gas in the sealed chamber and it was also irradiated, this particular device is unaffected by this TID level [1]. The TID depends strongly on the particular sensor location and therefore the TID increase rate is measured individually for each sensor.

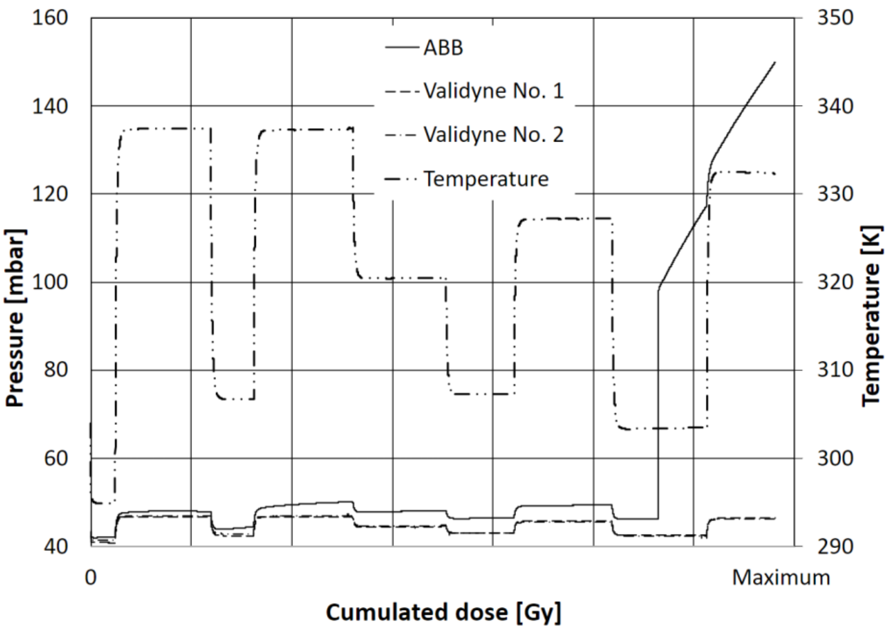

Figure 4. Pressure measurements while changing the sealed chamber temperature. The maximum TID is different for each individual pressure sensor, it varies between 100 and 160 kGy.

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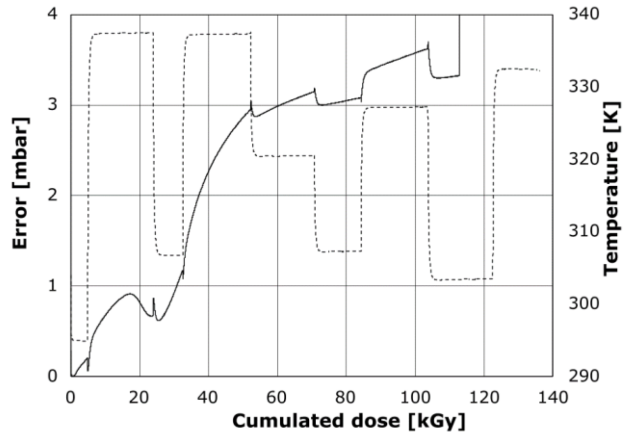

Figure 5. Measurement error for the ABB sensor with increasing TID. Temperature: dashing. Pressure: continuous line.

Figure 4 shows the measured pressure versus the sealed chamber gas temperature while increasing the TID. There were no leaks present in the set-up, the filling gas is nitrogen, its pressure is about 42 mbar and it is proportional to the temperature. The scale on Figure 4 does not permit to validate whether the sensors are reproducible within ± 0.3 mbar, but it shows that the ABB© sensor drifts with respect to the two AP 10 sensors that are superimposed, and a large sudden offset exceeding 100 mbar appears when exceeding about 110 kGy (Figure 4 and Figure 5).

Radiation effects impair the performance of the ABB® device, exceeding the 0.3 mbar limit after receiving less than 10 kGy. After the irradiation campaign the ABB® sensor provides a variable bridge impedance versus the applied pressure, however its pressure response does not correspond to the initial calibration (Figure 2a).

Two Validyne® AP10 sensors were irradiated in CERN's CALLAB facility. These sensors measure the diaphragm deformation through inductive coupling, they are therefore composed of coiled wires and magnetic materials that usually keep their properties within the radiation levels specified for the HL-LHC project [5]. During the irradiation campaign a sudden pressure variation

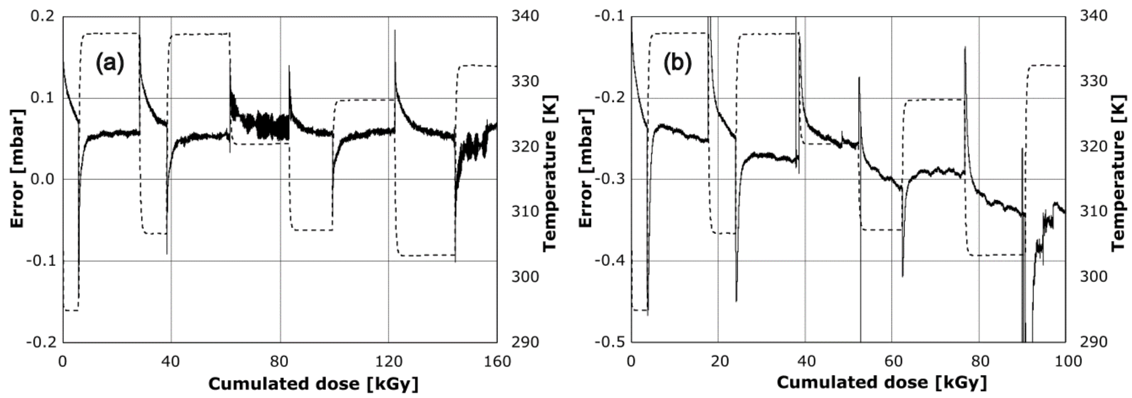

Figure 6. Measurement error for two different Valydine AP10 pressure sensors. Temperature: dashings. Pressure: continuous line.

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of about 0.65 mbar was observed on one of the devices, it is attributed to a problem solely caused by the CD15 signal conditioner. Figure 6 shows the measurement error versus the TID, there is no obvious drift caused by the TID level; when a temperature variation step is applied the slow pressure sensor response is attributed to the time required to homogenize the temperature inside the low pressure sealed chamber.

5. Conclusion

The Validyne® AP10 pressure sensors have demonstrated adequate radiation hardness till TID doses up to 160 kGy, this dose exceeds the HL-LHC requirement. It is planned to integrate the signal conditioning within CERN's custom-made radiation tolerant electronics [2]. For this purpose, an audio transformer with central taping, a 5 kHz excitation wave and signal rms amplitude measurement will be integrated in a readout card, this system has fixed gain avoiding the appearance of sudden signal excursions.

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