



Calibration of piezoelectric pressure and acceleration transducers

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Abstract

Among the multitude of tests performed in NC Laboratory Spiez, conventional as well as nuclear air blast and ground shock loadings are simulated. For these tests, piezoelectric transducers are used for both pressure and acceleration measurements. In order to keep the uncertainty of measurement as small as possible, NC Laboratory Spiez developed two facilities for the absolute calibration of piezoelectric pressure and acceleration transducers. With one of the facilities piezoelectric pressure gauges in the range of 0.5 to 30 bar can be calibrated. The calibration system is based on a so-called dynamic pressure equilibrium principle. The transducer sensitivity is determined by measuring the pressure in the equilibrium volume by using a pressure-transfer standard unit. The other system allows the dynamic calibration of piezoelectric accelerometers in the range of 50 to 1000 m/s². The sensitivity of the accelerometers [pC/g] is calculated from the measurement of a displacement-time history.

1 Introduction

In Switzerland, both military and civil defence shelters are designed in order to offer protection against the effects of conventional, nuclear and chemical weapons. The NC Laboratory Spiez has been officially appointed to perform all the relevant tests to prove the adequacy, reliability and durability of shelter equipment. Among the multitude of tests and experiments performed in our laboratory, conventional as well as nuclear air blast and ground shock loadings are simulated. For these tests, piezo-

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electric transducers are used for both pressure and acceleration measurements.

In order to keep the uncertainty of measurement as small as possible, it is necessary to determine the response characteristics (sensitivity, linearity etc.) of the transducers in the range of intended use. Therefore NC Laboratory Spiez developed two facilities for the *absolute* calibration of piezoelectric pressure and acceleration transducers, meaning that the calibrated values are directly related to SI units.

Since there is no corresponding service in Switzerland, NC Laboratory Spiez will be accredited by the Swiss Accreditation Service in 1998 according to the European Standard EN 45001 as a calibration laboratory for the absolute calibration of piezoelectric pressure and acceleration transducers.

2 Calibration of pressure transducers

In NC Laboratory Spiez equipment for Swiss civil defence shelters is tested against the effects of air blast. In these tests the loading values i.e. pressure and impulse are measured using piezoelectric pressure transducers.

Since many years, NC Laboratory Spiez is operating a so-called "reference-pressure-transducer" based calibration facility for these transducers, which means that the response of the pressure gauges to be calibrated is compared with that of a calibrated reference transducer.

With the introduction of an overall quality management system in NC Laboratory Spiez, the requirements on the calibration systems have rapidly increased. Therefore a new calibration facility called DACAL, which is based on the dynamic pressure equilibrium principle, was developed. This method was chosen because many tests have shown that the transducer sensitivity is not only pressure dependent, but also influenced by the loading characteristics.

The facility is operating in the pressure range between 0.5 bar and 30 bar, optional up to 100 bar. A total of twelve pressure levels within the calibration range are available and adaptable to customer requirements. Up to five transducers can be calibrated simultaneously.

2.1 DACAL: Concept and principle of function

Figure 1 shows the principle of the calibration facility. The "heart" of DACAL is the accredited high precision Pressure Transfer Standard unit DTS, recording the pressure applied on the transducers. Simultaneously the electrical signals from the transducers are measured. The whole cali-

bration procedure is monitored and controlled by a personal computer. In figure 2 the main components of DACAL are shown schematically. Once the pressure transducers to be calibrated are mounted in special Delrin adapters and all the necessary preparatory work is done, the calibration procedure is started with a short key command and runs automatically through the pressure levels chosen.

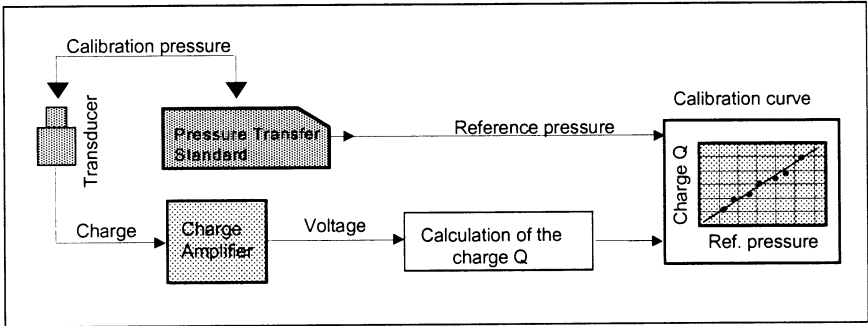


Figure 1: Principle of the DACAL calibration system

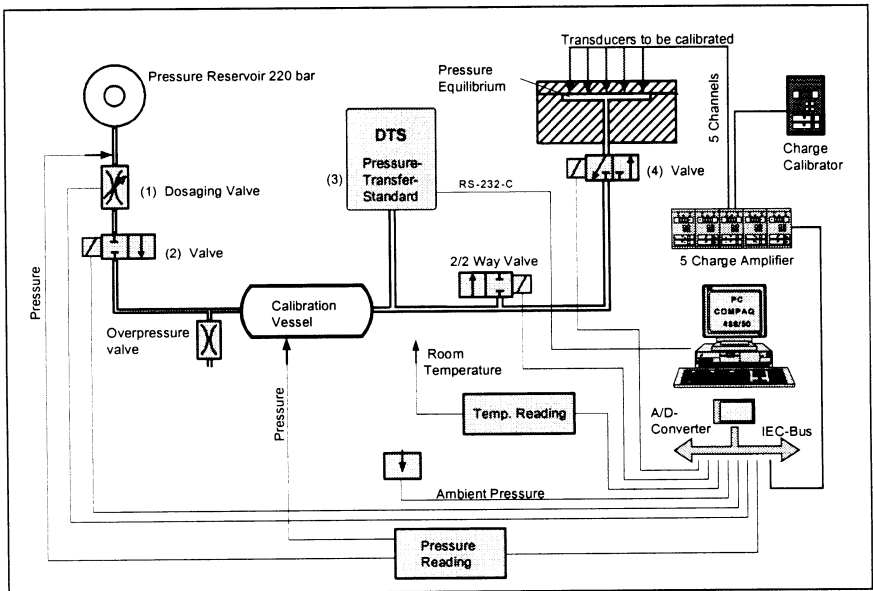


Figure 2: Functional outline of DACAL

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In a first step the desired airflow rate at the dosaging valve (1) is set. Then the air inlet valve (2) opens, until the selected pressure in the calibration vessel is reached. In the time needed for the temperature in the calibration vessel to reach equilibrium (a few minutes) the charge amplifiers and the A/D-converter are controlled by a charge signal provided by a charge calibrator. Then the pressure in the calibration vessel is measured using the pressure transfer standard unit (3). This value is now being used as reference pressure for this particular part of the calibration cycle. In a next step the valve (4) opens very quickly (ms) and the electrical output signals from the transducers are recorded. While the computer is processing the measured signals, the pressure equilibrium volume and with that also the transducers are reset to atmospheric pressure using valve (4). This step is repeated two more times, before the pressure in the calibration vessel increases to the next calibration pressure level. The procedure goes on until the highest calibration pressure is reached. Finally the calibration curve is determined.

2.2 Example of a calibration

Figure 3 shows a typical calibration curve for a piezoelectric pressure transducer. The curve is a third order polynomial fit over the measurement values and forms the base for the determination of the average sensitivity (pC/bar) of this particular transducer.

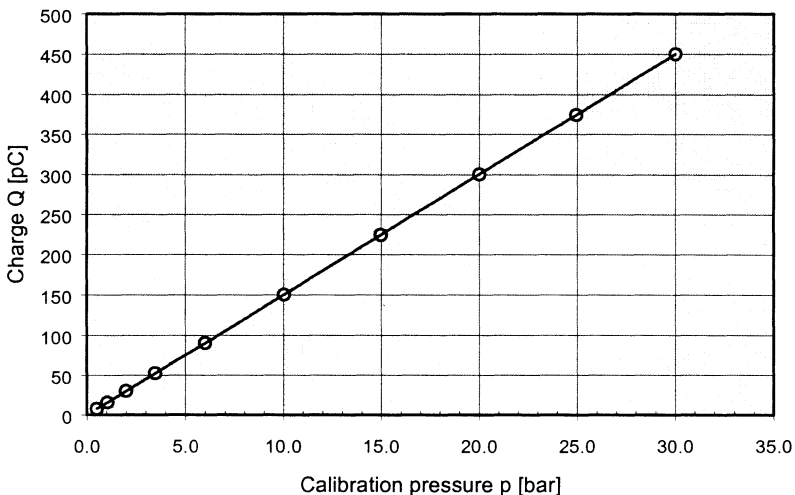


Figure 3: Calibration curve

3 Calibration of accelerometers

Because unprotected shelter equipment may be severely damaged by the ground shock loading due to conventional or nuclear weapons, shock protection measures to ensure the survivability of the shelter equipment are of great importance. In Switzerland shelter equipment is therefore systematically shocktested. In the tests the motion of the shock table and, if needed, the response of some parts of the test object are measured with piezoelectric accelerometers.

Usually accelerometers are calibrated by the comparison method using a vibration exciter. As it will be shown, this method is not fully satisfying for transient events. In order to keep the uncertainty of measurement as small as possible an absolute calibration of the accelerometers in the range of intended use is required.

Therefore NC Laboratory Spiez developed a calibration device, called BECAL (Figure 4), that allows the determination of the sensitivity of piezoelectric accelerometers directly from a simultaneous measurement of time and displacement.

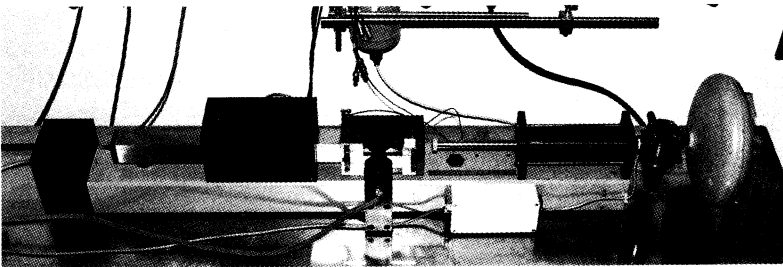


Figure 4: General view of BECAL

3.1 BECAL: Construction and principle of function

The main parts of BECAL are shown in figure 5. A steel bar with square cross section is moving frictionless on air-cushion bearings. The accelerometer to be calibrated is mounted in a casing fixed to one end of the bar. A precision ruler with an engraved scale (division $40\ \mu\text{m}$) is attached to this casing. At the other end of the moving bar penetrators of different shapes can be fixed. The moving bar is brought to the required velocity by a pneumatic cylinder. By penetrating a plastic target the bar is decelerated over a defined distance. By using plastic targets the generation of high frequencies is avoided.

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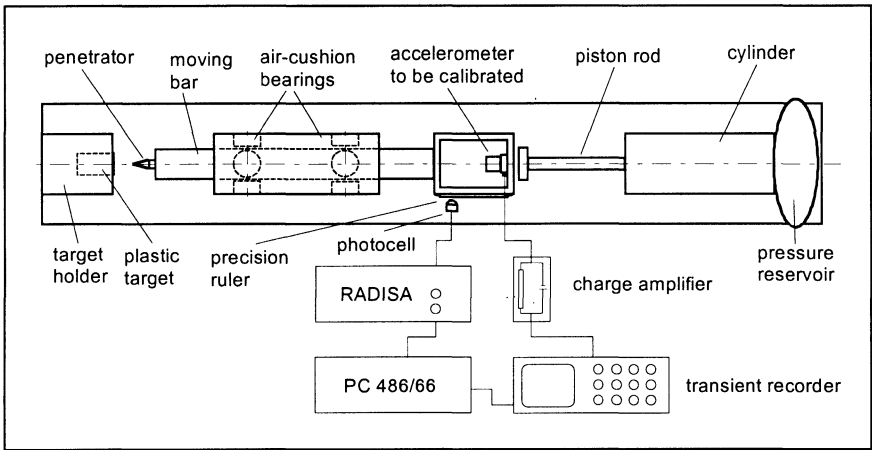


Figure 5: Schematic top-view of BECAL

During the deceleration the displacement as a function of time is measured on the precision ruler with a photocell and the specially designed electronic system RADISA. By doubly differentiating the measured displacement-time history, the absolute acceleration-time history is obtained. Calibration of the accelerometers results from a comparison of the maximum acceleration measured by the accelerometer and by BECAL. Thus it is ensured that the results of this calibration method are traceable to national standards.

Up to now a large amount of tests has been carried out using both, different types of penetrators and different target materials. The results of these tests confirm that BECAL allows absolute shock calibration of piezoelectric accelerometers in the range of 5 to 100 g. With BECAL accelerometers can be calibrated at one single acceleration level or over a defined acceleration range. As an example the results of a calibration are shown below.

3.2 Example of a calibration

The accelerometer to be calibrated is of the type Kistler 8005. The sensitivity given by the calibration certificate of the manufacturer is 5.0 pC/g. This sensitivity is set on the charge amplifier used (Kistler 5011).

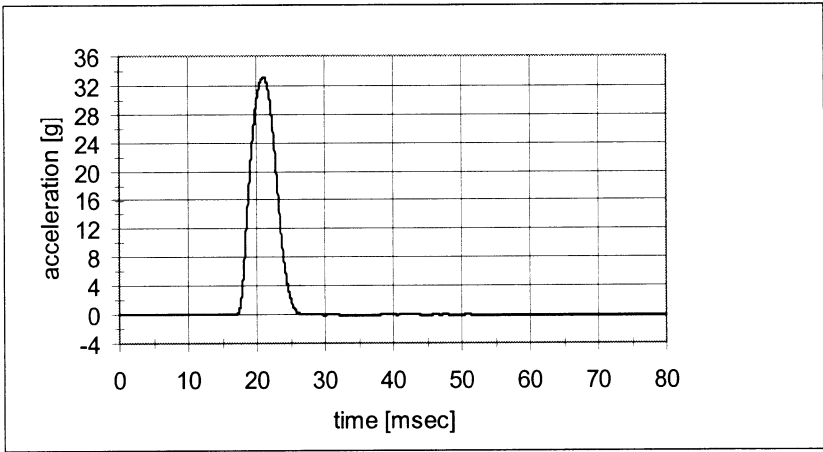


Figure 6: Data measured by the accelerometer

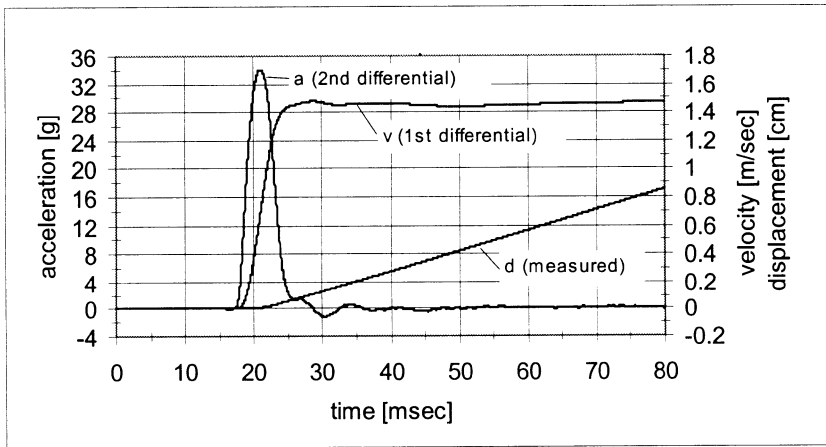


Figure 7: Data measured by BECAL

Figure 6 shows the data measured by the accelerometer to be calibrated. The measured maximum acceleration is 33.13 g. Figure 7 shows the data measured by BECAL. The maximum acceleration calculated from the measured displacement is 34.05 g. For the analysis of both the accelerometer data and the BECAL data a De Hamming filter (cosine weighted moving average) with a bandwidth of ± 35 samples was applied.

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As mentioned above, the calibration factor is obtained by calculating the ratio of the maximum value of acceleration measured by the accelerometer to be calibrated and the value calculated from the measured displacement-time history. In this example the calibration factor is 0.973. To calculate the calibration sensitivity for the generated acceleration level (33.13 g) the sensitivity set on the charge amplifier has therefore to be multiplied with the calibration factor. In this example the resulting calibration sensitivity is 4.86 pC/g.

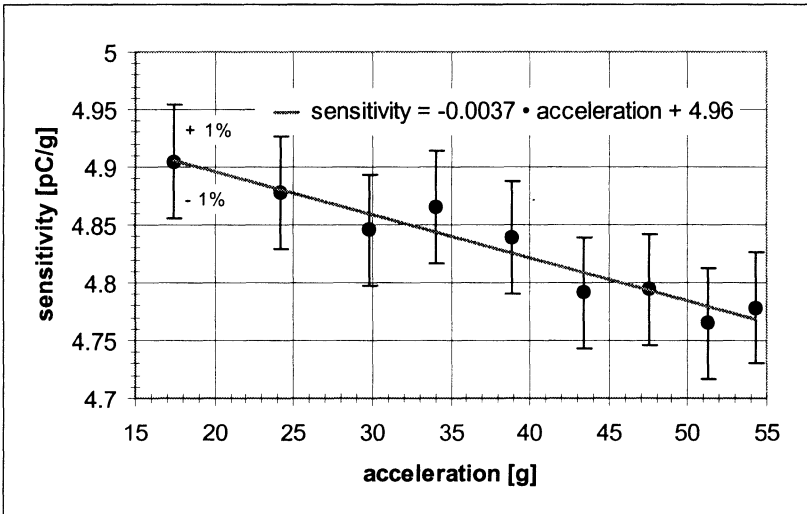


Figure 8: Sensitivity over an acceleration range

Figure 8 shows the results of a series of calibrations with the same accelerometer at different acceleration levels. It is clearly shown that the sensitivity of a piezoelectric accelerometer is dependent on the acceleration level. Therefore transient calibration of accelerometers is essential for shock measurements.

4 Uncertainty of measurement

Taking into account the individual uncertainties of all the measuring components used, an overall uncertainty of measurement of $\pm 1\%$ (2σ) for both, the calibration of pressure transducers and the calibration of accelerometers can be guaranteed. However the specific uncertainties in the measured physical quantities are many times smaller ($< 0.2\%$).

5 Concluding remarks

With putting into operation the calibration facilities presented in this paper, NC Laboratory Spiez will have at its disposal efficient high quality calibration systems for piezoelectric pressure and acceleration transducers. In detail:

- Both methods take into account the dynamic character of the relevant physical effects.
- Both methods provide an absolute calibration by measuring independently another physical quantity, which is a big advantage compared with calibration methods using reference transducers.
- The calibration steps are variable and adjustable to client requirements
- Both units will be accredited by the Swiss Accreditation Service in 1998 according to the European Standard EN 45001.

With this one of the main goals of NC Laboratory Spiez will be achieved i.e. to satisfy their customer needs.

6 Acknowledgements

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