



High pressure calibration

Calibration and dynamic verification of pressure sensors traceable to international standards

Calibration and dynamic verification of pressure sensors for ballistics applications

The demanding conditions inherent to ballistic testing prescribe strict quality control and maintenance for all measurement equipment. Pressure sensors, in particular, require regular maintenance and re-calibration.

Calibration of piezoelectric pressure sensors

Numerous guidelines and standards are available for the calibration of pressure sensors, but only a few guidelines include quasistatic procedures for piezoelectric measurement equipment. The ISA-S37.10, for example, calls for a quasi-static calibration procedures in which 'the source of calibration pressure may be either continuously variable over the range of the instrument or may be provided in discrete steps, as long as the pressure is returned to zero after each step.' This forms the basis of three quasi-static procedures for the calibration and verification of piezoelectric pressure sensors:

- Stepwise calibration
- for calibrating working standards
- Continuous calibration
 - standard procedure for the day-to-day calibration of test sensors
- Dynamic verification
 - to confirm the functionality of a test sensor under highly dynamic pressure loading

Definitions of main calibration expressions

Stepwise calibration

Pressure is applied in discrete steps. At each step, the applied pressure is allowed to stabilize, before rapidly dropping to atmospheric conditions. The output from the Unit Under Test (UUT) is measured directly before and after the pressure drop, thus recording the change in charge output resulting from the change in pressure.

A stepwise calibration is typically conducted with a deadweight tester (also known as piston pressure gage) that uses known traceable weights to apply pressure to a fluid. Deadweight testers are primary standards, i.e. the pressure measured by a deadweight tester is derived from other, fundamental quantities: length, mass and time. National Metrology Institutes and accredited laboratories typically use high quality deadweight testers to calibrate pressure standards (or reference sensors).

Continuous calibration

Piezoelectric pressure sensors are typically calibrated using a socalled continuous calibration procedure; i.e. a comparison of the output signal of the Unit Under Test with that of a reference sensor, while continuously increasing the pressure from zero to full scale and then back to zero. The test sensor's sensitivity is typically defined as the slope of a 'best straight line' through the calibration curve (test system output vs. reference system output).

The continuous calibration is generally recommended and widely accepted as the standard procedure for the calibration of piezo-electric high pressure sensors.



Calibration methods and traceability



Dynamic verification

The functionality of a sensor is verified under dynamic loading conditions similar to those found in internal ballistic testing. The output of the Unit Under Test is compared with that of a reference sensor, while rapidly applying and removing pressure. Pressure pulses up to 6 000 bar with gradients in excess of $3\cdot10^6$ bar/s are typically used for a dynamic verification.

A dynamic verification is conducted to confirm a sensor's functionality; it is typically conducted in addition to (and not as replacement of) a continuous calibration.

Calibration prerequisites

It is essential that the calibration equipment is maintained in good working order. It is generally recommended, that working standards and amplifiers used in calibration laboratories are calibrated at least once per year.

It is also important that the insulation of the high-insulation connecting cables is checked regularly. Cables with less than $10^{13}\;\Omega$ insulation resistance should no longer be used for calibration.

- The sensor insulation resistance should exceed $10^{12} \Omega$
- Always use the correct mounting torque as specified for each sensor type
- Use the correct tools when mounting and removing sensors or adapters
- Always use the correct calibration adapters

Typical system configuration for continuous calibration



PC or Laptop Operating system: Windows XP / Windows 7 Serial Interface: 1 x USB

Calibrate[™] Software Included with 5959A..

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Typical system configuration for dynamic verification



System for the continuous calibration of piezoelectric pressure sensors

Calibration procedure	Continuous calibration, com- parison with a reference sensor	
Nominal range	bar	8 000
Largest calibration range	bar	0 8 000
Smallest calibration range	bar	0 800

System for the dynamic verification of piezoelectric pressure sensors

Test procedure	Pressure pulse verification, com- parison with a reference sensor	
Nominal range	bar	5 000
Largest peak amplitude	bar	0 5 000
Smallest peak amplitude	bar	0 800

System components

Туре No.	Description	
6906	Hydraulic pressure generator (8 000 bar)	
6963A8000	Reference pressure sensor (8 000 bar)	
5959A	Calibrator (incl. Kistler's Calibrate™ software suite)	
1631C2	Connecting cable, high insulation	
Sensor-specific calibration adapters, depending on respective unit(s) under test, e.g.		
6925	Calibration adapter: M10x1 – M10x1, for sensor Types 6215 , 6229	
6923A	Calibration adapter: M10x1 – M12x1, for sensor Types 6213 , 6217	
6921	Calibration adapter: M10x1 – M10x1, for sensor Types 6201 , 6211	
69xx	Other calibration adapters available, please contact Kistler for more information	

System components

Туре No.	Description	
6909	Hydraulic pressure pulse generator	
6213BK	Reference pressure sensor for pressure pulse generator Type 6909	
2519	Transient recorder	
1631C2	Connecting cable, single wire, high insulation	
Sensor-specific adapters, depending on respective unit(s) under test, e.g.		
6931A3	Dynamic verification adapter: M12x1 – M12x1, for sensor Types 6213 , 6217	
6931A2	Dynamic verification adapter: M12x1 – M10x1, for sensor Types 6215 , 6229	
6931A1	Dynamic verification adapter: M12x1 – M10x1, for sensor Types 6201 , 6211	
69xx	Other calibration adapters available, please contact Kistler for more information	

Verification and recalibration intervals

For internal ballistics pressure measurements, periodic verification of sensor performance and subsequent recalibration is advisable. The calibration interval, however, depends on the specific testing conditions and the applicable standards.

The following table features the official NATO Guidelines (status January 2013) and general Kistler recommendations for verification and recalibration intervals as well as end-of-service-life criteria.

Criteria	NATO (EPVAT Guidelines section 12.5)	Kistler (Type 6215)	General recommendation
Verification required	S measured prior and after 'test', at least after 300 rounds (verification)	Peak pressure <5 000 bar every 1 000 rounds Peak pressure >5 000 bar every 200 rounds	Before each measuring campaign (verification at expected peak pressure)
Recalibration required	Complete calibration (S, L) at least every 1 000 rounds	l Delta p I _{at peak} >2,0 % (determined with dynamic verification)	l Delta p l _{at peak} >2,0 % (determined with dynamic verification) or disconti- nuities in pressure curve; resp. at least every 300 rounds, or once per year
End of service life	$ S_{current} - S_{previous} > 2 \% \text{ or}$ $ S_{current} - S_{original} > 10 \% \text{ or}$ $ L_{current} - L_{previous} > 1 \%$	L >1,5 %	S _{current} - S _{original} >5 % or L >1,5 %

L = Non-linearity S = Sensitivity

Overview of calibration products

Pressure generators

Pressure generator



Technical data	Туре	6906
Number of sensors		2
Sensor connection ¹⁾		M10x1
Pressure range	bar	0 10 000
Temperature range	°C	room temperature
Calibration procedure		continuous
Pressure medium		mineral oil

Туре

bar

°C

6909 2

pulse mineral oil

sensor-specific

room temperature

0...5000

¹⁾ Mounting adapters available for most Kistler pressure sensors

Pressure pulse generator

Technical data
Number of sensors
Sensor connection ¹⁾
Pressure range
Temperature range
Calibration procedure
Pressure medium

¹⁾ Mounting adapters available for most Kistler pressure sensors

Reference sensors

High pressure reference sensor

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	Technical data	Туре	6963A8000
	Pressure range	bar	8 000
	Overload	bar	10 000
	Linearity	%FSO	0,3
	Sensitivity	pC/bar	1,2
	Calibration		SCS-accredited
	Connection		KIAG 10-32 neg.
	Thread		M10x1
	Dimensions	mm	D = 14, L = 115

Calibrators

Calibration unit

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Technical data		Туре	5959A
Input signals	Reference		Charge
	UUT		Charge or voltage
Input range	Reference	pC	±2 2 200 000
	UUT	pC	±2 2 200 000
		V	±0 10
Sensor connecti	ons		BNC neg.
Number of UUT	-		1
ADC resolution			16
ADC sampling r	ate		400
Supply voltage			110/230
PC interface			USB
Dimensions			235x135x420
PC requirement	s		Windows [®] XP/7
Calibration proc	edures		continuous, stepwise

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Precision charge calibrator



Technical data		Туре	5395B
Source	Charge range	рС	±100 2 000 000
	Voltage range	mV	±100 10 000
Monitor voltage range		V	±100 30 000
Measurement	Charge	% _{rdg}	<0,03
uncertainty	Voltage	% _{rdg}	<0,02

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