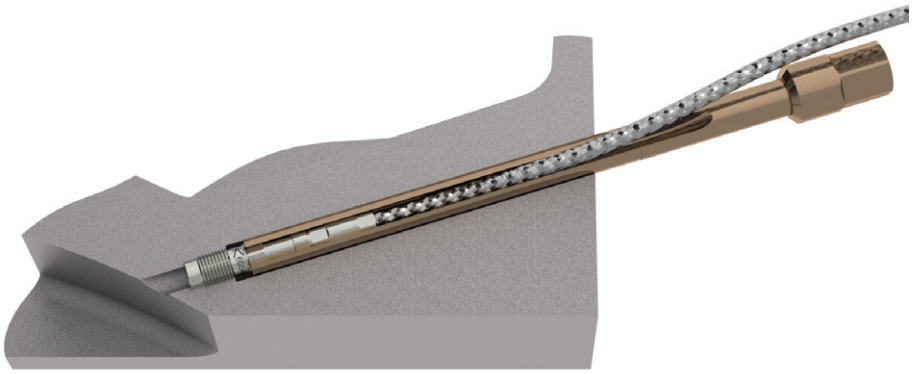
KISTLER

measure. analyze. innovate.

Instruction Manual



Uncooled piezoelectric pressure sensors
Types
6052...,
6054...,
6056...,
6058…,
6124...,
6125...,
6044…,
6045...

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Foreword

We thank you for choosing a Kistler quality product distinguished by technical innovation, precision and long life.

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1. Introduction

Please take the time to thoroughly read this instruction manual. It will help you with the installation, maintenance, and use of this product.

To the extent permitted by law Kistler does not accept any liability if this instruction manual is not followed or products other than those listed under Accessories are used.

Kistler offers a wide range of products for use in measuring technology:

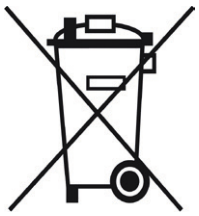
- Piezoelectric sensors for measuring force, torque, strain, pressure, acceleration, shock, vibration and acoustic-emission
- Strain gage sensor systems for measuring force and moment
- Piezoresistive pressure sensors and transmitters
- Signal conditioners, indicators and calibrators
- Electronic control and monitoring systems as well as software for specific measurement applications
- Data transmission modules (telemetry)

Kistler also develops and produces measuring solutions for the application fields engines, vehicles, manufacturing, plastics and biomechanics sectors.

Our product and application brochures will provide you with an overview of our product range. Detailed data sheets are available for almost all products.

If you need additional help beyond what can be found either online or in this manual, please contact Kistler‘s extensive support organization.

1.1 Disposal instructions for electronic equipment



Do not discard old electronic devices in municipal trash. For disposal at end of life, please return this product to an authorized local electronic waste disposal service or contact the nearest Kistler sales office for return instructions.

1.2 Software upgrades and updates

Kistler may from time to time supply upgrades or updates for embedded software. Such upgrades or updates must always be installed.

Kistler declines any liability whatsoever for any direct or consequential damage caused by products running on embedded software which has not been upgraded or updated with the latest software supplied.

2. Preface

Uncooled piezoelectric sensors are a highly efficient design of sensor. This allows easy access to the combustion chamber with minimal installation and in-service effort. They provide highly precise measurements and data quality, with a level of performance comparable to water cooled sensors (depending upon the application and installation). They are easily capable of performing high-precision thermodynamic studies such as assessment of the combustion curve and analysis of the gas exchange process. The design of the sensor body allows reliable measurements irrespective of engine operation mode and boundary conditions.

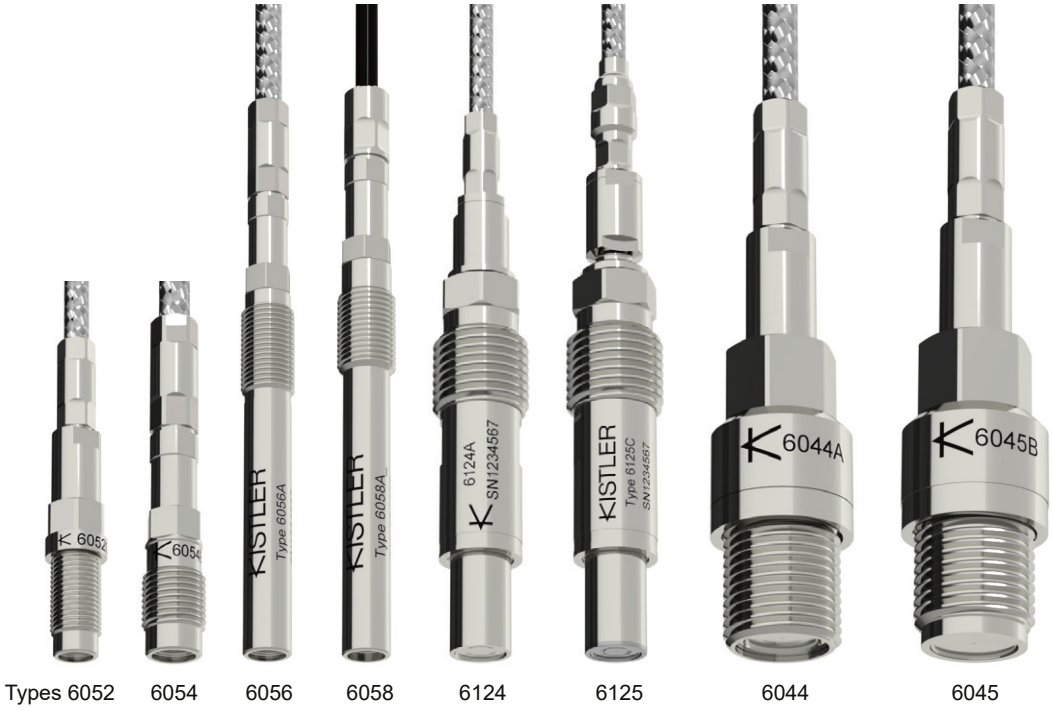


Fig. 1: Uncooled cylinder pressure sensors

2.1 Technical data and documentation

Data sheets are available on www.kistler.com.

2.2 Principle of operation

The sensor membrane converts the measured pressure into a force which is applied to the piezoelectric measuring element. In the piezoelectric crystal package this force generates an electrostatic charge proportional to the load. An electrode collects this charge and supplies it to the sensor connector, then via the piezoelectric cable; the charge amplifier converts this charge into an electric voltage for measurement and processing.

The piezoelectric principle is suitable for measurements of fast, dynamic and quasi-static pressure changes and thus plays a key role in engine pressure measurements.

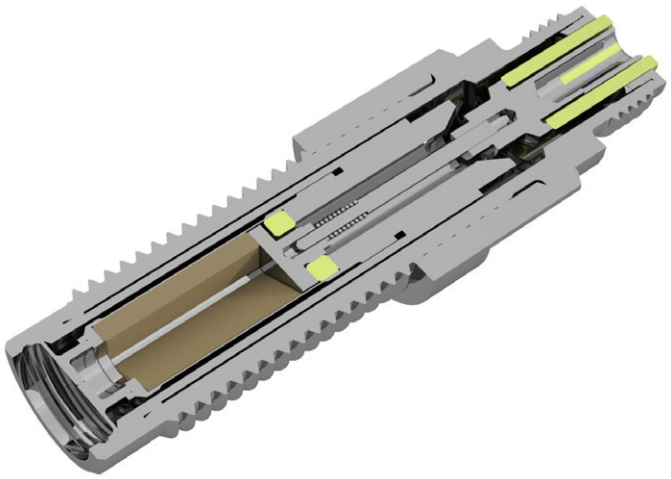


Fig. 2: Structure of a front sealing sensor Type 6052

2.3 Application purpose

The defined area of application of piezoelectric cylinder pressure sensors is limited exclusively to use in internal combustion engines.



The sensor may not be used to fulfill safety functions. Applications where the sensor material is exposed to 100% hydrogen are not permitted.

Kistler declines all liability for any use of the product outside the defined area of application.

3. Installation of the piezoelectric sensor

3.1 General information

The accuracy of a measurement and quality of the data are highly dependent on careful installation of the piezoelectric pressure sensor.

The sensor bore must be machined to the specified tolerances.

The specified tightening torque of the piezoelectric sensor must be observed.

The sensor installation plays a critical part in contributing to the overall accuracy and performance of the measurement chain itself. So a good understanding of the installation types and their strengths and weaknesses is essential information for the measurement and development engineer.

Sensors can be classified in several ways. In this document, relating to uncooled sensors, we shall look at sealing and installation securing technologies as the main differentiators. This means whether the sensor is front sealed or shoulder sealed. In combination with threaded or plug-in securing methods.

When planning the installation, it is possible with certain types, to consider the amount of recession of the sensor membrane itself relative to the inner cylinder head surface. This can have considerable benefits with respect to sensor temperature management - but must be traded off with the potential that the additional volume in front of the membrane can act as a resonator at certain conditions - thus adding undesirable high frequencies to the measured data at specific speeds or load operating points at the engine.

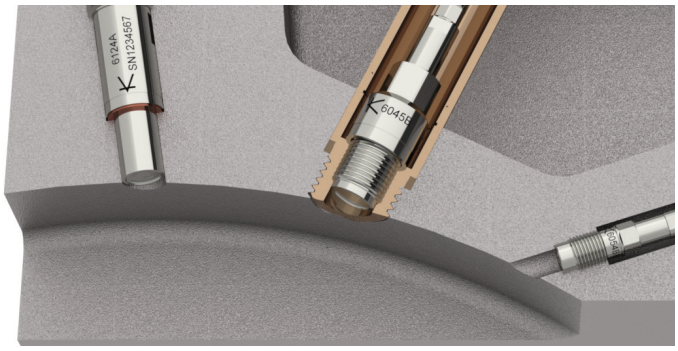


Fig. 3: Volume in front of sensor membrane

As a general rule 8mm, threaded (Type 6044/6045) and 1/4 inch plug-in sensor (Type 6124/6125) from Kistler can be completely flush mounted if desired. However, a slight recess of up to 2 mm can help considerably with sensor durability, without creating a resonance in a frequency range which is problematic for engine measurement applications.

Plug-in sensors (Type 6124/6125) are particularly sensitive to machining bore tolerances. This is due to the fact that the smooth, larger bore is used to correctly position the sensor concentrically, before the clamping device is applied. Any mis-alignment will create potential of incorrect sealing, excessive localised heat build-up and premature failure of the sensor itself.

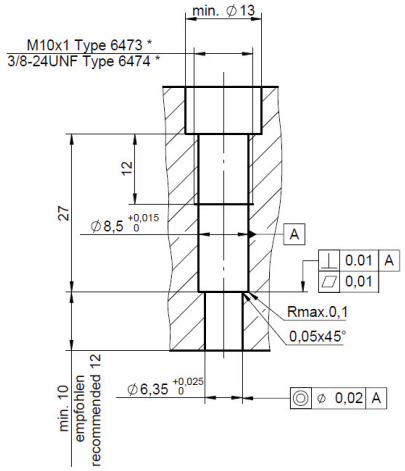


Fig. 4: Sensor Type 6124/6125 bore machining requirements

Front sealed sensors will always require some structural material at the front of the sensor in order to provide and support the sealing surface itself. This fact inevitably means that a front sealed sensor cannot be mounted flush with the cylinder head surface - there must always be volume in front of the membrane. The size of this volume depends upon the material surrounding the sensor installation - as higher strength material can provide the required support with less material and thus a smaller volume in front of the membrane.

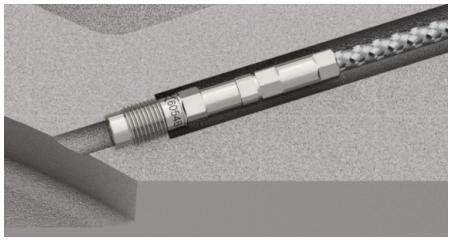


Fig. 5: Front seal sensor, dead volume in front of membrane

As a general rule, for aluminum, up to 4 mm of material is required to support the sealing face, whereas steel or cast iron needs approximately 2.5 mm. The effect of this volume needs to be considered and understood well - with respect to the measurement application and data quality - as an example - 3 mm of material means a „pipe“ of 3 mm diameter and length is created in front of the membrane. Typically this dimension gives a resonant frequency of approximately 30 kHz.

3.2 Direct installation

Direct installation requires the least installation space. A direct installation is only possible if it is not necessary to cross any water or oil galleries in the cylinder head casting.

In the case of repeated mounting and dismounting of the sensor, there is the risk of damaging the sealing mechanism and thread of the mounting bore. Typically, the cylinder head material is softer than that of the sensor. Before mounting the sensor in the bore, also to facilitate dismounting it at the end of the test, it is recommended to coat thread and sealing part of the piezoelectric sensor with high temperature resistant grease. Do not apply any grease on the membrane.

3.3 Installation with sleeve

In the case where the cylinder can only be accessed via an oil or cooling water gallery, a mounting sleeve is necessary to provide adequate sealing for the installation. At the front, the sleeve is screwed and sealed with a sealing ring, at the rear, sealing is achieved using O-rings and/or Loctite compound (Loctite 648 for shaft-hub, Loctite 290 for thread).

Benefits of using a mounting sleeve:

- Precise sensor bore inside the sleeve
- Machining of the bore for the mounting sleeve is simplified
- The mounting sleeve has the required strength to ensure that the sealing part can resist wear. This allows the sensor to be mounted and dismounted repeatedly without restrictions
- When removing the sensor, the mounting sleeve pre- vents cooling fluid from leaking into combustion chamber

Disadvantages of using a mounting sleeve:

- Can influence the cylinder head cooling performance (depending on size and position of the sleeve with respect to the water cooling channels)

3.4 Installation examples

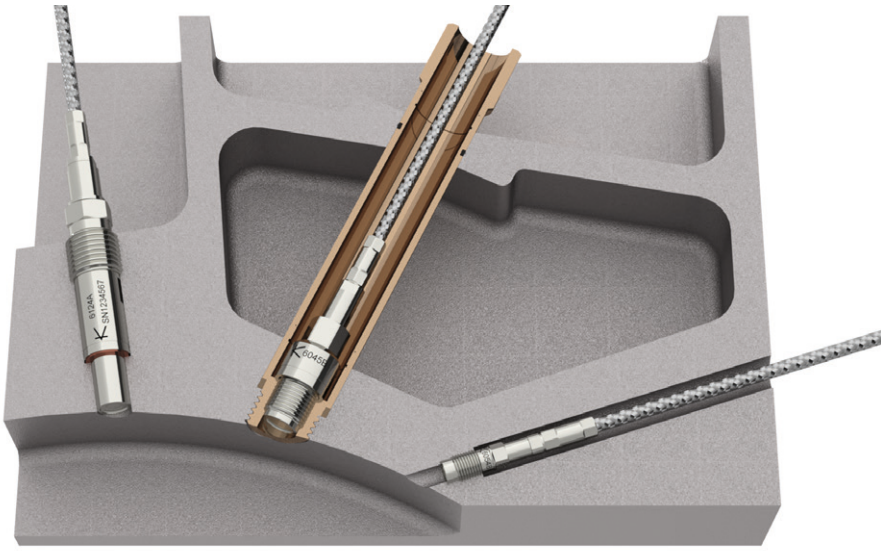


Fig. 6: Left direct mounting of shoulder sealing sensor, Middle: sleeve mounting of shoulder sealing sensor, Right: direct mounting of front sealing sensor

3.5 Machining the mounting bore

When preparing the sensor bore, ensure that the thread is concentric in relation to its individual steps. The sealing part must be completely flat. Refer to the specifications and tolerances stated on the datasheet of the sensor.

All machining steps with the drill, milling cutter, reamer and screw tap must be performed with the work held securely in the same position.

It is important to consider that the sealing surface has two functions - in addition to the pressure seal, this surface provides a heat transfer path for the sensor itself. For front sealed sensors this is particularly critical as the seal is in front of the measuring element - and thus directs heat away from the measuring element itself. This is part of the sensor temperature management strategy in the design of

the sensor. So any compromise at the sealing surface can cause an undesirable increase in operating temperature that can affect data quality - and reduce sensor life.

As mentioned above, plug-in sensors (Type 6124/6125) are particularly sensitive to machining bore tolerances. It is essential to use the correct machining tools and methods for creating the sensor bore and installation. This will provide a good quality installation with correct, concentric positioning of the sensor and a high quality sealing surface for optimised sensor operation.

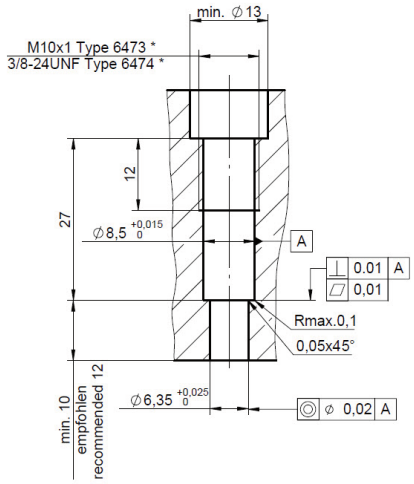


Fig. 7: Mounting bore specification of sensor Type 6124/6125, for mounting nipple

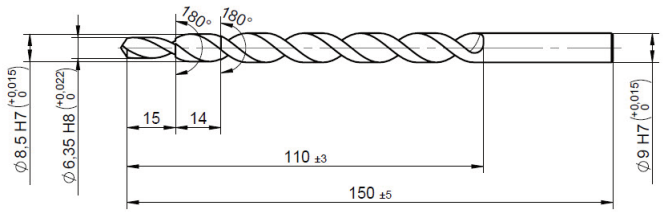


Fig. 8: Step drill Type 1337A for mounting nipple M10x1

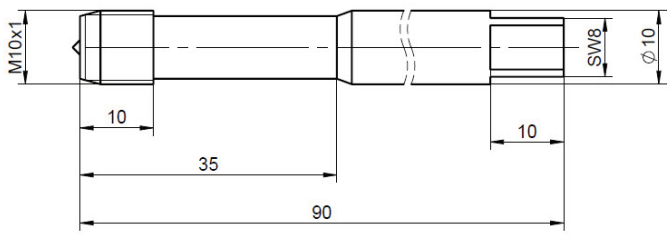


Fig. 9: Screw tap Type 1353 for mounting nipple M10x1

3.6 Check points before installation

- **Piezoelectric cable** – If the piezoelectric cable connected to the sensor is loose it must be retightened and made secure.

- Carefully check the piezoelectric cable for damage over its full length, and if necessary replace it completely if any mechanical damage is evident. The insulation resistance of sensor and piezoelectric cable should be checked by connecting the insulation tester at the end of the piezoelectric cable. The minimum requirement at room temperature is 10E13 Ω.

- **Sensor seal ring** – The sensor seal ring must always be applied to the shoulder sealing sensor as shown in Figure 4. If the sealing ring is damaged, it should be replaced. Front sealing sensors are mounted without any sealing ring - hence the surface finish requirements are critical.

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Fig. 10: Seal ring of a shoulder sealing sensor Type 6045

- **Mounting bore** – Check the condition of the mounting bore and sealing face; it must be machined to the specified dimensions and tolerances as described in the datasheet, and also clean and dry prior to installation.

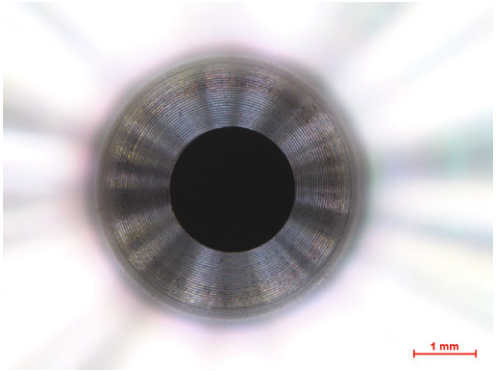


Fig. 11: Sealing surface within the installation bore of M5 sensor

The sealing face and mounting bore should be considered a service item during the lifetime of the sensor installation. The sealing face in particular requires maintenance and inspection. For this purpose a borescope should be used to evaluate the sealing surface during service. This allows inspection of the seal and determination of any leakage, or imperfections in the installation itself.



Fig. 12: A handheld optical boresope suitable for inspecting the sensor installation and sealing surface

3.7 Checks during operation

Piezoelectric cylinder pressure sensors are providing highly accurate measurement results if the operating conditions are within the sensor specification (see individual datasheet) and if they are operated in the defined intended use as described in chapter 2.3.

Irregular combustion (e.g. pre-ignition or strong knocking) can lead to short-term overheating or overloading of the sensor membrane and, in the worst case, to a change in the strength-relevant mechanical properties of the material.



To avoid irreversible damage to the sensor and further consequential damage, the sensor signal must be constantly monitored. If a sensor does not provide any output signal or shows implausible measurement data, the sensor must be checked immediately and replaced if necessary.

3.8 Flameguard for M5 sensors

- **Flameguard installation** – place the flameguard on a plane surface, then press the sensor on the flameguard. Work with both parts aligned in the same axis, otherwise the flameguard clips may get damaged.

- **Removal of flameguard** – the flameguard can be removed with the finger nail pressed in between the gap of diaphragm and flameguard. Possible is also the use of a tap wrench to hold and pull the flameguard.

- Do not use any hard tool to separate both parts, otherwise the sensor diaphragm can be damaged.



Fig. 13: Sensor Type 6054 with flameguard Type 6539A1Q01

4. Installing the sensor into the bore

Feed the piezoelectric cable through the mounting wrench, and then fit the mounting wrench on the hex of the sensor. Before installing the sensor in the bore, the thread and sealing part should be lubricated with high-temperature resistant grease (for example MOLYKOTE HSC plus or Metaflux 70-81). This will facilitate dismounting the sensor from the bore post-testing. During use, pay attention to protect the sensor's piezoelectric cable. Do not squash, twist or pull the piezoelectric cable.

Screw the sensor hand-tight and then use the torque wrench for tightening to the required value as specified in the datasheet of the sensor.

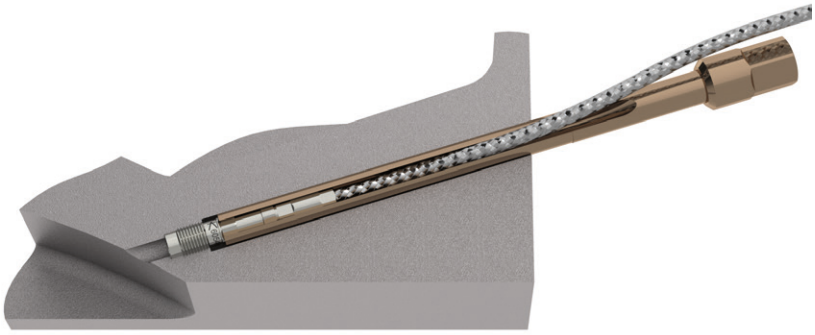


Fig. 14: Assembly with sensor and mounting wrench for installation

5. Piezoelectric sensor cable routing

The piezoelectric cable of the sensor must be routed to avoid other high- frequency, or power cables, as much as possible, e.g. ignition or fuel injection system cabling, dynamometer or motor power cables. If this cannot be avoided, the piezoelectric cables should be kept perpendicular to the high-frequency signal lines to reduce signal interference.

There must be no mechanical tension on the piezoelectric cable. It is absolutely essential to avoid deformation caused by sharp bends. During use, pay attention to protect the piezoelectric cable: do not squash, twist or pull it. Ensure the cleanliness of the piezoelectric cable connector. Do not allow water, oil, dust, or other dirt in the vicinity of the cable interfaces. If the piezoelectric connector becomes contaminated during use, use an electronic cleaning spray to clean it. Use the cap to cover and protect the piezoelectric connector when the piezoelectric sensor is not in use.

6. Setting up the measuring chain

6.1 Connecting the piezoelectric cable to charge amplifier



Fig. 15: Basic arrangement of a measuring chain

Piezoelectric sensor cable, adapter, and piezoelectric extension cable should be connected before connecting its end to the input socket of the charge amplifier.

Make sure the charge amplifier is not in measuring mode when connecting the piezoelectric sensor cable to the charge amplifier input. This avoids potential damage to sensitive electronic input circuitry.

The length of piezoelectric cables between sensor and charge amplifier should not exceed 10m. Interference from extraneous voltages and ground loop issues at the test cell can be avoided, or reduced, by using a short piezoelectric cable and positioning the charge amplifier close to the piezoelectric sensor.

6.2 Selecting the sensor sensitivity

The sensor is calibrated from production in several pressures and temperature ranges in order to fully characterise the sensor performance with respect to temperature variation. In addition, this allows the user to select an optimum sensitivity according to any expected temperature range of their measurements.

However, it is often the case that a single value must be selected as the unit under test maybe operating over a wide range of conditions - and that a single representative

sensitivity must be used to cover all operation points. In this case, it is recommended to use a representative temperature value where the sensor typically operates under most conditions, to select the sensitivity value.
For uncooled sensors of 8 mm and plug-in types this is recommended as 250 °C. For M5 type sensors, this is recommended as 200 °C.

7. Dismounting and maintenance

7.1 Dismounting

Allow the cylinder head to cool down before removing the sensor from the mounting bore. Dismount in reverse order than installation:

- Disconnect the piezoelectric sensor cable from the charge amplifier/from the extension cable.
- Feed the piezoelectric sensor cable through the mounting wrench, carefully slide it to the sensor, and then fit the mounting wrench on the hex of the sensor.
- Unscrew the sensor from the bore.

7.2 Maintenance

Piezoelectric pressure sensors are precision instruments; they will deliver measurements in the specified accuracy range only if they are handled with care. Special attention is required for the front part of the sensor – the diaphragm and sealing area must always be protected against mechanical damage.

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Do not tap impact or shock the front surface of the sensor with metal or any other objects – this will help to avoid damage to the membrane.

- **Visual inspection** – Sensor and piezoelectric cable should be carefully inspected for anomalies (damage, soot deposits, overheating due to combustion gas leakage).

- **Cleaning** – After the sensor is disassembled from the engine, combustion deposits may be cleaned with a soft brush and Isopropyl alcohol (CAS Number 67-63-0). The front part of the sensor (membrane) cannot be cleaned using mechanical means such as brushing, sand blasting, grinding, etc. as this will irreparably damage the diaphragm and therefore the sensor.

- **Visual inspection** – After cleaning, see above.

- **Insulation check** – The insulation resistance of the sensor with piezoelectric cable should be checked by connecting the insulation tester Type 5493 at the end

of the piezoelectric cable. The requirement at room temperature is 10E13 Ω. If the value is too low, all piezo-electric connectors should be disconnected and the insulators cleaned with electronic cleaning spray Kistler Type 1003 or a similar product. Do not touch the connector insulator with bare fingers and do not blow it out with shop compressed air.

- **Pressure calibration** – Recalibration is recommended every 200 hours of operation or after each disassembly of the sensor from the cylinder head.

- **Exchange of components** – it is possible to replace the piezoelectric cable, the sealing ring (shoulder sealing sensors), and the flameguard (M5 front sealing sensors), if not welded. Material numbers are listed in the datasheet of the sensor. The replacement of the sealing ring should be done by Kistler.

- **Removing a defective piezoelectric cable**
  Unscrew the piezoelectric cable connector by using an open ended wrench.

- **Installing a new piezoelectric cable**

Necessary material:
- Spare piezoelectric cable
- Open ended wrench
- Isolation tester Kistler Type 5493
- Cleaning spray Kistler Type 1003 or similar product

Procedure:
Clean the piezoelectric sensor connector on the sensor using cleaning spray Kistler Type 1003. Ensure that the respective O-ring is mounted on the piezoelectric sensor connector. Screw the piezoelectric cable on the piezoelectric sensor connector. Check the insulation of the assembly piezoelectric sensor and piezoelectric cable again, it must reach 10E13 Ω.

- **Inspecting M5 bores**

Necessary material:
- Borescope
- Cleaning spray Kistler Type 1003 or similar product
- Dusting spray

Procedure:
Remove the sensor from the installation bore and clean the bore thoroughly with cleaning spray. Dry the area with dusting spray ready for inspection. Using the borescope with integrated illumination, look down into the measurement bore paying particular attention to the front sealing face. There must be no visible surface roughness or chatter marks. The sealing surface must have a generally even appearance - examine with borescope from different angles in order to fully visualise all aspects of the bore.

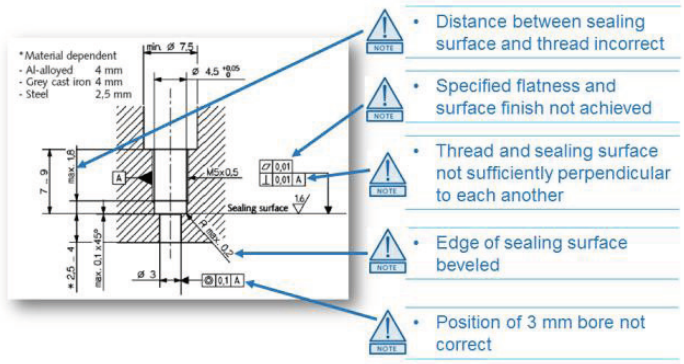


Fig. 16: Areas of focus for front sealing sensor installation quality topics

Another option to establish the quality of the sealing face is to apply engineers blue to the front seal. Again, fully clean and dry the bore, then apply a small amount of this blue paste to the front of the sensor (sealing surface only). Screw the sensor in gently by hand - do not apply the installation torque – tightening by hand is adequate. Inspect the sealing face in the measurement bore. The impression by the sensor left in the bore must be even.

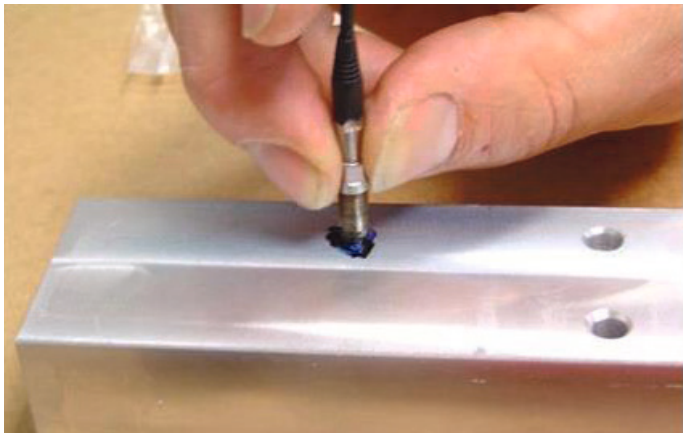


Fig. 17: Checking the quality of the sealing surface with Engineers

- **Ream M5 bores with reamer:**
  If the sealing face is found to be sub-optimal it is possible to recondition the sealing surface with the appropriate tools and knowledge.

Necessary material:
- Finishing tool Type 1300A79 for standard M5x0.5 bore
- Borescope
- Grease (Type 1063)
- Cleaning spray Kistler type 1003 or similar product
- Dust spray



Fig. 18: Reamer tool Type 1300A79 for reconditioning the front seal of a 5mm sensor bore

Procedure:
Clean and dry the sensor bore, fill the flutes of the cutter with grease - this collects any swarf building up and reduces the risk that the cutter sticks. Adjust the preloading force of the finishing tool with the barrel or chuck (using the M5 thread) so that the friction force is small when the cutting head is turned. The finishing operation must feel as if it is removing metal evenly and easily. After turning 3 to 5 times, remove and clean the finishing tool.

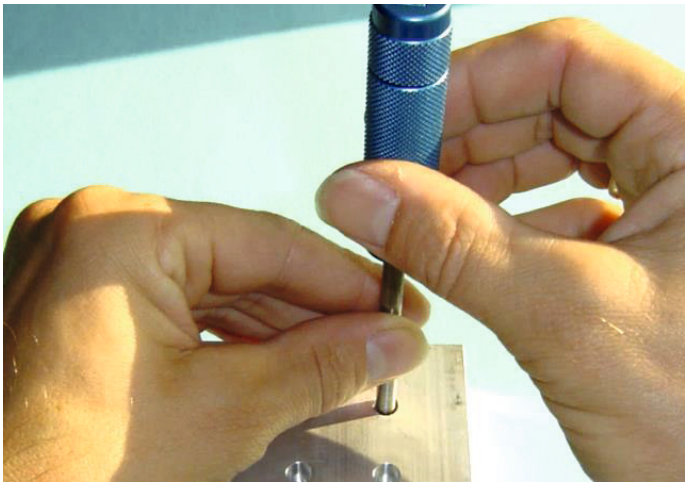


Fig. 19: Applying the reaming tool to a bore

After removing the tool, clean and dry the bore again, ensuring the removal of any swarf or contaminants.



Fig. 20: Cleaning the milling surface of the tool - removing swarf build-up

Re-inspect the measurement bore to monitor the improvement or otherwise to the sealing face. This should be considered an iterative process - a number of attempts should be made to improve the sealing face step-by-step. If this method is not followed and too much material is removed from the sealing face in one attempt, it is often the case that the sealing surface can be permanently damaged with chatter marks created by excessive material removal.



Fig. 21: The reconditioning process gradually bring the sealing face back to useable condition

The pictures above show a typical sealing face as it is reconditioned - the iterative process of gently removing material allows the sealing face to gradually be brought back to serviceable condition - but ensuring enough material remains to support the sensor installation and sealing performance. Once the sealing face is fully reworked (minimum 5 attempts) the bore can finally be cleaned, inspected and is ready for use - the sensor can now be installed as per the guideline in this document. It is recommended to inspect the sealing face every time the sensor is removed or re-installed in service.

Kistler Technical Center services

In order to ensure measurement data within the specified accuracy, the measuring equipment used for combustion development, performance tests, durability tests or engine calibration requires precise examination at regular intervals during its lifetime.

By using the service of Kistler Technical Centers located in Europe, Asia, and America the user benefits safe and reliable operation of the measuring equipment. Thanks to the proximity to the user, the response time is reduced to a minimum; the professional technicians in the Kistler Technical Centers are able to provide complete service locally.

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