Instruction Manual

SlimLine Sensors (SLS) for Shear Force Type 9143B… to 9147B…

9143B_002-285e-09.10

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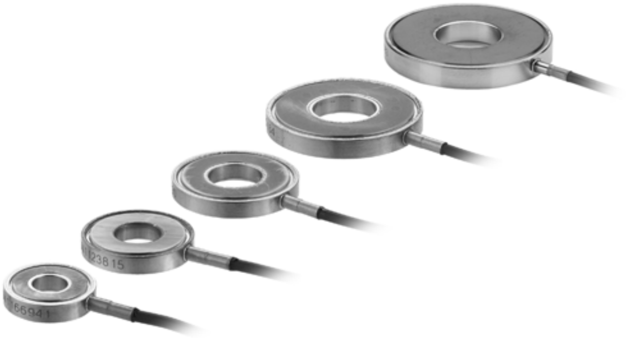

Instruction Manual

SlimLine Sensors (SLS) for Shear Force Type 9143B... to 9147B...

9143B_002-285e-09.10

Foreword

This instruction manual describes the characteristics and use of SlimLine sensors Types 9143B... to 9147B...

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Content

Total Pages: 41

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 engines, vehicles, manufacturing, plastics and biomechanics application 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 on-line or in this manual, please contact Kistler's extensive support organization.

2. Important Notes

It is absolutely essential to follow the instructions below, which are intended to ensure your safety when working with the equipment and guarantee a long, trouble-free service life.

2.1 For Your Safety

The SlimLine sensor has been thoroughly tested and has left the factory in a perfectly safe condition. In order to maintain this condition and to ensure hazard-free operation, the user must comply with the information and warning notes contained in this instruction manual.

The sensor must be installed, operated and maintained only by persons who are familiar with the instrument and are adequately qualified for the work concerned.

If it is accepted that safe operation is no longer possible, the instrument must be switched off and secured to ensure it cannot be switched on again accidentally.

It must be assumed that safe operation is no longer possible when the product

- shows visible signs of damage,
- is no longer operating,
- has been in lengthy storage under unsuitable conditions and
- has been subjected to rough transport conditions.

CAUTION

Mount the SlimLine sensor in position as described. Details can be found in section 4.

CAUTION

Secure all parts mounted on the SlimLine sensor according to anticipated forces.

2.2 Unpacking

Check all packaging for transport damage. Report any such damage to the transporters and to the authorized Kistler distributor.

Please also check the included accessories (Section 8.2). Please report any missing parts to the responsible Kistler distributor.

2.3 Notes on Handling the Sensor

- The sensor must only be used under the specified environmental and operating conditions.
- With piezoelectric sensors, insulation resistance is of crucial importance; it must be approx. $10^{14}\ \Omega$ (but not less than $10^{13}\ \Omega$).
- In order to preserve this value, all plug-and-socket connections must be kept absolutely clean and dry. The insulation resistance can be measured with the insulation tester Type 5493.
- Protect the sensor when it is not in use by storing it in its original packaging.
- Ensure the temperature of the SlimLine sensor remains as constant as possible during long-term measurements.

2.4 Hints on the Use of this Instruction Manual

We recommend that you read through the entire manual thoroughly. However, if you cannot spare the time and are already familiar with Kistler SlimLine sensors, you may skip to the sections with the information currently required.

We have tried to organize this manual clearly so that the required information is easily accessible.

Keep this manual in a safe place where it is readily accessible at all times.

If you lose your manual please contact your Kistler distributor for prompt replacement.

3. General Description

3.1 What is a SlimLine Force Sensor used for?

SlimLine piezoelectric force sensors feature an extremely flat design. The force to be measured is transferred to the quartz sensor elements via the cover plate and base plate of the tightly welded steel housing. The quartz elements produce an electric charge proportional to the mechanical load. A charge amplifier generates an electric voltage from this charge. These signals are displayed, recorded or processed in the familiar way.

Thanks to the extremely high resolution of quartz it is possible to measure a change in force of the order of 1 N under a preload of several tons.

The shape (load washer) and relatively small dimensions allow flexible use and easy mounting.

Sensitivity (charge per unit force) is a constant of quartz as a material. The associated threshold is virtually the same for all SlimLine sensors of different sizes.

This has three unique advantages:

- High level of overload protection, very small forces can be measured with one sensor with a large measuring range
- High rigidity; a sensor with a larger measuring range undergoes less deformation
- Several sensors can be electrically connected in parallel to a single charge amplifier. The output signal is then the sum of all of acting forces

SlimLine quartz force links are supplied calibrated. This ensures they are easy to mount and immediately ready for measurement.

3.2 Applications

The compactness of SlimLine sensors makes them ideal for measuring dynamic forces. Their very high rigidity has an extremely small effect on the dynamic response of the measured object in which they are mounted.

Depending on the size of the force, quasistatic measurement can be performed over several minutes or even hours (the signal drift is only about ±50 mN/s). However, truly static measurements over any length of time are not possible.

On the other hand, after a pause of any length a sensor under continuous static load (for example, mounted in a threaded connection) can be reconnected to a charge amplifier and the changes in load then measured accurately.

Measurements of dynamic forces (AC mode) are also possible over any length of time. Kistler SlimLine sensors have a virtually unlimited life and are not subject to sensitivity drift caused by aging.

The most important typical applications are

- Monitoring of tools
- Monitoring of shear forces in machines, tools and assembly processes
- Manufacture of force plates and dynamometers with small dimensions

3.3 Design and Principle of Operation

A SlimLine sensor consists of two crystal ring washers, an electrode and a housing with connector.

The force to be measured must be evenly distributed over the ring surface. The mechanical shear stress results in an electric charge being generated in the quartz crystal. This charge is proportional to the applied force and does not depend on the dimensions of the quartz washers.

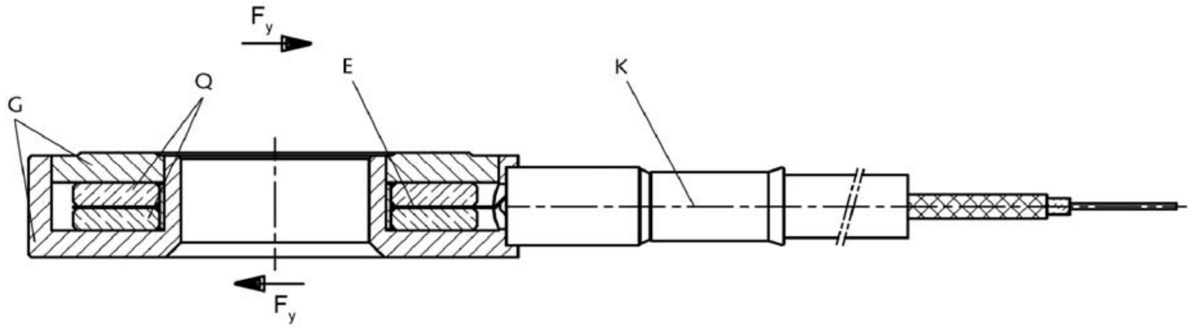


Fig. 1: Schematic section through a SlimLine sensor

Q = Quartz washers
E = Electrode
G = Housing
K = Connector
F = Force acting on force sensor

The generated charge is conducted from the electrode and supplied to the plug connection. The polarity is chosen so that a shear force generates a negative charge, which is then converted into a positive voltage in the charge amplifier. The housing serves as ground connection. Unloading of the sensor produces a positive charge if the negative charge generated beforehand by the load is reset to zero by the charge amplifier being reset.

Connecting several SlimLine sensors in parallel adds the charges of the individual force sensors and the charge amplifier measures the total force.

To ensure the forces to be measured are distributed uniformly over the ring surfaces, the mating surfaces on the measured object must be flat, rigid and machined as precisely as possible.

4. Mounting, Installation and Commissioning

The SlimLine sensor is a precision instrument whose inherent accuracy can only be exploited and maintained if it is handled with care.
SlimLine sensors are **only used preloaded**. The reasons for this as follows:

- Between the always imperfect surfaces inside and outside the sensor there are microgaps that act as interposed spring elements. Preloading closes these gaps to ensure force measurement is in the linear range and free from disturbing influences.
- Without preloading, shear forces cannot be transferred to the sensor.

The preload is applied by mounting the sensor in a mechanical structure (machine, system, force plate, etc.). It can be mounted directly in the load path of a system or in a force shunt. The preloading disk Type 9410A... can be used to make this easier. To ensure uniform force distribution the bearing surfaces must always be flat and rigid.
In a force shunt only part of the force to be determined is measured. The measurement signal has to be calibrated in situ against the force to be determined.

NOTE

Contact your local Kistler distributor for advice if anything is not clear or difficulties are encountered when mounting, installing or commissioning SlimLine sensors. To enable your query to be handled effectively it is important to describe the measurement problem and provide drawings or sketches that make the type of load, its introduction and point of application, etc., evident.

4.1 Force Application

Ideal force application produces a uniform surface pressure on the load washer and is free from shear forces or moments.

The bearing surfaces on the load washer must be ground. A good grease (such as Kistler Type 1063) must be used to reduce friction.

The full measuring range can only be exploited if the force is distributed uniformly. The mounting surfaces should preferably be ground. The maximum permissible load on all sizes of load washer produces a surface pressure G_{max} of approx. 150 N/mm^2.

If the force is applied eccentrically or the object being measured deforms, bending moments arise. The resultant bending stress is superimposed on the direct stress. In these cases the measuring range specified in the table of technical data no longer applies. The maximum permissible surface pressure σ_{max} must not be exceeded. The maximum allowed bending moments specified in the technical data can be used to determine the total load (see section 4.1.2).

As a SlimLine sensor cannot take any tensile stress, the direct stress must always be greater than the maximum bending stress. The direct stress is produced by the sum of the preload force and any loads or forces acting perpendicular to the shear direction.

4.1.1 Measurement of Force between Roughly Machined and Angled Surfaces

Measurement between rough and/or oblique surfaces should be avoided if possible (Fig. 2). Machine the mounting surfaces, preferably by grinding.

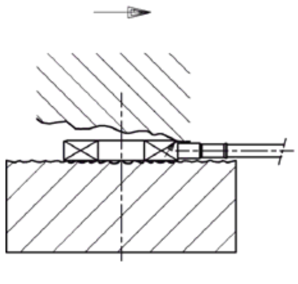


Fig. 2: Measurement of force between roughly machined and angled surfaces

4.1.2 Reduction in Measuring Range with Additional Bending Moment for SlimLine Sensors

The additional bending moment depends on the distance h of the applied shear force F_y from the SlimLine sensor. The shear force should therefore be applied as closely as possible above the mounted SlimLine sensor. This avoids reduction of the measuring range.

Please see the following table for the maximum bending moment of the sensors.

Basic Type	Max. Bending Moment $M_{b,max}$[1] (F_z = 0) [N·m]	Reduction of measuring range F_y when allowable bending moment [kN/N·m] exceeded
9143B…	10,2	0,0456
9144B…	24,0	0,0369
9145B…	30,5	0,0290
9146B…	96,5	0,0231
9147B…	100,0	0,0201

[1] The allowable bending moment $M_{b,max}$ must not be exceeded. If this is unavoidable in the particular application, the measuring range F_y must be simultaneously reduced as shown in the following example.

Example

A bending moment M_b of 35 N·m acts on a sensor Type 9144B… . What is the magnitude of the maximum measuring range $F_{y,max}$?

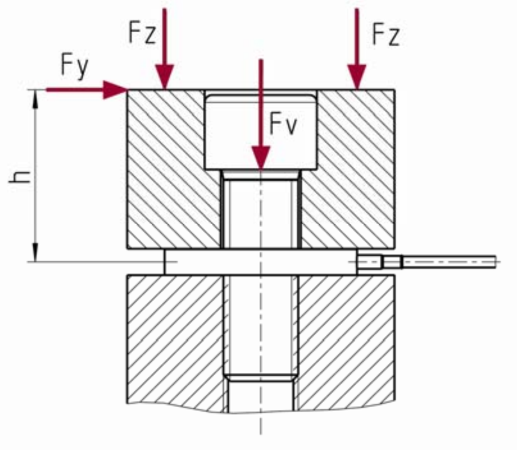


Fig. 3: Bending moment $M_b = F_y \cdot h$

Max. bending moment $M_{b,max.}$ = 24 N·m
Max. shear force F_y = 1,70 kN
Reduction in measuring range f = 0,0369 kN/N·m

The acting bending moment M_b is 11 N·m greater than the allowable bending moment

$M_b - M_{b,max} = \Delta M_b = 11$ N·m

This reduces the measuring range by

ΔM_b x f = 11 N·m x 0,0369 = 0,41 kN

The maximum measuring range is therefore

$F_{y,rmax}$ = 1,70 kN – 0,41 kN = 1,29 kN

4.2 Bearing Surface Materials

The housing of the sensor is manufactured from stainless steel. We suggest you use a similar material for the base plate and cover plate.

Suggested Materials for Base Plate and Cover Plate

Standard	Corrosion-resistant	Heat-treated
DIN	• 22CrNi17 • 1.4057 • Z15CN16.02 • XC42H1;XC45B.S.	• Ck45 • 1.1191AFNOR • 431 S29 080
H46JIS	• SUS 431 • 431	• S45CAISI/SAE • 1045

4.3 Installation of Sensor

A shear force sensor must always be fitted under preload, since the shear forces are transmitted by stiction. The contact surfaces with the sensor must be absolutely free of grease, finish machined and rigid. The adjacent table contains the most important information concerning preloading.

CAUTION

Note!
The stated tightening torque applies only to the screw thread M mentioned (lightly greased).

Markings on the sensor case facilitate its alignment. Two pins can be used to prevent the sensor from turning during its installation.

Basic Type mounted with preloading bolt

Basic Type	Measuring Range F_y [kN]	Preloading Force F_v [kN]	Tightening Torque [N·m]
9143B...	0,9	9,0	10,0
9144B...	1,7	17,0	23,0
9145B...	2,7	27,0	46,0
9146B...	4,0	40,0	79,0
9147B...	8,0	80,0	135,0

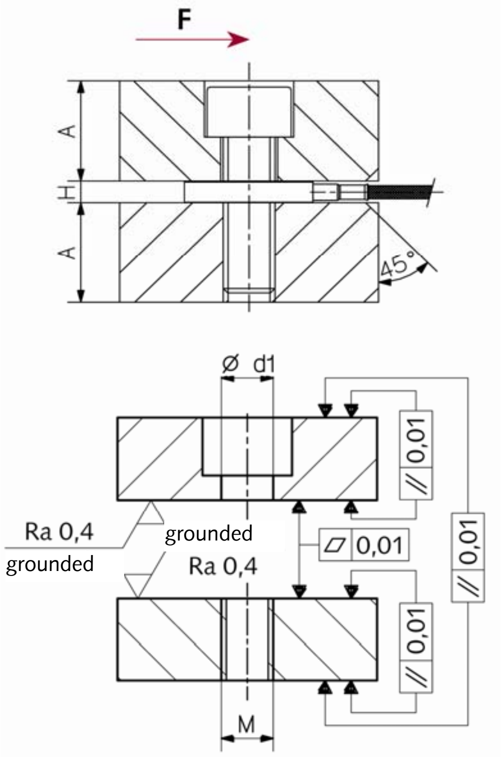


Fig. 4: Mounting dimensions with direct force measurement

Mounting Dimensions

Type	Thread	Bore diameter D1 [mm]	Plate thickness[1] A [mm]
9143B…	M6	6,4	12,0
9144B…	M8	8,4	16,0
9145B…	M10	10,5	20,0
9146B…	M12	13,0	24,0
9147B…	M14	15,0	27,0

[1] Recommended minimum value

4.3.1 Effect of Elasticity Relationships on Measurement Result

With preloaded connections, it is essential to take account of force diversion.

In the ideal case the force shunt via the preloading elements is very small, so that almost all of the measured force is transferred and thus measured by the load washer.

If the force shunt is large, it is still basically possible to perform measurements, provided the setup is calibrated. However, there is a risk of the size of the force shunt changing during operation (for example as material compression, together with changes in temperature or deformations), and falsifying the measurement result despite calibration. Recalibration with the sensor mounted and preloaded is necessary.

4.3.2 Preparation for Mounting

Prior to assembly, the bearing surfaces on the base plate and the cover plate as well as on the sensor must be carefully **cleaned** with a degreasing cleaner (such as ethanol). To reduce torques transmitted to the sensor during preloading as a result of the friction of the head and thread of the preloading bolt, these surfaces of the bolt must be greased sparingly with Kistler special grease Type 1063.

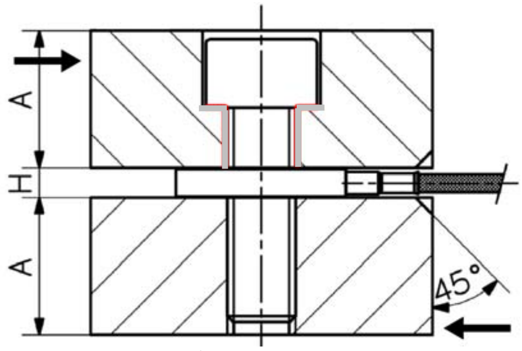


Fig. 5: SlimLine force sensor with preloading bolt (greased surfaces and thread shown in gray).

Caution!
Do not allow any grease to get onto the surfaces of the sensor. The head bearing surface and thread of the preloading bolt must be greased before the bolt is screwed in.

4.3.3 Cable Routing

The sensor cable must be secured and provided with strain relief so it cannot kink or twist. The **bending radius must not be less than than 3 mm**.
The cable connection can be secured with devices such as pins, which also serve to position the sensor (see Fig. 6).

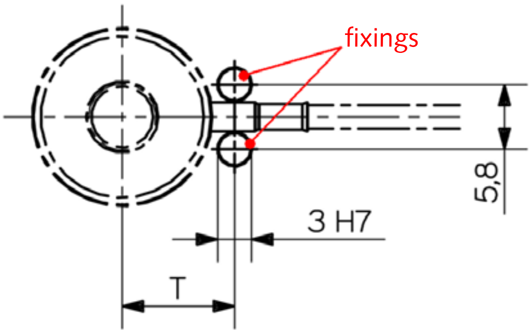


Fig. 6: Positioning of SlimLine sensor with pin on either side of cable connection

4.4 Dynamometer with Six SLS Shear Force (F_y) Sensors for Measuring Torque (M_z)

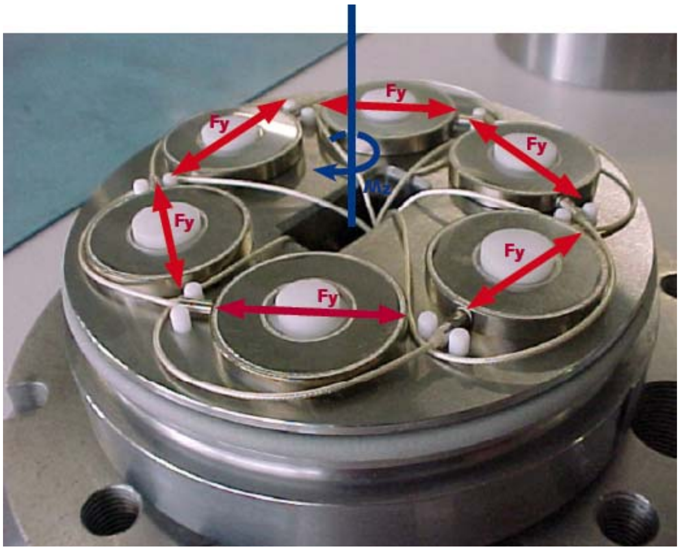


Fig. 7: Six SLS shear force sensors on dynamometer base plate for measuring torque

SLS Dynamometer
A dynamometer with six SLS shear force sensors has six signal outputs. There is, however, no need to connect six individual charge amplifiers in order to subsequently add the signals for the single component.

Electrical charge can be connected in parallel in order to further process the sum of the signals. If the six mounted sensors have the same sensitivity, the sum of the charges corresponds to the sum of the force components. Only one charge amplifier is therefore needed. The dynamometer shown in Figure 7 is used to perform torque measurements.

4.5 Preloading SlimLine Sensor

SlimLine sensors have to be preloaded to enable reliable use.

To produce the required preload force the sensor is first mounted in the structure involved **without being preloaded**.

The preload force cannot be measured with the sensor. It is checked with a torque wrench. Please see the following table for the required torque.

Basic Type	**Measuring Range F_y [kN]**	**Tightening Torque [N·m]**
9143B…	0,9	10,0
9144B…	1,7	23,0
9145B…	2,7	46,0
9146B…	4,0	79,0
9147B…	8,0	135,0

As the thread of the preloading bolt is self-locking no further measures are required to secure it.

5. Measurement

5.1 Basic Arrangement of a Measuring System

A measuring system is assembled from a SlimLine sensor, a highly-insulated low-noise connecting cable and charge amplifier, a display and/or data acquisition and processing unit.

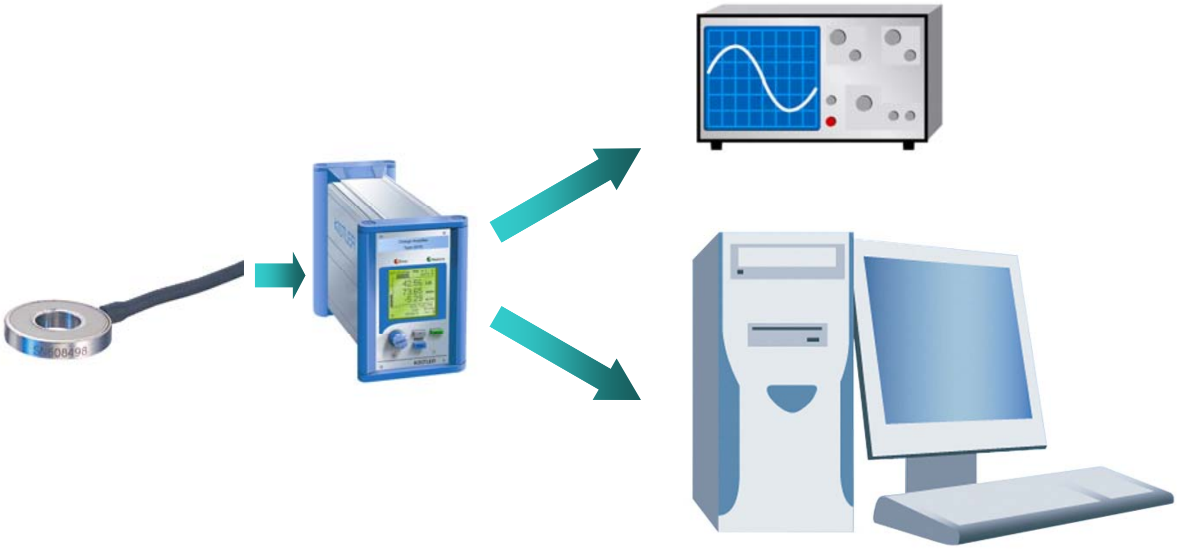


Fig. 8: Measuring system configuration

The connecting cable for the transducer must be highly insulating and low-noise. The effect of the cable length (>15 m) can be obtained from the instruction manual for the charge amplifier employed.

From the charge amplifier to the display or recorder, ordinary coaxial cables may be used.

5.2 Range Selection and Threshold

A distinction must be made between the measuring range of the SlimLine sensor and that of the charge amplifier.

The measuring range required to perform a particular measurement can be freely set on the charge amplifier.

Example
The charge amplifier Type 5015A… offers continuous measuring range adjustment. Together with the SlimLine sensor it would give the following force ranges in N: 0,5 … 50 000 N/V or 5 N ... 500 kN for 10 V output voltage. The maximum force allowable for the utilized sensor must naturally not be exceeded. For ranges above 50 kN/V a 10:1 charge attenuator (such as the Type 5361) is used.

It is for example possible to select a measuring range of 10 N and measure small force fluctuations superimposed on a static preload of, say, 10 kN. Briefly overloading small measuring ranges by a factor of 50 does not normally harm the charge amplifier. With bigger overloads it depends on the capacitance of the input cable whether the amplifier is damaged or not.

The instruction manual for the particular charge amplifier used will provide information regarding is overload capacity.

For practical purposes at least, the threshold of a load washer may be regarded as infinitely low. Together with a standard charge amplifier the practical limit is around 0,01 N (signal-to-noise ratio about 50 %).

5.3 Measuring High-Frequency Phenomena

Thanks to their high rigidity, SlimLine sensors are eminently suited for measuring rapidly changing processes. As the mounting situation has a decisive effect, the natural frequencies specified in the table of technical data are more of theoretical importance.

If a SlimLine sensor is installed into a cylinder of the same diameter for measuring axial force, it can be said without contradiction that the dynamic properties of the measuring object are not affected by installing the sensor. There is no need whatever to take the natural frequency of the force sensor into consideration.

If on the other hand a large mass has to be supported on three or four SlimLine sensors, this assembly constitutes a spring-mass oscillator. Obviously the natural frequency of this system depends on the rigidity and not on the natural frequency of the sensor and the magnitude of the mounted mass. The natural frequency becomes higher as SlimLine sensors used become larger (that is more rigid). The fact that the natural frequency of a larger SlimLine sensor is itself smaller is not important as far as the natural frequency of the system is concerned. Thus dynamometers with natural frequencies of several kHz can readily be manufactured.

5.3.1 Useful Frequency Range

At the upper frequency limit, the frequency response of the dynamometer reveals relatively little vibration damping. Frequencies can be triggered up to about a third of the natural frequency without excessive measuring errors.

The lower frequency limit is determined by the drift of the charge amplifier and the quality of the insulation. In quasistatic measurements, a drift of up to ±10 mN/s can occur. Depending on the measuring range, therefore, measurements from a few minutes up to several hours are possible.

The illustration shows the example of a frequency curve in which:

f = measuring frequency
f_n = natural frequency
X/X_n = amplitude ratio

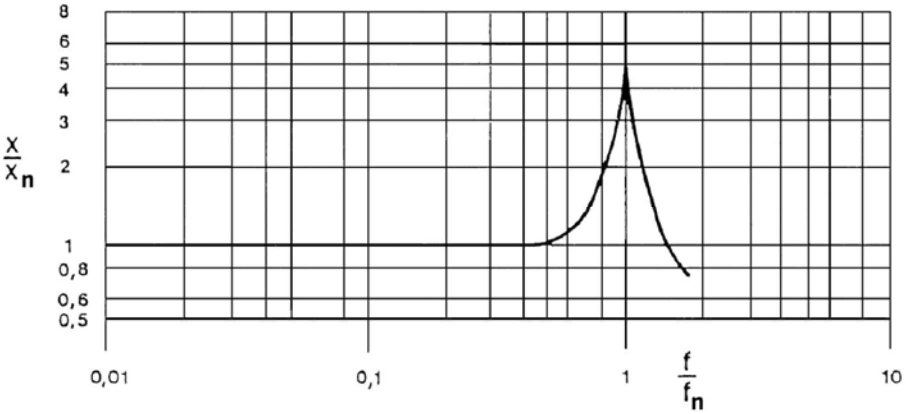


Fig. 9: Amplitude frequency response

When the largest possible frequency is needed in critical work, the dynamic response of the entire measuring system must be investigated. For example, a heavy workpiece mounted on the dynamometer will change the dynamic response.

For better determination of the useful frequency range, a frequency analysis with the dynamometer has to be carried out

Rule
The better the mounting of the measuring device (force link, dynamometer) on a base structure and the better the attachment of the force introduction parts – the higher the resonant frequency and the wider the usable frequency range.

Most piezoelectric force sensors behave as a single-mass vibration system and follow the rule:

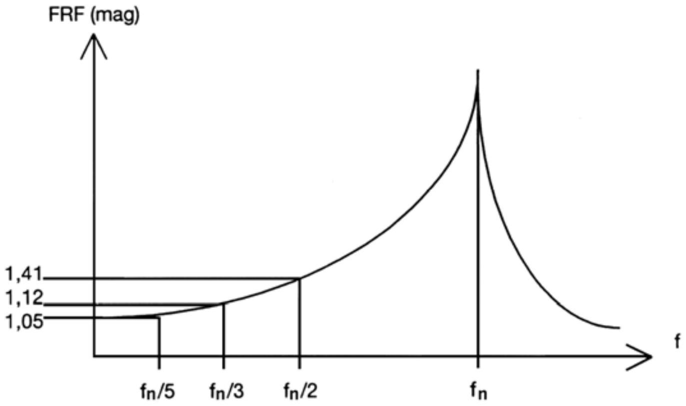
$$f_n = \frac{1}{2\pi}\sqrt{\frac{c}{m}}$$

$$f_{+5\%} \approx f_n/5$$

$$f_{+10\%} \approx f_n/3$$

$$f_{+3dB} = f_{+41\%} \approx f_n/2\text{; see drawing.}$$

c: Rigidity
m: Mass of the structure above the sensor



5.4 Measuring Quasistatic Shear Forces

Purely static measurements over any length of time are not possible with the piezoelectric measurement principle. The period of time over which so-called "quasistatic" measurements can be performed is determined by the insulation resistance of the measuring chain and by the time constant of the charge amplifier. An insulation resistance of approximately $10^{13}\ \Omega$ and charge leakage (drift current) of approximately 0,03 pC/s can typically be assumed.

For measurement over a period of 10 minutes with SlimLine force sensors Types 9144B... (sensitivity 7,5 pC/N), the expected error can be estimated as follows::

$$\frac{0{,}03\ \text{pC}/\text{s}\cdot 600\ \text{s}}{7{,}5\ \text{pC}/\text{N}} = 2{,}4\ \text{N}$$

This absolute error is related to the measured force and amounts to, for example, 0,14 % at 1 700 N. Depending on the torque and required accuracy, measurements from a few minutes to several hours are therefore possible.

5.5 Effect of Temperature

The temperature coefficient of the sensitivity (change in sensitivity as a function of temperature, with the entire SlimLine force link at the same temperature) is negligible.

However, changes in temperature during measurement result in an error signal in the form of a drift of the zero. This temperature drift is a function of the quantity of heat introduced. For critical applications, design measures protecting the SlimLine force link against substantial temperature fluctuations are recommended.

5.6 Instructions and Safety Precautions

- The supporting surfaces for a SlimLine sensor must be finely machined (Ra = 0,4), flat and rigid.
- The maximum measuring range (100 %) may be exploited only if the force is distributed uniformly over the entire supporting surface.
- With uneven surface loading, due to superimposed flexure for example, the maximum measuring range is limited not by the range given in the table of technical data but by the highest local surface pressure (see chapter 4.1.2)
- If a load washer is used to measure screw force, the friction surface should be lubricated well (special grease Type 1063). With high surface pressure a thin washer of beryllium copper will prevent pitting.
- To maintain the high insulation resistance the connecting plug must be kept clean. If necessary they should be cleaned with Freon or rectified benzene.

6. Maintenance and Servicing

Periodic maintenance or servicing is not necessary. Any connectors that get dirty (resulting in insufficient insulation resistance) can be cleaned with isopropyl alcohol or light petrol and a clean paper towel.

As the SlimLine Sensor is fully welded, any repair work that becomes necessary is extremely rarely feasible and can only be carried out in the manufacturer's factory if at all.

SlimLine sensors have to be calibrated after mounting. Sensors used as intended do not require periodic recalibration.
In cases of doubt or after prolonged service recalibration is advisable. This requires the availability of a calibrated press. If the testing is to be performed on the object under test, i.e. with the sensor mounted, a means of producing a force of the requirement magnitude must be available. In this case the test force must be measured with a reference force link.

7. Troubleshooting

7.1 Diagnosis and Rectification of Faults

The following chart lists typical causes of faults and methods of rectification. Please contact your Kistler distributor if you cannot rectify a fault.

Fault	Cause	Rectification
No measurement signal at the output of the charge amplifier	Signal cable interrupted	Check measurement setup (connections).
	Charge amplifier faulty	Check charge amplifier for fault as described in the instruction manual or, if necessary, repeat mounting and commissioning of the amplifier.
	Sensor faulty	Have repaired in the manufacturer's factory. See section 7.2 for procedure.
Quasistatic measurements not possible (pronounced signal drift)	Insulation resistance of measuring chain poor	Check insulation resistance of the individual components with the insulation tester Type 5493. Clean connector. Check charge amplifier as described in the instruction manual.
Charge amplifier reaches limit during measurement	Force to be measured too large for the chosen measuring range.	Select a larger measuring range on the charge amplifier.

7.2 Repairing SlimLine Force Sensor

Please note that repairs of certain types of damage that cannot be undertaken cost-effectively will not be carried out by the manufacturer's factory.

Fig. 10: Cable connection broken off

Fig. 11: Cable break

Broken cables and broken cable connections cannot be repaired.

If your SlimLine sensor is faulty and is not damaged as shown in Figures 10 und 11 please adopt the following procedure:

- Contact your Kistler distributor to notify return of the faulty instrument.
- Return the faulty sensor to the distributor in its original packaging.
- Enclose a detailed description of the fault and the attendant circumstances with the sensor.
- Describe the measurement operation during which the fault arose.
- You will receive a cost estimate if a major repair is involved.
- Kistler will try to repair your sensor at minimal cost in the shortest possible time and return it to you in as-new condition.

8. Technical Data

Please note that all of the technical data and all other information in this section are subject to change at any time without prior notice.

8.1 SLS Shear Force Type 9143B… to 9147B… – Technical Data and Dimensions for Mounting with Preloading Bolts

Type		9143B…	9144B…	9145B…	9146B…	9147B…
Measuring range shear force F_y	kN	0 … ±0,9	0 … ±1,7	0 … ±2,7	0 … ±4,0	0 … ±8,0
Overload shear force F_y	kN	1,1	2,0	3,3	4,7	10
Sensitivity	pC/N	–6,5	–7,5	–7,5	–7,5	–8,1
Bolt preload force	kN	9	17	27	40	80
Tightening torque	N·m	10	23	46	79	135
Linearity	%FSO	<1	<1	<1	<1	<1
Hysteresis	%FSO	<1	<1	<1	<1	<1
Threshold	N	0,01	0,01	0,01	0,01	0,01
Max. compression force ($M_{b,max}$ = 0 N·m)	kN	9	17	27	40	80
Max. bending moment ($F_{z,max}$ = 0 kN)	N·m	10,2	24	30,5	96,5	100
Rigidity	kN/µm	≈2,5	≈5,6	≈7,0	≈8,0	≈16,0
Outside diameter D	mm	16,0	20,0	24,0	30,0	36,0
Inside diameter d	mm	6,1	8,1	10,1	12,1	14,1
Height H	mm	3,5	3,5	3,5	4,0	5,0
Weight m	g	3,0	5,0	7,0	14,0	27,0

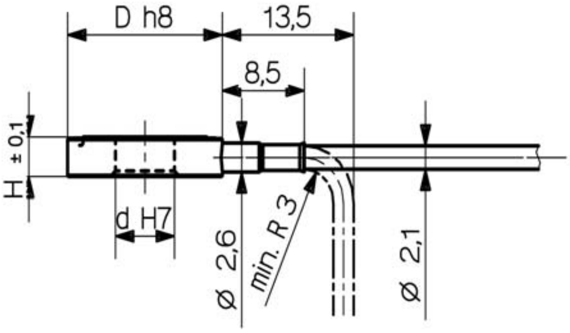


Fig. 12: Dimensions Type 9143B… to 9147B…

8.2 Included Accessories

An integral Viton® seal ring is supplied as an accessory with the SlimLine sensors with KIAG 10-32 pos. connector. This ring must be fitted in the connector if the connection has to meet the requirements of IP65 degree of protection.

	Type
▪ Viton® O-ring	5.110.063

8.3 Optional Accessories

The following accessories are available for sensors Types 9143B... to 9147B...:

- Preloading disks

Type	**Unit**	**9410A3**	**9410A4**	**9410A5**	**9410A6**	**9410A7**
For SlimLine sensor		9143B...	9144B...	9145B...	9146B...	9147B...
Thread size		M3	M4	M5	M6	M8
External diameter	D2 (mm)	16	20	24	30	36
Internal diameter	d2 (mm)	3,2	4,3	5,3	6,4	8,4
Disk thickness	H1 (mm)	4,25	4,25	4,25	5,5	7,0
Screw length	L (mm)	10	10	10	14	16

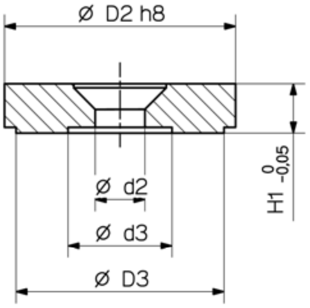


Fig. 13: Preloading disk Type 9410A... incl. table

- Coupling Type 1721, KIAG 10-32 neg – BNC pos.
- Coupling Type 1729A, KIAG 10-32 neg – KIAG 10-32 neg.
- Insulation tester Type 5493

Examples of Measuring Chains

SlimLine sensor
Type 914XA21

Coupling
Type 1721

maXYmo
Type 5867A…

SlimLine sensor
Type 914XA21

Coupling
Type 1721

Charge amplifier
Type 5015A…

SlimLine sensor
Type 914XA21

Coupling
Type 1721

Charge amplifier
Type 5073A111

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9. Annex

9.1 Glossary

Best straight line	see Annex 9.3.
Cable capacitance	The cable capacitance, and thus the length of the connecting cable, has no noteworthy influence on the measuring result when Kistler special cables and Kistler charge amplifiers are used.
Calibrated range	Measuring range or part of the measuring range for which the sensor has been calibrated. Note: Because of the high linearity of quartz crystal sensors, the sensitivity of a measuring range can usually also be used for smaller measuring ranges.
Calibration certificate	Document for sensors and devices stating the results of the factory calibration.
Charge amplifier	Part of a measuring chain which converts the charge signal from the sensor into a proportional voltage signal or current signal. Note: The linearity of charge amplifiers is typically within the range of ±0,01 % of the measuring range selected. For the accuracy of the measurement, this is usually negligible compared with other influence quantities.
Charge signal	Physical quantity which a piezoelectric sensor yields on its mechanical load.
Coulomb	Unit of electric charge. 1 coulomb corresponds to 1 Ampere-second (1 C = 1 As).
Crosstalk	Signal at the output of a sensor, produced by a measurand acting on the sensor, which is different from the measurand assigned to this output. For example, when a load in the F_y direction produces an F_z signal in a three-component sensor. In terms of electrical devices, it is a measure for the signal impact acting from a channel to the neighboring ones.
Degree of protection	Protection of electrical equipment by suitable enclosures, covers etc. according to EN60529. The protection class is stated by IP (International Protection) followed by two digits. The first digit stands for protection against touching and the ingress of solid bodies, the second for the degree of protection against the ingress of water.

	Example: IP65 indicates a complete protection against touching, as well as against the ingress of dust and spray water from all directions.
Disturbance	Quantity that is not the measurand but that affects the result of the measurement. The contributions are expressed in terms of the measurand related to the acting quantity. Examples: • additional bending moment acts on a force sensor: $M_{x,y} \rightarrow F_z$ • additional axial force acts on a torque sensor: $F_z \rightarrow M_z$ • additional shear force acts on a force/torque sensor: $F_{x,y} \rightarrow F_z$ and $F_{x,y} \rightarrow M_z$
Drift	Unwanted changes in the output signal independent of the measurand as a function of time.
Frequency range	see Annex 9.4.
FSO	Full Scale Output. Range of measurement signal of a sensor, corresponding to the full scale of the measurand. It is the algebraic difference of the upper and lower limit of the measurement signal range. Example: A pressure sensor having the measuring range from 0 bar to 2 bar and the corresponding range of measurement signal from –5 … +5 V presents the FSO: 10 V. An electrical monitoring system having an input range from 0 … 10 V and the corresponding output range from 4 … 20 mA shows the FSO: 16 mA
Ground insulation	High electrical resistance of a sensor between signal line and ground, or of a charge amplifier between connector screen and ground.
Hysteresis	see Annex 9.3.
Insulation resistance	Electric resistance of a sensor, cable or the input of a charge amplifier measured between the signal line and the connection ground (sensor body), while the test voltage is stated accordingly. The insulation resistance applies for piezoelectric sensor, strain gauge sensors and semi-conductor sensors
Linearity	see Annex 9.3.
Measurand	Physical quantity, state or characteristic which is measured, e.g. force, torque, pressure etc.
Measuring chain	Interconnection of several individual components to meet measuring requirements. Measuring chains usually consist of sensors and amplifiers in conjunction with data acquisition, display, evaluation and recording equipment (e.g. PC, printer).

Measuring range, charge amplifier	Charge, voltage or current range of the signal input. Entry in units of the measurand is also possible depending on the type of charge amplifier.
Measuring range, sensor	Range in which the quality of the measurement within the stated tolerances is guaranteed. This range must be regarded as a binding maximum range.
Natural frequency	Frequency of free (not forced) oscillations of the entire sensor. In practice the (usually lower) natural frequency of the entire mounting structure governs the frequency behavior.
Operating temperature range	Range of ambient temperatures in which the sensor is to be operated. The temperature-dependent tolerances stated apply only within this range.
Output signal	see "Charge signal"
Overload	Maximum value of the measurand with which a sensor can be loaded without sustaining damage. This refers to a safety margin and is not an extended measuring range. The characteristics specified in the calibration certificate are no longer guaranteed in the event of an overload. Nevertheless, measurements made during an overload in most cases provide useful results
pC (picocoulomb)	1 picocoulomb = 10^{-12} coulomb. See "Coulomb".
piezoelectric	Characteristic of crystals (e.g. quartz) in which mechanical loading produces a proportional electrical charge
quasistatic	Describes the ability of Kistler sensors and charge amplifiers to undertake short-term measurements or DC-similar measurements.
Range	see "Measuring range"
Scaling	Output voltage per unit of the measurand at the analogue or monitor output of a charge amplifier..
Sensitivity	Nominal value or calibrated value stated in the calibration certificate of the change in the response of a sensor divided by the corresponding change in the value of the measurand. Note: sensitivity of piezoresistive and strain gauge sensors is additionally dependent on the excitation current or voltage.
Sensor	System which produces a definite change in the output signal as a function of the change of the measurand acting on it. Note: The term "Sensor" is equivalent to "Transducer"
Temperature influence	see Annex 9.5.

Threshold	Largest change in the measurand that produces a measurable change in the sensor output, while the change of the measurand takes place slowly and monotonically. Note: In practice, the rule of thumb applies that the threshold is about two to three times as large as the typical noise signal of a charge amplifier. This value can, however, only be achieved in dynamic measurements, whereas with quasi-static measurements, drift and environmental influences are limiting factors
Time constant	The time constant describes the behavior of a high-pass filter and represents the time after which the signal is reduced to 1/e of the output value. Note: The time constant enables the measuring error to be estimated in relation to the measuring duration. You will find detailed information on time constants and sensitivity ranges in the operating instructions for your charge amplifier. Example: The time constant depends on the measuring range selected on the charge amplifier. Possible values vary from approx. 0,01 s in the most sensitive range to approx. 100 000 s in the least sensitive range. The largest possible time constant must be selected for quasi-static measurements

9.2 Measurement Uncertainty

Systematic errors, accuracy
Accuracy is the extent of the conformity between a measured value and a true value of the measurand. In a piezoelectric measuring chain it is determined by many systematic errors, such as

- Sensor linearity
- Sensor hysteresis
- Crosstalk from other measurands
- Charge amplifier linearity
- Disturbance (forces, moments)
- Disturbance (environmental influences, like temperature)
- Duration of the measurement
- etc.

Experience with a measuring chain consisting of sensor, cable and charge amplifier shows that an accuracy in the range of 1 ... 2 % of the measuring range is achieved. This value does not include errors due to influences from external sources acting on the measuring chain, due to mechanical adaptation of the sensor and environmental influences. For the highest accuracy requirements, we recommend calibration of measuring ranges specific to the application.

Measurement uncertainty of charge amplifiers
When random and systematic errors together are quantified as variance, measurement uncertainty can be derived. With charge amplifiers, this mainly depends on type. The following typical values apply:

Laboratory charge amplifier	±0,2 ... 0,5 % FSO
Industrial charge amplifier	±1 % FSO

Higher accuracy can be achieved with the following procedures:

- Calibration in the Kistler factory
- Calibration with charge amplifier Type 5395A
- Restriction of the temperature range

Random errors, **precision, reproducibility**
Precision or reproducibility is the extent of conformity between independent data measured under specified conditions.

Repeatability
Repeatability is understood as "serial precision" for example conformity between several measurements in sequence under largely unchanged conditions.

This requirement is found mainly in repetitive measurements in production processes, where good repeatability is usually sufficient for process monitoring. Accuracy primarily plays only a subordinate role, when measurements can be directly related to conforming/nonconforming parts.

For good repeatability, piezoelectric measuring technology offers the particular advantage that the charge can be discharged with <Reset> before every measurement, enabling the zero point to be re-determined. Errors due to zero drift caused by influences changing with time, such as the temperature, are thus basically excluded.

With Kistler piezoelectric measuring chains, a typical repeatability within 0,1 % FSO can be assumed.

9.3 Linearity

Sensor linearity
The quartz crystal produces an electric charge, which is exactly proportional to the load. However, certain unavoidable deviations occur due to the mechanical construction of the sensor. Linearity represents the maximum deviation between ideal and actual output signal characteristics in relation to the measurand in a specific measuring range. It is expressed in percentage of the particular measuring range limit and is defined according to ANSI/ISA-S37.1 as the closeness of the calibration curve to a "best straight line" passing through the zero point:

"Best Straight Line" – A line midway between the two parallel straight lines closest together and enclosing all Output vs. Measurand values on a Calibration Curve.

The best straight line can be determined as follows:

Best straight line – geometric definition
A line midway the two parallel straight lines closest together and enclosing all output versus measurand values on a calibration curve. In addition, it must pass through the zero point based on the assumption that zero measurand results in zero output signal.
Note: The slope of this center line corresponds to the sensitivity of the sensor. Half the distance between the two parallels (measured in the ordinate direction) is the linearity

Best straight line – mathematical definition

The minimization of maximum deviation is known as Chebyshev's approximation. The best straight line is determined as follows:

- x = measurand (reference)
- Q = sensor charge signal or output signal from the charge amplifier
- $Q(x)$ = calibration curve, rising and falling
- s = slope of the best straight lines
- Best straight line: $y_i = s\,x_i$ (with starting value for slope s)
- Form residues: $res_i = Q_i - y_i$
- $\Sigma_{res} = res_{max} + res_{min}$ sum min. + max. deviation
- Recursive minimization of $\Sigma_{res} = f(s)$ by changing s until $\Sigma_{res} = 0$
- Linearity $a = res_{max} = |res_{min}|$

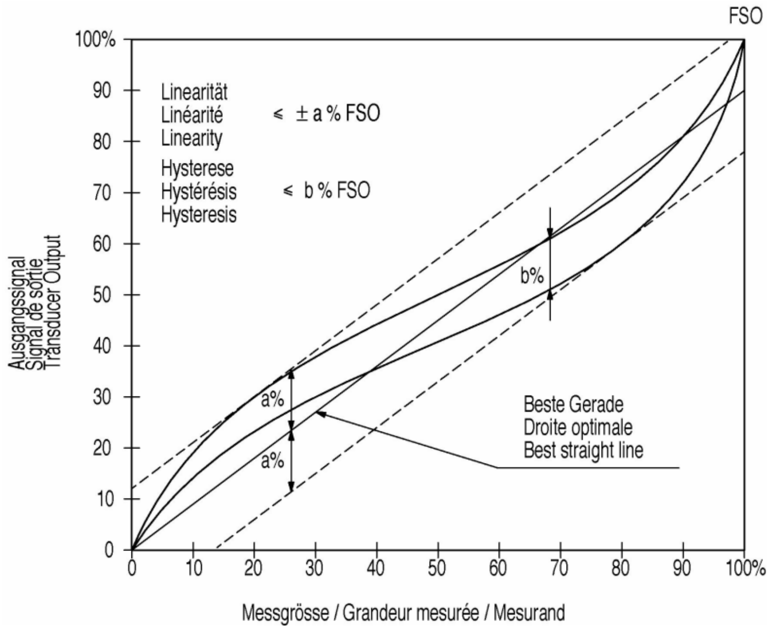

Fig. 14: Best straight line, linearity and hysteresis

Hysteresis

The maximum difference in output, at any measurand value within the specified range, when the value is approached first increasing and then decreasing measurand (source: ANSI/ISA-S37.1).

Note: The quartz crystal itself has a scarcely measurable hysteresis. However, the mechanical construction of the sensor can result in slight hysteresis. If the hysteresis is above the specified values (in %FSO), then the sensor is faulty or has not been correctly installed.

Charge amplifier linearity

The linearity of charge amplifiers is typically within the range of ±0,05 % of the measuring range selected. For the accuracy of the measurement, this is usually negligible compared with other influences.

9.4 Frequency Range

Because of their mechanical quality, piezoelectric sensors have very low damping. The useful frequency range is limited in the upwards direction by the increasing resonance rise.

Key: **f** = **Measuring frequency**
f_n = **Natural frequency**
A/A_n = **Amplitude ratio**

The following approximate values apply to the amplitude error or achievable accuracy as a function of frequency:

Accuracy 10 % → f_{max} ≈ 0,3 · natural frequency
5 % → f_{max} ≈ 0,2 · natural frequency
1 % → f_{max} ≈ 0,1 · natural frequency

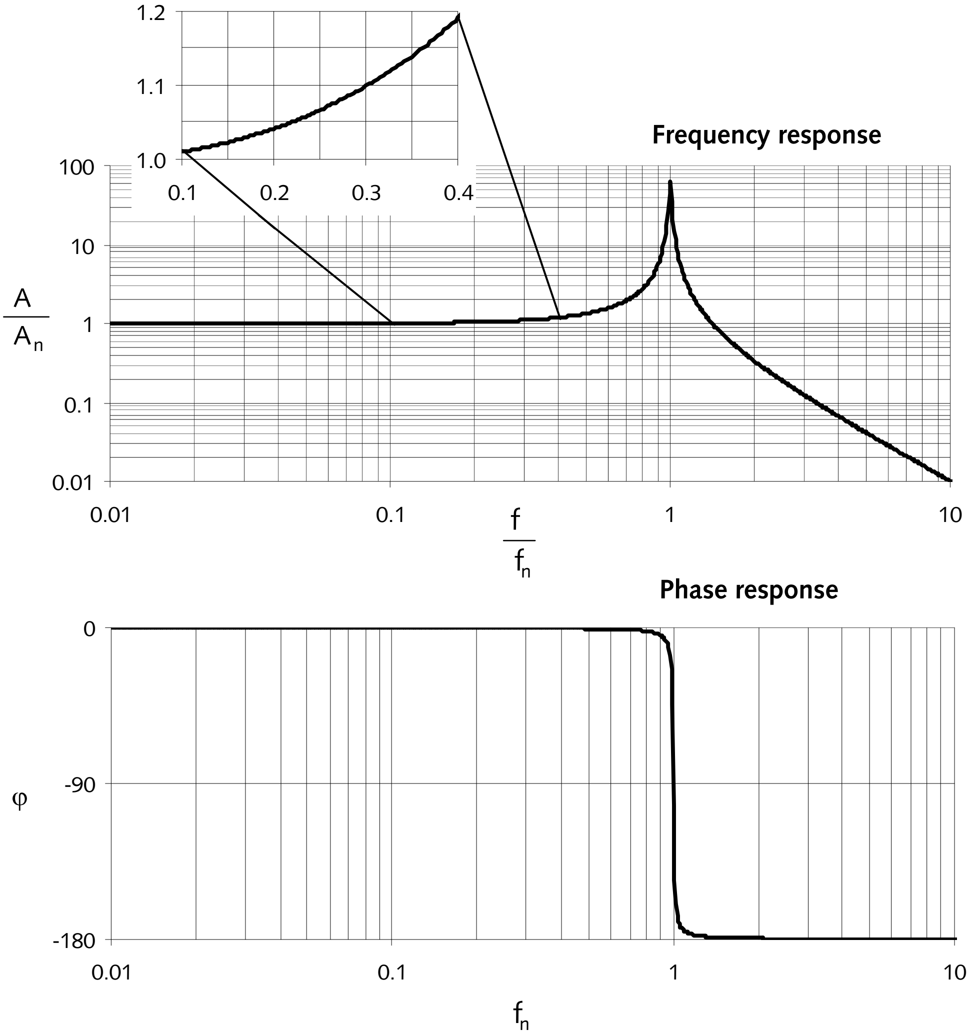

Fig. 15: Schematic representation of frequency response and phase response

In their dynamic behavior, piezoelectric sensors are superior to all other measuring methods. Their high rigidity results in the highest possible natural frequencies. Piezoelectric sensors are thus ideal for measuring measurands which change rapidly over time. Their dynamic behavior is thereby largely determined by the surrounding structure. Therefore the frequency response of the entire measuring arrangement must be investigated for the largest possible, useful measuring range.

There are two possibilities here:

Frequency Analysis
The measuring arrangement is stimulated with a pulse hammer and the sensor output signal then subjected to a frequency analysis.

FEM
In the finite-element method, a homogeneous body is substituted for the sensor closely approximating to the dimensions and average density of the sensor. The average modulus of elasticity of this equivalent body is then continuously varied until its natural frequency coincides with that of the actual sensor (Technical data). An equivalent body defined in this way is usually a good approximation of the sensor. The equivalent substitute body is inserted into the structure to be simulated, and by this means the natural frequency of the structure is calculated. Using this procedure, the FEM can be used to determine the frequency behavior of a measuring arrangement with good approximation.

9.5 Influence of Temperature

Temperature changes during a measurement result in an error signal in the form of a zero drift. In critical applications, we recommend that protection be provided for the sensor as far as possible against changes in temperature.

Temperature error of the zero point (static error)
Temperature error [unit of the measurand/°C] is the greatest change to the output signal in a specified measuring range after a specific sensor temperature change, following which the sensor is again in thermal equilibrium with its environment. Temperature errors are caused by changes in stress in the sensor, which in turn are influenced by the preload or installation conditions.

Temperature gradient error (dynamic error)

A temporary change in the output signal is denoted as temperature gradient error, when the temperature of the environment or surrounding medium changes with a certain rate. In this case, the sensor is not in thermal equilibrium with the environment.

The temperature gradient error is primarily determined by the installation conditions and the application, and cannot be generally specified. However, the temperature gradient error can be significant, particularly in the case of sensitive measurements and small measured values. It is therefore extremely important to keep the sensor temperature constant during the actual measuring time.

Immersion Bath Error 150 ... 200 °C

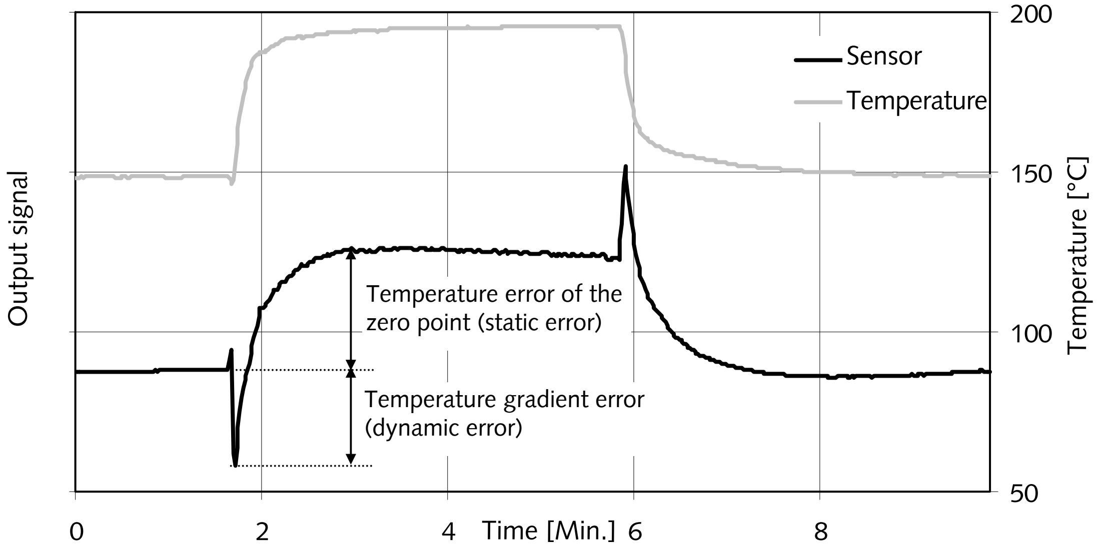

Fig. 16: Example of a temperature error of the output signal zero for a temperature rise from 150 °C to 200 °C (immersion bath).

Temperature coefficient of sensitivity

Change in the sensitivity, i.e. the slope of the best straight line, as a function of temperature. The temperature distribution in the sensor is assumed to be homogeneous, and in thermal equilibrium with the environment. The temperature coefficient of the sensitivity is typically only approx. 0,02 %/°C, and is thus mostly negligible compared with other influences.