KISTLER

measure. analyze. innovate.

Cutting Force Measurement

Precise Measuring Systems for Metal-Cutting

Kistler –
Your Partner for Efficiency and Quality

Sensors and systems for measuring forces and torques, analyzing force-displacement and force-time characteristics, and documenting quality data during assembly and product testing are just a few elements of the solutions for the sector provided by Kistler Instruments AG. From our headquarters in Switzerland, we supply assembly and testing technology as well as specific sensors and monitoring systems for combustion engines, automotive engineering, plastics processing and biomechanical engineering.

Kistler's core competency lies in the development, production and implementation of sensors for pressure, force, torque and acceleration measurement. Kistler electronic systems and expertise used for conditioning measurement signals allow analysis, control and optimization of physical processes as well as enhancement of product quality for the manufacturing industry.

Year after year the company invests 10 % of its sales in R&D to facilitate technically innovative yet cost-effective state of the art solutions.

With a combined workforce of around 1 000, the Kistler Group is the world market leader in dynamic measurement technology. Twenty-three group companies worldwide and more than 30 distributors ensure close contact with the customer, individual application engineering support and short lead times.

PiezoStar® – Kistler has been growing its own highly sensitive and thermally stable crystals for more than ten years

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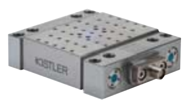


Cutting Force Measurement

Significant cutting force and spindle or drilling torque data is very important in ensuring the process optimization involved in metal cutting machining. Analyzing cutting forces prior to the start of production increases process capability and boosts productivity. The detection of overloads, tool collisions and tool breakage can also be monitored with the aid of Kistler sensor systems.

Machining remains the most important type of forming. However, this method of production has changed significantly over recent decades, with cutting process requirements becoming ever more stringent. Products of impressive quality are expected to be achieved with individual machining operations while remaining cost-effective and sustainable. Detailed knowledge of the cutting processes is indispensable in actually meeting these requirements. The acting forces and torques, which are essential prerequisites for drawing conclusions about the technology and cutting parameters, are important indicators here. These forces can only be measured and hence analyzed with sophisticated sensor solutions.

Kistler has been involved in challenging multi-component force measuring technology for use in cutting force measurement for more than four decades. Ongoing development of sensor technology now allows recording of the cutting force during grinding, drilling, turning, milling and tapping. This is achieved with stationary or rotating "dynamometers". The acquired signals are evaluated with the aid of electronics and software solutions.

New, forward-looking products for economically optimizing machining processes or developing new tools has given Kistler its leading international position.

What is Achieved by Measuring the Cutting Forces?

- Analysis of cutting technology
- Optimization of cutting parameters
- Improvement of cutting processes

Cutting

Grinding *Drilling* *Turning* *Milling* *Tapping*

Process Optimization

Because general cutting value documents cannot be transferred from factory to factory or from machine to machine, each user must have his own cutting data available.

Dynamometers, which measure all of the components of the cutting force, are invaluable in research, tool manufacture and production technology. They are used in analyzing, comparing and selecting materials, tools and machines. Additional areas of application result from defining optimum cutting conditions, analyzing the breakage behavior of tools and the chip formation process and their influence on cutting forces.

Profitability and superlative quality combined in Kistler dynamometers
Process optimization, in which Kistler dynamometers play an important role, allows a considerable increase in the efficiency of cutting processes in manufacturing plants. The data provided by Kistler dynamometers can be used to reduce production costs. Critical factors during production and production engineering can be eliminated in advance.
Tool manufacturers have the confidence that they are offering optimized products.

Factors Determining the Magnitude and Direction of Cutting Forces

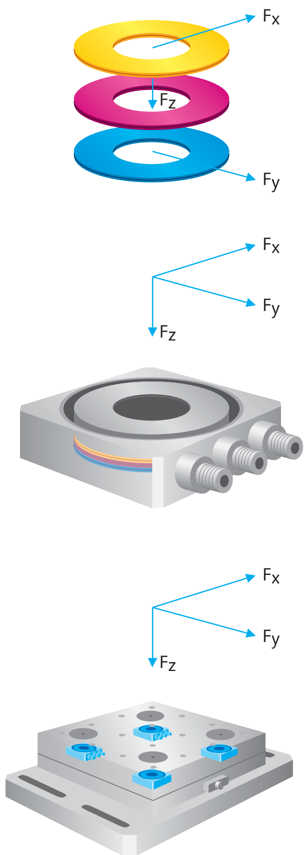
- Cutting speed
- Cutting depth
- Feed rate
- Stock material
- Cutting material
- Coating cutting edges
- Cutting geometry
- Cutting fluid

Measuring Instruments

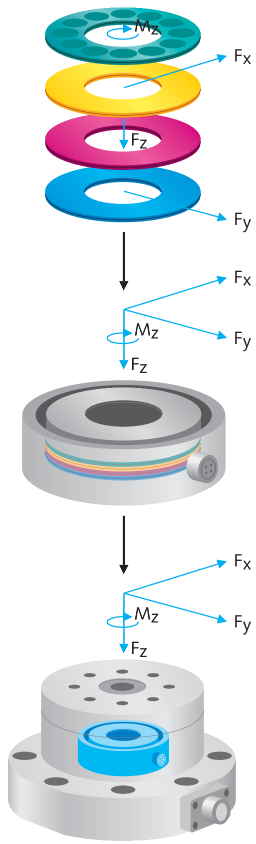
Technology

Piezoelectric force measuring systems are considerably different from other methods of measurement. The forces acting on the quartz crystal element are converted to a proportional electric charge. The measuring path of a piezoelectric force measuring element amounts to just a few thousandths of a millimeter. The measuring range of such an element is very large.

Dynamometers from Kistler are very compact, rigid systems and therefore have a high natural frequency. This allows precise measurement of highly dynamic events. Dynamometers are designed to ensure that, at less than 1 %, the problem of crosstalk becomes very minor. Their rust-resistant design is protected against ingress of cutting fluid to achieve an IP67 rating. The quality of these systems ensures an almost unlimited service life. Piezoelectric force sensors do not require zero adjustment for this purpose – they are ready to operate at the push of a button.



Construction of a 3-component dynamometer (F_x, F_y, F_z)



Construction of a 4-component dynamometer (F_x, F_y, F_z, M_z)

Advantages of Kistler Dynamometers

+ High rigidity and consequently high natural frequency
+ Wide measuring range
+ Extremely low crosstalk (below 1 %)
+ Compact design
+ Unlimited life
+ Cutting fluid proof according to degree of protection IP67
+ Simple operation (ready to measure at the "push of a button")

3-Component Dynamometer

Two shear quartz – for F_x and F_y – and one pressure quartz – for F_z – incorporated in a single case constitute a 3-component sensor.

Four of these 3-component sensors are installed between a base plate and a top plate under high preload and connected in parallel. They thus constitute a 3-component dynamometer. The outputs of the four built-in force sensors are interconnected in the dynamometer in such a manner that multi-component force and moment measurements are also possible. The four sensors are ground-isolated thereby largely eliminating ground loop problems.

4-Component Dynamometer

Multiple quartz plates can be connected electrically and mechanically in parallel. When shear-sensitive plates are arranged in a circle so that their shear-sensitive axes are tangential, this results in an arrangement which responds to a moment M_z.

When these are combined with two shear quartz – for F_x and F_y – and one pressure quartz – for F_z – this results in a 4-component sensor assembled in a single case.

When this sensor is fitted between a base plate and a top plate under high preload, a 4-component sensor is created for F_x, F_y, F_z and M_z.

Measuring Chain

The Measuring System

The heart of a system for measuring cutting forces is the actual instrument, a dynamometer. It is used to measure the acting forces and (depending on type) torques. Dynamometers based on the piezoelectric principle output a charge proportional to the measurand. These charges are then passed on via a high-insulation cable to the charge amplifier for conversion into proportional voltages.

The reliability of the system is also extremely important when measuring cutting forces. In order to be able to guarantee this, Kistler places great emphasis on coordinating components properly at the planning stage. In the measuring system for cutting forces, particular attention is given to the stability and sealing of individual components against cutting fluid and other contamination. All dynamometers and cables are ground-isolated and guarantee interference-free operation.

Uniform Cable Concept

A reliable connection between the dynamometer and the in-line charge amplifier is of paramount importance to measurement stability. The ground-isolated cables for measuring cutting force are protected with a sealed metal sheath that makes them suitable for use in a machining shop. Both ends of the cables are provided with robust connectors that ensure the connection to the stationary dynamometer achieves IP67 degree of protection. A uniform cable concept provides clarity and simplifies application.

Multichannel Charge Amplifier

Multi-component dynamometers require a corresponding number of measuring channels. In this respect, Kistler's multichannel charge amplifiers leave nothing to be desired. These instruments are available with optional numbers of channels. Thanks to the intuitive menu system the parameters can be conveniently configured on the charge amplifier or activated directly with the computer via the built-in interface.

Data Acquisition

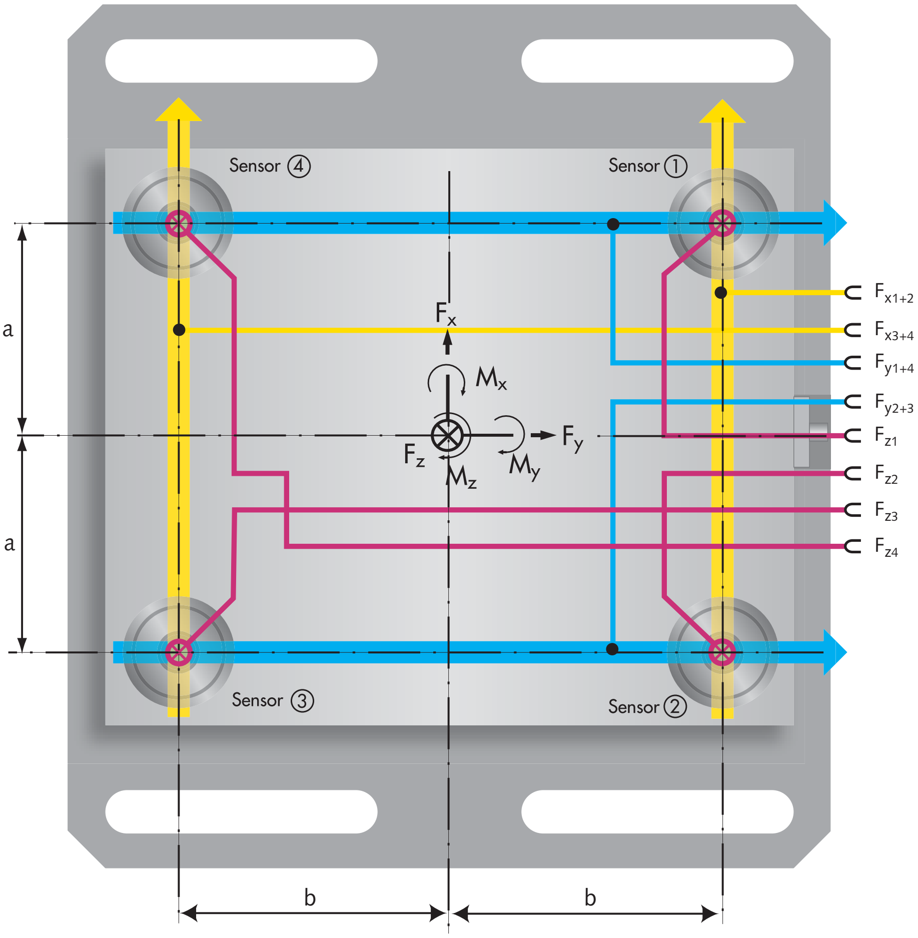
Kistler provides extremely useful software for data acquisition and analysis. Kistler's DynoWare allows setting of all of the important charge amplifier parameters to data acquisition. The acquired data is represented graphically and, in conjunction with the various signal processing functions, makes it easier to analyze the cutting force. DynoWare also provides a simple means of documenting and exporting the data. This software package is an important instrument allowing any user to acquire and subsequently analyze cutting force data.

Multi-Component Force and Moment Measurement

Stationary dynamometer Types 9129AA, 9253B..., 9255B, 9256C..., 9257B, 9265B and 9366CC... can be used both as 3-component dynamometers and optionally for 6-component force and moment measurement.

For cutting force measurement, in addition to the three orthogonal force components F_x, F_y and F_z, only the moment M_z is relevant for determining the drilling moment.

In addition to cutting force measurement, there are innumerable other measuring tasks, in which both the three components of the resulting force and the three components of the resulting moment vector are of interest.



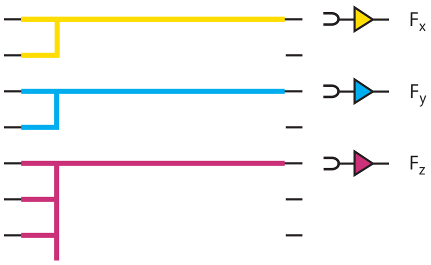
Calculation the forces
Three forces F_x, F_y and F_z and the moments M_x, M_y and M_z are calculated in a computer or with the 6 component summing amplifier in the charge amplifier. To calculate the moments, the distance of the sensors must be included. The dynamometer must be appropriately calibrated for accurate moment measurement.

Calculation of the three forces F_x, F_y, F_z and three moments M_x, M_y, M_z

F_x	=	$F_{x1+2} + F_{x3+4}$
F_y	=	$F_{y1+4} + F_{y2+3}$
F_z	=	$F_{z1} + F_{z2} + F_{z3} + F_{z4}$
M_x	=	$b\,(F_{z1} + F_{z2} - F_{z3} - F_{z4})$
M_y	=	$a\,(-F_{z1} + F_{z2} + F_{z3} - F_{z4})$
M_z	=	$b\,(-F_{x1+2} + F_{x3+4}) + a\,(F_{y1+4} - F_{y2+3})$

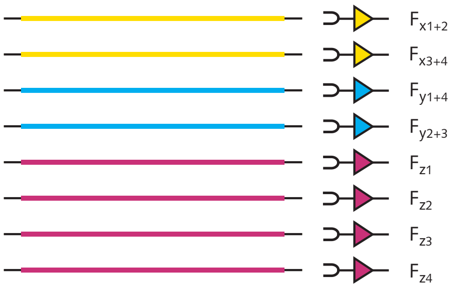
3-core connecting cable

3 charge amp. channels



8-core connecting cable

8 charge amp. channels



3-component force measurement
In 3-component force measurement, the eight output signals from the dynamometer, as shown in the illustration, are summed in the three-core connecting cable. Three charge amplifiers are needed to convert the charge signal to a proportional output voltage.

6-component force measurement
In 6-component force and moment measurement, the eight output signals are fed directly to the eight charge amplifiers by the eight-core connecting cable.

In General, a 6-Component Measuring System Provides

- The three components of the resultants of all applied forces, their direction but not their location in space
- The three components of the resulting moment vector related to the coordinate origin

Kistler Measurement Technology

Kistler supplies piezoelectric, piezoresistive, capacitive and strain gage sensors. Piezoelectric designs are particularly suitable for measurement imposing extreme requirements in terms of geometry, temperature range and dynamics. Kistler therefore relies on the piezoelectric principle for measuring cutting forces.

Piezoelectric (derived from the Greek piezein, which means to squeeze or press) materials generate an electric charge when subjected to mechanical load. Pierre and Jacques Curie discovered the piezoelectric effect in 1880. As electric charges do not readily lend themselves to experimental research, piezoelectricity only gained practical significance in the middle of the 20th century. With the help of so-called electrometer amplifiers, the charge produced by piezoelectric material could then be converted into a proportional electric voltage for the very first time.

In 1950, Walter P. Kistler received a patent for the very first charge amplifier for piezoelectric signals, paving the way for exploitation of an effect that had been known for decades. The development of highly insulating materials such as Teflon® and Kapton® significantly improved the performance of these measuring systems and propelled the use of piezoelectric sensors into virtually all areas of modern technology and industry.

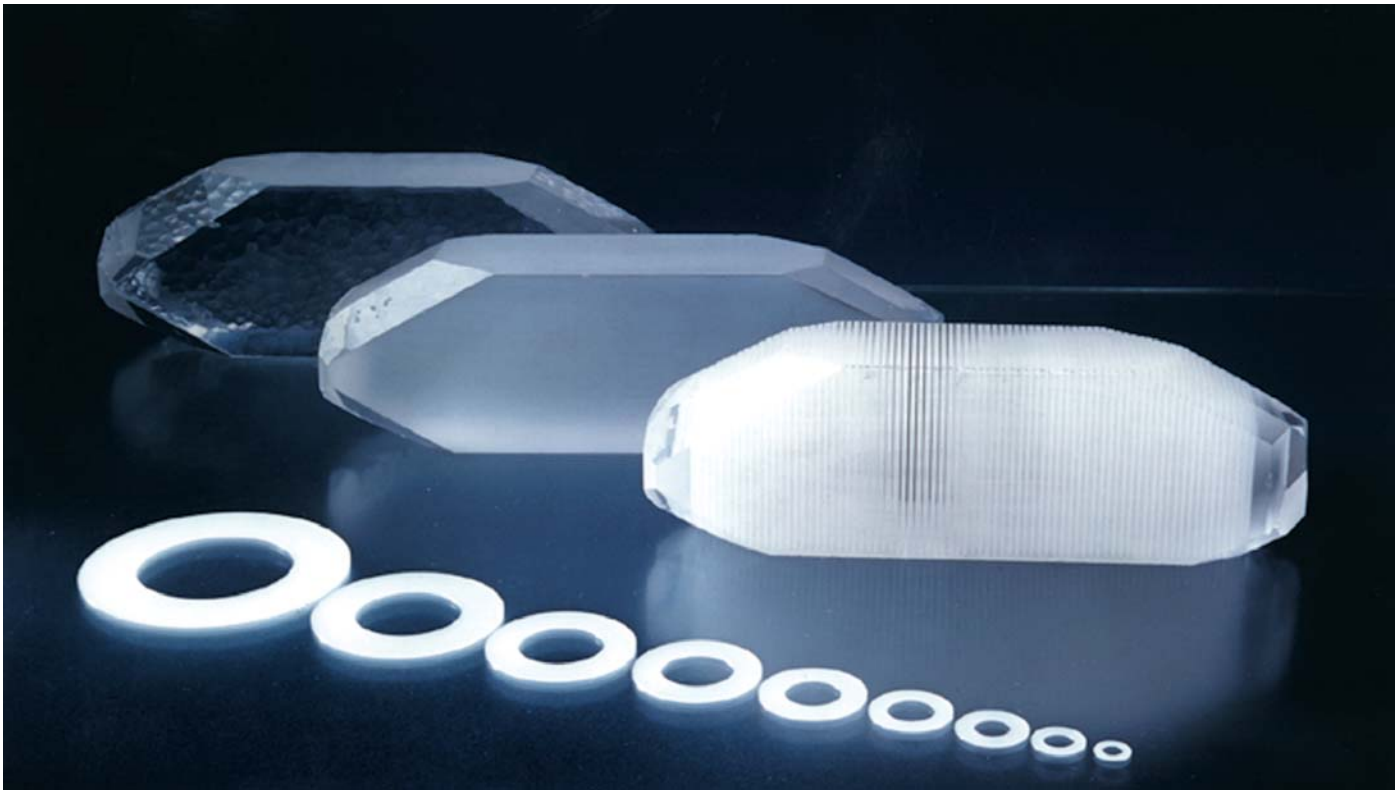
Most Kistler sensors rely on a quartz force link, which basically consists of thin quartz plates, disks/washers or rods. The sensor is connected to an electronic device for converting the charge signal into a voltage signal proportional to the mechanical force. The conversion is made either by means of a separate charge amplifier or an impedance converter with coupler, which is usually integrated into the sensor.

The finite insulation resistance does not permit truly static measurement with piezoelectric sensors. Nonetheless, used in combination with suitable signal conditioners, piezoelectric sensors offer excellent quasistatic measuring properties.

Quartz at a Glance

Quartz has excellent properties for use as a measuring element:

- High permissible surface pressure of at least 150 N/mm^2
- Withstands temperatures up to 300 °C
- Very high rigidity
- High linearity
- Negligible hysteresis
- Virtually constant sensitivity over a wide temperature range
- Wide frequency range
- Virtually unlimited number of load cycles



Basics of Piezoelectric Measurement Technology

Longitudinal effect
A charge is developed on the surfaces to which the force is applied, where it can be measured. In the case of the longitudinal piezoelectric effect, the magnitude of the electric charge Q depends only on the applied force F_x and not on the dimensions of the crystal disks. The only way to increase this charge is to connect several disks mechanically in series and electrically in parallel. The magnitude of the output charge then becomes:

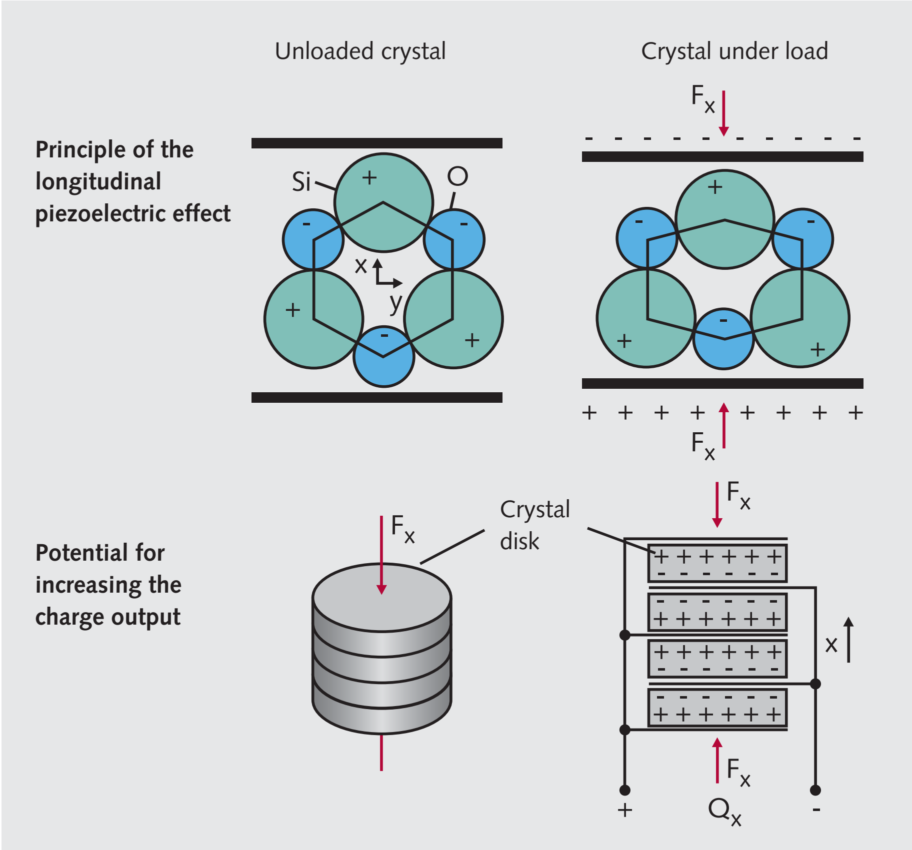
$$Q_x = d_{11} \cdot F_x \cdot n$$

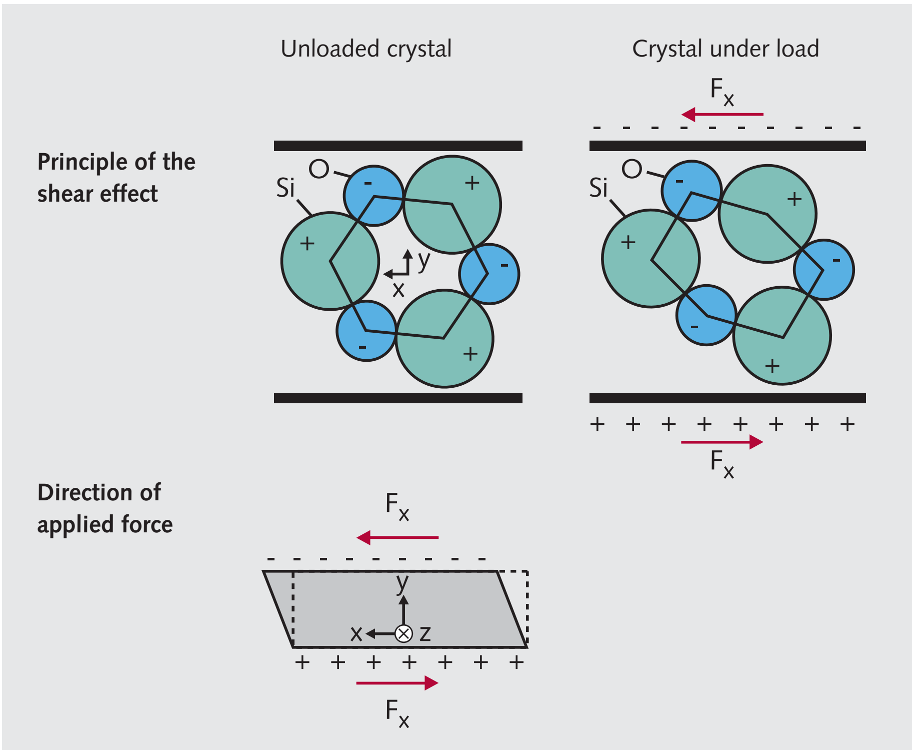
The piezoelectric coefficient d_{11} is dependent on direction and indicates the crystal's degree of force sensitivity in the direction of the corresponding axis. The position of the crystal cut therefore determines the properties and the area of application of the quartz force link. Piezoelectric elements cut to produce the longitudinal effect are sensitive to compression forces and therefore suitable for simple and sturdy sensors for measuring forces.

Shear effect
Similarly to the longitudinal effect, the piezoelectric sensitivity involved in the shear effect is independent of the size and shape of the piezoelectric element. The charge is also developed on the piezo element's loaded surfaces. In the case of a load in the x-direction applied to n elements connected mechanically in series and electrically in parallel, the charge is:

$$Q_x = 2 \cdot d_{11} \cdot F_x \cdot n$$

Shear-sensitive piezo elements are used for sensors measuring shear forces, torque and strain. They are suitable for manufacturing sensors whose excellent performance is unaffected by temperature changes, as the changes in the stresses in the sensor structure caused by changes in the temperature act in a direction perpendicular to the sensitive shear axis.





d_{11}: piezoelectric coefficient
(−2,3 pC/N for quartz crystals)

F_x: force in x-direction
n: number of crystal disks

Kistler Measurement Technology

Charge Amplifiers

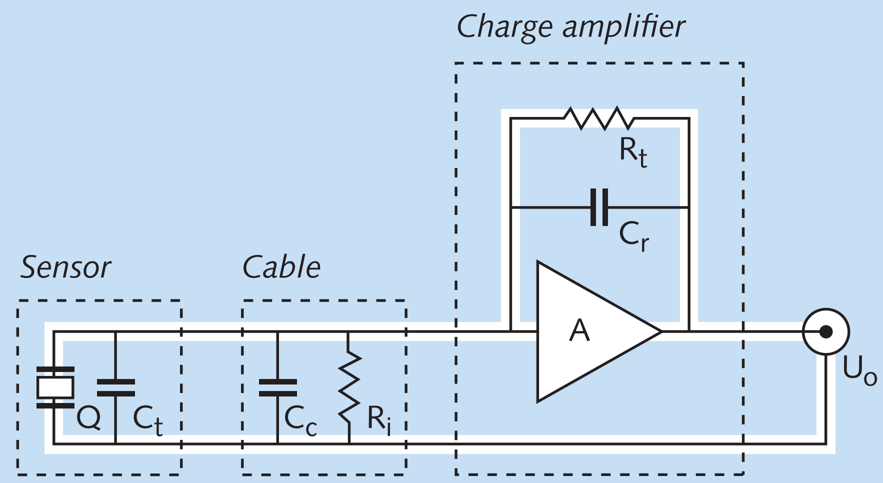
Charge amplifiers convert the charge produced by a piezoelectric sensor into a proportional voltage, which is used as an input variable for monitoring and control processes. A charge amplifier basically consists of an inverting voltage amplifier with high open-loop gain and capacitive negative feedback. It has a metal oxide semiconductor field effect transistor (MOSFET) or a junction field effect transistor (JFET) at its input to create the necessary high insulation resistance and ensure a minimum of leakage current. Neglecting R_t and R_i, the resulting output voltage becomes:

$$U_o = \frac{-Q}{C_r} \cdot \frac{1}{1+\frac{1}{AC_r}(C_t + C_r + C_c)}$$

If the open-loop gain is sufficiently high, the quotient $1/AC_r$ will approach zero. The cable and sensor capacitance can therefore be neglected, leaving the output voltage dependent only on the input charge and the range capacitance.

$$U_o = \frac{-Q}{C_r}$$

The amplifier acts as a charge integrator that constantly compensates for the sensor's electrical charge with a charge of equal magnitude and opposite polarity on the range capacitor. The voltage across the range capacitor is proportional to the charge generated by the sensor and therefore proportional to the acting measurand. In effect, the charge amplifier converts an electric charge input Q into an easily usable proportional output voltage U_o. As most Kistler charge amplifiers allow adjustment of sensor sensitivity and measuring range, the measured value is displayed directly in mechanical units of the measurand and the output signal is an integer multiple of the measurand.



U_o = Output voltage
A = Gain
C_t = Sensor capacitance
C_c = Cable capacitance
C_r = Range or negative feedback capacitor
R_t = Time constant resistance (or insulation resistance of range capacitor)
R_i = Input insulation resistance (cable and sensor)
Q = electric charge yielded by the piezoelectric element

Block diagram of a measuring chain

Time constant and drift

Two of the more important considerations in the practical use of charge amplifiers are time constant and drift. The time constant τ is defined as the discharge time of a capacitor by which 1/e (37 %) of the initial value has been reached. The time constant of a charge amplifier is determined by the product of the capacitance of the range capacitor C_r and the time constant resistance R_t:

$$\tau = R_t \cdot C_r$$

Drift is defined as an undesirable change in the output signal over a long period of time that is not a function of the measurand. Even the best MOSFETs and JFETs have leakage currents (MOSFET: $I_l < 10$ fA, JFET: $I_l < 100$ fA), which are the main cause of drift. If the input insulation resistance R_i is too low, it can cause additional drift. However, as long as the input insulation resistance in the negative feedback circuit is sufficiently high ($>10^{13}$ Ω) and no additional time constant resistor is connected in parallel, the charge amplifier will drift relatively slowly towards the negative or positive limit (MOSFET: <±0,03 pC/s, JFET: <±0,3 pC/s). This determines the potential duration of quasistatic measurement and is independent of the selected measuring range.

Frequency and time domain

The time constant affects the time domain as well as the frequency range. It determines the lower cut-off frequency f_u = ½ πτ at an amplitude attenuation for sinusoidal signals of 3 dB (30 %). The longer the time constant, the better this frequency and the longer the usable measuring time. For quasistatic measurement during assembly and testing, the longest possible time constant is always selected.

Basics of Calibration

Basic Calibration Terms

Calibration
Calibration is the use of a defined method under specified conditions to determine the relationship between a known input variable and a measured output variable. The calibration standard is the reference value. For example, the calibration of scales involves placing a defined and calibrated test weight (calibration standard) on the scales to reveal deviations in the weight reading.

Calibration certificate
The calibration certificate documents all values measured during calibration and the calibration conditions.

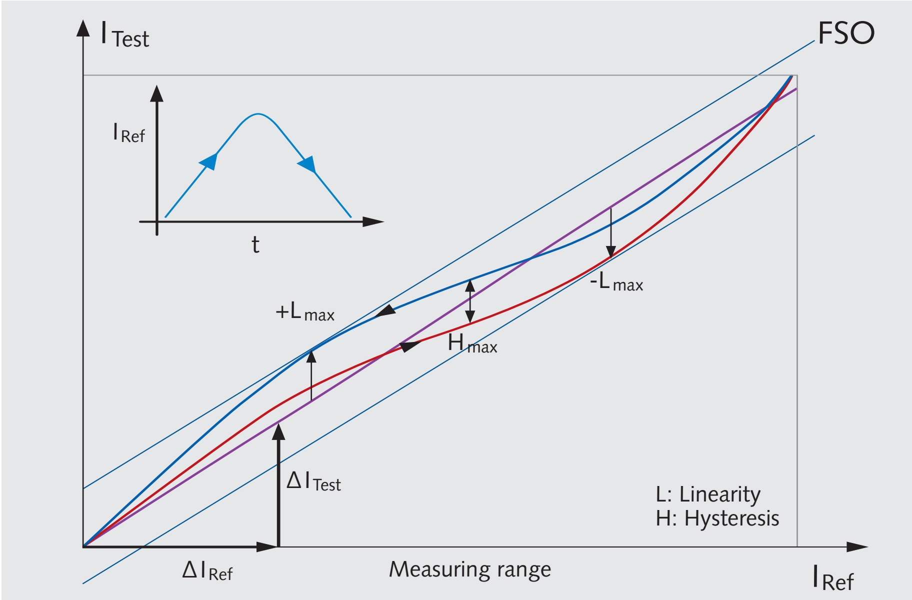
Calibration curve
This curve shows the output variable of a sensor as a function of the input variable.

Calibration standard
The calibration standard, which is traceable to national or international "standards", is the reference value used for calibrating sensors or measuring instruments.

Characteristic value
Output signal of the strain gage sensor at rated load, reduced by the zero signal after mounting.

FSO
Full Scale Output or full range signal. The difference between the output signal at zero and at the end of the measuring range.

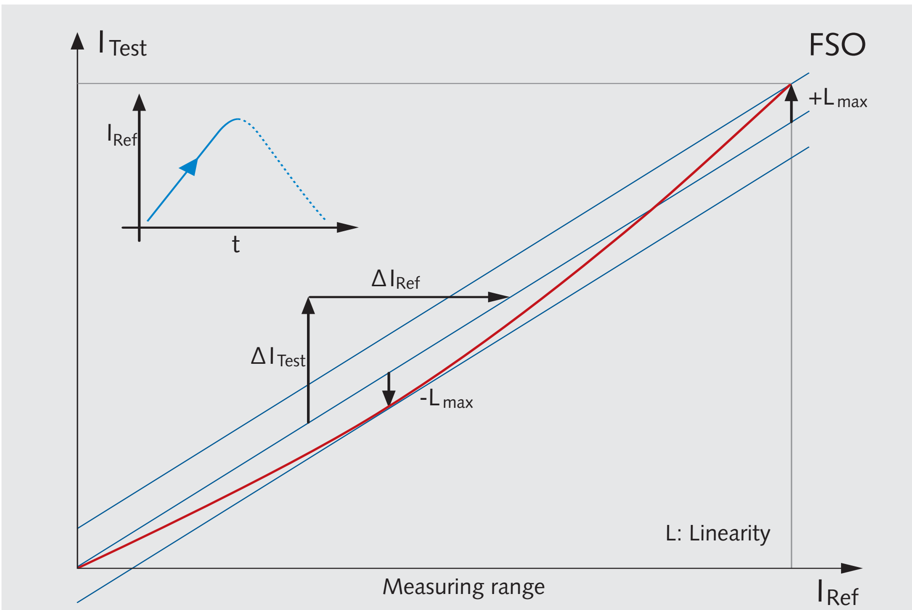
Hysteresis
Maximum difference, H_{max}, between rising load characteristic and falling load characteristic.



Hysteresis: maximum difference between rising and falling load characteristic

Linearity
In practical application there is not an exactly linear (or constant) relationship between the measurand and the output variable of the sensor. The linearity L_{max} of a sensor corresponds to the maximum deviation of the ideal from the actual output signal curve in relation to the measurand within a certain measuring range. It is expressed as a percentage of the limit of the full measuring range (% FSO).

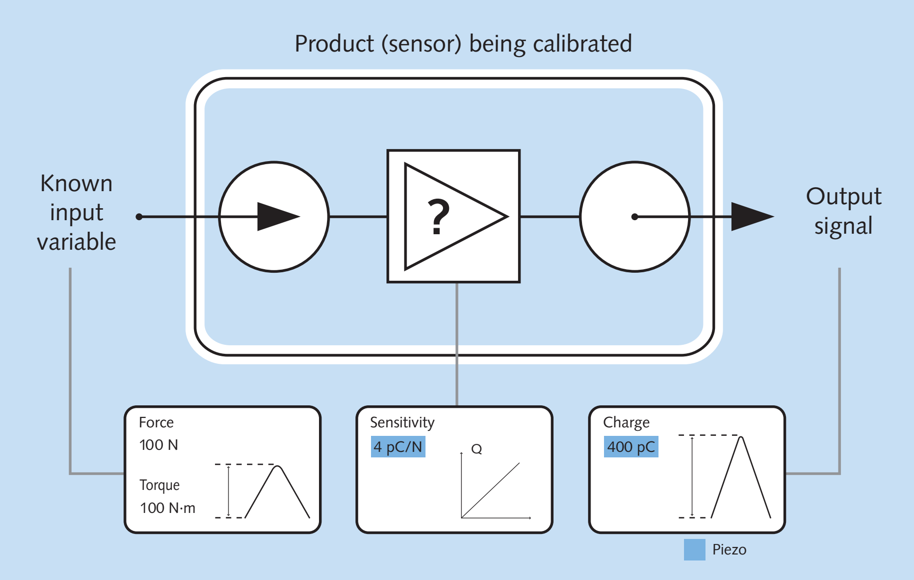
Sensitivity
Value of the change in output signal divided by the corresponding change in the input variable: $\Delta Q/\Delta I_{Ref}$ for piezoelectric sensors.



The relationship between the true value of the measurand and the output variable of the sensor is not exactly linear

Kistler Measurement Technology

Sensors and measuring instruments must be calibrated at regular intervals, as their characteristics and hence the measurement uncertainties can change over time as a result of frequent use, aging and environmental factors. Instruments used for calibration are traceable to national standards and subject to a uniform international quality control. Calibration certificates document calibration values and conditions.



Safe and reliable measurement
Quality assurance systems and product liability laws call for systematic monitoring of all test equipment needed for measuring quality characteristics. This is the only way of ensuring measurement and test results provide a reliable and dependable benchmark for quality control.

All sensors and almost all electronic measuring devices are subject to certain measurement uncertainties. As the deviations involved can change over time, the test equipment must be calibrated at regular intervals.

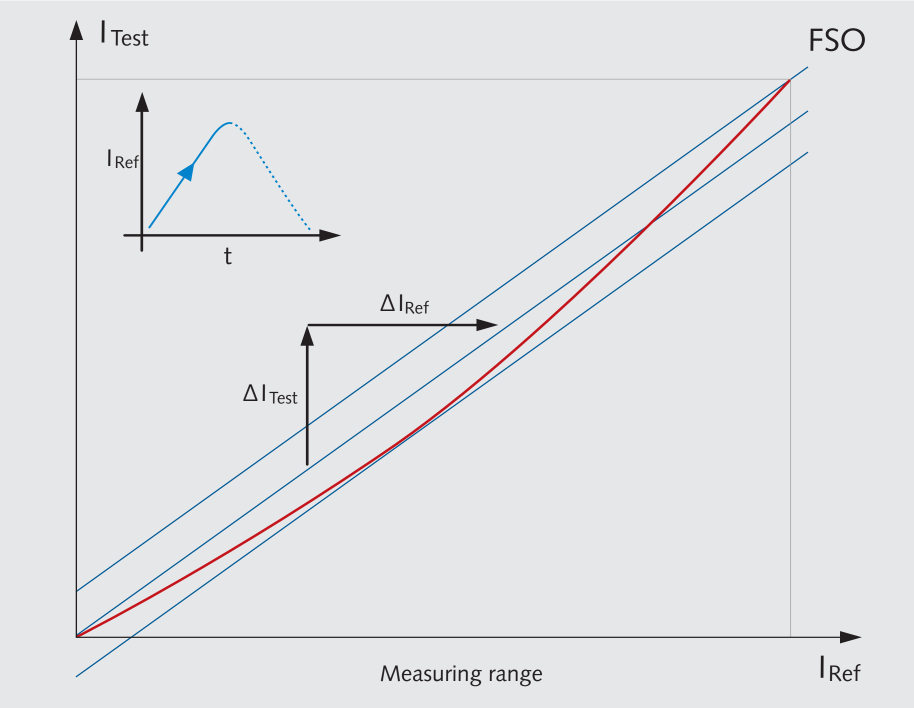
Basic principle: Calibration is the use of a defined method under specified conditions to determine the relationship between a known input variable and a measured output variable.

This involves determining the deviation of the measured value from an agreed reference value, which is also referred to as the calibration standard. The result of a calibration can either be used to assign the actual values of the measurand to the readings or for establishing correction factors for them. The required information is documented on the calibration certificate.

Calibration at a Glance

Calibration helps ensure

- Precise and reliable measurement
- Internationally comparable measurements
- Similar products are metrologicaly compatible



Sensitivity: Ratio of the change in the signal ΔI_{Test} and the change in the reference variable ΔI_{Ref}, where I represents a charge, voltage or other indicated variable

Basics of Calibration

The relationship between measurand and sensor output variable is determined by means of a simple linear regression analysis. The linearity including hysteresis indicates that the calibration curve of the loading and unloading characteristic has been used to determine the characteristic values.

Best straight line
Determination of a linear function passing through the origin to form the calibration curve, with two parallel straight lines with the same gradient and shortest distance apart enveloping all of the calibration values.

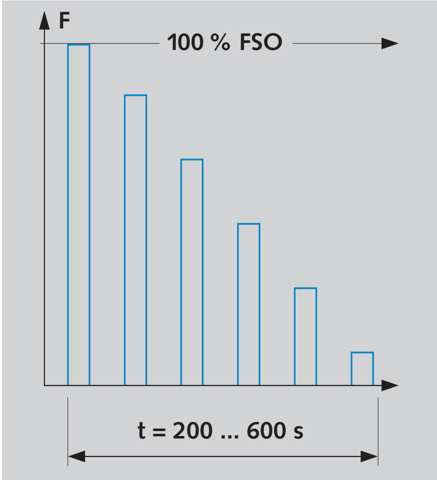
Least squares function
Determination of a linear function to form the calibration curve that minimizes the sum of the squares of the errors (differences between calibration curve and linear function).

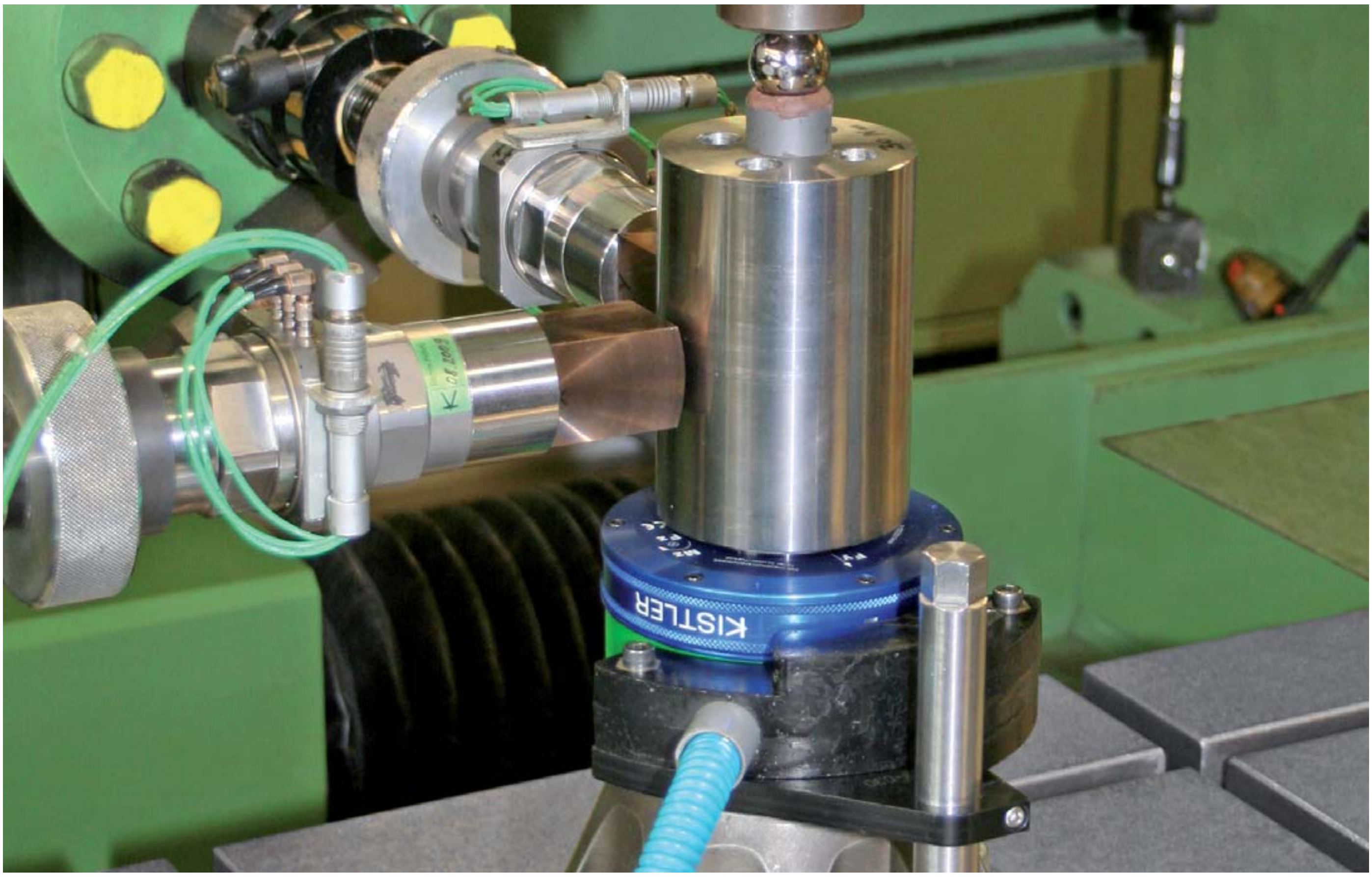
Calibration Methods

During calibration, sensors are subjected to known quantities of a physical measurand such as force or torque and the corresponding values of the output variable recorded. The magnitude of this load is accurately known, as it is measured with a traceably calibrated "factory standard" at the same time. Depending on the method, sensors are calibrated either across the entire measuring range or in a partial range:

- at a single point,
- stepwise at several different points or
- continuously.

Step-by-step calibration involves the application of a defined load with or without unloading between successive increases or decreases, depending on the calibration method used. The process is halted after each increment until the measurement stabilizes.



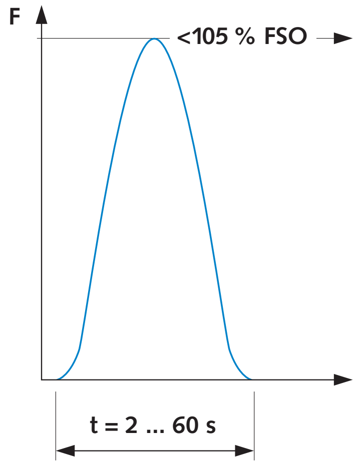


Kistler Measurement Technology

During **continuous calibration**, the load is continuously increased to the required value within a defined time and then reduced to zero within the same time. A "best straight line" passing through the origin is defined for the resultant characteristic, which is never exactly linear. The gradient of this line corresponds to the sensitivity of the sensor within the calibrated measuring range.

Linearity is determined by the deviation of the characteristic from the best line. Hysteresis corresponds to the maximum difference between rising and falling characteristic.

Dynamometers that are used for cutting force measurements are factory calibrated.

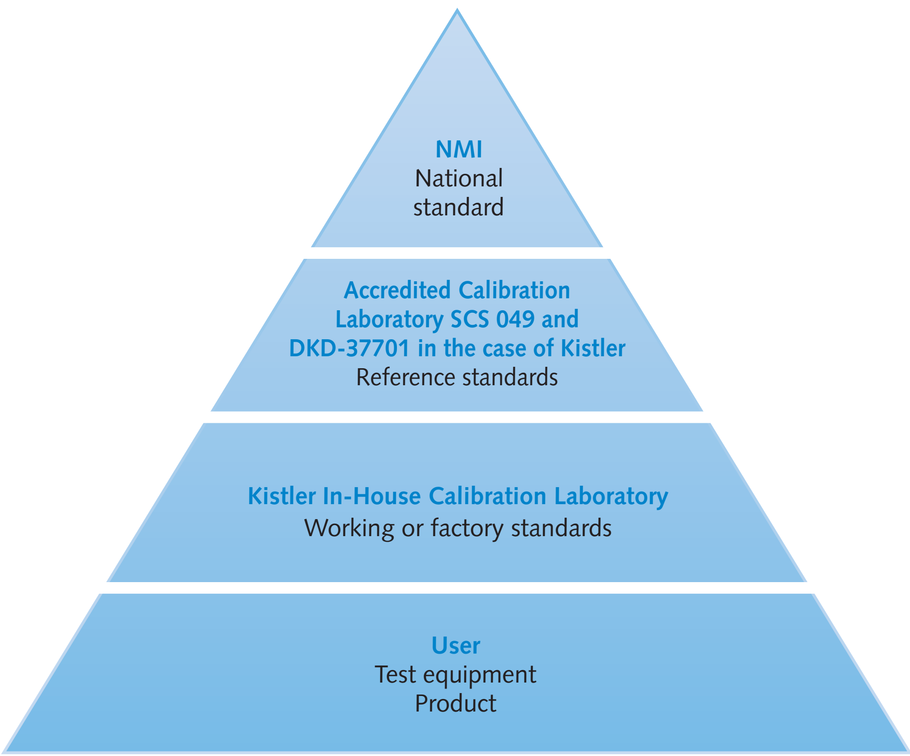


The continuous approach is the most suitable calibration method for piezoelectric sensors.

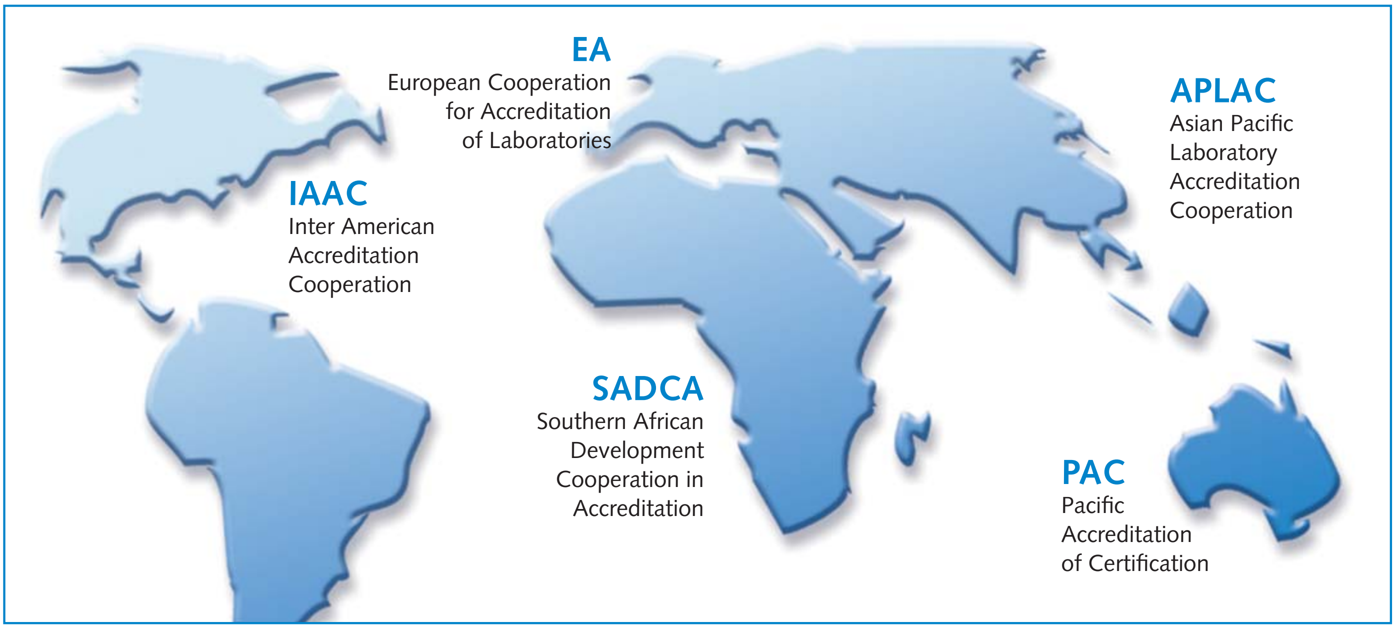
Calibration Documents

To ensure consistent quality standards worldwide, the test equipment has to meet standard quality assurance criteria. The European series of standards for quality management systems (EN 29000) – which is identical to the international ISO 9000 – demands traceability to the national measuring standards for all measuring instruments used for this purpose.

Hence the result of calibrating a measuring device or system is compared with a higher measurement standard. This results in a "calibration hierarchy" with the national measurement standard at the top.



Basics of Calibration



International standards specify the required calibration methods and measurement uncertainties.

Different institutes coordinate international cooperation on calibration. They are also responsible for the accreditation of national calibration laboratories. Documentation guidelines may differ slightly from one country to another.

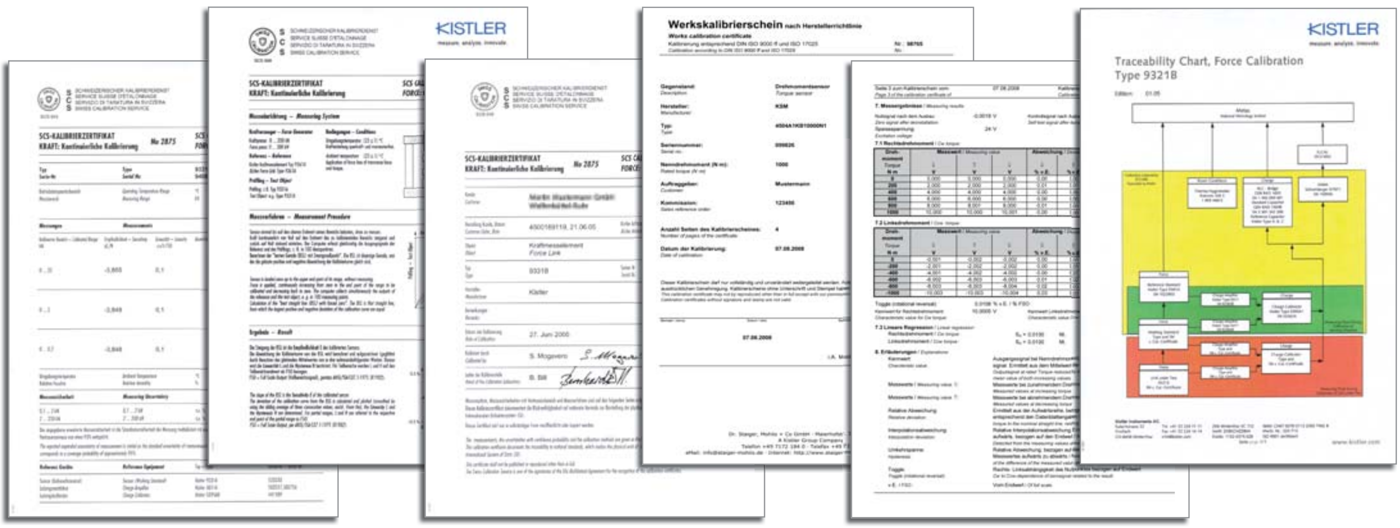
The following calibration documents are available for most Kistler sensors:

- Manufacturer's declaration
- CE declaration of conformity
- Factory certificate
- Test certificate
- Factory test certificate
- Calibration certificate
- SCS calibration certificate
- Traceability chart

At a Glance

Kistler offers comprehensive calibration service:

- Calibration of test equipment
- Accredited calibration laboratory (SCS 049 DKD-37701)
- Extensive functional testing
- Range of different calibration documents



Kistler Measurement Technology

Numerous mechanical, electrical and climatic parameters affect the calibration result and hence the accuracy of a measuring chain. For maximum calibration accuracy, assembly errors have to be avoided and the correct position and angle of force application achieved. Factors such as the non-linearity of various electrical parameters along the measuring chain must be considered. Last but not least, temperature and humidity also have a decisive effect.

Simultaneous calibration of three force components or three moments is one of the greatest challenges in calibrating multicomponent sensors. On Kistler's 3-component calibration system the loading is applied sequentially, with the sensor being calibrated remaining in its mounted position.

Linearity
The overall characteristic of electrical devices is usually non-linear, as linear behavior of all structural components is rare. This also applies to charge calibrators, charge amplifiers and bridge amplifiers, whose very slight non-linearity affects the calibration result. Force and torque sensors also exhibit non-linear characteristics. The linearity determined by the calibration is documented on the calibration certificate and affects evaluation of the measuring uncertainties involved in calibration. The linearity of the reference sensor is already included in the measurement uncertainty and need not be further taken into account.

Humidity
Relative humidity influences the behavior of electronic components including the capacitors used in charge amplifiers and charge calibrators. Type approval tests record and document the thermal characteristics of electric measuring instruments. This information can be used to determine the effects of variations in humidity on the calibration result.

Effective number of bits (ENOB)
Measuring cards, for example, have a measuring range of –10 … 10 V and a resolution of 16 bits. The true signal is rounded up or down to the nearest bit value, which causes a maximum rounding error of half a bit.

Best measurement capability
Comparative calibration involves the use of a reference sensor with best measurement capability, which has a documented measurement uncertainty as a result of being calibrated against a higher standard. Prior to calibration of the sensor, the charge amplifier must also be calibrated using a precision charge calibrator to ensure that the output voltage displayed by the amplifier is matched with the charge generated by the force sensor. The absolute standard method employs a calibration system with preset physical input variable. This system also has best measurement capability.

Effect of temperature
Mechanical components are subject to thermal expansion and the resistance of electronic components depends on temperature. Temperature variation during the calibration process therefore has a direct effect on the result. The effect of this parameter on the sensitivity of piezoelectric sensors is analyzed as part of the type approval test. There is also reliable data on the thermal behavior of charge calibrators and charge amplifiers. Charge calibrators have temperature compensation that makes their thermal dependence very slight.

Accuracy Evaluation

Range errors in charge amplifiers and charge calibrators
The tolerance of electric components limits the accuracy of charge amplifiers and charge calibrators. It manifests itself as a range error, which depends on the preset measuring range and the measured value. The maximum range error is specified for each device.

Drift
The drift of a charge amplifier is a global description of the shift of the signal zero level, which is mainly due to a loss of feedback capacitor charge and leakage currents at the amplifier input. A leakage current across the insulation resistance causes an exponential decay in the feedback capacitor charge with a time constant given by the product of insulation resistance and the capacitor's capacitance. As a sufficiently high insulation resistance leads to a very high time constant, the problem of discharge only affects very long measuring periods. Given the drift characteristics of charge amplifiers are well known from extensive research, the peak value can be used to evaluate the effect of drift on the calibration result.

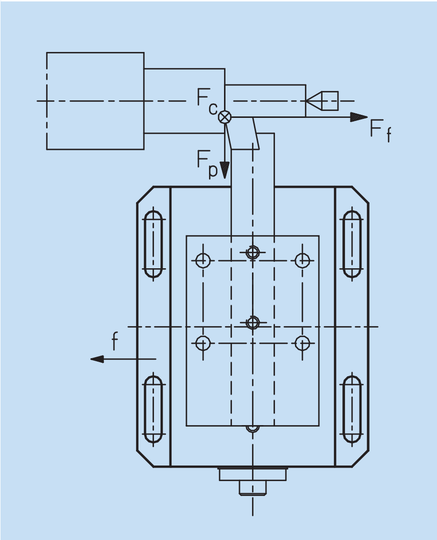
Instability of charge amplifiers over time
Charge amplifiers are subject to instability over time. To minimize the effect of this instability on force sensor calibration, it is advisable to calibrate the charge amplifiers of both the reference measuring chain and the measuring chain of the device together with all corresponding cables, display and evaluation devices, in advance with a precision charge calibrator. This approach also identifies all potential influences from contacts and electrical connections within the measuring chain.

Stability of charge calibrators
Under normal circumstances, charge calibrators are calibrated at regular intervals (generally annually). Within these intervals the calibration values undergo slight changes, which are characteristic of specific devices and as such constant. The stability of charge calibrators must be considered in evaluating the calibration results.

Crosstalk in multiaxial sensors and sensor systems
Complex sensor systems such as dynamometers are generally fitted with multicomponent sensors. With such configurations crosstalk of individual variables is observed in other measurement components. With a unidirectional force load in the direction of one axis minimal signals in the direction of the other two orthogonal axes or minimal moment will be indicated. This phenomenon affects all of the possible force and moment directions and the values involved have to be taken considered in assessing measurement uncertainties.

Threshold
The threshold is the smallest change in the input variable that leads to a discernable change in the value of the output variable of a force or torque sensor. From experience, it is two or three times the rms value of the signal noise. This noise consists of the background noise of sensor and amplifier.

Cutting Force Measurement during Turning



Forces during longitudinal cylindrical turning

Turning with dynamometer Type 9129A...

Turning is machining with a geometrically defined cutting edge and a circular cutting motion. Normally the workpiece carries out the rotational movement. The single-point tool (turning tool) is firmly clamped on the dynamometer for cutting force measurement.

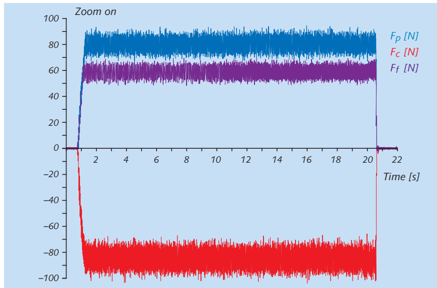
The machining force produced by the turning process is resolved directly into three significant components by the multi-component dynamometer.

Forces Measurable During Turning

- Main cutting force F_c
- Feed force F_f
- Passive force F_p

Cylindrical turning is the model situation of machining with a geometrically determined cutting edge, and is particularly suitable for determining the specific machining force $k_{i1,1}$ of materials. With universal lathes, stationary bench dynamometers are mounted on the tool slide in place of the tool holder. The tool edge must be accurately set to the workpiece center.

For lathes with a turret-head style tool holder, the the 3-component measuring system Type 9129A... is used. The exact position of the tool edge is ensured by the tool holder fixture on the turret head. The modular measuring system Type 9129A... accommodates different combinations of lathe adapters and toolholders. All of the popular types and sizes of adapter as well as toolholders for boring and outside turning tools are available.



Measured turning data

Material	C45E
v_c	495 m/min
f	0,05 mm/rev.
a_p	0,5 mm
Dynamometer	Type 9129A...

Cutting Force Measurement during Milling

Milling with stationary dynamometer Type 9255B

During milling, the rotating multiple-point tool carries out the cutting movement. With each tool rotation each cutting edge is brought into contact once. As a result of the interrupted cut, the cutting force at the cutting edge fluctuates according to the angle of contact and the number of cutting edges.

There are two different ways of making cutting force measurement during milling:

The workpiece to be machined is mounted on the top plate of an appropriately dimensioned **stationary multi-component dynamometer.**

Forces Measurable With Stationary Dynamometer During Milling

- Feed force (Force in the feed direction of the tool) — F_f
- Feed normal force (Force perpendicular to F_f) — F_{fn}
- Passive force — F_p

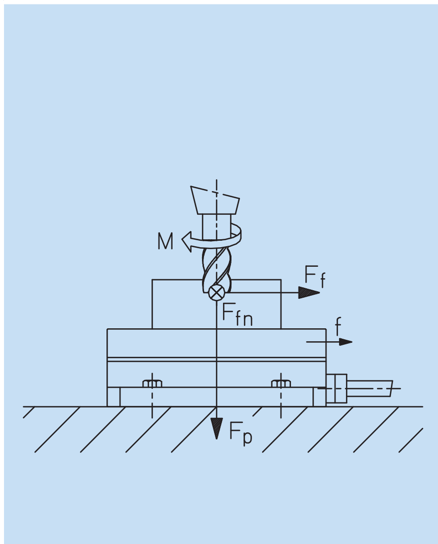
Hard milling (56 HRC) with rotating dynamometer Type 9125A...

The **rotating cutting-force dynamometer** is inserted into the spindle and holds the tool. The position of the tool edge with respect to the sensor is always the same. The rotating system is the only method of measuring the spindle torque during milling. The following components are measured:

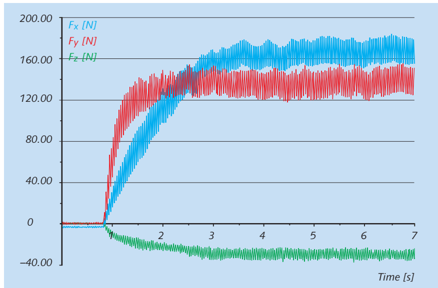
Forces Measurable With Rotating Dynamometer During Milling

- Spindle moment — M_z
- Passive force — F_p
- Forces F_x and F_y in the active cutting plane

The DynoWare data acquisition software enables the active force F_a or the tangential force F_t and radial force F_r at the tool to be calculated.



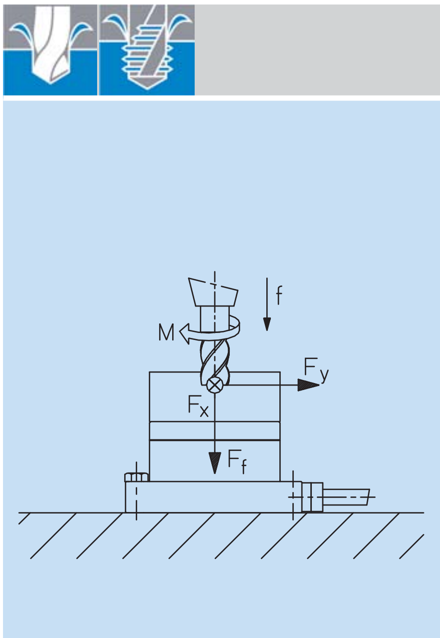
Forces during face milling



Data measured during milling

Material	C45E
v_c	34 m/min
f_z	0,065 mm
a_p	4 mm
a_e	4 mm
Tool	Shank-type milling cutter Diameter 6 mm 3 cutting edges
Dynamometer	Type 9257B

Cutting Force Measurement during Drilling



Forces during drilling

Drilling with the rotating system Type 9125A...

Drilling with stationary dynamometer Type 9272

Drilling, countersinking, reaming and tapping all use a similar machining process. The tools are mostly multiple-point cutting tools.

For analyzing the drilling process the following forces are of particular interest:

Forces Measurable During Drilling

- Drilling moment M_z
- Feed force F_f
- Deflective forces F_x, F_y

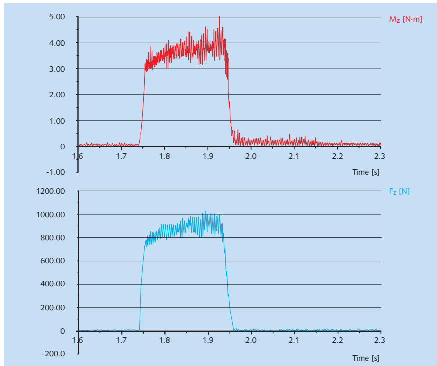
Deflective forces F_x, F_y perpendicular to the rotary axis provide additional information on the machining process.

Depending on requirements, two different types of measurement can be used for measuring the cutting force during drilling:

With **stationary dynamometers**, the workpiece is mounted on the top plate of the stationary dynamometer. It is essential for the machining to be kept in the center of the dynamometer at all times. A suitable work holding fixture must be used to ensure that the workpiece is appropriately repositioned for each new machining operation.

Rotating systems offer great advantages for cutting force measurement. The drilling moment and feed force can be measured precisely, regardless of the size of the workpiece and the drilling position.

Measuring torque during machining places great demands on the measuring instrument.



Data measured during drillling

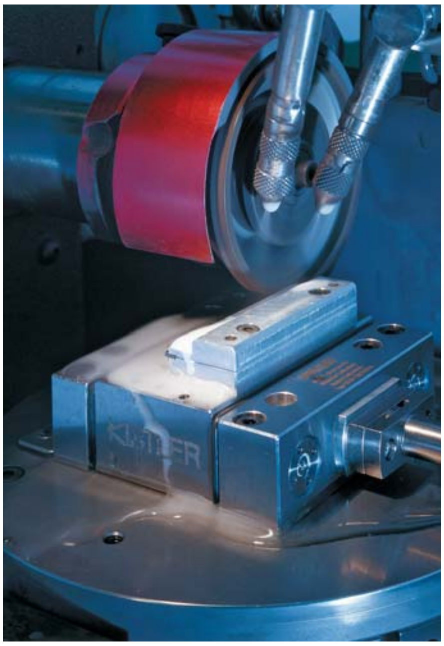
Material	Aluminum
Tool	Twist drill
	Diameter 8,5 mm
Dynamometer	Type 9125A...
v_c	1 400 m/min
f	0,4 mm/rev.
n	15 000 1/min

Cutting Force Measurement during Grinding

Creepfeed grinding with force plate Type 9253B23

Grinding is cutting with geometrically non-defined tool angles.

Stationary multi-component dynamometers are mainly used for measuring cutting forces during surface grinding. They are suitable both for measuring small forces during oscilating grinding and for large forces during full-width grinding.



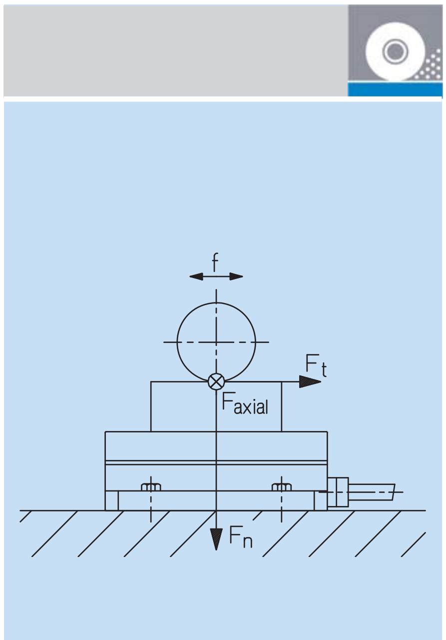
Lateral grinding of silicium workpieces with dynamometer Type 9256C1

The dynamometer is mounted on coordinate tables of face or profile grinding machines. The workpiece is mounted on the dynamometer top plate.

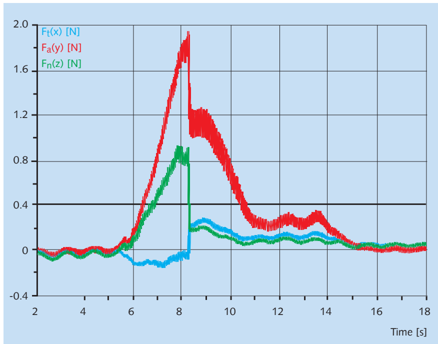
When the surface to be machined is parallel with the surface of the dynamometer top plate, the following force components of the grinding wheel can be measured:

Forces Measurable During Grinding

- Tangential force F_t
- Normal force F_n
- Axial force F_{axial}



Cutting force during face grinding



Data measured during grinding

Material	Silicium
Tool	Cup wheel
Dynamometer	Type 9256C1
v_c	2 340 m/min
v_f	60 mm/min
a_p	0,3 mm

Cutting Force Measurement for Special Applications

Evaluation of the new powerful machining processes requires appropriate sensors.

Precision machining requires force measuring instruments that will provide reliable and accurate measurement of forces in the Newton range. In practical terms, this means sensors with higher sensitivity. MiniDyn Type 9256C is designed with special sensors whose sensitivity is three times greater than that of quartz.

There are two requirements for analyzing the high-speed machining process:

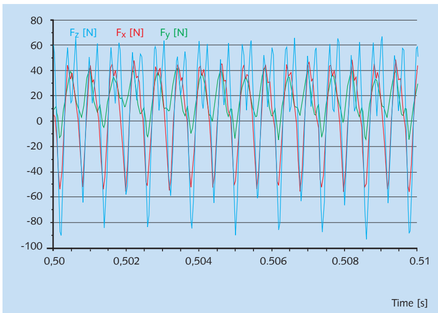
1. Rotating systems for high speeds. HS RCD Type 9125A... measures cutting forces reliably up to 25 000 1/min.

2. MiniDyn Type 9256C has an extra light titanium top plate and reaches natural frequencies of over 5 kHz in all three force components.

The unconventional design of dynamometer Type 9129AA and MiniDyn Type 9256C provide a low structural height (32 mm respective 25 mm) as well as a small temperature error in all three axes.

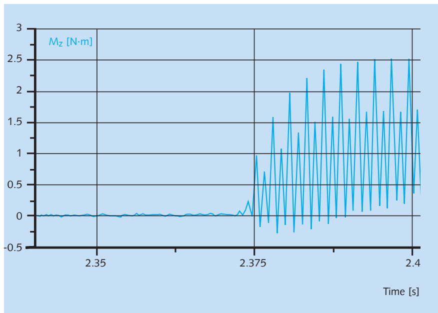
High-speed milling of aluminum with dynamometer Type 9256C2

Measurement of forces and torques when drilling the central bore in quartz washers with Type 9272



Data measured during high-speed milling with Type 9256C2

Material	Hardened steel HRC 56
Tool	Carbide spherical end-milling cutter, r = 1 mm, twin cutters
n	50 000 1/min
v_f	40 mm/s
a_p	0,3 mm
a_e	0,3 mm



Data measured during high-speed milling with Type 9125A...

Material	Aluminum
Tool	End mill ø10 mm
n	22 281 1/min
v_c	700 m/min
v_f	6 684 mm/min
a_p	4 mm
a_e	10 mm

Torque Measuring during Machining

3 Methods

Rotating dynamometer with torque sensor

Rotating torque sensor

Measuring torques on rotating tools provide useful data in cutting force measurement.

The ideal measuring instruments for this are the rotating measuring systems (Types 9123C..., 9124B..., 9125A...). The center of the rotating tool is located in the reference point of the moment measuring system.

The torque of the rotating tool will then always be correctly measured no matter what the machining position is.

The rotating measuring system is suitable for torque measurement during drilling and milling.

Stationary dynamometer with torque sensor

Stationary torque sensor

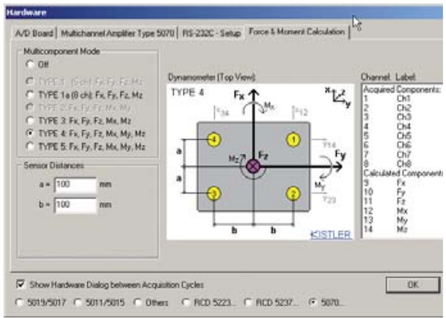
The stationary 4-component dynamometer Type 9272 is also suitable for measuring the torque during drilling.

In order to prevent measuring errors, the drilling position must always be in the center of the dynamometer, in other words the reference point of the torque measuring system.

Torque measurement is then not independent of the machining position as with a rotating dynamometer.

Torque measurement with the stationary system is only possible during drilling.

Stationary multi-component dynamometer with calculated torque



Calculated torque

Stationary dynamometer Types 9129AA, 9253B, 9255B, 9256C..., 9257B and 9265B provide special solutions for measuring the torque during drilling.

The drilling moment M_z is thereby calculated from the components of the reaction forces F_x and F_y. This requires at least five charge amplifiers and the DynoWare data acquisition software.

The drilling torque M_z is calculated with either an 8-channel charge amplifier with summing calculator or in DynoWare data acquisition software.

Torque measurement is only possible during drilling and is not suitable for demanding tool wear analyses. The coordinates of the drilling position must be entered in the software before data acquisition.

Dynamometer Selection Table

Kistler offers a comprehensive range of measuring equipment. Some dynamometers are universal and can be used for various tasks. Others were developed for a specific measuring task or a particular machining method.

The table below will help the user to choose the right device.

Dynamometers particularly designed for a specific machining method are indicated by a **blue field**. The dynamometer can also be used for applications indicated by a **gray field**. In these cases there may be limitations, for example regarding accuracy or dynamic behavior.

When measuring cutting forces, the principle of the 6-component force and moment measurement only applies to a few dynamometers. The machining method is restricted to drilling. By using the DynoWare evaluation software, the spindle moment M_z can be calculated for a drilling position to be defined. Dynamometers that can measure torques directly are preferable for determining wear values on drilling tools.

Dynamometer				**Process**								
				Turning outside	outside	inside	Milling		Drilling		Grinding	
				Cut heavy	light	light	Cut heavy	light	Cut heavy	light	Cut heavy	light
Type	Components	stationary	rotating									
9123C...	F_x, F_y, F_z, M_z		X					[blue]	[blue]	[gray]		
9124B...	F_x, F_y, F_z, M_z		X				[blue]	[gray]	[blue]	[gray]		
9125A...	F_z, M_z		X					[blue]		[blue]		
9129AA	F_x, F_y, F_z	X						[blue]		M_z		[blue]
9129A...	F_x, F_y, F_z	X		[blue]	[blue]	[blue]						
9253B...	F_x, F_y, F_z	X					[blue]	[gray]		M_z	[blue]	[gray]
9255B	F_x, F_y, F_z	X					[blue]	[gray]	M_z	M_z	[blue]	[gray]
9256C...	F_x, F_y, F_z	X			[blue]			[blue]		M_z		[blue]
9257B	F_x, F_y, F_z	X			[blue]			[blue]		M_z		[blue]
9257BA	F_x, F_y, F_z	X			[blue]			[blue]				[blue]
9265B	F_x, F_y, F_z	X		[blue]	[gray]		[blue]	[gray]		M_z	[blue]	[gray]
9272	F_x, F_y, F_z, M_z	X			[gray]			[gray]		[blue]		[gray]

[blue] Dynamometer suitable

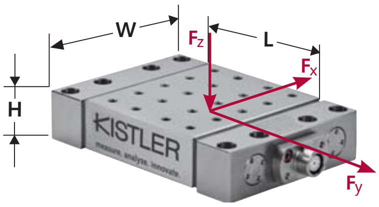
[gray] Measurement possible with restrictions

heavy/light Do not exceed maximum dynamometer load

M_z Spindle torque calculated

Stationary Dynamometer

Multi-Component Dynamometer with Top Plate 90x105 mm up to 10 kN



Type 9129AA

Specifications			Type 9129AA
Measuring range	F_x, F_y, F_z	kN	–10 ... 10
Calibrated measuring ranges	F_x, F_y, F_z	kN kN kN	0 ... 0,1 0 ... 1 0 ... 10
Sensitivity	F_x, F_z F_y	pC/N pC/N	≈–8 ≈–4,1
Natural frequency	$f_n x$ $f_n y$ $f_n z$	kHz kHz kHz	≈3,5 ≈4,5 ≈3,5
Operating temperature range		°C	0 ... 70
LxWxH		mm	90x105x32
Weight		kg	3,2
Degree of Protection IEC/EN 60529			IP67 with connected cable
Connection			Fischer Flange 9-pole neg.

This sensor is calibrated and ready for measurement.

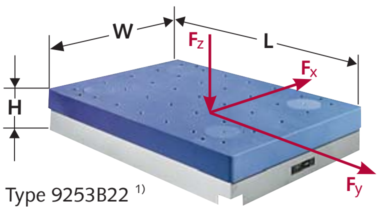
Characteristics
The low profile, large measuring range and small temperature error make this dynamometer the ideal instrument for measurements on precision machinery. Its design ensures high natural frequencies in all three force directions.

Applications
Measuring cutting forces involved in milling and grinding.

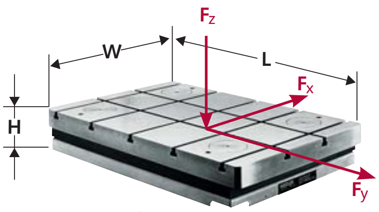
Accessories
- Connecting cable
  - Type 1687B5/1689B5 (3-Comp.)
  - Type 1677A5/1679A5 (6-Comp.)

Data sheet 9129AA_000-709

Multi-Component Force Plate with Top Plate 400x600 mm in Steel up to 30 kN



Type 9253B22 [1)]



Type 9253B23 [2)]

Specifications			Type 9253B22	Type 9253B23
Measuring range	F_x, F_y, F_z	kN kN	–15 ... 15 –15 ... 30	–12 ... 12 –12 ... 25
Calibrated measuring ranges	F_x, F_y F_z	kN kN kN kN	0 ... 15 0 ... 1,5 0 ... 30 0 ... 3	0 ... 12 0 ... 1,2 0 ... 25 0 ... 2,5
Sensitivity	F_x, F_y F_z	pC/N pC/N	≈±7,8 ≈±3,7	≈±7,8 ≈±3,7
Natural frequency	$f_n x$ $f_n y$ $f_n z$	Hz Hz Hz	≈580 ≈550 ≈720	≈610 ≈570 ≈570
Operating temperature range		°C	–20 ... 70	–20 ... 70
LxWxH		mm	600x400x100	600x400x100
Weight		kg	90	85
Degree of Protection IEC/EN 60529			IP67 with connected cable	
Connection			Fischer Flange 9-pole neg.	

This sensor is calibrated and ready for measurement.

Characteristics
With a top plate size of 400x600 mm, large workpieces can also be securely mounted. The measuring plate is mounted on the machine table through the center of the four feet.

Applications
Cutting force measurement during milling and grinding of large workpieces.

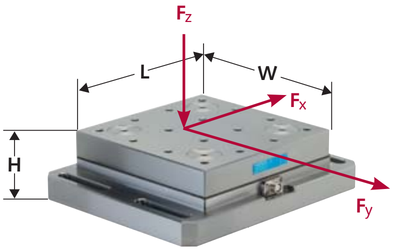
Accessories
- Connecting cable
  - Type 1687B5/1689B5 (3-comp.)
  - Type 1677A5/1679A5 (6-comp.)

Data sheet 9253B_000-146

1) Top plate with tapped hole M10x18
2) Top plate with T-grooves 10H12

Stationary Dynamometer

Multi-Component Dynamometer with Top Plate 260x260 mm up to 40 kN



Type 9255B

Specifications			Type 9255B
Measuring range	F_x, F_y F_z	kN kN	–20 ... 20 –10 ... 40
Calibrated measuring ranges	F_x, F_y F_z	kN kN kN kN	0 ... 20 0 ... 2 0 ... 40 0 ... 4
Sensitivity	F_x, F_y F_z	pC/N pC/N	≈–8 ≈–3,7
Natural frequency	f_nx f_ny f_nz	kHz kHz kHz	≈2 ≈2 ≈3,3
Operating temperature range		°C	0 ... 70
LxWxH		mm	260x260x95
Weight		kg	52
Degree of Protection IEC/EN 60529			IP67 with connected cable
Connection			Fischer Flange 9-pole neg.

This sensor is preloaded and calibrated.

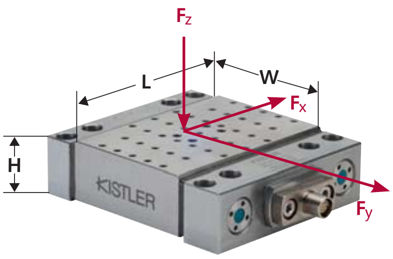
Characteristics
Rugged dynamometer ideal for heavy machining. For better coupling of the base plate to the machine table, the dynamometer can additionally be fixed through the center of the four sensors. This achieves a higher natural frequency of the measuring arrangement.

Applications
Cutting force measurement during milling and grinding.

Accessories
- Connecting cable
  - Type 1687B5/1689B5 (3-comp.)
  - Type 1677A5/1679A5 (6-comp.)

Data sheet 9255B_000-148

MiniDyn: Multi-Component Dynamometer up to 250 N



Type 9256C2

Specifications			Type 9256C1	Type 9256C2
Measuring range	F_x, F_y, F_z	N	–250 ... 250	–250 ... 250
Calibrated measuring ranges	F_x, F_y, F_z	N N	0 ... 250 0 ... 25	0 ... 250 0 ... 25
Sensitivity	F_x, F_z F_y	pC/N pC/N	≈–26 ≈–13	≈–26 ≈–13
Natural frequency	f_nx, f_ny, f_nz	kHz	≈5	≈4
Operating temperature range		°C	0 ... 70	0 ... 70
LxWxH		mm	80x39x25	80x55x25
Weight		g	750	870
Degree of Protection IEC/EN 60529			IP67 with connected cable	
Connection			Fischer Flange 7-pole neg.	

This sensor is preloaded and calibrated.

Characteristics
The dynamometer with the smallest mounting dimensions. The top plate is made of titanium. This achieves natural frequencies of over 5 kHz in all three force directions. The extremely high sensitivity (three times higher than that of quartz dynamometers) means that very small machining forces can be reliably measured.

Applications
Cutting force measurement in precision machining, wafer-cutting, grinding of hard disk read heads, diamond-turning, high-speed machining, ultra-precision machining of brittle-hard materials.

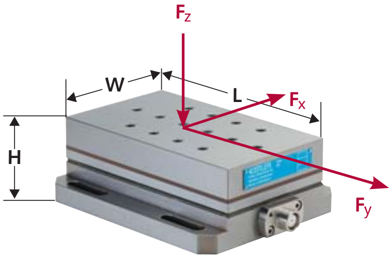
Accessories
- Connecting cable
  - Type 16897A5 (3-comp.)
  - Type 1696A5 (5-comp.)
- Tool holder Type 9402

Data sheet 9256C_000-484

Measuring

Stationary Dynamometer

Multi-Component Dynamometer with Top Plate 100x170 mm up to 10 kN



Type 9257B

Specifications			Type 9257B
Measuring range	F_x, F_y, F_z F_z	kN kN	–5 ... 5 –5 ... 10 (Range during turning, with force applied according specification. F_x and F_y ≤0,5 F_z)
Calibrated measuring range	F_x, F_y F_z	kN kN	0 .... 5; 0 ... 0,5; 0 ... 0,05 0 ... 10; 0 ... 1; 0 ... 0,1
Sensitivity	F_x, F_y F_z	pC/N pC/N	≈–7,5 ≈–3,7
Natural frequency	f_{nx}, f_{ny} f_{nz}	kHz kHz	≈2,3 ≈3,5
Operating temperature range		°C	0 ... 70
LxWxH		mm	170x100x60
Weight		kg	7,3
Degree of Protection IEC/EN 60529			IP67 with connected cable
Connection			Fischer Flange 9-pole neg.

This sensor is calibrated and ready for measurement.

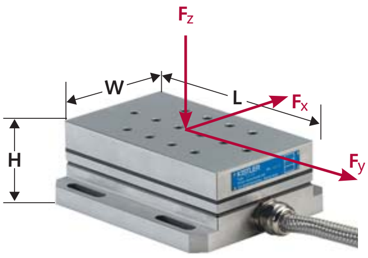
Characteristics
The universal dynamometer. Its handy size and ideal measuring range for many applications have made the Type 9257B one of the most popular multi-component dynamometers.

Application
Cutting force measurement during turning, milling or grinding.

Accessories
- Connecting cable
  - Type 1687B5/1689B5 (3-comp.)
  - Type 1677A5/1679A5 (6-comp.)
- Tool holder Type 9403

Data sheet 9257B_000-151

3-Component Dynamometer with Built-in Charge Amplifiers up to 10 kN



Type 9257BA

Specifications			Type 9257BA
Measuring range	F_x, F_y, F_z	kN	–5 ... 5
Range 1 Range 2 Range 3 Range 4	F_x, F_y F_z F_x, F_y F_z F_x, F_y F_z F_x, F_y F_z	kN kN kN kN kN kN kN kN	–0,5 ... 0,5 –1 ... 1 –1 ... 1 –2 ... 2 –2 ... 2 –5 ... 5 –5 ... 5 –5 ... 10 (Force applied according specifications; for F_x and F_y ≤0,5 F_z)
Sensitivity	F_x, F_y F_z	mV/N mV/N	≈10 ≈5
Natural frequency	f_{nx}, f_{ny} f_{nz}	kHz kHz	≈2,0 ≈3,5
Operating temperature range		°C	0 ... 60
LxWxH		mm	170x100x60
Weight		kg	7,4
Degree of Protection IEC/EN 60529			IP67
Connection			MIL connector 14-19

This sensor is calibrated and ready for measurement.

Characteristics
The successful model in a version with integral three-channel charge amplifier. The low-impedance connecting cable is permanently integrated in the dynamometer. The Control Unit Type 5233A1 makes this measuring instrument extremely easy to operate.

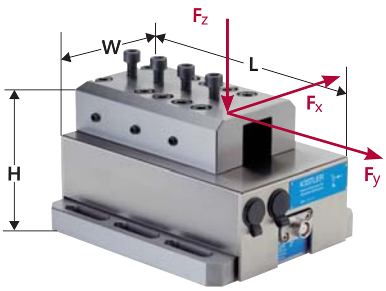
Application
Cutting forces during turning, milling, grinding.

Accessories
- Control unit Type 5233A1
- Tool holder Type 9403

Data sheet 9257BA_000-150

Stationary Dynamometer

Multi-Component Dynamometer with Tool Holder or Clamping Plate up to 30 kN



Type 9265B & 9441B

Specifications			Type 9265B with 9441B	Type 9265B with 9443B
Measuring range	F_x, F_y F_z	kN kN	–15 ... 15 0 ... 30	–15 ... 15 –10 ... 30
Calibrated measuring ranges	F_x, F_y F_z	kN kN kN kN	0 ... 15 0 ... 1,5 0 ... 30 0 ... 3	0 ... 15 0 ... 1,5 0 ... 30 0 ... 3
Sensitivity	F_x, F_y F_z	pC/N pC/N	≈–8 ≈–3,7	≈–8 ≈–3,7
Natural frequency	f_nx, f_ny f_nz	kHz kHz	≈1,5 ≈2,5	≈1,7 ≈2,7
Operating temperature range		°C	0 ... 70	0 ... 70
LxWxH		mm	175x100x126	203x135x100
Weight		kg	20	19,8
Degree of Protection IEC/EN 60529			IP67 with connected cable	
Connection			Fischer Flange 9-pole neg.	

This sensor is calibrated and ready for measurement.

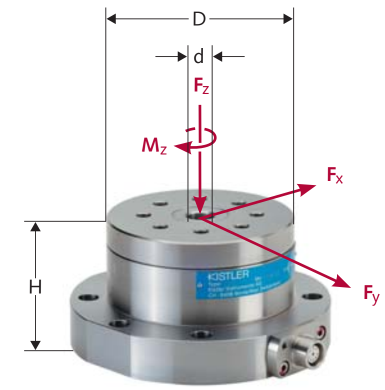
Characteristics
The cutting force dynamometer with integral cooling channels for temperature-stable measurement. The basic unit must only be used in conjunction with the steel holder Type 9441B (for turning) or with the clamping plate Type 9443B (for milling or grinding).

Application
Cutting forces during turning, milling or grinding.

Accessories
- Connecting cable
  - Type 1687B5/1689B5 (3-comp.)
  - Type 1677A5/1679A5 (6-comp.)
- Tool holder Type 9441B for cutting tools max. 32x32 mm
- Clamping plate Type 9443B

Data sheet 9265B_000-152

4-Component Dynamometer for Cutting Force Measurement in Drilling



Type 9272

Specifications			Type 9272
Measuring range	F_x, F_y F_z M_z	kN kN N·m	–5 ... 5 –5 ... 20 –200 ... 200
Calibrated measuring ranges	F_x, F_y F_z M_z	kN kN N·m	0 ... 5 0 ... 0,5 0 ... 20 0 ... 2 0 ... ±200 0 ... ±20
Sensitivity	F_x, F_y F_z M_z	pC/N pC/N pC/N·cm	≈–7,8 ≈–3,5 ≈–1,6
Natural frequency	f_nx, f_ny f_nz f_n (M_z)	kHz kHz kHz	≈3,1 ≈6,3 ≈4,2
Operating temperature range		°C	0 ... 70
DxdxH		mm	100x15x70
Weight		kg	4,2
Degree of Protection IEC/EN 60529			IP67 with connected cable
Connection			Fischer Flange 9-pole neg.

This sensor is calibrated and ready for measurement.

Characteristics
The stationary 4-component measuring instrument for cutting force measurements during drilling. The through-hole in the center of the dynamometer enables shafts to be inserted for torque measurements, for example.

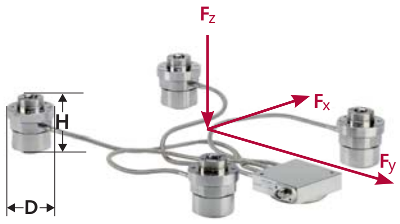
Applications
Cutting force measurement during drilling. For training purposes, this instrument can also be used in cutting force measurements during milling, grinding or turning.

Accessories
- Connecting cable
  - Type 1679A5 (4-comp.)
- Tool holder Type 9404

Data sheet 9272_000-153

Stationary Dynamometer

Multi-Component Sensor Kit for Force Measurement up to ø72 mm –25 ... 60 kN



Type 9366CC...

Specifications			Type 9366CC...
Measuring range	F_x, F_y F_z	kN kN	–25 ... 25 *) –25 ... 60 *)
Calibrated measuring ranges	F_x, F_y F_z	kN kN kN kN	0 ... 25 0 ... 2,5 0 ... 60 0 ... 6
Sensitivity	F_x, F_y F_z	pC/N pC/N	≈–7,8 ≈–3,8
Natural frequency	f_nx, f_ny, f_nz	Hz	≈200 ... 1 600 *)
Operating temperature range		°C	–20 ... 70
DxH		mm	72x90
Weight		kg	7
Degree of Protection IEC/EN 60529			IP67 with connected cable
Connection			Fischer Flange 9-pole neg.

This sensor is preloaded and calibrated.

Characteristics
This ready-to-connect and calibrated multi-component kit allows the user to assemble multi-component measuring plates. Top plate sizes from 300x300 mm to 900x900 mm are possible.

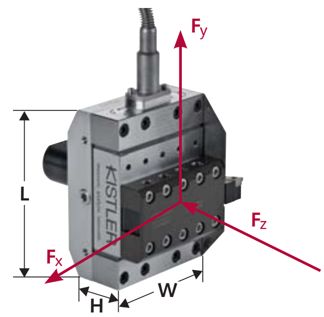
Application
Cutting force measurement during milling and grinding.

Accessories
- Connecting cable
  - Type 1687B5 (3-comp.)
  - Type 1677A5 (6-comp.)

Data sheet 9366CC_000-681

*) depending on material and size of the top plate

3-Component System for Measuring Cutting Forces up to 8 kN During Turning



Type 9129A...

Specifications			Type 9129A...
Measuring range, max. allowable	F_x, F_z F_y	kN kN	–5 ... 5 *) –8 ... 8 *)
Calibrated measuring ranges	F_x, F_z F_y	N N	0 ... 5; 0 ... 0,5 0 ... 8; 0 ... 0,8
Sensitivity	F_x, F_z F_y	pC/N pC/N	≈–8 ≈–4,1
Natural frequency	f_nx f_ny f_nz	kHz kHz kHz	≈1,5 **) ≈1,5 **) ≈2,5 **)
Operating temperature range		°C	0 ... 70
Clamping surface		mm	90x105
LxWxH		mm	150x107x63 *)
Weight		kg	7,6 *)
Degree of protection IEC/EN 60529			IP67 with connected cable
Connection			Fischer Flange 9-pole neg.

This sensor is calibrated and ready for measurement.

Characteristics
This is a modular measuring system based on the dynamometers Type 9129AA with a large measuring range. Its special mounting arrangement ensures a small temperature error. The lathe adapter is readily mounted on the dynamometer. The available toolholders for lathe tools and boring bars are equally easily mounted.

Applications
Measuring cutting forces during turning on turret lathes.

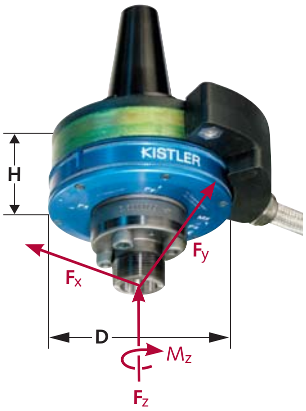
Accessories
- Lathe adapter with straight shank (VDI) Type 9129AB...
- Lathe adapter with Capto C6 Type 9129AC6
- Lathe adapter with clamping wedge Type 9129AD...
- Toolholder for lathe tool Type 9129AE...
- Toolholder for boring bar Type 9129AF40
- Connecting cable Type 1687B5/1689B5 (3-Comp.)

Data sheet 9129A_000-710

*) Depending on adapter
**) Applies to dynamometer Type 9129AA with lathe type 9129AB40 and toolholder Type 9129AE25, without tool

Rotating Dynamometer

Rotating 4-Component Dynamometer RCS for Cutting Force Measurement up to 10 000 1/min



Type 9123C...

Specifications			Type 9123C...
Measuring range FSO	F_x, F_y F_z M_z	kN kN N·m	–5 ... 5 * –20 ... 20 –200 ... 200
Speed		1/min	10 000 max.
Sensitivity	F_x, F_y F_z M_z	mV/N mV/N mV/N·m	≈2 ≈0,5 ≈50
Natural frequency	f_nx, f_ny, f_nz and f_n (M_z)	kHz	≈2
Operating temperature range		°C	0 ... 60
DxH		mm	115x52
Weight		kg	3
Degree of Protection IEC/EN 60529			IP67 with connected cable
Signal transmission			Non-contacting

This sensor is calibrated and ready for measurement.

Characteristics
Various standard adapters (ISO 40, ISO 50, HSK). This adapter is usually integrated with the dynamometer. A tool adapter for collet chucks is available for the tool holder. Internal cutting fluid feed is possible. Signal transmission is non-contacting and wear-free. Max. spindle speed of 10 000 1/min.

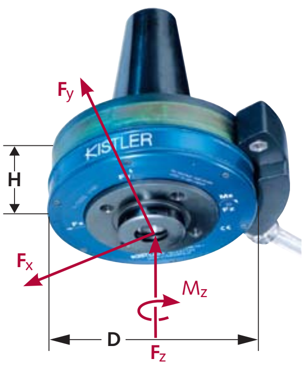
Applications
4-component force and moment measurement. Cutting force measurement at the rotating cutting edge during drilling and finish milling.

Accessories
- Stator Type 5221B1
- Cable Type 1500B19
- Signal conditioner Type 5223B...
- Tool adapter Type 9163

Data sheet 9123C_000-121

* Depending on force application point

Rotating 4-Component Dynamometer RCD for Cutting Force Measurement up to 5 000 1/min



Type 9124B...

Specifications			Type 9124B...
Measuring range FSO	F_x, F_y F_z M_z	kN kN N·m	–20 ... 20 * –30 ... 30 –1 100 ... 1100
Speed		1/min	5 000 max.
Sensitivity	F_x, F_y F_z M_z	mV/N mV/N mV/N·m	≈0,5 ≈0,33 ≈9
Natural frequency	f_nx, f_ny, f_nz und f_n (M_z)	kHz	≈1
Operating temperature range		°C	0 ... 60
DxH		mm	156x55
Weight		kg	7,5
Degree of Protection IEC/EN 60529			IP67 with connected cable
Signal transmission			Non-contacting

This sensor is calibrated and ready for measurement.

Characteristics
A dynamometer with similar characteristics to Type 9123C... The max. speed is approx. 5 000 1/min. For cutting force measurements during heavy machining.

Applications
4-component force and moment measurement. Cutting force measurement at the rotating cutting edge during drilling and milling.

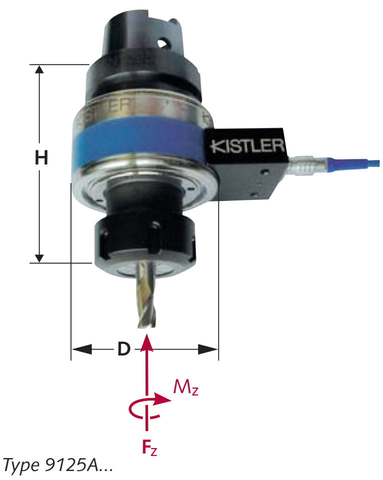
Accessories
- Stator Typ 5221B1
- Cable Type 1500B19
- Signal conditioner Type 5223B...
- Tool adapter Type 9165

Data sheet 9124B_000-122

* Depending on force application point

Rotating Dynamometer

Rotating 2-Component Dynamometer HS-RCD for Cutting Force Measurement up to 25 000 1/min



Type 9125A...

Specifications			Type 9125A...
Measuring range	F_z M_z	kN N·m	–3 ... 3 –50 ... 50
Speed		1/min	25 000 max.
Sensitivity	F_z M_z	mV/N mV/N·m	≈3 ≈185
Natural frequency	f_nz f_n (M_z)	kHz kHz	≈5 ≈2,5
Operating temperature range		°C	0 ... 60
DxH		mm	74x105
Weight		kg	1,5
Degree of Protection IEC/EN 60529			IP67
Signal transmission			Non-contacting

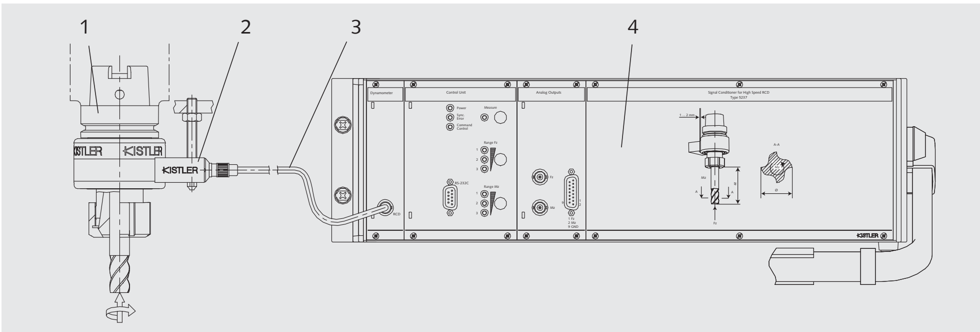
Characteristics
The 2-component dynamometer for high-speed machining.
A selection of adapters for all standard spindle capacities. Non-contact signal transmission. Internal cutting fluid feed is possible. Max. spindle speed of 25 000 1/min.

Applications
2-component force-moment measurement for high-speed machining, investigation of wear and cutting processes in milling and drilling.

Accessories
- The measuring system Type 9125A... comprises rotor, stator, connecting cable and signal conditioner
- Collet chuck Type 9169A...

Data sheet 9125A_000-123

This sensor is calibrated and ready for measurement.



1 Rotor Type 9125A...
2 Stator Type 5235
3 Cable Type 1500A37 L = 8 m
4 Signal conditioner Type 5237A1/A2

Signal conditioning becomes particularly important when measuring mechanical quantities such as force, strain and torque. Piezoelectric sensors output a charge linearly proportional to the load acting on the sensor. The charge amplifier converts this charge into normalized voltage and current signals, which can then be evaluated in the in-line signal processing system. To meet practical industrial requirements, Kistler offers a wide range of charge amplifiers with different designs, numbers of measuring channels, precision, measuring ranges, sensitivity, bandwidth, filter characteristics, scaling options and signal processing.

PCs are often used to acquire measurement data. This imposes special requirements on the functionality and user-friendliness of the software for visualizing and evaluating the force signals. Kistler DynoWare is an easily used general-purpose software package ideal for dynamometer force measurements with single- or multi-component force sensors. For signal analysis DynoWare offers the measurement technician online visualization of the measurement curves as well as useful calculation and graphics functions.

In addition to simple configuration of the most important measuring instruments, it supports individual documentation of measurement and saving of configuration and measured data.

The sensor technology is constantly driven by microelectronic developments and allows incorporation of the charge amplifier right into the case of the sensor. This eliminates the need for sensor cables and external signal conditioning.

Charge Amplifier

Multi-Channel Charge Amplifiers for Multi-component Force Measurement

Type 5080A...

Specifications		Type 5080A...
Number of channels		2 ... 8
Measuring range FS	pC	±2 ... 2 200 000
Measuring range adjustment		continuous
Frequency range (–3 dB)	kHz	0 ... 200
Output signal	V	±10
Supply voltage	VAC VDC	100 ... 240 11 ... 36
Input signal	Type/ connector	Piezoelectric, optional with • BNC neg. • Fischer 9-pole neg. Voltage, with • BNC neg.
Degree of protection to IEC/EN 60529		IP40
Interface		• RS-232C • USB 2.0
Case		optional with • 19" rack module (DIN 41494) • Desktop unit with support bracket
Other features		Display of mechanical measurands

Available from 12/2009

The parameters of this charge amplifier can be quickly and easily configured with the DynoWare software package for the PC.

Characteristics
The outstanding characteristics of this charge amplifier enable very accurate measurement of even small forces. Each of the several available variants of the individual charge amplifier module is pushed into the rack separately. This provides the user with an extremely flexible system upgradeable at any time to meet changing requirements.

Applications
This charge amplifier is employed for all aspects of cutting force measurement. It is suitable for use with piezoelectric multi-component dynamometers in the laboratory, research and development.

Accessories
- RS-232C null modem cable, l = 5 m, D-Sub 9-pol. pos./D-Sub 9-pol. neg. Type 1200A27
- Connecting cable for signal outputs from charge amp to data acquisition card, l = 2 m D-Sub 15-pol. pos. / D-Sub 37-pol. neg. Type 1500B15A1
- Inductive proximity switch Type 2233B

Data sheet 5080A_000-744

Charge Amplifier

Multi-Channel Charge Amplifier for Multi-component Force Measurement

Type 5070A...

Technical data		5070Ax0xxx	5070Ax1xxx	5070Ax2xxx
Number of channels		4	8	8 with 6-component summing calculator
General technical data				
Measuring ranges FS	pC	optional ±200 ... 200 000 ±600 ... 600 000		
Measuring range adjustment		continous		
Frequency range (–3 dB)	kHz	≈0 ... 45		
Output signal	V	±10		
Supply voltage	VAC	100 ... 240		
Input signal	Type/connector	piezoelectric, optional with • BNC neg. • Fischer 9-pole neg.		
Degree of Protection to IEC/EN 60529		IP40		
Interface		optional • RS-232C • RS-232C and IEEE-488		
Case		optional • 19" cassette for rack mounting • Desktop unit with support bracket • 19" cassette with panel mounting set		
Other features				
		• Display of peak values • Display of mechanical measurands		

The parameters of this charge amplifier can be quickly and easily configured with the DynoWare software package for the PC.

Characteristics
This amplifier is ideal for multicomponent force-torque measurement with piezoelectric dynamometers or force plates for cutting force measurement.

Application
The 4-channel amplifier is effective for measuring cutting forces with Kistler dynamometers. The 8-channel amplifier is suitable for 6-component force-torque measurement in laboratories, research and development.

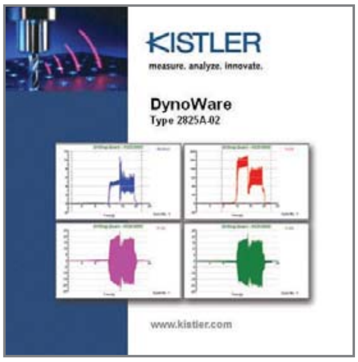
Accessories
- RS-232C null modem cable, l = 5 m, D-Sub 9-pole pos. / D-Sub 9-pole neg. Type 1200A27
- Connecting cable for signal outputs from charge amp to data acquisition card, l = 2 m, D-Sub 15-pole pos./D-Sub 37-pole neg. Type 1500B15
- Connecting cable for signal outputs from 6-component summing calculator to data acquisition card, l = 2 m, D-Sub 15-pole pos. / D-Sub 37-pole neg. Type 1500A7
- Inductive proximity swith Type 2233B

Data sheet 5070A_000-485

Analyzing

Software

DynoWare Type 2825A...



Type 2825A

Technical data	Windows® Software for Data Acquisition and Evaluation
Supported charge amplifier:	Type 5011/5015A.../5018A... Type 5017/5019 Type 5070A... Type 5080A...
Supported Signal Conditioners (for rotating dynamometers)	Type 5223B... Type 5237A...
More information	see data sheet

Characteristics
Simple operation, configuration and control of Kistler measuring instruments via RS-232C interface, high-performance graphics, useful signal evaluation and calculation functions, simultaneous recording of measuring channels. Is also ideal for acquisition and evaluation of any physical measurands.

Applications
Windows® software for data acquisition and evaluation. All-purpose, operator-friendly software, especially effective for force measurement with dynamometers and single- or multicomponent force sensors. For signal analysis DynoWare provides an online display of measurement curves as well as useful calculation and graphics functions. In addition to easy configuration of the most important measuring instruments, DynoWare supports individual documentation of the measurement process as well as storage of configuration and measurement data.

Options
None

Accessories
- Data acquisition card PCIM-DAS 1602/16 Type 2855A4
- Data acquisition card PC-Card-DAS 16/16 Typ 2855A5
- Data acquisition box Type 5697
- Connecting cable Type 1500B15
- Connecting cable Type 1500A67
- Connecting cable Type 1500B69
- USB-RS232C converter Type 2867

Data sheet 2825A_000-371

Connecting cable

Cables, High Insulation, Temperature Range –5 ... 70 °C

Type 1677A5

Specifications		Type 1677A5
Connection		Fischer 9-pole pos. Fischer 9-pole pos.
Length	m	5
Diameter	mm	12,3 (metal sheath)
Number of conductors		8
Used for		6-component measurement

Type 1679A5

Specifications		Type 1679A5
Connection		Fischer angle 9-pole pos. Fischer 9-pole pos.
Length	m	5
Diameter	mm	12,3 (metal sheath)
Number of conductors		8
Used for		6-component measurement

Type 1687B5

Specifications		Type 1687B5
Connection		Fischer 9-pole pos. Fischer 9-pole pos.
Length	m	5
Diameter	mm	12,3 (metal sheath)
Number of conductors		3
Used for		3-component measurement

Type 1689B5

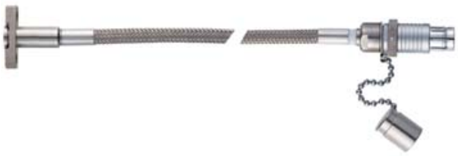
Specifications		Type 1689B5
Connection		Fischer angle 9-pole pos. Fischer 9-pole pos.
Length	m	5
Diameter	mm	12,3 (metal sheath)
Number of conductors		3
Used for		3-component measurement

Data sheet 1687B_000-545

Connecting

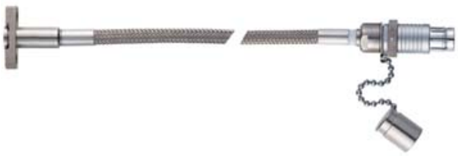
Connecting cable

Cables, High Insulation, Temperature Range –5 ... 70 °C



Type 1696A5

Specifications		Type 1696A5
Connection		Fischer 7-pole pos. Fischer 9-pole pos.
Length	m	5
Diameter	mm	8 (insulating plastic tube)
Number of conductors		6
Used for		5-component measurement for dynamometer Type 9256C



Type 1697A5

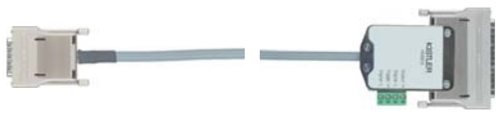
Specifications		Type 1697A5
Connection		Fischer 7-pole pos. Fischer 9-pole pos.
Length	m	5
Diameter	mm	8 (insulating plastic tube)
Number of conductors		3
Used for		3-component measurement for dynamometer Type 9256C

Data sheet 1687B_000-545

Connecting

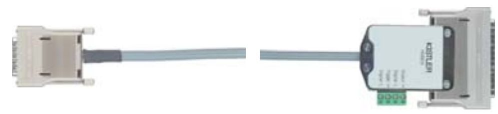
Cable

Cables, Low-resistance



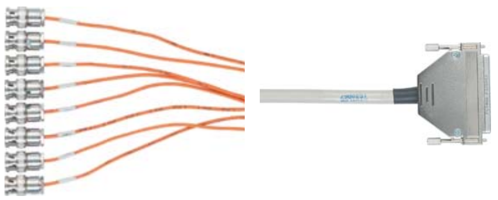
Type 1500A7

Specifications		Type 1500A7
Connection		D-Sub 15-pole pos. D-Sub 37-pole pos.
Length	m	2
Diameter	mm	7
Number of conductors		9
Used for		Connection of summing amplifiers Type 5070Ax2xxx to Type 2855A4



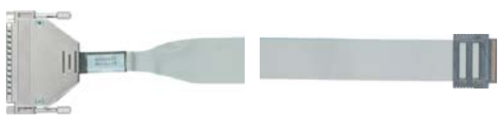
Type 1500B15

Specifications		Type 1500B15
Connection		D-Sub 15-pole pos. D-Sub 37-pole pos.
Length	m	2
Diameter	mm	7
Number of conductors		9
Used for		Connection of Types 5070A, 5223B..., 5237A... to Type 2855A4



Type 1500A67

Specifications		Type 1500A67
Connection		8 x BNC pos. D-Sub 37-pole neg.
Length	m	2
Diameter	mm	9,5
Number of conductors		8
Used for		Connection of BNC neg. outputs to Type 2855A4



Type 1500B69

Specifications		Type 1500B69
Connection		D-Sub 37-pole pos. 50-pole pos.
Length	m	1
Diameter	mm	Flat cable
Number of conductors		50
Used for		Connection of Types 1500A7, 1500B15 to Type 2855A5 (PC card)

Data sheet 2825A_000-371

Accessories

Electronic Accessories

Distributing Box, Fischer 9-pole neg. – 8 x BNC neg.

Type 5405A

Specifications		Type 5405A
Input signal		Fischer 9-pole neg.
Output signal		8 x BNC neg.
Dimensions LxWxH	mm	73x99x33

Distributing Box, Fischer 9-pole neg. – 3 x BNC neg.

Type 5407A

Specifications		Type 5407A
Input signal		Fischer 9-pole neg.
Output signal		3 x BNC neg.
Dimensions LxWxH	mm	73x99x33

Electronics

Data Acquisition Card

Type 2855A4

Specifications		Type 2855A4, PCIM-DAS 1602/16
Number of measuring channels		8 differential
PC bus		PCI
Resolution	Bit	16
Sampling rate, max.	kS/s	100
Connection		D-Sub 37-pole pos.

Data sheet 2825A_000-371

Data Acquisition Card

Type 2855A5

Specifications		Type 2855A5, PC-CARD-DAS 16/16
Number of measuring channels		8 differential
PC bus		PCMCIA, PC-CARD
Resolution	Bit	16
Sampling rate, max.	kS/s	100
Connection		50-pole neg.

Data sheet 2825A_000-371

Data Acquisition Box

Type 5697

Available from 02/2010

Specifications		Type 5697
Number of measuring channels		32
Resolution	Bit	16
Sampling rate, max.		(continuously adjustable in DynoWare)
with 1 channel	kS/s	1 000
with 8 channels	kS/s	125
with 16 channels	kS/s	62,5
Interface to PC		USB 2.0 Type B, female
Dimensions	mm	208x70x250
Weight	kg	2,5

Data sheet 5697_000-745

Technical Literature

Special Prints and Application Brochures

Cutting Force Measurement	
Measuring the Cutting Force in Five-Axis Milling	20.162
Cutting Force Measurements on Rotating Tools	20.163
Measurement of Cutting Forces in High-Precision Machining	20.176
New Cutting Force Dynamometers for High-Precision Machining	20.185
Kraftmessung bei der Hoch- und Ultrapräzisions-Bearbeitung	20.202
Zerspankräfte unter Kontrolle	20.206
New Rotating Dynamometer for the Analysis of high speed metal-cutting Processes	920-229
Advanced Machining Process Analysis – Experience with the new Rotating High Speed Dynamometer	920-335
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Product Overview According to Type Numbers

Kistler worldwide

Europe

Austria
Kistler GmbH
Lemböckgasse 49f
1230 Wien
Tel. +43 1 867 48 67 0
sales.at@kistler.com

Czech Republic/Slovakia
Kistler, s.r.o.
Zelený pruh 99/1560
140 00 Praha 4
Tel. +420 296 374 878
sales.cz@kistler.com

Denmark/Norway/Sweden
Kistler Nordic AB
Aminogatan 34
431 53 Mölndal
Tel. +46 31 871 566
info.se@kistler.com

Finland
Kistler Nordic AB
Särkiniementie 3
00210 Helsinki
Tel. +358 9 612 15 66
info.fi@kistler.com

France
Kistler France
ZA de Courtabœuf 1
15, avenue du Hoggar
91953 Les Ulis cedex
Tel. +33 1 69 18 81 81
info.fr@kistler.com

Germany
Kistler Instrumente GmbH
Daimlerstrasse 6
73760 Ostfildern
Tel. +49 711 34 07 0
info.de@kistler.com

Italy
Kistler Italia s.r.l.
Via Ruggero di Lauria, 12/B
20149 Milano
Tel. +39 02 481 27 51
sales.it@kistler.com

Netherlands
Kistler B.V. Nederland
Leeghwaterstraat 25
2811 DT Reeuwijk
Tel. +31 182 304 444
sales.nl@kistler.com

Spain
Kistler Ibérica S.L, Unipersonal
C/Pallars, 6 Planta 2
08402 Granollers
Barcelona
Tel. +34 93 860 33 24
info.es@kistler.com

Switzerland/Liechtenstein
Kistler Instrumente AG
Verkauf Schweiz
Eulachstrasse 22
8408 Winterthur
Tel. +41 52 224 12 32
sales.ch@kistler.com

United Kingdom
Kistler Instruments Ltd.
13 Murrell Green Business Park
London Road
Hook, Hampshire RG27 9GR
Tel. +44 1256 74 15 50
sales.uk@kistler.com

Asia

China, People's Republic of
Kistler China Ltd.
Unit D, 24/F Seabright Plaza
9-23 Shell Street North Point
Hong Kong
Tel. +852 25 915 930
sales.cn@kistler.com

India
Kistler Instruments (Pte) Ltd.
India Liaison Office
2B Century Plaza
560/562 Anna Salai
Teynampet, Chennai 600 018
Tel. +91 44 4213 2089
sales.in@kistler.com

Japan
Kistler Japan Co., Ltd.
23rd floor, New Pier Takeshiba North Tower
1-11-1, Kaigan, Minato-ku
Tokyo 105-0022
Tel. +81 3 3578 0271
sales.jp@kistler.com

Korea, Republic of
Kistler Korea Co., Ltd.
Gyeonggi Venture Anyang
Technical College Center 801
572-5, Anyang-Dong, Manan-Gu,
Anyang-City, Gyeonggi-Do 430-731
Tel. +82 31 465 6013
sales.kr@kistler.com

Singapore
Kistler Instruments (Pte) Ltd.
50 Bukit Batok Street 23
#04-06 Midview Building
Singapore 659578
Tel. +65 6316 7331
sales.sg@kistler.com

Taiwan
Kistler Representative Office in Taiwan
Room 9, 8F, No. 6, Lane 180
Sec. 6, Mincyuan E. Road
Taipei 114
Tel. +886 2 7721 2121
sales.tw@kistler.com

Thailand
Kistler Instrument (Thailand) Co., Ltd.
26/56 TPI Tower, 20th Floor
Nanglingee Rd., (Chan Tat Mai Rd.)
Thungmahamek, Sathorn
Bangkok 10120
Tel. +66 2678 6779-80
sales.thai@kistler.com

America

USA/Canada/Mexico
Kistler Instrument Corp.
75 John Glenn Drive
Amherst, NY 14228-2171
Tel. +1 716 691 5100
sales.us@kistler.com

Australia

Australia
Kistler Instruments Australia Pty Ltd
G21 / 202 Jells Rd.
Wheelers Hill, Victoria 3150
Tel. +61 3 9560 5055
sales.au@kistler.com

Other countries

Kistler Instrumente AG
Export Sales
Eulachstrasse 22, 8408 Winterthur
Switzerland
Tel. +41 52 224 11 11
sales.export@kistler.com

Headquarters

Switzerland
Kistler Group
Eulachstrasse 22, 8408 Winterthur
Tel. +41 52 224 11 11
Fax +41 52 224 14 14
info@kistler.com

www.kistler.com

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