



Instruction manual

**Quartz
4-component
dynamometer
Type 9272**

Foreword

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1. Introduction

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

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

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

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

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

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

2. Important information

Please keep to the following rules without fail. This will ensure your personal safety when working, and assure long, trouble-free performance by the instrument.

2.1 For your safety

- This instrument has been tested thoroughly, and it left the works in a perfectly safe condition. To maintain this condition and ensure safe operation, the user must observe the directives and warnings contained in these instructions
- The dynamometer must be installed, operated and maintained only by persons who are familiar with it and adequately qualified for their particular tasks
- When it must be assumed that safe operation is no longer possible, the instrument must be taken out of operation and secured against unintentional use

It must be assumed that safe operation is no longer possible if:

- The instrument is visibly damaged,
- It no longer functions,
- It has been in lengthy storage under adverse conditions,
- It has received rough treatment during transport



For measuring cutting forces, fix the dynamometer on the machine tool according to the instructions. See section 4.2: Assembling the Dynamometer, for details.



Fix all parts mounted on the top plate of the dynamometer according to the forces expected!

2.2 How to treat the instrument

- The dynamometer may be used only under the specified environmental and operating conditions
- The insulation resistance is crucially important with piezoelectric measurements. It must be around $10^{14} \Omega$ (but at least $10^{13} \Omega$)
- To obtain this resistance, all plug and socket connections must be kept meticulously clean and dry
- The insulation resistance can be measured with the insulation tester Type 5493
- Protect the signal output against dirt and do not touch it with your fingers. When the connection is not being used, cover it with the cap provided
- The connecting cable from dynamometer to charge amplifier is highly insulating. Use only the proper cable
- Do not remove the connecting cable from the dynamometer
- When the dynamometer is not in use, protect it by keeping it in the packing case supplied
- When performing long-time measurements, make sure that the temperature of the dynamometer remains as constant as possible

2.3 Tips for using the operating instructions

We recommend reading the entire Operating Instructions as a matter of principle. If you're in a hurry, however, and you've already gathered experience with Kistler dynamometers, you can confine your reading to the information that you really need.

We have endeavored to arrange these instructions so that you can find the information you need without difficulty.

Please keep these Operating Instructions in a safe place where they can be consulted any time.

If the instructions get lost, just turn to your Kistler customer service station and they will be replaced without delay.

All information and directives in these instructions may be modified at any time without prior notification.

2.4 What happens after modifications?

Modifications to instruments result in alterations of the operating instructions as a rule. In such cases, enquire at your Kistler customer service station about the possibilities of updating your documentation.

Please note that all technical data and all other information in this section may be altered at any time without prior notice.

3. General description of the instrument

3.1 What does a multicomponent dynamometer do?

The multicomponent dynamometer provides dynamic and quasistatic measurement of the 3 orthogonal components of a force (F_x , F_y , F_z) acting from any direction onto the top plate as well as the moments M_z .

The dynamometer has high rigidity and hence high natural frequency. The high resolution enables very small dynamic changes to be measured in large forces.

The dynamometer measures the active cutting force regardless of its application point. Both the average value of the force and the dynamic force increase may be measured. The usable frequency range depends mainly on the resonance frequency of the entire measuring rig.



Fig. 1: 4-Component Dynamometer Type 9272

Most important applications for the multicomponent dynamometer are:

- Measuring feed force, side force and moment in drilling, tapping etc.
- Measuring cutting forces in milling and grinding and turning high sensitivity and calibrated part ranges allow exact measurements even on small tools and when grinding;
- Measurements on wind tunnel models
- Ergonomic measurements
- Testing of torque wrenches
- Testing of springs (torsion)
- Measurements on small thrust bearings, slip clutches etc.
- Measurements of starting torques of small motors and step motors
- Measurements in ergonomics

3.2 Functional principle

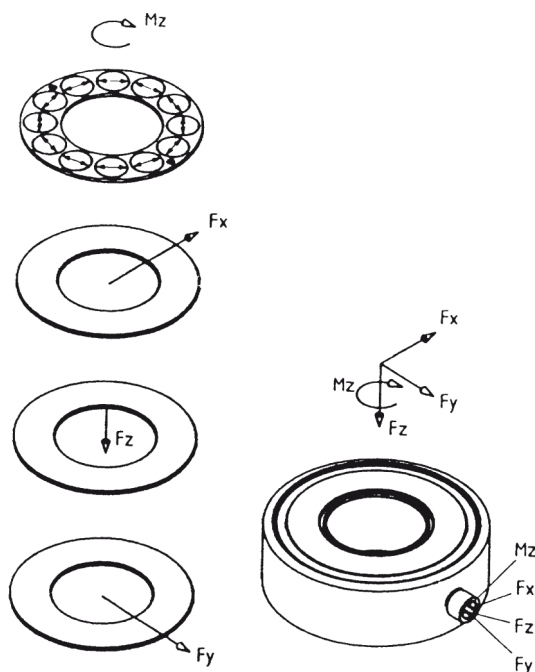


Fig. 2: Construction of a 4-component sensor

The force and the moment M_z acting on the dynamometer are transmitted through the top plate to a 4-component load washer.

This 4-component sensor contains 3 pairs of quartz rings, where by one is sensitive to compression and the other two are sensitive to shear either in x- resp. in y-direction. An additional set of shear sensitive quartz plates is arranged on such a way to yield an electrical charge proportioned to the Moment M_z acting about the axis of the sensor. The acting force is directly resolved into its three components. The charges yielded by the quartz plates are collected with electrodes connected to the connector of the sensor.

Depending on the direction of the force and moments, positive or negative charges occur at the connections. Negative charges give positive voltages at the output of the charge amplifier, and vice versa.

3.3 Design of the dynamometer

The dynamometer consists of a 4-component load washer sandwiched under high preload between a baseplate and a top plate.

This preload is needed to transmit the friction forces.

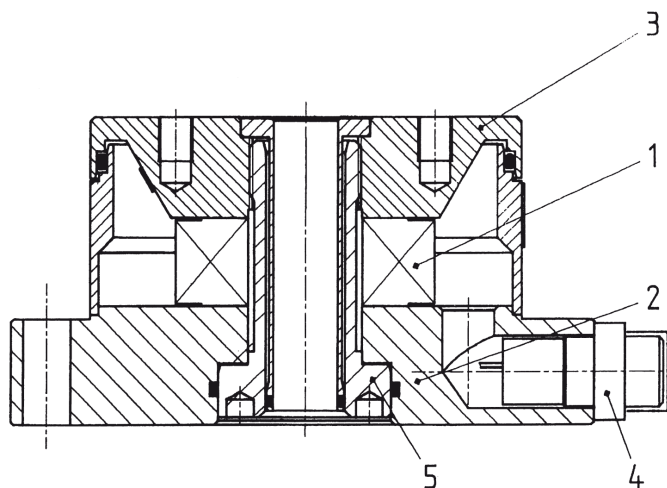


Fig. 3: Construction of the dynamometer Type 9272

- 1 4-Component Sensor
- 2 Baseplate
- 3 Top plate
- 4 Connecting plug
- 5 Preloaded screw

The sensor is mounted ground-insulated. Ground loop problems are largely eliminated in consequence.

The dynamometer is rustproof and protected against ingress of splash water and coolant. Together with the connecting cable Type 1677BA5/1679BA5 the dynamometer meets the requirements of protection class IP67.

4. Assembly, installation and putting into operation

4.1 Important remarks

The multicomponent dynamometer Type 9272 is a precision instrument, but its inherent accuracy can be exploited and retained only if it is treated with care. The following rules should therefore be noted:

- Never drop the dynamometer or expose it to heavy impacts! The maximum force of a shock of this kind could exceed the measuring range of the instrument and cause permanent deformations
- Never use a hammer to position the workpieces, as such blows might also cause deformation

On the following pages you will find directions for installing the dynamometer and basic data for designing the measuring facility.

4.2 Assembling the dynamometer

The following directions must be observed if the dynamometer is to be mounted properly:

- The dynamometer must be installed only by persons who are familiar with it and sufficiently qualified for this work
- First the connecting cable has to be mounted. Both connector sides (dynamometer and cable) have to be cleaned with Kistler cleansing and insulating spray Type 1003. To seal the connector the O-Ring is used (scope of delivery). The mounting surface for the O-Ring must be clean. The O-Ring is placed properly and the flange of the cable is mounted onto the dynamometer by means of two screws and tightened
- Before mounting the dynamometer on a machine tool or testing device, make sure that the mounting surface is flat. Uneven supporting surfaces will cause internal stresses, which may expose the force sensors to severe additional stressing and cause increased crosstalk
- The bottom surface of the dynamometer is ground, i.e. fine-machined. The instrument should therefore be mounted on ground or equivalently machined supporting surfaces. Use of symmetrically disposed claws is recommended. Alternatively the dynamometer may be fixed directly with bolts

The tightening torque of the M10 bolts is 75 N·m

Clean the contact surfaces thoroughly before mounting

- To align the dynamometer on the machine table one of the use the three reference flats on the base plate
- Make sure that the dynamometer rests absolutely flat. Even the smallest air gap will cause undesirable elasticity and reduce the resonant frequency of the measuring rig. All mountings must therefore be considered from the vibration aspect also
- Whenever possible, the connecting cable should be left connected permanently to the dynamometer
- Lay the connecting cable so that it cannot get cut off or torn out when working
- The top plate has 8 tapped mounting holes M8 for fixing the work. Tightening torque of the M8 bolts is 30 N·m

4.3 Basic circuitry and cabling of the measuring system

The electrical charges (in pC) delivered from the measuring platform are converted by charge amplifiers into proportional voltages, which may be displayed, recorded or further processed with usual instruments. The following rules should be observed when cabling the measuring rig:

- The connecting cable from dynamometer to charge amplifier must have high insulation and low frictional electricity. Use only the specified cables therefore
- Ordinary cables may be used to link the charge amplifiers with the display or evaluation instruments
- Make sure that all work with electrical connections is done carefully and cleanly. Remove the protective caps from the connections only immediately before connecting a cable
- Cabling instructions for specific configurations are given in the two sections following

4.4 Cutting force measurement in drilling



Fig. 4: Cutting force measurement in drilling

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

Drilling moment	M_z
Feed force	F_f

Are of particular interest for analyzing the drilling process.

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

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.

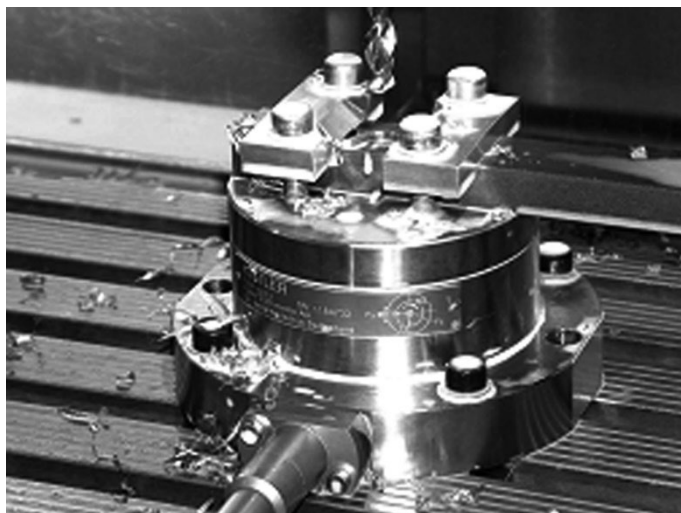


Fig. 5: Fixing Workpiece

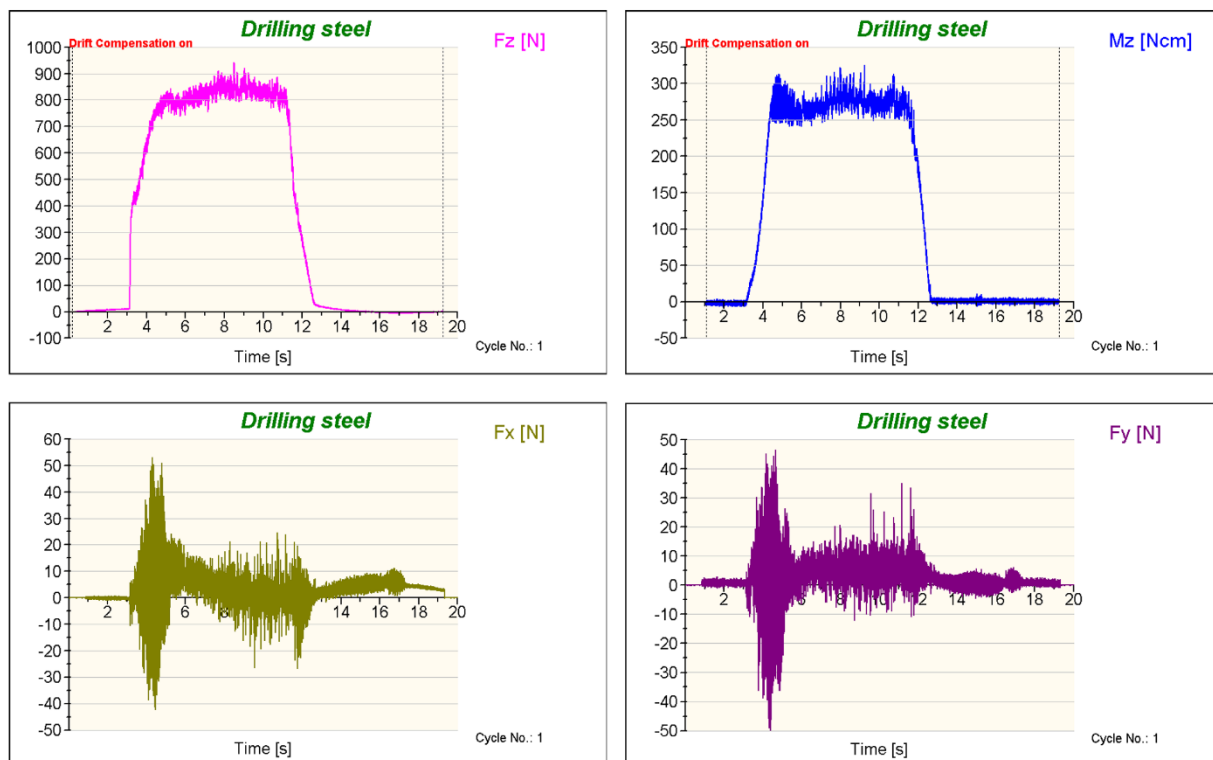


Fig. 6: Measuring results in drilling of steel

Parameter

Material:	USt 37-2
Diameter of drill	10 mm
a_p	10 mm
n	1 250 1/min
v_c	35 m/min
f	0,1 mm/U

4.4.1 Force and moment measuring with 4 components (F_x , F_y , F_z , M_z)

The following diagram shows the elements required for connecting the dynamometer to a multichannel charge amplifier (e.g. Type 5080Axx4x002) for 4-component measurement. This measuring chain is ground-isolated and uses an 8-core cable.

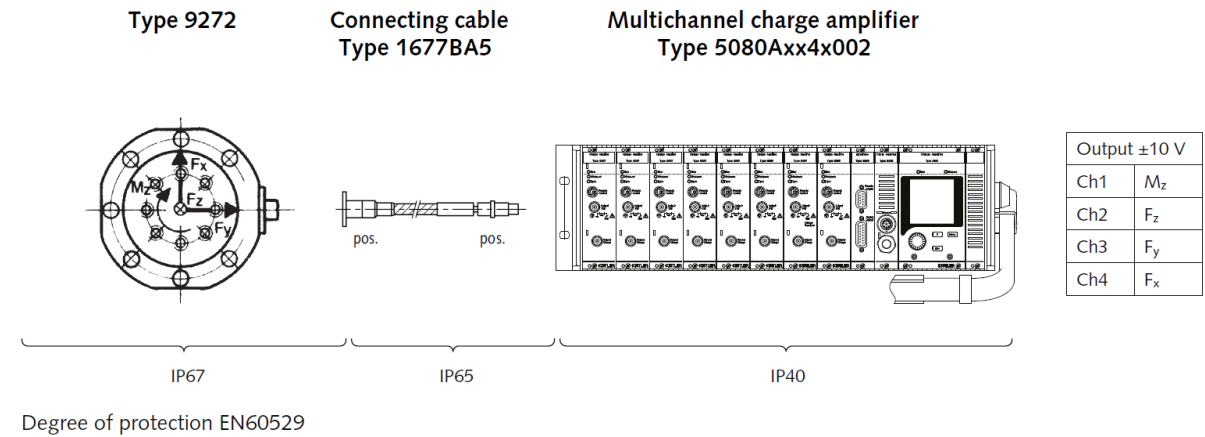


Fig. 7: Measuring system for 4-component measurement F_x , F_y , F_z , M_z

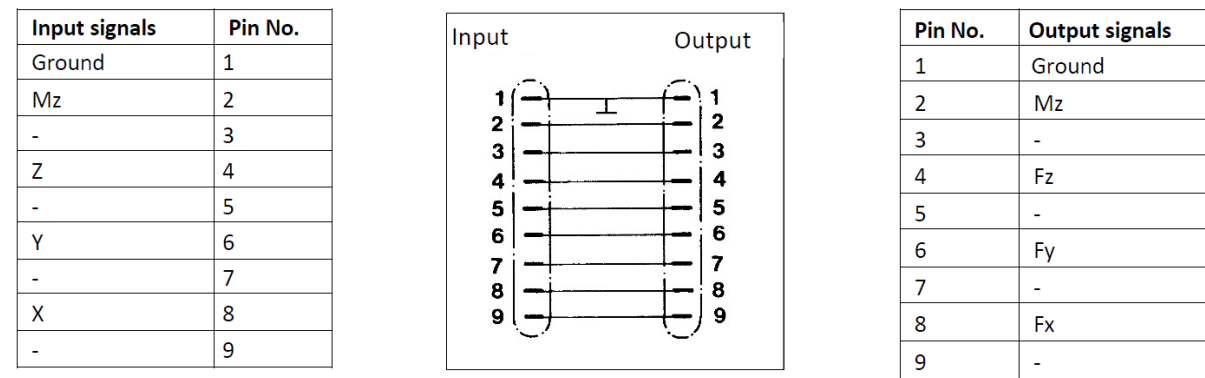


Fig. 8: Cable diagram connecting cable Type 1677BA5

4.4.2 Signal conditioning

In addition to the dynamometer, a four-component measuring system needs a multi-core high-insulation connecting cable and four charge amplifier channels. These convert the charge signals from the dynamometer into output voltages. The output voltage is proportional to the forces and moments occurring. The multichannel charge amplifier Type 5070A... is ideal for this purpose. For details, see the data sheet 5070A_000-485.

4.4.3 Data acquisition and evaluation

Kistler DynoWare is an easy-to-use universal software and is ideal for multi-component force measurement with dynamometers.

For details, see the data sheet 2825A_000-371.

4.5 Force application

4.5.1 Correlations for simultaneous loading in two or more components

The best results are obtained by nature of the system when set up out loading are symmetrical. The dynamometer is designed however to show minimal variations in sensitivity under eccentric loading.

When measuring Tensile forces take care that they are properly transmitted.

The nominal measuring ranges of the different components are maximum ranges (see 8.1), valid when forces and the moment are applied only one at a time, and centrally. However, are the forces F_x , F_y and F_z eccentric and acting together with a moment M_z , a combined loading results and the usable measuring range will be reduced.

E.g. for measuring moments the full range is only available if there are no shear forces F_x and F_y acting.

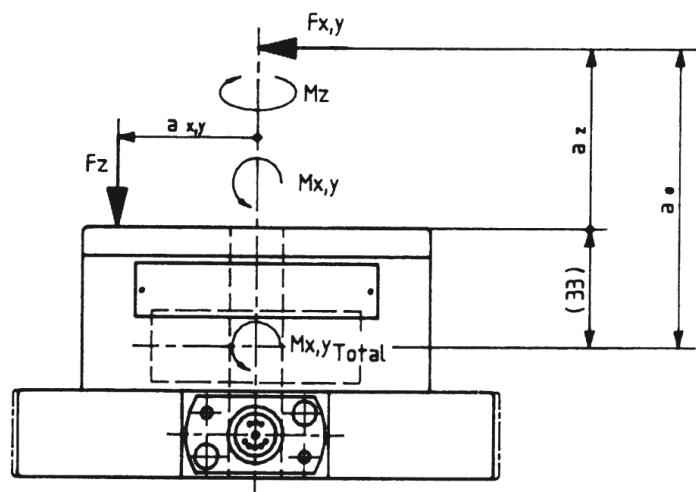


Fig. 9: Eccentric loading with simultaneously acting moments M_z and $M_{x,y}$

4.5.2 Correlation $F_{x,y} - M_z$

If $F_{x,y}$ and M_z act simultaneously verify with the diagram that the loading falls inside the hatched area.

If $F_{x,y}$ is acting eccentrically with respect to the z-axis, the resulting additional moment M_z must be considered for M_z (admissible).

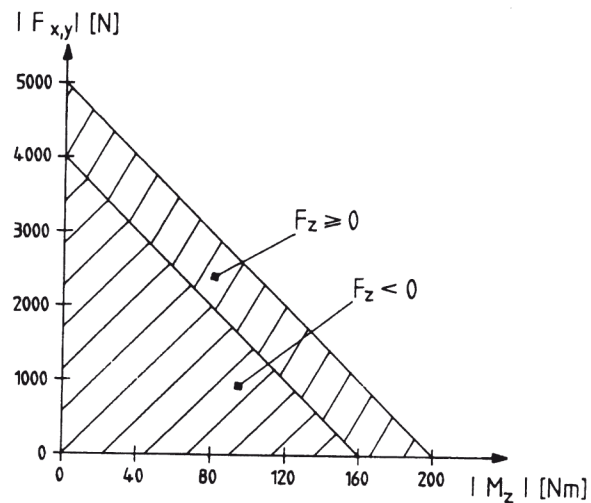


Fig. 10: Correlation $F_{x,y}, M_z$

4.5.3 Correlation $M_z - M_{x,y}$

If M_z and $M_{x,y}$ act simultaneously, verify with the diagram that the loading falls within the hatched area.

Caution: For $M_{x,y}$ the amounts resulting from eccentric F_z and/or $F_{x,y}$ must be added up.

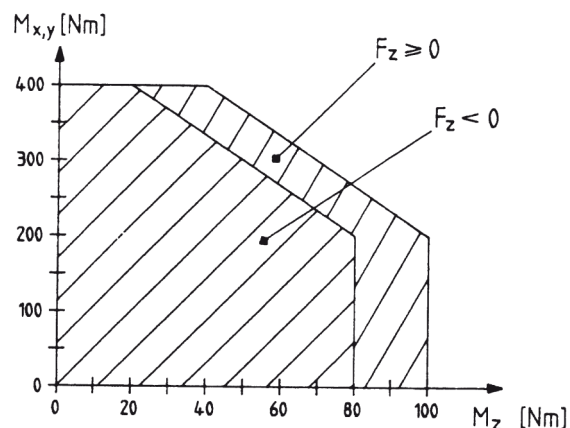


Fig. 11: Correlation $M_z - M_{x,y}$

4.5.4 Correlation $F_{x,y} - F_z$

If $F_{x,y}$ and F_z act simultaneously and eccentrically, use the nomogram whether the loading remains within the admissible moment $M_{x,y}$.

The vertical eccentricity of $F_{x,y}$ relates to the center of the sensor, which is 33 mm below the surface of the top plate.

Korrelation $F_{x,y} - F_z$

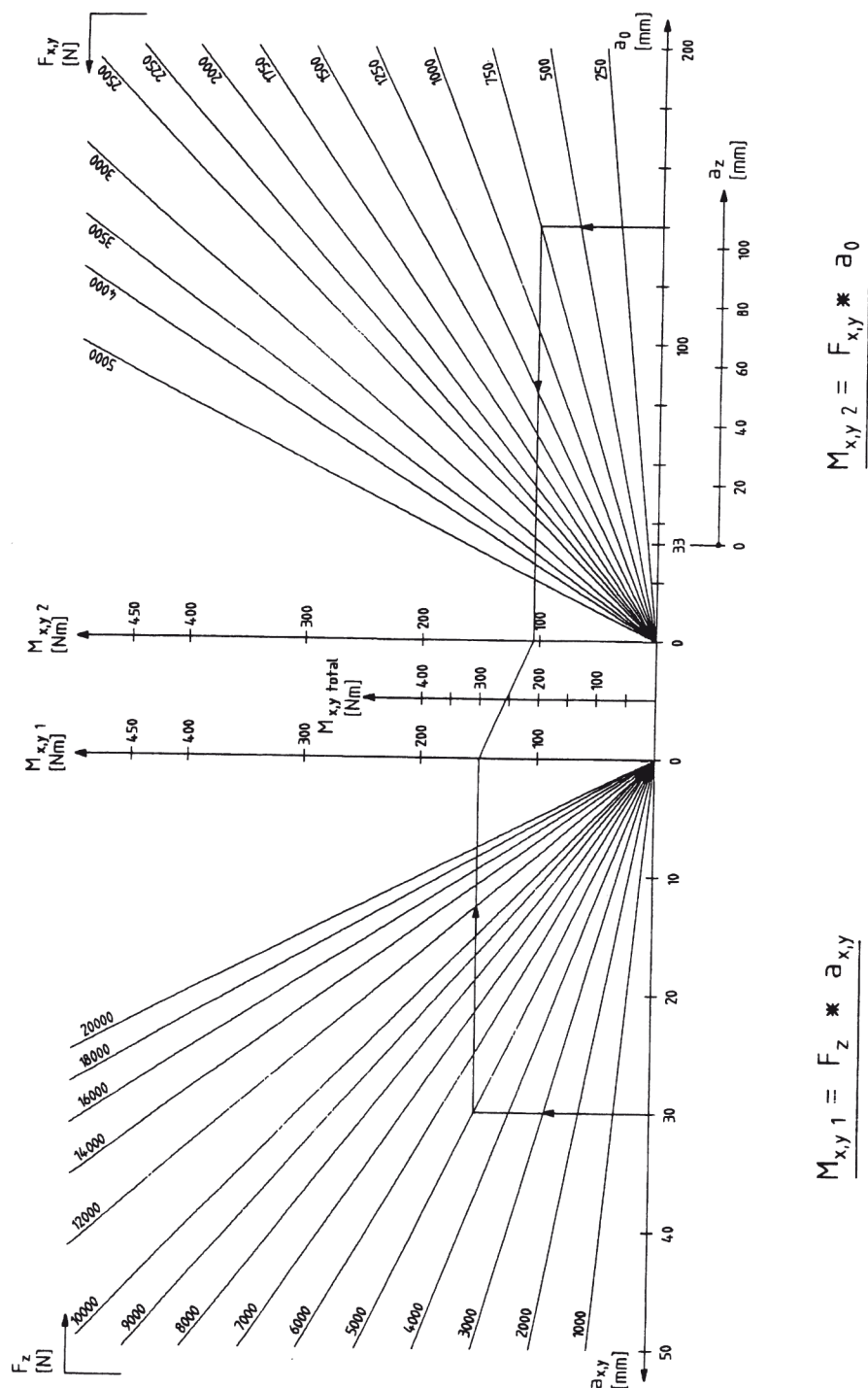


Fig. 12: Correlation $F_{x,y} - F_z$

5. Operation

5.1 Range selection

Use of charge amplifiers with sensitivity adjustment (such as Type 5070A...) is recommended for the multicomponent dynamometer Type 9272A.

Adjust the sensitivities according to the data in the calibration sheets for the channels F_x , F_y , F_z and M_z . The output voltage is then set directly to the value corresponding to the selected scale (... N/V, ... N·m/V). To adjust the sensitivity, consult the operating instructions for the charge amplifier.

5.2 Measuring small force changes

The piezoelectric measuring technique allows very accurate measurement of small force changes in the presence of high preload. If for example ΔF_z fluctuations around 10 N are superimposed upon a main cutting force F_z of some 20 kN, the following rules can be applied:

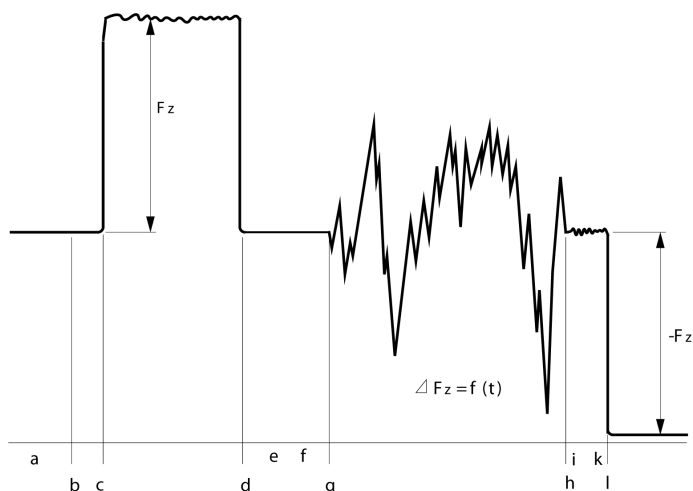


Fig. 13: Range switch over

- a Set the amplifier to <Reset>. Select the range for F as follows: $2 \cdot 10^3$ N/V (amplifier to <Long Time Constant>)
- b Switch the amplifier to <Operate>
- c Apply F_z (put the machine tool into operation)
- d After reading and/or recording the force, switch the amplifier back to <Reset> so that the charge corresponding to F_z is led off
- e Switch the amplifier over to a more sensitive scale (e.g. 1 N/V for F_z)
- f Set the amplifier to <Short Time Constant>
- g Switch the amplifier to <Operate>

The variations of ΔF_z can now be measured with great accuracy, because the dynamic response threshold is around 0,02 N. This means that a ΔF_z of 0,02 N (as a change in $F_z \approx 20$ kN) gives an output voltage of about 20 mV.

The attainable resolution is thus:

$$\frac{1}{1\,000\,000} \quad !$$

- h Switch the amplifier to <Reset>
- i Switch the amplifier back to a less sensitive scale ($2 \cdot 10^3$ N/V). Select <Long Time Constant> and switch the amplifier to <Operate>
- k The disappearance of F_z (tool withdrawn) can also be detected

5.3 Usable frequency range

At the upper frequency limit the frequency behavior of the dynamometer shows oscillation with relatively little damping. Frequencies up to about one-third of the natural frequency can be resolved without excessive measuring errors.

The lower frequency limit is determined by the drift of the charge amplifier and the quality of the insulation. In quasi-static measurements a drift up to $\pm 10 \text{ m}\cdot\text{N/s}$ may appear. Depending on the measuring range, measurements from a few minutes up to several hours are possible, therefore.

The illustration shows a typical frequency curve, where:

f = measuring frequency;

f_n = natural frequency;

X/X_0 = amplitude ratio

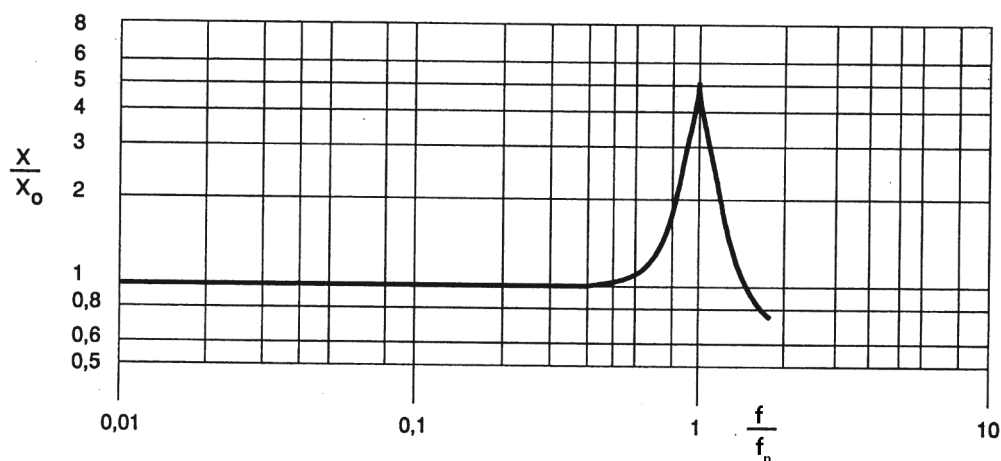


Fig. 14: Frequency curve

Where the widest possible frequency range is needed for critical work, the dynamic behavior of the entire measuring rig must be examined. Thus for example a heavy workpiece mounted on the dynamometer may alter the dynamic behavior.

5.4 Temperature influences

The temperature coefficient of the sensitivity (sensitivity change with temperature, the entire dynamometer being at the same temperature) is negligibly small.

Temperature changes on the other hand give rise to an error signal in the form of a zero drift. This temperature drift is a function of the heat input.

For critical applications the use of protective covers is therefore recommended, to prevent hot swarf accumulating on the dynamometer or in its immediate proximity.

5.5 Polarity of the measuring signal

X and Y directions

When a force acts on the surface and in the direction of the engraved arrow, a negative charge results on the corresponding plug. It is converted into a positive output voltage in the charge amplifier.

Z direction

A compressive force (vertical to the supporting surface) likewise generates a negative charge signal and hence a positive output voltage on the charge amplifier.

M_z direction

A clockwise moment around the positive z-axis yields a negative charge as well which results in a positive output voltage from the charge amplifier.

6. Maintenance

The multicomponent dynamometer Type 9272 is a dependable instrument requiring virtually no maintenance.

To ensure long and reliable operation of the dynamometer, please read the next two sections.

6.1 Recalibrating the instrument

The dynamometer must be recalibrated for example after an uncontrolled overloading.

This must be carried out in the maker's works. The appropriate Kistler distributor should then be contacted.

6.2 Maintenance tasks

The following points are to be noted concerning dynamometer maintenance:

- Always inspect your dynamometer for visible damage before using it. Do not put a damaged instrument into operation
- Leave all repairs (e.g. replacement of damaged plug and socket connections or defective sensors) to the maker's works. The procedure in such cases may be found in section 0 of these Operating Instructions



- **Important:**
The base and top plate surfaces of the dynamometer are ground parallel and flat to very close tolerances. These surfaces must not be re-machined! Visible scratches and notches may be corrected with a bench stone
- Clean the free nine-pin plug and socket connection of the dynamometer or connecting cable regularly with an extremely pure cleansing agent, such as Kistler cleansing and insulating spray Type 1003 or rectified benzene

7. Trouble shooting

7.1 Tracing faults and remedying them

Below is a list of typical faults, together with their causes and remedies. If you cannot deal with a fault, please consult your Kistler distributor.

Fault	Cause	Remedies
No measuring signal at charge amplifier output	Signal line broken	Check measuring rig (connections). The connector box on the Dynamometer should never be opened.
	Charge amplifier defective	Proceed according to charge amplifier operating instructions.
	Dynamometer defective	Repair at maker's works. Proceed according to section 7.2
Quasistatic measurements not possible (signal drifts badly)	Measuring chain has poor insulation resistance.	Check the insulation resistance of the individual components with the insulation tester Type 5493. Clean the plug and socket connections. Test charge amplifier according to its operating instructions.
Charge amplifier saturates during measuring	The force to be measured is too much for the measuring range selected.	Select wider measuring range on the charge amplifier.
Chatter marks on the machined work piece	The resonance frequency of the measuring rig is too low.	Check the mounting of the dynamometer and work piece with the instructions in section 4. Use a bigger (more rigid) dynamometer. Reduce the metal removal rate.

7.2 Defective dynamometer

Proceed as follows if your dynamometer is defective:

- Contact your Kistler distributor and advise him that you are sending in the defective instrument
- Send the defective dynamometer in its original packing to your Kistler distributor
- Give an exact description of the trouble and the accompanying circumstances together with the dynamometer
- Describe the measuring operation being performed when the fault occurred
- If a major repair is involved, you will receive a cost estimate
- Kistler will endeavour to repair your dynamometer as quickly as possible and at minimum cost, and to return it as good as new
- After any repair the dynamometer is recalibrated in the works

8. Technical data

8.1 4-Component dynamometer Type 9272

Measuring range	F_x, F_y	kN	-5 ... 5 ¹⁾
	F_z	kN	-5 ... 20 ²⁾
	M_z	N·m	-200 ... 200
Calibrated measuring range 100 %	F_x, F_y	kN	0 ... 5
	F_z	kN	0 ... 20
	M_z	N·m	0 ... 200 0 ... -200
Calibrated measuring range 10 %	F_x, F_y	kN	0 ... -0,5
	F_z	kN	0 ... 2
	M_z	N·m	0 ... 20 0 ... -20
Overload	F_x, F_y	kN	-6/6
	F_z	kN	-6/24
	M_z	N·m	-240/240
Max. bending moment	M_x, M_y	N·m	-400 ... 400
Threshold	F_x, F_y	N	<0,01
	F_z	N	<0,02
	M_z	mN·m	<0,2
Sensitivity	F_x, F_y	pC/N	≈-7,8
	F_z	pC/N	≈-3,5
	M_z	pC/N·m	≈-160
Linearity, all ranges		% FSO	≤±1
Hysteresis, all ranges		% FSO	≤1
Crosstalk	$F_x \leftrightarrow F_y$	%	≤±2
	$F_z \rightarrow F_{x,y}$	%	≤±1
	$F_{x,y} \rightarrow F_z$	%	≤±2
	$F_z \rightarrow M_z$	mN·m/N	≤±0,2
	$M_z \rightarrow F_z$	N/N·m	≤±1
	$F_{x,y} \rightarrow M_z$	mN·m/N	≤±0,7
	$M_z \rightarrow F_{x,y}$	N/N·m	≤±0,5
Rigidity	C_x, C_y	kN/μm	≈0,4
	C_z	kN/μm	≈2
	cM_z	N·m/μrad	≈0,7
Natural frequency (mounted on rigid base)	$f_n(x, y)$	kHz	≈3,1
	$f_n(z)$	kHz	≈6,3
	$f_n(M_z)$	kHz	≈4,2
Operating temperature range		°C	0 ... 70
Temperature coefficient of sensitivity		%/°C	-0,02

Capacitance	F_x, F_y, F_z	pF	185
	M_z	pF	420
Insulation resistance (20 °C)		Ω	$>10^{13}$
Ground isolated		Ω	$>10^8$
Connector		Fischer-Flansch 9-pol. neg.	
Degree of protection EN60529		–	IP67 ³⁾
Weight		kg	4,2

- 1) Force application point inside and max. 25 mm above top plate area
- 2) Force application point max. 20 mm from center
- 3) With connecting cable Types 1677BA5, 1679BA5

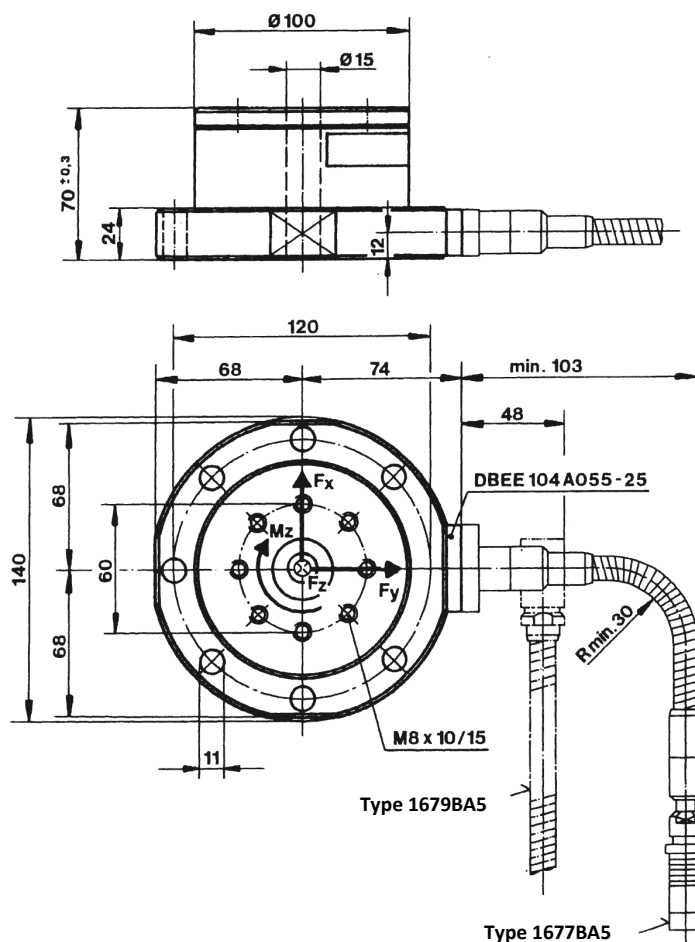


Fig. 15: Dimensions of Dynamometer Type 9272

8.2 Technical data for turning; force acting onto point A

Range	F_x, F_y	kN	-2 ... 2
	F_z	kN	0 ... 4
Crosstalk	$F_x \leftrightarrow F_y$	%	$\leq \pm 5$
	$F_z \rightarrow F_{x,y}$	%	$\leq \pm 2$
	$F_{x,y} \rightarrow F_z$	%	$\leq \pm 5$
Natural frequency (mounted on flanges) with tool holder	$f_n(x, y)$	kHz	$\approx 1,5$
	$f_n(z)$	kHz	≈ 4

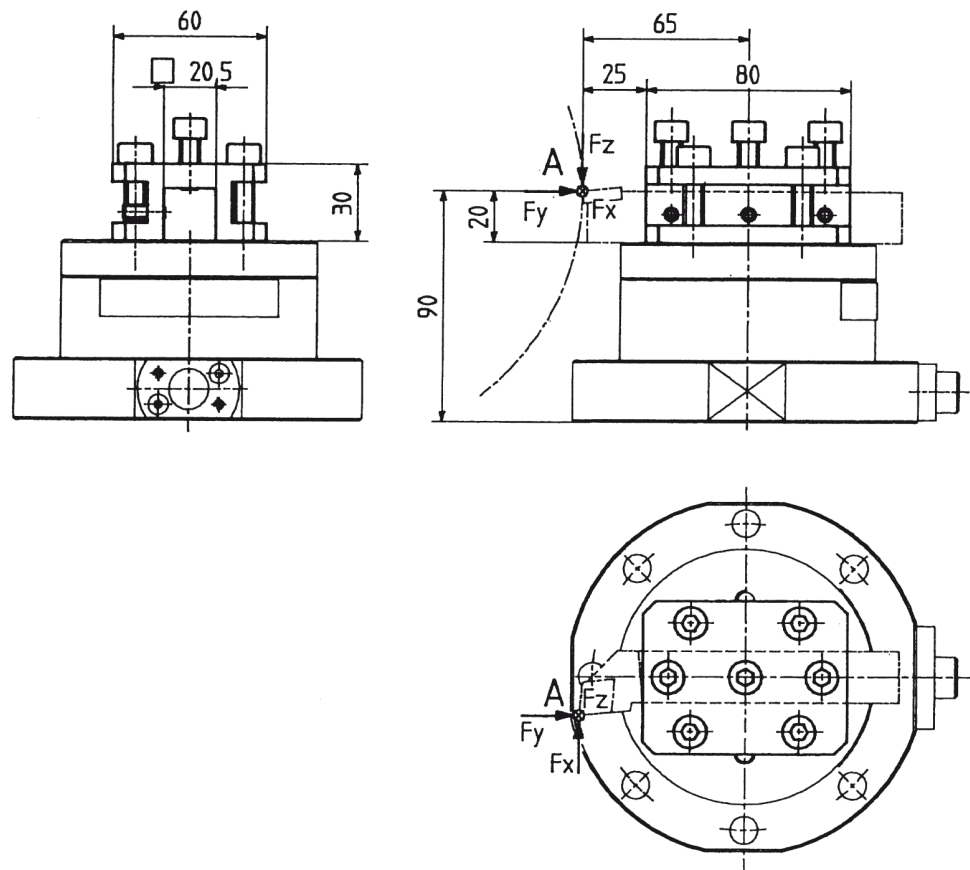


Fig. 16: Dimensions with mounted tool holder Type 9404

8.3 Included accessories

Included with Type 9272:	Mat. Nr.
Waterproof protective cover made of made of stainless steel, for Fischer connector	1431A1

8.4 Optional accessories

The following accessories are available for the 4-component dynamometer Type 9272:

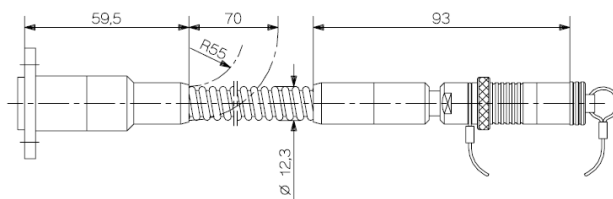
Type 9404, Tool holder

- Connecting cable, 8-wire 1677BA...

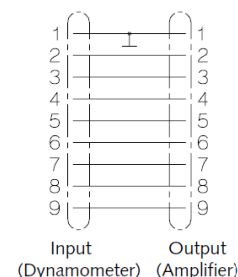
Technical data

Type 1677BA... Connecting cable for multi-component dynamometer with Fischer flange 9-pole neg. connector

Number of conductors 8
Length (m) 5/sp ($L_{\min} = 0.5 \text{ m}/L_{\max} = 20 \text{ m}$)
Cable PFA green $\varnothing 2 \text{ mm}$
Cable protection Flexible stainless steel hose
Temperature range $-5 \dots 70^\circ\text{C}$
Used for 6-component measurement



Cable diagram



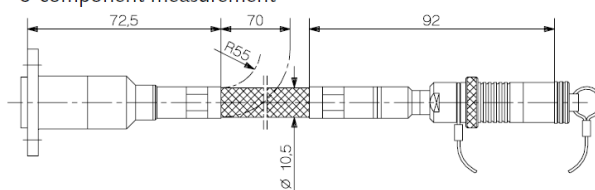
Cable plug Fischer-Flansch 9-pol. pos.
Protection (EN60529) IP67

Fischer 9-pole pos.
IP65

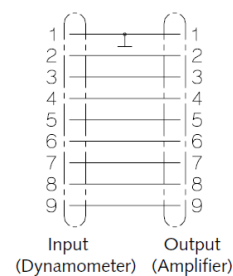
Connecting cable, 8-wire 1677BB...

Type 1677BB... Connecting cable for multi-component dynamometer with Fischer flange 9-pole neg. connector

Number of conductors 8
Length (m) 5/sp ($L_{\min} = 1 \text{ m}/L_{\max} = 10 \text{ m}$)
Cable TPC black $\varnothing 5.6 \text{ mm}$
Cable protection Fluoro-polymer hose, steel braided
Temperature range $-5 \dots 70^\circ\text{C}$
Used for 6-component measurement



Cable diagram



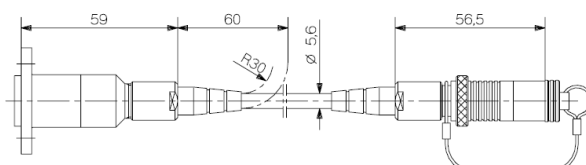
Cable plug Fischer flange 9-pole pos.
Protection (EN60529) IP67

Fischer 9-pole pos.
IP65

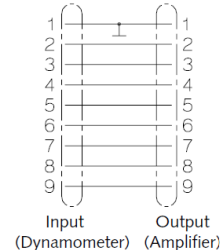
Connecting cable, 8-wire 1677BC...

Type 1677BC... Connecting cable for multi-component dynamometer Fischer flange 9-pole neg. connector

Number of conductors 8
Length (m) 5/sp ($L_{\min} = 0.5 \text{ m}/L_{\max} = 20 \text{ m}$)
Cable TPC black $\varnothing 5.6 \text{ mm}$
Temperature range $-5 \dots 70^\circ\text{C}$
Used for 6-component measurement



Cable diagram



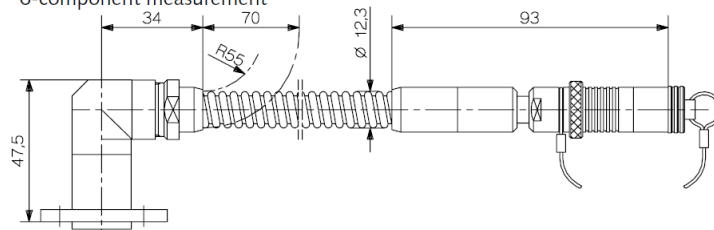
Cable plug Fischer flange 9-pole pos.
Protection (EN60529) IP65

Fischer 9-pole pos.
IP65

Connecting cable, 8-wire 1679BA...

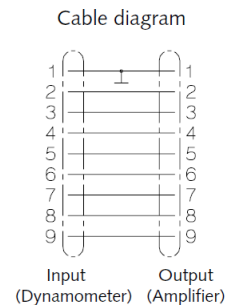
Type 1679BA... Connecting cable for multi-component dynamometer with Fischer flange 9-pole neg. connector

Number of conductors 8
Length (m) 5/sp ($L_{\min} = 0.5 \text{ m}/L_{\max} = 20 \text{ m}$)
Cable PFA green $\varnothing 2 \text{ mm}$
Cable protection Flexible stainless steel hose
Temperature range $-5 \dots 70^\circ\text{C}$
Used for 6-component measurement



Cable plug Fischer flange 9-pole pos. 90°
Protection (EN60529) IP67

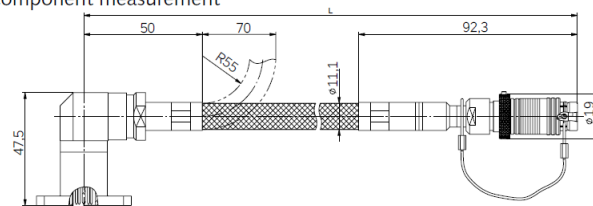
Fischer 9-pole pos.
IP65



■ Connecting cable, 8-wire 1679BB...

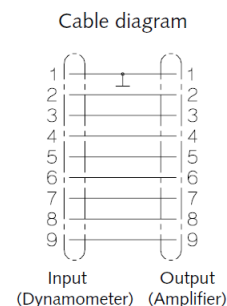
Type 1679BB... Connecting cable for multi-component dynamometer with Fischer flange 9-pole neg. connector

Number of conductors 8
Length (m) 5/sp ($L_{\min} = 2 \text{ m}/L_{\max} = 10 \text{ m}$)
Cable TPC black $\varnothing 5.6 \text{ mm}$
Cable protection Fluoro-polymer hose, steel braiding
Temperature range $-5 \dots 70^\circ\text{C}$
Used for 6-component measurement



Cable plug Fischer flange 9-pole pos. 90°
Protection (EN60529) IP67

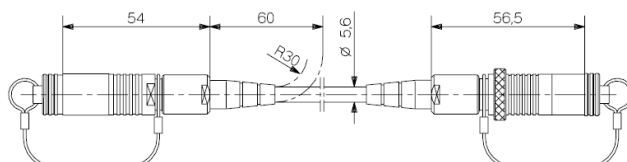
Fischer 9-pole pos.
IP65



■ Extension cable, 8-wire 1678A...

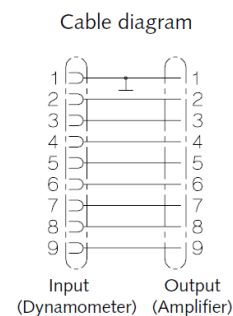
Type 1678A... Extension Cable

Number of conductors 8
Length (m) 5/10/25/sp ($L_{\min} = 0.15 \text{ m}/L_{\max} = 25 \text{ m}$)
Cable TPC black $\varnothing 5.6 \text{ mm}$
Temperature range $-5 \dots 70^\circ\text{C}$
Used for 6-component measurement



Cable plug Fischer 9-pole neg.
Protection (EN60529) IP65

Fischer 9-pole pos.
IP65



9. Annex

9.1 Glossary

Best straight line	see Annex 9.3.
Cable capacitance	The capacitance, and thus the length of the connecting cable, has no influence on the measuring result when Kistler special cables and Kistler charge amplifiers are used.
Calibrated measuring range	Measuring range or part of the measuring range for which the sensor has been calibrated. 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 in the mounted condition is advisable in the case of unusual measuring arrangements and/or if the measurement must meet very high requirements for accuracy. For applications in shunt mode, calibration in the mounted condition is essential.
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.
Charge signal	Output signal in picocoulomb (pC) of a piezoelectric sensor without integral charge amplifier.
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.
Degree of protection	Protection of electrical equipment by suitable enclosures, covers etc. according to EN60529. The degree of protection is stated by IP (International Protection) followed by two digits. The first digit stands for the level of protection against touching and the entry of solid bodies, the second for the level of protection against the entry of water. IP65 indicates, for example, complete protection against touching, as well as against the entry of dust and water spray from all directions.

Disturbance	Forces, moments and environmental influences acting on the sensor such as the temperature, which the sensor does not measure as a measurand and which produce an output signal (error). Example: when an additional bending moment acts on a force sensor.
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. Difference in output signal between the zero and end points of the measuring range
Ground insulation	Electrical resistance of a sensor between signal line and ground, or of a charge amplifier between connector shielded and ground.
Hysteresis	see Annex 9.3.
Insulation resistance	Electrical resistance of a sensor, cable or the input of a charge amplifier, measured between signal line and ground connection.
Linearity	see Annex 9.3.
Measurand	Physical quantity, state or characteristic which is measured, e.g. force, torque 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 such as PC or 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, see also Annex 9.4.
Operating temperature	Range of ambient temperatures in which the sensor is to be operated. The temperature-dependent tolerances stated apply only within this range. Higher temperatures can cause irreversible damage to the sensor.
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

The characteristic of quartz crystals in which mechanical loading produces a proportional electric 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 analog or monitor output of a charge amplifier.

Sensitivity

Nominal value or calibrated value stated in the calibration certificate of the change in signal produced by the sensor per change in measurand.

Sensor

System which produces a definite change in the output signal as a function of the change of the measurand acting on it.

Temperature influence

see Annex 9.5.

Threshold

Smallest change in the measurand, which produces a measurable change in the sensor signal. 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 quasistatic measurements, drift and environmental influences are limiting factors.

Time constant

The time constant describes the behavior of a high-pass filter (RC element) and represents the time after which the signal has fallen to $1/e$ of the output value. 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 quasistatic measurements. 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.

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	$\pm 0,2 \dots 0,5 \%$ FSO
Industrial charge amplifier	$\pm 1 \%$ 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

Two parallel straight lines must be located which are as close as possible to one another and enclose the entire calibration curve. In addition, the center parallel must pass through the zero point (no force, no output signal). The slope of this center parallel 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: $y_i = s \cdot x_i$ (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 $a = res_{max} = |res_{min}|$

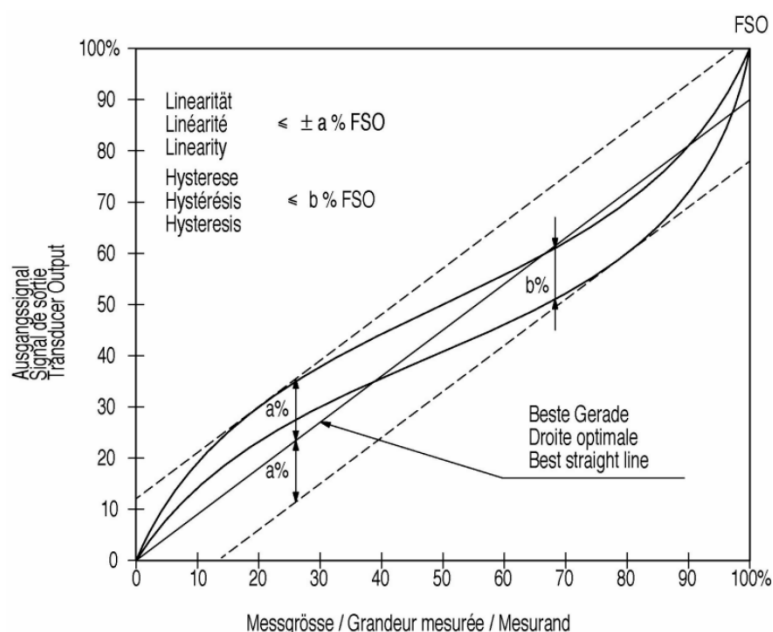


Fig. 17: Best straight line, linearity and hysteresis

Hysteresis

Quartz itself has a scarcely measurable hysteresis. However, the mechanical construction of the sensor can result in slight hysteresis, but this is below the specified value

(% FSO) in every measuring range. If a greater hysteresis occurs, then the sensor has not been correctly installed.

Hysteresis (b%) is included in the linearity ($\pm a\%$) and does not have to be additionally taken into account in estimating the measurement uncertainty.

Charge amplifier linearity

The linearity of charge amplifiers is typically within the range of $\pm 0,05\%$ 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_0 = Amplitude ratio

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

Accuracy 10 % $\rightarrow f_{\max} \approx 0,3 \cdot \text{natural frequency}$
 5 % $\rightarrow f_{\max} \approx 0,2 \cdot \text{natural frequency}$
 1 % $\rightarrow f_{\max} \approx 0,1 \cdot \text{natural frequency}$

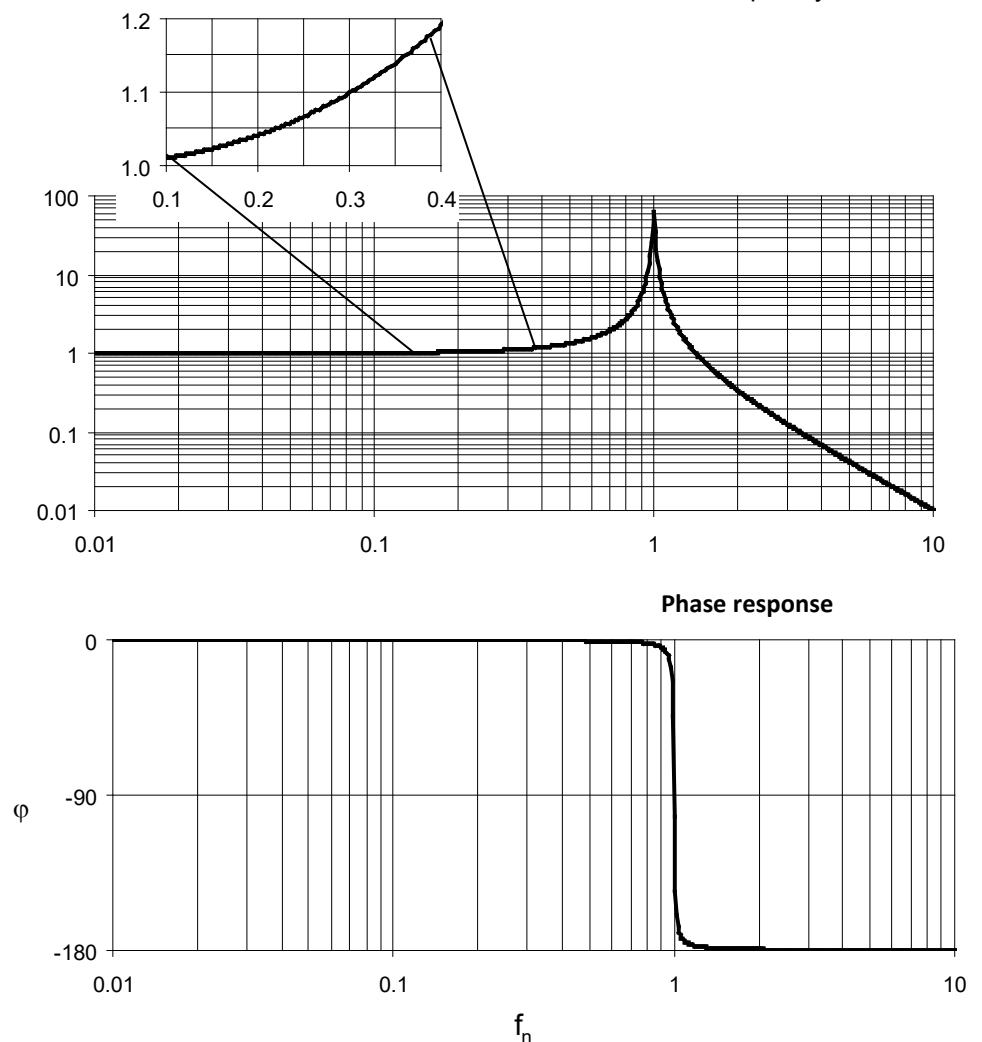


Fig. 18: Schematic representation of frequency response and phase response

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.

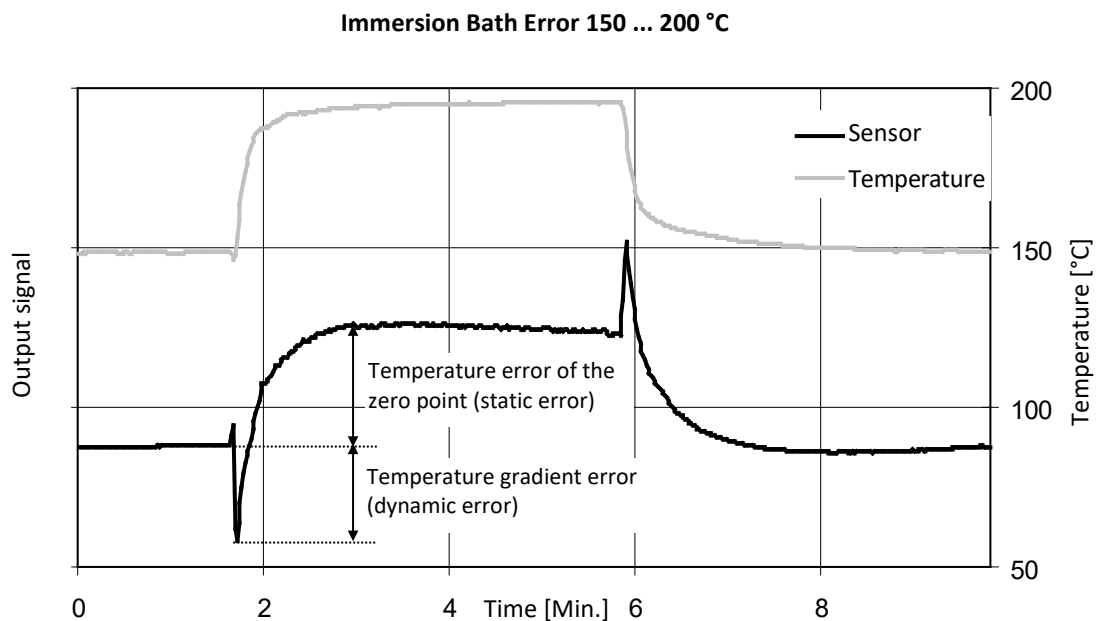


Fig. 19: Example of a temperature error of the output signal zero for a temperature rise from 150 °C to 200 °C (immersion bath).

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.

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