



# KISTLER

measure. analyze. innovate.

## Torque Sensors

**Measurement  
Technology for Test  
Rigs, Drives, Process  
Monitoring and  
Quality Assurance**



**Dr. Staiger Mohilo**  
A Kistler Group Company

# Kistler – the right partner for cost-effective quality

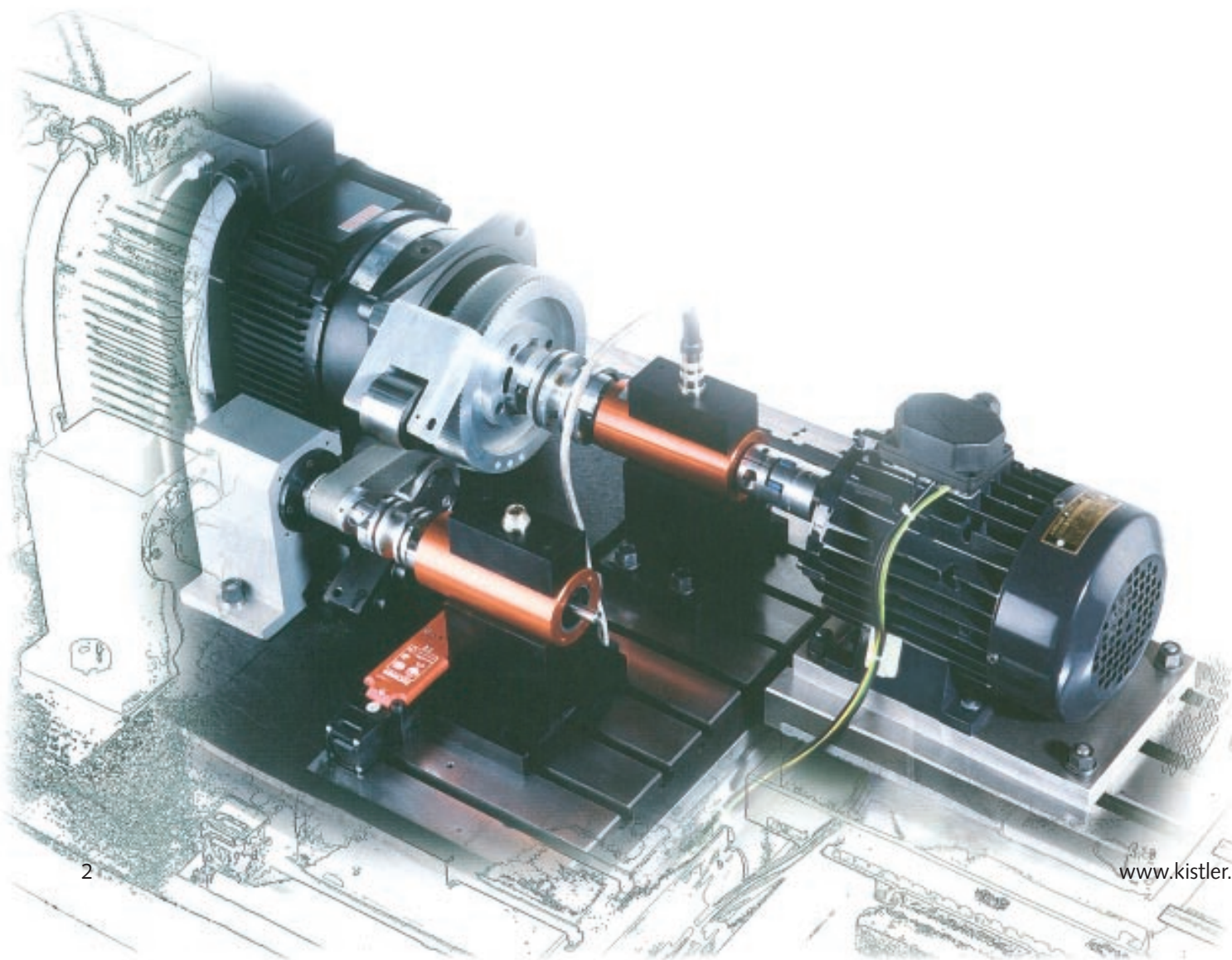
Sensors and systems for analyzing the angular and time-based curves of torque are one of Kistler Group's key product lines. Manufactured by Group company Dr. Staiger Mohilo, they demonstrate their versatility in a wide variety of applications – research and development, test rigs, drives, handling systems, production and process monitoring, production instrumentation and quality assurance. Last but not least they allow documentation of process and quality data.

In addition to these torque sensors, the Swiss Kistler Group offers special sensors for measuring force, pressure and acceleration, and monitoring systems for mechanical production, development and monitoring of internal combustion engines, vehicle manufacture, plastics processing and bio-mechanics.

Kistler's core competency is the development, production and use of sensors for measuring pressure, force, torque and acceleration. Its expertise and electronic systems allow measurement signals to be conditioned and used to analyze physical processes, control and optimize operations and boost product quality in the manufacturing industry.

Year after year Kistler invests 10 % of its turnover in R&D to come up with technically innovative yet cost-effective state-of-the-art solutions. With a combined workforce of around 800, the group is the global market leader in dynamic measurement technology.





20 member companies worldwide and more than 30 distributors ensure close contact with the customer, individualized application engineering support and short lead times.



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## Product details and range

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# KISTLER

measure. analyze. innovate.

### measure.

Kistler develops and produces high quality measurement technology. Its core competence is sensor-related expertise.

### analyze.

The analysis of sensor data calls for in-depth knowledge of the processes involved. Kistler has acquired this in major fields of application and is able to offer complete analysis systems.

### innovate.

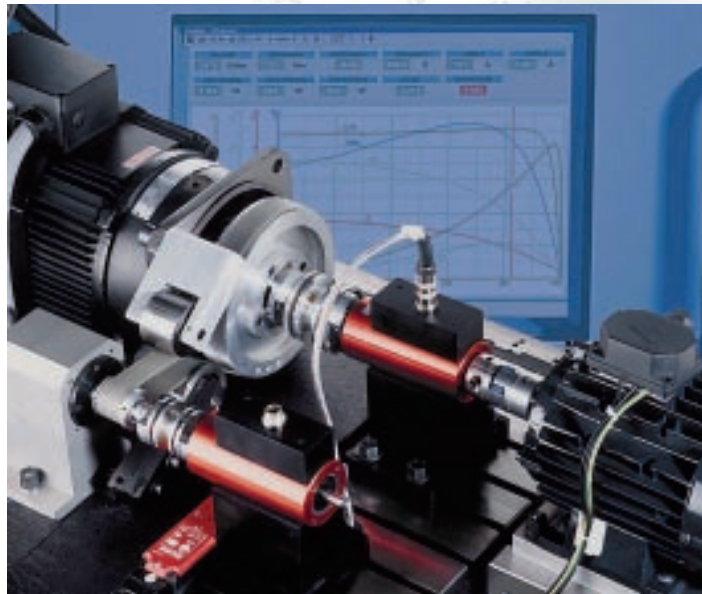
Kistler products are developed in close cooperation with key customers and universities. This inspires product innovation and technological progress.

# Torque measurement applications

Dr. Staiger Mohilo's core competency is strain gage technology for sensors for static and dynamic measurement. Close ongoing collaboration with research and

industry ensures continuous development of measurement technology and sensor designs. Noncontact digital signal transmission from rotor to stator, integrated signal

conditioning, interfaces such as CAN bus and RS-232C, and normalized analog and frequency outputs make integration into existing test systems easier for the user.



## Electric motor testing

The mechanical and electrical characteristics, thermal design, overload capacity and all technical data of electrical machinery are subjected to intensive testing. The determination of efficiency and power factor in particular impose tough demands on the accuracy and flexibility of a test system. Torque sensors play a central role.

Accurate measurement of torques applied to rotating drives and components is an important criterion for effective product development and reliable quality assurance in production and assembly. Kistler's versatile universal torque sensor, Type 4503A..., opens up a multiplicity of applications across this sector.

## Production process monitoring

Accurate measurement of torques applied to rotating drives and components is an important criterion for evaluating manufacturing efficiency and quality assurance in production and assembly.

These days process monitoring demands comprehensive, traceable acquisition of measurement results from torque sensor systems.

Examples include:

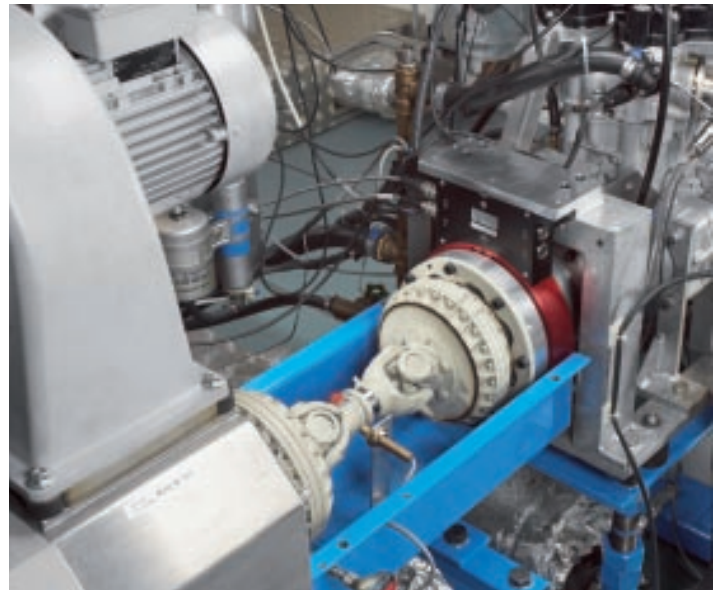
- Automated screw connection processes
- Viscosity monitoring
- Measurement of friction coefficients in production control



## Research and development

The development of internal combustion engines and gearing, and test rig simulation as a means of investigating drive trains, require a robust, high-precision torque sensor.

A short, highly torsionally rigid design is also needed to map dynamic load cycles onto a realistic operating profile. The torque measuring flange, Type 4504A..., has been specially tailored to these requirements.



## Product testing

Each and every assembly step in the production of safety components is monitored with sensors. Automobile suppliers can only guarantee their components will work properly by testing their production as a reliable means of avoiding the customer suffering failures.

### Testing ignition switches with torque sensors

The operation of mounted ignition switches can be tested at the production stage with the aid of torque sensors. The torques required to turn their spring-loaded components must remain within specified tolerances.



# Torque measurement

A knowledge of the torques arising in components from torsion bars through to high-speed drive shafts provides information about static and dynamic loads and transmission operating characteristics. Combined with speed measurements they reveal the power transmitted by a drive train.

Torque measurements on rotating shafts are preferably based on strain gage technology. A high degree of thermal stability, extremely high precision and maximum test rig rigidity are some of the key requirements.

With modern torque measuring shafts the supply and measurement signals are generally transmitted without contact.

If – as with the Type 4504A... – the measuring shaft does not have any mechanical bearings, an extremely accurate, completely wear-free measuring instrument results. In applications involving the measurement of reaction torques, which demand wide measuring ranges, extremely good overload capacities and high resolution, piezoelectric sensors have proven effective. Even under very high mechanical loads they readily allow detection of minute fluctuations in torque.

With strain gage and piezoelectric sensors the Kistler range now offers solutions to all measurement problems.

## Strain gage or piezoelectric? Solutions to meet every need!

### Strain gage torque sensors for

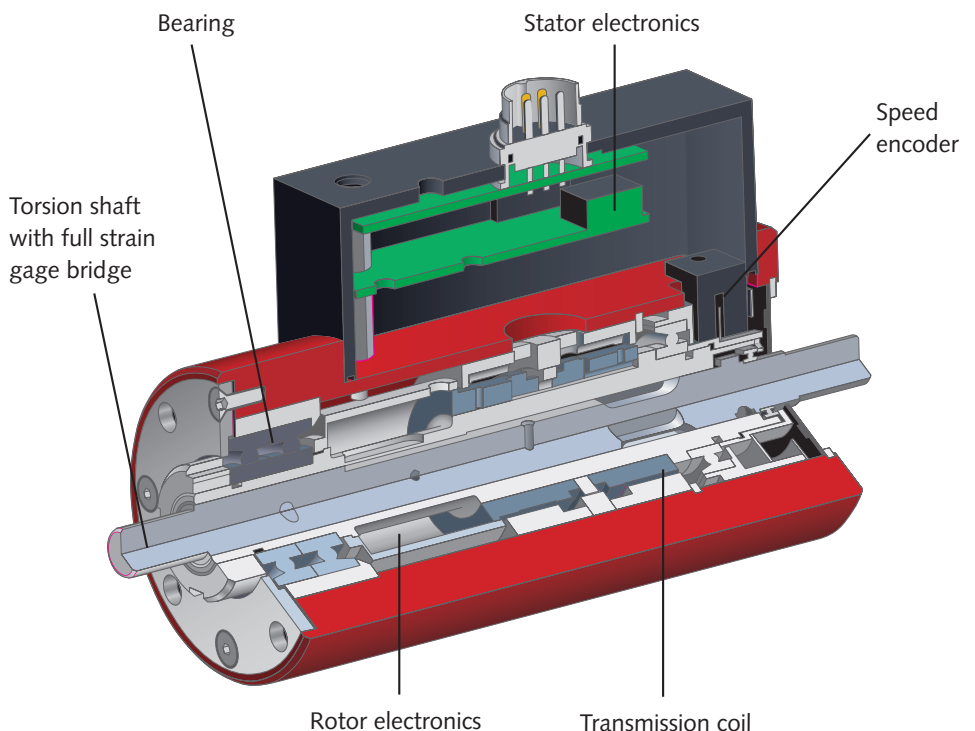
- + Measurements on rotating shafts
- + Maximum precision
- + Dynamic and static continuous measurement

### Piezoelectric reaction torque sensors for

- + Extremely high overload capacity
- + High signal resolution even in extremely narrow partial ranges
- + Wide frequency range

## Basic design of measuring chains

A measuring chain consists of the sensor and an evaluation system for analysis. Depending on type, the sensor can be connected to the evaluation system either directly or via a suitable signal conditioning system. Torque sensors are always fitted with self-aligning couplings in order to decouple the measuring shaft from misalignment, ensure accurate measurement and increase the service life of the sensor.



Design of torque sensor, Type 4503A...

# Ideal solution to any measurement challenge

## Torque sensors correctly mounted

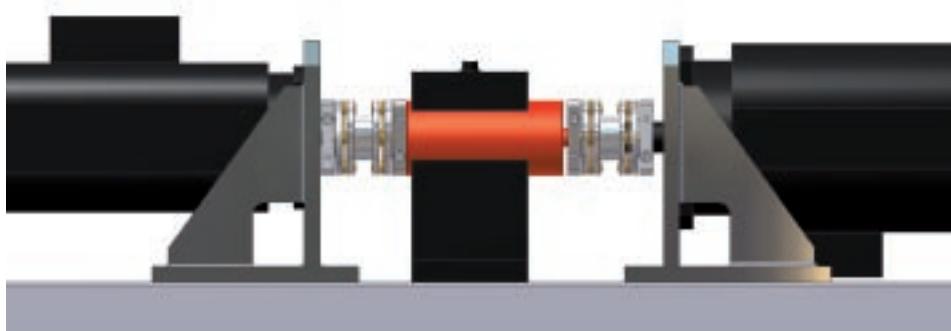
It is vital to ensure the measurement setup is correct when mounting torque sensors. The choice of suitable couplings depends on whether the sensor is to be overhung, just provided with torsional restraint, or mounted with its own flange, base or retaining bracket. Kistler provides its customers with advice that ensures each setup is successful from the outset.

## Torque measuring system

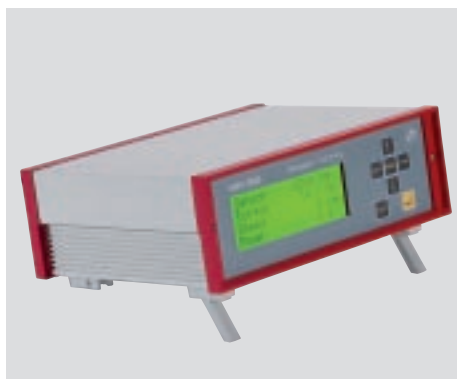
The performance of the measuring system as a whole is what counts when measurements are performed on test rigs, for process monitoring or product testing.

- Precise and reliable sensor systems
- Mounting versatility
- User friendliness
- Traceable measurement data
- Cost-effective operation

The new supply and evaluation unit, Type 4700A..., provides the key measurement data at a glance. Standard USB and RS-232C interfaces allow easy acquisition and evaluation on a PC of relevant data such as mechanical power, torque, speed or rotation angle.



Mounting example: Torque sensor, Type 4503A... with mounting base



Supply and evaluation system, Type 4700A... (UMV 3000)



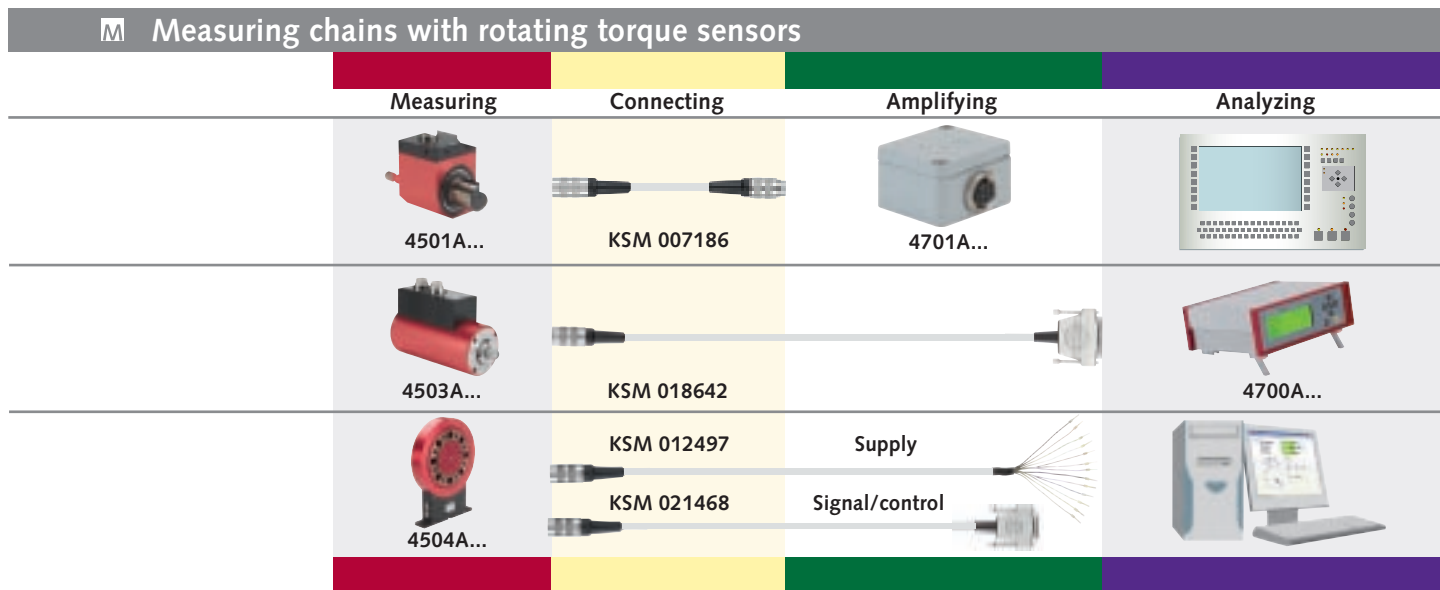
Fully automatic calibration system DKD-K-37701






## Calibration

The reference-standard torque measuring system with electric motor drive represents the state of the art in calibration of torque sensors. It was developed in conjunction with the Torque Laboratory of the "Fachlaboratorium Drehmoment, Physikalisch-Technische Bundesanstalt" in Braunschweig, Germany. Torques are applied with automatically configurable weights that can be moved along a load lever. This system extends the usual static calibration to now allow quasi-continuous calibration of torque sensors over their entire measuring range. Dr. Staiger-Mohilo has based its computer-controlled calibration process on DIN ISO 9001 in order to offer users of torque sensors comprehensive, measuring machine generated calibration documentation that dovetails seamlessly with their DIN ISO requirements.

The Calibration Laboratory has been accredited by the German Calibration Service (DKD) since Spring 2004. A factory calibration certificate and a DKD calibration certificate can be provided.

# Range and typical measuring chains

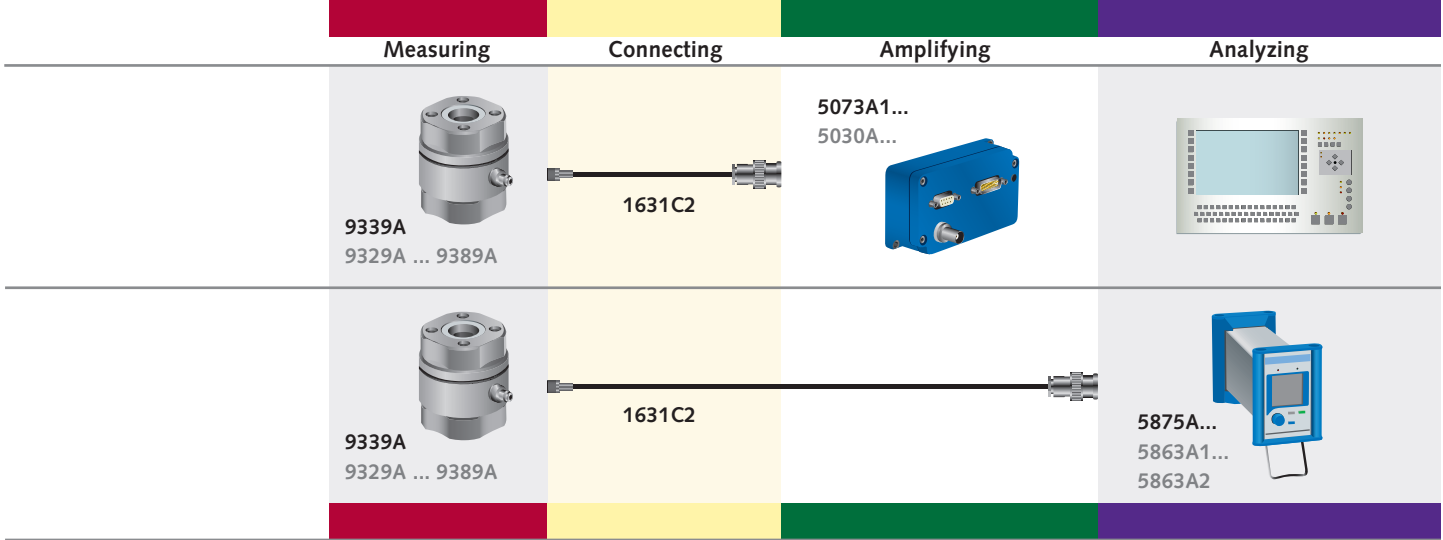


Type		Sensor		Rated torque in N·m <sup>1)</sup> Measuring range in N·m <sup>1)</sup>				
				fixed	rotating	-0,1	1	10
4501A...	Slipping torque sensor, strain gage 		✓			6 ... 1 000 <sup>1)</sup>		
4502A...	Mini-Smart torque sensor, strain gage 		✓	0,5 ... 1 000 <sup>1)</sup>				
4503A...	Dual range sensor, strain gage 		✓	0,2 ... 5 000 <sup>1)</sup>				
4504A...	Torque measuring flange, strain gage 		✓					200 ... 10 000 <sup>1)</sup>
9329A... to 9389A...	Reaction torque sensor, piezoelectric 	✓		0 ... 1 000 <sup>2)</sup>				

<sup>2)</sup> Piezoelectric sensors offer a resolution to a range of milli-newton – independent of

Further details of measuring systems with piezoelectric torque sensors are to be found in the catalog "Force and Torque sensors for Monitoring, Manufacturing, Assembly and Testing Processes".  
(Document No. 300-460e)

**M Measuring chains with piezoelectric reaction torque sensors**



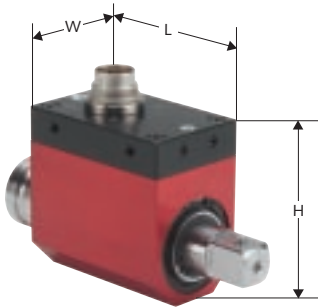
		Max. speed	Signal output	Signal transmission		Bearings	Connection			
10 000				slip ring	noncontact		square	hexagonal	shaft	flange
		<3 000 min <sup>-1</sup>	±2 mV/V	✓		✓	✓	✓	✓	
		12 000 min <sup>-1</sup>	±5 VDC		✓	✓	✓	✓	✓	
		50 000 min <sup>-1</sup>	100 ±40 kHz or ±5 VDC or ±10 VDC and RS-232C		✓	✓			✓	
		15 000 min <sup>-1</sup>	100 ±40 kHz 60 ±20 kHz 10 ±5 kHz 0 ±10 VDC and RS-232C		✓					✓
		-	-2 170 ... -100 pC/N·m (depending on size)	cable						✓

ent of the measuring range.

# Measuring

## Torque sensors

### Slipping torque sensor, 0 ... 6 N·m to 0 ... 1 000 N·m



Type 4501A...

Technical data		Type 4501A...
Measuring range (Nominal torque)	N·m	2 / 12 / 25 / 63 / 169 / 500 / 1 000
Maximum torque		1,5 x rated torque
Alternating torque		0,7 x rated torque
Accuracy class	%	0,2
Output signal (Rated value)	mV/V	±1 ... 2 (depending on version)
Speed measurement	pulses/rev.	2 x 360
Nominal speed	1/min	≤3 000
Balancing grade	Q	-
Operating temperature range (Rated temperature range)	°C	5 ... 50
Case material		Aluminum, hard anodized
L	mm	44 ... 73
W	mm	28 ... 73
H	mm	52 ... 90
Degree of protection		IP40
Electrical connections		6 pin or 12 pin Binder connector

#### Properties

Universal torque sensor. Compact, various shaft connections.

#### Areas of application

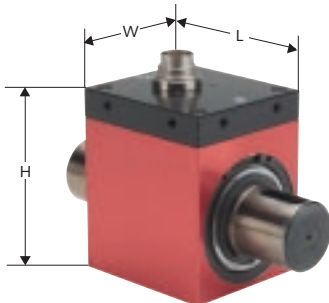
Designed specifically for use in screw connection. Typical applications include the testing of built-in nutrunners or torque measurement with hand screw driving tools. For brief, intermittent operation at low speeds.

#### Accessories

Female cable connector  
 6 pin Type KSM000822  
 12 pin Type KSM000703  
 Connecting cable Type KSM007186  
 Type KSM010382  
 Type KSM018315  
 see data sheet for further details

Data sheet 4501A\_000-596

### Mini-Smart torque sensor, 0 ... 0,5 N·m to 0 ... 1 000 N·m



Type 4502A...

Technical data		Type 4502A...
Measuring range (Rated torque)	N·m	0,5 / 1 / 2 / 6 / 12 / 18 / 50 / 63 / 100 / 150 / 160 / 250 / 300 / 500 / 1 000
Maximum torque		1,5 x rated torque
Alternating torque		0,7 x rated torque
Accuracy class	%	0,2
Output signal (Rated value)	VDC	±0 ... 5
Speed Measurement	pulses/rev.	2 x 360 or 60
Nominal speed	1/min	<12 000
Balancing grade	Q	6,3
Operating temperature range (Rated temperature range)	°C	10 ... 60
Case material		Aluminum, hard anodized
L	mm	44 ... 73
W	mm	28 ... 73
H	mm	52 ... 90
Degree of protection		IP40
Electrical connections		12 pin Binder connector

#### Properties

Torque sensor with noncontact signal transmission, integral measurement electronics and high level of interference immunity. Compact design, various shaft connections and noncontact signal transmission.

#### Areas of application

Suitable for dynamic measurement of tightening and release torques in screw connection and assembly, and for quality control in production and the laboratory. Suitable for continuous use, for example in process monitoring.

#### Accessories

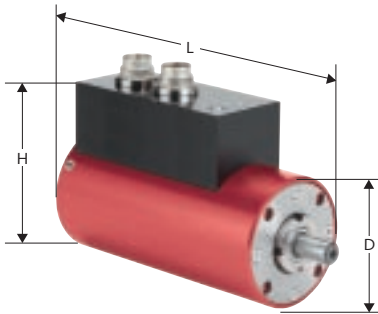
Female cable connector 12 pin Type KSM000703  
 Connecting cable Type KSM012497  
 see data sheet for further details

Data sheet 4502A\_000-597

# Measuring

## Torque sensors

### Dual range sensor with noncontact transmission, 0 ... 0,2 N·m to 0 ... 5 000 N·m



Type 4503A...

Technical data		Type 4503A...
Measuring range (Rated torque)	N·m	0,2 / 0,5 / 1 / 2 / 5 / 10 / 20 / 50 / 100 / 200 / 500 / 1 000 / 2 000 / 5 000
Maximum torque		1,5 x rated torque
Alternating torque		0,7 x rated torque
Accuracy class	%	0,1 or 0,05 (depending on version)
Output signal (Rated value)	VDC kHz	±0 ... 5 or ±0 ... 10 or 100 ±40 and RS-232C
Speed measurement	pulses/rev.	60 or 2 x 360
Nominal speed	1/min	<50 000
Balancing grade	Q	2,5 or 6,3 (depending on version)
Operating temperature range (Rated temperature range)	°C	10 ... 60
Case material		Aluminum, hard anodized or stainless steel (depending on version)
L	mm	113 ... 137
D	mm	58 ... 148
H	mm	74 ... 178
Degree of protection		IP40
Electrical connections		7 pin or 12 pin Binder connector

#### Properties

Ideal sensor for two separately calibrated measuring ranges. Integral measurement electronics, extremely high accuracy, extremely high speed ranges and digital signal processing. This sensor is also available as a single range sensor.

#### Areas of application

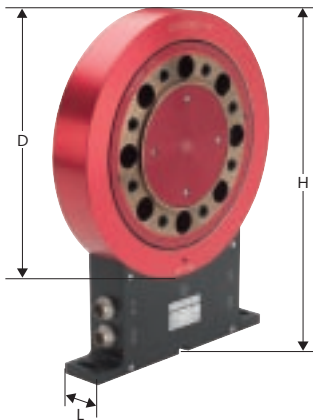
Universal application in the development laboratory, production or quality assurance.

#### Accessories

Female cable connector,  
7 pin Type KSM000517  
12 pin Type KSM000703  
Connecting cable Type KSM012497  
Type KSM021971  
see data sheet for further details

Data sheet 4503A\_000-595

### Torque measuring flange – short design, robust, without mechanical bearings, extremely accurate, 200 ... 10 000 N·m



Type 4504A...

Technical data		Type 4504A...
Measuring range (Rated torque)	N·m	50 / 100 / 200 / 500 / 1 000 / 2 000 / 3 000 / 5 000 / 10 000
Maximum torque		2 x rated torque
Alternating torque		1 x rated torque
Accuracy class	%	0,1 or 0,05 (depending on version)
Output signal (Rated value)	VDC kHz	±0 ... 10 or 10 ±5, 60 ±20, 100 ±40 and RS-232C
Speed measurement	pulses/rev.	60 or 2 x 180 ... 2 x 3 600 or 2 x 128 ... 2 x 5 120 (dep. on version)
Nominal speed	1/min	<15 000
Balancing grade	Q	6,3
Operating temperature range (Rated temperature range)	°C	10 ... 60
Case material		Aluminum, hard anodized
L	mm	30,5 ... 64
D	mm	192 ... 311
H	mm	263,5 ... 382
Degree of protection		IP54
Electrical connections		Binder connector (7-, 8- and 12 pin)

#### Properties

Torque measuring flange based on the strain gage principle. The integral digital measurement processing system produces analog or digital output signals transmitted without contact. The rotor has no mechanical bearings and therefore runs without wear in the stator ring.

#### Areas of application

This extremely short design is ideal for internal combustion engines, gearing, roller, wheel load, electric motor and pump test rigs.

#### Accessories

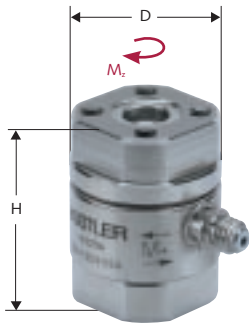
Female cable connector,  
7 pin Type KSM000517  
12 pin Type KSM000703  
Connecting cable Type KSM012497  
Type KSM021971  
see data sheet for further details

Data sheet 4504A\_000-598

# Measuring

## Torque sensors

Reaction torque sensor, -1 ... 1 N·m up to -1 000 ... 1 000 N·m



Type 9329A

Technical data		Type 9329A	Type 9339A	Type 9349A	Type 9369A
Measuring range	N·m	-1 ... 1	-10 ... 10	-25 ... 25	-200 ... 200
Calibrated measuring ranges	N·m	0 ... 1 0 ... -1 0 ... 0,1 0 ... -0,1	0 ... 10 0 ... -10 0 ... 1 0 ... -1	0 ... 25 0 ... -25 0 ... 2,5 0 ... -2,5	0 ... 200 0 ... -200 0 ... 20 0 ... -20
Sensitivity	pC/N·m	≈-2 170	≈-460	≈-230	≈-130
D	mm	20	30	36	54
H	mm	26	34	42	60
Weight	g	50	137	243	800
Operating temperature range	°C	-20 ... 80	-40 ... 120	-40 ... 120	-40 ... 120

Technical data		Type 9389A
Measuring range	N·m	-1 000 ... 1 000
Calibrated measuring ranges	N·m	0 ... 1 000 0 ... -1 000 0 ... 100 0 ... -100
Sensitivity	pC/N·m	≈-100
D	mm	100
H	mm	130
Weight	g	6 720
Operating temperature range	°C	-40 ... 120

General technical data	
Degree of protection (EN 60529)	IP65 with connected cable IP67 with cable Type 1983AD... and molded connector
Connection	KIAG 10-32 neg.

### Properties

Compact reaction torque sensor ready for mounting, flexible adapter, centering seat.

### Areas of application

Measurement of a torque acting about the axis of the sensor, torque setting and testing of threaded connections, calibration of hand torque wrenches, torsional testing of springs, measurements on friction clutches and electric motors, and testing of rotary switches (product testing).

### Accessories

Mounting flange Type 9580A...

Data sheet 9329A\_000-463

# Amplifying

## Industry

ICAM - Industrial Charge Amplifier for Applications in Manufacturing



Technical Data		Type 5073A...
Number of channels		1, 2, 3, 4
Measuring range	pC	±100 ... ±1 000 000
Output signal	V	0 ... ±10
Supply	VDC	18 ... 30
Sensor connection		BNC (neg.)
Operating temperature range	°C	0 ... 60 (noncondensing)
Interface		RS-232C
Degree of protection (EN 60529)		IP60

### Properties

Industrial charge amplifier housed in a rugged metal case. Outstanding for ease of operation and faithful technical data over a very wide measuring range.

### Areas of application

Suitable for applications with nearly all piezoelectric sensors.

### Accessories

see data sheet

Data sheet 5073A\_000-524

# Connecting

## Connecting cables

### Connecting cables for sensors



Technical data		Type KSM 007186
Connection		6-pin, neg. – 6-pin, pos.
Length	m	5
Diameter	mm	6
Degree of protection (EN 60529)		IP40



Technical data		Type KSM 010382
Connection		6-pin, pos. – free ends
Length	m	5
Diameter	mm	6
Degree of protection (EN 60529)		IP40



Technical data		Type KSM 018315
Connection		12-pin neg. – free ends
Length	m	5
Diameter	mm	6
Degree of protection (EN 60529)		IP40



Technical data		Type KSM 012497
Connection		12-pin neg. – free ends
Length	m	5
Diameter	mm	6
Degree of protection (EN 60529)		IP40



Technical data		Type KSM 021971
Connection		7-pin neg. – free ends
Length	m	5
Diameter	mm	6
Degree of protection (EN 60529)		IP40



Technical data		Type 1631C...
Connection		KIAG 10-32 pos. – BNC pos.
Length	m	0,5 / 1 / 2 / 3 / 5 / 10 / 20
Diameter	mm	2 (PFA)
Degree of protection (EN 60529)		IP65 – IP40

See **data sheet** KSM\_000-615 for other cables

## Connectors

### Connectors/female cable connectors



Technical data		Types KSM 000822, 000517, 000703
Connection		6-, 7-, 12-pin neg.
Degree of protection (EN 60529)		IP40

See **data sheet** KSM\_000-615 for other connectors/female cable connectors

# Amplifying

## Industry

### Measurement amplifiers for strain gage sensors



Technical data		Type 4701A...	
No. of channels		1	
Input (strain gage)	mV/V	0,5 ... 3,0 (full or half bridge)	
Frequency range (-3 dB)	kHz	≈0 ... 1	
Output signal	V	±5 or ±10	
Supply	VDC	options: 24 10 ... 15	unstabilized (±10 %) stabilized and filtered
Input signal	Connector	strain gage	options: gland with soldering terminals 6-pin connector
Degree of protection (EN 60529)		IP40 ≈ IP54	IP40 (with connector), IP54 (with gland)

#### Properties

Industrial measuring amplifier with robust metal case. Amplification and zero adjustment are set with fixed resistors and potentiometers.

#### Areas of application

This amplifier is designed for industrial applications and intended for panel mounting. Universal measurement amplifier for strain gage sensors. Suitable for torque sensors, Type 4501A...

#### Accessories

Cable Type KSM 007186  
Cable Type KSM 010382

**Data sheet** 4701A\_000-621

## Control and monitoring units

### Supply and evaluation system for torque sensors



Technical data		Type 4700A...	
No. of channels		1	
Input for torque		0,5 ... 3,5 (full bridge, 4-/6-wire)	
Strain gage	mV/V	±5 ... ±10	
Active	VDC	≤300	
Frequency	kHz	0,001 ... 5	
Frequency range (-3 dB)	kHz	≤300 BNC neg. connectors	
Input for speed/rotation angle		≤300 BNC neg. connectors	
Tracks A, B and Z	kHz	24 V stabilized DMS 5 V unipolar 5 V stabilized ±12 V stabilized	
Sensor supplies		25-pin D-Sub female connector	
Input signal	Connector	±10 (9-pin D-Sub neg. connector) BNC neg. connector	
Output signals	V	8 digital inputs 8 digital outputs 25-pin D-Sub neg. connector	
3 channels		RS-232C, USB 2.0	
Digital control			
Interfaces			

#### Properties

Universal measurement amplifier for connecting passive and active force and torque sensors. It is possible to evaluate torque / speed or torque / rotational angle measurements. The mechanical power is calculated and indicated by the unit. The unit also has digital inputs and outputs and circuitry for measuring extreme values and saving measurement curves.

#### Areas of application

The unit is ideal for use in production instrumentation and in the test and laboratory environment.

#### Accessories

Connection cable Type KSM018535  
Type KSM018537  
Type KSM018538  
Type KSM018642

**Data sheet** 4700A\_000-620

# Accessories

## Couplings

### Miniature coupling, torsionally rigid, with single flexibility, clamping hub



Technical data		Type 966...				
		...25	...37	...50	...62	...75
Rated torque	N·m	0,39	1,56	6,17	24,7	36,2
Maximum torque	N·m	0,54	2,19	8,64	34,6	50,7
Compliance, axial	mm	0,8	0,8	0,8	0,8	0,8
Compliance, radial	mm	0,7	0,7	0,7	0,7	0,7
Compliance, angular	°	2	1,5	1	0,7	0,7
Torsional spring constant	10 <sup>6</sup> N·m/rad	3,89	25,986	39,768	103,572	161,76
Maximum speed	min <sup>-1</sup>	64 000	44 000	36 000	28 000	24 000
Mass moment of inertia	10 <sup>-6</sup> kg·m <sup>2</sup>	1,83	11,1	28,56	78,61	159,4

### Miniature coupling, torsionally rigid, with dual flexibility, clamping hub



Technical data		Type KK 965...				
		...25	...37	...50	...62	...75
Rated torque	N·m	0,39	1,56	6,17	24,7	36,2
Maximum torque	N·m	0,54	2,19	8,64	34,6	50,7
Compliance, axial	mm	0,8	0,8	0,8	0,8	0,8
Compliance, radial	mm	0,7	0,7	0,7	0,7	0,7
Compliance, angular	°	2	1,5	1	0,7	0,7
Torsional spring constant	10 <sup>6</sup> N·m/rad	3,89	25,986	39,768	103,572	161,76
Maximum speed	min <sup>-1</sup>	64 000	44 000	36 000	28 000	24 000
Mass moment of inertia	10 <sup>-6</sup> kg·m <sup>2</sup>	2,33	14,01	37,99	104,28	203,55

### Bellows coupling with clamping hub



Technical data		Type BK2...				
		...15	...30	...60	...80	...150
Rated torque	N·m	15	30	60	80	150
Total length	mm	59 / 66	69 / 77	83 / 93	94 / 106	95 / 107
Compliance, axial	mm	1 / 2	1 / 2	1,5 / 2	2 / 3	2 / 3
Compliance, radial	mm	0,15 / 0,2	0,2 / 0,25	0,2 / 0,25	0,2 / 0,25	0,2 / 0,25
Torsional spring constant	10 <sup>6</sup> N·m/rad	0,02 / 0,015	0,039 / 0,028	0,076 / 0,055	0,129 / 0,085	0,175 / 0,110
Maximum speed	min <sup>-1</sup>	<10 000 >10 000 for precision-balanced version				
Mass moment of inertia	10 <sup>-6</sup> kg·m <sup>2</sup>	70 / 80	140 / 150	230 / 260	650 / 670	2 500 / 3 200

Technical data		Type BK2...				
		...200	...300	...500	...800	...1500
Rated torque	N·m	200	300	500	800	1 500
Total length	mm	105 / 117	111 / 125	133 / 146	140	166
Compliance, axial	mm	2 / 3	2,5 / 3,5	2,5 / 3,5	3,5	3,5
Compliance, radial	mm	0,25 / 0,3	0,25 / 0,3	0,3 / 0,35	0,35	0,35
Torsional spring constant	10 <sup>6</sup> N·m/rad	0,191 / 0,140	0,450 / 0,350	0,510 / 0,500	0,780	1,304
Maximum speed	min <sup>-1</sup>	<10 000 >10 000 for precision-balanced version				
Mass moment of inertia	10 <sup>-6</sup> kg·m <sup>2</sup>	4 500 / 5 400	8 500 / 10 500	17 300 / 19 600	24 300	49 200

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measure. analyze. innovate.

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