Aviation and aerospace

Acceleration measurement
Accelerometers and force sensor solutions

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Aviation and aerospace acceleration measurement

Accelerometers are commonly used for aviation and aerospace applications to measure and analyze performance criteria. They complement research, development and testing to ensure that operational specifications are satisfied. Force sensors are also well-suited supplements to these measurements.

Kistler IEPE accelerometers offer many application benefits. For example, PiezoStar® and K-Shear® quartz accelerometers feature very low temperature sensitivity, which is ideal for minimizing measurement errors for dynamic temperature applications common in flight testing. Similar Kistler IEPE accelerometer technology is also used operationally on the International Space Station (ISS), in conjunction with the control movement gyro that provides attitude control of the ISS.

PiezoBeam® modal accelerometers provide high dynamic range and low mass for ground vibration testing (GVT), while complementing DAQ systems and analysis software with IEEE 1451.4 compliant Transducer Electronic Data Sheet (TEDS) technology. Those sensors also offer inexpensive solutions for Single Input Multiple Output (SIMO) and Multiple Input Multiple Output (MIMO) structural testing.

PiezoStar and K-Shear quartz IEPE accelerometers have been engineered to satisfy demanding cryogenic applications (−196 °C/−320 °F) to test and qualify space-based equipment. They have been designed to offer a very low thermal sensitivity when temperature stability is a must.

Kistler single and 3-component piezoelectric force sensors enable the user to measure imparted forces in structures for mechanical transfer function and Frequency Response Function (FRF) measurements. These force sensors are also used in environmental testing to simulate launch environment conditions using force limited vibration.

K-Beam® variable capacitance accelerometers offer DC response with low noise and stability with temperature-to-measure low frequency vibrational modes for large structures, motion measurement and dynamic structural response during ground and flight testing. Their low profile and various mounting option makes it ideal for limited mounting space.

Kistler’s quartz shear shock sensors accurately measure transient events, as well as high-level cyclical events typically found in separation events and landing gear/brake testing. Their design has been optimized for ruggedness and stability during harsh applications, such as pyro-shock.

High impedance accelerometers provide measurements up to 250 °C/482 °F, in addition to measurement range flexibility with an external charge amplifier. These accelerometers are well-suited for environmental testing or measurement of engine vibration.

Aviation and aerospace testing standards associated with space payloads and aircraft flight/ground applications demand sensor technologies that can cover the wide application needs. From modest laboratories to the most demanding operational environments, Kistler accelerometers and force sensors satisfy the requirements.

Many countries have one or more accrediting bodies responsible for the accreditation of their nation’s laboratories. These accreditation bodies have adopted ISO/IEC 17025 as a uniform standard to accredit testing and calibration laboratories.

Globally, over forty International Laboratory Accreditation Cooperation (ILAC) accreditation bodies are included in mutual recognition arrangements, which greatly enhance the acceptance of data worldwide. The Kistler North American Product Center is ISO/IEC 17025 accredited by ACLASS and Kistler’s European Product Centers are ISO/IEC 17025 accredited by the Swiss Accreditation Service (SAS Switzerland) or Deutscher Kalibrierdienst (DKD-Germany). These accrediting bodies are ILAC Mutual Recognition Arrangements (MRA) signatories ensuring full compliance with ISO/IEC 17025.
Cryogenic applications: environmental, background vibration and modal testing

Cryogenic environmental and modal testing is associated with systems, sub-systems and components for R&D.

Space-based equipment is exposed to environmental conditions, including vibration, shock and temperature.

Types 8730A and 8793A500M8 quartz single and triaxial accelerometers provide 10 kHz response at cryogenic temperatures. These sensor types have performed in liquid helium environments.

Modal analysis, at cryo temperatures, is performed with the low mass PiezoStar 100 mV/g, Type 8703A500M8 accelerometer and Type 9712M011 IEPE internally preloaded force sensor to measure the input force to resolve the FRF’s.

Background vibration testing at cryogenic temperatures become possible with the high sensitivity 1 000 mV/g Piezostar Type 8712B5D0CB *.

GOCE – gravity field and steady-state ocean circulation explorer

Type 8730A500M8
• K-Shear miniature accelerometer
• (~−196 ... 120 °C/−320 ... 250 °F)
• 500 g range

Type 8793A500M8
• K-Shear triaxial accelerometer
• (~−196 ... 120 °C/−320 ... 250 °F)
• 500 g range

Types 8703A ... M8
• IEPE accelerometer for cryogenic applications
• Ultra-high stability for dynamic temperature applications
• (~−196 ... 120 °C/−320 ... 250 °F)
• 50 and 250 g range

Type 8705A ... M8
• PiezoStar IEPE accelerometer for cryogenic applications
• Ultra-high stability for dynamic temperature applications
• (~−196 ... 120 °C/−320 ... 250 °F)
• 50 and 250 g range

Type 8712B5D0CB *
• PiezoStar high sensitivity IEPE accelerometer for cryogenic applications
• Ultra-high stability for dynamic temperature applications
• (~−196 ... 120 °C/−320 ... 250 °F)
• 5 g range (1 000 mV/g)

Type 9712M011
• Quartz IEPE load cells
• (~−196 ... 120 °C/−320 ... 250 °F)

* Product Availability: Please contact Kistler

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Space payload: shock and vibration testing

Testing of space payloads may utilize higher g range accelerometers to perform a variety of testing due to the complexity of sensor mounting for the application. Testing includes vibro-acoustic, environmental and modal analysis where a single sensor is selected by a measurement resolution compromise. Single-axis accelerometers, such as Type 8715A5000M5 and Type 8730A500..., may also be mounted on a cube for triaxial measurement. Triaxial accelerometers may also be used.

At times, accelerometers are not removed after testing and will reside with the payload during the mission. These accelerometers have hermetic titanium construction and have materials which do not outgas.

When modal analysis is performed with separate sensors, Type 8688A... offers high dynamic range and low mass, as well as IEEE 1451.4 Transducer Electronic Data Sheet (TEDS).

Triaxial Type 8763B... shows a unique housing construction with a mounting thread for each measuring direction. This allows for an easy stud mounting in each direction but also for a more accurate high frequency calibration on x- and y- axis where mounting adapters are usually needed.
Space payload: force limited vibration

Space payload test vibration specifications are representative of the enveloped actual flight environment.

In actual flight, input acceleration is notched at the payload resonant frequencies, as the mechanical impedance of the structural mount and payload is similar.

In shaker testing, space payload interface forces are higher at the payload resonances because the shaker has very high mechanical impedance and is controlled by the enveloped interface acceleration.

By measuring and limiting the reaction forces between the payload and the slip table, the acceleration at the payload resonances will be notched; preventing over testing which could damage expensive space payloads.

Interface force measurement is performed by a force dynamometer to resolve the forces (and moments) during vibration testing. Kistler 3-component force sensors are sandwiched between 2 metal rings. The ring assembly is attached to the slip table and to the payload under test to measure the reaction forces.

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3-component force links mounted on base plate, which is connected to the shaker. A force ring is then mounted to the load cell, which is sandwiched between the top and bottom ring. The space payload is mounted on the top ring for the FLV-test.

Types 9027C... and 9077C... are examples of un-preloaded 3-component force sensors. Types 9327C... and 9377C... are externally preloaded force links, which interface directly to the force rings and do not require additional preloading.

Kistler 3-component force sensors provide extremely low crosstalk resulting in more accurate measurements. These quartz PE force sensors can be easily ranged with an external charge amplifier to support various payload sizes.

Type 8766A... miniature IEPE triaxial accelerometers complement FLV testing and may include optional IEEE 1451.4 Transducer Electronic Data Sheet (TEDS).
Environment test: components and subsystems

Environmental testing subjects test items to one, some, or all of the following: temperature, humidity, altitude/pressure, sinusoidal vibration, random vibration and shock.

This testing is performed to verify product design and reliability, as well as to ensure survivability in the application. Miniature accelerometers, such as Types 8278A500, 8778A5000 and 8714B, can be mounted in the tightest locations and have low mass loading.

PiezoStar Type 8703A500 provides the lowest temperature sensitivity, minimizing temperature errors in both control and response accelerometers.

Triaxial Type 8766A... shows a unique housing construction with a mounting thread for each measuring direction. This allows for an easy stud mounting in each direction but also for a more accurate high frequency calibration on x- and y-axis where mounting adapters are usually needed.

Space payload, launch vehicle shock and mid-far field pyroshock

Wide bandwidth and high-level shocks result from mechanical and explosive separation events. Quantifying these shock levels is required to ensure structural integrity and survivability of equipment to support the mission requirements.

IEPE quartz accelerometers, such as Types 8742A... and 8743A..., provide over 100 kHz natural frequency to accurately measure these wide-band events. 3-component measurements are performed by mounting the shock sensors on an electrically isolated cube. Type 8044 is a high impedance shock accelerometer that can be mounted similarly to Type 8742A... An external charge amplifier is needed to range the measurement chain.

Source: NASA

- Type 8703A...
  - PiezoStar triaxial miniature IEPE accelerometer
  - For high temperature applications up to 165 °C (330 °F)
  - High thermal stability
  - 100 g range
- Type 8742A... or Type 8743A...
  - Up to 100 000 g range
- Type 8744
  - High impact quartz accelerometer
- Type 8766A...
  - PiezoStar triaxial miniature IEPE accelerometer
  - For high temperature applications up to 165 °C (330 °F)
  - High thermal stability
  - 50 ... 1 000 g range
- Type 8278A...
  - PiezoStar IEPE accelerometer
  - For high temperature applications up to 165 °C (330 °F)
  - 50 g or 250 g range
- Type 8778A500
  - Ultra miniature Ceramic Shear IEPE accelerometer
  - Charge output for up to 180 °C (355 °F)
- Type 8714B
  - Miniature Ceramic Shear IEPE through hole accelerometer
  - For high temperature applications
- Type 8044
  - High impact quartz accelerometer
Ground vibration test (GVT): modal/structural testing

Modal/structural tests – systems, sub-systems and components.

Triaxial modal accelerometers, like PiezoBeam® Type 8688A... and Ceramic Shear Type 8762A..., offer inexpensive solutions for SIMO or MIMO structural testing.

Such investigations typically require a large number of high performing accelerometers at low cost. Kistler modal accelerometers have three measurement ranges of 5 g, 10 g and 50 g and offer an accurate frequency and phase response in the specified frequency range.

Modal analysis was regularly performed on the Space Shuttle. Computing the results to original baseline data is used to detect structural changes and potential damage.

Types 8688A... and 8640A... provide an optional IEEE 1451.4 Transducer Electronic Data Sheet (TEDS). TEDS provides automatic transfer of sensor parameters to TEDS capable signal conditioning minimizing transcription errors and record keeping tasks.

Type 8688A...
- PiezoBeam IEPE triaxial accelerometer for modal testing
- TEDS option
- (~−40 °C ... 65 °C/−40 °F ... 150 °F)
- 5 g, 10 g or 50 g range

Type 8762A...
- Triaxial annular Ceramic Shear, lightweight IEPE mode accelerometer for modal testing
- TEDS option
- (~−55 °C ... 80 °C/−65 °F ... 180 °F)
- 5 g, 10 g or 50 g range

Type 8640A...
- PiezoBeam IEPE accelerometer for modal testing
- TEDS option
- (~−40 °C ... 65 °C/−40 °F ... 150 °F)
- 5 g, 10 g or 50 g range

Type 8770A
- IEPE Impedance Head for simultaneous measurement of force and acceleration
- (~−55 °C ... 120 °C/−65 °F ... 250 °F)

Type 872x...
- IEPE Impulse Hammer
- 500 ... 20 000 N (110 lbf ... 4 500 lbf)

Type 9712B...
- IEPE Force Sensor for modal analysis applications
- 22 ... 22 000 N (5 lbf ... 5 000 lbf)
Flight vibration testing

Quartz IEPE accelerometers, such as Type 8794A500M5, have historically delivered good performance in dynamic temperatures common to flight testing. PiezoStar accelerometers, such as Type 8765A250M5, Type 8766A...H and Type 8703A...M5, offer the lowest temperature sensitivity.

Accelerometers mounted on the outside of the aircraft must have low profile and low drag. Quartz triaxial accelerometers, such as Type 8794A500M5, provide these benefits for on-wing mounting. For accelerometers mounted outside the aircraft, it is common to use a sandable, 2-part rapid cure epoxy over the sensor and cabling to reduce drag. Accelerometers are also mounted throughout the aircraft, including the fuselage, control surfaces, inside wings and near avionics.

K-Beam variable capacitance accelerometers like Type 8315A... are low profile and provide DC response to measure in-flight motion, as well as lower frequency vibration, such as flutter.

Triaxial Type 8766A... exhibits a unique housing construction with a mounting thread for each measuring direction. This allows for easy stud mounting in each direction, in addition to more accurate high frequency calibration on x- and y- axis where mounting adapters are typically needed.
Landing gear/brake testing

Flight and ground based testing:

Landing exerts high-level forces and shocks onto the landing gear strut and aircraft structure. PiezoStar single-axis accelerometer Type 8703A250M1 provides 10 kHz response, as well as stability with temperature to assess strut integrity. Quartz rotational accelerometers provide a durable solution with the capability to reject high level linear accelerations in order to resolve the torsional components when landing the aircraft.

Maintenance of landing gear/braking is critical to safety. Aircraft brake dynamometer testing simulates actual operating conditions including taxiing, take-offs and landings. The resulting high-level cyclic vibration may not be easily measured with conventional shock sensors.

Kistler Type 8742A5 provides a durable solution suitable for both transient events and high-level cyclic vibrations. Such sensors are typically mounted on a cube for 3-axis measurement.
# Key product overview

## Single-axis accelerometers

<table>
<thead>
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<th>Type</th>
<th>Range g</th>
<th>Sens. mV/g</th>
<th>Freq. res. (5 %)</th>
<th>Temperature range °C</th>
<th>Temperature range °F</th>
<th>Threshold g</th>
<th>Mass gram</th>
<th>Gnd Iso</th>
<th>TEDS</th>
<th>Payload test</th>
<th>Shock</th>
<th>Enviro test</th>
<th>Ground test</th>
<th>Flight test</th>
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## Triaxial accelerometers

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<th>Freq. res. (5 %)</th>
<th>Temperature range °C</th>
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<th>Threshold g</th>
<th>Mass gram</th>
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Key product overview

Force sensors

<table>
<thead>
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<th>Type</th>
<th>Z range, kN (klbf)</th>
<th>Z sen. pC/N (pC/klbf)</th>
<th>X, Y range kN (klbf)</th>
<th>Temperature range °C</th>
<th>Temperature range °F</th>
<th>Crosstalk Fz -&gt; Fx, Fy %</th>
<th>Pre-loaded</th>
<th>Cryogenic</th>
<th>Payload test</th>
<th>Shock</th>
<th>Enviro-test</th>
<th>Ground test</th>
<th>Flight test</th>
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<td>9077C</td>
<td>±150 (±33,7)</td>
<td>-2 (8 900)</td>
<td>±4</td>
<td>-4,2 (-18 682)</td>
<td>-40 ... 120</td>
<td>-40 ... 250</td>
<td>&lt;±0,5</td>
<td>No</td>
<td></td>
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</tr>
<tr>
<td>9327C</td>
<td>±8 (±1,8)</td>
<td>-3,8 (-16 888)</td>
<td>±75</td>
<td>-7,8 (-34 696)</td>
<td>-40 ... 120</td>
<td>-40 ... 250</td>
<td>&lt;±1</td>
<td>Yes</td>
<td></td>
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<tr>
<td>9377C</td>
<td>±150 (±33,7)</td>
<td>-1,95 (-8 679)</td>
<td>±75</td>
<td>-3,9 (-17 348)</td>
<td>-40 ... 120</td>
<td>-40 ... 250</td>
<td>&lt;±1</td>
<td>Yes</td>
<td></td>
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<tr>
<td>9712M011</td>
<td>±66 (±15)</td>
<td>76 mV/N</td>
<td>— (1)</td>
<td>— (1)</td>
<td>-196 ... 120</td>
<td>-320 ... 250</td>
<td>— (1)</td>
<td>Yes</td>
<td></td>
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</table>

(1) Does not apply to a single-component force sensor

Additional information

Acceleration

Accelerometer catalog 900-380

PiezoStar® crystals – a new dimension in sensor technology 920-240

PiezoStar® accelerometers – a unique piezoelectric measuring technology for vibration and dynamic temperature applications 700-340

Force and moment measurements in aerodynamics 920-363

NASA Discovery Modal Test 920-243

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