Aviation and Aerospace

Acceleration Measurement

Accelerometers and Force Sensor Solutions
Aviation and Aerospace Acceleration Measurement

Accelerometers are commonly used for aviation and aerospace applications to measure and understand performance criteria and at times force sensors supplement these measurements. Such measurements complement research, development and testing to ensure that the operational specifications are satisfied.

Kistler IEPE accelerometers offer many application benefits. For example, PiezoStar® and K-Shear® quartz accelerometers have 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 moment 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.

PiezoStar and K-Shear quartz IEPE accelerometers have also been engineered to satisfy demanding cryogenic (~196 °C) applications to test and qualify space based equipment.

Kistler single and three-component piezoelectric force sensors provide the ability to measure imparted forces in structures for mechanical transfer function and FRF measurements as well as environmental testing to simulate the launch environment using force limited vibration.

K-Beam® variable capacitance accelerometers provide 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.

Kistler’s quartz shear shock sensors accurately measure transient events as well as high level cyclical events as found in separation events and landing gear/braking testing.

High impedance accelerometers provide measurements to 250 °C (482 °F) and measurement range flexibility with an external charge amplifier for environmental testing or measurement of engine vibration.

Aviation and aerospace testing requirements associated with space payloads and aircraft flight/ground applications demand sensor technologies that span the applications needs – as provided by Kistler accelerometers and force sensors.

Many countries have one or more accrediting bodies responsible for the accreditation of their nation’s laboratories. These accrediting 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.
Space Payload: Cryogenic Environmental and Modal Testing

Cyrogenic 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.

GOCE – Gravity Field and Steady-State Ocean Circulation Explorer
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 Types 8715A5000M5 and 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 to not out gas.

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).
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.

Diagram of force ring for a force limited vibration 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 8793A500 IEPE triaxial accelerometers complement FLV testing and may include optional IEEE 1451.4 Transducer Electronic Data Sheet (TEDS).
Environmental 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.

Such testing is performed to verify product design, manufacturability 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.

Space Payload and 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 Type 8742A... and 8743A... provide over 100 kHz natural frequency to accurately measure such 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 which can be mounted similar to Type 8742A... however an external charge amplifier is needed to range the measurement chain.

Investigation of pyroshock initiated separation processes

Source: NASA
Ground Vibration Test (GVT)

Modal/structural tests – systems, subsystems 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 is 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 8772A... 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.

Source: NASA

Modal accelerometers mounted to Space Shuttle body flap

Type 8772A...
Uniaxial PiezoSmart®
cube accelerometer, 5, 10 and 50 g range for modal testing, optional TEDS available (0... 65 °C)

Type 8688A...
Triaxial PiezoBeam® IEPE accelerometer in 5 g, 10 g or 50 g range for modal testing, optional TEDS available (0... 55 °C)

Type 8762A...
Triaxial annual Ceramic Shear light weight IEPE mode accelerometer; in 5 g, 10 g or 50 g range for modal testing available (0... 65 °C)

Type 8640A...
PiezoBeam® IEPE accelerometer in 5 g, 10 g or 50 g range for modal testing, optional TEDS is available (0... 55 °C)
Flight Vibration Testing

Quartz IEPE Accelerometers like Type 8794A500M5 historically have delivered good performance in dynamic temperatures common to Flight Testing. However, new PiezoStar accelerometers, like Types 8765A250M5, 8766A...H and 8703A...M5, offer the lowest temperature sensitivity.

Accelerometers mounted on the outside of the aircraft must have a low profile and low drag. Quartz triaxial accelerometers like Type 8794A500M5 provide such 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.
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 to resolve the torsional components when landing the aircraft.

Maintenance of landing gear/braking is critical to safety. Aircraft brake dynameter 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 be mounted on a cube for 3-axis measurement.

Aircraft landing gear/brakes

Source: NASA

Type 8703A250M1
Uniaxial high temperature PiezoStar® IEPE accelerometer, ultra high stability for dynamic temperature application (–55 ... 120 °C)

Type 8742A5
Shock accelerometer (–55 ... 120 °C)

Type 8838/40
Axial/lateral rotational accelerometer for angular acceleration up to 150 krad/s² (–55 ... 120 °C)
## Product Overview

### Accelerometers

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<th>Mass gram</th>
<th>Gnd Iso</th>
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<th>TEDS</th>
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*Note: TEDS indicates whether the product has Test Equipment Data Sheets.*
## Force Sensors

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<th>Type</th>
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<th>Z Sen. pC/N</th>
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<th>X, Y Sen. pC/N</th>
<th>Temperature °C</th>
<th>Crosstalk Fz -&gt; Fx, Fy %</th>
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(1) Does not apply to a single component force sensor

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Selected sensors and measurement ranges are shown in the tables. Refer to Kistler Accelerometer Catalog (900-380) or www.kistler.com for the entire Kistler product portfolio and all measurement ranges.

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Technical Literature

### Additional Information

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<tr>
<th>Accelerometer Catalog</th>
<th>900-380</th>
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<tr>
<td>PiezoStar Crystals – A New Dimension in Sensor Technology</td>
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<td>PiezoStar Accelerometers – A Unique Piezoelectric Measuring Technology for Vibration and Dynamic Temperature Applications</td>
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<td>NASA Discovery Modal Test</td>
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www.kistler.com