Optimizing DC and Very Low Frequency Acceleration Measurement with a Small Sensor

15th Annual ITEA Test Instrumentation Workshop

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LM INSTRUMENTS

1. **Piezoelectric accelerometers**
2. **Servo force balance accelerometers**
   - Construction, performance & applications
3. **Inclinometers**
4. **Angular accelerometers**
5. **Future?**
6. **Summary**

Piezoelectric accelerometers

- Late 40's to evaluate airframes
- Piezo-ceramic disk between reaction mass and cylindrical base
- Low strain sensitivity and low cross axis error
- Shear and KONIC (pat.) designs
- Dynamic behavior of structures & machines, predictive maintenance and fault diagnosis

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Piezoelectric accelerometers

- Excellent and simple devices for wide frequency range vibration measurement
- Robustness and small size which can be mounted directly on the sample
- Basic technology can be used effectively in dynamic pressure sensors and in industrial microphones
- Design suitable for very high temperature applications (up to 750°F)
- Design also suitable for complete hermeticity – industrial applications
- Built-in amplifier can delivery “friendly” 4 - 20 mA or 0 to 10 Volts electrical output

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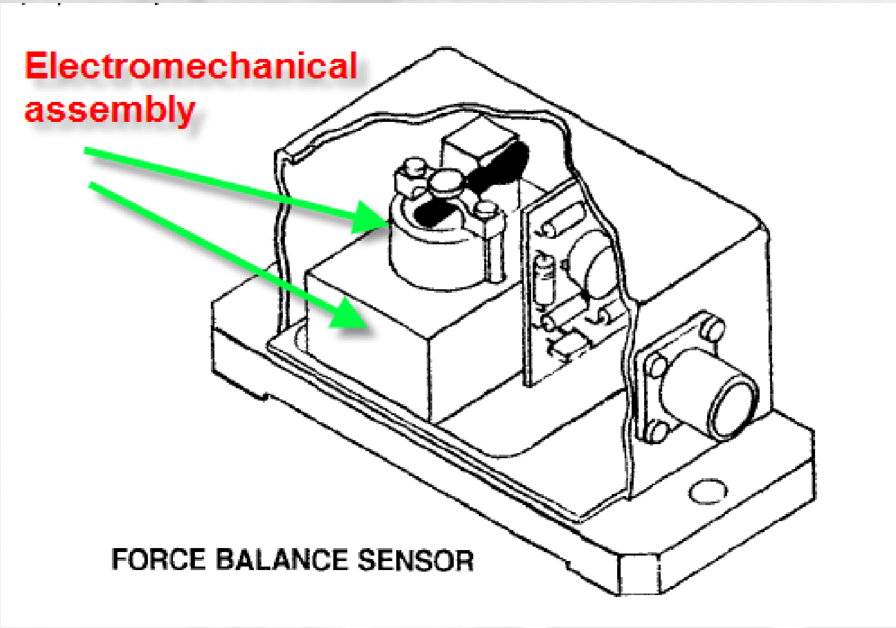
Servo force balance accelerometers



- Freely suspended mass constrained by an electric equivalent mechanical spring
- Two types – pendulous and linear displacement
- Newton’s second law of motion
  F = ma
- For pendulous **T = (ml)a** where (l) distance from axes of rotation to center mass, (m) pendulous mass and T is torque
- Ability to measure very low acceleration from 0.0001 to 200g, from DC up to 300Hz
- Platform leveling, pipeline leveling, structural measurements, borehole mapping, seismic measurements, gun sight control, flight avionics and in-flight control of weapon systems.

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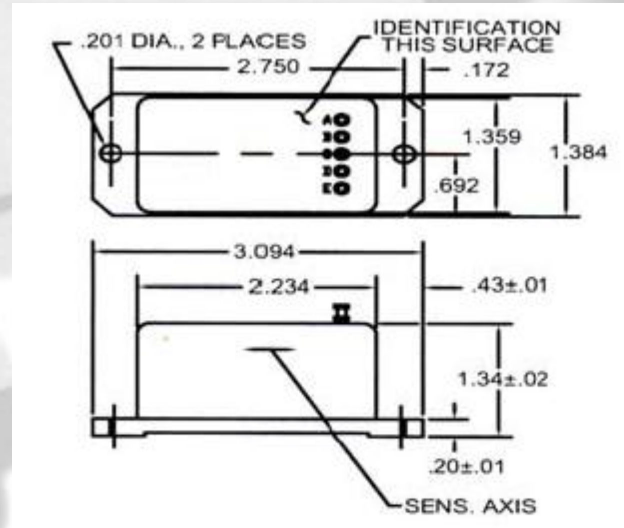
Servo force balance accelerometers



Specifications

Operational		
Ranges Available	±0.25 G To ±100 G	±0.1 G To ±100 G
Output Voltage	±7.5 Volts Into 10K Load	
Excitation	±15 ±1 VDC 10 mA Max.	
Output Impedance	<100 Ohms	

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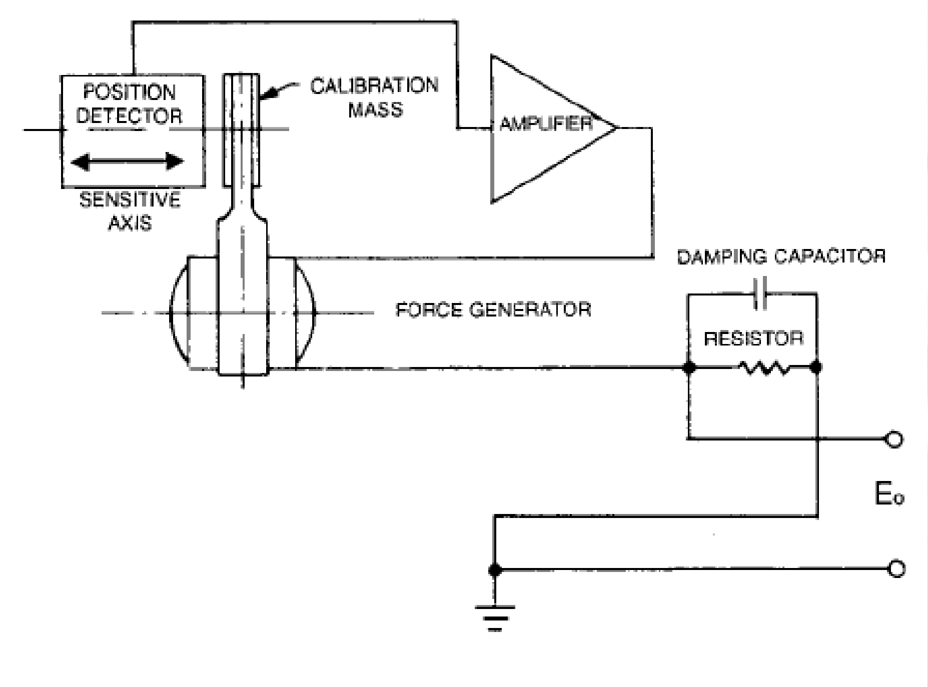
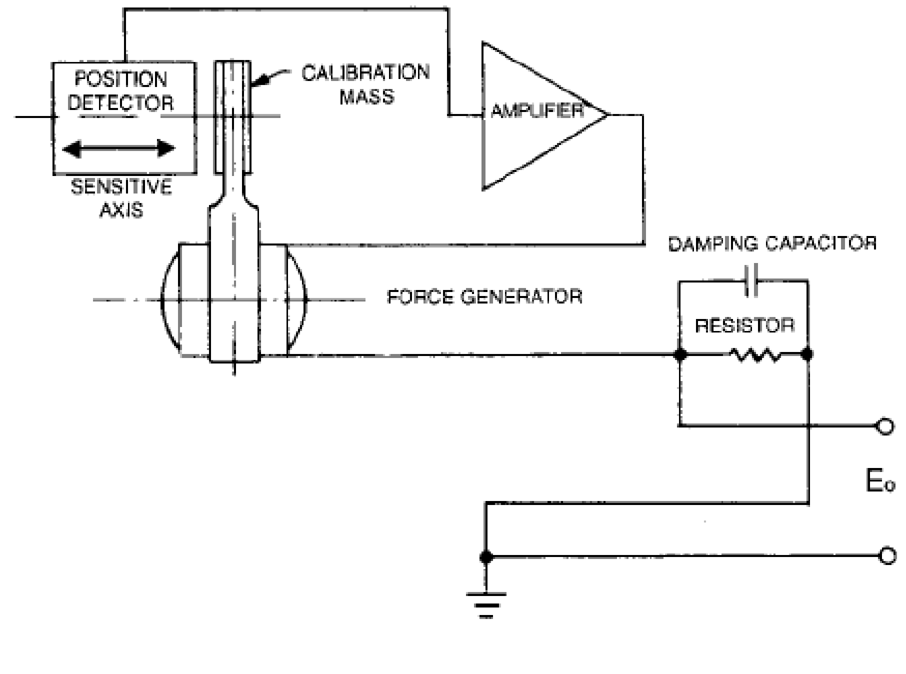
Servo force balance accelerometers



BLOCK DIAGRAM OF FORCE BALANCE SENSOR

- Position detector, amplifier and electromechanical system
- Converts a mechanical force into a proportional current, in turns converts into an equal but opposing mechanical force
- Position detector monitors position of the mass coupled to the force generator
- External induced mass changes the mass position – force generator drives mass to original position
- Sensor output is a measure of current through the force generator – proportional to restoring force – equal and opposite to the input force

Servo force balance accelerometers



BLOCK DIAGRAM OF FORCE BALANCE SENSOR

- Input acceleration is equal to the input force through the calibrated mass.
- No acceleration current through force generator is zero.
- Force generator current monitored by the resistor providing voltage proportional to original mechanical input
- Capacitor provides damping

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Servo force balance accelerometers

Mass suspension system

- Flexures, taut bands and bearings
- Flexures and taut bands are frictionless – excellent repeatability
- Flexures and taut bands are susceptible to shock and vibration
- Applications related - either pivot and jewel mechanism or bearings and shaft
- Bearings have excellent tolerance to mechanical shock and high vibration environments

Servo force balance accelerometers

Mass suspension system

- Bearings/shaft suspension versus etched-quartz seismic systems
- Bearing/shaft suspension is extremely rugged in shock environments
- Etched-quartz is fragile in rough industrial environments (i.e., down-hole drilling applications)
- Both designs are suitable for aerospace applications

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Servo force balance accelerometers

Advantages – exceptional performance, why?

- No internal displacements – LVDTs, pots, variable reluctance – errors hysteresis, non-linearity and non-repeatability
- Output non dependent on internal element displacement
- Strain gauge type sensors suffer temp. instability, creep and aging
- Force balance accelerometers are entirely self contained and interface directly to regular DAS.

Force balance accelerometers performance I

1. High temperature range stability → **0.02% / °C**
2. Linearity and hysteresis → ± **0.1% FS** up to **0.02% FS**
3. Cross axis sensitivity → **negligible** (minimized during calibration)
4. Warm up time → **1 sec**
5. Higher level output →**100mV/g**
6. No external signal conditioning required!

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Force balance accelerometers performance II

1. Frequency response → **DC** up to **300Hz**
2. Self test input → Current injected to stimulate input, can evaluate linearity and frequency response signal output
3. Highly adaptable design – inclinometers, accelerometer switch
4. Ability to introduce Z axis **1g bias** in tri-axial models

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Inclinometers

1. Uses the same suspension type pendulum including, position detector, amplifier and electromechanical force generator (torquer)
2. No tilt current through force generator is zero
3. Typically incorporates a 2 to 3Hz low pass filter
4. Sensor output is proportional to SINE of angle
5. Two mechanisms in one housing for X and Y tilt
6. 4 – 20 mA or ± 5VDC output choice
7. Fluid filled for extreme vibration and shock environments

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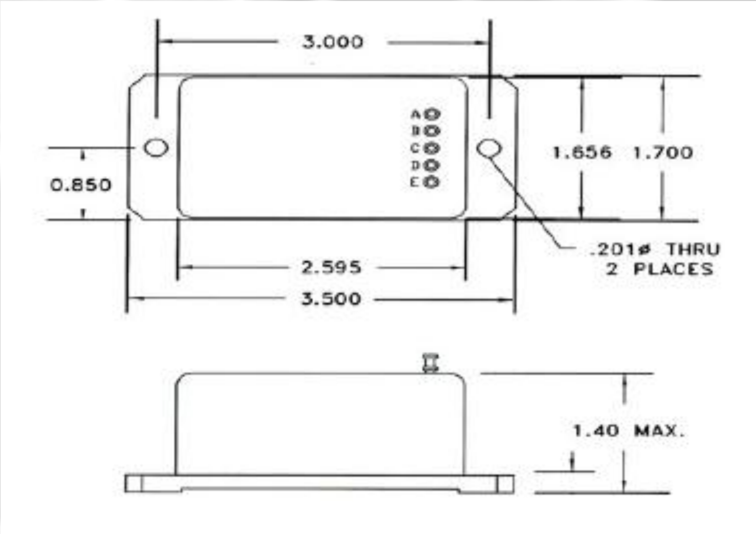
Inclinometers



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Inclinometers

Specifications **Operational**		
Ranges Available	±15°, ±30°, ±45°, ±90°	±5°, ±10°, ±15°, ±30°, ±45°, ±90°
Output Voltage	±5 VDC at Full Range Output Proportional to the Sine of the Angle	
Recommended Load	100K Ohms or Greater	
Excitation	±12 VDC to ±15 VDC <15 mA Each Supply	
Output Impedance	<100 Ohms	

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Inclinometers

Full Range Scale	Accuracy #1	Accuracy #2	Accuracy #3
±1°	±0.006°		
±5°	±0.01°	±0.02°	
±10°	±0.02°	±0.03°	
±15°	±0.03°	±0.05°	±0.10°
±30°	±0.06°	±0.09°	±0.18°
±45°	±0.1°	±0.15°	±0.30°
±45° to ±80°		±0.15°	±0.30°
±85°		±0.20°	±0.40°

⇒Accuracy varies over FSR due to gravity influence

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Angular accelerometers

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Angular accelerometers

1. Uses again same mechanism but in a rotary configuration
2. Only near DC design required – pure DC angular acceleration corresponds to body continually increasing in angular acc.
3. Ranges from ± 0.01 to ± 200 rad / sec² available, some models settable by the user
4. Excitation of ± 15VDC or +24 to +32 VDC possible
5. Fluid filled for extreme vibration and shock environments
6. Low angular acceleration used in rotational studies of stabilization of structures, platforms, antennas and ships
7. High angular acceleration used in weapon systems

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Future?

Inertial Measurement Units

Gyroscopes

- Guided weapons
- Unmanned vehicles
- Precision farming
- Factory automation
- Medical - orthopedic

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Summary

1. DC response
2. High accuracy
3. No external signal conditioning
4. High application customization

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