VBB VIAK

APPENDIX 1
EEP19/81

ICE FORCE STUDIES IN THE BOTHNIAN BAY Phase 2

DATA ACQUISITION SYSTEMS

ENZ/Iceproj14/ap-fs.18

DATA ACQUISITION SYSTEMS

1. Overview

The following instrument systems were developed and tested during Phase 1:

Instruments	Measured quantities	Derived quantities
Accelerometer system	Accelerations over the whole frequency range of interest	Dynamic ice forces (poor resolution for low-frequency accelerations)
Inclinometer system	Accelerations, (focused on low-frequencies)	Tilt angles and low-frequency ("static") ice forces
Pendulum system	Differential displacement between pendulum mass and reference point of lighthouse	Inclination and lateral displacements of the structure. Static and dynamic ice forces.

In principle, each system has a potential for measuring all the parameters needed for evaluating static and dynamic ice forces. There are, however, limitations which are basically associated with the problem of measuring static or nearly static and dynamic deflections at the same time and then separating the effects. This calls for a certain diversification in setting the measuring range, the resolution and the triggering levels for each system. After the introduction of the Fourier transformation technique for the processing of response data, it became evident that the inclinometer records had to be used for the low-frequency components of the responses. Since these records did not cover all the larger amplitudes of high-frequency accelerations, the accelerometer records had to be used for the high-frequency components of the accelerations.

In addition to the response measurement systems the instrumentation includes video camera systems and monitoring systems.

In the summer 1987 three ice force measurement panels were also installed on NORSTRÖMSGRUND. This system is described separately.

5.2 Accelerometer and inclinometer systems

As indicated above there is no distinct difference between the functions of the so called accelerometers and inclinometers and moreover, the pendulum system has a typical inclinometer function. However, we hope that a strict application of the nomenclature introduced above will prevent confusion.

The instruments are both operating as inertial instruments. (See Figure A1:1) An eccentrically supported mass exerts a torsional moment around the supporting axis and this moment is taken as a measurement of the inertia force and thus the acceleration of the instrument. If the instrument is tilted, the corresponding fraction of gravity force affects the mass and is consequently superimposed on the inertia force due to horizontal acceleration, if any. The most important difference between the instruments in the actual application is that the "inclinometers" (Manufacturer's nomenclature) can measure the tilt angle with a resolution of 0.5×10^{-6} radians as a minimum.

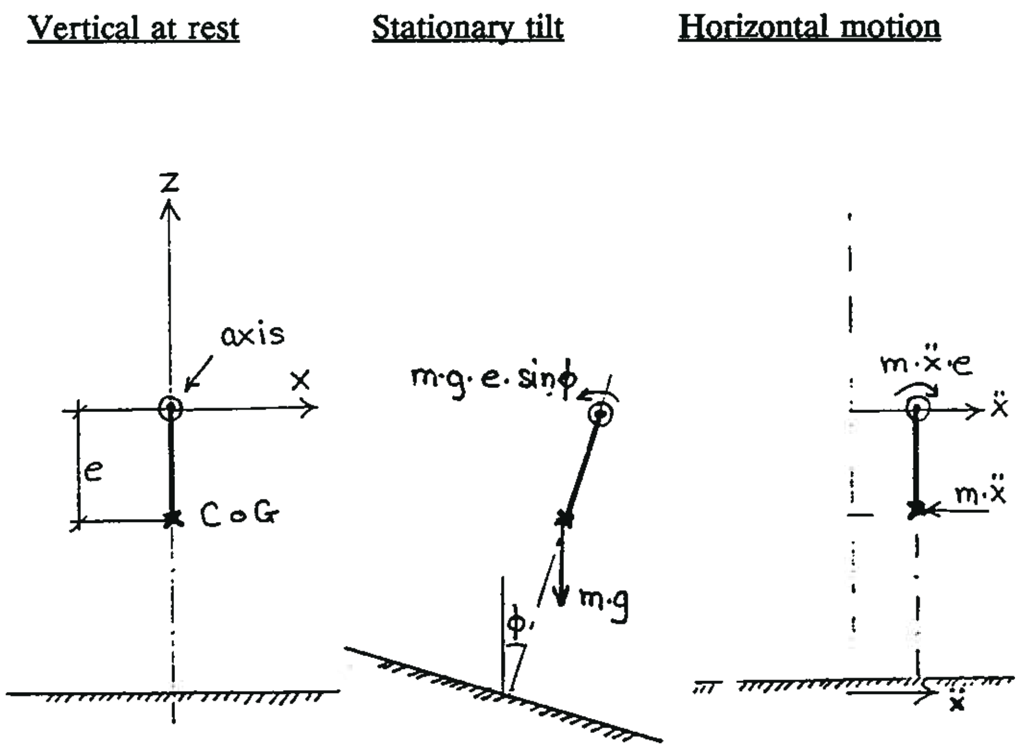


Figure A1:1

The moment turning around the instrument axis is $M = m \cdot e \cdot (\ddot{x} - g \sin\phi)$ where $\ddot{x}$ is the horizontal acceleration of the axis and $g \cdot \sin\phi$ is the gravity component as a function of the tilt angle.

The manufacturer's description of the instruments are attached to this appendix.

The normal data collection frequency is 50 readings per second.

Two of the accelerometers have been in operation on NORSTRÖMSGRUND since 1972. Whereas the signals were previously recorded in analogous form they are now digitized directly, which eliminates low-frequency disturbances.

The new data processing system was installed on NORSTRÖMSGRUND in the beginning of March 1986.

At each measurement point the acceleration components are measured in two orthogonal directions.

Descriptions of the entire accelerometer systems including manufacturer's specifications are given at the end of this section.

The pendulum system (Figure A1;2) was tested during springtime 1986 and the following observations and experiences were made during these tests.

The pendulum mass consists of two iron discs (10 kg each) separated by an adjustable rod. The mass was suspended from a slab in the lighthouse superstructure by a piano wire of 7.58 m length giving a natural period of about 5.5 seconds. To reduce effects of air flow disturbances on the wire it was run through a steel tube.

The position of the pendulum was measured by a two dimensional optical system which allowed a touchless measurement of the position in a plane.

The position measurement device was composed of a bar code reader and a bar pattern which was engraved on a plate attached underneath the pendulum. The resolution of the system was about 0.2 mm and maximum measurement range 5 cm.

The pendulum system was developed and tested in parallel with the installation and testing of the inclinometer system. Since the latter proved to perform satisfactorily, no further efforts were made with the development of the less mature pendulum system.

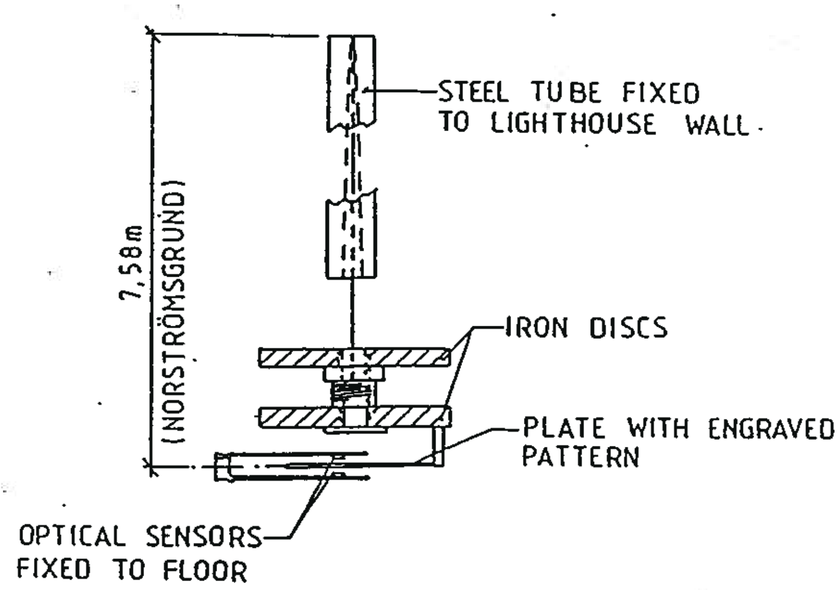


Figure A1:2

The pendulum system

3. Video camera system

Three video cameras were installed during Phase 1 on the superstructures of each of the lighthouses NORSTRÖMSGRUND and FARSTUGRUND. In 1992 the cameras on the latter lighthouse were moved to NORSTRÖMSGRUND.

The cameras are enclosed in protecting casings which are heated to keep the front glasses free from condensation. The cameras are provided with automatical iris adjustment devices, to make them adapt to different light conditions. They are not sensitive enough, however, to give good quality pictures during nighttime, so additional spotlights are arranged to improve the ordinary floodlights from the lighthouses.

The cameras are of mark KOYO with high sensitivity new-vicon tube 8 mm optics with F1.4 2/3" aperture. They are permanently connected to the power supply of the lighthouse.

A switching device connects the cameras sequentially to Video Cassette Recorders (VCR).

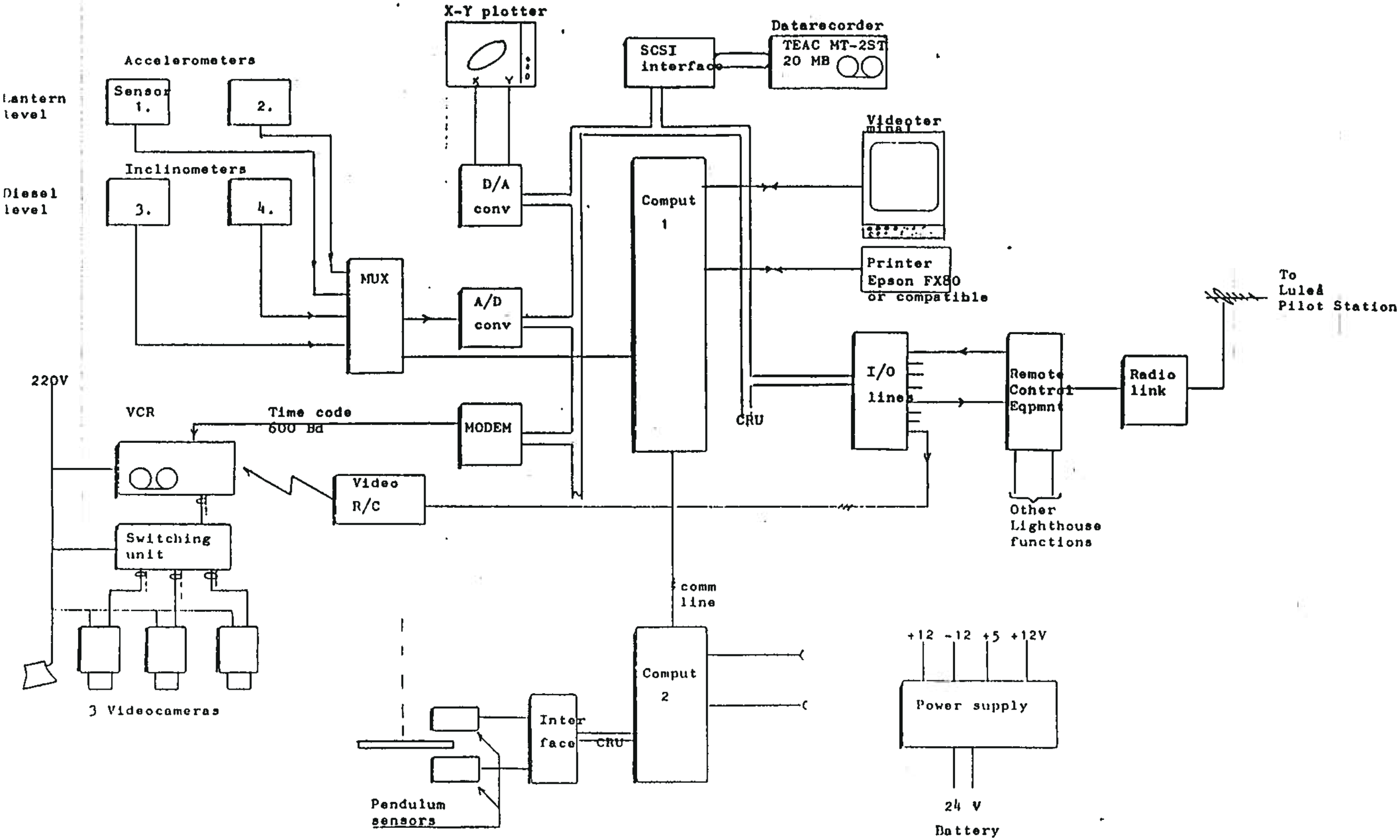
The switching device is synchronized with the accelerometer and inclinometer system, whereby the pictures can be correlated to the vibration measurements with a timing accuracy of 20 ms.

Absolute date and time information is also recorded on the audio channel to the VCR.

The VCR is a Panasonic G10 with a modified remote control unit connected to the accelerometer system which controls the start and stop of the recording.

4. Remote monitoring

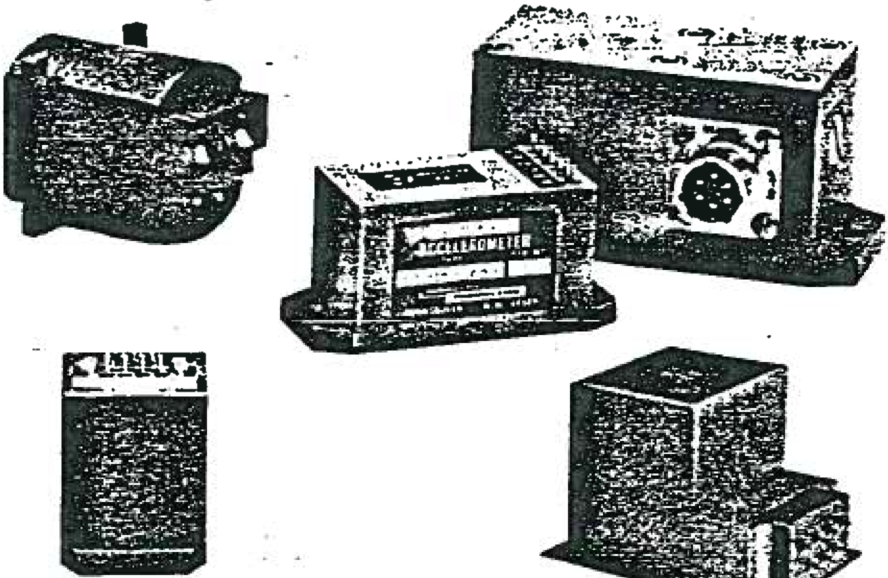
Remote control and monitoring is arranged between the lighthouse and a Central Monitor in Norrköping (CMN). Communication is established via a radiolink path to Luleå Pilot Station and then to the CMN over dialled-up telephone connections. The pilot station is provided with an automatic dialling equipment which dials the CMN in case of an alarm condition on the lighthouses. At present the remote control equipment is capable of transferring 7 maneuvres to the lighthouse and 14 indications from it. A number of these indications and maneuvres are already used for the operation of the lighthouse. One maneuvre is, however, used to start the accelerometer recording system and one indication is used to indicate the proper functioning of that maneuvre. When the accelerometer system starts recording, this indication is also sent to the CMN as an alarm to alert the personnel that there are indications of ice movements. The control personnel at the CMN are instructed to relay this information to people concerned so that proper actions can be taken.



Block schematic
Ice Force Measurement Arrangement at
Norströms Grund

APPENDIX 1:6

LINEAR AND ANGULAR SERVO ACCELEROMETERS



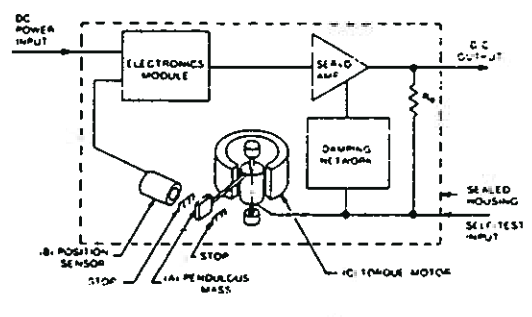
- DC Input — DC Output
- Small Size — Light Weight
- Electrical Self-test Feature
- High Reliability
- TSO Qualified Units
- MIL Qualified Units

Schaevitz servo accelerometers are DC-operated closed-loop force balance transducers for the measurement of acceleration. They are more stable and accurate than open-loop accelerometers by several orders of magnitude. Undesirable characteristics inherent in open-loop accelerometers such as sensitivity to supply voltage, non-linearity in the acceleration-to-position pickoff, and high thermal coefficients of scale factor and zero shift are negligible in closed-loop force balance accelerometers.

Typical applications of Schaevitz servo accelerometers are in high reliability guidance systems for missiles, torpedoes, or related military devices; stable platforms for spacecraft and shipboard requirements; monitoring and controlling deceleration in mass transit systems; and in roadbed analysis and fault detection equipment for high speed railways. Low range instruments can be used to level gun platforms, monitor the angle-of-elevation of naval guns or field artillery, and check-slope and grade in earthmoving or paving operations.

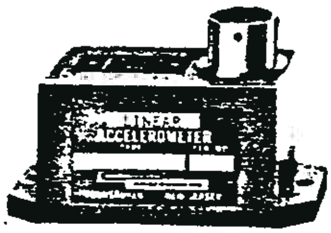
Many Schaevitz servo accelerometers have been MIL-qualified for use in a broad variety of weapons systems. Schaevitz also offers servo accelerometers that have been TSO-qualified by the FAA for flight avionics. For nearly twenty years, high reliability for such critical applications has been a significant feature of Schaevitz Inertial products. Depending on the application, the MTBF for Schaevitz servo accelerometers ranges between 25,000 and 100,000 hours.

In addition to the instruments offered in this catalog, Schaevitz Engineering designs and produces servo accelerometers specifically for a customer's particular application. These custom-designed units can be manufactured and tested in conformity with current military standards, utilizing the quality assurance procedures described in MIL-Q-9858A or MIL-Q-45208A.



A Schaevitz servo accelerometer is a closed-loop torque balance system. In the illustration above, pendulous mass (A) develops a torque proportional to the product of its mass unbalance and the applied acceleration. Motion of mass (A) is detected by position sensor (B) whose output signal is applied to an electronic amplifier. The output current from the servo amplifier is applied to torque motor (C), which then develops a torque exactly equal to, but directly opposed to, the initial torque from the pendulous mass (A). Thus mass (A) stops moving, assuming a position minutely differing from its original position before acceleration. The current through the torque motor is accurately proportional to input acceleration, and when passed through a stable resistor (Ro), an accurately proportional output voltage is developed. The instrument can be checked for proper servo operation (self-test) by applying an independent current input to the torque motor. By adjusting the parameters of the servo-amplifier and related electronic networks, the operating characteristics of a servo accelerometer can be changed or modified to suit a particular application. This same flexibility gives rise to a variety of optional features in some models.

SB Series



SB series accelerometers are intended for general use in the measurement of acceleration, guidance control systems, vehicle ride analysis, and a variety of other applications. A durable pivot-and-jewel sensor and miniature electronic module are integrated within a common housing, leaving space for several optional electronic circuits including telemetry output, output bias around a non-zero level, unipolar output, output limiting, bipolar output with a single supply voltage, and low impedance output. Pin or connector terminations are available.

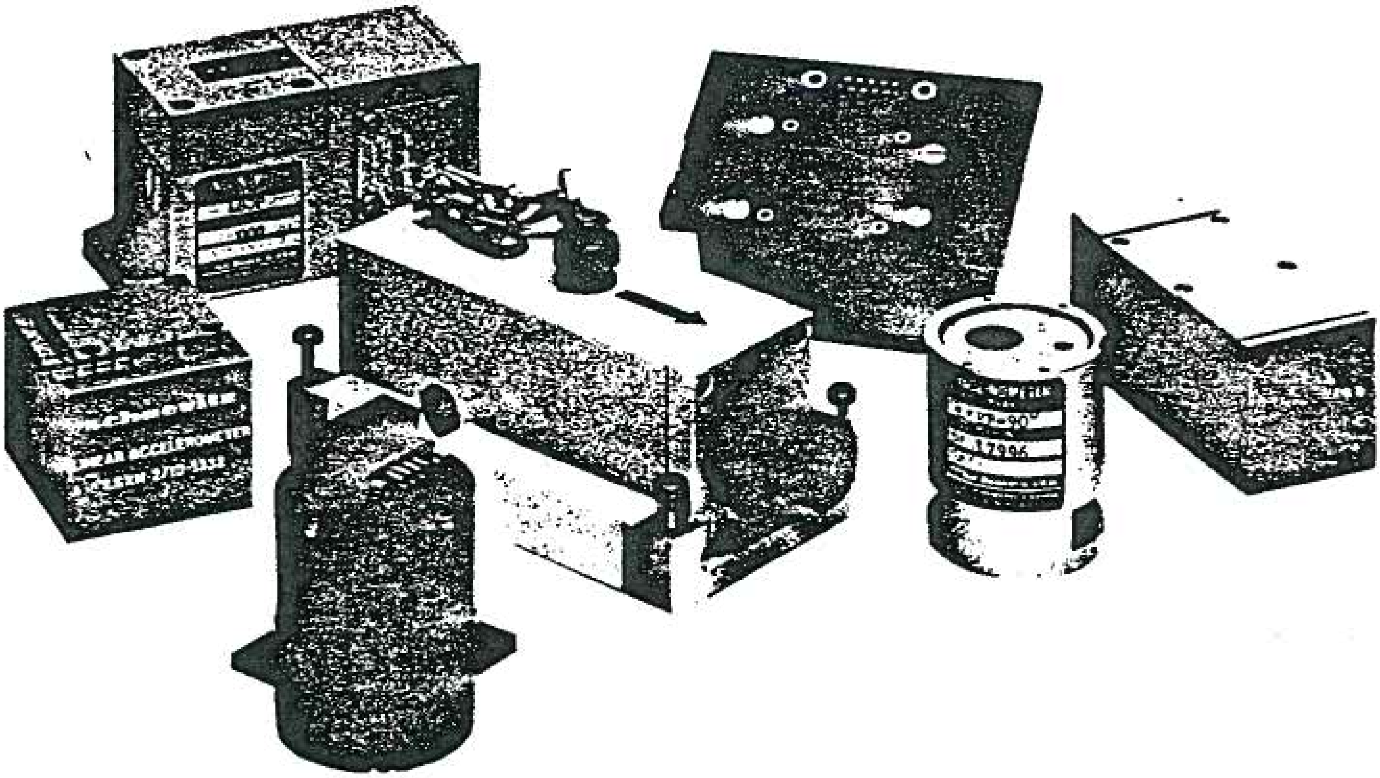
Specifications at 20°C

LSB Linear

Range g	Nominal Natural Frequency Hz	Nominal Output Impedance kilohms
± 0.25	50	20
± 0.5	70	10
± 1.0	100	5
± 2.0	140	2.5
± 5.0	125	5
±10.0	140	2.5
±20.0	160	5
±50.0	200	5

Input Voltage	±15V DC nominal
Input Current	10 mA DC maximum (6mA DC average)
Full-Range Open-Circuit Output Voltage	±5.0V DC
Damping Ratio	0.6 typical (0.3 to 1.0 on request)
Linearity (Notes 1 & 2)	±0.05% of full scale output to 10 g, ±0.1% of full scale output over 10 g
Hysteresis (Note 2)	0.02% of full scale
Resolution (Note 2)	0.0005% of full scale
Cross-Axis Sensitivity (Note 3)	±0.002 g per g up to ±10 g range, inclusive ±0.005 g per g over ±10 g range
Bias	Less than 0.1% of full scale
Sensitive Axis to Case Alignment	±1°
Noise Output	5mV rms maximum
Operating Temperature	−55°C to +95°C
Storage Temperature	−65°C to +105°C
Thermal Coefficient of Sensitivity	0.02% per °C
Thermal Coefficient of Bias	0.002% per °C
Shock Survival	100 g − 11 ms
Weight	3 oz.
Options (Note 4)	1-g bias (or any bias) Unipolar output 28 VDC input, 0.2-4.8 VDC Telemetry output 28 VDC input, bipolar, non-isolated output Low output impedance

INCLINOMETERS DC-OPERATED GRAVITY-REFERENCED TILT SENSORS



APPLICATIONS

- Borehole mapping, dam and rock shifts, and other geophysical, seismic, and civil engineering studies
- Ballast transfer systems for offshore barges, ships, and other marine applications
- Gunsight level control and calibration, weapons platforms, missile launchers
- Pipeline leveling, setting tilt of grading machines, crane overturning-moment alarms, and other heavy construction control requirements
- Large machinery installation, and other electronic level applications

FEATURES

- Units are fully self-contained. Connect to a DC power source and a readout or control device for a complete operating system
- High-level DC output signal proportional to sine of the angle of tilt from as little as ±1° full scale to ±90° full scale
- Responds to changes of slope as small as 0.000006"/ft, and changes in angle as small as 0.1 second of arc
- Hysteresis less than 0.0005% of full range output
- Vibration rectification less than 10 arc seconds/g^2

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DESCRIPTION

The Schaevitz inclinometer is an extremely sensitive transducer that measures horizontal angle or vertical deviation with virtually infinite resolution. Rugged enough to withstand severe shock and vibration, its "all weather" construction makes it ideally suited for use in the construction industry for setting tilt of road grading and paving machines; in the geophysics field for tilt and strong motion studies; in the civil engineering field for evaluation of tilt of supporting walls in dams and other structures; and other applications where high-accuracy measurement of tilt is required.

The Schaevitz inclinometer is fully self-contained and designed to operate from a standard DC power source. Its output is an analog DC signal directly proportional to the sine of the angle of tilt. In level (horizontal) position, the DC output is zero. When tilted in one direction, the inclinometer output is 0 to +5V DC. When tilted in the opposite direction, the output is 0 to –5V DC.

The inclinometer operates as a closed-loop torque balance servo system (Figure 1). The heart of this gravity-referenced angle detector is a torsional flexure-supported moving mass system that is rugged enough to withstand severe shock and vibrations and still maintain excellent precision and accuracy. The servo system electronics, torque motor, and feedback sensor are all enclosed within an environmentally sealed housing, permitting operation under hostile conditions without degrading performance.

PRINCIPLES OF OPERATION (Refer to Figure 1)

The Schaevitz inclinometer is a precision inertial instrument (accelerometer) that responds to the normal component of the gravitational acceleration vector (gravity). Pendulous mass (A) is attached to the torsionally suspended armature of torque motor (C). Stops on either side of the mass (A) limit its travel when the device is not powered. When the power is applied, the pendulous mass (A) automatically moves to its "zero" position.

As the inclinometer is tilted through some angle (Θ) along its sensitive axis, mass (A) tries to move in the direction of tilt as a result of a force (torque) applied to the mass by the normal component of gravitation acceleration. The resulting change in position of mass (A) is detected by position sensor (B), which produces an error signal output. This DC error signal is fed to a servo amplifier whose output is a DC current coupled to the armature of torque motor (C) through R_o. Current applied to the torque motor armature produces a torque that opposes the gravitational force acting on the mass (A) and moves it back toward its original position. When the torque developed by the servo system output current just balances the torque developed by the gravity vector component acting on pendulous mass (A), the mass no longer moves and is at rest almost in its original position, being displaced by some minute amount that produces the required error signal from position sensor (B). Because the gravity component's force is exactly equal in magnitude to the torque motor's output, which, in turn, is directly proportional to the applied current, this current, passed through R_o generates a voltage across R_o that is proportional to the normal component of the gravity vector. The normal component is the product of the essentially constant gravity vector times the sine of angle (Θ). Therefore, the output voltage, E_o x across R_o is proportional to the sine of the tilt angle Θ.

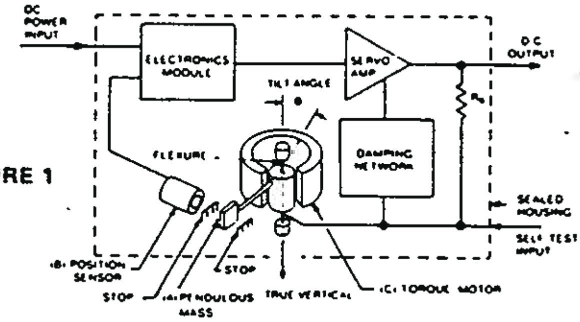

FIGURE 1

GENERAL OPERATING CHARACTERISTICS @ 20°C

Range	±1°	±3°	±14.5°	±30°	±90°
Input Voltage, V DC (Note 1)	±12 to ±18	±12 to ±18	±12 to ±18	±12 to ±18	±12 to ±18
Input Current, mA (nominal)	±15	±15	±15	±15	±15
Full Range Output (FRO) VDC (Note 2)	–5to +5	–5to +5	–5to +5	–5to +5	–5to +5
Output Standardization, % FRO	±1	±1	±1	±1	±1
Output Impedance, Ohms	15k	5k	16k	8k	4k
Output Noise, Vrms (Nominal)	0.002	0.002	0.002	0.002	0.002
Non-linearity, % FRO (Note 3)	0.05	0.02	0.02	0.02	0.02
Non-repeatability and Hysteresis, % FRO (maximum)	0.02	0.01	0.002	0.001	0.0005
Resolution, arc seconds	0.1	0.1	0.1	0.1	0.1
-3dB Frequency, Hz (typical)	0.5	1	15	20	40
Sensitive Axis-to-Case Misalignment, ° (maximum)	±0.1	±0.15	±0.25	±0.5	±1.0
Cross-axis Sensitivity, g/g cross (Note 4)	0.001	0.001	0.001	0.001	0.001
Output Offset at Zero Case Tilt, VDC (maximum) (Note 5)	±0.1	±0.04	±0.02	±0.02	±0.02
Vibration Rectification, arc seconds/g² (maximum)	10	10	10	10	10
Zero Tilt Offset Thermal Sensitivity, % FRO/°C	0.05	0.03	0.01	0.005	0.003
Scale Factor Thermal Sensitivity, % Reading/°C	0.02	0.01	0.003	0.003	0.003

ENVIRONMENTAL CHARACTERISTICS

Operating Temperature Range	–18°C to +71°C
Survival Temperature Range	–40°C to +75°C
Constant Acceleration Overload	50g
Shock Survival	1500g
Vibration Endurance-Sinusoidal	50g peak
Vibration Endurance-Random	35g rms, 20Hz to 2000Hz
Environmental Sealing	MIL-STD 202, Method 112

NOTES:

1) Units can be easily adapted to operate from single-ended, floating power supplies of 24 to 36 Volts DC.
2) Full Range is defined "from negative full input angle to positive full input angle".
3) Non-linearity is specified as deviation of output referenced to theoretical sine function value.
4) Cross-axis sensitivity is specified as the inclinometer output with a 1-g acceleration applied perpendicular to the sensitive axis, independent of case alignment errors.
5) Zero tilt offset is specified under static conditions with no vibration inputs; it represents the combination of mechanical bias, electrical bias, and axis-to-case alignment errors.