DIGITAL QUARTZ PRESSURE TRANSMITTERS FOR ACCURATE WATER LEVEL MEASUREMENTS

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ABSTRACT

Digital pressure transmitters have been developed for accurate, reliable, water level measurements. They upgrade and replace expensive, mechanically complex, high-maintenance, mercury manometers in gas bubbler systems. The transmitters use vibrating quartz crystal sensors and microprocessor based intelligent electronics to provide fully temperature-compensated, linearized, pressure output information in the new, standard SDI-12 format. This Serial Data Interface was defined and developed as an industry standard by transducer and data logger manufacturers in response to needs identified by the United States Geological Survey. The construction, operation, performance, and water level measurement applications of these transmitters are described.

BACKGROUND

The accurate measurement, recording, transmission, and analysis of water levels are of vital importance to the United States Geological Survey. As described in Reference 1, the Water-Resources Division of the USGS introduced a bubbler-gage manometer system in 1956. A number of subsequent design changes were made by the U.S.G.S. to improve reliability and reduce cost.

The bubbler-gage manometer system is shown in Figure 1. It consists of a gas bubble generating system feeding pressure in parallel to a mercury manometer and a tube/orifice placed in the water.

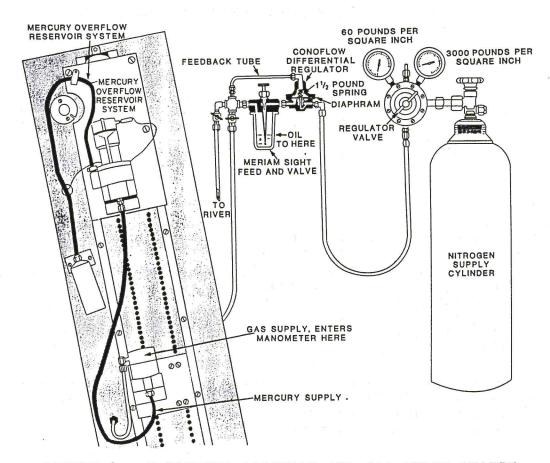


FIGURE 1: MANOMETER ASSEMBLY AND GAS-PURGE SYSTEM

The gas pressure necessary to balance out the water stage (height or head of water) also displaces the free surface of the liquid mercury in the pressure-cup reservoir of the manometer. A float switch and servo amplifier/control/servo motor unit drives the mercury reservoir up or down a threaded shaft (or roller chain, cable belt and sprocket drive system) until there is sufficient head of mercury to balance out the gas pressure. Because the density of mercury varies with temperature, all uncorrected mercury manometers used by the Geological Survey will have an error of 0.01 percent per degree Fahrenheit. These thermal errors can be reduced through an optional correcting device to the STACOM manometer which controls the angle of the manometer relative to vertical as a function of ambient temperature. Analog and digital water-stage shaft and punched paper tape recorders can be mechanically driven by sprockets on the manometer unit.

The desire for improved reliability and the need for a modern electrical interface prompted the Water Resources Division to search for an alternative system. Several years ago, the Hydrologic Instrumentation Facility evaluated high accuracy DIGIQUARTZ® Pressure Transmitters made by Paroscientific, Inc. of Redmond, Washington. Although the SDI-12 interface had not been defined at that time, these all solid state transmitters already had an intelligent RS-232 serial output. Subsequently a contract was let for the development and procurement of these pressure transmitters configured with the SDI-12 interface.

PRESSURE TRANSDUCER DESIGN

References 2, 3 and 4 describe the construction and operation of these vibrating quartz crystal sensors. The basic gauge pressure transducer design is shown in Figure 2.

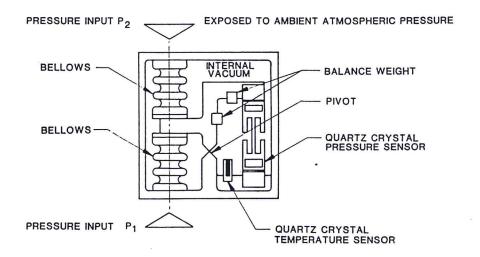
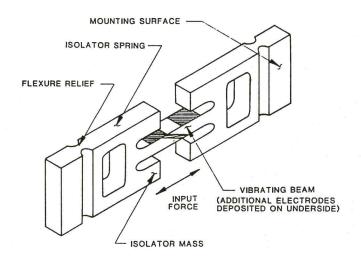


FIGURE 2: GAUGE PRESSURE TRANSDUCER

Gas input P1 from the bubbler system is at a pressure equal to the water stage plus ambient atmospheric pressure. Input P2 is at outside atmospheric pressure. The opposing bellows arrangement cancels out atmospheric pressure and results in a net force on the lever arm proportional to the water level. This force is transmitted through the lever arm to a load-sensitive vibrating quartz crystal (Figure 3).

The central beam of the crystal is piezoelectrically induced to vibrate in its fundamental resonant mode. An integral isolator mass/spring system ensures high Q operation in the internal vacuum of the housing. A change in fluid pressure at the bellows pressure port changes the axial load applied to the vibrating quartz beam and therefore changes its resonant vibrational frequency. An oscillator circuit tuned to the resonant frequency of the quartz beam tracks changes in the beam's vibrational frequency with time. Fluid head can therefore be calculated from a measurement of the output frequency or period of the oscillator circuit.



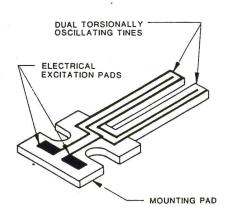


FIGURE 3: LOAD-SENSITIVE QUARTZ RESONATOR

FIGURE 4: TEMPERATURE-SENSITIVE QUARTZ RESONATOR

Each transducer also contains a second quartz crystal sensor which is used for precise temperature compensation of the pressure output. The temperature sensing crystal consists of two torsionally oscillating times connected to a mounting pad through a mechanical isolation system (Figure 4).

TRANSMITTER ELECTRONICS

The transmitter electronics measures the periods of the two transducer signals and calculates fully temperature-compensated pressure or depth output. As shown in Figure 5, the interface board has a microprocessor-controlled counter and SDI-12 port. The microprocessor operating program is stored in permanent memory (EPROM). User settable parameters are stored in EEPROM. The user interacts with the transmitter via the two-way SDI-12 bus. When a "measure" command is received, the microprocessor measures the periods of the transducer signals using the 14.4 MHz timebase counter, calculates pressure or depth, and holds the data in digital form for collection by a subsequent "data" command on the bus.

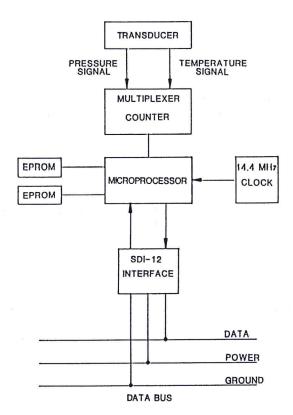


FIGURE 5: DIGITAL INTERFACE BOARD

SDI-12 is a hardware and software standard developed as an industry standard in response to needs identified by the U.S. Geological Survey. SDI-12 transmitters must be compatible with a standard hardware interface and must respond to standard software commands. This assures that all SDI-12 sensors will work directly with all standard SDI-12 data loggers. The transmitter receives commands from a data logger or user computer via the data bus and returns data via the same bus. The data bus is a 1200 baud serial ASCII multi-drop two-wire data bus using 0 and 5 volt logic levels.

The transmitters are designed for reliable field use under adverse environmental conditions. They are reverse polarity protected and incorporate surge and radio frequency interference suppression for use in proximity to telemetry systems. Current drain has been minimized (averaging less than 1 ma) for use in solar-powered and battery-powered applications.

The transmitters are available in a wide variety of pressure ranges. They support all standard SDI-12 commands, as defined in Reference 5, and meet the performance requirements of U.S.G.S. specification HIF-S-02 (Reference 6).

SPECIAL FEATURES

In addition to the standard SDI-12 commands, Paroscientific transmitters support a full set of extended commands which provide enhanced capabilities.

Users can select outputs in eight standard sets of engineering units or in user definable units.

Integration time is user settable over the range from 0.003 seconds to 40 seconds. A longer averaging time could be used to smooth over surface waves.

The transmitter supports much higher resolution than the standard U.S.G.S. increment of 0.01 foot. Users can select additional digits of precision as needed.

The transmitter can be used either with an SDI-12 bus or with a standard computer serial RS-232 port. All capabilities are supported with either bus.

An optional six-digit LCD digital display is available which can be used either with the SDI-12 bus or a stand-alone pressure readout.

The transmitter can also provide a shaft encoder output for use with Handar Model 550A shaft encoder data loggers.

Special commands are provided which make recalibration a simple field procedure.

SDI-12 WATER LEVEL SYSTEM

A typical SDI-12 water level system is shown in Figure 6. Systems of this type are now being used by the U.S. Geological Survey as direct replacements for mercury manometer systems. Note the similarity to Figure 1. Compared with the older designs, the new systems are smaller, simpler, more reliable, more rugged and lighter in weight. They have many fewer parts, and are easier to transport, install, and maintain. They have lower current drain and are directly compatible with standard data loggers and telemetry systems.

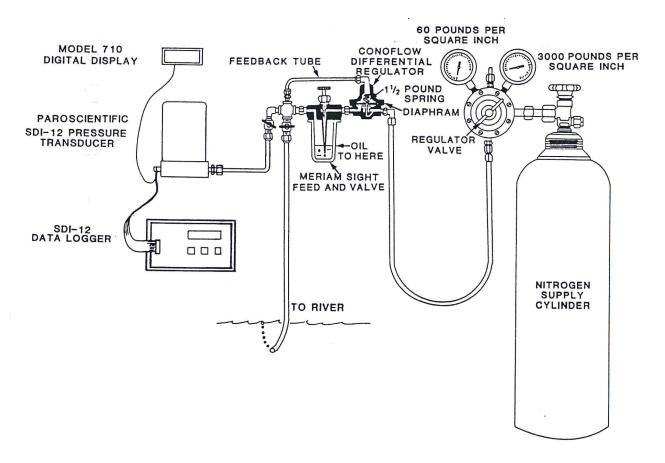


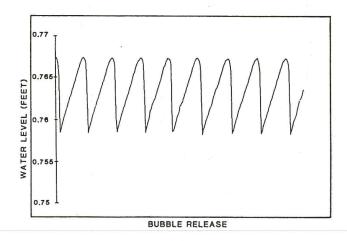
FIGURE 6: SDI-12 WATER LEVEL SYSTEM

The bubbler system generates static gas pressure that is approximately the same as the water pressure at the orifice of the gas line.

The digital quartz pressure transmitters are sensitive enough to view bubble formation and release. Figure 7 shows high resolution measurements taken with a transmitter on a gas bubbler system. Formation of individual bubbles is readily seen. The pressure rises slightly during bubble formation and then drops abruptly as the bubble breaks free from the orifice. The total effect is approximately 0.009 feet of water. The most accurate measurement is obtained by averaging the pressure over a number of bubble cycles.

The standard bubble rate in the U.S.G.S. furnished bubbler system is 60 bubbles per minute in a sight glass. This low rate conserves gas supplies and keeps friction in the polyethylene tubing to less than an equivalent 0.01 ft. of water in feed lines as long as 250 feet.

Figure 8 shows the resolution that can be obtained with a 10 second averaging time. In this mode, the stability approaches 0.0001 foot or one thousandth of an inch. Every few minutes, the water level was increased by 0.0005 foot by pouring a small amount of water into the water tank.



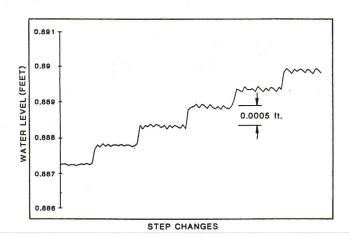


FIGURE 7: INDIVIDUAL BUBBLES
IN HIGH RESOLUTION

FIGURE 8: PRESSURE TRANSMITTER RESOLUTION

Extensive first-article testing for the U.S. Geological Survey demonstrated that the transmitters measured water levels from 0 to 50 ft. with an accuracy better than 0.01 ft. under extreme environmental conditions. Testing simulated the worst case environment that might be encountered in a remote location.

- Temperatures from -20 to 55 deg C
- Humidity from 5% to condensing
- Diurnal temperature variations
- Storage temperatures of -40 and 60 deg C
- Instantaneous temperature shock from 50 to -8 degrees C
- Overpressure to 60 psig
- Low external pressure of 572 mbar
- Electromagnetic radiation between 500 kHz and 1 GHz
- Vibration and shipping/handling conditions

CONCLUSION

New SDI-12 digital pressure transmitters have been developed which directly replace manometers in water level bubbler systems. The new transmitters have a modern electronics interface and have performance and operational advantages over the older systems.

ACKNOWLEDGEMENT

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