Digiquartz® Water-Balanced Pressure Sensors for AUV, ROV, and other Moving Underwater Applications

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Summary:

Paroscientific, Inc., has developed a new line of deep-water high-pressure sensors with outputs that are balanced underwater even if the orientation of the sensors change under pitch and roll maneuvers. These new depth sensors are ideally suited for applications that are not fixed, such as moving, remotely operated, and autonomous underwater vehicles, submarines, profiling instruments, and towed sensors.

Background:

Many Digiquartz® High-Pressure Sensors are used either in fixed installations on the ocean floor, or deployed in a fixed vertical orientation in deep-sea probes, profilers, and some underwater vehicles. An orientation sensitivity can be observed in the laboratory if the sensors are flipped in the vertical direction. Depending on the type and range of the pressure sensor, a substantial portion of the orientation sensitivity is produced by the pressure head of the internal oil lines, which are filled with a fluorosilicone polymer of moderate viscosity and a specific density of 1.25. These external pressure heads are additive and do not change the sensitivity of the pressure sensor. For that reason, a simple zero adjustment of the output in the final orientation of the deployed sensors removes the residual orientation sensitivity.

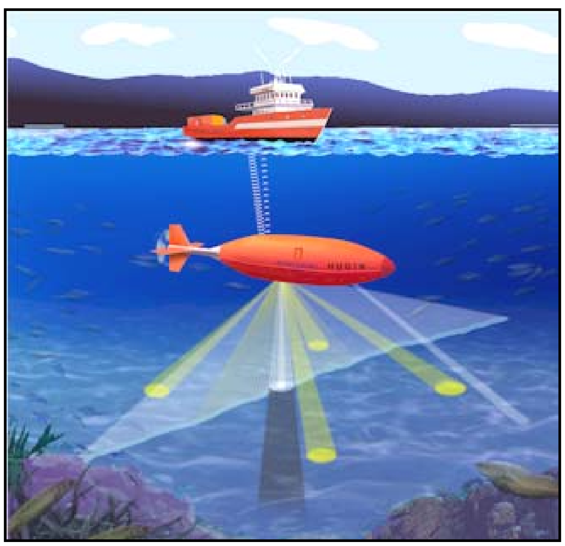

Figure 1. The Hugin AUV is equipped with a Digiquartz® Water-Balanced Pressure Sensor

Recently, much activity and research in underwater exploration involves vehicles that undergo substantial changes in pitch and roll orientation as they dive and climb. Routine pitch changes can be as large as ± 45 degrees. One goal of this development is to minimize the orientation sensitivity to match the overall accuracy of Digiquartz® Pressure Sensors in underwater deployments that are not fixed. Also, it is desirable to calibrate the sensor in the laboratory prior to deployment, regardless of orientation and external pressure lines.

New Water-Balanced Pressure Sensors:

Figure 2. Digiquartz® Water-Balanced Pressure Sensor

A careful review of the orientation sensitivity of existing pressure sensors used in depth-sensing applications revealed that improvements were possible in several areas, which include the definition and measurement of residual orientation sensitivity (called the pitch-and-roll testing procedure), the accounting and correction of internal and external pressure heads, and improvements in the sensor design and assembly. In at least two directions, the orientation sensitivity can be improved by approximately ten times.

Reference position and orientation:

In order to quantify and verify the improvements of the orientation sensitivity of water-balanced sensors, it was necessary to define the reference position and the reference orientation of the instrument. The reference position is now marked on the cylindrical body of water-balanced sensors and is assumed to be on the co-axial center line. Physically, it is located at the exit port of the internal pressure sensor. A perfectly water-balanced sensor is one that is insensitive under water to any rotation about its reference position. The reference position is fixed for a given model, but may vary slightly between various final configurations, depending on the location of the internal sensor. The reference location is also shown on the specification control drawing.

The pitch-and-roll testing procedure defines a reference orientation with respect to the sensor body. The orientation of the installed sensor in a vehicle may be chosen differently. As shown in Figure 3, the reference orientation is horizontal along the cylindrical sensor body, defined as the x-axis. If the vertical direction is along the z-axis, the x-z plane defines the pitch direction from + 90 degrees (pressure port vertically up) to –90 degrees (pressure port vertically down). The horizontal reference position is at 0 degrees pitch.

As shown in Figure 3, the y-z plane defines the roll angle of the sensor. The 12 o’clock reference position of the body as seen from its pressure port end is marked on the housing. The roll sensitivity is measured by rotating the sensor in its horizontal orientation from 12 to 3, 6, 9, and back to 12 o’clock.

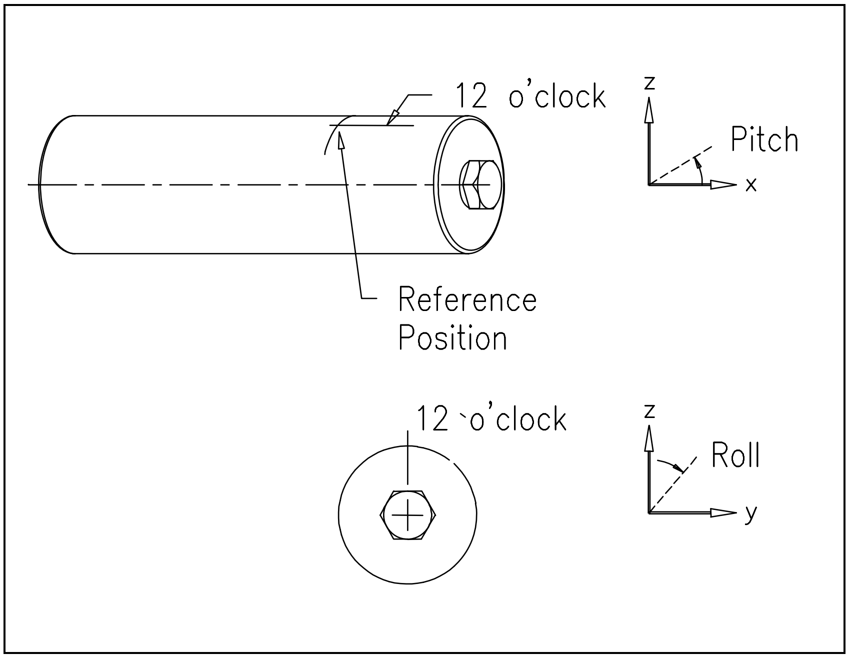

Figure 3. Pitch and Roll Reference Orientation

By construction, the output of the pressure sensor is very close to the best mean value if the sensor is in its reference orientation (horizontal, 12 o'clock position). Under water, the sensor is balanced, so the orientation can vary. In the lab (in air), the pitch of the sensor is usually not balanced because of internal or external pressure lines. But if the pressure lines are horizontal, the output in the reference orientation is most nearly at the mean value. It is thus convenient to calibrate the zero output at ambient pressure in this position.

The correct assessment of pitch-and-roll should be done under water, for instance with a gimbaled suspension, but it can be conveniently performed in the lab in air as follows: The head pressure of the internal pressure line from the exit port to the reference position on the body must be subtracted in the +90 degree pitch direction (pressure port vertically up), and added in the –90 degrees pitch direction. The roll data in the horizontal direction are valid as measured in the lab if the internal and external pressure lines are horizontal.

New hydraulic fluid:

The pressure lines of the Water-Balanced Pressure Sensors are now filled with a colorless silicone fluid with a viscosity of 300 cs and a specific density of 0.97. This fluid improves the overall orientation sensitivity significantly for two reasons. First, the internal pressure sensors are fine-tuned to this fluid during construction. Secondly, the pressure heads of internal and external pressure lines are balanced by the surrounding water which is essentially at the same density.

Residual orientation sensitivity:

During assembly, the sensors are actively balanced in two directions, which correspond to the vertical pitch direction, and to the roll sensitivity from 12 to 6 o'clock. According to the pitch-and-roll test data, the results are typically within ± 0.002 % of full scale per g (% fs/g). In absolute magnitude, this corresponds to a range of ± 1.4 cm water depth per g (700 m full scale) to ± 8 cm water depth per g (4000 m water depth). In the third axis, which corresponds to a 180 degree roll from the 3 to the 9 o'clock position, the orientation sensitivity is not actively balanced. Somewhat larger variations are observed with nominal values at ± 0.005 % fs/g. Averaged mean residuals over arbitrary directions are typically within ± 0.003 % fs.

Installation considerations:

For most practical purposes, the installation orientation of the pressure sensor can be chosen by convenience, since the sensors are water-balanced over pitch and roll changes.

If additional pressure lines are attached between the sensor and the water, they are best filled with the new silicone-based fluid to match the displaced water head pressure. External lines must be air-free and can be meshed onto the sensor port. Alternatively, a bleed valve may vent air bubbles. Generally, horizontal pressure lines are preferred to avoid external pressure heads, either from the weight of the hydraulic fluid, or from unexpected air bubbles. Some users prefer a vertical orientation with the pressure port up to ensure that the interface between the water and the hydraulic fluid is flooded readily at deployment.

Most underwater vehicles undergo limited pitch changes, for instance within ± 45 degrees, as the vehicle dives or climbs. In that case, a deliberate choice of orientation may yet improve the insensitivity to pitch angles. This choice may be determined from experience, however, it may be inferred from the previous discussion of residual orientation sensitivity. There are two preferred directions to minimize pitch errors: vertical or sideways in the 3 o'clock position. In the vertical direction, the sensors are actively balanced and the sensitivity is low. In addition, the error curve is a sinusoidal function of the pitch angle. From vertical to ± 45 degrees, only 30 % of the sensitivity is seen. The sensitivity is thus reduced to ± 0.5 cm water (700 m full scale) to ± 3 cm water (4000 m full scale). Alternatively, the depth sensor could be installed horizontally in the y-direction (sideways or perpendicular to the forward direction of the underwater vehicle). It is then best installed with the 3 or 9 o'clock orientation vertical (rotated by 90 degrees from the 12 o'clock orientation). This would correspond to minimum or a maximum of the sensor roll sensitivity. Pitch changes of the underwater vehicle are now roll changes of the sensor. Again, the roll sensitivity is sinusoidal and a limited pitch range of ± 45 degrees about a maximum or a minimum limits the sensitivity to less than 0.002 % fs.

(G8006 Rev NC 16-Dec-09)

