PELLISSIER MODEL H5

PORTABLE HYDROSTATIC LEVEL / TILTMETER

The Pellissier Model H5 is an exceptionally accurate water tube level, especially designed to be portable, which incorporates the experience of more than 30 years of work with precise hydrostatic instruments. Designed to be operator friendly, the user requires less than an hour of training and practice to obtain accurate readings. The instrument and its connecting tube are insulated and temperature stabilized so that the connecting tube need not be level to attain accurate results. The instrument's range of +/- 25 millimeters per setup is adequate for most precise work. In operation, it is impossible to inject operator bias or editing into the readings as they are obtained from a motor driven probe which controls the moment of contact with the water surface. All data are automatically recorded and elevations are computed in the field using a leveling program on a built-in computer. Field data are then uploaded to a Mac or IBM spreadsheet program for reports.

An optional accessory is being developed, (available August, 1992) which permits unattended monitoring of tilt at 20 minute intervals for periods of up to a month. Given suitably stable monuments, the H5, installed and operated as a tiltmeter, is capable of observing and measuring the Earth tide effect with an overall accuracy of +/- 3 microns.

The H5 is now available for those applications where very accurate work is required, or for applications where the integrity of the data, free from operator bias or recording error, is essential. Extensive testing has assured that the performance specified below will be attained under any expected conditions.

Specifications: Leveling work

Tube length (optional maximum, 25 meters)	14 meters
Vertical range, each setup (+ / - 1 inch)	+/- 25 millimeters
Accuracy, each setup (+ / - .0002 inch	+/- 5 microns
Repeatability, each setup (+ / - .0001 inch)	+/- 2 microns
Resolution, each end well (+ / - .00005 inch)	1 micron
Surface detection method	Motor driven platinum probe
Progress, 2 men, double run	100 meters / hour
Tube assembly, outside diameter	60 millimeters
Slave end	5 " w x 16" l x 14" h, 15 lb
Master end	9 "w x 22" l x14" h, 40 lb
Power, Battery and charger included	12 Volts, 0.4 amp average
Weight, complete instrument	125 lbs

INTRODUCTORY PRICE: $9700.00

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Hydrostatic Level With Micron Accuracy

An instrument and its associated measurement process must have an integrity of design and of operating procedures which does not easily permit inaccurate measurements. A precise optical level is used with a procedure which assures accuracy by requiring balanced sights, closed circuits or double runs, and other error reducing or error detecting methods. The instrument must be operated in accordance with the carefully crafted procedure and by a highly trained observer if the results are to be valid. The H5, a different kind of precise level, is operated with procedures similar to those used for optical leveling.

General Notes

Hydrostatic levels have been built as permanently installed devices which produce accuracies of a micron or two in 50 meter lengths, and tens of microns over a kilometer or so. A hydrostatic level intended for use in the field must be user-friendly. It should be easy to set up and to move. When used in accordance with appropriate procedures, it should never allow inaccurate measurements to be taken as real data. Except for the instrument described by Eaton[1], no serious portable instrument has found extensive use. Eaton's instrument has not been in regular use for many years because it's accuracy depended upon operation by skilled personnel, preferably on a rainy night when ambient conditions are stable. Accuracy also depended upon making measurements during the short period after filling the bare plastic water tube and before thermal gradients led to inaccurate results.

U-Tube Errors Are The Real Killers

The primary source of inaccuracy which remains after the effects of atmospheric pressure, capillary rise, settling time, differential thermal expansion, accurate detection of surface location, etc, have all been dealt with, is what is commonly called U-tube error. This error occurs whenever a vertical run of tube is at a temperature different from that of some other vertical run. When a micron or two matters, vertical runs of as little as a centimeter and temperature differences of one degree C between these runs give micron size errors. The U-tube error for water at room temperature is about 0.7 micron per centimeter per degree C. A 'vertical run' of only a centimeter in a 30 meter long tube is really only a small unlevelness in the route and is not usually recognized as a potential error source. Temperature differences of 2 or 3 degrees are not even felt by the average person. Small undulations, as in crossing a furrowed field, all add up as error sources if there are temperature differences between upward and downward runs. It is nearly impossible to measure the height of each of the inevitable small vertical runs or the temperature associated with each of them so that a correction can be calculated. It is true that if the tubing is perfectly level there will be no U-tube error, no matter how large the temperature difference is across the instrument setup. My conclusion, after years of experience, is that it is impractical to depend upon level runs of tubing to eliminate U-tube error if accuracy of a few microns per setup is required.

Instruments which use a second liquid in a second parallel tube can, in principle, make the required correction. I have built and field tested two quite different versions of this type, as have others. Limitations in the properties of available liquids and other problems described by Murphy's Law intrude so that the needed correction is not dependably accurate in an instrument that can be considered to be portable.

A Solution To The U-Tube Error Problem

The only solution which seems to work at all reliably is the brute force one used by Eaton in which water is pumped in the liquid filled tube to force it to a uniform temperature throughout its length. The essential improvement on Eaton's equipment is the addition of thermal insulation to the tube to prolong the measurement period, and the provision of a pump, reservoir, and valves to easily refill and recycle the water for a fresh start on a new measurement set. If these things are done properly, the tube assembly with its protective outer cover are a bit more than two inches in diameter.

The H5 Solution

The H5 is accurate and easy to use. Readings are recorded automatically. It can be reasonably extended in length to about 30 meters if the application requires, but it is probably a three man instrument at that length. The tubing run between the measuring wells need not be level. Vertical loops in the tubing of up to a meter or two are no problem. Higher vertical runs carry the risk of some U-tube error if the thermal environment is not reasonably uniform. As a two man portable level, each individual backsight or foresight requires 4 or 5 minutes, giving a double run progress of about 100 meters per hour. Preliminary testing shows an overall accuracy of better than +/- 5 microns per setup with repeatability of +/- 2 microns. There is reason to expect that , eventually, the traceable accuracy can be improved to about +/- 3 microns with improvements in procedures and in the circulating water system.

Well Diameter And Settling Time

The time constant of the assembled instrument should be as short as is reasonably possible. The well diameter is determined by the acceptable error associated with capillary rise and surface tension effects. With the well diameter fixed, all that can be done about the time constant is to be certain that the tube diameter is at least large enough to assure that the system response is not overdamped. Typical single time constants for these systems are in the range of 5 to 10 seconds. Allowing ten time constants for settling, the instrument must sit for a minute or so before taking final readings. The operating procedure quickly shows whether enough time has elapsed because it requires three readings which fall within a maximum range of +/- 5 microns.

Temperature Effects

The system must be shielded from temperature changes which occur at rates which are fast compared with the system response time. Much of the strange behavior of hydrostatic levels which has been experienced or reported when trying for accuracy of a few microns results from the fact that thermally induced system volume changes occur faster than the system can settle down to a stable reading. The practical solution is to isolate the water tube so that does not experience significant temperature changes during the measurement period.

Long Systems

A longer tube than about 30 meters leads to further difficulties with volume expansion because a larger diameter tube is needed to avoid overdamped response times. The larger tube (and greater liquid volume) leads to a need for more insulation, which makes the whole thing more bulky. At some point, the term 'portable' no longer applies. For fixed installations, lots of insulation and in addition, if necessary, a fixed large well to reduce the height of thermal common mode excursions leads to systems up to a mile or more in length which do not exhibit rapid changes in liquid height. In Holland, systems up to a few kilometers long have been used as portable instruments deployed from barges along the bottom of canals. These instruments had a one centimeter diameter tube and very long time constants. A measurement usually was extended over several days to arrive at a reasonable long term average for a data set. The thermal stability of the water in the canals made it possible to operate these very long instruments without thermal insulation.

Finding The Surface

For detection of the liquid surface with high resolution, wide range and long term accuracy , it is hard to improve on the CERN instrument in which a probe is advanced downward with a micrometer screw until electrical contact is made with the surface. Repeatable, reliable measurements to at least +/- 5 microns can be made manually. Manual readings are possible to an accuracy of +/- 1 micron, but it is tedious and frustrating for the operator if more than a very few measurements are required. Vibrations caused by attempts to obtain manual readings can easily cause wavelets a few microns high. Upon contact of the probe with the surface, surface tension forces cause the water to wet the probe. Once wetted, the probe must be withdrawn about 500 microns to force the surface to 'let go' of the probe tip. This means that if vibration causes waves - say 5 microns high - on the surface, the probe will be wetted by the first wavetop it meets. The water at the top of the wavelet will 'stick' to the probe. This results in a reading which is too high. A simple motorized advance and retract system using a slow speed motor which does not generate troublesome vibrations or waves is the method used in the H5 to make readings which are accurate to a micron. These automated, motorized readings are independent of operator skill, fatigue level, or concentration. It also is a simple means for obtaining readings automatically in an instrument installed to monitor elevation, settlement, or earth tide effects. Because of the wavelets mentioned above, the instrument cannot be used with high accuracy on an operating machine which is vibrating, or on other vibrating or oscillating structures such as long bridges which cause small waves in the water or prevent settling to a stable reading. This is also a serious problem with other types of precise levels for reasons specific to each type of instrument.

There are reports that in long term use, a probe which is withdrawn and dries between reading sessions develops evaporated solids, salts, etc. on the tip which prevent accurate work. In the arrangement now used, the humidity is 100%, the probe tip does not dry, and so far, in several months, no residue has developed. According to Murphy's Law, any probe tip will eventually somehow pick up some deposits. In the H5, a probe can be removed, cleaned, and accurately replaced at any time in about a minute. Eaton's approach, in which a pointed probe approaches the surface from below, avoids waves and wavelets and makes it possible to obtain manual readings accurate to a micron or two fairly easily, but there is no readily apparent way to make readings automatically.

Bubbles

A very serious practical concern in the operation of any hydrostatic instrument is the necessity of knowing that there are no air bubbles in the liquid line. Bubbles cause two sorts of problems. One is a serious nuisance, but it still permits accurate work. The other prohibits accurate work entirely. If small bubbles which do not completely block the water tube are present, they affect the thermal common mode response because the air in the bubbles expands much more than water with a change in temperature. This causes more rapid variations in the surface level at each well, as if the thermal insulation of the water tube were defective or absent. If these small bubbles coalesce to completely block the tube with a single large bubble, surface tension forces cause the bubble to resist water pressure differences of up to a millimeter or two, giving a 'dead' and completely erroneous response. If a bubble is suspected in the H5, it is a simple matter to recirculate the water, completely refilling the tube. The measurement set can then be quickly repeated. With the procedure used, which always circulates water through the tube before each set of measurements, it is unlikely that a bubble will ever be encountered.

Well Thermal Coefficient

An ideal instrument would be designed so that it is not necessary to measure and correct for temperature effects at each end. The H5 is designed to have a thermal well coefficient of less than 1 micron per degree C. Since the wells are never more than about 1/2 degree C different in temperature, the thermal error can be safely neglected.

1. Eaton, J. "A portable Water-Tube Tiltmeter", Bull. Seis. Soc. of Amer. Vol. 49, No. 4, pp 301-316, October, 1959

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