GBT MEMO 205

Enhancements to the Pellissier H5 Hydrostatic Level

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1 Introduction

The Pellissier H5 Hydrostatic Level is used for applications requiring an order of magnitude improvement in accuracy over conventional optical leveling. The H5 has been used on such applications as the 32-meter radius track for the National Radio Astronomy Observatory (NRAO) Green Bank Telescope (GBT) alidade, the Final Focus Test Beam (FFTB) project at Stanford Linear Accelerator Center (SLAC), the Superconducting Super Collider (SSC), measurements of the Golden Gate Bridge, etc. For the GBT alidade track, 16 benchmarks on a 32-meter radius were measured 3 times over a 2-week period. In each case, the levels closed to better than 0.050 mm over the 200-meter run. The H5 has been well described in the literature by Imfeld, Pellissier, Plouffe, and Ruland [1], so a description will not be repeated in this article.

The GBT metrology system [2,3] will employ 12 ground-based laser ranging instruments on a 120-meter radius, i.e., 12 monuments on 62-meter spacing (0.75 km loop). The metrology system will use measured distances only, so the 3-D coordinates of the instrument locations are required in order to do trilateration calculations. The goal is to establish the (x,y,z) coordinates to an accuracy of less than 0.1 mm. The x and y coordinates can be measured by the instruments, but due to the insensitivity of the monument geometry in the z direction, and the need to orient the ground instruments with respect to the gravity vector (to point the telescope), hydrostatic leveling is required.

2 Enhancements

While the H5 is semi-automated, two operators are required to work in synchronization to achieve accurate results. The sense probe is motor-driven down, but the return is manually operated. Touching the instrument to drive the probe up introduces small vibrations that can introduce errors by detecting the crest of a small wave instead of the steady state level. Operator fatigue can also be a problem for extended measurements. The H5 measurement heads are connected by a fixed 15-meter hose; thus, a measurement between a set of monuments would require 4 stable, temporary bench marks to span the 62-meter distances. Due to the 0.75-km run to close the circle, it was decided to extend the hose length to 63 meters, and automate the operation. The model NPH6 (the NRAO enhanced version of the Pellissier H5) includes: motor driven probes on digital indicators; modular coaxial hoses that are quickly removable from the measurement heads; electrically operated solenoid valves; 120 VAC operation; an external pump and reservoir (both measurement heads are identical); RTD temperature probes at each well and both sides of the pump; total computer control, with RS485 interface to all components, and real-time display of all parameters. See Figure 1.

3 Operation

There are two fundamental sources of error in a hydrostatic level. Due to the change in the density of water with temperature, any difference in temperature between two legs of a sag in the hose will result in a difference in the static height of the water at the two ends. The other source of error is the dilation of the connecting hose. When the water is pumped through the hose to purge air bubbles or equalize the temperature, the pressure dilates the hose

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slightly. As the hose relaxes after pumping the water level rises in the measurement wells. This dictates that a pair of measurements be made nearly simultaneously in order to minimize the error of the rising water level. Of course, there are many additional ways to go wrong.

With the NPH6, outdoor measurements are made in the evening to avoid temperature gradients introduced by the sun. The hose is supported and held level on a temporary strut rail, as defined by a masonry line, to avoid the "U" tube error. The water is circulated through a coaxial hose arrangement, with the inner hose acting as the sense line and the outer hose acting as a return and moderator.

The dilation problem is minimized by using a wire reinforced sense line, synchronizing the sense probes to contact within 0.5 seconds of each other, and signal processing. Due to the automation, it is easy to take data for 30 minutes or more. By plotting the data and looking at the individual well levels, the sum of the well levels, and the differential between the well levels, errors can usually be detected. For example, spikes easily detect contamination of the water in a well in one well level. Contamination always causes the probe to drive deeper in the water before making contact. A leak or drop of condensate into the well is seen in the sum of the well levels. Of course, the differential level is the ultimate goal of the measurement. By looking at trends over minutes, errors can be detected.

Synchronized measurements are made at the rate of about 2.5 per minute. Data is typically taken for about 30 minutes (75 points) and then plotted and analyzed. After an initial characteristic transient period of around 10 minutes, a section of data is selected as the actual measurement.

4 Calibration

The instrument zero point was calibrated in the lab, on a surface plate with a short hose, to minimize thermal errors. Repeatability of the zero point is around 0.002 mm. Repeatability of the measurement with a 63-meter hose is checked in the lab by coiling the hose on a table level to the surface plate. Repeatability of the 63-meter hose is around 0.006 mm. The differential was checked by raising one instrument on a gage block.

5 Results

Four outdoor monuments were measured in November 1999 on calm evenings (one pair each evening). Multiple sets of data were taken, after circulating the water between measurements. The standard deviations for the 63-meter distances were 0.0046 mm, 0.0038 mm, and 0.0075 mm — about the same as in the lab.

Figure 2 shows the well levels for 5 water circulation and measurement cycles. Note that a shorter length indicates a higher water level. Note that immediately after a circulation operation, the level shows a characteristic exponential decay (rising water level) as the hose relaxes. This is followed by a period of gently increasing or decreasing level. Figure 4 shows the differential level. Note that the sun set around 17:30 and there is a significant change (0.050 mm) in the differential for the following measurement cycles. Figure 5 shows an expanded version of the levels around 19:00.

6 Acknowledgement

The authors wish to acknowledge the contribution of Pierre Pellissier, the leading authority on hydrostatic leveling. who kindly taught us the tricks of the trade and provided the enabling technology to make the NPH6 a reality. Though he has passed on, his contribution to the science continues.

7 References

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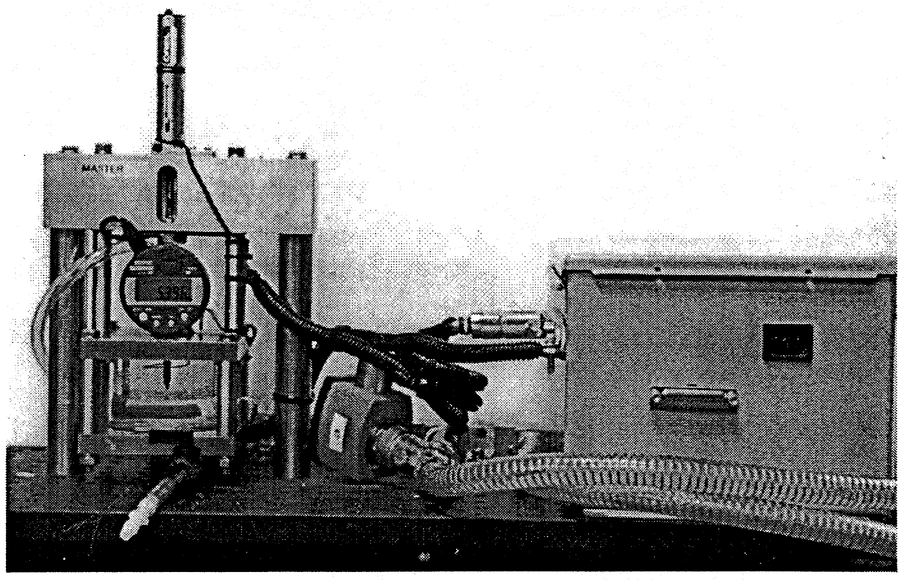

Figure 1

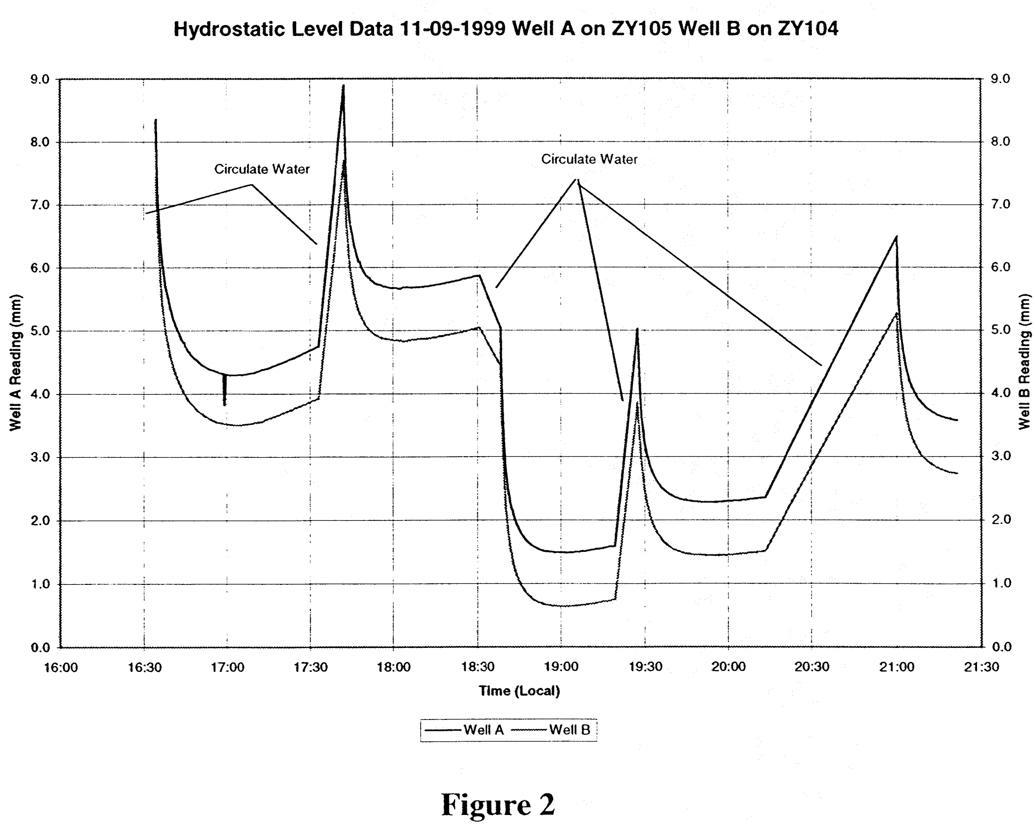

Figure 2

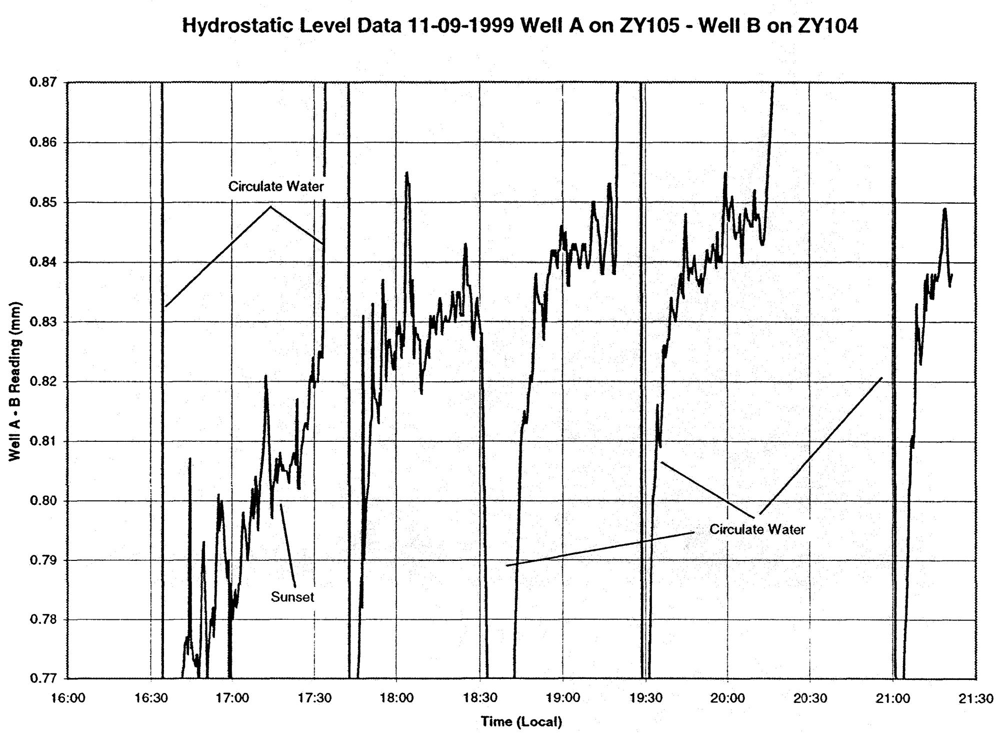

Figure 3

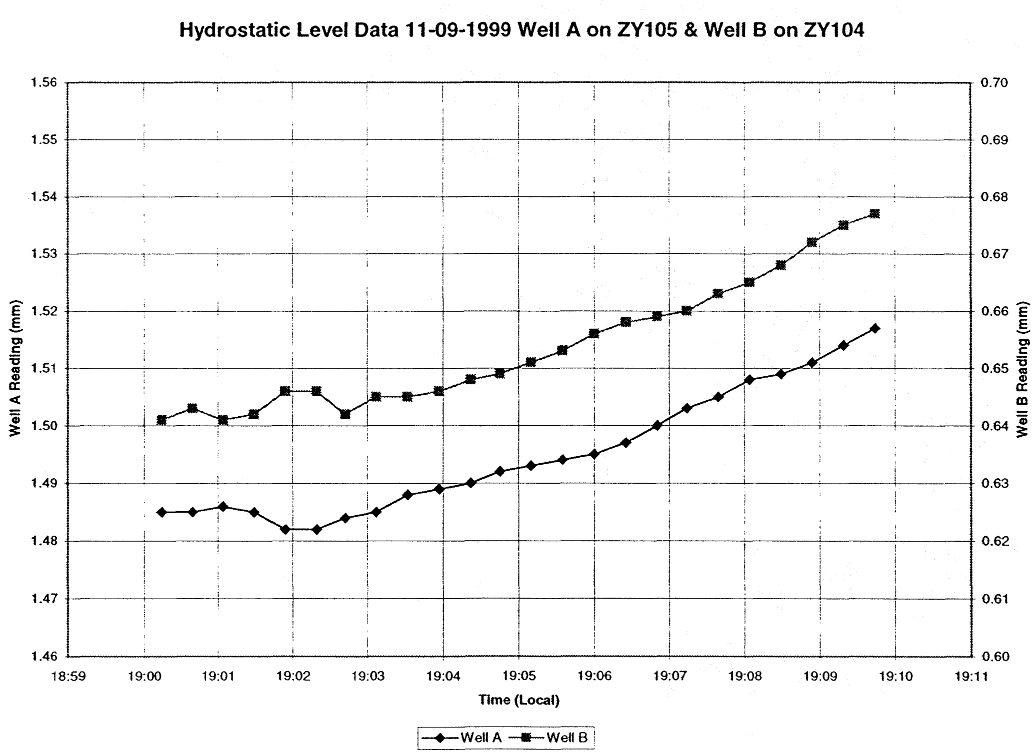

Figure 4