LBL-11747

# THE PEP LIQUID-LEVEL SYSTEM*

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March 1981



*This work was supported by the Director, Office of Energy Research, Office of High Energy and Nuclear Physics, High Energy Physics Division of the U.S. Department of Energy under Contract No. W-7405-ENG-48.

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## Summary

A liquid level system has been installed in the accelerator housing of the PEP storage ring. This instrument spans the entire 2.2 km circumference of the PEP project, and over one hundred readouts provide reference elevations which are used for the accurate alignment of accelerator components. The liquid level has proven to be extremely precise (± 0.10 mm) and quick to use, and it has contributed to the accurate alignment of PEP before beam turn-on. Since the liquid level readouts are rigidly attached to the accelerator housing, the liquid level has been a convenient means to monitor the settling of the accelerator housing.

## Introduction

The precise alignment of a large particle accelerator depends upon an accurate survey of the construction site and of the accelerator components. Usually, this precision surveying task can be decomposed into two distinct operations: the establishment of a network of survey monuments through a "global" site survey, and the location of groups of accelerator components in "local" surveys. In the construction of the PEP electron-positron storage ring, the horizontal positions of accelerator components were surveyed relative to a network of survey monuments. Certain key monuments were located by an overall site survey performed by the National Geodetic Survey, and subsidiary monuments were then located relative to these established monuments. However, the reference elevations used in the local surveys were not provided by a traditional surveying method; they were provided by a special instrument, the PEP liquid level system.

The PEP liquid level is a simple device which locates the same elevation (i.e., points on a gravitational equipotential surface) at widely separated locations. The liquid level is a permanently installed instrument which runs around the entire circumference of PEP. This instrument consists of a series of "wells" or half-filled water containers which are connected by a water-filled pipe. When the instrument is operated, the water surface levels in the various wells lie at the same elevation, and these surface levels provide the reference elevations. In PEP, the reference elevations are used in surveying and aligning accelerator components with the Laser Surveying System.[1]

## Liquid Level Design

Figure 1 is a photograph of a liquid level "well", a readout device for the liquid level system. The well consists of a glass container partially filled with water, and the container is sealed except for two plastic tubes which lead to the water line and the air return line. The water and air lines (not shown) are 2.5 cm diameter copper pipes which run around the entire 2.2 km circumference of the PEP project, and over 100 wells provide reference elevations all around PEP.

Mounted on the top of the well is a digital depth micrometer in which the rod has been replaced by a pointed stainless steel probe. In order to read the elevation of the water surface, the probe is advanced until it is seen just to touch the surface. Then the micrometer setting can be read to a resolution of ±0.01 mm. The micrometer has a range of ± 12 mm, so the liquid level system can operate with some variation in the elevations of the various wells. Figure 2 is a cross-sectional line drawing of the liquid level well, and internal details of the assembly may be seen.

There are several potential sources of large systematic errors in liquid levels, so it is imperative for a liquid level to be carefully designed to avoid these potential problems.[2] Foremost among these potential sources of errors are the following: air pressure differences from well to well, fluid density variations due to temperature differences, and failure of the system to return to equilibrium quickly after a disturbance.

The PEP liquid level has a number of features which minimizes the possibility of various systemmatic errors. The use of an air return line permits the liquid level to be operated as a sealed system (except for a single air vent), so the system is not sensitive to variations of air pressure caused by the wind or by ventilation fans. The water line was carefully installed to be at the same elevation around the PEP tunnel, and its elevation probably does not vary more than ± 3 cm in its 2.2 km length. This design minimizes the height of vertical columns of water in the system, and errors due to temperature and density differences in vertical columns are therefore also minimized. For the same reason, the water line and the wells were installed at approximately the same elevation. While the plastic tubing which runs from the water line to each well does have larger excursions in elevation, these elevation differences cannot cause a cumulative systemmatic error along the length of the liquid level. Furthermore, even the possibility of local errors at individual wells is not serious, because temperatures tend to be quite uniform within a small portion of the PEP accelerator housing. Water was selected as the working fluid because of its low coefficient of thermal expansion, its low viscosity, its low cost, and its easy availability. Of course, it is convenient that accidental spills dry out by themselves and that there is no problem with toxicity (unlike with mercury, for example). The use of large diameter (2.5 cm) pipes and a low viscosity fluid means that the damping time constant for the entire PEP liquid level is only about 6 minutes. Rather wide wells, 5 cm in diameter, are used to avoid meniscus errors. Lastly, a small amount of commercial algae control solution is added to the water to keep it clean.

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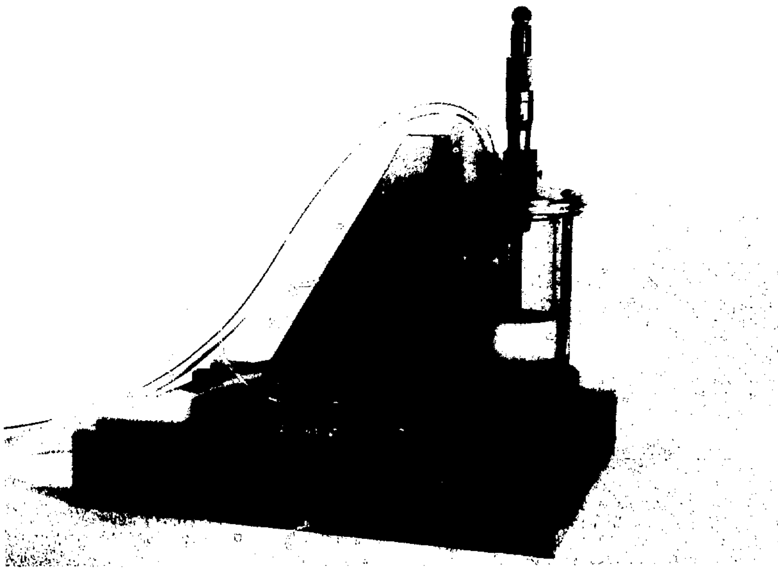

Figure 1. PEP Liquid Level "Well" with Support Stand

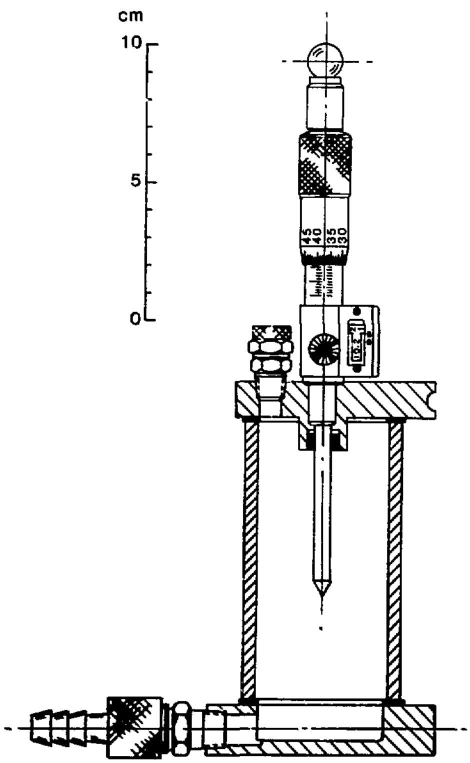


Figure 2. Cross-Sectional View of PEP Liquid Level "Well"

Taking liquid readings is a simple matter. A micrometer reading measures the elevation of the top of the liquid level well, relative to the water surface. Since the total volume of water in the liquid level system is not precisely controlled, a single measurement has no particular significance. However, two readings at different wells measure the elevation difference between the tops of the two wells. Since the elevations of some wells are known from previous surveys, many pairs of simultaneous readings serve to establish the elevations of all liquid level wells. Pairs of simultaneous readings are used to avoid any errors from an overall drift in the level of the liquid.

After the elevations of the various wells have been established, the micrometers are set so that the *tooling balls* at the tops of the micrometer barrels all lie at the same elevation. These tooling balls can then be used as elevation reference points.

Before the PEP liquid level was constructed, two prototypes were built: one was 54 m long, and one was 1 km long. Tests of these prototypes[3] showed that the readings were accurate to about ± 0.07 mm and that slope measurements could be made to an accuracy of $\pm 2 \times 10^{-7}$ radians or ± 0.04 arc seconds.

## PEP Liquid Level

The water line for the PEP liquid level system was mounted on the wall of the accelerator tunnel, very close to the floor. Care was taken to keep the elevation of this pipe constant as the pipe passed through utility shafts and experimental areas. The air line, on the other hand, was permitted to vary in elevation for convenience in installation.

Eight valves were installed in the water line at various points around PEP, for use in filling the liquid level. These valves had large apertures (2.5 cm) in order to avoid restricting the flow and increasing the damping time. Also, smaller valves were installed in the lines which connected each well to the water line. As the liquid level was installed during the construction of PEP, it was filled in sections by filling barrels with water and then pumping the water through portions of the liquid level water line. There were no serious operational problems with the liquid level.

## Results

The PEP liquid level has a resolution of ±0.01 mm in elevation. However, comparisons of measurements taken on different days show that residual systemmatic errors reduce the repeatability of the elevation measurements to about ±0.10 mm. We believe that ±0.10 mm represents the true accuracy of this instrument, both because of the prototype tests and because the closed orbit errors in PEP were small during beam turn-on. Therefore, the liquid level, although a very simple instrument, is far more accurate than traditional surveying instruments. It is interesting to note that the liquid level can be used to measure elevation differences far smaller than the corrections required for the earth's curvature (typically 1 to 10 mm) within the PEP site.

An important function of the PEP liquid level has been to provide a convenient method to monitor the vertical settling of the accelerator housing. The liquid level wells, just like the accelerator components, are rigidly attached to the concrete floor. Therefore, if the housing settles unevenly and causes an accelerator misalignment, the misalignment will be revealed by taking a new set of liquid level readings. Figure 3 shows some liquid level data which reveal considerable vertical settling of a portion of the PEP ring over a six-month period in 1980. Note the pronounced settling at Interaction Region 12, probably due to the weight of experimental apparatus and radiation shielding. Only three or four man-days of effort are required to take a complete set of liquid level readings all around PEP.

## Acknowledgement

We wish to thank Mr. Fred Linker for his help in taking the recent liquid level measurements.

## References

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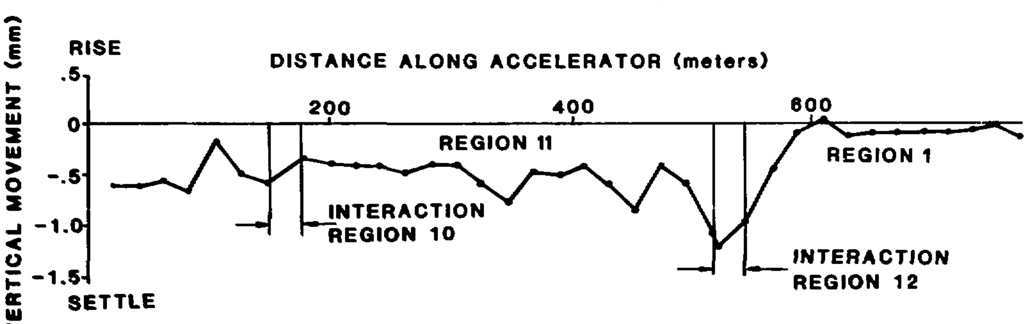


**Figure 3** **Vertical Movement of a Portion of the PEP Accelerator Housing over Six Months.**