GBT MEMO 229

Calibration of Kelvin clamp Euler angles for absolute instrument orientation

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Abstract

A method is described for calibrating the Euler angles of a kinematic Kelvin clamp in order to absolutely calibrate the orientation of an instrument. This paper covers a method for calibrating all three Euler angles, with an emphasis on the rotation about the vertical axis. This method uses a fixture employing a theodolite with an autocollimating eyepiece and an autocollimating prism.

Keywords: kinematic, Kelvin clamp, autocollimate

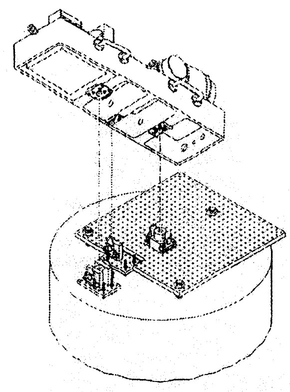

Figure 1: Instrument and Kelvin clamp arrangement.

1 Introduction

The kinematic Kelvin clamp is a common method for repeatably registering two instrument components[1, 2, 3, 4, 5]. There are various configurations, but this paper deals with a construction using three tooling balls on one component and mating socket, groove, and flat on the other component. In general, the method should be adaptable to other configurations.

The socket constrains 3 degrees of freedom, the groove constrains 2 degrees of freedom, and the flat constrains 1 degree of freedom. Thus the Kelvin clamp uniquely locates and orients the part by constraining all 6 degrees of freedom, without over constraining, i.e., there are no inherent internal forces between the three tooling balls. For example, if the temperature changes, the ball in the socket remains fixed. The ball in the groove is free to move in one direction, and the ball resting on the flat is free to move in two directions.

For the Robert C. Byrd Green Bank Telescope (GBT), 12 stable instrument monuments were constructed equally spaced on a 120 meter radius, with kinematic Kelvin clamps. This architecture absolutely locates and orients model PSH97 laser ranging instruments, and thus facilitates instrument replacement and tracking of moving targets on the telescope[6]. Field calibration of the Euler angles[7, 8] that describe the rotations about the x and y axes is relatively straightforward, but measuring the rotation angle about the z (vertical) axis is a little more difficult.

The PSH97 laser ranging instruments use a Kelvin clamp in order to get a repeatable mating with the fixed mounting. By calibrating the instrument pointing, with respect to the three tooling balls in the lab, and calibrating the monument location and orientation in the field, the instrument's mirror system can direct a laser beam through a coordinate in the local surveyed coordinate system. The PSH97 uses a socket under the mirror head, a groove 14 inches down the instrument axis and a flat 4 inches off the line between the socket and groove. Thus the line between the socket and groove defines the instrument rotation about the z (vertical) axis.

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2 Rotations about the x and y axes

Rotations about the x and y axes are relatively straightforward. We use a template that holds three 0.7500 inch balls in the nominal 14×4 inch clamp configuration (thin plate with 0.75 inch holes and balls epoxied in place), with the top and bottom sides of the balls exposed. This is rested on the Kelvin clamp with the top of the balls exposed. A granite plate that is finished on both sides and parallel, top and bottom, is gently placed on top of the three balls. A precision split-bubble coincidence level clineometer is used to measure the tilt, with respect to the gravity vector, about the two orthogonal axes.

3 Rotation about the z axis

To measure the rotation about the z axis, a fixture was built with the mating tooling ball configuration and a breadboard plate. The press fit shoulder tooling balls, available from Te-Co Tooling Components (Union, Ohio), come with a centered shank which is press fitted into holes drilled in the breadboard. Alternate methods, such as truncated balls, are available from Bal-Tec (Los Angeles).

A surveying instrument tribrach is centered over the socket mating tooling ball by use of a threaded $\times$ plain-end centering dowel screwed through the top of the tribrach-to-tripod mounting hole and centered on the tooling ball shank hole in the plate. The tribrach is clamped to the breadboard using ThoreLabs (Newton, New Jersey) table clamps, and the dowel is screwed out of the tribrach. A theodolite is then mounted in the tribrach.

The objective is to reference the horizontal angle of the theodolite to the line between the socket and groove hidden under the breadboard. For this we use a Davidson Optronics model D-523-102 autocollimating prism. This is a porro prism which has the interesting property that the reflection is insensitive to the angle of incidence in one direction and sensitive like a mirror in the other axis, i.e., it works like a retroreflector for rotations about the prism roof axis, but it works like a mirror for rotations about an orthogonal axis. Thus, with the prism oriented so it is sensitive to horizontal angles but insensitive to the vertical angles, and the sensitive axis parallel to the socket-groove axis, the theodolite can be referenced using the autocollimating eyepiece.

To orient the prism with respect to the tooling balls, the fixture is placed on a granite surface plate with the socket and groove tooling balls pressed against a straight edge, as shown in Figure 2. An autocollimating mirror is mounted on a granite block, which is finished and square on at least 3 sides. The Starrett Croblox mirror is a chrome carbide metal mirror that is finished on both sides and parallel. Note that this mirror must be the same height as the theodolite in order to autocollimate. The unusual height requirement is the reason for using the tall granite mirror mount (which we had on hand). An alternate method using a more conventional height autocollimator mirror is described below.

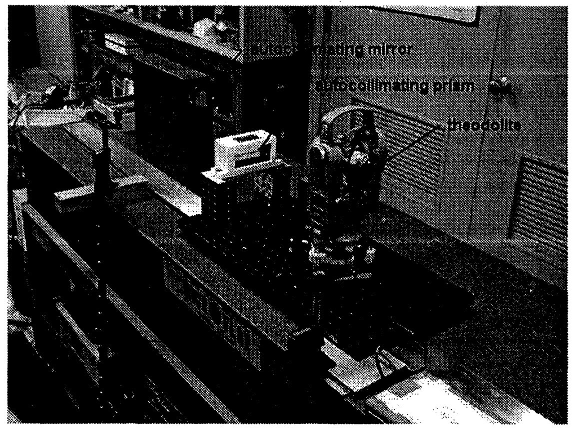

Figure 2: Fixture in calibration lab

As shown in figure 2, the fixture and granite block are pressed against the straight edge with the Croblox mirror normal vector parallel to the straight edge/surface plate. The theodolite is adjusted until it is autocollimated on the mirror. Without moving the theodolite horizontal angle, the theodolite is directed at the autocollimating prism located on the fixture. The prism is then adjusted until it autocollimates, and thus the horizontal angle on the socket-groove line is transferred to the autocollimating prism. The prism is then clamped in place and checked against the Croblox mirror again.

Care must be taken to avoid a secondary error if the autocollimating prism is not mounted at the height of the theodolite. If the roof edge of the porro prism and axis of the theodolite are exactly parallel, the horizontal rotation of the theodolite is independent of the vertical axis, i.e., a sweep of the theodolite in the vertical direction will autocollimate at the same horizontal setting. However, if the porro prism roof and instrument axis are not parallel, sweeping the prism in the vertical will autocollimate at different horizontal angles, and thus introduce an error. This is covered in detail by Polasek[9]. Since the top of the instrument monuments will not necessarily be level (as measured in the previous section), leveling the theodolite will throw them out, even if they were perfect in the lab. This is best compensated for by mounting the autocollimating prism at instrument height. This is a subtle effect, and it is recommended that anyone using an autocollimating prism read Polasek's paper.

It should be noted that the reference direction is set by the mounted autocollimating prism. The centering error of the theodolite is not coupled to the angle orientation. For example, if the tribrach is off center, the null angle of the prism will still be correct. The error will be in sighting in on another target and the fact that the theodolite is not exactly over the monument target. So, the precision required to center the theodolite over the tooling ball is of the order of the precision one can sight a target. Therefore, the theodolite can be removed for transportation, but great care should be taken to protect the autocollimating prism.

3.1 Alternate mirror configuration

As shown above, the reference is set by the autocollimating prism. There is no inherent reason to require that the autocollimator used to set the prism be mounted on the tribrach. If a tall autocollimating mirror is not available, the autocollimator can be set up behind the fixture plate on a tripod.

4 Field use

In the field, the fixture is latched into place on the Kelvin clamps and the theodolite is set in the tribrach. The theodolite is autocollimated on the prism, and the horizontal angle is zeroed and/or recorded. Sightings are then taken on other targets in the network. Thus, the orientation of the socket-groove line is brought into the network.

5 Calibration of the PSH97 instrument

In order to point the instrument, it is also necessary to calibrate the translations and rotations of the instrument mirror with respect to the Kelvin clamp. This procedure will be covered in another article.

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