Models 771, 75, & 76-RH Optical Tooling Transits

Operation and Field Adjustment Manual

BRUNSON Instrument Company

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Thank you for purchasing a Brunson Transit. Remember that our customer support does not stop after shipment of a product—we are here to help you with any measurement challenges that you may have.


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Chapter 1 - Introduction

In this chapter we will address the following topics:

- What is a transit?
- What are the components?
- What does a transit do?
- The difference between the three Brunson transits

What is a transit?

The most important thing about a transit is that it has a telescope on a gimballing mechanism, so it can rotate back and forth horizontally (azimuth direction), but it can also rotate up and down (elevation direction).

Almost everyone is familiar with a surveyor's transit. However, it is worth explaining the general difference between our transits and those used by surveyors. Optical Tooling transits have a number of modifications to make them deadly accurate when shooting over distances which, to a surveyor, would seem short (less than a couple of hundred feet). In addition, we do not need to take readings in two telescope positions (direct and reverse) in order to achieve this accuracy. This is possible because our transits have several special characteristics:

*Please refer to **Figure 1.1** for a general orientation to component terminology.*

a) They have an extremely straight *line of sight*. As you focus the telescope from near to far, the line of sight travels in an extremely straight line. That is, picture putting an imaginary, weightless, taut string down the center of the telescope, stretching straight out a couple of hundred feet— the string would always be in the center of the crosshairs as you focus from near to far and back again.

b) A transit's three major axes are all mutually *orthogonal* (all at right angles to each other). There are two rotational axes on your transit, and one axis which does not rotate (see Figure 1.2). The first rotational axis is the *vertical axis*. The spindle and bearings which create the vertical axis are housed in the transit's base. The entire upper portion of the transit (standards and telescope) rotate horizontally around this axis. The second rotational axis is the *cross-axis*. This is the horizontal axis around which the telescope rotates. The third axis is the line of sight.

c) Lastly, all three of the major axes meet at one precise point. Just because the axes are all mutually orthogonal

Note: This manual applies to the following Brunson products:

- **771** and **771-H** Jig Transits
- **75** and **75-H** Optical Transit Squares
- **76-RH**, **76-RH190,** and **76-RH190M** Telescopic Transit Squares

At this time, the models 771, 771-H, 75, and 75-H are no longer produced by the factory. However, we have included them in this manual due to their past popularity and the fact that many of these instruments remain in the hands of alignment technicians who may find this information useful.

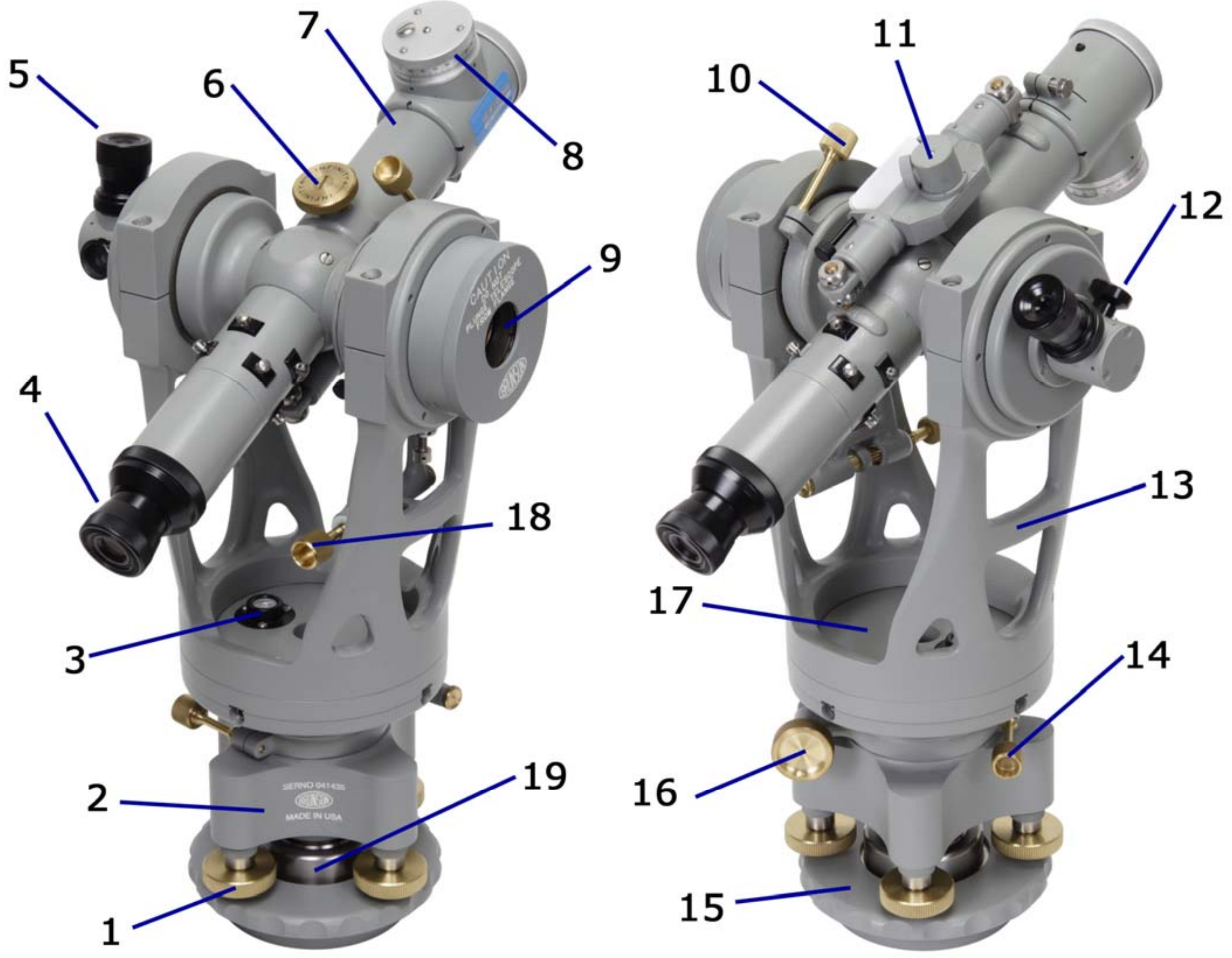


Figure 1.1
Orientation to Components

1. Leveling screws (4)
2. "Spider" base
3. Plate vial
4. Telescope (eyepiece end)
5. Cross-axis telescope eyepiece
6. Focus knob
7. Telescope (objective end)
8. 190-x Optical Micrometer
9. Cross-axis telescope objective lens
10. Vertical tangent clamp lock
11. Coincidence level
12. Cross-axis telescope lighting adapter
13. Standards
14. Horizontal tangent clamp lock
15. Base plate
16. Horizontal tangent adjustment screw
17. Plate
18. Vertical tangent adjustment screw
19. Shifting center

doesn’t necessarily mean that the lines would all intersect at the same exact point in space. However, on our transits, these lines *do intersect.* This is an important characteristic when accuracy is paramount, particularly at shorter distances. Of course, you can’t see this intersection point – it is buried in the middle of the telescope.

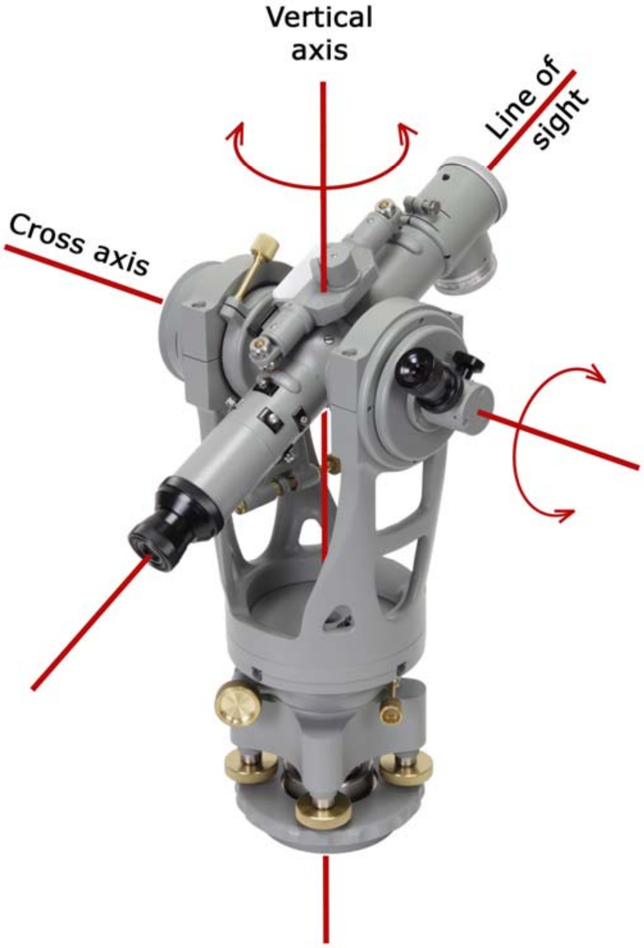
These are the three distinct characteristics that our telescopes have which allow them to make very precise measurements over relatively short working distances. However, there is one more very distinctive characteristic which separates Optical Tooling transits from all others – the optical cross-axis. Our 76-RH190 has an infinity-focused telescope, complete with a second eyepiece and second set of cross wires, housed in the cross axis. This cross-axis telescope is used in a number of operations to set the main telescope perpendicular to another telescope or a mirror (which may be mounted on a rotating shaft or other reference plane).

So what does a transit do?

A transit is a very flexible measuring tool. It can establish vertical or horizontal optical planes which are extremely flat. It can establish optical lines which are extremely straight, extending in any direction. Once these planes and lines are established, you can use them as references from which to measure other points of interest. You can determine whether machine components are parallel, flat, level, square, or straight. This means you can evaluate the geometric relationships related to the alignment of almost any part, structural component, machine, tool, surface, substrate, wall – or just about anything else. A very few examples of this would be:

- Alignment of bearings and bearing journals.
- Roll parallelism in paper and metals mills, or printing presses
- Machine tool evaluation: bed leveling, bed flatness, geometric integrity of spindles and other components
- Layout for machining
- Crankcase alignment
- Straightness of engine bores, turbine cases, torpedo tubes, line shafts, etc.
- Check relationships of right angle planes

Figure 1.2



The Optical Tooling instruments are extremely flexible. You can use them to make just about any measurement or geometric evaluation that you can design in your mind.

As we indicated earlier, the 76-RH190 is the only currently produced Optical Tooling transit. Although this manual was written specifically for the 76-RH190, much of the information it contains is applicable to the other transits as well.

The three different transits

The differences between the 771-x, 75-x, and 76-x transits relate solely to the way in which the cross-axis is constructed and used. All transits share the same base, standard assembly, bearings, and telescope optics. On all transits, the telescope rotates in a vertical plane around a horizontal axis (the *"cross-axis"*). The cross-axis is perpendicular to the line of sight.

Figure 1.3

75-H **76-RH190**

The 75-H transit (above, left) has been discontinued but many are still in use, and most of the information contained in this manual still applies.

The most basic transit is the 771 or 771-H. These transits have no optics in the cross axis. They are used as "jig" transits to establish straight lines and planes. However, they have no capability to make an accurate right angle turn.

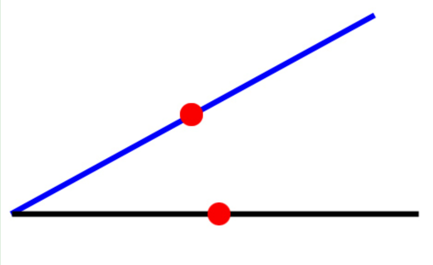
One step "up" is the model 75 or 75-H (on the left in Figure 1.3). These transits have a cross axis which is hollow and can be seen through. On one side of the cross-axis is a clear glass window, and on the other side is a partially reflective mirror. The 75(-H) does everything that the 771(-H) can do, but can also be used in conjunction with another instrument to produce a very accurate right angle.

The most flexible transit (and the only one currently produced) is the model 76-RH190. The cross-axis of this transit contains a telescope that is permanently focused at infinity and is equipped with reticle lighting. A right angle eyepiece is provided as standard equipment on the cross-axis telescope. The 76-RH190 may be used to establish straight lines, horizontal or vertical planes, and create accurate right angles with respect to other transits, alignment telescopes, mirrors, or other physical targets. When the cross wires of the transit's cross-axis telescope are set on those of a reference telescope or mirror, the main telescope of the transit will sweep a plane at precise right angles to the cross-axis reference line.

The "-H" in the various model numbers refers to a "Hollow" vertical axis. Transits that have the -H designation allow you to look straight down through a hollow vertical spindle and to see targets or collimators which are directly below the base of the instrument.

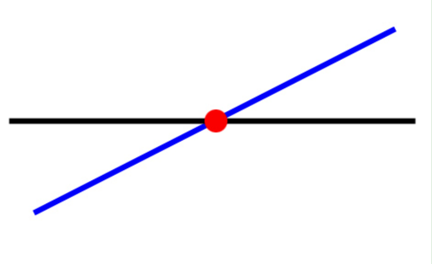
Why do we use four "feet" (leveling screws) instead of three?

We are often asked this question, since most theodolites have three leveling screws. The reason is that when adjusting four leveling screws, the instrument height is not affected.

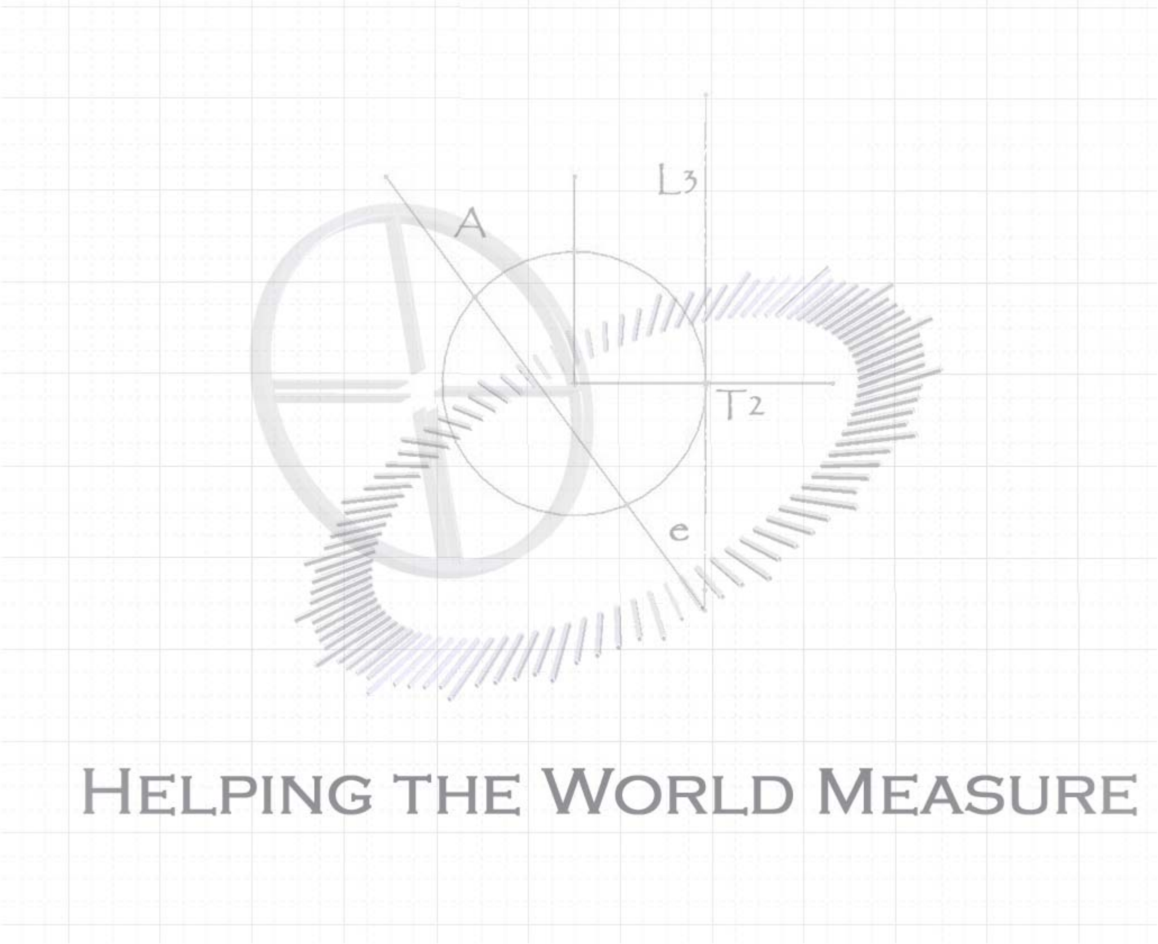


When three leveling screws are used, two of them must necessarily form a pivot axis, and the third is used to raise or lower one side to tilt the instrument. It gives the effect shown at left. The red dot indicates the relative instrument height between two positions of the instrument (tilted and not tilted).

However, when four leveling screws are used, the instrument position (again, red dot), effectively, does not change. This gives the effect shown at right. One side goes up by the same amount as the other side goes down, and the instrument pivots at its center, not on one side or the other.



This is just another example of the way that we have crafted our instruments to be more accurate at shorter ranges. Over longer distances, minor changes in instrument height are not important. But when measuring very accurately over shorter distances, avoiding changes in instrument height can become crucial.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HELPING THE WORLD MEASURE

Chapter 2 - Getting Started with Your Transit

In this chapter, we will discuss

- How to handle your transit
- Removing it from the case
- Using the shifting center
- Rough leveling
- Precise leveling
- The Reticle
- Focusing the eyepiece and telescope
- Finding Infinity focus
- Pointing the telescope
- Installing lighting accessories

Handle your transit with care

Note that these products are precision instruments and should always be handled with care.

- Do not force any of the screws. A firm (but not tight) tension gives the best results.
- Keep your instrument clean and dry. Protect it from the weather if used outdoors.
- Allow your instrument to "soak" for at least 4 hours in the temperature in which it will be used, so that shifts due to thermal changes are minimized. If you are moving the transit across thermal differentials of more than 20°F, allow it to soak for 8 hours. The instrument should be out of the case during this time for better air circulation.
- When taking a sighting, or reading one of these instruments, remove your hands, and make sure any other pressure is also removed.

Keep your instrument calibrated. Make the recommended field checks (see Chapter 4) as well as performing a complete calibration at least annually.

Note that there is a warning printed on the side of your transit which says "Caution—Do Not Plunge Telescope From Flange". *Plunging* the telescope means to rotate it in the vertical plane, as you might when you want to look further up or down. Specifically, *plunging* refers to reversing the direction of the telescope by rotating it 180°

Figure 2.1

in the vertical plane. The *"flange"* is the component upon which the warning is printed. This simply means not to rotate the telescope by grabbing the flange and twisting it. To rotate the telescope properly, put your hand on the telescope barrel itself.

Removing from the case

Loosen both the horizontal and vertical tangent clamp screws. Grasp the standards firmly with one hand, and the base with the other hand. Lift gently from case and place on a stand or other support. While maintaining a hold on the standards with one hand, rotate the base so that the bottom plate is firmly threaded on to any 3½" – 8 external threaded mount or stand. When replacing the transit into the case, slightly tighten the horizontal and vertical tangent clamp lock screws— but only do so gently.

Using the shifting center

A special centering mount, different than most of our instrument adapters, may be employed to physically place the horizontal center of the transit in a known location. The shifting center of the transit extends above and below the base plate (visible between the leveling screws and also from below as a 2" diameter ring centered on the bottom of the base plate). This shifting center (radius = 1 ± 0.0001") fits into special mounts having an accurately bored inner diameter. If the transit is to be located on one of these mounting rings, the leveling screws should be loosened slightly so the base plate can move around in relation to the shifting center. Re-tighten the leveling screws only after base plate is tightened on the mount.

Rough leveling

Once mounted on a stand or other stable instrument mount, the following process will *"rough-level"* the transit, meaning that the transit will be brought roughly to plumb, and be within range of the precision level vial mounted along the telescope axis.

To rough level, loosen any two adjacent leveling screws and turn the four arm "spider" base so that two diagonally opposed leveling screws are in line with the principal sighting direction that will be used. Figure 2.2 illustrates this, with the spider base lined up "square" with the telescope and cross axis. Re-tighten the leveling screws.

A circular "bull's eye" vial rests on the horizontal "plate" above the base but below the telescope axis (Figure 2.3). We call this the "plate vial". Center this bubble in the following manner: Put a

Figure 2.2

Figure 2.3

thumb and forefinger on each of two diagonally opposed leveling screws. To move the bubble, turn the leveling screws at the same time, and in opposite directions (thumbs moving together or thumbs moving apart). The bubble will move in the direction of movement of your left thumb. Move the bubble so that it is in the middle of the plate vial, and at least in line with the inscribed circle (it probably won't be exactly centered). Now move your hands to the other set of leveling screws. Using the same process, move the bubble directly under the inscribed circle in the center of the plate vial. You may have to repeat this entire process a couple of times to get the bubble centered. Keep a light but firm tension on the screws all the time. Never put heavy tension on leveling screws.

Now rotate the transit 180° about its vertical spindle. The bubble should stay centered under the inscribed circle. If it doesn't, the vial is out of adjustment (refer to Chapter 4 of this manual for the calibration procedure to correct this).

Precise leveling

To precisely level (sometimes called "precision plumb") the transit using the coincidence vial, rotate the standards of the transit until the telescope is in line with one pair of diagonally opposed leveling screws. Plunge (rotate) the telescope so that the coincidence vial is on top of the telescope, and level the telescope by eye (Figure 2.4). To assist you, look at the side of the coincidence vial and position the bubble roughly in the center of its travel. Gently tighten the

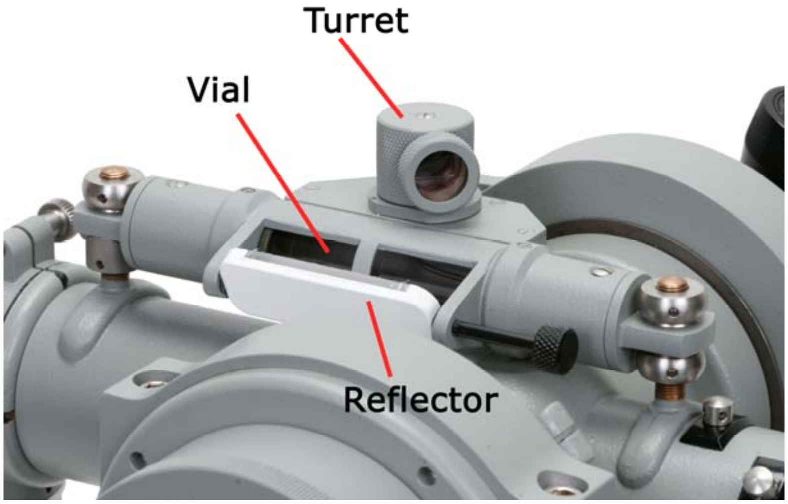


Figure 2.4

vertical tangent lock.

The bubble in the coincidence vial operates like any other level vial, but the operator views a "folded image" of both ends of the bubble simultaneously. If the telescope is tilted, the two bubble images move in opposite directions. However, when both ends of the bubble are brought "into coincidence" (Figure 2.5), the vial is dead level. You will see something similar to Figure 2.5 by looking into the vial's turret. Since the human eye is extremely skillful at detecting even tiny breaks in otherwise continuous lines, this system makes reading the level extremely sensitive and accurate.

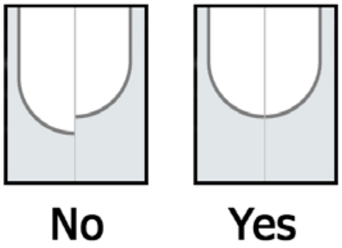


Figure 2.5

Rotate the turret on the coincidence vial so that you can conveniently view the split image of the bubble inside. A reflector having one white side and one mirrored side is provided to help illuminate the image. Position the reflector for optimal bubble illumination.

Note that the transit's vertical spindle may be brought into plumb (exactly vertical) even if the coincidence vial itself is not calibrated properly with respect to the telescope barrel.

1. Using the vertical tangent adjustment screw, bring the split image of the bubble into coincidence (Figure 2.5).
2. Rotate the standards 180° so that the telescope is now pointing in the opposite direction. If the bubble is off center, remove one-half the error with the two leveling screws which are located directly under the telescope. Remove the other half of the error using the vertical tangent screw. Remember that you can see the bubble by looking into the side of the vial itself rather than into the turret window—this may help you determine which way the bubble must move.
3. Now rotate the standards 90° so that the telescope is located directly over the other pair of leveling screws. Bring the bubble to center, using only the two leveling screws under the telescope.
4. From this position, rotate the standards 180°. Again, if the bubble is off center, remove one-half the error with the vertical tangent screw, and the remaining one-half error with the two leveling screws which are located under the telescope.
5. Repeat steps 2-4, alternating over each pair of leveling screws, until the bubble remains in coincidence in all four "compass point" positions.

The Reticle (crosshairs)

The telescope of each Optical Tooling instrument contains a reticle – or crosshair – which defines the center of the line of sight. When you look into a telescope, you see the reticle "superimposed" upon the image of whatever you have the telescope focused on. The reticle is split into four quadrants; two have a single "wire" (filar), the other two have a double "wire" (bi-filar). This configuration was originally adopted because the human eye is extremely good at detecting tiny differences in alignment between closely spaced objects. Therefore, this pattern makes it much easier to visually align the reticle with other images (ex., optical targets, scales, and reticle images reflected from mirrors).

Figure 2.6

The filar/bi-filar reticle image as seen when looking into the telescope.

How to properly focus

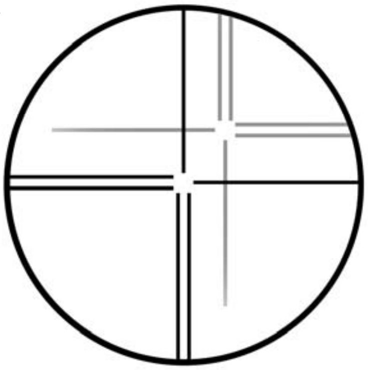
Focusing sounds easy, but it’s surprising how many people don’t understand the effects of something called *parallax*. Here’s how to properly focus your instrument. First, point the telescope at a sheet of white paper or other light colored background. Don’t worry about focusing the telescope using the focus knob, the image can remain blurry. Instead, use the knurled ring on the eyepiece to focus the reticle so that it is sharp and black.

Now point the telescope at a target of interest and focus the image using the focus knob on the telescope. Slightly shift your head left and right while looking at the reticle as it is “superimposed” over the image of the target. If the reticle appears to float slightly to the left and right over the target, *parallax* is present in the system. This occurs when either the telescope’s main optical system or the ocular (eyepiece) system, or both, are not focused precisely on the plane of the reticle. Parallax can lead to erroneous measurements if not removed. To remove the parallax, repeat the two steps again, being careful to achieve critical focus in each step.

Finding infinity focus

There are many occasions when it will be important to put your telescope at infinity focus (e.g., autocollimating your telescope on a mirror). Infinity is important because, from an optical standpoint, light rays coming from an “infinite distance” are all parallel to each other, or *collimated*.

Figure 2.7



The reflected image of a reticle (here, located above and to the right of center) will appear ***only*** *at infinity focus.*

The focus knob on the telescope has an indicator of the direction you must turn it to find infinity focus, but you can't just turn it all the way in that direction and expect to the telescope to be focused at infinity.

The easiest way to find true "infinity focus" is to hold an optically flat mirror (such as our model 185) right up against the objective end of the telescope. Turn on the transit's internal illumination (see "Installing lighting accessories" below). Turn the focus knob all the way in the direction of infinity (indicated on top of the focus knob). Then, turn the knob slowly in the opposite direction, and watch closely for the reflected image of the reticle. It can go by pretty quickly, so going slowly is important while looking through the telescope. Once you have focused the telescope so that you can clearly see the reflected reticle image, you know that the telescope is, by definition, focused at infinity.

Pointing the telescope

Release both the horizontal and vertical tangent clamp locks, and move the instrument by hand. Precise pointing is accomplished by re-locking both clamps when you get close to the target, and then turning the tangent adjustment screws for precise placement of the reticle. Both tangent adjustment screws are outfitted with wobble pins which allow for smooth translation of the axes. The final setting should be made by turning the tangent screw in a clockwise, or pushing, direction. This will eliminate any potential subsequent movement due to friction of the spring-loaded plungers which oppose the tangent adjustment screws.

Installing lighting accessories

For certain procedures that we will discuss in this manual, (e.g., collimation, autocollimation, and reticle projection) it is necessary to illuminate the reticle of your transit from the inside. A model 76-x transit has two reticles (one in the main telescope and one in the cross-axis telescope) which may need to be illuminated, depending upon what you are doing.

Illuminating the cross-axis telescope reticle. Your transit comes equipped with a light source for the cross-axis telescope (model 76-

x only). This LED light source fits into the receptacle (red arrow in Figure 2.8). The supply transformer works with either 110V or 220V sources. Installation or removal of the light source is simple and quick. Simply install the two-way adapter on the cross-axis lighting receptacle, and push the LED lamp housing in until it clicks into place. The light source has an in-line switch for easy control of the light.

Remember that the focus of the cross-axis telescope is permanently fixed at infinity. This telescope is meant to be used as a collimator or autocollimator. We will discuss this more, later on in the manual.

Figure 2.8

Illuminating the main telescope reticle. When you wish to use the main telescope for collimation, autocollimation, or reticle projection, you must install a model 196-1 combination eyepiece unit. To do this, remove the short section of the main telescope barrel located just in front of the eyepiece (See Figure 2.9), and replace it with the 196-1 eyepiece adapter. Note that the 196-1 has a knurled lock ring which allows you to tighten the adapter in any given orientation on the telescope barrel.

Before installing this eyepiece adapter on the telescope, make sure the knurled lock ring (red arrow in Figure 2.10) is secured against the adapter. It should be "bottomed out" on the threads rather than loose on the threads or near the open end of the adapter. Then thread the adapter into the main telescope barrel as far as you can. Next, back off the adapter to the desired radial orientation (lamp receiver pointing up or pointing down) and lock it in place by turning the knurled lock ring toward the front of the telescope.

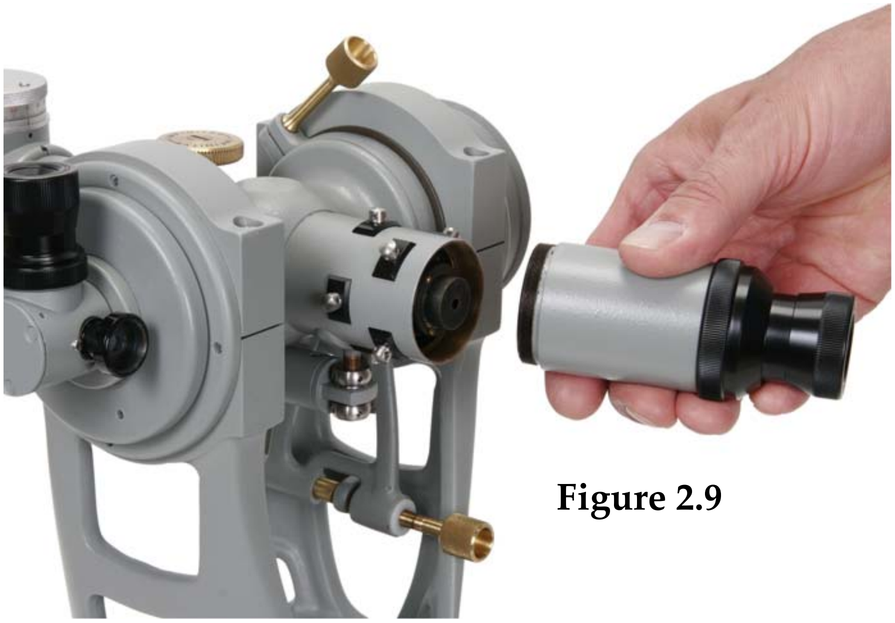


Figure 2.9

Next, remove the eyepiece assembly that is still connected to the short section of the telescope barrel which was removed, and install it on the 196-1 eyepiece adapter.

To install the light, remove the cap from the lamp receiver (under the right thumb in Figure 2.10). Then install the two-way adapter by threading its knurled ring onto the lamp receiver. Plug in the LED light source until it clicks in the adapter.

Note: To install a right angle viewing eyepiece on the main telescope (convenient for very high angle shots), you may wish to install a 193-L rather than the 196-1. These accessories are installed in basically the same way, by first removing the short tube section in front of the eyepiece.

Figure 2.10

Later in this manual, we will discuss some of the optical tooling techniques which require backlighting of the reticle using one of these adapters.

Chapter 3 - Measuring Techniques

There are many jobs that you can do with your transit, which may be purchased with a 190-type micrometer in a standard configuration. You can evaluate a number of alignment-related characteristics of machinery or other structures, such as straightness, plumb, level, flatness, and others. However, to perform certain Optical Tooling procedures, other accessories are required. We will mention some of these accessories as we discuss the related topics.

In this chapter we will discuss the following topics:

- "Bucking in"
- Autoreflection
- Autocollimation
- Collimation
- Collineation
- Reticle projection
- Measuring with micrometers

This discussion is meant to make you aware of some of the Optical Tooling procedures that you can use in alignment and measurement work. This manual is not a good substitute for our training classes, in which we offer hands-on training of these and many other Optical Tooling techniques.

We'll explain what these terms mean, and how to accomplish them using your transit.

"Bucking in"

In many alignment jobs, it is necessary to put the line of sight of your transit directly on a line created by two known reference targets. For example, in Figure 3.1 (showing a view from overhead), some targets have been installed in the floor. These targets represent a line which is parallel to the centerline of a machine on which you need to align components. In preparation for doing this alignment job, it could be necessary to bring the instrument in line with these two floor monuments.

Note in Figure 3.1, the transit must not only be rotated so that it is parallel to the line defined by the targets, but it must also be shifted sideways. "Bucking in" is a repetitive process in which you adjust both the instrument's angle as well as its lateral position so that the transit is placed directly in line with two targets. Or to be more accurate, so that the transit's vertical spindle lies in the vertical plane which also runs through the center of the floor targets.

Note that angular adjustments are easy enough to make using the horizontal tangent adjustment screw on the transit itself. However, lateral shifts of the entire instrument are not as easy. To greatly simplify this, we recommend the use of a lateral slide mounted between the transit and the stand on which it is mounted.

*Always set the telescope on the **far** target by making **angular** moves using the horizontal and vertical tangent screw(s).*

*Always set the telescope on the **near** target by making **lateral** moves using a lateral slide or precision lift.*

Steps to buck the transit into the target line:

1. **Roughly position the transit.** Set up the instrument stand nominally in line with the two targets.
2. **Rough level.** Rough level the transit as described in Chapter 2 “Rough Leveling”.
3. **Precise level.** For many applications, precise leveling your transit is required prior to buck-in (covered in Chapter 2). Technically is it possible to buck into targets without precise leveling, but the transit will not end up in the vertical plane defined by those targets unless the transit itself is precisely plumb. A full discussion of this fact is beyond the scope of this manual, but is covered in more detail in our Optical Tooling classes.
4. **Set to far target.** Focus the telescope on the far target and set the crosswires directly over that target using the horizontal and/or vertical tangent adjustment screws. If the transit is between the targets (as in Figure 3.2), simply assign one of the targets to be the “far target”, and set on it.
5. **Set to near target.** Without moving the horizontal tangent screw or turning the standards of the transit, turn the telescope downward and focus on the second target. Note that if the transit is located *between* the targets (as in Figure 3.2), you will have to turn the telescope “through” the standards to point in the opposite direction. Regardless of whether you are in a situation like Figure 3.1 or Figure 3.2, this second target will invariably be off to one side of the field of view unless you are incredibly lucky. For purposes of illustration, let’s say that the observed lateral distance to the near target is “L” (see Figure 3.1 or 3.2). Now you must move the transit laterally toward the near target using the cross slide—but how much? The amount that you move the transit depends upon the geometry of the setup. The equation to calculate the proper amount of shift is:

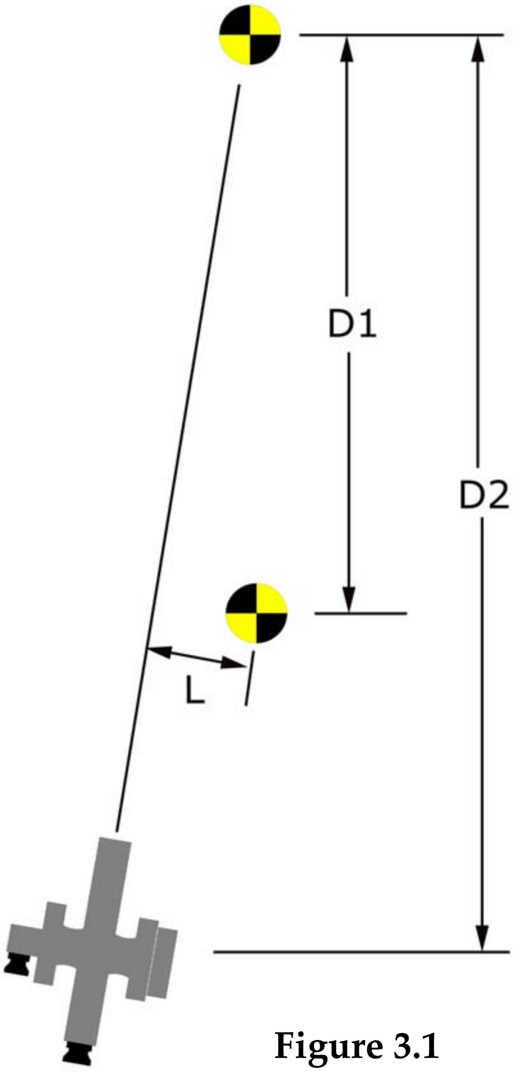


Figure 3.1

Transit Lateral Shift = L x (D2/D1)

where

D1 = Distance between targets

D2 = Distance from far target to transit
L = Observed distance from line of sight to near target

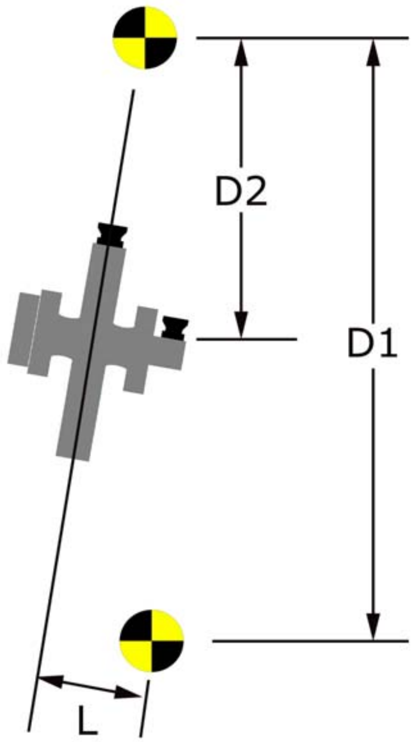


Figure 3.2

The amount of movement will depend upon whether the transit is located *between* the targets or is *not located between* the targets. Let's take a look at these two cases.

Note that if *the transit is NOT located between the targets* (Figure 3.1), you will shift the transit "past" the image of the near target, because the ratio D2/D1 will always be larger than 1. "L" is the observed distance to the near target, and a shift of greater than "L" will appear to move you to the other side of the near target. When you have made the required shift using a cross slide, proceed to step 6.

Note: When the transit is in between the targets, and just about equidistant from both, you can simply pick one of the targets as the "far" target. Then use the rules as well as the definitions of D1 and D2 to calculate the shift required to buck the transit in to both targets. As long as you are consistent with your arbitrary definitions of "near" and "far", you will be successful.

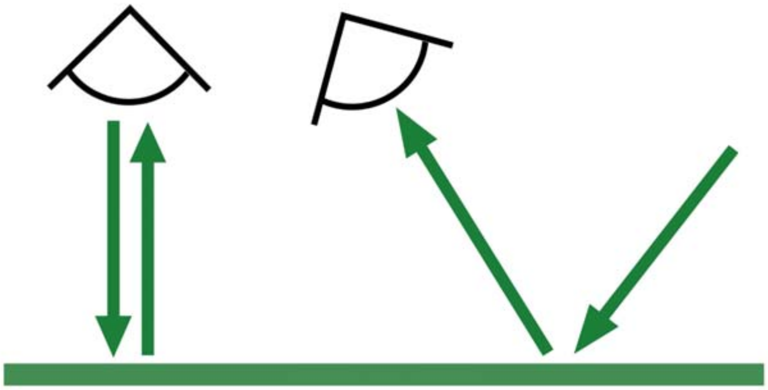
On the other hand, *if the transit IS located between the targets* (Figure 3.2), you will not shift the transit even *as far as* the near target, because the ratio D2/D1 will always be *less* than 1. Again, "L" is the observed offset distance from the near target, and a shift of less than "L" will not even move your line of sight as far as the near target. When you have made the required shift, proceed to step 6.

6. Now simply repeat steps 4 and 5 until the transit's reticle remains centered on *each* target as the telescope is rotated from one target to the other, and no more adjustment is required. When this is accomplished, the transit is "bucked in" to the line defined by those targets.

Autoreflection

You probably already understand autoreflection intuitively, even if you don't yet know how to do it with a transit. Imagine yourself looking in a mirror, except that you close one eye. If you look with only the one eye at the reflection of your shoes, or something in the background, or your elbow, you may notice that your line of vision will not be at right angles (orthogonal) to the mirror. However, if you train your eye on the reflected image of your own eye in the mirror, then your line of vision *will be orthogonal to the mirror*. This idea is illustrated in Figure 3.3. Knowing this, it is easy to figure out how to look at a mirror so that your line of vision is at right angles to that mirror—you just find the image of your own eye.

Figure 3.3



Autoreflection is the technique of performing this process with your transit. If you look into a telescope which is pointed directly at a mirror, and the mirror is perpendicular (90°) to the line of sight, you could focus on an image of the objective end of your own telescope, just like you did with your own eye. If you put a target (available as an accessory) on the end of the telescope itself, you would be able to position your own instrument's internal reticle over the image of that target that you see in the mirror. This concept of autoreflection is used to put an instrument's line of sight (LOS) close to perpendicular to a mirrored surface. It is important to note that autoreflection is not as accurate as *autocollimation* (discussed later), and is most often used as the first step to autocollimation.

Figure 3.4

An autoreflection target is mounted on the objective end of a telescope to help center a reflected line of sight on the telescope itself. Note that if you have lots of experience and a convenient setup, using an autoreflection target is not mandatory.

In some ways, the autoreflection procedure is similar to the buck-in process discussed previously. However, this time, the "near target" is the actual surface of the mirror itself, while the far target is the reflection of the telescope face (or a target mounted on the telescope). Therefore we know that the distance to the far target is always twice the distance to the near target.

Here are the basic steps for autoreflection:

1. **Define the "working" mirror.** We'll assume that you have a mirror situated at the end of a shaft or mounted in a machine tool chuck, or in some other relevant location.

2. **Install proper autoreflection target.** Mount an autoreflection target (example shown in Figure 3.4) on the objective end of the telescope. We have two different basic types. The type in Figure 3.4 is used for longer distances. The other type has a smaller target printed on glass, is used for closer distances, and often requires internal lighting of the transit.

3. **Roughly position the transit.** Position the instrument stand in front of the mirror by finding the reflection of your own eye in the mirror, and then putting the stand's instrument mount on the line between your eye and the

mirror. Mount the transit to the stand.

4. **Point at the mirror.** Point and focus the telescope at the center of the mirror, then lock the horizontal and vertical axes with the tangent lock screws.

5. **Set on the "far" target.** Focus the telescope to view the autoreflection target (or the end of the telescope itself) in the mirror. *This is the "far target".* Just as when "bucking in" before, make angular adjustments as needed to align the reticle with the far target.

6. **Set on the "near" target.** Now focus the telescope to view the mirror itself. *This is the "near target".* Make lateral (shifting) adjustments left and right, or up and down, as needed to align the crosswires generally with the center of the mirror. You can approximate this if the mirror has no target printed on its surface.

7. Alternately repeat steps 6 and 7 until no further adjustment is needed.

A ***precision lateral slide*** *allows shifting the instrument back and forth; a* ***precision lift*** *allows moving the instrument up and down.*

Autocollimation

Ultimate accuracy in angular control requires the use of *autocollimation*. In autoreflection, the reticle of the telescope is aligned with the reflected image of a target which is mounted on the objective end of the telescope itself. But in autocollimation, the reticle is aligned with its own reflection from the mirror, not that of a secondary target. This makes autocollimation much more accurate than autoreflection. However, in practice, autoreflection is performed first, making autocollimation easier to achieve.

A reticle image which is reflected from a mirror is ***only visible when the telescope is focused at infinity.***

To autocollimate an instrument, the main telescope reticle must be illuminated (discussed earlier). Our illumination adapters are built in such a way that your ability to view the reticle is not impeded, even though it is backlit. When the reticle is backlit *and the telescope is focused at infinity*, parallel light rays will exit the objective end. If you then look into the telescope, when pointed at a mirror, the parallel light rays bounce back from the mirror, and you see a reflected image of your own instrument's reticle.

When the mirror (or the instrument) is adjusted so that the reflection of the reticle falls exactly back on the original reticle itself, the telescope has been very accurately positioned perpendicularly to the surface of the mirror.

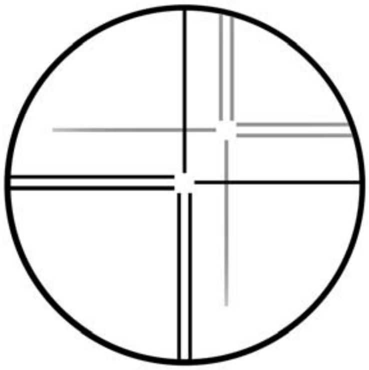
This is an extremely accurate way to establish a right angle with respect to an optical reference line defined by a mirror.

One of the most powerful capabilities of optical tooling is its ability to transfer optical reference lines from one place to another, with extremely accurate results. Transfer of lines is most accurately accomplished using autocollimation (which uses a mirror) or collimation (which uses a second instrument). Autocollimation is extremely useful when setting your instrument to mirrors which may be mounted on drive shafts, spindles, machine tools, other optical tooling instruments, laboratory equipment, etc.

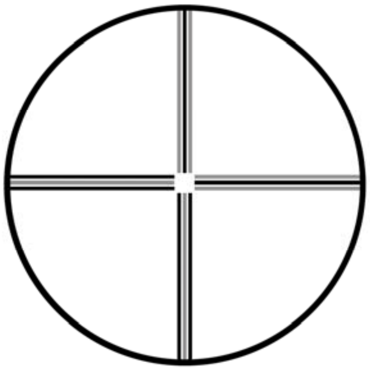
In the previous section, we discussed autoreflection, which can be used to make the transit's line of sight perpendicular to the surface of a mirror. Autocollimation is a refinement of this process, squeezing out most of the remaining angular error. You should be able to autocollimate to a mirror so that the line of sight is perpendicular to that mirror within about ±1 arcsecond.

The autocollimation process is able to accomplish these accuracies because the focal lengths involved are much longer. This gives you far more leverage and angular control. We'll discuss autocollimation using first the main telescope of your transit, then using the cross-axis telescope.

Figure 3.5



Above: the reflected reticle is seen off-center. After the transit is adjusted, the reflected image is brought directly into register with the transit's actual reticle (below).



Autocollimation using the main telescope

The autocollimation procedure is simply another type of buck-in process. Therefore, the near and far targets must be defined. The near target is always the mirror itself, while the far target is the returned (reflected) reticle image.

Follow these steps for autocollimation:

1. **Install transit illumination.** Install one of our lighting accessories into the barrel of your telescope (described in Chapter 2). Turn on the light source.

2. **Autoreflection.** Set your transit perpendicular to the mirror using the technique of autoreflection (discussed in the previous section).

3. **Focus at infinity.** Once you have autoreflected the transit, you may be tempted to turn on the transit's light source and try to focus on the reticle image that is reflected from the mirror. You can try this, but you may have trouble finding the image due to the fact that autoreflection does not always set the transit perpendicular to the mirror within the minimal range required for autocollimation. If you can't find the reflected reticle image, focus the instrument at infinity using the procedure discussed in Chapter 2. Remember that at infinity, even the tiniest angular difference can make very large shifts in the apparent position of the reflected reticle. This

"leverage" is what gives the technique of autocollimation its capability for extreme accuracy, but it's also what makes the reflected reticle image (at infinity) more difficult to find.

Once you have focused the telescope at infinity, proceed to the next step. But remember, *don't change the telescope focus when performing the next step.*

4. **Center transit on "far" target. (Put reflected reticle image over actual reticle.)** See if you can locate the reticle image that is reflected from the "working" mirror. Use the horizontal and vertical tangent adjustment screws on the transit to rotate the telescope slightly in the elevation (up and down) or azimuth (left and right) directions. Watch for the reflected image. Performing the autoreflection procedure should have put you right in the ballpark, but small adjustments may still be needed to find the reflected reticle image. Once you find it, we'll define it as the *far target***.** Make angular adjustments as needed to align the reflected reticle image directly over the transit's internal reticle.

Remember that when focused at infinity, only the transit's angular controls produce visible results. Lateral shifts using a cross-slide or precision lift will not help you align to the reflected reticle when focused at infinity.

5. **Center transit on "near" target.** If you had to move significantly to find the reflected reticle image, or if you found only a partial or poor quality reflected image, you probably need to shift the transit laterally up/down or right/left in order to center it more precisely on the working mirror. This type of problem often indicates that you are looking at the edge of the mirror rather than a full-on, centrally aligned view. To achieve a better result, focus the telescope again to view the surface of the working mirror. Remember that in the buck-in process, this is the *near target*. Make lateral shifting adjustments as needed, using the cross-slide or precision lift to align the reticle more nearly in the center of the mirror. Then focus back to infinity (by watching for the reflected reticle image near infinity focus using either the working mirror or another mirror held against the objective end of the telescope as discussed previously).

6. Repeat steps 4 and 5 until you have a good quality reflected reticle image which is centered directly over the transit's actual reticle. Remember that if you start the process with an accurate autoreflection, you will have an important advantage in this process.

Autocollimation using the cross-axis telescope

(76-RH only)

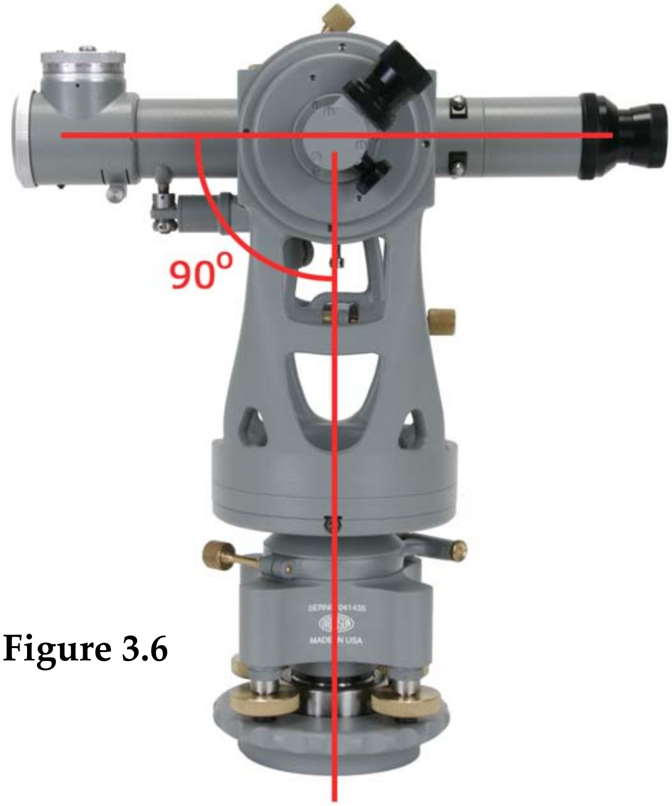


Figure 3.6

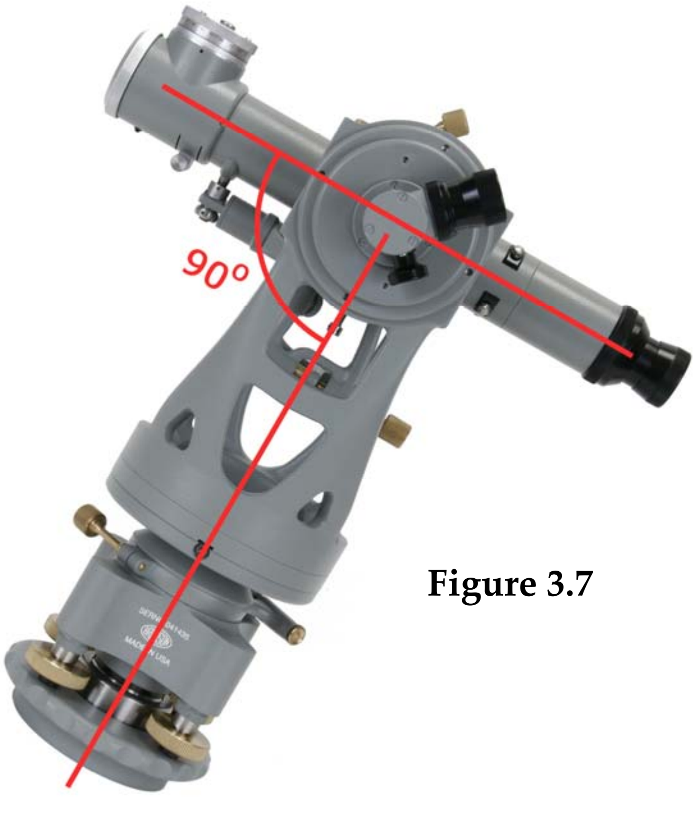


Figure 3.7

For some applications, it is necessary to autocollimate the cross-axis telescope (“*cross scope*”) to a mirror.

When we autocollimated the main telescope to a mirror, we used autoreflection as the first step, to get us in the ballpark and make autocollimation easier. However, remember that the cross scope is permanently focused at infinity, so you can’t autoreflect it to a mirror (which requires focusing alternately from near to far). So you must use a special procedure to prepare for autocollimation when using the cross scope.

1. Install telescope and cross-axis telescope illumination. Install a lighting attachment on both the main telescope and the cross-axis telescope as described in Chapter 2. (It is not necessary to actually have a light source in both at the same time.)

2. Make the main telescope square to the vertical spindle. We must bring the main telescope axis “square” to the vertical spindle (See Figure 3.6). This may be accomplished by precise leveling the transit as discussed in Chapter 2 (“Precise Leveling”). Precise leveling (a.k.a. precision plumbing) actually accomplishes two things at once. First, the transit’s vertical spindle is brought to plumb (i.e., straight up and down; parallel to the gravity vector). Second, the main telescope is brought to horizontal, which of course makes it square to the vertical spindle (Figure 3.6). This latter part is what we care about—we want the main telescope perpendicular to the vertical spindle. When this is true, the cross scope and the main scope will “follow” each other as the transit is rotated in the azimuth direction, about its vertical spindle. That is, the line of sight of both the main telescope and the cross-scope will be in the same horizontal plane. Therefore, if you turn the main telescope to look at point “A”, and then turn the transit 90°, the cross-scope will now point at the same point “A”. Now here’s the important part: *this is true whether or not the transit remains precisely plumb.* As long as you don’t rotate the main telescope up or down with respect to the standards, both telescopes (main and cross-axis) will rotate in the same plane, even if the transit is tilted from a vertical orientation (Figure 3.7). For example, if you now laid the entire transit over on its side, the main telescope and cross-scope would still rotate in the same plane around the central axis of the transit. Once you have precision plumbed the transit, proceed to the next step.

Even when the transit is tilted, it is possible to maintain a 90° relationship between the main telescope's line of sight and the transit's vertical spindle (which of course is no longer actually vertical).

3. **Autocollimate the main telescope.** Follow the steps previously described to autocollimate the main telescope to the mirror. *However,* you must observe one important difference when performing that process this time. During the autocollimation process, *do not change the relationship of the telescope to the vertical spindle.* That is, leave the vertical tangent adjustment screw alone—don't use it to tilt the telescope for proper autocollimation. Instead, if you need to tilt the main telescope, use the leveling screws at the base of the transit and tilt the entire transit instead. Once you have achieved autocollimation in this manner, proceed to the next step.

4. **Turn transit to autocollimate the cross scope.** It should now be a simple matter to turn the transit 90° in order to view the mirror with the cross scope. Rotate the main telescope's focus knob all the way in the direction *opposite* of infinity. This keeps the main telescope's focusing slide from obstructing the view through the cross-axis telescope. Be sure the cross scope illumination is switched "on". Carefully look into the cross scope eyepiece for the reflected reticle image as you slowly turn the transit back and forth with the cross scope pointed toward the mirror. You should not have to adjust anything— just rotate the upper body of the transit to find the reflected image. When you see it, you can bring the reflected reticle image into precise register with the cross scope's actual reticle by using the horizontal tangent adjustment screw to precisely rotate the standards, and, if need be, the leveling screws to bring the reflected image to dead center.

Collimation

As we have said, parallel light rays are said to be "collimated". When a telescope is focused at infinity, it means that only parallel light rays which are entering the telescope's objective lens will be clearly seen by an observer looking into the eyepiece. When the telescope is focused in this manner, images from closer than "infinity" are out of focus.

Before we get too far, let's bring up another important point: your telescope is capable of working "backwards". If you put a light near the eyepiece (i.e., backlight the reticle), you can shine light rays out the objective end. This means that if you illuminate the reticle of an instrument which is focused at infinity, it *projects* collimated (parallel) light rays out the front.

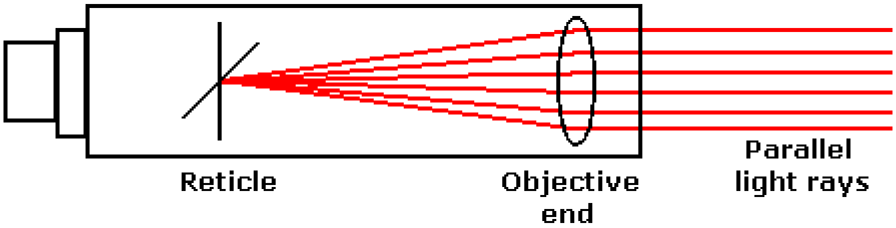


Figure 3.8

Any telescope which is focused at infinity may be referred to as a "collimator". Any two telescopes which are focused at infinity, pointed at each other, and whose reticles are brought into registration are said to be "collimated".

Pointing your transit's telescope directly "down the barrel" of an infinity-focused instrument (and thereby toward collimated light rays) will allow you to see an image of the illuminated reticle of the instrument into which you are looking. *Both instruments' telescopes must be focused at infinity for this to be true.* If your transit is bucked into the other telescope's line of sight, you can precisely superimpose your transit's reticle image over the reticle of the other telescope, and the lines of sight of the two telescopes will be established as exactly parallel.

This is an extremely accurate way to transfer a reference line established by a second transit or other instrument.

Remember that if the lines of sight are parallel, it doesn't mean that they necessarily travel down the exact same line in space— if they did, they would also be defined as "collinear".

Let's take a closer look at this. Think about walking down a road on a moonlit night. As you walk, you pass a lighted streetlight on the road. As you pass this streetlight, you cast a shadow. Initially, the shadow is behind you, but as you pass the streetlight, it moves around in front of you. The light rays from the streetlight are not all parallel—they extend out from the source (the lamp in the streetlight) in all directions. As you walk, you "pass through" light rays which are going in different compass directions, and your shadow moves around accordingly (Figure 3.9).

Now, after you are further down the road away from the streetlight, you notice that you are casting a shadow by the moonlight, off to your left-hand side. However, it doesn't move around you like the shadow from the streetlight did. The shadow cast by the moonlight always appears to be in the same place with respect to your position, regardless of how far you walk down the road. This is because the moon is so far away, light rays that reach the Earth from the moon are effectively parallel.

Additionally, when you look straight at the moon, your line of sight is “collimated” or parallel to the moonbeams. You can walk back and forth however far you want (make lateral shifts), but you will not need to rotate your head back and forth to keep your eyes aligned to the moon—the moon appears to move right along with you.

Using this thought experiment, you might begin to see how collimated instruments, whose lines of sight are parallel, are not necessarily on the same exact line in space. One instrument can move back and forth laterally, with the image from the other instrument (analogous to the moon) still appearing to be in the same relative position. It’s important to remember this characteristic of collimation so that you don’t fool yourself into thinking that collimated instruments actually share the same physical line of sight.

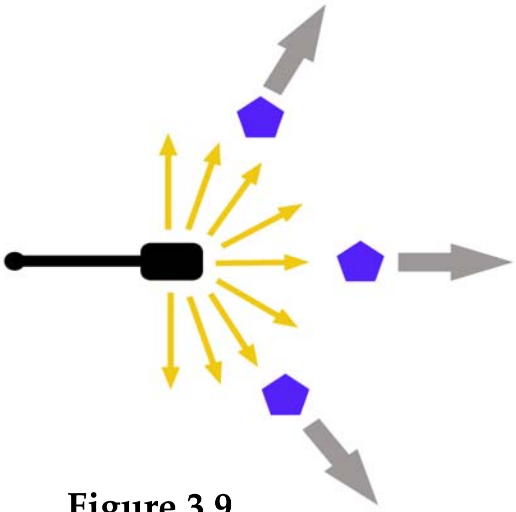


Figure 3.9

A streetlight from above: shadows (gray arrows) cast by an object near a light source are parallel to the light rays which travel from that light source to the object.

The bottom line is: collimated*, but not necessarily collinear*, lines of sight are exactly parallel, like the rails on a section of train track; parallel *but not occupying the same physical space*. This *collimation* procedure is very useful for transferring reference lines from one instrument to another.

Let’s discuss how to collimate two instruments. In collimation, one instrument remains stationary, and is focused at infinity. This is designated as the reference instrument, because it represents some reference line that is of importance (e.g., a shaft or bore centerline, etc). Then, collimation occurs when the optical axis of a second (“working”) instrument is brought into parallel alignment with the reference instrument.

To collimate the “working” instrument to the reference instrument, perform the steps below. Again, this is a buck-in process.

1. **Illuminate the reference instrument.** Make sure that the reference instrument has a light source which is illuminated so that its reticle is backlit.

2. **Focus at infinity.** Focus the reference instrument to infinity using a mirror as described previously.

3. **Point to the reference instrument.** Point the working instrument at the face of the reference instrument and focus on its objective end. Lock the horizontal and vertical tangent screws on the working instrument.

4. **Center transit on the “far” target.** Now focus the working instrument at infinity. The focus is now set so that

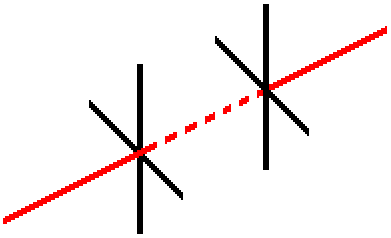
you can “look down the barrel” of the reference instrument, and try to find its reticle image. When you find it, *this is the far target.* Make angular adjustments to the working transit as needed to align the working instrument’s reticle to the reference transit’s reticle image.

5. **Center transit on the “near” target.** Focus the telescope to view the reference instrument’s objective end face. *This is the near target.* Make lateral adjustments with a cross slide or precision lift as needed to center the reticle (approximately) on the objective lens of the reference instrument.
6. Repeat steps 4 and 5 until bucked-in.

Collineation

Collimation can be taken one step further if necessary — the two collimated telescopes may be adjusted so that their lines of sight are *collinear* as well. Picture two collimated telescopes, pointing at each other. As we've discussed, if you look into either telescope, you should see two reticle images, if both telescopes are backlit. One reticle is in the telescope you're looking into, and the other is in the far telescope. If collimated, the reticles of the two instruments will appear to be in perfect register, one over the other.

Figure 3.10



Above: When two telescopes are collinear, their lines of sight are not only parallel but also exist in exactly the same line in space.

However, if you were to focus both telescopes on a target plane (such as a piece of paper) held up about halfway between the instruments, the reticles would no longer be superimposed unless you were incredibly lucky. As we’ve said, when two telescopes are “collimated”, the lines of sight are parallel but not necessarily superimposed upon each other. But there is a procedure that you can use to superimpose the reticles at this *near target plane* while the instruments are still collimated at infinity. After performing this procedure, the lines of sight actually become *collinear*. They're not just parallel any more - they actually exist along the exact same line in space.

Note: Illuminating both your transit and the reference instrument is very helpful but is not absolutely necessary for collineation. You can hold up a white sheet of paper behind the eyepiece of an instrument, and light it with a flashlight, in order to backlight the reticle in that instrument. Of course, this usually requires the assistance of a second person.

In the collineation process, you can align your transit to the vertical wire of the reference instrument’s reticle, or the horizontal wire, or both—depending upon whether you want to transfer a specific vertical or horizontal plane, or both.

Why is collineation useful? Most of the time, the transfer of a reference line requires only collimation. But sometimes, if you are trying to transfer a specific horizontal elevation or a vertical plane from one side of an object to another, the technique of collineation can provide the answer.

As with most of the other techniques discussed, the collineation procedure is simply a buck-in. To understand the definitions of the *near* and *far* targets in this instance, let's take a look at the procedure.

1. **Collimate.** As the first step, collimate your transit to the reference instrument.

2. **Bring focal points to a middle distance.** Temporarily insert a piece of paper or other very thin material (it helps to have a white non-reflective surface) about midway between the two instruments and focus both telescopes on this surface.

3. **Center your transit on the "near" target.** Remove the paper and look through the working instrument—you should be able to see the reticle image of the reference instrument. Focus precisely on this image. We'll define this as the *near* target. Make lateral adjustments using your cross slide or precision lift as needed to bring the reticle of your transit into alignment with the reference instrument's reticle.

As always, when focused on the far target, only the transit's angular controls produce visible results. For setting to the near target, make lateral shifts using a cross-slide or precision lift.

4. **Return reference instrument focus to infinity.** Focus the reference instrument back out to infinity with a mirror.

5. **Center your transit on the "far" target.** Focus the working instrument at infinity and find the reference instrument's reticle image. This is defined as the *far* target. Make angular adjustments on your transit (horizontal and vertical tangent adjustment screws) as needed to align the reticle images.

6. Repeat steps 2 through 5 until bucked-in. When your transit can be focused on both the near and far targets without making further adjustments, you have accomplished collineation. The two instruments no longer simply have parallel lines of sight, but have been adjusted onto precisely *the same* line of sight.

Reticle Projection

We have already discussed the fact that a telescope may be used "backwards" (see "*Collimation*" in this section). Accordingly, your transit can also be put in *reticle projection* mode. This allows you to project an image of the reticle onto some surface at which the telescope is pointed. To do this, you must focus the telescope on the surface on which you want the reticle image to appear (rather than at infinity). Low ambient light levels are required to see the projected image. This is sometimes useful when you have established a reference line, and in turn need to project an image of the crosshairs on a surface to give a clear visual indicator of the reference line. This is useful for building, component positioning, etc.

Projecting a reticle image onto a surface is sometimes used in "build" or "set-out" procedures. The projected reticle lines give real-time feedback as to the position of some component of interest.

To do this, you must use an eyepiece adapter capable of reticle projection (model 196-1). This unit has settings for straight-through viewing as well as reticle projection. With one of these installed, look through the telescope at the surface on which you wish to project the reticle. Focus the telescope on that surface. Turn on the illumination, and switch the eyepiece to projection mode. This will project the reticle image onto the surface. Again, remember that the surrounding lighting conditions must be very subdued in order to see the projected image.

Measuring with Micrometers

So far we have discussed a number of techniques which allow you to set your telescope to reference lines established by target points, other telescopes, or mirrors. Once those reference lines and planes are established, measurements of physical objects relative to those reference lines may be made using *optical micrometers*.

Figure 3.11

The graduated drum on an optical micrometer reads the lateral shift of a line of sight.

Optical micrometers are designed to offset the line of sight by amounts which may be read on a graduated drum. In a sense, they "pick up the line of sight and set it over" using a very flat block of glass which is manually rotated. This technique shifts the line of sight laterally rather than changing the angle at which it "enters" the telescope. The amount of the lateral shift is then read on the micrometer itself. Since the shifted line of sight remains parallel to the original line, *the measured offset deviation is the same for all distances.* (There is one exception to this rule—micrometers do not function at infinity focus. At infinity focus, when light rays are parallel, lateral deviations produced by a micrometer are not visible.)

Let's take a look at what you see when you look through a telescope, and measure with a micrometer. Say that you have pointed the telescope directly at a target so that you see the image in Figure 3.12. Say also that the micrometer on the telescope is set to zero. Now, for some reason, the target moves to the right. You see the image shown in Figure 3.13. To measure the distance that the target moved, you can turn the micrometer drum and shift the reticle back

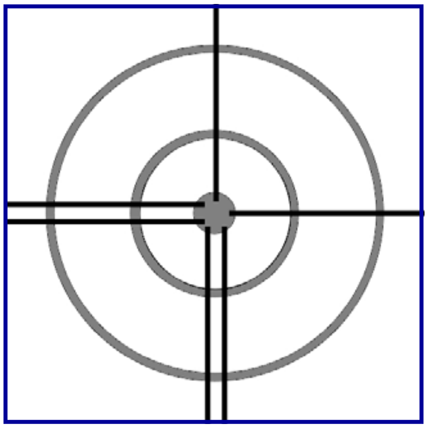


Figure 3.12

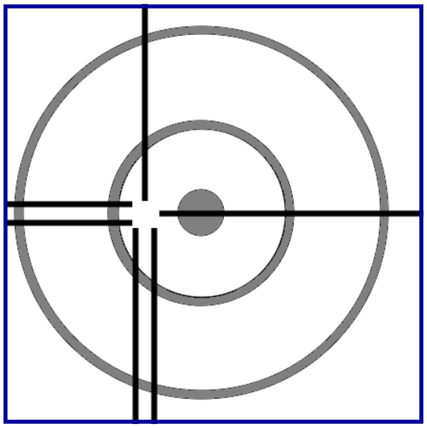


Figure 3.13

over the center of the target, and the image will once again look like Figure 3.12. You can then read the graduated drum on the micrometer to see how far you moved the line of sight. Let's say that the drum now reads 0.080″ instead of zero. This of course means that the target moved 0.080″ to the right and that you have offset the line of sight laterally to the right by 0.080″ to compensate for the target movement.

You can also see from this illustration that if you had established a reference line with the transit, based for example on important machine parameters or centerlines, and then observed a target that was *supposed to be in line* with these important machine features, you could use the micrometer to measure that target's distance away from the reference line.

Never *put the micrometer on the telescope without securing it using the knurled thumbscrew. More than once we have repaired micrometers that have flown off the end of telescope barrels!*

Your 76-RH190 comes equipped with an optical micrometer which reads in English or metric units. Various micrometers are available—some have a smaller range, some a bigger range, and some read in two directions (horizontal and vertical) at the same time.

The micrometer is easily mounted on your telescope. There is a small knurled locking thumbscrew on the micrometer which may be loosened or tightened by hand. The telescope barrel has a pin which fits into one of four détente positions on the micrometer. Carefully put the micrometer over the objective end of your telescope (it's a close fit) and seat it against the stop edge, with the pin on the telescope barrel situated in one of the four détente positions on the micrometer. It you wish to measure horizontally (so that the vertical wire appears to move left and right) then mount the micrometer so that the top of the graduated drum is facing up or down. Usually the graduated drum is mounted on the same side of the telescope as the focus knob, but this can be a matter of personal preference.

CAUTION: When the micrometer drum is on the left or right side of the telescope, or if you are using a dual axis micrometer, the telescope will not rotate through the standards without causing a collision between the standards and the micrometer. When using the micrometer in this position, you may reverse the direction of the telescope when needed by rotating the eyepiece, rather than the micrometer, through the standards.

If you wish to measure vertically (horizontal wire appears to move up and down) then mount the top of the drum facing to the right or left.

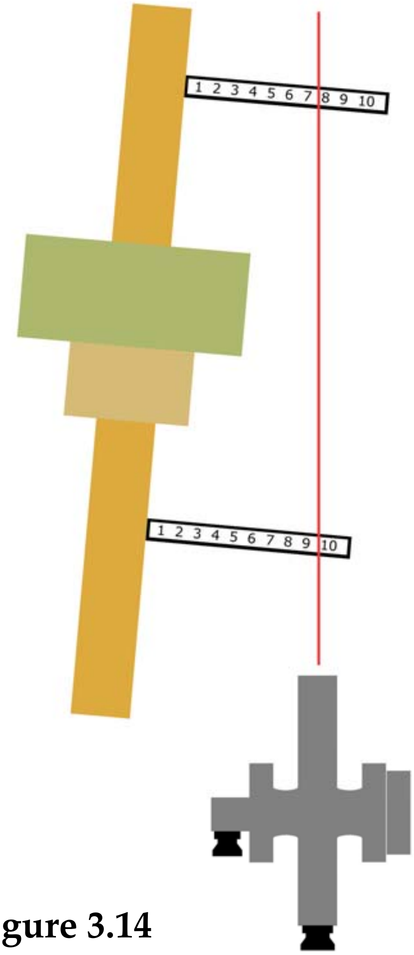


Figure 3.14

Once the micrometer is located in the desired position, tighten the knurled locking knob to secure it. Be firm but don't use excessive force.

Next, let's consider how to measure distances that are larger than the micrometer's short range. This is accomplished using *optical tooling scales* and *Invar scale extension rods,* which effectively extend the range of the optical micrometer by several feet or meters if necessary.

Let's look at how to take a reading from an optical tooling scale. An optical tooling scale is like a very precise ruler which is optimized for viewing through a telescope. The micrometer acts as a vernier for the scale, providing an exact measurement.

In this example, machine components are evaluated for parallelism to a known reference line (see Figure 3.14, a view from above). The transit is first brought into alignment with the reference line (whether established by targets, a mirror, a collimator, etc.) *At this point it is extremely important that the micrometer's graduated drum be set to zero.* Then, optical tooling scales are held horizontally against machine components which are supposed to be parallel with the reference line.

The scales may be leveled using scale levels to ensure that they are horizontal. In this example, we will take a reading on the far scale. Let's say that when you focus on the far scale, you see the image in Figure 3.15. The reticle overlays

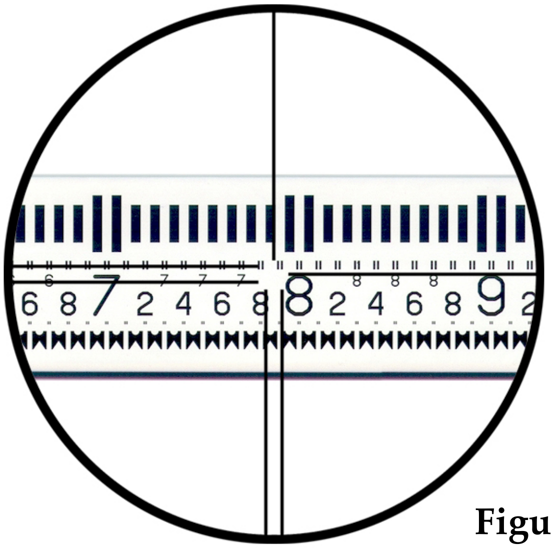


Figure 3.15

the scale image at some random point, but you can read that it is somewhere between 7.8″ and 8.0″.

Before we proceed, let’s take a closer look at the optical tooling scales. They have a repeating pattern of lines and gaps. The *gaps* are actually the targets that are of importance. The scale is made to be read by placing the vertical (or horizontal) reticle wire precisely in the target gap between two adjacent lines. In Figure 3.16, the four red boxes point out four rows of repeating lines. The lines are of different heights *but the targeting gaps—the gaps between any pair of adjacent target lines—are always 0.1″ (or 2 mm) apart. That is, any two adjacent are 0.1″ (or 2 mm) apart, center-to-center.* The four differently sized patterns simply allow the scale to be used at different distances. The large row at the top is used for further distances from the transit, and the smallest row is used when the scale is close to the transit.

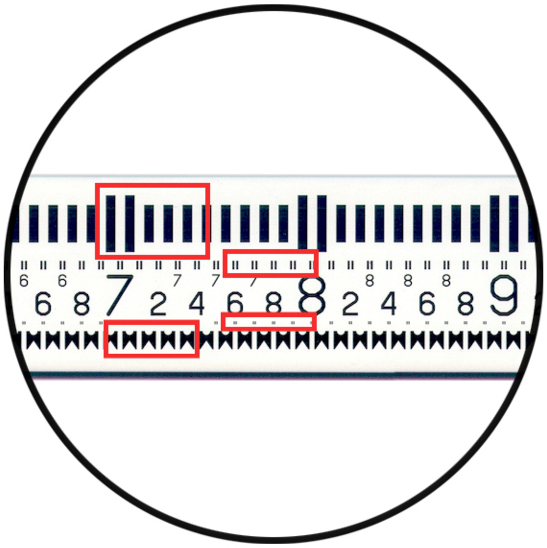


Figure 3.16

We are using an English scale in our example, so the distance from one target gap to the next, between any two adjacent lines, is exactly 0.1″. In Figure 3.17, both of the red lines pass through four target gaps in the four target rows, and the two red lines are exactly 0.1″ apart. The red line on the left passes through all of the 7.3″ target gaps, and the one on the right passes through the 7.4″ target gaps.

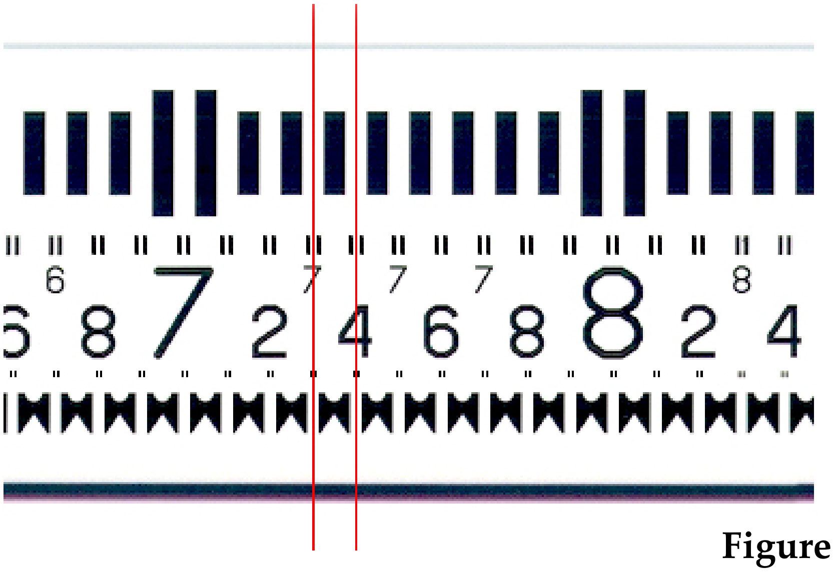


Figure 3.17

The target gaps are further outlined for clarity in Figure 3.18.

In figure 3.19, the blue square highlights a row of sevens. These figures indicate which inch increment you are viewing and are only necessary when the transit is so close that you can’t see the larger inch increment numbers.

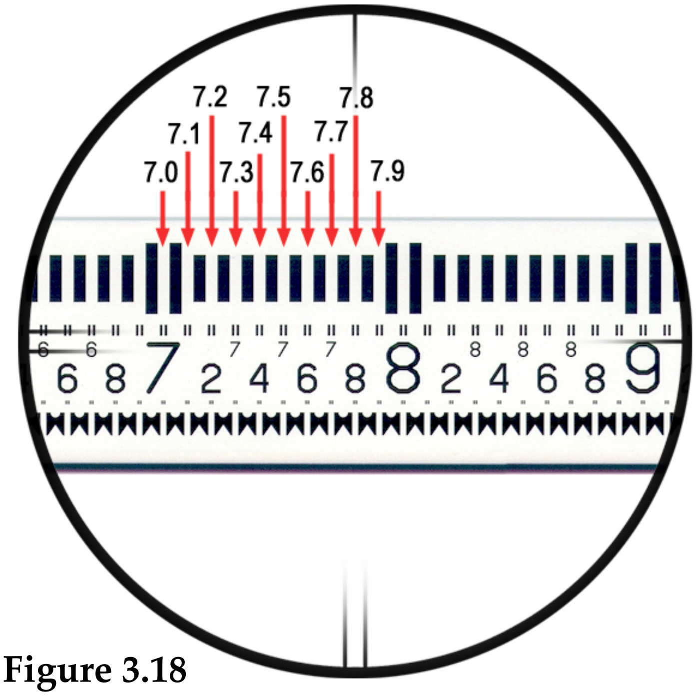


Figure 3.18

Now let's get back to our example. When we looked at the far scale when measuring the machine in Figure 3.14, we saw the image in Figure 3.15. Since we have learned a little more about scales, we can tell that the vertical reticle wire is between the 7.8" and 7.9" target gaps. Now we'll use the optical micrometer as a vernier to get the exact scale reading. We turn the graduated drum on the micrometer so that the reticle moves to the left, and we place the vertical wire exactly on the 7.8" target gap (Figure 3.20). Then we read the graduated drum, and it indicates that we have moved 0.085". Since the unaltered line of sight (with the micrometer set at 0.0) was more than 7.8 but less than 7.9, we know that the final reading is:

7.8" + 0.085" = 7.885"

So the distance of the machine component from the reference line of sight was 7.885".

Now let's say that we take a reading from the near scale in the same manner, and we get a figure of 9.734". We then know that the machine is out of parallel with the reference line by:

9.734" - 7.885" = 1.849"

over the distance between the two scales.

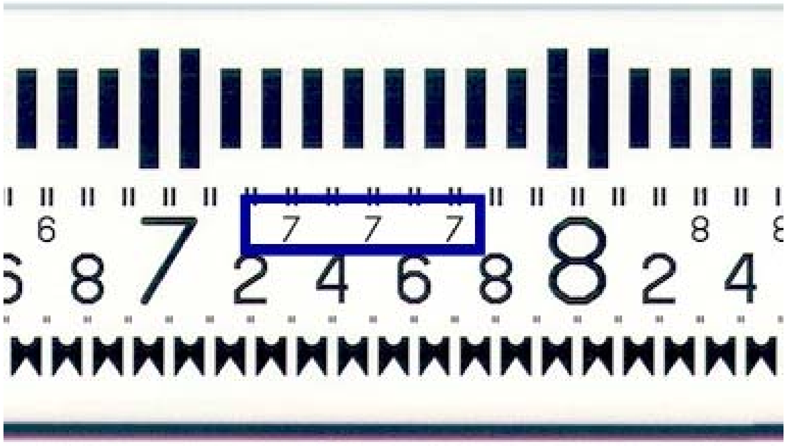


Figure 3.19

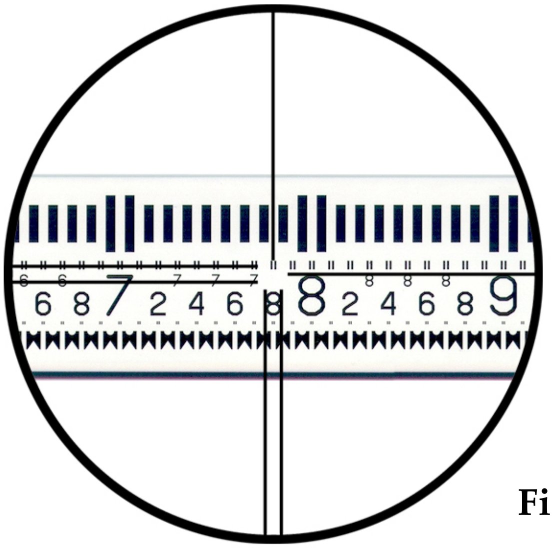


Figure 3.20

Here's a helpful tip to increase measurement accuracy: Good measurement practice tells us always to come to our measurement from the same direction. This minimizes or eliminates backlash from the micrometer reading. So, it is useful to adopt a discipline of always coming to a measurement by moving the micrometer drum in, say, a clockwise direction. This includes initially setting the micrometer to zero by moving the drum in the same direction. If the final reading is counterclockwise from the current micrometer position, back the drum beyond the desired location and move it once again in the clockwise direction back to the reading point.

We've now introduced a number of optical tooling techniques that can be used to measure and align any number of machines, components, or assemblies:

- Bucking in
- Autoreflection
- Autocollimation
- Collimation
- Collineation
- Reticle Projection
- Measuring with micrometers

These are all the building blocks you need to perform a wide variety of measurements and alignments in the field—the applications are limited only by your imagination.

The great thing about Optical Tooling is that there are a number of checks that you can do in the field to make certain that your instrument is functioning properly.

Chapter 4 - Field Calibration Checks

Your transit is capable of establishing extremely accurate geometric relationships between various points, lines, and planes. In order to do so, a number of parameters on the transit must be periodically maintained and adjusted. The newer a transit is, the more often that calibration and adjustment is required. As your transit ages, and the stresses of manufacture and initial calibration slowly work themselves out, it will become more stable. Also playing a very large role are your patterns of usage and the environment(s) in which your transit is stored or used. So initially, you may wish to test your transit more frequently so that you can determine how it is responding to your particular situation.

We recommend that you have your transit fully cleaned and calibrated at least once a year.

You can perform the field calibration checks (and some of the adjustments) yourself if you have the desire and a few required items. These are checks and adjustments that you can do in the field without any specialized calibration equipment. They are a subset of the checks which constitute a full calibration procedure. It isn't a bad idea to test out your instrument using these field checks after shipment to a job site.

For each test outlined in this chapter, we will describe five things:

1. The intended result—we will describe what you are trying to accomplish.

2. The achievable tolerance.

3. The "affected parameters". Some of the adjustments that must be made may affect other adjustments (this phenomenon is also called "cross-coupling"). Therefore, after accomplishing a particular adjustment, you must go back and check the "affected parameters" and make subsequent adjustments if necessary. Note that some transit adjustments are mutually dependent and require a repetitive approach. That is, two or more adjustments may affect each other, requiring that you make sequential adjustments of all affected parameters. When successfully accomplished, each subsequent adjustment is smaller than the last, until all parameters are within tolerance.

4. Items required to complete the test, if any. For example, some of the field adjustments require scales or other impromptu targeting be made available.

5. Proper adjustment procedures.

The following field tests will be discussed in this chapter:

- Plate vial adjustment
- Micrometer backlash, centering, and range
- “Double center” check
- Horizontal axis runout
- Vertical spindle runout
- Horizontal centering
- Horizontal collimation
- Plumb line check
- Cross-axis telescope collimation
- Peg test (coincidence vial)

We recommend doing these checks in the order listed above. Performing them out of order can sometimes yield misleading results. For example, we describe how to use finite targets (scales) to perform a field check of the instrument’s horizontal collimation. However, the horizontal centering must be established first. Otherwise, horizontal collimation tests are inconclusive.

We also describe a “double center” check, which is our nickname for a special check that can be easily and quickly performed. If the transit passes this test, you can skip the horizontal centering, horizontal collimation, plumb line, and micrometer centering checks.

Remember that we offer classes detailing the operation and calibration of our Optical Tooling instruments. Like anything else that is a new experience, handling of these precision measurement instruments becomes much faster and easier with a little practice.

NOTE: This manual generally pertains to the 771, 75, and 76-RH190 transits. This chapter, however, focuses on field checks for the 76-RH190. While most of the field checks described herein also apply to the 75 and 771, we don’t focus on those instruments specifically.

DON’T SWEAT THE DETAILS IF IT’S NOT NECESSARY:
We describe a number of field checks in this chapter which allow you to determine whether your transit is in top operating calibration. But good judgment can be a time saver—if you don’t need the ultimate in accuracy for a particular job, you can edit or ignore these field checks accordingly. We present them here to give you a complete picture of instrument field calibration.

Plate ("bull's eye") Vial

Description: Establish whether the plate vial indicates a line which is parallel to the vertical spindle.

Tolerance: Bubble stays within the inscribed black circle.

Affected parameters: None

Required equipment: Instrument stand, small screwdriver

Mount the transit firmly on any stand having a 3½" - 8 external thread. Loosen the horizontal tangent screw lock.

1. View the plate vial from above and bring its bubble to the center using both opposing pairs of instrument leveling screws. This is identical to the rough leveling process described in Chapter 2.

2. Now, rotate the standards 180° so that the telescope is pointing in the opposite direction. Check to see whether the bubble is still in the center of the plate vial. If so, the plate vial is in adjustment. If the bubble does not remain centered when the instrument is rotated to this second position, remove **one half** of the bubble error using the leveling screws (move it toward the inscribed circle, but only by halfway).

3. Secure the horizontal tangent clamp lock to keep the standards from moving. Remove the **other half** of the bubble error using the three small screws located around the perimeter of the base of the plate vial. Under the vial is a thin spring which allows the vial to tilt, so tightening any given screw will move the bubble away from that screw, and likewise, loosening any given screw will move the bubble toward that screw. When you're finished adjusting the bubble with these small screws, it should be precisely centered under the inscribed circle.

Figure 4.1

4. Loosen the horizontal tangent lock and turn the telescope 180° back to the first position. The bubble should still be centered under the inscribed circle. If not, repeat the process above until the bubble remains inside the circle in both positions.

CAUTION: Don't "bottom out" the plate vial adjustment screws. If you do this, the spring under the vial will be flattened and proper adjustment will be impossible. If this happens, loosen all of the screws by the same amount (a turn or two), and continue the adjustment process.

Micrometer Checks

Description: Ensure that the micrometer is not introducing any error into the adjustment process.

Tolerance (backlash): 0.0005″

Tolerance (centering): ±0.001″ observed error (0.0005″ actual error)

Tolerance (range): ±0.0005″ observed error at each end of range.

Affected parameters: None.

Required equipment: Stable instrument stand and scale held at finite distance.

There are three simple checks for micrometer error. These are *backlash, centering error,* and *range adjustment.*

First, check backlash:

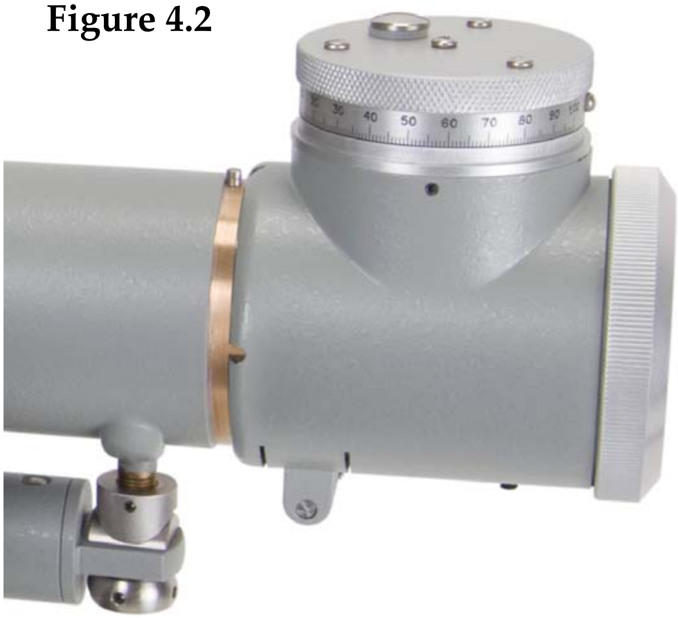
1. Point the telescope at an arbitrarily placed scale, held at a finite distance (we recommend about 4 feet away). Place the scale in a horizontal orientation.

2. Install the micrometer on the transit so that the drum is either up or down (your preference). Rotate the micrometer drum to the black-number side, to at least 0.020″ or 0.030″, and then return precisely to zero. Be sure not to overshoot the zero mark. It is important to come to zero from the black-number side.

3. Tighten the horizontal and vertical tangent locks on the transit. Using the tangent adjustment screws, center the reticle precisely at some arbitrary target point along the scale (e.g., the three inch mark).

4. Now rotate the micrometer drum to the red-number side by at least 0.020″ or 0.030″, and again look through the telescope. Use the micrometer drum to set back on the chosen target. Don't overshoot this mark, it is important to set back on the same target position from the red-number side. Make note of the micrometer reading. If this reading is more than 0.0005″ away from zero, the micrometer has an unacceptable backlash error and should be returned to the factory for repair. If it is within tolerance, proceed to the next micrometer check.

Figure 4.2



Next, check for centering error:

1. First, let's discuss how to install the micrometer to make this check as easy as possible. Slide the micrometer on to the transit's objective end, *but don't push the micrometer all the way on.* (See Figure 4.2) Gently tighten the knurled thumbscrew, but leave it loose enough that the micrometer body may be rotated around the telescope barrel to different clocking positions. Finally, align the top détente position in the micrometer body with the pin in the telescope (Figure 4.2), but again, don't actually seat the micrometer into its normal position. Make sure that the micrometer dial is set exactly on "0".

2. Point the telescope at an arbitrarily placed scale, held at a finite distance (we recommend about 4 feet away). Place the scale in a horizontal orientation and choose some arbitrary target point, e.g., the three inch target. Tighten the horizontal and vertical tangent locks, and use the tangent screws to set precisely on the target.

For information on the calibration of the 190 type micrometers, please refer to the manual for your specific product.

3. Without disturbing the micrometer drum, gently rotate the micrometer body on the telescope barrel 180°. Now the détente position on the bottom of the micrometer should be aligned with the pin on the telescope barrel, although again not seated.

4. Now look through the telescope to see if the reticle is still centered on the chosen scale target. If it has moved, rotate the micrometer drum so that the target comes back into register directly in the center of the reticle as it was before.

5. Read the micrometer dial. If it has deviated from zero in either direction by more than 0.001″, the micrometer is out of adjustment and will introduce error into the field checks described in this chapter. Please refer to the micrometer manual for information regarding how to make the appropriate adjustments. On the other hand, if the micrometer is within the acceptable ±0.001″ band (indicating an actual error of half the reading), then you may proceed.

To check for range adjustment:

The range adjustment field check described here is only valid for micrometers having a range of ±0.100″ or ±2.5mm.

1. Install and seat the micrometer on the telescope barrel. Set the micrometer drum to zero.

2. Point the transit once again to an arbitrarily chosen target location (line pair) on a horizontally mounted scale. Be sure that the scale is nominally square to the transit.

3. Using the micrometer only, shift the reticle over to the next adjacent line pair, representing a shift of either 0.100″ (English scale) or 2 mm (metric scale). Note the micrometer reading at this point.

In describing the range check, we are assuming that you are using a metric scale in conjunction with a metric micrometer; or likewise, an English scale in conjunction with an English micrometer.

4. Again using the micrometer only, shift the reticle in the opposite direction back past the starting point, to the next adjacent line pair. Note the micrometer reading at this point as well.

5. If the error *in either position* is greater than ±0.0005″ (English scale) or 0.01 mm (metric scale), the micrometer should be calibrated prior to use. Please refer to the micrometer manual or return to the factory for adjustment.

“Double Center” check

Description: Simultaneous check of several calibration parameters.

Tolerance: ±0.002”

Affected parameters: Not applicable, no adjustment is made as a result of this check.

Required equipment: Optical micrometer, instrument stand, and two scales.

This field check is made in order to eliminate the necessity of making several other field checks. If the “double center” check is successful, there is no need to perform the Horizontal Centering, Horizontal Collimation, Plumb line, and micrometer centering field checks.

Two horizontally mounted scales must be used. The first is placed about 30 - 35 feet away from the transit, and between 2 - 5 feet above a level sight line from the transit.

The second scale is placed very near the transit, on the floor. The idea is that we want both horizontal separate and vertical separation between the two scales. Also note that the transit need not be precision plumbed to perform this test. Once the transit is secured to a stand and the scales are placed, perform these steps:

1. Make sure the micrometer is set to zero. Focus on the far scale. Using the horizontal tangent adjustment screw, set on some arbitrary scale target position (e.g., the five inch paired line target). Make certain that the horizontal tangent clamp is secured.

2. Swing the telescope down to the near scale and take a reading on the scale.

3. Reverse and plunge the transit (rotate the standards by 180°, and also rotate the telescope by 180°). The telescope should be pointing in the same direction as it was before the reverse and plunge, but will now be upside down relative to its previous position.

4. Focus again on the far scale. Be sure to re-zero the micrometer, and set on the original scale position that was established in step 1 above.

5. Swing the telescope down again to the near scale, and take a reading on the scale.

If the reading on the near scale taken in step 5 differs from the reading taken in step 2 by 0.002” or less, you may skip the Horizontal Centering, Horizontal Collimation, Plumb line, and micrometer centering field checks.

Horizontal Axis Runout

Description: Initial indication of whether the telescope rotates accurately about the horizontal axis.

Tolerance: ±1 arcsecond (0.001″ in this test procedure.

Affected parameters: All adjustments.

Required equipment: Optical micrometer, instrument stand, and a scale placed 17 feet away in horizontal orientation.

This is a quick and easy check to help determine whether there has been any major damage to the horizontal axis bearings such as ball or race denting.

1. Mount the transit on a stand. Install the micrometer to read horizontal deviations (i.e., position the micrometer drum on the top or bottom of the telescope rather than on the side). Hold a scale horizontally using a magnet or other convenient mount, about 17 feet away, and approximately on a level sight line from the telescope.

2. Rotate the telescope about its horizontal axis roughly 5 times in the same direction. This ensures the individual balls in the horizontal axis bearings have all made at least one complete revolution.

3. Make sure that the horizontal tangent clamp is secured. Using the horizontal tangent screw, achieve accurate register between the transit's vertical reticle wire and some arbitrary position on the scale. Note the position of the transit's horizontal reticle wire so that you can return to the same elevation position, but keep the vertical tangent clamp loose.

4. Gently rotate the telescope around its horizontal axis once in the same direction that it was rotated in step 2. Re-point back to the same scale target, putting the horizontal wire in approximately the same position as it was placed in step 3 (if you overshoot the target, go around again). Measure any horizontal error with the micrometer. Repeat this process 4 or 5 times, noting any error each time.

If an error greater than 0.001″ is observed, rerun the test to ensure that the observed error is actually bearing runout and not movement of the entire instrument. If it is determined the error is bearing runout, repairs are required and the transit should be returned to the manufacturer for repair.

*NOTE: It is important to say that this test **may** indicate problems with the horizontal axis. It is at least a good initial indicator of problems like bearing denting. However, other indicators of horizontal bearing problems may show up later, such as an inability to make plumb line or cross-axis telescope collimation adjustments, even if this test does not reveal any problems.*

Vertical Spindle Runout

Description: Initial indication of whether the instrument rotates accurately about its own vertical spindle.

Tolerance: ±2 arcseconds (0.002″ in this test procedure.)

Affected parameters: All adjustments.

Required equipment: Optical micrometer, instrument stand, and a scale placed 17 feet away in vertical orientation.

This is a quick and easy check to help determine whether there has been any major damage to the vertical spindle such as ball or race denting.

1. Mount the transit on a stand. Install the micrometer to read vertical deviations (i.e., position the micrometer drum on the side of the telescope rather than the bottom or top). Set the micrometer to zero. Remember to use the good micrometer measuring practices described in Chapter 3 of this manual—always come to zero and any desired reading position from the same direction.

2. Hold a scale vertically using a magnet or other convenient mount, about 17 feet away, and approximately on a level sight line from the telescope.

3. Rotate the transit about its vertical axis roughly 5 times in the same direction. This ensures the individual balls in the vertical axis bearings have all made at least one complete revolution.

We choose to put the scale 17 feet away because at this distance, 0.001″ equals 1 arcsecond. If you're using a metric scale and a metric micrometer, place your scale 4.125 meters away. At this distance, 0.02 mm yields 1 arcsecond.

4. Using the vertical tangent screw, achieve accurate register between the transit's horizontal reticle line and an arbitrary target position on the scale (e.g., the three inch target). Make sure the vertical tangent clamp is secure. Note the position of the vertical reticle line of the transit as well, so that you can return to this approximate azimuth position. Keep the horizontal tangent clamp loose.

5. Gently rotate the transit about its vertical axis in the same direction as it was rotated before, and re-point back at the scale target to observe any error. If you overshoot the target, go around again. Be sure to reposition the vertical reticle line at its original position. Use the micrometer to read any error. Repeat this process 4 or 5 times, rotating the transit in the same direction each time, and reading any error after each revolution.

If an error greater than 0.002″ is observed, rerun the test to ensure that the observed error is actually bearing runout and not movement of the entire instrument. If it is determined that the error is bearing runout, the transit should be returned to the manufacturer for repair.

*NOTE: As with the horizontal bearing runout test, it must be said that this test **may** indicate a spindle runout problem, but does not necessarily **prove** that the instrument has a good vertical bearing. Vertical spindle runout is somewhat sneaky, and may show up in an inability to perform other calibrations, such as the plumb line check. One of the places that vertical spindle runout is most likely to show up is in the precision plumbing process (see Chapter 2). If the transit may be made precisely level in several azimuth orientations spanning 270°, but other positions are not level, the vertical spindle may be suspect.*

Horizontal Centering

Description: Determine if the line of sight intersects the vertical axis (or whether it passes to the right or left of the vertical axis).

Tolerance: ±0.001 inch.

Affected parameters: None.

Required equipment: Instrument stand with precision lift and lateral slide, lighted eyepiece adapter and light source, optical micrometer, mirror and scale.

Horizontal centering is also called "side-to-side" centering. For this test, place a mirror on a stable vertical surface such as a wall, column, or machine. Our magnetic mirrors are very useful for this type of application. Next, mount a scale horizontally under the mirror (Figure 4.3). The mirror will provide an infinity target, and the scale will provide a "near" target. You can also use a mirror which has a target imprinted on the face, such as our model 6250, rather than the mirror-and-scale combination described here.

The transit must be equipped with a lighted eyepiece and a light source for this test. Follow these steps:

1. Situate the transit approximately five feet from the mirror, and make sure the mirror is nominally on a level sight line from the telescope.

2. Install the micrometer so that the drum is facing up or down, and set the micrometer to zero.

3. Autocollimate the main telescope's vertical reticle wire precisely on the reflected image in the mirror (described in Chapter 3 of this manual). The horizontal wire should be close to center but is not required to be precisely set. This represents an infinity target for our test.

4. Now tilt the telescope slightly and focus on the scale. The transit will be pointing at some random point on the scale. Note this reading using the micrometer.

5. Release the horizontal tangent clamp and rotate the transit 180° about its vertical axis. Release the vertical tangent clamp and plunge the telescope 180°. Autocollimate once again on the mirror and make certain that the vertical reticle wire is precisely in register with its reflection. Be sure the horizontal tangent clamp is secured when doing this.

6. Tilt once again to the scale, and take a reading. Determine the difference between this reading and the reading take in step 4. If the difference is 0.002" (0.05 mm) or less, the horizontal centering is within tolerance. The actual error is half of the observed error. If the horizontal centering is out of tolerance, the instrument should be adjusted in a calibration laboratory.

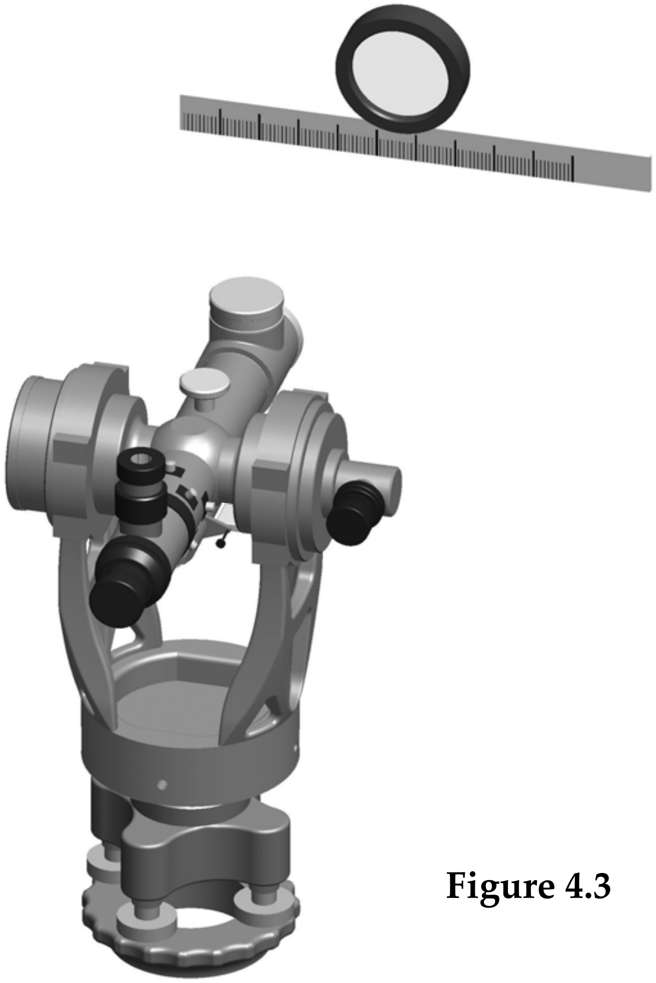


Figure 4.3

Horizontal Collimation

Description: Determine if the line of sight is perpendicular to the horizontal axis.

Tolerance: ±1 arcsecond.

Affected parameters: Reticle orientation.

Required equipment:
Optical micrometer, instrument stand and two scales.

For best results during this test, leave the vertical tangent clamp loose and the micrometer drum pointing up or down. Make sure the micrometer drum is set to zero.

For this test, we want to set up two scales on opposite sides of the transit (Figure 4.4). Each of the scales should be 17 feet from the transit. The scales should nominally be on a level sight line from the telescope. These scales will allow us to compare the line of sight established in the “forward” position of the transit with a line of sight which is established in the “reverse” position. We will be verifying that no angular error exists between the lines of sight in these two positions.

1. Rough level the transit.

2. Point the telescope toward one of the scales, and align the vertical reticle wire with some arbitrary position on the scale (e.g., the five inch target position). Make sure the horizontal tangent clamp is locked.

3. Plunge the transit's telescope 180° to sight at the other scale. *Do not* turn the entire transit— turn only the telescope around its horizontal axis. The transit will be pointing at some random location on

Again, we choose to put the scales 17 feet away because at this distance, 0.001” equals 1 arcsecond.

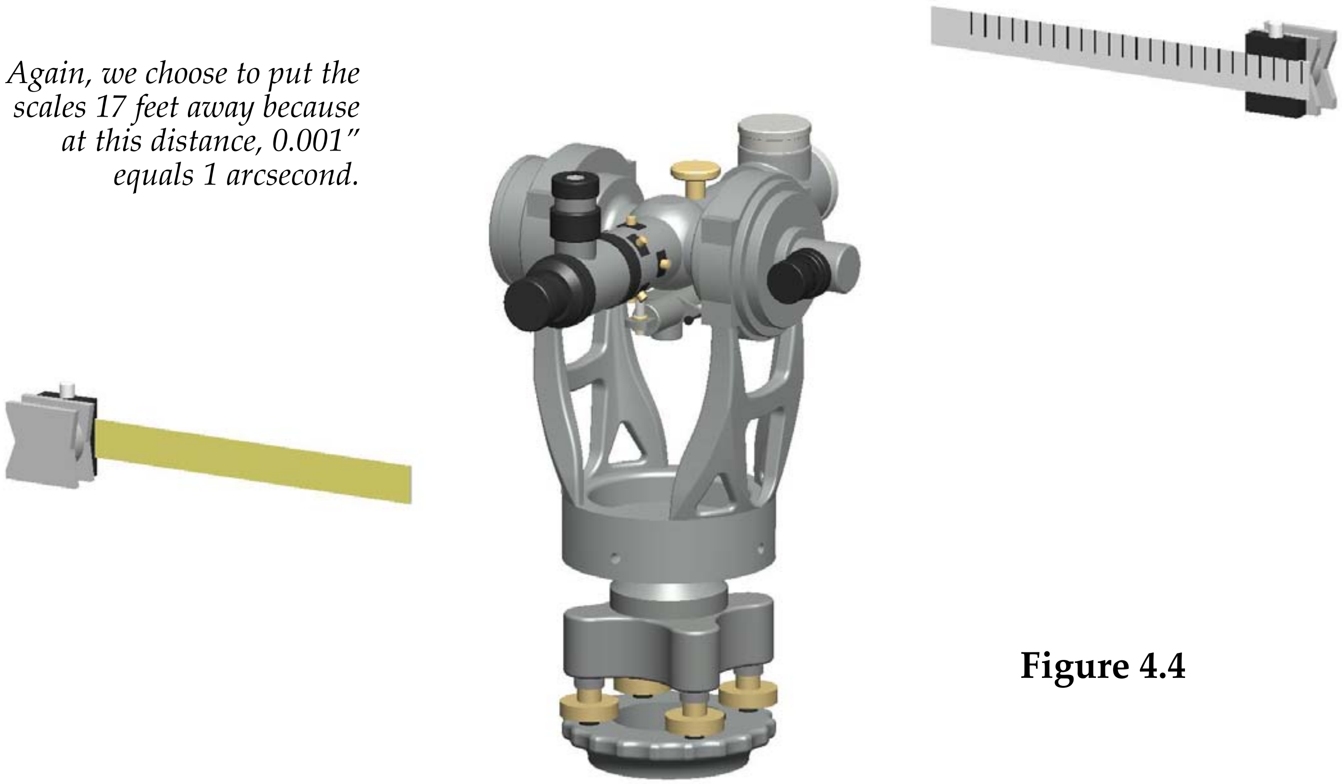


Figure 4.4

the second scale. Make a note of this reading.

4. Now rotate the standards 180° about the vertical axis (this time, don't rotate the telescope around the horizontal axis). Using the horizontal tangent adjustment screw, set back on the position originally chosen in step 2.

5. Once again, plunge the telescope 180° to sight at the second scale. Take a second reading on this scale using the micrometer.

6. Determine the difference between the readings taken in step 3 and step 5. If the difference is 0.004″ (0.10mm) or less, the horizontal collimation is within tolerance. Note that the observed error is 4 times the actual error, so a difference of 0.004″ between the readings indicates a 0.001″ actual error at 17 feet, equating to one arcsecond.

NOTE: Reticle orientation is listed as a parameter affected by this adjustment. However, we do not address that topic here because generally, minor field adjustments of the reticle don't cause the reticle orientation to be negatively affected.

7. If an error is detected, the instrument may be adjusted in the field. Locate the capstan screws furthest from the eyepiece, at the 3 o'clock and 9 o'clock positions (Figure 4.5). Using an adjusting pin, gently loosen one and tighten the other, so that approximately 1/4 of the observed error is removed. Be advised that the slightest movement makes a big difference.

For example, if the reading in step 3 was 3.402″, and the reading in step 5 was 3.418″, the difference between the readings is 0.016″. Therefore, we want to make an adjustment so that the reticle appears to move 0.004″ (one-fourth of 0.016″). You can do this by moving the micrometer back toward the first reading, setting it on (in this case) 3.414″. This represents a move of 0.004″ back towards the original 3.402″ reading. This will slightly offset the image from the scale's paired line target currently being viewed. Then, adjust the reticle so that it appears to be centered once again on the scale target.

Figure 4.5

8. Repeat steps 2 through 7 until the error is within tolerance.

Plumb Line Check

Description: Determine if the vertical spindle is perpendicular to the horizontal axis.

Tolerance: ±1 arcsecond.

Affected parameters: None.

Required equipment:
Optical micrometer, instrument stand and two scales.

For this test, we want to put a couple of scales in front of the transit, one up high and one down on the floor or close to it (Figure 4.9). The high scale should be about the same distance above the transit as the low scale is below the transit. The low scale may be laid flat on the floor, basically square to the line of sight. The sighting distance should be about 4-5 feet from the transit to each scale. Optimally we would like to have about 90° of telescope movement (difference in sighting angle) between the top scale and the bottom one.

1. Rough level the transit. Focus on the upper scale. Make sure the micrometer is set to zero and that the vertical tangent clamp is loose. Using the horizontal tangent adjustment screw, set to some easily repeatable target on the scale (e.g. the three inch paired line target).

2. Without loosening the horizontal tangent clamp, rotate the telescope downward to point at the lower scale. Take a reading on this scale.

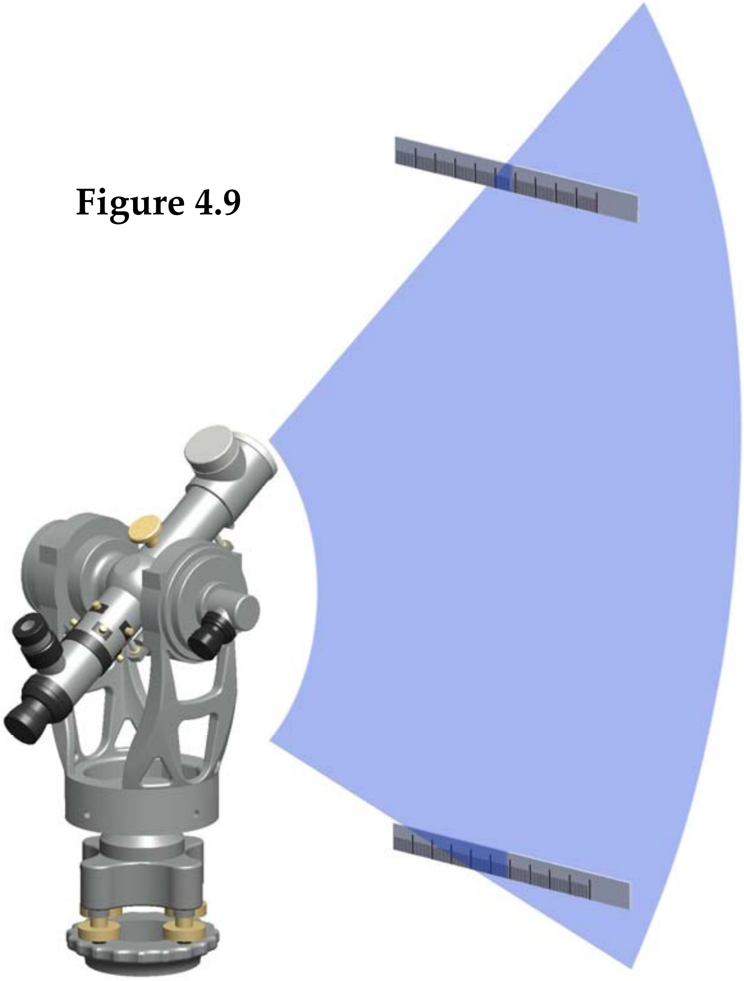


Figure 4.9

3. Now loosen the horizontal tangent clamp and rotate the transit 180° about its vertical axis. Plunge the telescope 180° about its horizontal axis as well. Point back at the upper scale and secure the horizontal tangent clamp. Set back on the same scale location that was used in step 1.

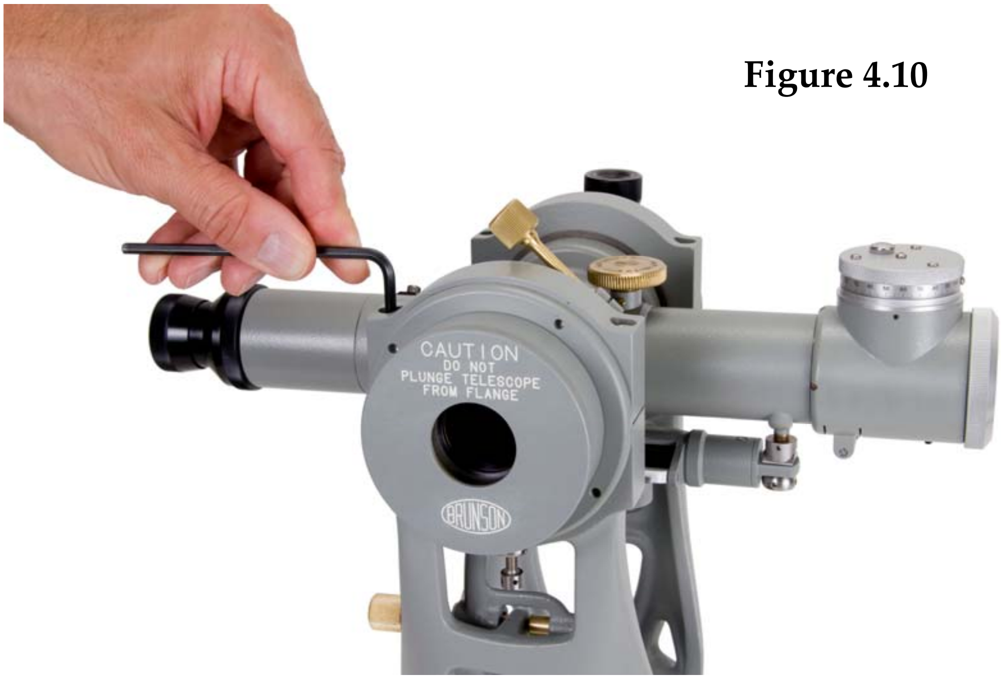
4. Once again, rotate downward to the lower scale and take a reading. Compare this reading with the one taken in step 3. If the difference is less than or equal to 0.002”, the transit is within tolerance. If it isn’t, proceed to the next step.

5. Note whether the reading on the lower scale taken in step 4 is to the *right* or to the *left* of the prior reading on the same scale. If the reading is to the *right*, the cross-axis (also called the *trunnion* axis) is tilted up on the right. Likewise, if the reading was to the *left* of the original reading, the trunnion axis is high on the left.

Using this information, we make an adjustment to tilt the trunnion axis in the appropriate direction. To do this, we make an upward or downward adjustment on the side of the transit which has the objective lens of the cross-axis telescope.

There are two ways to accomplish the desired adjustment. We first try the method requiring the least effort. If a more aggressive adjustment is required, we'll move on to the second method.

Figure 4.10



The first, and easier method, is as follows. Try slightly loosening or tightening one or both of the socket head cap screws in the bearing cap above *the objective end of the cross-axis* (Figure 4.10). Remove one -half of the apparent error in this manner if possible. Remember that the axis bolts should not be overly tightened nor should they be anything resembling loose. The bolts should be firmly finger/hand tight, not elbow/shoulder tight. Whether you have success in removing the error by using only these bolts depends upon how tight the bolts already are, and how far they need to be moved.

If this procedure cannot compensate for the error, it will be necessary to adjust the capstan-headed bolt located under the horizontal bearing (Figure 4.11).

Figure 4.11

Both the capstan bolt and the bearing cap push on the horizontal bearing which is captured between them. The capstan bolt has a locknut cinched against the standards at the bottom of the bearing housing.

In order to adjust the capstan bolt, slightly loosen the locknut. It is also necessary to slightly loosen the socket head cap screws in the bearing cap *regardless of whether you need to move the capstan bolt up or down.* This is because the compression on the capstan bolt from above generally creates too much friction for the capstan bolt to move freely. Use an adjusting pin in one of the holes in the capstan head, and rotate it only to the extent that you slightly perceive motion in the adjusting pin. Re-tighten the locknut on the capstan bolt.

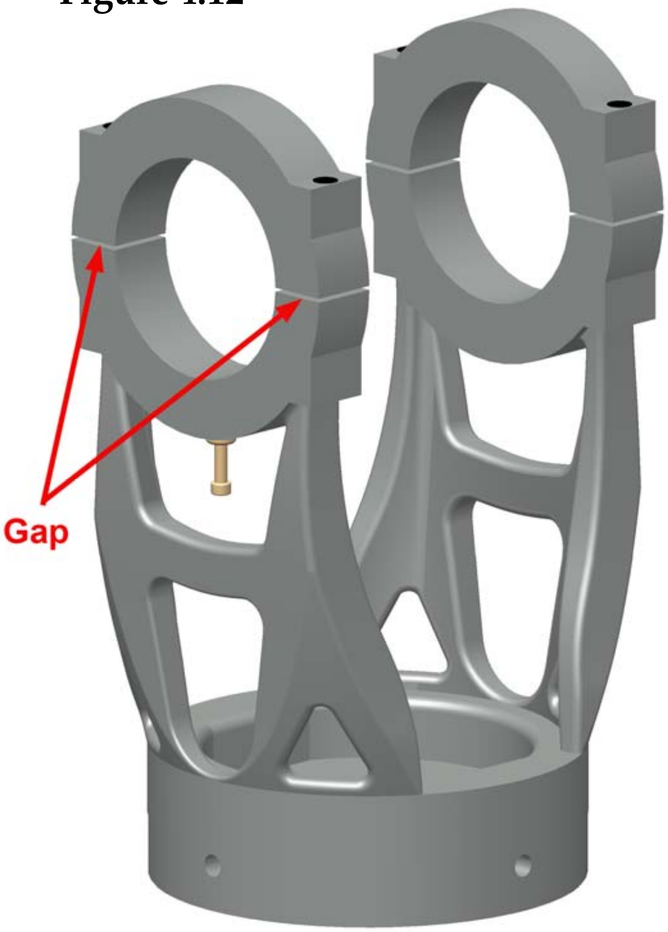
What is going on here? Adjusting the capstan bolt "gets you in the neighborhood", but is too coarse to be used as a fine adjustment. The bolts which secure the bearing cap are always used to bring the axis to the desired location.

Now re-tighten the bolts in the bearing cap, and use these to bring pressure on the bearing so that the horizontal axis is brought to the proper position. Try to maintain equal pressure on both of the axis cap bolts. Also try to maintain an equal gap between each side of the bearing cap and the standard below (Figure 4.12).

As always, firmly tighten all adjustments without over tightening, for the best results.

6. Repeat steps 1 through 5 until the transit passes the plumb line check.

Figure 4.12



CAUTION: Do not allow gorillas to adjust your optical instruments.

Cross-axis Telescope Collimation

Description: Determine if the line of sight of the cross-axis telescope is parallel to the horizontal axis.

Tolerance: ±1 arcsecond.

Affected parameters: None.

Required equipment:
A second 76RH transit or other instrument, lighting attachment, two instrument stands.

This test should only be conducted if you intend to turn a right angle using the cross-axis telescope. If you do intend to do this, chances are very good that you have a second instrument at your disposal—and this instrument will be used as a reference instrument to conduct the test. We'll call the transit that you wish to adjust the "*test transit*", and we'll call the second instrument the "*reference instrument*".

1. When setting up the test transit, we need to observe one simple rule. We want the cross-axis telescope situated directly over one pair of leveling screws (Figure 4.6). Rough level this instrument, and illuminate the cross-axis telescope. Be sure that the main telescope's focus knob is turned all the way in the direction *opposite* from infinity (to extreme near focus). This will ensure that the focus slide is out of the way so that light is visible through the cross-axis. You can verify this by eye, simply by looking into the cross-axis objective lens with the light turned on. The vertical tangent clamp should be left loose for this entire test.

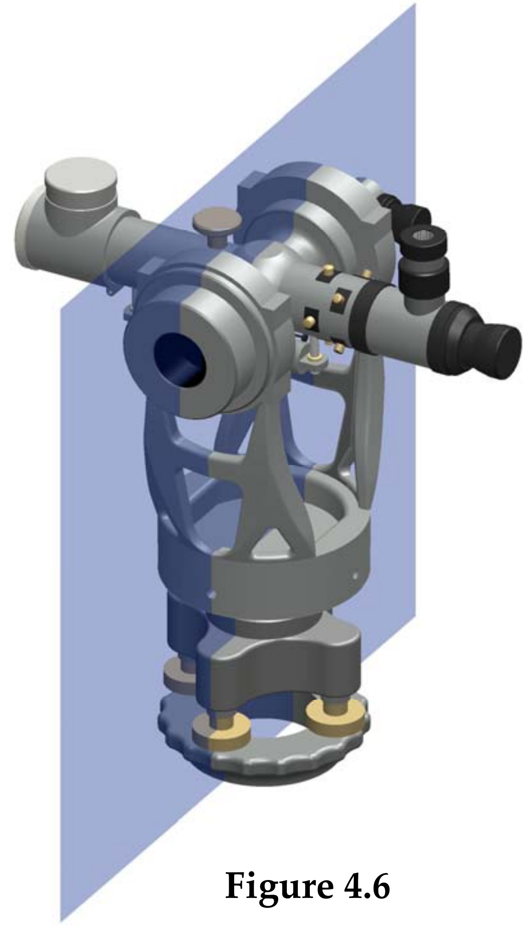


Figure 4.6

2. Set up the reference instrument nearby, and bring it to the same height as the first. (*You can use a level or an alignment telescope as the reference instrument just as well. The same general steps apply.)*

3. Make sure the reference instrument is set at infinity focus by using a mirror or by finding the reticle in the test transit's cross-axis telescope. Then collimate these two telescopes, using the procedure described in Chapter 3 of this manual. Make adjustments to the position of the reference instrument until its reticle is fairly closely aligned with the reticle in the test transit's cross-axis telescope.

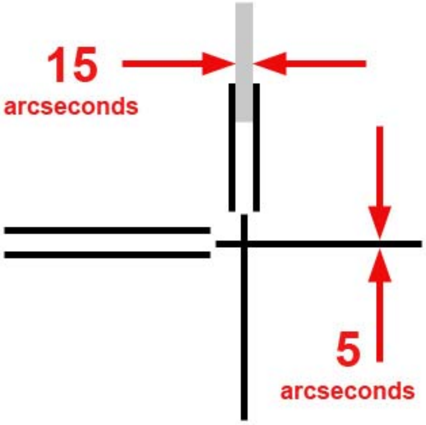
Generally it is handy to find infinity focus by holding a mirror up to the objective lens of an illuminated telescope. While this is convenient, it isn't mandatory. It is possible to find infinity by turning the focus knob all the way toward infinity focus, then slowly "coming back" while watching for the reticle to appear in the reference instrument.

4. Now turn off the lighting in the test transit's cross-axis telescope and turn on the

lighting in the reference instrument's main telescope (or switch the light source from one instrument to the other).

5. Look through the test transit's cross-axis telescope eyepiece and you should see the reference instrument's backlit reticle. When you rotate the test transit's main telescope, you will see its cross-axis reticle rotate as well. By doing this, put the cross-axis reticle directly into register with the reference instrument's reticle. You can now make any necessary adjustments to the test transit to bring the reticle images precisely into register. Use the horizontal tangent adjustment screw for horizontal adjustments, and use the two leveling screws which are in line with the reference instrument to make vertical adjustments.

Figure 4.7



6. Once the test transit's cross-axis is precisely registered with the reference instrument, rotate the main telescope 180°. Any error in the cross-axis telescope will show up as a deviation between the two reticles. If there is any error, it may be in the vertical direction, horizontal direction, or both. It is necessary to estimate this error, since in general we do not have an angle-measuring optical wedge in the field. Therefore we rely on reticle geometry.

We know that the width of a reticle wire is 5 arcseconds, and the gap between the reticle pair is 15 arcseconds wide (Figure 4.7). Therefore, we can make an estimate of the observed error, remembering that the observed error is twice the actual error. This fact makes the error easier to see.

7. If the observed error exceeds 2 arcseconds, adjustment is required. Remove the flange cover from the objective end of the cross-axis telescope simply by pulling it straight off (it's a friction fit). Then move the socket head set-screws in the cross-axis telescope objective lens *mounting* flange to physically push the lens from side to side to correct this error. As you'd expect, use the horizontally opposed adjustment screws to shift the image horizontally, and the vertically oriented screws to shift the image vertically (Figure 4.8). Remember that you should remove only half of the apparent error.

Figure 4.8

8. Repeat steps 5 through 7 until the error observed is within the allowable tolerance.

Peg Test

Description: Determine if the coincidence vial indicates a line which is parallel to the telescope's line of sight.

Tolerance: ±1 arcsecond.

Affected parameters: None.

Required equipment:
Optical micrometer, instrument stand and two scales. A precision lift makes this test easier but is not mandatory.

In Chapter 2 of this manual, we discussed precise leveling (precision plumbing) of the transit. With a little thought, it becomes obvious that the precision plumbing procedure *does not depend* on the fact that the coincidence vial is in adjustment or not. That is, you can precisely plumb the transit (bring the vertical spindle truly to vertical) with the coincidence vial in any old position relative to the telescope, as long as the adjustment of the vial does not change during the process. However, if you want the transit's telescope to be truly level after that process, or if you simply want to bring the telescope to a level line at any point, it is necessary to adjust the vial so that its bubble image is "in coincidence" when the telescope's line of sight is precisely level.

This test is not hard to perform, nor is it complicated—but it does require more words to describe that some of the other tests! Once we're finished with our explanation, we provide a "quick guide" at the end of this section.

1. Set up two scales in a vertical orientation, about 30 feet apart, at instrument height, and on a nominally level sight line from one another. Try to bring the scales as close to vertical as possible without making a career out of it. (A model 563 scale level works great for this.)

To successfully adjust the vial, we must first determine the vertical separation of the two randomly placed scales. In other words, if you drew a level line between the scales, the line would not intersect the scales at the same point unless you were incredibly, amazingly lucky. For example, a level line might hit one scale (call it Scale A) at 2.283" and the other scale (Scale B) at 3.697". This is illustrated in Figure 4.12. If we knew these intersection points, we could calculate the vertical separation between the scales:

3.697" - 2.283" = 1.414"

We would then know that Scale A is *1.414" higher* than Scale B. Knowing the vertical separation between the two scales is critical to our vial calibration process. But how can we determine where a level sight line would intersect the two scales, when a level sight line is exactly what we don't have? *We can do it with a knowledge of geometry.*

Figure 4.12

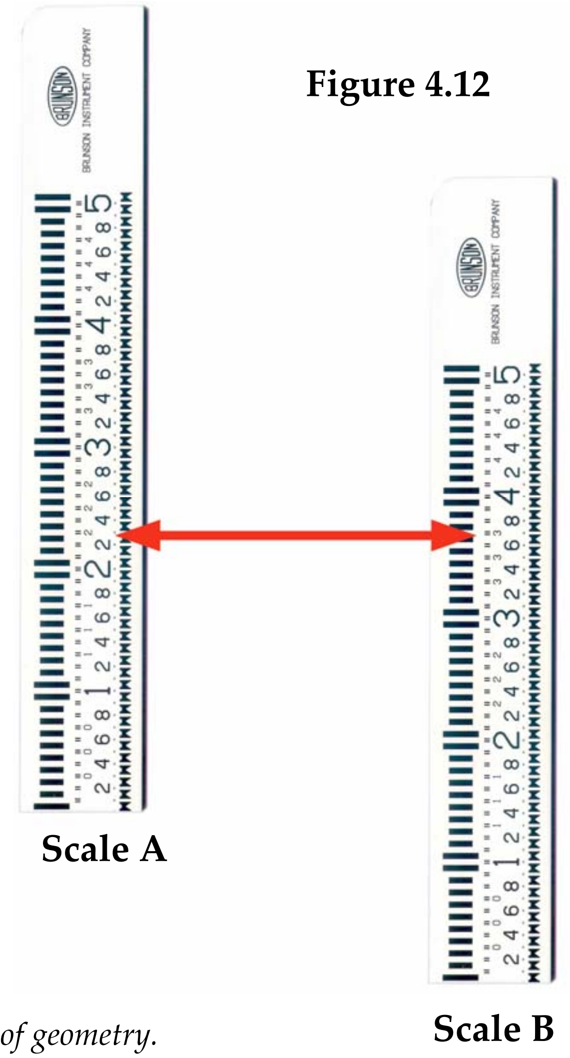
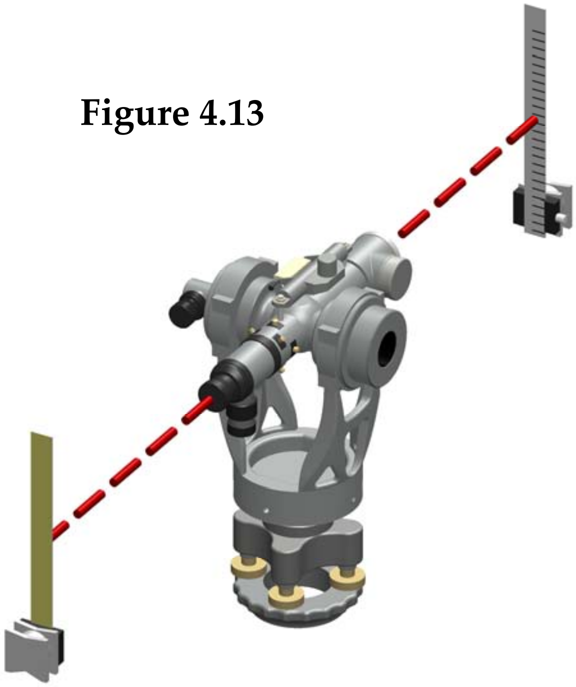


Figure 4.13



Here are the steps with which you can amaze and mystify your colleagues:

2. Set up the instrument on an imaginary line between the scales, at the halfway point between the scales (Figure 4.13). A good way to judge whether you are halfway between the scales is to focus on one of the scales, then flip the telescope over to look at the other one—if it's also in good focus, you're the same distance from each scale.

3. Rotate the telescope so that the coincidence vial is on top of the telescope and easily viewable. Install the micrometer on the telescope with the graduated drum to the side (Figure 4.13). Set the micrometer to zero.

4. Rough level the transit using the plate vial.

Before we go on, there are a couple of things to realize. First, the relationship between the vial and the line of sight is constant, as long as the vial is not adjusted. In Figure 4.14, the line of sight (red arrow) will always point at the same downward angle if the vial is "in coincidence". Remember that when the vial is in coincidence, it indicates a level line (blue arrow). In the procedure that we'll do in a minute, we know that if we look at one of the scales and turn the vertical tangent adjustment screw to level our vial (put it into coincidence), the line of sight will be pointing at some arbitrary angle up or down. Then, if we turn to look at the other scale, and again level the vial using the tangent screw, the telescope will also be pointing up or down at the exact same angle as before.

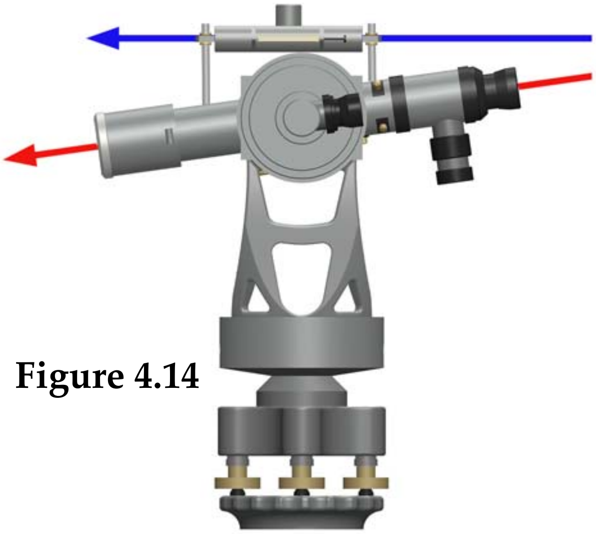


Figure 4.14

Since we have placed the transit the same distance from each scale, and since we know the telescope will always point downward (or upward) at exactly the same angle when looking at either scale, then we know that the telescope will intersect the two scales at the same point as an arbitrary level line (Figures 4.15 and 4.16). It is easy to see in the sketch that the coincidence vial is far from being properly adjusted—it's not at all parallel to the line of sight.

So, this is the way you can determine the vertical offset between two scales, even when you have no level line of sight to use. So let's continue and do this:

5. Point in the direction of one of the scales. Bring the vial into coincidence using the vertical tangent adjustment screw. Read the scale with the micrometer and record this number. In our example, we read Scale A (at left in Figure 4.15). Our reading is 2.283".

Even when the vial is not adjusted properly, a telescope's line of sight will intersect two arbitrarily placed scales at the same place as an arbitrary level line would intersect them, as long as the coincidence vial indicates level in both the left-looking and right-looking positions. This is only true when the transit is the same distance from each scale.

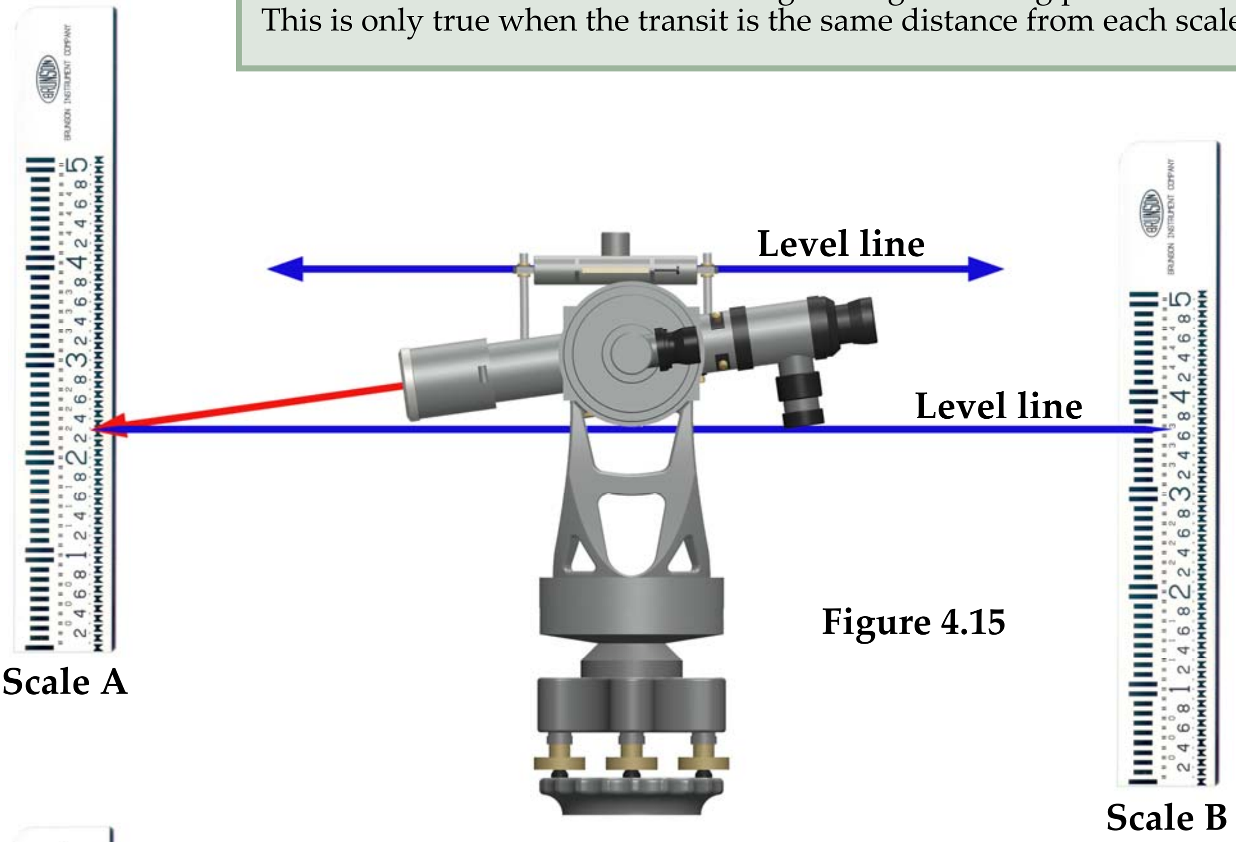


Figure 4.15

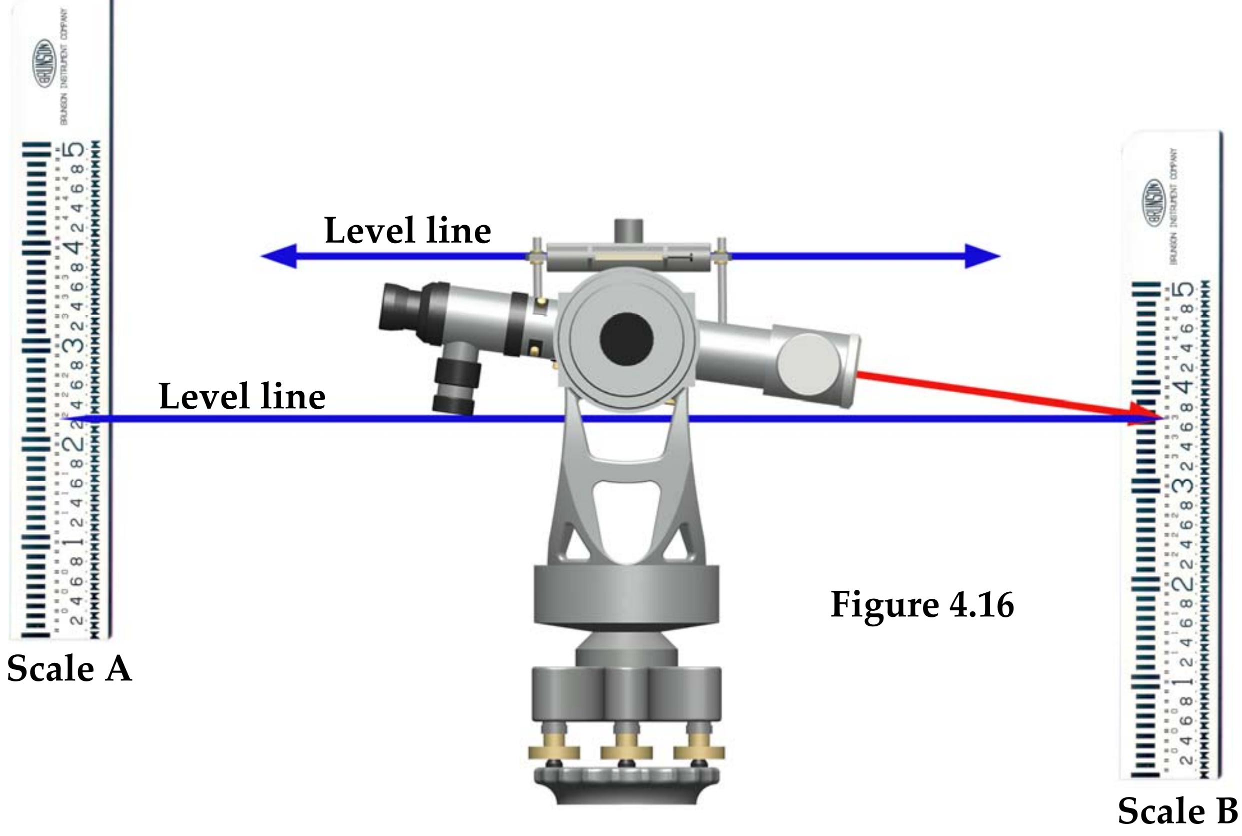


Figure 4.16

Note: If you want to make the arithmetic much easier, use a precision lift to bring the transit up or down to an even number on Scale A, setting on something like 2.000″ or 2.500″, with the micrometer set on zero.

6. Now turn the instrument toward Scale B and relevel the coincidence vial using the vertical tangent adjustment screw. Take a reading on Scale B and record this number. In our example, we read Scale B as 3.697″. As we have learned, we can now calculate the vertical offset of these two scales:

3.967″ - 2.283″ = 1.414″.

7. Now, move the instrument close to one of the scales and on the line between them (we moved close to Scale "B" in Figure 4.17). Preferably, the instrument should be located about 1/10 of the distance between the two scales. In our example, we would try to set the instrument about 3 feet away from one of the scales, since the total distance between them is 30 feet. Again, rough level the instrument using the plate vial and the leveling screws.

This procedure is one of those things which becomes much easier after you've gone through it once, and understand what's going on!

8. Point at the near scale and precisely level the coincidence vial using the vertical tangent adjustment screw. Take a reading on the scale. *(If you have a precision lift, you can make your life easier at this point by setting at some nice even number on the scale.)* In our example, since we don't have a precision lift, we read 4.035″.

9. Turn the instrument toward the far scale, and re-level the coincidence vial using the vertical tangent adjustment screw. Now, before we take a reading, we can calculate what we want to see. We know that the far scale in our example is 1.414″ higher than the near scale. So we can calculate what number we would hopefully see on the far scale *if the vial is in fact adjusted correctly*. Do this by taking the reading on the near scale and adding (or subtracting) the vertical offset between the scales. In our example, we subtract the near scale's reading from the vertical offset distance, since we have already determined that the far scale is higher than the near one:

4.035″ - 1.414″ = 2.621″

So if the vial is perfectly adjusted, we should see 2.621″ on the far scale. Now, since the suspense is killing us, we actually read the far scale with the micrometer. In Figure 4.18, the reading on the far scale is determined to be 1.958″.

Now, notice that 1.958″ is less than the optimal 2.621″ reading that would have indicated a level line. This tells us that the line of sight is pointing downward. If we had taken a reading on the far scale which was greater than 2.621″, we would know that the line of sight is pointing upward with respect to a level line.

10. To correct this error, we will calculate what the far scale should be reading if the instrument were in calibration, re-point the telescope at that proper reading, and adjust the coincidence vial back into coincidence. ***Now hold on here, why do we need to recalcu-***

Figure 4.17

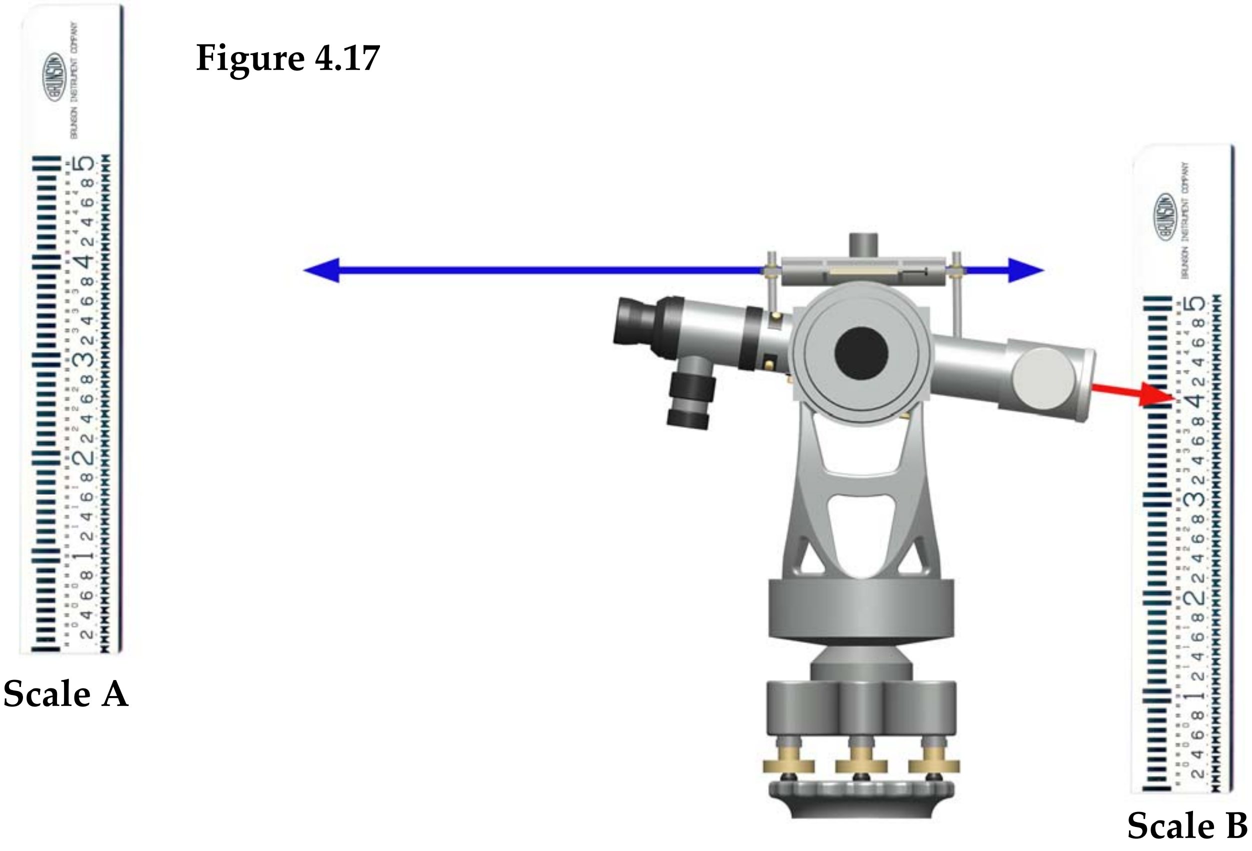
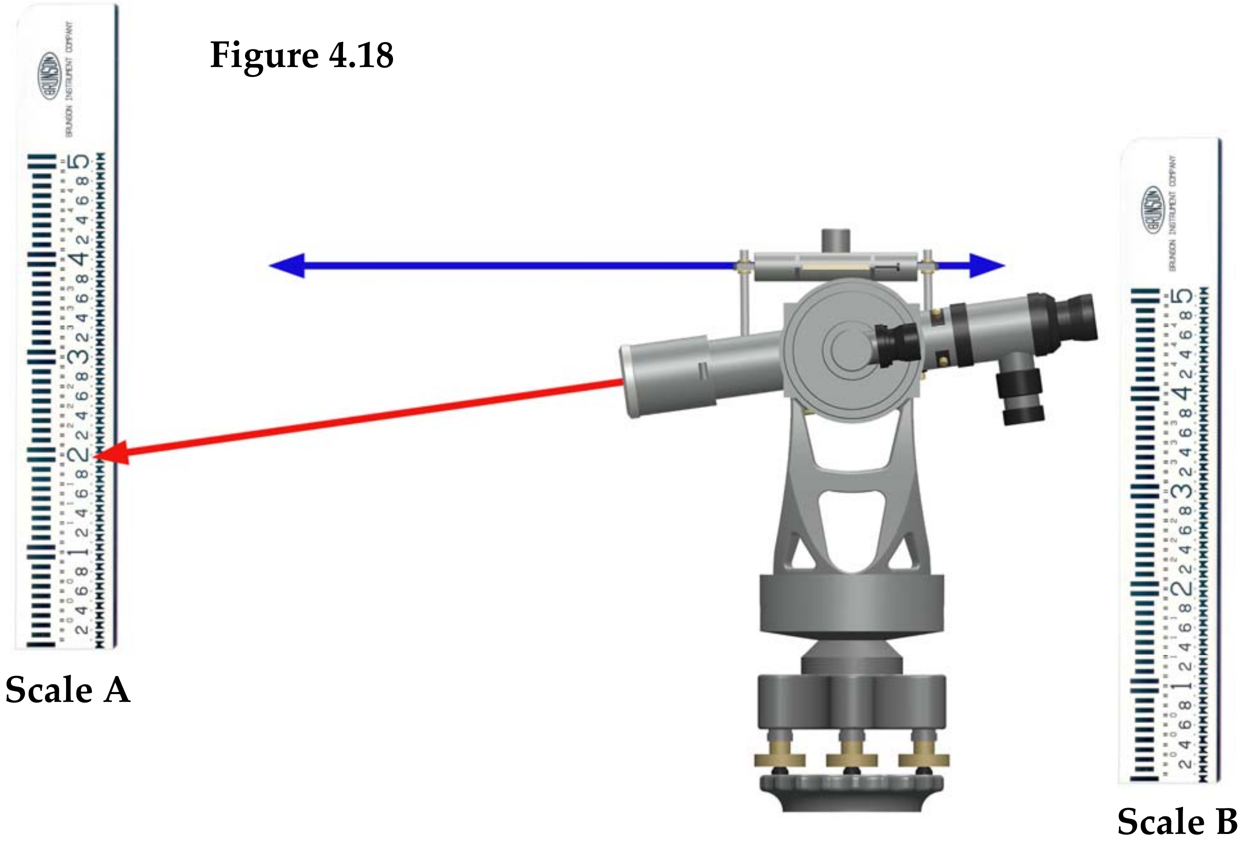


Figure 4.18



late? *Didn't we just say that the reading on the far scale should be 2.621" if the vial were adjusted properly?* Yes we did, but since we just learned that the vial is *not* adjusted properly, we know that our *initial reading of 4.035" on the near scale cannot be trusted; it is not on a level line from the telescope.* Remember that we are no longer halfway between the scales, where geometry allows us to determine a true level line, whether the line of sight is actually level or not.

What we are going to do now is determine what the far scale's reading should be, if the line of sight were actually brought level. How do we do that? What we need here is a good rule of thumb:

> **Rule of Thumb:** When the transit sits 1/10 of they way from one scale to another, take the far scale reading minus the "optimal reading" and divide it by 8. Then, on the far scale, rotate the telescope **toward and past** the optimal reading by the resulting amount.

Let's work through this in our example. Remember that our reading on the far scale was 1.958". Our "optimal reading" (the one we would have liked to have seen) was 2.621". So we subtract these two numbers:

2.621" - 1.958" = 0.663"

Now we divide the result by 8:

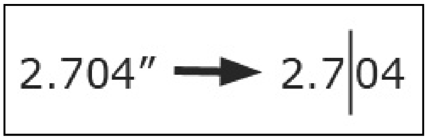
0.663" / 8 = 0.083"

So, we need to rotate the telescope up from our current 1.958" position to the 2.621" position, and then go 0.083" *further*. What that means is that we want to set the telescope on the far scale at this reading:

2.621" + 0.083" = 2.704"

> *CAUTION: When determining the desired scale position on which to set the telescope in the step above, you will always move the telescope from its current position toward the "optimal reading", and then beyond, by 1/8 of the distance. In our example, we are moving in the direction of an increasing scale reading (going from 1.958" to 2.704"), so we **add** the 0.083" above. But if you needed to move in the direction of a decreasing scale reading you would be **subtracting** the numbers. Remember the rule of thumb, not the arithmetic, of our example.*

11. So now, let's rotate the telescope to set on 2.704" at the far scale, which is our desired scale position. There's an easy way to do this. Look at the last two digits in the desired position—"04" (forget about the 2.7 for a moment.) Look into the telescope and rotate the



micrometer so that the line of sight *moves toward the zero end of the scale*. Rotating the micrometer drum in this direction, set the micrometer on the last two digits of the desired reading. In our example, you'd then set the micrometer on 4 (as in 0.004″). Likewise, if the desired reading had been 2.753″, you would set the micrometer on 0.053″ - but always by rotating the micrometer's graduated drum in the direction which appears to *move the line of sight toward the zero end of the scale.* Finally, use the vertical tangent adjustment screw to rotate the telescope to the 2.7″ mark on the far scale. You can check to make sure you did things right by putting the micrometer temporarily back to zero—the line of sight will move up a little, between the 2.7″ and 2.8″ target pairs on the scale.

This method of setting on a particular scale reading works with the micrometer in any position and the scale in any orientation.

12. With the telescope in this position, adjust the coincidence vial until the bubble is back in coincidence. The vial is held in position on two threaded studs, each having opposing nuts on the top and bottom of the vial ends. We recommend slightly loosening one of the nuts on the eyepiece end of the vial, depending upon whether you want to move that end of the vial up or down. Then bring the opposing nut up (or down) so that the vial is once again held securely. Remember that it takes almost no movement to make significant adjustments to the vial. Our rule at the factory is "if you feel it move, you went too far".

13. Repeat steps 8 through 12 until the transit can be turned from one scale to the other, and you read only the vertical offset between the two scales (in our example, the 1.414″ differential).

Quick Steps Guide

Here is a quick recap of the steps in the peg test:

1. Set up two vertical scales about 30′ apart.

2. Install the micrometer with the drum on the side, set to zero.

3. Set up and rough level your transit halfway between the two scales, with the coincidence vial on the top side of the telescope.

4. Focus on Scale A, and adjust the telescope so that the coincidence vial indicates level. Take a reading on Scale A.

5. Turn around to focus on Scale B, again adjust the telescope so that the vial indicates level. Take a reading on Scale B. Calculate the vertical offset between the two scales.

6. Move the instrument closer to Scale B, 1/10 of the way between the two scales.

7. Put the vial into coincidence (level) and take a reading on the

near scale (Scale B).

8. Calculate what the reading *should* be on the far scale (the "optimal" reading), given that we know the vertical offset between the scales. Then turn to point at the far scale, re-level the telescope, and take a reading.

9. Find the difference between the *optimal* reading and the actual reading, and divide this difference by 8. Call this result the "compensation factor".

10. Looking at the far scale, move the telescope toward the optimal reading, and then beyond it by an amount equal to the *compensation factor*. Set the micrometer appropriately to accomplish this.

11. Adjust the vial so that the bubble is back in coincidence.

12. Repeat steps 7 through 11 until difference in readings of the two scales is the same as the vertical offset between the scales.

You are now a Master of the Universe.