OPTICAL ALIGNMENT MANUAL

CUBIC PRECISION

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K+E® Electro-Optical Products

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OPTICAL ALIGNMENT MANUAL

Cubic Precision/K&E Electro-Optical Products creates, designs, and manufactures optical, mechanical, and electro-optical systems and components for the precise measurement of lengths and angles. Drawing on more than 100 years of experience and leadership in optical instruments, Cubic/K&E offers broad facilities and outstanding scientific and engineering personnel capable of handling optical alignment projects, from consultation or basic research to design, development, and quantity production.

Cubic/K&E's complete line of optical and laser alignment equipment and accessories includes: jig transits, alignment telescopes, levels, collimators, targets, instrument stands, tooling bars, and a wide range of supporting equipment.

CONTENTS

1. The Fundamentals of Optical Alignment Equipment

1-1. Accuracy. Optical alignment instruments and procedures are designed to give accuracies of one part in 200,000. For example, if an object is placed at a distance of 200 inches from the point from which the measurement is made and 200 inches from the optical instrument by which the direction is determined, the distance and direction of the object will each be in error by less than 0.001 inch.

1-2. Line of Sight. Nearly every optical alignment procedure is based on the use of one or more lines of sight. These are established by telescopic sights.*

A telescopic sight consists of a tube with an objective lens near the front end, a reticle with cross lines or a similar pattern near the rear end, and an eyepiece mounted behind the reticle. A movable lens called a focusing lens is placed between the objective lens and the reticle. By moving this lens, objects in front of the telescope can be focused on the reticle. This forms an inverted image on the reticle pattern. The eyepiece erects and magnifies this image and the reticle pattern together so that the observer sees the cross lines apparently on the object at the point where the line of sight strikes it. See Fig. 1-1.

In use, certain precautions are necessary to focus a telescopic sight. The eyepiece must be moved in or out by turning the knurled drum (eyepiece focusing ring) nearest the eye to bring the reticle mark sharply into focus for the particular observer's eye. Since the eye can change focus itself, this is not at an exact position.

The focusing lens must be moved forward and back by the focusing knob. This brings the object sighted into sharp focus. But due to the possibility of the eye changing focus, the image may not be on the reticle. This introduces parallax so that if the eye is moved, the reticle pattern will apparently move with respect to the target sighted.

To eliminate parallax, the best procedure is as follows:

1. Aim at a white object and focus the eyepiece until the reticle pattern is sharp when the eye is relaxed.
2. Aim at the target and focus the telescope.
3. Move the eye slightly left and right or up and down. If there is apparent motion between the target and the reticle, eliminate it by changing the telescope focus slightly. Finally, sharply focus the eyepiece. Continue alternately until the apparent movement is eliminated and both the object sighted and the reticle pattern are sharp.

   Note the plus or minus reading on the diopter scale around the focusing ring and use this setting for future sights with this particular instrument.

To Aim the Line of Sight. Since the reticle can never be adjusted so that the cross lines are *exactly* vertical and horizontal, always use as nearly as possible the center of the reticle pattern. When using the vertical cross line, use the part nearest the horizontal cross line and vice versa.

1-3. Targets. The line of sight is aimed at a target. Special targets are used which are designed so that the error of pointing the line of sight at them is not more than 0.5 second of arc. See Fig. 1-2.

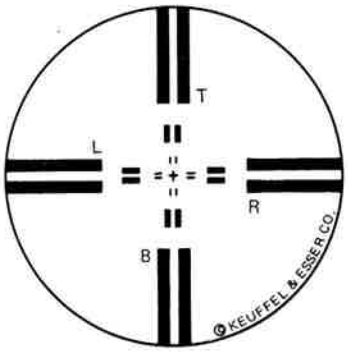


Figure 1-2. A paired-line target. The sets of paired lines used depend on the length of the sight.

*In some applications, the use of lasers has supplemented optical alignment techniques. For information about laser procedures, contact Keuffel & Esser Co., Morristown, N.J. 07960.

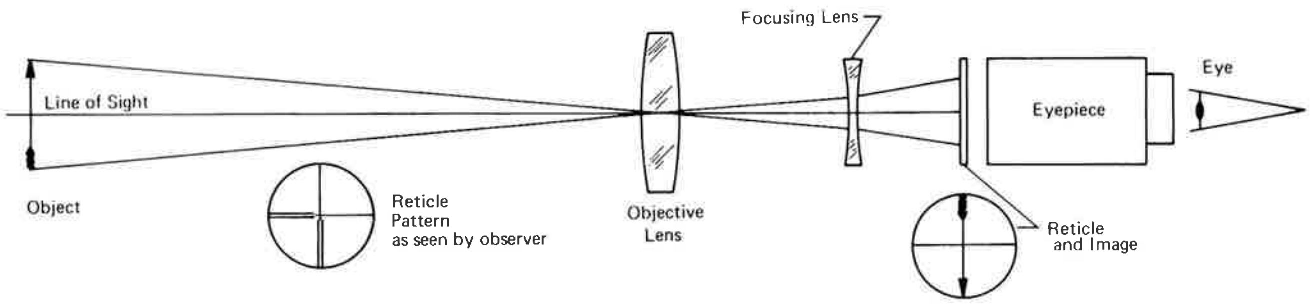


Figure 1-1. A telescopic sight. The direction of the line of sight is determined by the center of the reticle pattern and the optical center of the objective lens.

1-4. Collimation. The principal focus of a lens is the plane where parallel light rays which enter the lens meet behind the lens. Parallel rays can be created by a light source at infinite distance. When the focusing lens of a telescopic sight is placed so that parallel rays are focused on the reticle, the telescope is said to be set at infinite focus. Without a focusing lens the same result can be attained by placing the reticle at the principal focus of the lens. See Fig. 1-3. Since all optical effects are reversible, when the reticle is illuminated in either of these devices, the shadow of the cross lines is projected through the lens in parallel rays. Such a device is called a collimator.

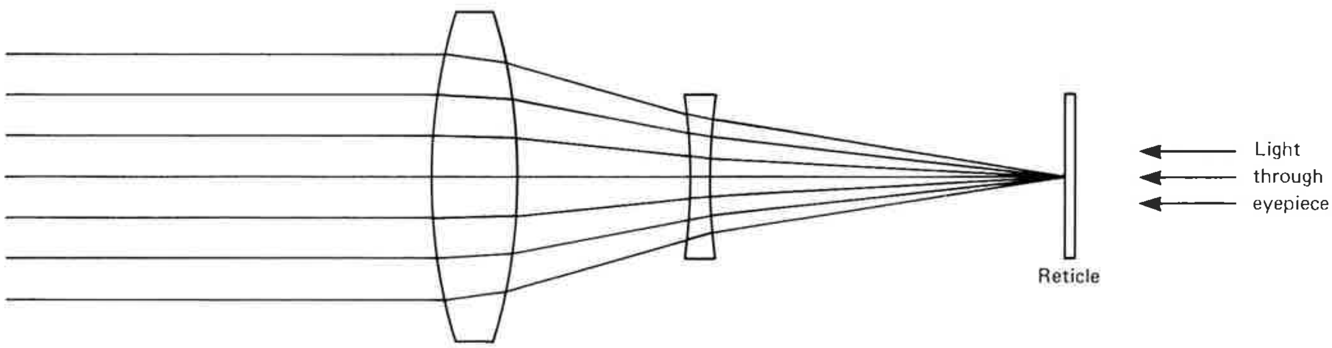
Figure 1-4 shows that when a telescopic sight, focused at infinity, picks up any of the parallel rays from a collimator, the cross lines of the collimator can be seen on the reticle of the telescope. If the telescopic sight is aimed so that the collimator cross lines appear to coincide with those of the telescopic sight, the lines of sight of the two instruments are parallel although they do not necessarily coincide. The instruments are then said to be collimated. Due to lens aberrations, the two lines of sight must be placed so that they very nearly coincide to be perfectly parallel. See Fig. 1-5.

1-5. Auto-Collimation. Auto-Collimation is a process of setting a mirror perpendicular to a telescopic line of sight. An eyepiece containing a semi-transparent mirror and a light, called an auto-collimation eyepiece, is used on the telescope. See Fig. 1-6.

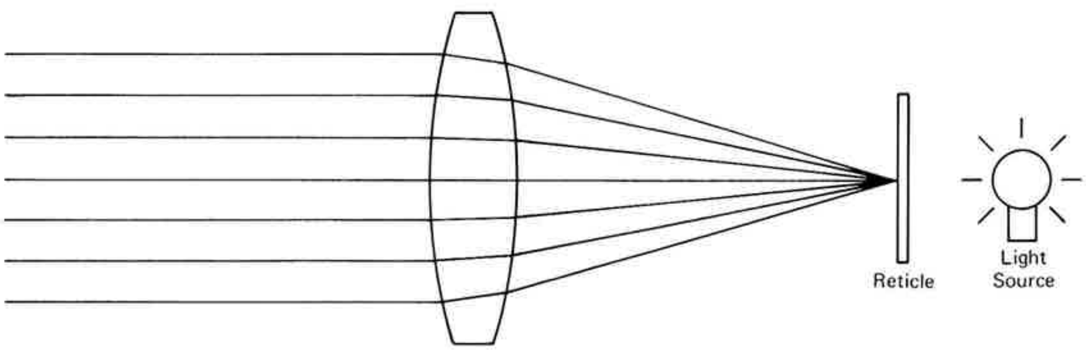
While the light illuminates the reticle, the observer can see the reticle and also through the telescope. When the telescope is aimed at a mirror, the instrument serves as a telescopic sight and its image in the mirror serves as a collimator. When the observer focuses on the image of the cross lines as seen in the mirror, the instrument is at infinite focus and the observer can see the actual reticle and its reflected image. When the mirror is turned so that the reflection of the cross lines coincides with the actual cross lines, the mirror is perpendicular to the line of sight.

1-6. Auto-Reflection. When an auto-collimation eyepiece is unavailable, auto-reflection can be used. This is not quite as accurate as auto-collimation. An auto-reflection target Fig. 1-7A is mounted on the front end of the telescope, or imprinted on the objective lens of the instrument, Fig. 1-7B. Focus and aim at the auto-reflection target, Fig. 1-7C. The mirror is adjusted until the reflection of the target coincides with the reticle pattern.

To Focus at Infinity. Frequently two telescopic sights must be aimed at each other when both are focused at infinity, i.e., set at infinity focus. They are focused by one of the three following methods:



A Telescopic Sight used as a Collimator



A Collimator

Figure 1-3. When parallel rays meet on the reticle, the instrument is focused at infinity and it becomes a collimator.

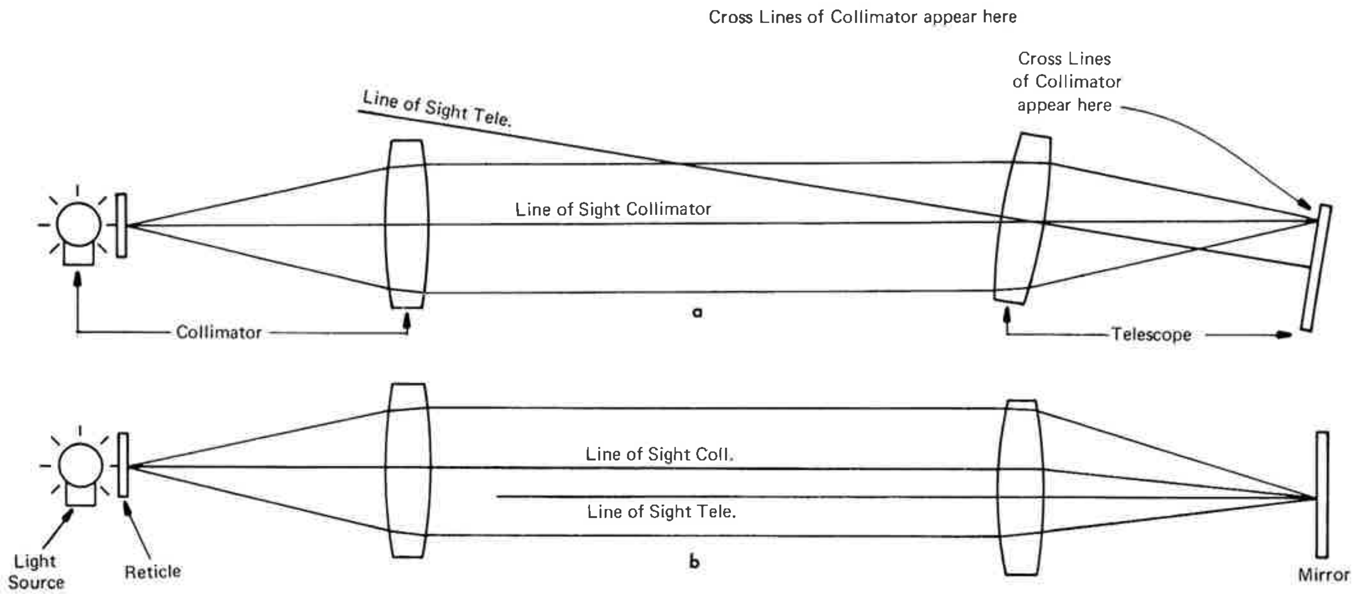


Figure 1-4. (a) Rays from collimator picked up by telescopic sight. (b) Image of collimator cross lines on telescope cross lines. The lines of sight are parallel but not coincident. The instruments are collimated.

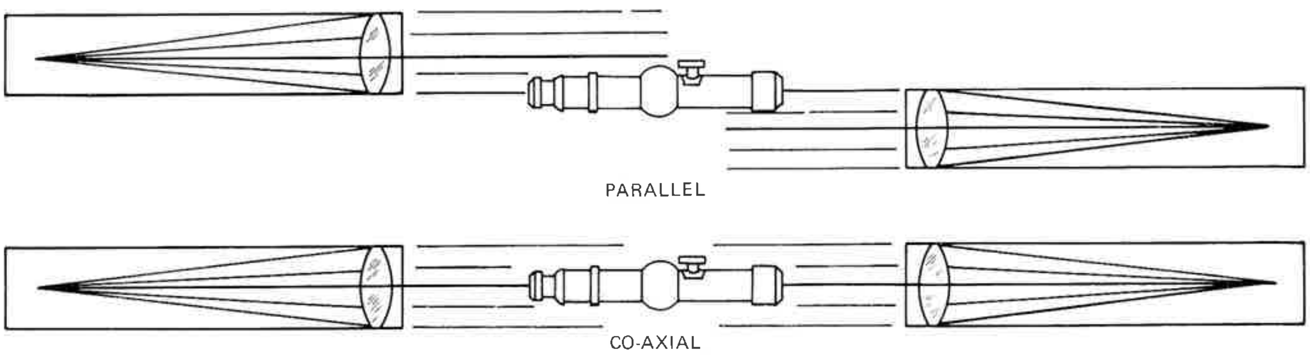


Figure 1-5. Collimators aligned with a telescope.

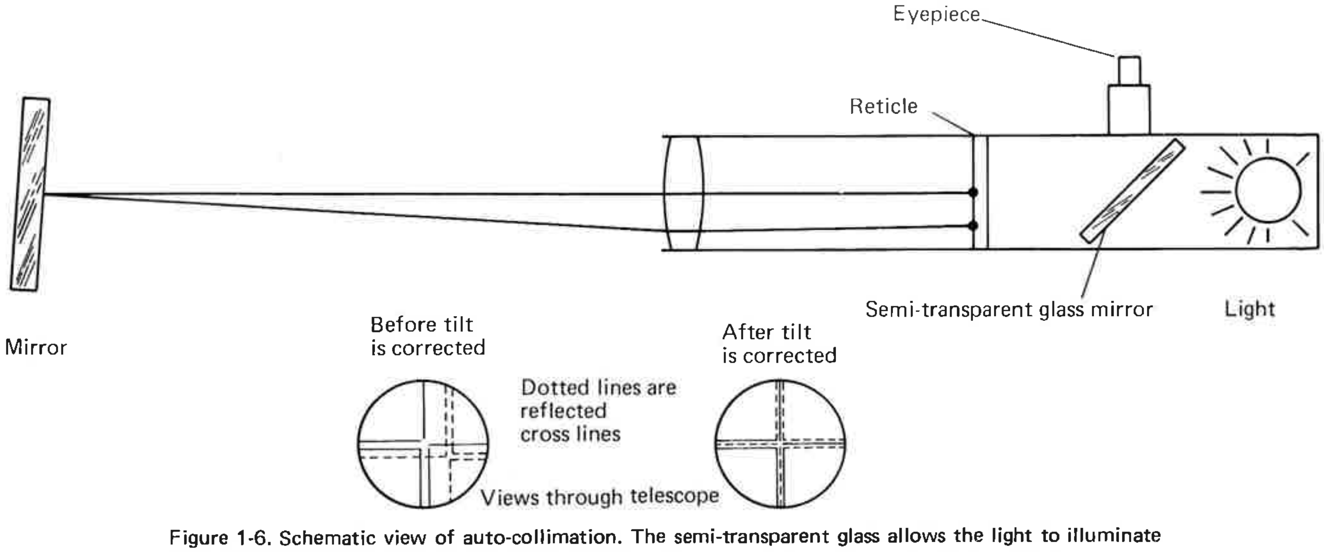


Figure 1-6. Schematic view of auto-collimation. The semi-transparent glass allows the light to illuminate the reticle and at the same time serves as a mirror and thus allows the observer to see the reticle.

Figure 1-7A. Slip-on auto-reflection target.

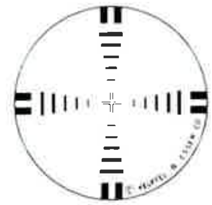


Figure 1-7B. Built-in auto-reflection target.

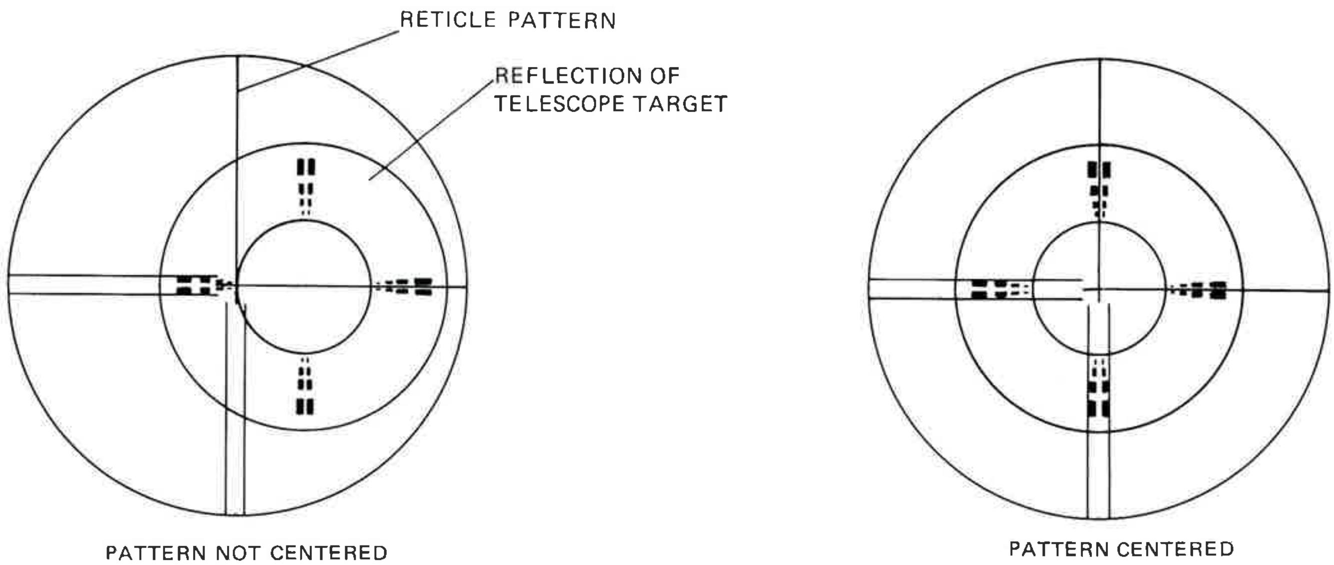


Figure 1-7C. Auto-reflection. What the observer sees.

1. If either has an infinity focus mark, set the focus accordingly and focus the second instrument on the reticle of the first.
2. If neither has an infinity focus mark, but one has an auto-collimation eyepiece, place a mirror against the front of the telescope and focus it on the reflection of the reticle. Remove the mirror and focus the other instrument on that reticle.
3. If neither has an infinity mark or an auto-collimation eyepiece, focus one on some point as far distant as possible, then focus the other on the reticle of the first.

1-7. Right Angles. Accurate right angles are formed by three methods: by auto-collimation, by pentaprisms, or with a Jig Transit Telescope Square 71 1025. By each method, a line of sight is established which will sweep a plane that is perpendicular to the original line of sight.

Figure 1-8 shows how a telescope-axle mirror perpendicular to the elevation axis of a Jig Transit can be used for this purpose by auto-collimation or auto-reflection.

A pentaprism turns the line of sight 90° independent of its orientation. See Fig. 1-9. A pentaprism is often mounted in front of a telescopic sight so that it can rotate on an axis that coincides with the line of sight. When it is rotated, it causes the part of the line of sight that passes through it to sweep a plane perpendicular to the original direction of the line of sight. See Fig. 1-10.

The procedure with a Jig Transit Telescope Square is described in Chapter 2, Sect. 2-11.

1-8. Spirit Levels. Since the direction of gravity is determined so easily and so accurately by spirit levels,

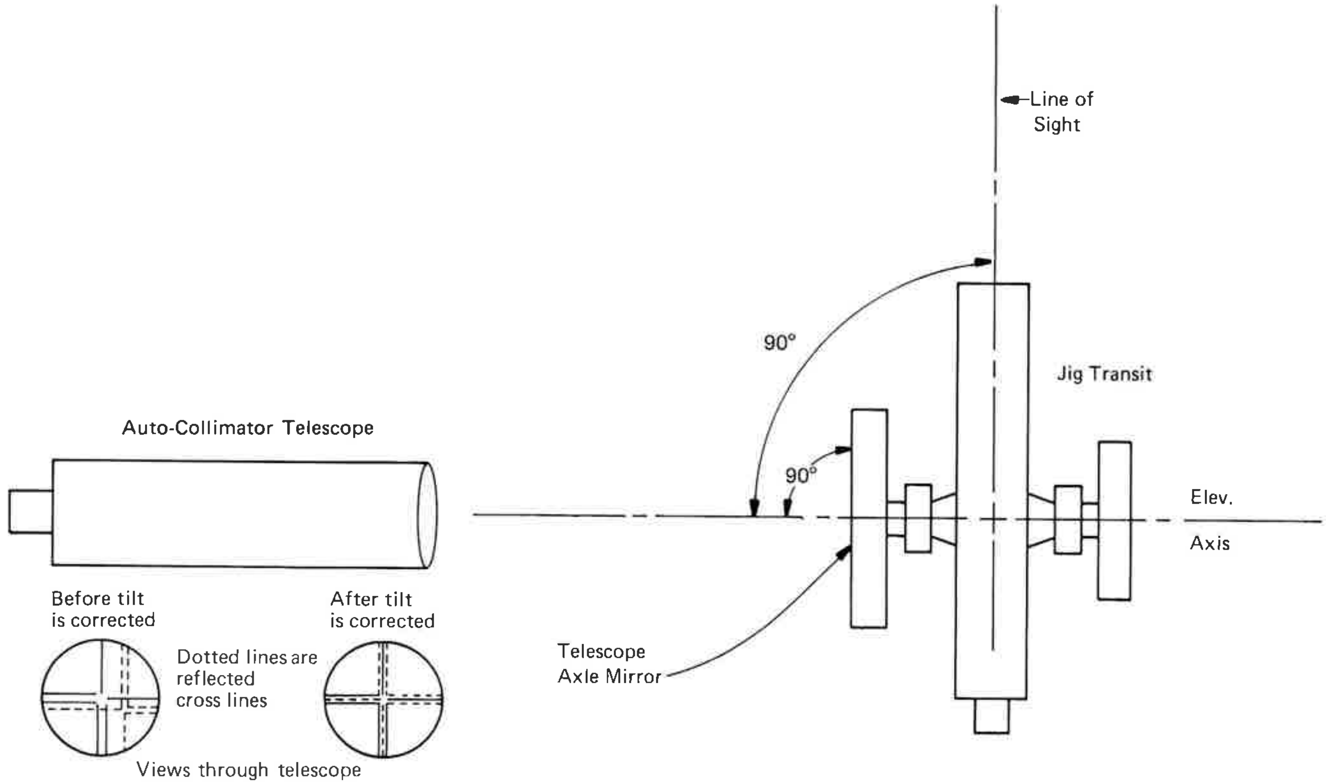


Figure 1-8. A right angle by auto-collimation. A jig transit has a telescopic sight mounted to turn on an elevation (horizontal) axis. At the end of the axis is a front surface mirror perpendicular to the axis and therefore parallel to the plane swept by the line of sight.

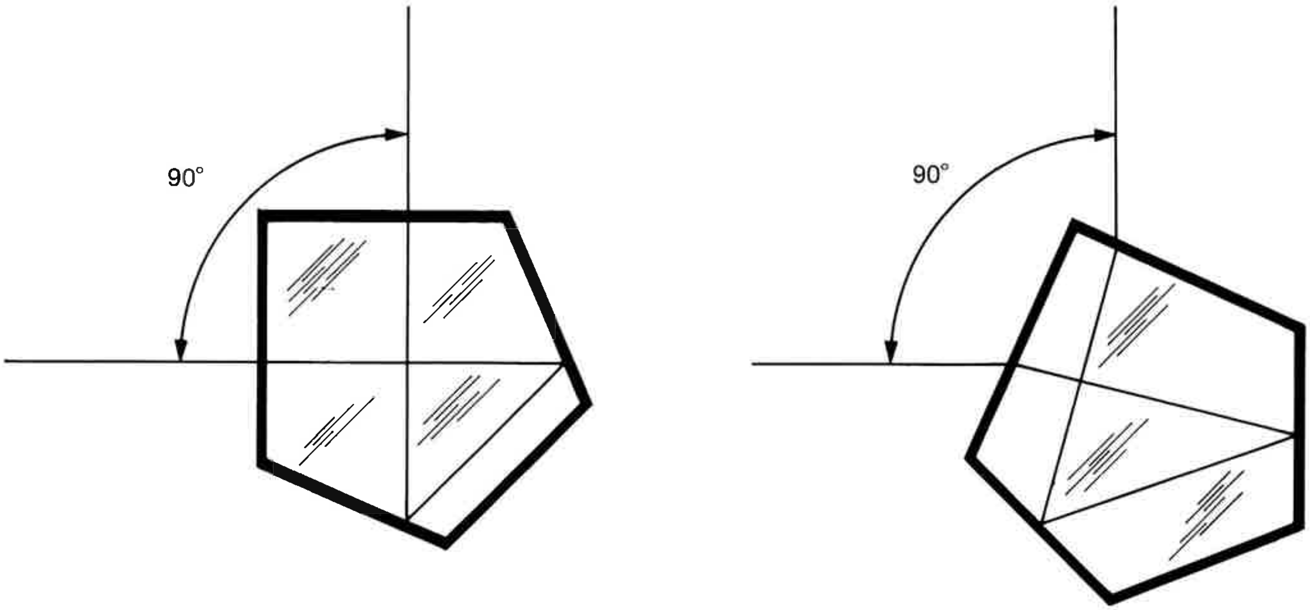


Figure 1-9. A pentaprism turns a line of sight 90° independent of its orientation.

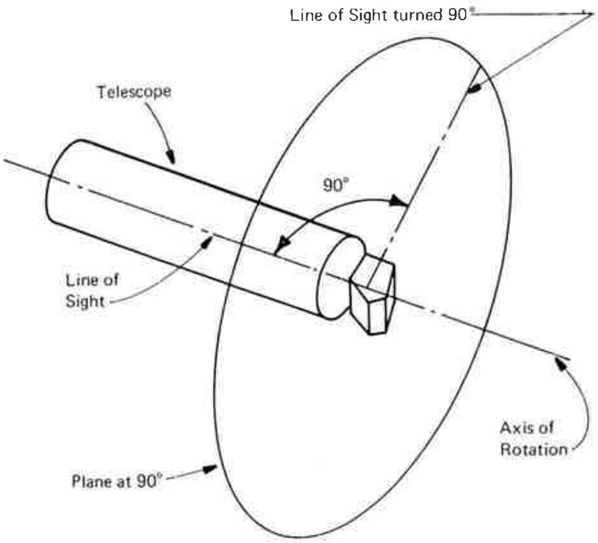


Figure 1-10. A telescopic sight and a pentaprism sweeping a plane at 90°.

gravity is usually used as a reference direction. (In optical alignment, the word "vertical" means in the direction of gravity and the word "horizontal" means perpendicular to the direction of gravity.) Spirit levels are used on many instruments to show the direction of gravity.

A spirit level consists of a vial partially filled with a low viscosity liquid so that a bubble is formed. The inside surface is ground to a barrel shape. The sensitivity of the level is increased when the length of the radius of the longitudinal curvature is increased. See Fig. 1-11. The unit used in measuring sensitivity is the number of seconds of arc the vial must be tilted to move the bubble two millimeters.

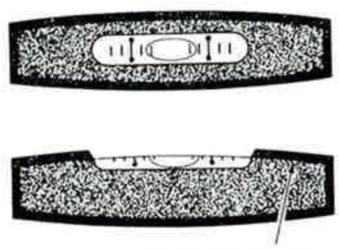


Figure 1-11. The cross section of a level vial. The inside surface is ground to a barrel shape. The scale is usually ground into the vial surface.

Since the liquid increases in volume with increased temperature, the bubble changes length over a considerable range. Somewhat arbitrary scales are placed near or on the vials which show how far each end of the bubble has moved from a zero position.

The vial is considered level when each end of the bubble is the same distance from its zero.

A coincidence level (Fig. 1-12) can be centered more accurately. When the two ends are made to coincide as shown, the bubble is centered. The two ends appear to move up or down *together* as the bubble *changes length* so that the device is undisturbed by changes in temperature.

Circular levels are used for approximate leveling. Their upper inside surfaces are spherical.

1-9. Scales. K&E Wyteface® optical tooling scales are used to measure short distances from lines of sight. They are graduated in units of 0.100 inch. At each 0.100 inch is a set of paired-line targets designed so that the error is not more than 0.5 second of arc. See Fig. 1-13. They are read with an optical micrometer attached in front of, or made part of, the telescopic sight used to observe them (see paragraph 1-10).

1-10. Optical Micrometers. An optical micrometer displaces a line of sight parallel to itself. The extent of the movement is read to 0.001 inch. The principle is shown in Fig. 1-14. Some have verniers that read to 0.0001 inch.

To Mount an Optical Micrometer. Free the split-ring clamp screw of the optical micrometer. Slide the micrometer onto the front end of the telescope with the micrometer drum on top or underneath to measure left or right, or turned 90° to measure up or down. Slightly tighten the split-ring clamp screw so that the micrometer will turn without play.

Set the micrometer in the proper orientation as follows. Aim at a target. Turn the micrometer drum back and forth throughout the full extent of its run. Rotate the micrometer until the appropriate cross line remains on the target and tighten the split-ring clamp screw.

1-11. Linear Measurements. Linear measurements too long to be measured with optical tooling scales are measured with optical tooling tapes, or optical tooling bars. See Chapter 5, Optical Tooling Bars.

1-12. Care of Instruments; Jars and Vibration. Handle all instruments with great care. Never subject them to a jar or to vibration.

Never store or transport an instrument within the shop or in shipment unless freely supported on resilient material.

Vibration loosens screws and often destroys all adjustments dependent on adjusting screws.

Deflection. The effect of deflection in instruments is sometimes as high as 50 to 100 times as great as the accuracy required. To avoid deflection:

1. Always support an instrument in its normal position during storage, use, or adjustment.
2. Allow an instrument to adjust to surrounding air temperature before operating it.

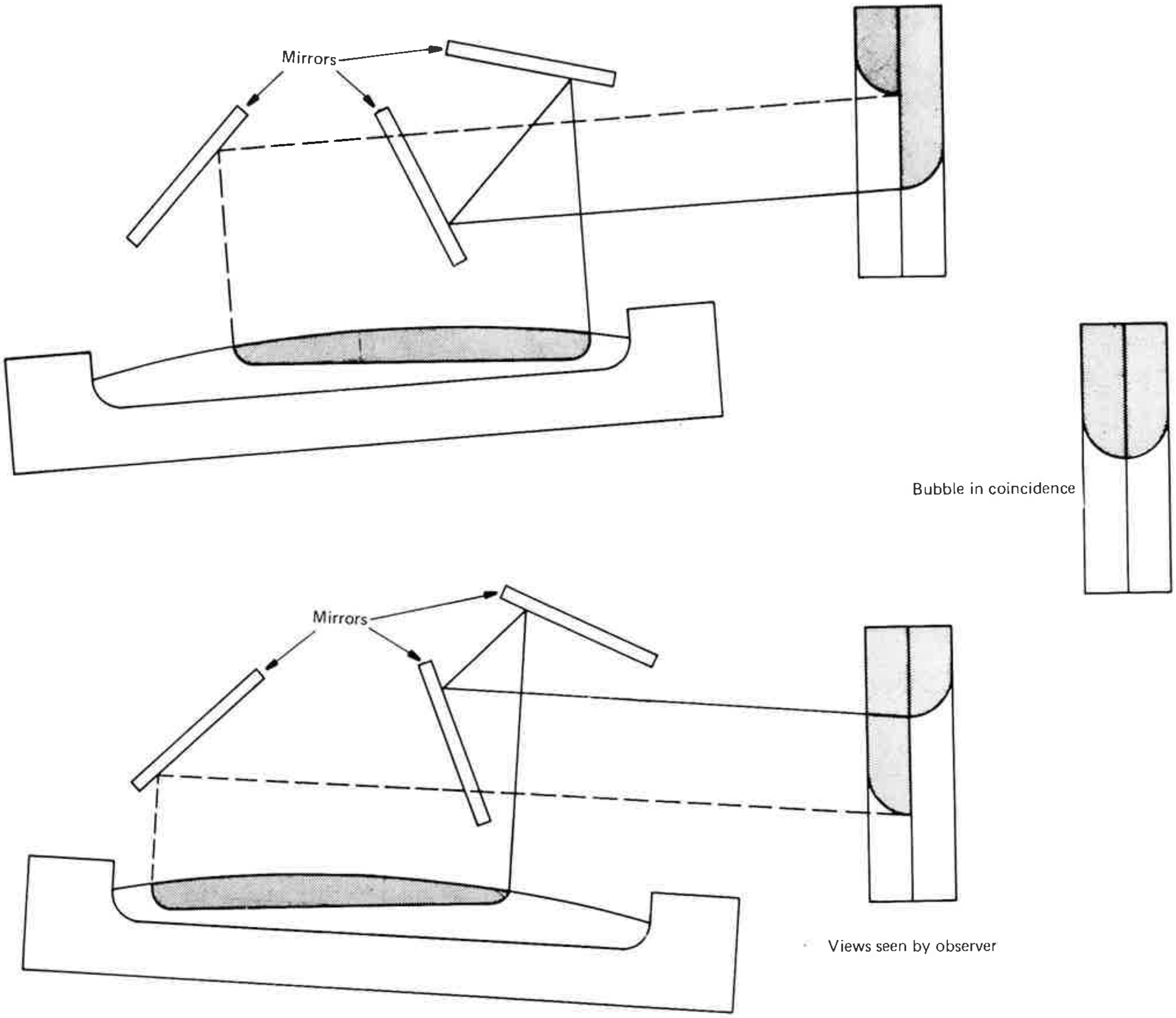


Figure 1-12. Coincidence level. It gives very precise indications. The single mirror reflects one half the bubble divided longitudinally and the pair of mirrors reflects the other half.

3. Any attachments to a telescope, that are to be used, must be in place when the instrument is adjusted.

4. It is best to handle an instrument by its base to avoid a temporary set due to hysteresis.

Temperature. Spirit levels are extremely sensitive to ambient temperatures. If the vial is unevenly heated so that the vapor pressure in the liquid is greater at one end than the other, the bubble will not come to rest at the highest point in the vial.

A spirit level is useless when in the direct rays of the sun and unreliable when near an ordinary electric light or when touched with the finger.

Refraction. A column of hot or cold air anywhere along a line of sight will make it wobble and bend it, thus destroying its accuracy.

Obstruction. If any object prevents any light rays from a target reaching the entire area of an objective lens the line of sight will not be reliable.

Lubrication. The lubrication of an instrument is a shop operation. However, in use, the threads of the leveling screws may be lubricated with a very small quantity of fine instrument lubricant. This should be worked-in by turning the screws up and down throughout their range and carefully wiping off the excess lubricant with a lint-free rag.

Dust. Protect instruments from dust as much as possible.

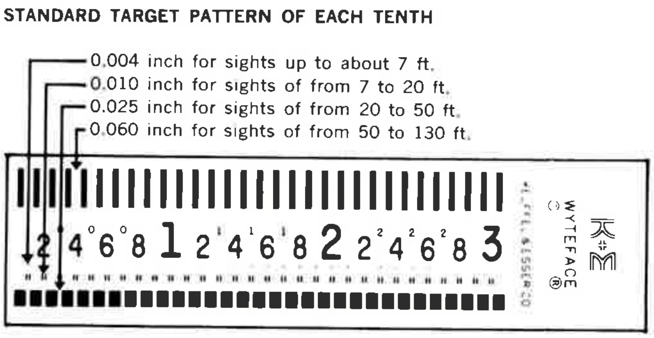


Figure 1-13. The pattern used on K&E scales.

If subjected to dust, the view through the telescope may be slightly dimmed. This is due to dust on the eyepiece lens nearest the eye. Clean this lens with a cotton swab dampened with alcohol or acetone.

1-13. Adjustments. Two adjustments apply to a number of instruments. They are given here and referred to in appropriate chapters.

An instrument should be tested frequently but adjusted only if three successive tests show the same error.

Many adjustments affect other adjustments. Minimum interference occurs when the adjustments are made in the order given. Interferences are stated.

Reticle Adjustments. In most instruments, a reticle is held by four capstan-headed screws in tension. See Fig. 1-15. To reach these screws, unscrew the protective cover just in front of the eyepiece.

To raise the aim of the line of sight, lower the reticle. Loosen screw (2) or (4) slightly; loosen (1) slightly; tighten (3) slightly. Continue with (1) and (3) as far as necessary. Never lose all tension. Tighten the screw first loosened, (2) or (4).

Left and right adjustment is made in a similar manner, using the appropriate screws.

The Peg Adjustment. This is a standard adjustment for instruments used for accurate leveling.

Object. To make the line of sight level when the bubble is centered or in coincidence.

Test (Known as Peg Test).

1. Set K&E optical tooling scales at points 1 and 2, see Fig. 1-16, at a distance approximately 40 feet apart. These scales must be vertical (use K&E 71 3270 Scale Level) and must be on a firm base not subject to vibration or settlement. Provide good illumination for the scales.
2. Set up instrument equipped with optical micrometer at point M, exactly midway between points 1 and 2.
3. With the main bubble centered or in coincidence, take five readings at A & B. Record the average of each set of these readings.
4. Move the instrument to position P. P should divide the distance between scales into the ratio of 1 : 4. For example: If the distance between scales is 40 feet, P should be 8 feet from scale #1 and 32 feet from scale #2.
5. With the main bubble centered or in coincidence, take five readings at C and D. Record the average of each set of these readings. If the instrument is in adjustment, A minus B will equal C minus D. If this is not the case, calculate what reading D_1 should be to make the line of sight level by using this formula:

$$D_1 = 4/3[(B + C) - (A + D)] + D$$

Adjustment "A". For K&E Levels 71 3001 and 71 3010.

1. Loosen the outer two of the three capstan screws located on the back of the main bubble housing; set into the micrometer the correct D_1 reading. For example, if D_1 equals 4.671, set plus 0.071 on the optical micrometer by rotating drum forward.
2. With the tilting drum, move the cross line until it reads D_1 on scale #2. (4.600 in the example above.)
3. With the adjusting pin, turn the center capstan screw on the back of the main bubble housing until the bubble is in coincidence. Lock the bubble adjustment with the two outer capstan screws.
4. If there is not sufficient adjustment available, repeat the peg test before going to the next step.
5. Remove the screws at the top and bottom of the eyepiece end of the main bubble housing; this will expose the coarse bubble adjusting screws. With the fine capstan adjustment in the center of its range, bring the bubble approximately to coincidence with the coarse adjusting screws and then lock them firmly. Make the final fine adjustment with the capstan screw as outlined in step 3.

Adjustment "B". For K&E Jig Transits 71 1002, 71 1010, 71 1020, and 71 1025.

1. Set into the micrometer the correct D_1 reading. For example, if D_1 equals 4.671, set plus 0.071 on the optical micrometer by rotating drum forward.
2. With the vertical tangent screw, move the telescope until the reticle reads D_1 on scale #2. (4.600 in example above.)

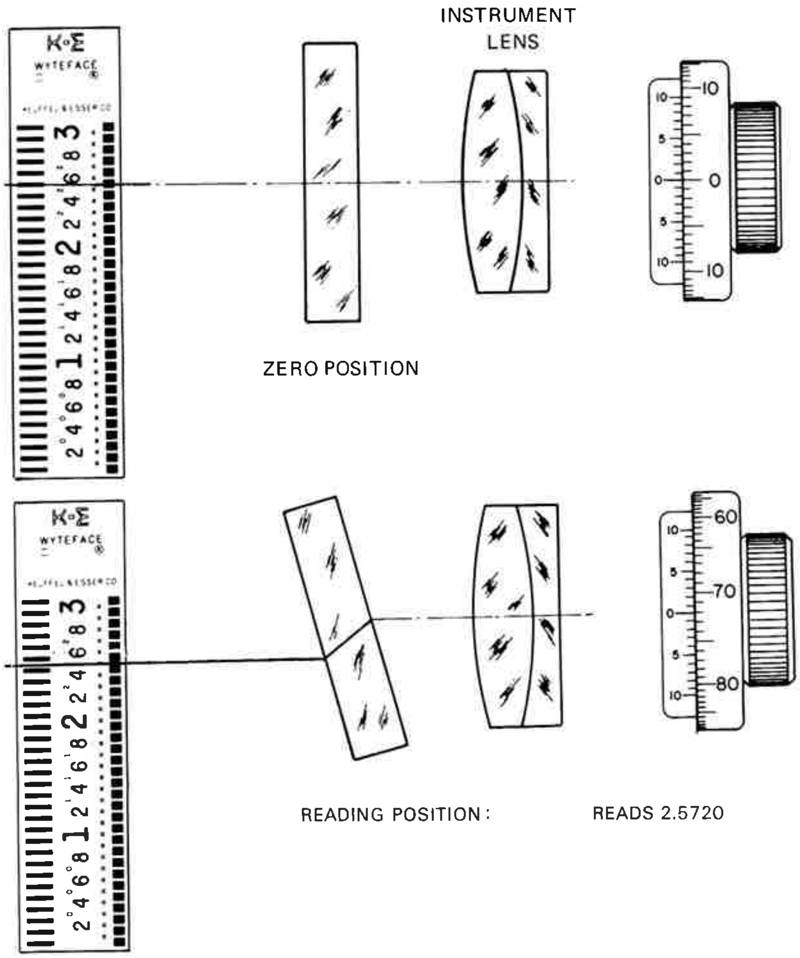


Figure 1-14. The principle of an optical micrometer.

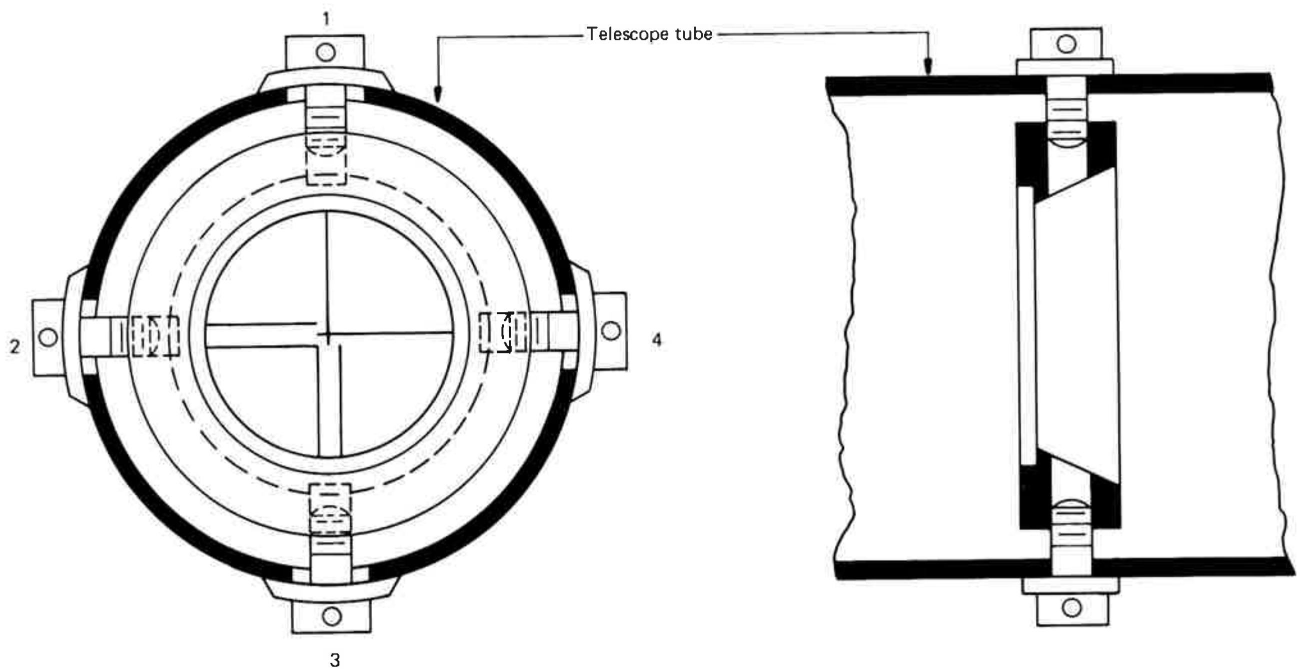
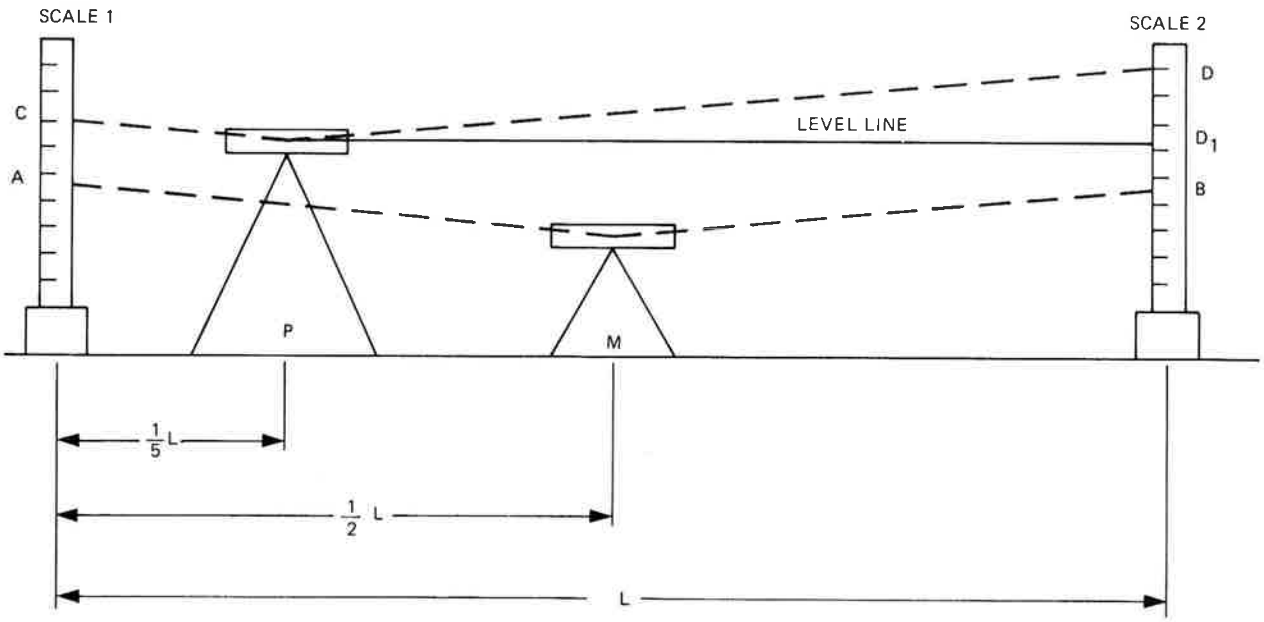


Figure 1-15. The reticle is held by four adjusting screws in tension. Numbers indicate screws.



$$D_1 = \frac{4}{3}\left[(B + C) - (A + D)\right] + D$$

Figure 1-16. Peg Test Diagram.

3. Adjust the bubble with the two opposing capstan nuts.

If your work was carefully done, the instrument will now be in adjustment.

1-14. Four-Screw Leveling. The leveling heads of all K&E optical alignment instruments, except the Plumb Aligner Bracket 71 5160, are leveled with four leveling screws. An instrument leveled with four leveling screws is held absolutely stationary in elevation, horizontal position, and the base is stationary in azimuth. When the leveling screws are tight, a half ball is forced upward into an inverted socket. Unless the instrument has a shifting center, if releveled, the instrument takes up exactly the same elevation and horizontal position but the base may have been slightly turned in azimuth.

With three-screw leveling the instrument height changes when any leveling screw is turned. The orientation in azimuth depends on the fit of the leveling-screw threads, unless the instrument is provided with special devices.

1-15. Glossary.

Aim, to. To regulate the direction of a sighting device. It does not mean to focus.

Alidade. All the upper part of an instrument that turns in azimuth with the sighting device (usually the telescope).

Azimuth. Direction in a horizontal plane.

Azimuth, to turn in. To change direction in a horizontal plane.

Azimuth Axis. The vertical axis. The axis of the bearing and spindle which confines rotation to a horizontal plane.

Azimuth Motion. The clamp and tangent screw which controls rotation in azimuth.

Buck-In, to. To place an instrument so that the line of sight satisfies two requirements (like aiming at two targets) simultaneously. It is usually accomplished by trial and error.

Circular Level. The round level attached to the alidade.

Clamp. In the sense of a tangent clamp. The clamp which is used to connect the part to be aimed with the stationary part of an instrument so that the tangent screw will operate.

Elevation, of a line of sight. The direction of a line of sight in a vertical plane.

Elevation Axis. The horizontal axis. The axis of the bearing and the journal of the telescope axle which confines rotation to a vertical plane.

Elevation Motion. The clamp and tangent screw which controls rotation in elevation.

Focus, to. To move the optical parts so that a sharp image is seen. It does not mean to aim.

Horizontal. Perpendicular to the direction of gravity.

Objective Lens. The lens at the front end of a telescope and therefore nearest the object sighted.

Plate, of a jig transit. The base to which the standards are attached. It forms the connection between the standards and the azimuth spindle (journal) and carries the plate level and the circular level.

Plate Level, of a jig transit. A comparatively sensitive tubular level mounted on the plate, used to place the azimuth axis in the direction of gravity.

Position, of an instrument. The position in a horizontal plane of the center of the half ball or the spherical adapter about which the instrument turns when it is being leveled. Once a jig transit is leveled, it is the point at which the vertical and horizontal axes intersect.

Reference Line. A line of sight from which measurements are made.

Standards, of a jig transit. Uprights which support the telescopic axle bearings.

Station. The distance given in inches and decimal parts of an inch measured parallel to a chosen centerline from a single chosen point.

Tangent Screw. A hand-operated screw which changes the direction of the line of sight either in azimuth or in elevation.

Telescope Axle, of jig transit. The horizontal axle which supports the telescope.

Telescope Direct. The normal position of a jig transit telescope, as opposed to telescope reversed.

Telescope Reversed. The position of a jig transit telescope when it is turned over (transited) so that it is upside down to its normal position.

Telescopic Sight. An optical system that consists of an objective lens and a focusing device that forms an image on a cross-line reticle which is viewed through an eyepiece that magnifies the image and the cross lines together.

Vertical. In the direction of gravity.

1-16. CONVERSION TABLES

Seconds of arc in terms of thousandths of an inch

	10 ft.	20 ft.	30 ft.	40 ft.	50 ft.	100 ft.
1 sec.	.0006	.0012	.0018	.0024	.0030	.0060
2 sec.	.0012	.0024	.0036	.0048	.0060	.0120
3 sec.	.0018	.0036	.0054	.0072	.0090	.0180
4 sec.	.0024	.0048	.0072	.0096	.0120	.0240
5 sec.	.0030	.0060	.0090	.0120	.0150	.0300
10 sec.	.0060	.0120	.0180	.0240	.0300	.0600
15 sec.	.0090	.0180	.0270	.0360	.0450	.0900
20 sec.	.0120	.0240	.0360	.0480	.0600	.1200
25 sec.	.0150	.0300	.0450	.0600	.0750	.1500
30 sec.	.0180	.0360	.0540	.0720	.0900	.1800
60 sec.	.0360	.0720	.1080	.1440	.1800	.3600

Angles to linear measurement

angle	per inch	per 10 inches	per foot
1 sec.	.000005	.000048	.000058
5 sec.	.000024	.000242	.000291
10 sec.	.000048	.000485	.000582
20 sec.	.000097	.000970	.001163
30 sec.	.000145	.001454	.001745
1 min.	.000291	.002909	.003491

Linear measurement to angles

linear	per inch	per 10 inches	per foot
.000001″	0.206 sec.	0.021 sec.	0.017 sec.
.000025″	5.157 sec.	0.516 sec.	0.430 sec.
.00005″	10.3 sec.	1.03 sec.	0.86 sec.
.0001″	20.6 sec.	2.06 sec.	1.71 sec.
.001″	3 min. 26. sec.	20.6 sec.	17.2 sec.
.005″	17 min. 11. sec.	1 min. 43. sec.	1 min. 26. sec.

2. The Jig Transit and Its Accessories

Jig Transits. There are four types of Jig Transits. All four will accept all appropriate accessories.

Name	Catalog Number	Identifying Characteristics
Jig Transit	71 1002	Simplest, cannot sight vertically downward.
Jig Transit	71 1010	Standard, can perform all operations.
Jig Transit Square	71 1020	Has hollow elevation axle for aligning other instruments on same sight line.
Jig Transit Telescope Square	71 1025	Has 90° telescope in elevation axle for one-man operation.

Since most of the operations with these instruments are identical, the No. 71 1010 is used as an example. For the others, the exceptions only will be described. The complete line of accessories is listed in Catalog 9.

2-1. Jig Transit 71 1010. Fig. 2-1 shows Jig Transit 71 1010 with all essential accessories. The legend gives the names of the parts. Fig. 2-2 is a schematic view to show how it operates.

The Shifting Center. See Fig. 2-2. The shifting center is used with certain accessories of the optical tooling bars. These require the instrument to be screwed onto a screw base and at the same time plugged into a gauge hole in the base. When two adjacent leveling screws are loosened, the alidade can be shifted horizontally a short distance in any desired direction so that the plug can be fitted into the hole.

2-2. Operation. To use the instrument, the base is first screwed onto an instrument stand. The thread is the United States Standard for surveying instruments: 3½″ x 8 threads per inch. The stands usually employed are the following:

1. Portable Instrument Stand, Fig. 2-3
2. Instrument Stands, Fig. 2-4
3. Optical Tooling Bars, Fig. 2-5

2-3. To Level the Instrument. This is accomplished with the four leveling screws according to the plate levels. The procedure is as follows. See Fig. 2-2.

1. Free all leveling screws slightly. This frees the leveling head. Turn the leveling head so that a pair of opposite leveling screws is approximately in line with the sight line to be established.
2. Slightly loosen the leveling screw toward which the circular level bubble stands. Slightly tighten the opposite screw toward which the bubble should move. Allow the first screw to retain a slight pressure. Usually both pairs of opposite leveling screws must be used.
3. When the circular level bubble is centered, turn the alidade until the long plate level is in line with a pair of opposite leveling screws. Center level bubble by using the leveling screws as before.

   Turn the alidade until the long plate level is approximately in line with the other pair of leveling screws and center the bubble.

   Repeat until the bubble centers in both positions. When leveling is finished, the leveling screws should be firm but not tight. Tightening them binds the leveling head and deforms the azimuth bearing.
4. If the instrument is moved slightly by shifting the carriage on which the base is screwed, the leveling must be checked and corrected if necessary. See also Sect. 1-14, Chapter 1.

2-4. The Geometry of a Jig Transit. Leveling places the azimuth axis in the direction of gravity. The elevation axis is perpendicular to the azimuth axis and is thus made horizontal. The line of sight is perpendicular to the elevation axis and thus will sweep a vertical plane when the telescope is swung on its elevation axis.

The telescope axle mirror is perpendicular to the elevation axis so that when auto-collimated with a reference sight line, the plane swept by the line of sight is perpendicular to the reference line. See Sect. 1-7.

2-5. To Aim at a Target. See Fig. 2-1. Free the azimuth clamp (9) and the elevation clamp (11), and direct the telescope at a white or light colored object. Look through the telescope and rotate the eyepiece focusing ring (14) until the reticle pattern is sharp. It is well to note the setting of the diopter scale for future use. It is found in front of the eyepiece focusing ring. The setting may be different for different observers and sometimes for different instruments, but it is the same for sights of different lengths. Set the optical micrometer at zero. Direct the telescope by sighting over it so that it points toward the target. Correct this aim so that the target can be seen through the telescope. It may be necessary to change the telescope focus to recognize the target. When the target appears, focus precisely, set the two clamps firmly, and aim the line of sight precisely with the tangent screws.

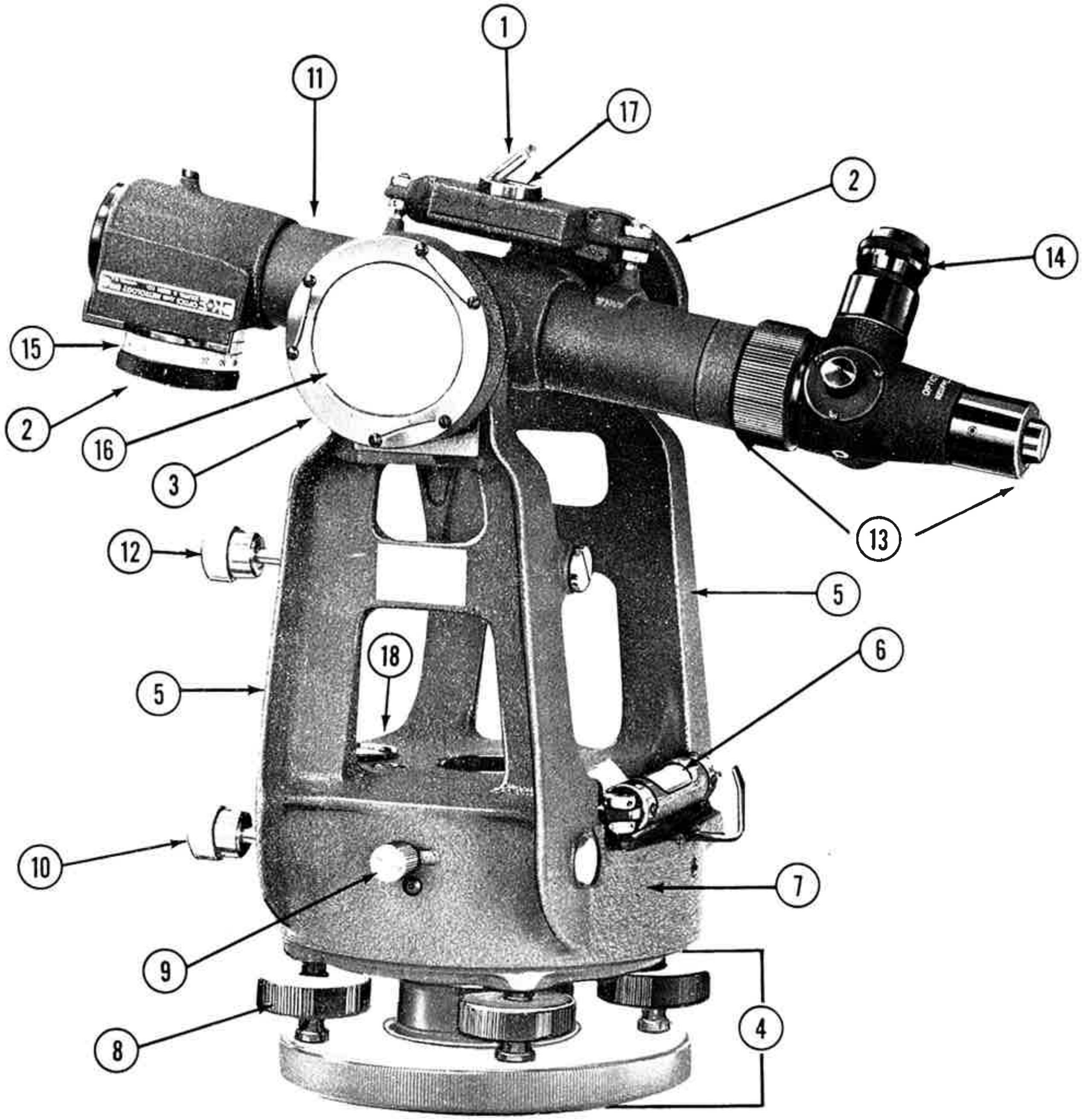


Figure 2-1. Jig Transit 71 1010 with accessories. It is possible to observe vertically downward through a hole in the base and the hollow azimuth axle.

Nomenclature

1, 1	Azimuth axis				
2, 2	Elevation axis	7	Base (part of standards)	13	Auto-collimation eyepiece
3	Focusing Knob (under telescope)	8	One of four leveling screws	14	Eyepiece focusing ring
		9	Azimuth clamp	15	Micrometer scale
4	Leveling head*	10	Azimuth two-speed tangent screw	16	Telescope axle mirror
5, 5	Standards (alidade)	11	Elevation clamp behind mirror	17	Telescope level (coincidence type)
6	Plate level (long)	12	Elevation two-speed tangent screw	18	Circular plate level

*Entire instrument above the leveling head is the alidade. The alidade also includes a vertical axle through the leveling head.

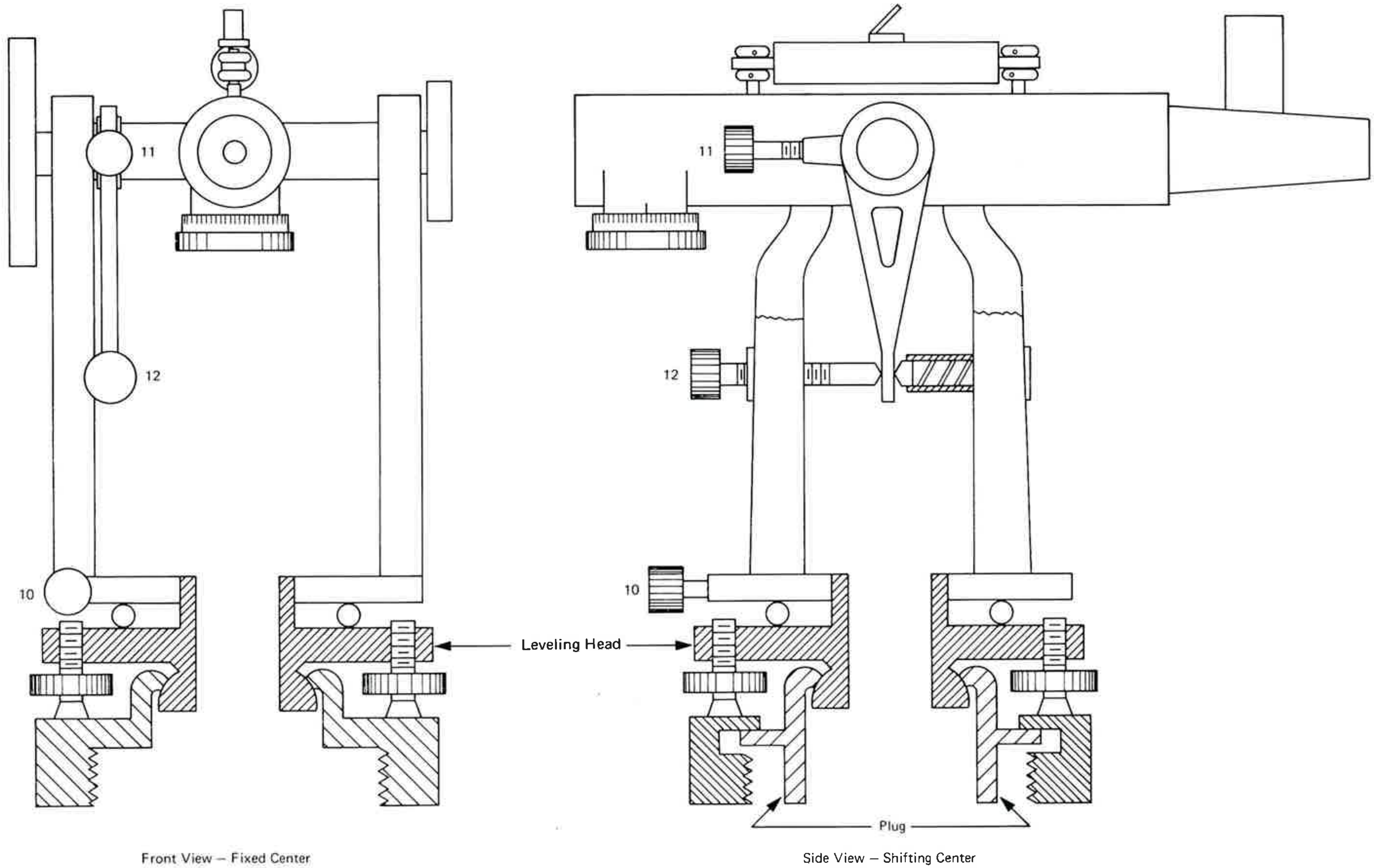


Figure 2-2. Jig transit, schematic views. (10) Azimuth tangent screw. (11) Elevation clamp. (12) Elevation tangent screw.

Figure 2-3. Portable Instrument Stand 71 5030.

The tangent screws move the line of sight very slowly. In addition, they are two-speed screws (except on Jig Transit 71 1002). With two-speed screws, turn until the cross line passes the target. When the direction of turning is reversed, low speed will operate in both directions for a short distance.

Never try the tightness of the clamps after aiming, as tightening changes the aim slightly.

2-6. To Use the Optical Micrometer. Set the micrometer at zero. Aim the line of sight at the reference target.

To measure a distance from the reference line. Position an optical tooling scale horizontally with its zero end against the object whose distance from the reference line is required. Note where the line of sight strikes the scale. Turn the micrometer knob so that the line of sight is moved until it coincides with the smaller value of the two 0.100 inch marks. See Fig. 1-14, Chapter 1. Record the inches and tenths to this mark and add the number of thousandths of an inch read from the micrometer scale. Units of 0.0001 inch can be read from the vernier.

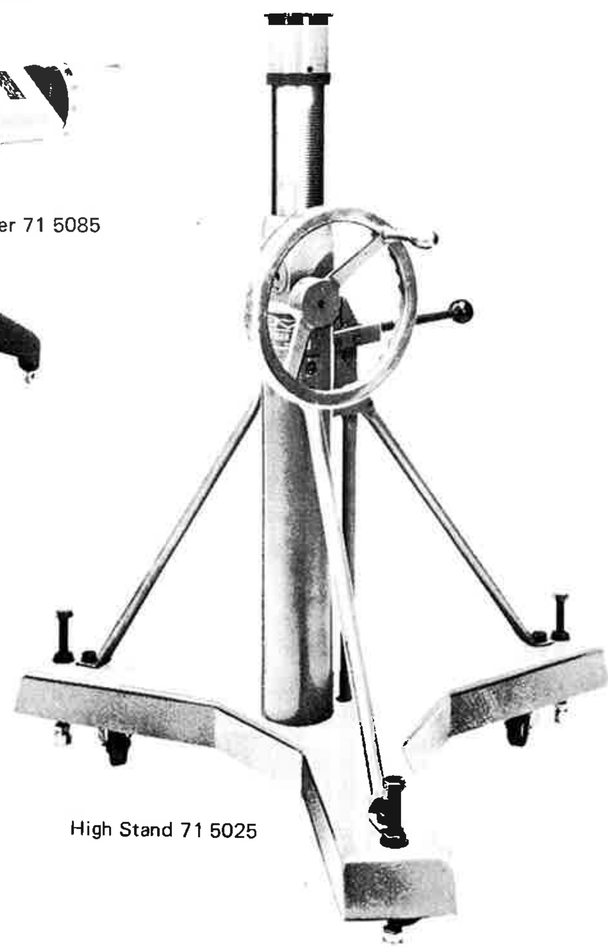
2-7. To Use the Telescope Level. After the instrument has been leveled, center the telescope bubble with the elevation clamp and tangent screw. The line of sight will be level.

Lateral Adjuster 71 5080

Precision Lateral Adjuster 71 5085

Low Stand 71 5015

Trivet 71 5070



High Stand 71 5025

Figure 2-4. Instrument Stands.

Horizontal Bar System using Jig Transit

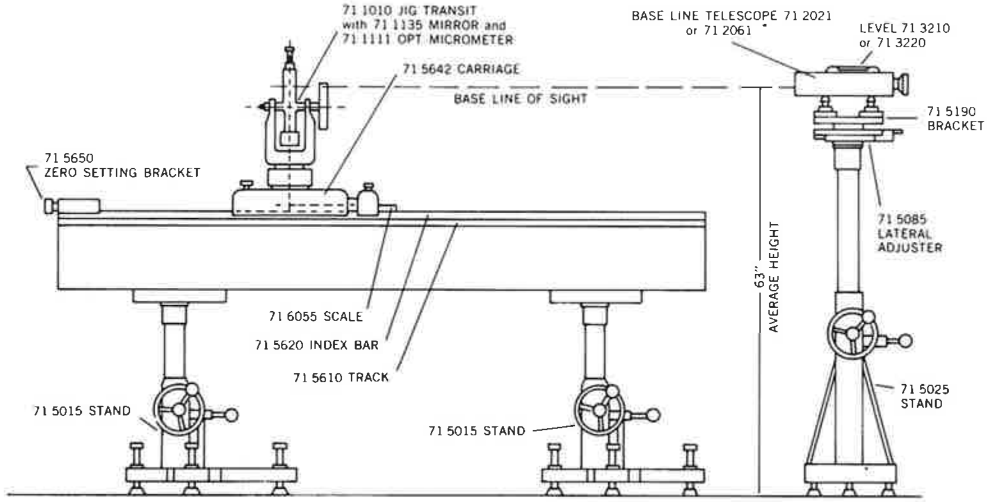


Figure 2-5a. Horizontal optical tooling bar in use. The instrument is mounted on a movable carriage.

Vertical Bar System

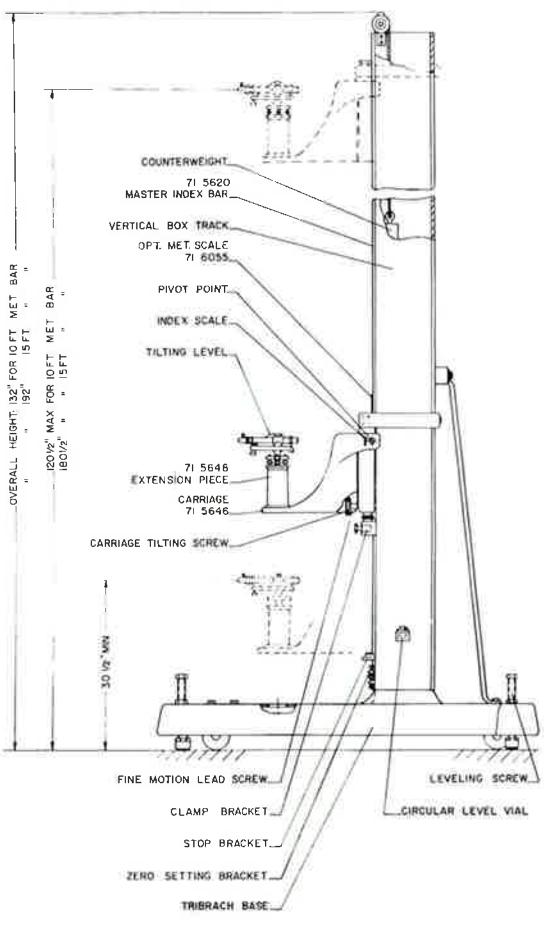


Figure 2-5b. Vertical optical tooling bar in use. The instrument is mounted on a movable carriage.

To Determine the Difference in Height Between Two Objects. Usually there is a rounded surface, or a marked point on a horizontal plane surface, on the work which is used as a reference height.

Mount the optical micrometer for vertical measurement. See Sect. 1-10.

Set up the jig transit so that the horizontal distances are about the same from the instrument to the reference mark and from the instrument to the part whose height is to be established.

If the line of sight has a slight slope when the telescope is leveled, the error that this might cause is eliminated by making the horizontal distances equal. See Fig. 2-6.

Place an optical tooling scale vertically on the reference mark. Direct the telescope toward it. Just before taking the sight, center the telescope level bubble using the elevation clamp and tangent screw. Read the scale using the micrometer as shown in Fig. 1-14, Chapter 1. Check the bubble immediately after taking the reading.

Compute the desired scale reading on the part. Set the micrometer for the desired reading. Direct the telescope toward the part. Center the bubble. Adjust the part so that when the optical tooling scale is held on it, the correct mark is on the line of sight.

Check by taking a reading as described above for the sight on the reference mark.

Set the micrometer at zero, then turn the micrometer drum to move the line of sight toward the tenth division on the scale that shows the smaller reading.

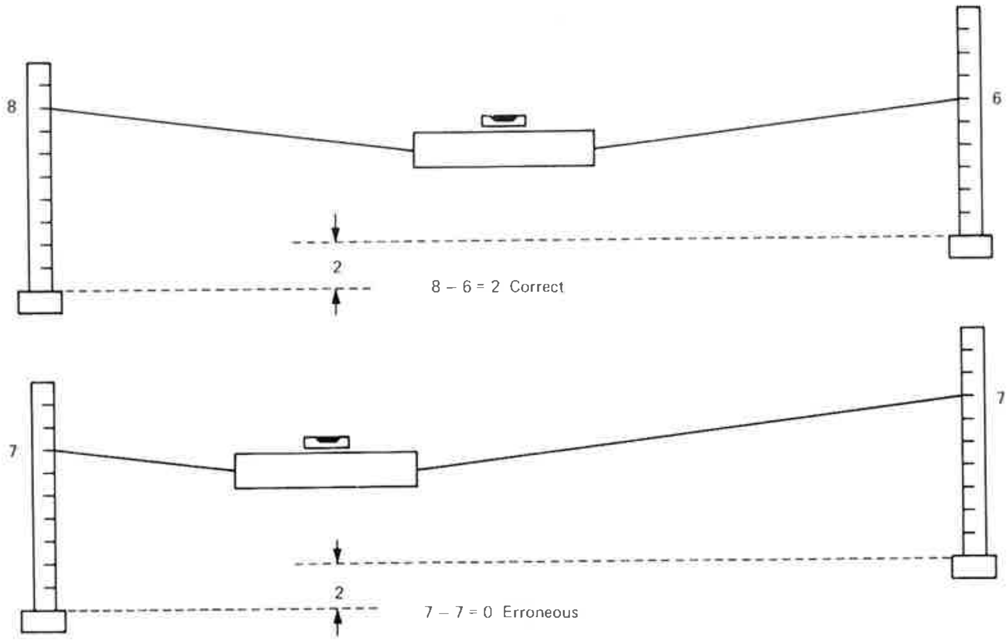


Figure 2-6. Any slight slope in the line of sight, when instrument is leveled, is canceled out when the two horizontal distances are made equal.

2-8. To Install an Auto-Collimation Eyepiece. Unscrew the complete eyepiece system and screw on the auto-collimation eyepiece (71 1241). Fig. 2-1 shows the auto-collimation eyepiece installed.

To install conversion unit (71 1211), remove plate (2 screws) from eyepiece end of telescope and insert auto-collimation conversion unit. This converts telescope to an auto-collimating scope.

2-9. To Aim a Jig Transit with a Telescope-Axle Mirror at 90° to a Reference Line. Figs. 1-6, 1-7, 1-8, Chapter 1.

Set up the jig transit so that the elevation axis is nearly on the reference line, with the mirror toward the reference instrument. Focus the reference instrument on your reflection in the mirror. Hold your hand where the cross lines appear to fall.

Have the assistant change the azimuth of the jig transit. As the cross lines appear to move, follow them with your hand. The assistant should turn the jig transit until he sees your hand come to the telescope of your instrument. Now focus on the auto-reflection target, Fig. 2-7, or use auto-collimation. To use auto-collimation, back light reticle. See Sect. 1-5.

Have the assistant turn the jig transit slowly, with the azimuth tangent screw, until the reflected vertical cross line (or your target) coincides with your actual vertical cross line.

To move the reflected cross lines to the right, turn the jig transit to the right.

2-10. To Aim a Jig Transit with Cross-Axis Telescope at 90° to a Reference Line. Jig Transit Telescope Square 71 1025 has a hollow telescope axle (the elevation axle) in which an objective lens and a reticle are mounted near each end. In each case the reticle is at the principal focus of the lens at the opposite end. See Fig. 2-8. A removable eyepiece can be attached to either end. Thus the axle in effect contains two telescopes aimed in opposite directions, each focused at infinity and hence capable of being aimed at a collimator.

The lines of sight through the axle are parallel to the elevation axis so that when either is aimed at a collimator, or any instrument focused at infinity which establishes the reference direction, the line of sight of the main telescope will sweep a plane at right angles to the reference direction.

This instrument has the great advantage that the observer at the instrument can set it himself without being forced to depend on signals from an assistant.

2-11. To Cause the Lines of Sight of Two Instruments to Coincide. This is not as simple as it appears. When both instruments are set at infinity focus and aimed at each other so that the reticles appear to coincide, the lines of sight are parallel, but they are not necessarily coincident. See Fig. 2-9a. When both are focused at some point between them, the reticle of each instrument can be seen on the reticle of the other. When aimed so that the reticles coincide, the lines of sight meet at a point but usually at an angle to each other. See Fig. 2-9b. It follows that the instruments must be aimed so that the reticles appear to coincide when focused at infinity and also when focused at a point between them. The reticle of each must be illuminated. Proceed as follows:

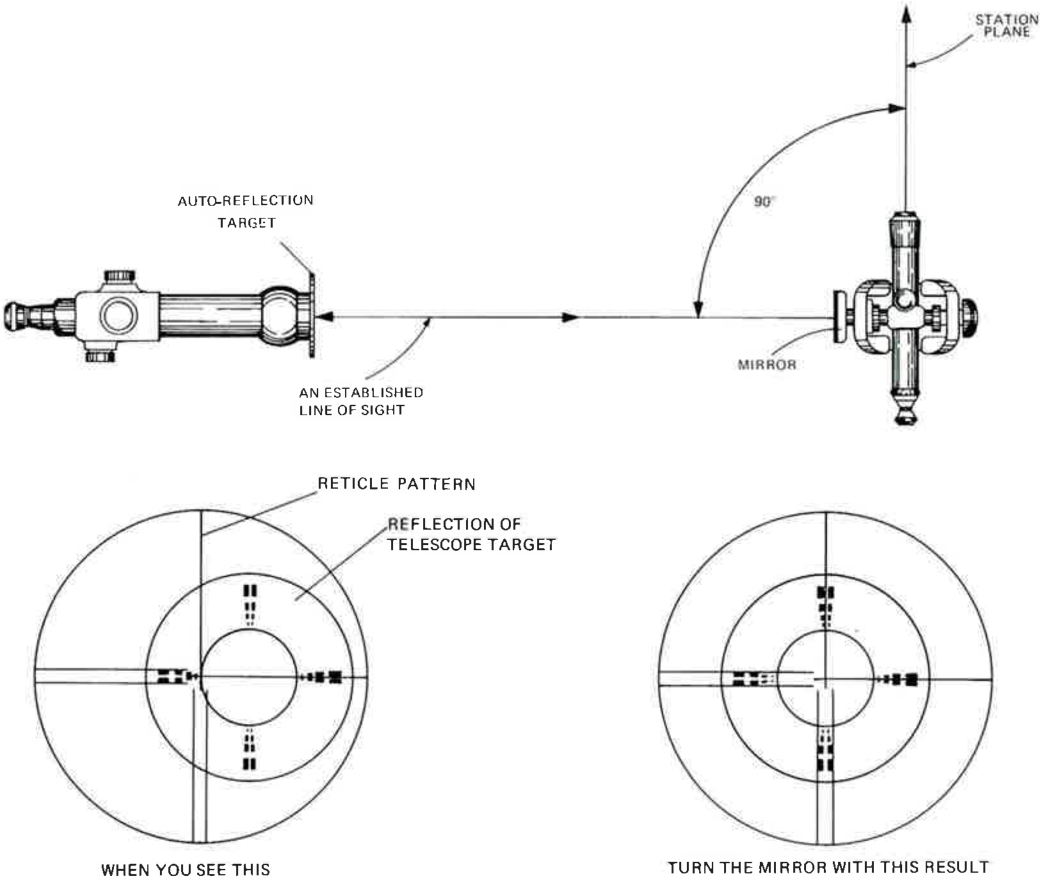


Figure 2-7. Auto-reflection.

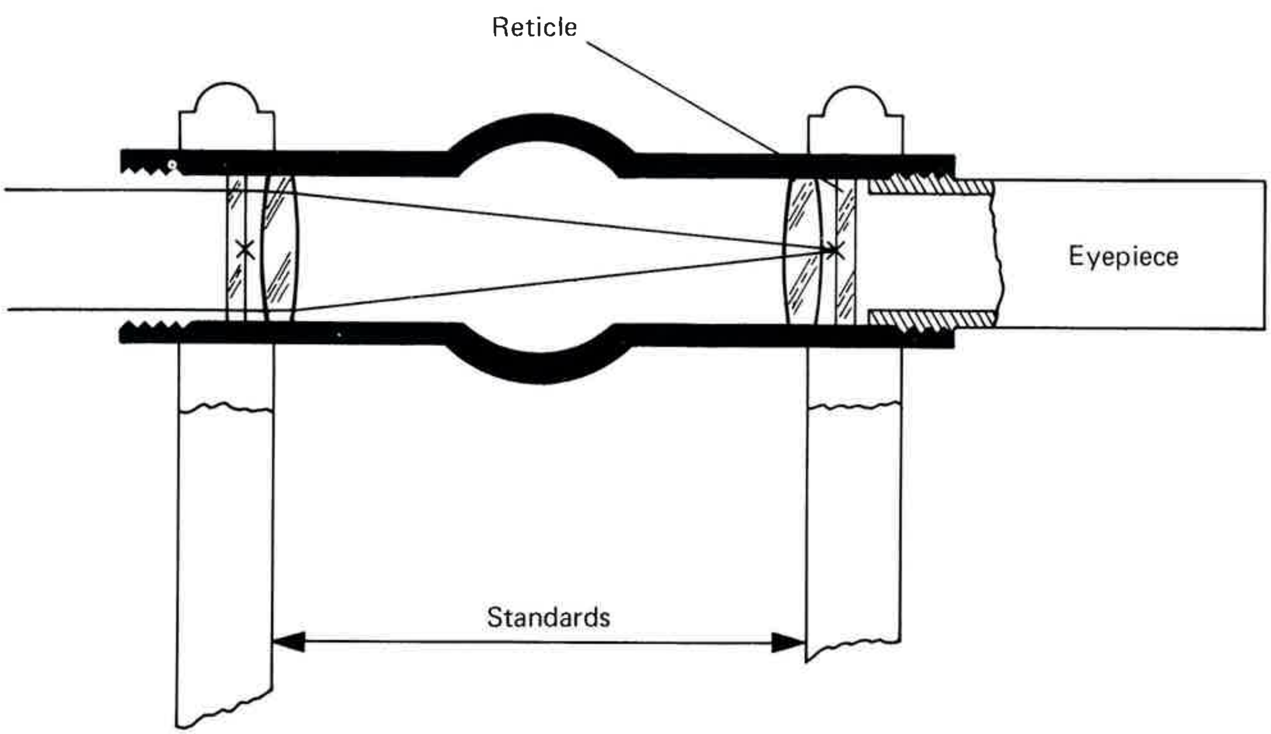


Figure 2-8. Schematic view of the two telescopes in the elevation axis. The eyepiece can be mounted on either end.

1. Simultaneously aim each instrument at the center of the objective lens of the other.
2. Mount a white card, with marks on each side for focusing, about half-way between the two instruments, and focus both instruments on the card without changing the aim of either.
3. Remove the card, look through the instruments and, if the cross lines do not coincide, take up half the error with each.
4. Now focus both instruments at infinity. If the reticle patterns do not coincide, take up half of the error with each instrument.
5. Continue alternately with the card and then with infinity focus until the reticles coincide under both conditions.

2-12. To "Buck-In". It is frequently necessary to place a jig transit in line with two targets or to satisfy any two conditions simultaneously. Such a process is called, to "buck-in". Usually a mechanical lateral adjuster is mounted (Fig. 2-4) on an instrument stand and the instrument mounted on the lateral adjuster. Lock the adjuster so that its ways are approximately perpendicular to the final direction of the line of sight. Level the jig transit. Aim at the far target. Take up any error on the near target with the adjuster. Repeat until the instrument is nearly in line. See Fig. 2-10.

The instrument mount on the Lateral Adjuster (71 5080) slides on ways. When approximately in position, the right-hand clamp in the illustration is set and the mount is moved with the large screw knob. When in final position the left-hand clamp is tightened.

The Precision Lateral Adjuster (71 5085) can be clamped in the approximate position and then positioned accurately with a micrometer screw that reads in units of 0.001 inch.

Relevel and perfect the alignment with the optical micrometer and the azimuth tangent screw.

2-13. To Sight Downward through the Base. This procedure is followed when the metrological bars are used. See Chapter 5.

2-14. Adjustments.

Object 1. To make the plate level bubble center when the azimuth axis is vertical (in the direction of gravity). This affects no other adjustment.

Test 1. Center the bubble over a pair of opposite leveling screws. Turn 180° in azimuth. The bubble should center.

Adjustment 1. Bring the bubble halfway toward the center with the leveling screws. Then center it with the capstan nuts at one end of the level tube.

Repeat test.

Object 2. To make the circular level bubble center when the azimuth axis is vertical. This affects no other adjustment.

Test 2. Level the instrument with the plate level over each pair of opposite leveling screws. The bubble should center.

Adjustment 2. Center the bubble with the three screws. The vial mount rocks on a central support. First, loosen one screw and tighten another. The bubble will move parallel to the pair used and toward the screw loosened.

Repeat test.

Object 3. To rotate the reticle until the vertical cross line lies in a plane perpendicular to the elevation axis. This destroys Adjustments 4, 6, and 7 which follow.

Test 3. Aim at a target. Swing the line of sight up and down with the tangent screw. The vertical cross line should remain on the target.

Adjustment 3.

1. Expose the reticle-adjusting screws by unscrewing the protective cover just in front of the eyepiece.
2. Partly loosen two adjacent screws. See Sect. 1-13, Chapter 1.
3. Gently tap the same screws until the vertical cross line is rotated to its correct position.
4. Tighten the same screws with equal tension and without strain.

Repeat test.

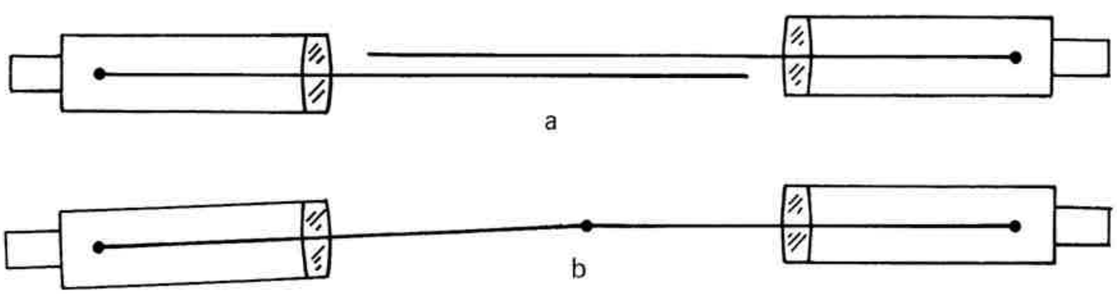


Figure 2-9. a. Collimated. b. Aimed at an intermediate point. In both cases the reticles appear to coincide. In neither case are the lines of sight coincident.

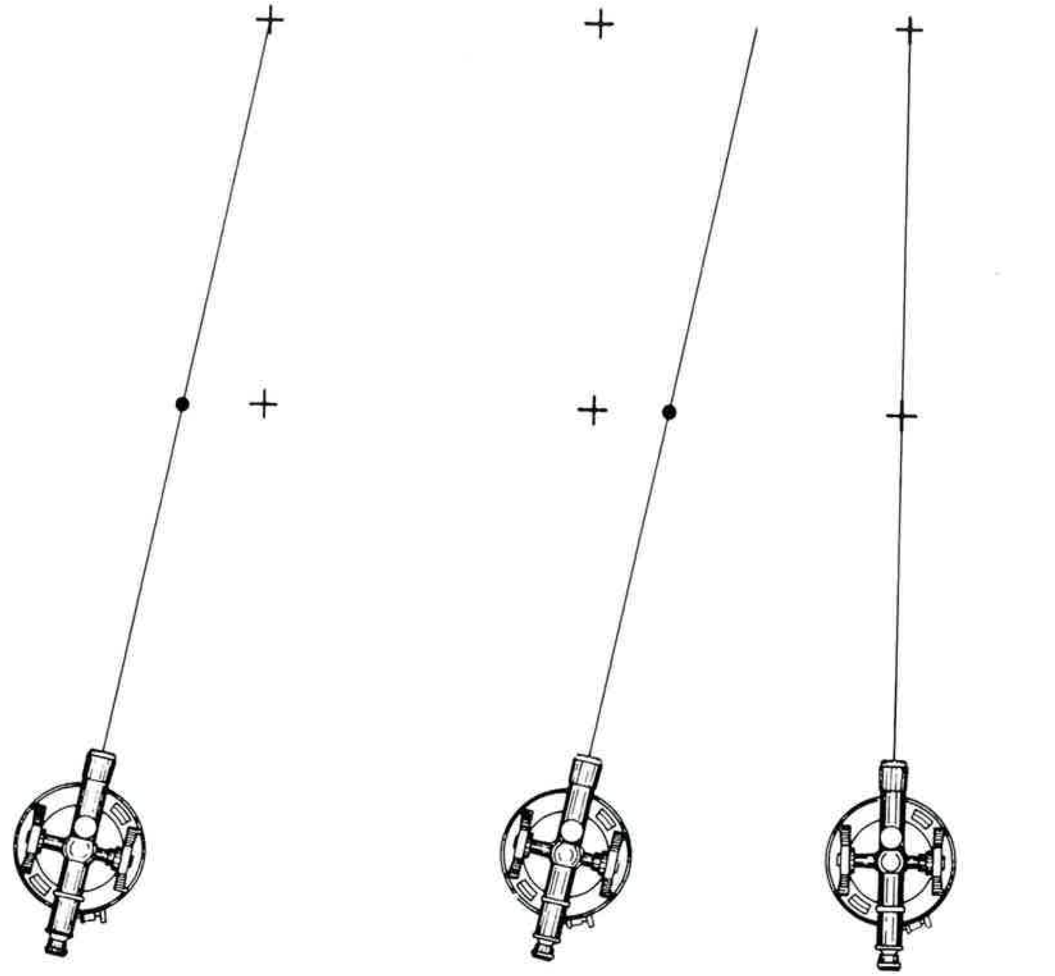


Figure 2-10. Bucking-in. (This operation is easier with an optical micrometer. The micrometer measures the exact error and reduces the time required to buck-in).

Object 4. To make the line of sight pass through the elevation axis. This will affect Adjustment 3 if tension is lost. It will destroy Adjustments 6, 7, and 9 which follow.

The adjustment is required only if the following accessories are used:

1. A reversion (reversible) telescope level.
2. An auto-reflection target mirror that has a target which indicates the center of the elevation axis.

Test 4. Aim at a distant target. Focus on and read a vertical scale placed as near the instrument as possible. Reverse the telescope and aim at the distant target. Focus on the near scale. The reading should be the same as before.

Adjustment 4. Adjust the reticle up or down to *increase* the apparent separation between the cross line and the correct scale reading 3 or 4 times. See Sect. 1-13.

Repeat test.

Object 5. To make the elevation axis perpendicular to the azimuth axis. This may slightly affect Adjustment 7 which follows.

Test 5. Aim at a high target (elevation angle about 45°), then aim down at a horizontal scale (angle of depression about 45°) and read the scale. Reverse telescope and repeat. The scale reading should be the same.

Adjustment 5. For Jig Transits 71 1002 and 71 1010. On the side of the standard which carries the elevation tangent screw, unscrew the telescope axle mirror, the weight, or the cap on the end of the axle. Remove the cover plate. This exposes two capstan nuts below the axle. The top screw, above the axle, controls the friction in the axle bearing.

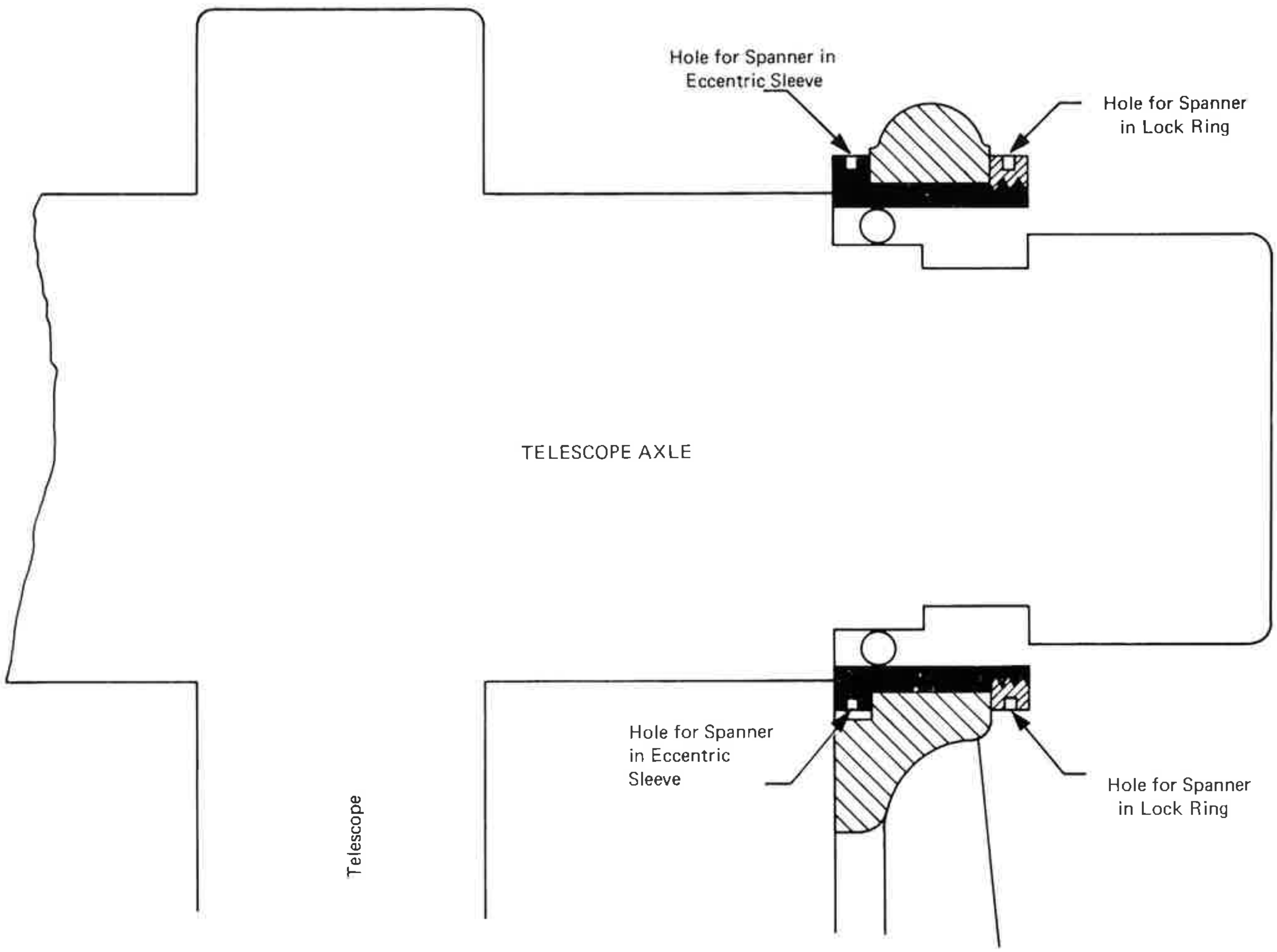


Figure 2-11. Schematic illustration of telescope axle adjustment (adjustment 5) for Transit Square 71 1025.

Adjust by loosening one capstan nut and tightening the other until a quarter of the error is eliminated.

For 71 1020 and 71 1025 see Fig. 2-11. Free lock ring. Rotate eccentric sleeve until a quarter of the error is eliminated. (Use spanner provided.) Tighten lock ring.

Repeat test.

Object 6. To make the line of sight perpendicular to the elevation axis. This may affect Adjustment 4.

Test 6. Aim at a distant target at nearly the elevation of the instrument. Reverse telescope and read a distant scale in the opposite direction. Keeping telescope reversed, aim back at distant target. Erect telescope and read the same distant scale. The readings should be the same.

Adjustment 6. Adjust the reticle to eliminate a quarter of the error. See Sect. 1-13.

Repeat test.

Alternate Method 6a. Aim two collimators at each other and place the Jig Transit in the position used to align them. See Sect. 1-4.

Test 6a. Aim at one collimator, reverse the telescope and observe the other. The vertical cross lines should coincide.

Adjustment 6a. Adjust the reticle to eliminate half of the error. See Sect. 1-13.

Object 7a. To make the line of sight pass through the azimuth axis. This may slightly affect Adjustments 5 and 6.

Test 7a. Aim at a distant target. Focus on and read a horizontal scale placed as near the instrument as possible. Reverse the telescope and aim at the distant target. Focus on near scale. The reading should be the same as before.

Adjustment 7a. See Fig. 2-12. Remove the two plug screws under the two standards. Screw in two special adjusting tools (see Fig. 2-12) until they stop. Loosen slightly the three socket-head screws on the plate. Turn the special adjusting tools and slide the standards until half of the error is eliminated. Tighten the three socket-head screws on the plate.

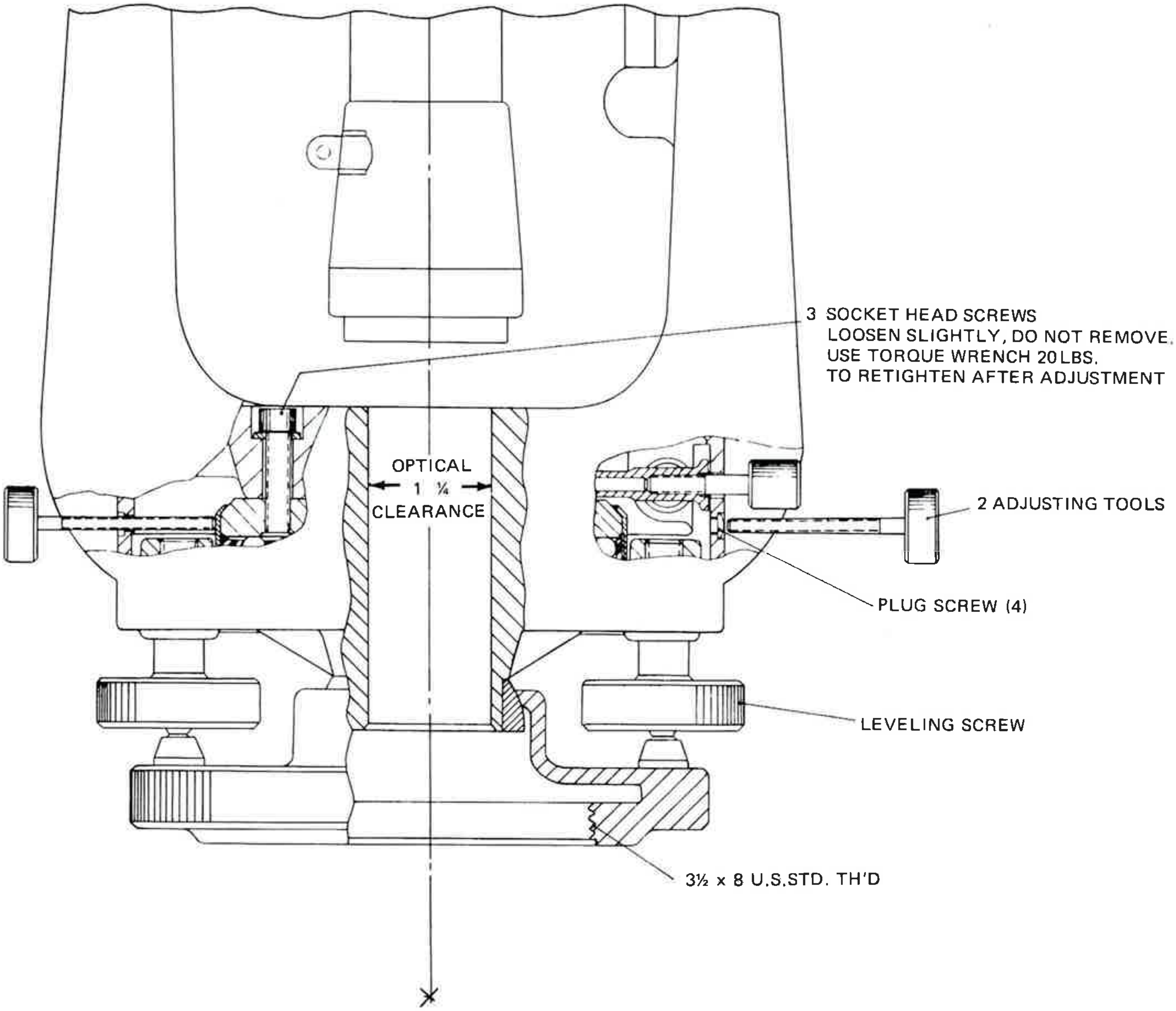


Figure 2-12. How the line of sight and the elevation axis are made to intersect the azimuth axis.

Repeat test. Remove adjusting tools and replace the plug screws.

Object 7b. To make the elevation axis intersect the azimuth axis. (Not applicable to Jig Transit 71 1002.) Adjustment 7a must be correct before starting Adjustment 7b.

Test 7b. There are several methods of accomplishing this test depending on the equipment available. It requires a near and a distant target (preferably at infinity by collimation) placed above or below the transit. The best method is described. This method requires an auto-collimation eyepiece and mirror target 71 6250.

Mount the transit on a K&E instrument stand or trivet. See Figs. 2-3 and 2-4. Under the transit place the mirror target located and leveled only accurately enough to perform the test described below. To auto-collimate on the mirror, use the leveling screws as well as the elevation motion to aim the telescope and bring the image into coincidence. Rotate the transit 180° in azimuth. If not in coincidence, repeat adjustment 5 and/or 6. Focus on the mirror target, set the micrometer at zero, and aim at the mirror target using the leveling screws as well as the elevation motion. Rotate the transit 180° in azimuth. If there is an error, measure the distance with the micrometer.

Adjustment 7b. Set the micrometer at the average of the two readings. Remove the four plug screws located as shown in Fig. 2-12. Screw in the special adjusting tools until they stop. Loosen slightly the three socket-head screws on the plate.

By turning the special tools, slide the standards until the cross lines are on the target center. Tighten the three socket-head screws on the plate.

Repeat test. Remove the adjusting tools and replace the plug screws.

Object 8. To make the reflecting surface of the telescope axle mirror perpendicular to the elevation axis. This affects no other adjustment.

Test 8. Set up an auxiliary transit in the position shown in Fig. 2-13. Aim it at the reflection in the mirror of a precise point on the scale. Reverse the jig transit telescope on its elevation axis. The reflection of the point should remain on the cross lines of the auxiliary transit.

Adjustment 8a. For Jig Transits 71 1002 and 71 1010.

On the face side of the mirror (rectangular or round) there are three spring clips. Behind the center of each clip is a support that holds the mirror against the pressure of the spring clip. Two of the supports are capstan-headed screws whose heads are behind the mirror mount. One of the supports is a fixed hidden rounded point.

Turn the telescope on its elevation axis so that one of the screws ("A" in Fig. 2-14) is level with the hidden point (P) as in Fig. 2-14(1). Aim the vertical cross line of the auxiliary telescope at a certain line on the scale. Reverse the jig transit telescope so that Fig. 2-14(2). results. Adjust screw "A" until half the error on the scale is eliminated.

Turn as in Fig. 2-14(3). Aim the vertical cross line of the auxiliary telescope at a certain line on the scale. Reverse the jig transit telescope so that Fig. 2-14(4) results. Adjust screw "B" until half the error on the scale is eliminated.

Repeat test.

Adjustment 8b. For Jig Transit Square 71 1020, see Fig. 2-15.

Adjust the four screws marked "A" to take up half the error. The reflection of the point will move toward the screw tightened. Loosen one screw and tighten the diametrically opposite screw by small equal amounts. Do not lose pressure.

Repeat test.

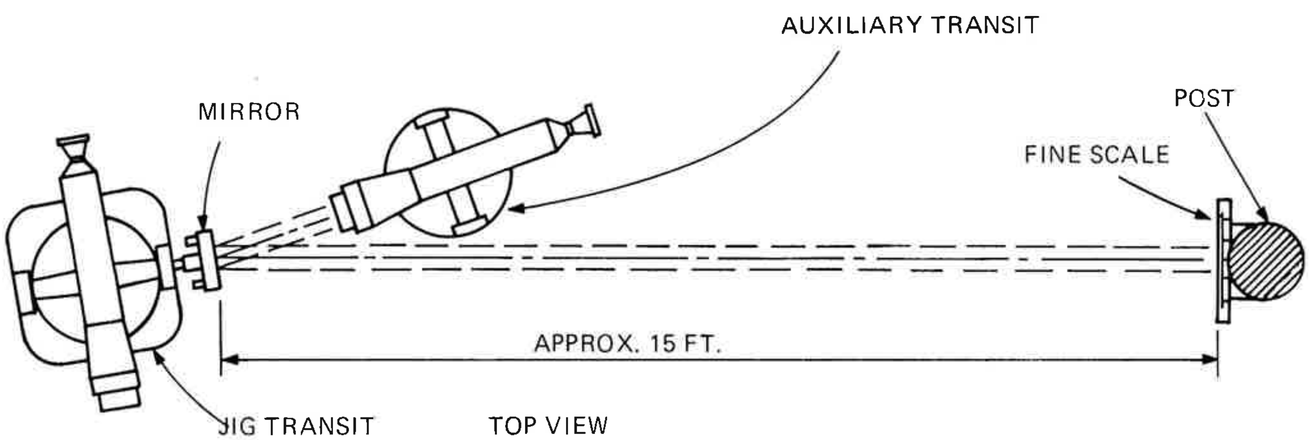
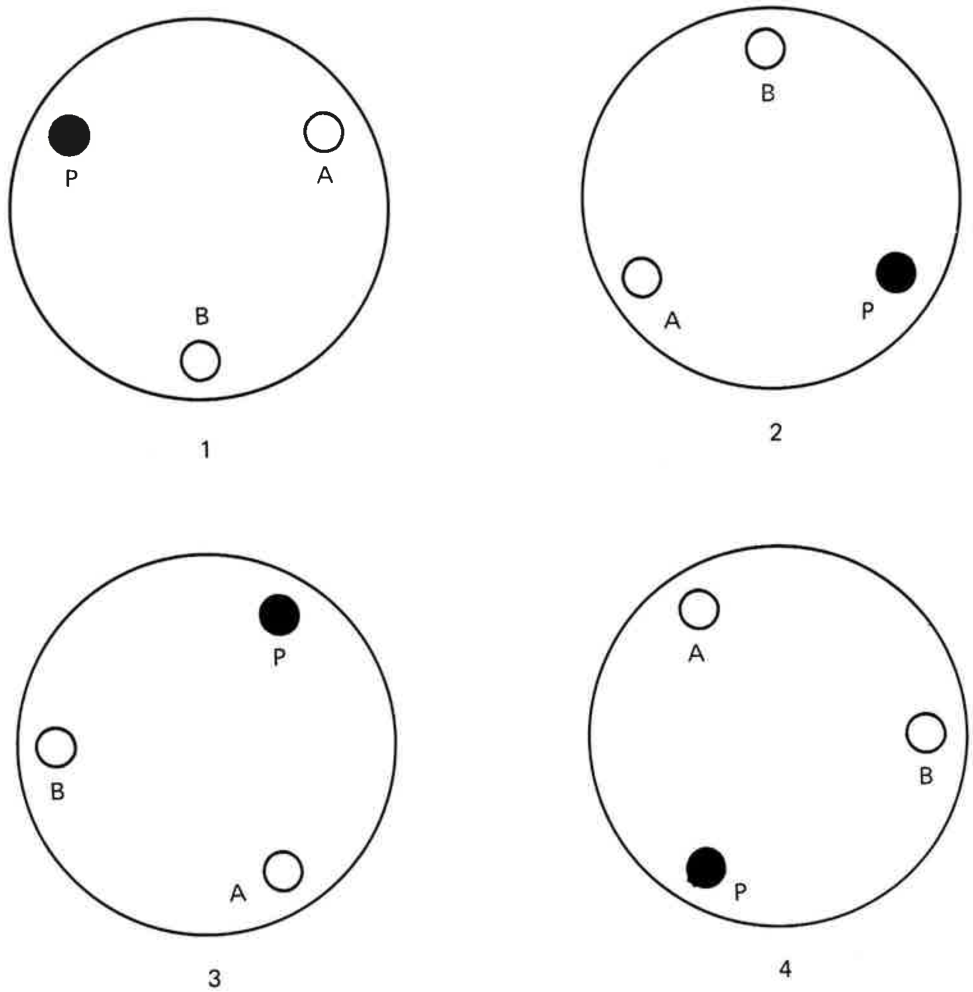


Figure 2-13. Jig transit and auxiliary transit arranged for telescope-mirror adjustment.



Position 1. B at bottom. Aim auxiliary telescope.
2. B at top. Adjust screw A.
3. B at left. Aim auxiliary telescope.
4. B at right. Adjust screw B.

Figure 2-14. Positions of the telescopic mirror used in its adjustment. This is looking at the face of the mirror. It is necessary to look down behind the mirror to see screws A and B. Support point P is not visible.

Object 9. To adjust the reticles of the cross-axis telescope so that their lines of sight are parallel to the elevation axes. For Jig Transit Telescope Square No. 71 1025 only.

Test 9. Aim one cross-axis telescope at the infinity reticle of a collimator. Turn the main telescope 180° in elevation. The aim should be undisturbed.

Adjustment 9. See Fig. 2-16. Unscrew cover ring from eyepiece end. Adjust reticle to eliminate half the error. See Sect. 1-13.

Repeat test.

Unscrew eyepiece and screw it on the other end of the telescope axle. Repeat the procedure for this cross-axis telescope.

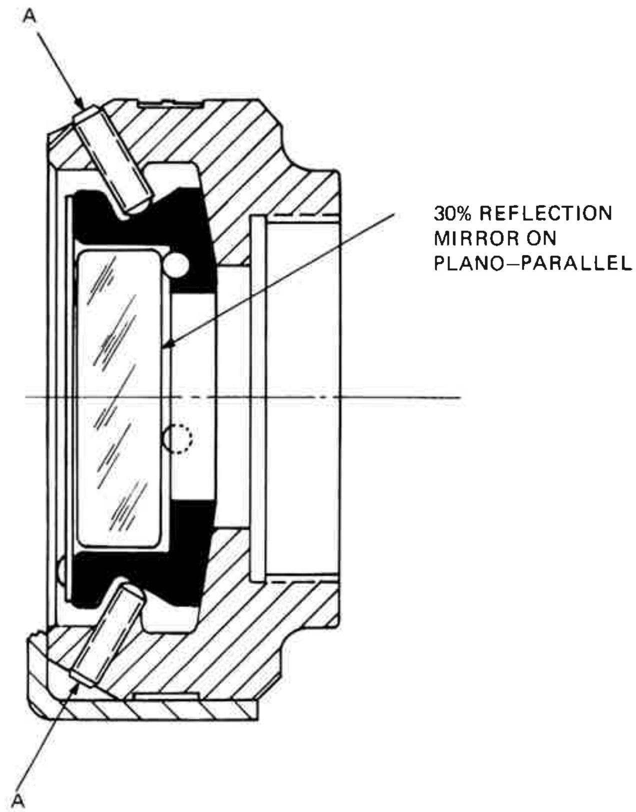


Figure 2-15. Telescope-axle mirror on Jig Transit Square 71 1020. One pair of adjusting screws is shown. The other pair is at right angles to the first pair.

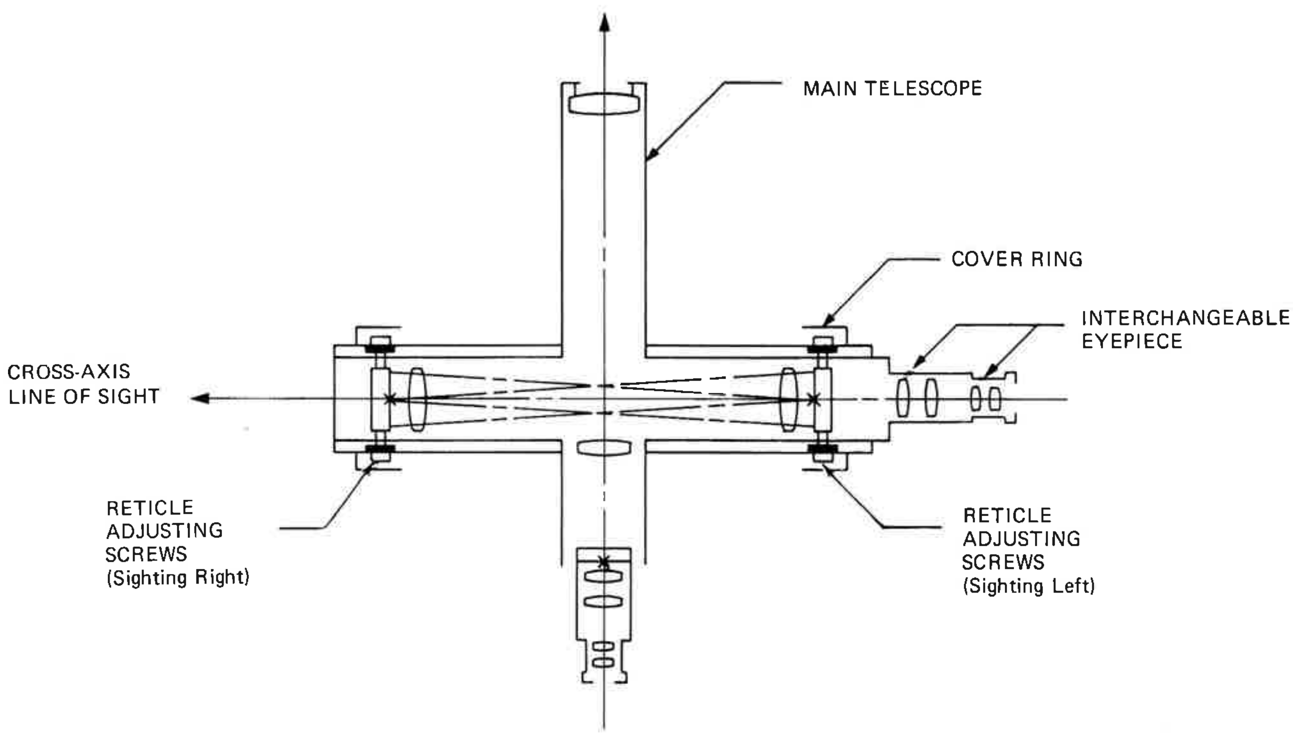


Figure 2-16. Schematic view of cross-axis optical system in Jig Transit Telescope Square 71 1025.

3. The Alignment Telescope and Its Accessories

3-1. Method of Presentation. The basic type of alignment telescope is catalog number 71 2020. (See Fig. 3-1.) The features of the different types are as given below.

Catalog Number	Identifying Characteristics
71 2020	Two-plane micrometer.
71 2021	Two-plane micrometer and an auto-collimation eyepiece.
71 2022	Two-plane micrometer, an auto-collimation eyepiece, and a built-in auto-reflection target.*

In addition, there are three line of sight telescopes, as listed below.

Catalog Number	Identifying Characteristics
71 2060	Telescope without micrometer.
71 2061	Same as 71 2060 but with auto-collimation unit.
71 2062	Same as 71 2060 but with auto-collimation unit and a built-in auto-reflection target.

Accessories are available for all line of sight telescopes which make it possible for them to perform most of the functions of the alignment telescope. They do not have optical micrometers so do not permit displacement of the line of sight parallel to itself.

*A built-in auto-reflection target is a target on the back surface of the objective lens. It is used exactly as an external auto-reflection target, but must have light source.

The operation of 71 2022 only will be described as its functions include all the functions of the other alignment telescopes.

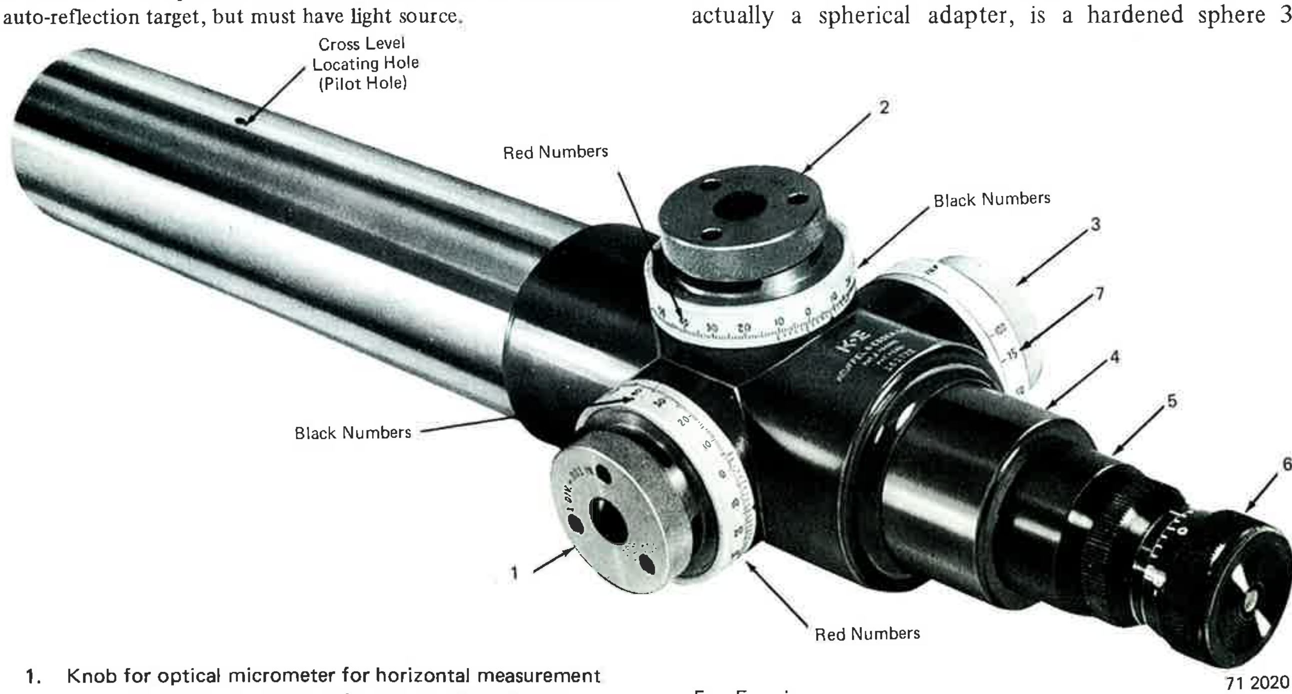
3-2. Basic Principle. An alignment telescope and its reference target are designed to establish a reference line of sight in such a way that, when both devices have been removed, and then replaced, the line of sight will be in exactly the same position as before (Fig. 3-2).

3-3. The Telescope. The telescope barrel consists of a heavy through-hardened, stabilized tool steel tube. The objective end is a cylinder about 9 inches long with a hard chrome surface ground to a standard diameter, 2.2498 (+ zero, – 0.0003) inches, Aircraft Industries Association standard. The rear section contains optical micrometers, the focusing knob and the eyepiece. The line of sight is adjusted so that it coincides with the axis of the cylinder surface.

The telescope is erecting and can be focused from zero to infinity. A cross level, located by a hole provided in the cylinder, is used to show when the reticle pattern is level.

3-4. Methods of Mounting. The telescope is held in many types of mounts. One type holds the telescope vertically. The others, which hold the telescope in a horizontal position, can be divided into two general groups: the sphere and cup type; and the cone-type V-block.

3-5. The Sphere and Cup Type. The sphere, which is actually a spherical adapter, is a hardened sphere 3½



1. Knob for optical micrometer for horizontal measurement
2. Knob for optical micrometer for vertical measurement
3. Focusing knob
4. Cover for reticle
5. Eyepiece
6. Eyepiece focusing knob (diopter control)
7. Distance scale (reads in feet)

Figure 3-1. An Alignment Telescope.

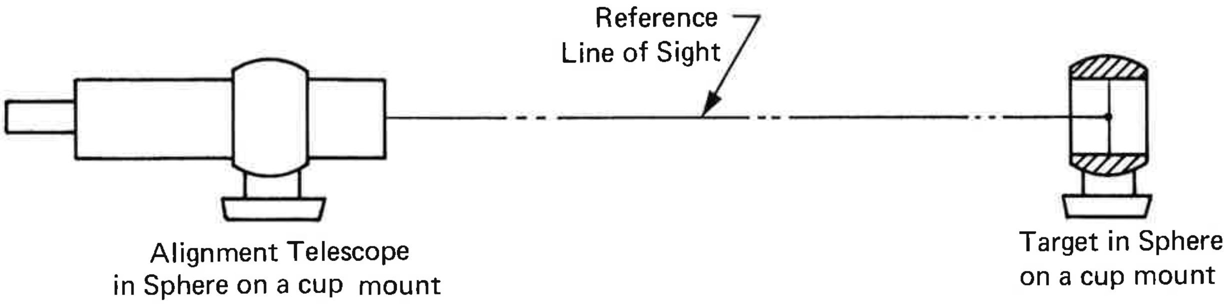


Figure 3-2. A reference line that can be re-established whenever desired. The positions of the cup mounts are fixed.

inches in diameter with a centered hole through which the telescope cylinder makes a slide fit. The sphere (71 5100) has a collet for clamping it at any point along the cylinder. Thus the line of sight passes through the center of the sphere.

The sphere is held by a cage-type clamp (71 5142) to the cup mount (Fig. 3-3). The cup is supported on a large-diameter screw, threaded in the base of the mount, by which the height of the cup can be adjusted. The screw can be locked in position by a screw-tightened collet on the base. The base of the cup mount is locked to the work or to the type of support required. Clamped to the base is a bracket (71 5170) which provides tangent screws for aiming the telescope up and down and left and right by slow motion through a few degrees (Fig. 3-4).

The spherical adapter (71 5100) will take a target stop ring which holds a target in the sphere so that the center of the target pattern is precisely at the center of the sphere.

To establish a reference line of sight, spheres are placed in the mounts and the mounts for both the telescope and the target are positioned by measurements to the spheres. The mounts are then bolted and clamped in position, the telescope with its brackets, and the target, are placed in the adapters and the telescope aimed at the target.

Once this has been accomplished, the telescope target and the spherical adapters can be removed. The reference line can be regained whenever desired by replacing the devices in the mounts and aiming the telescope at the target.

3-6. The Cone-Type V-Block. A cone-type V-block consists of two or four cones on elevating screws (Fig. 3-5). The telescope cylinder rests on the cones. Clamps on the base hold the cones where they are set. The two-screw type can be used with a cup mount instead of a bracket to aim the telescope. The four-screw type gives complete

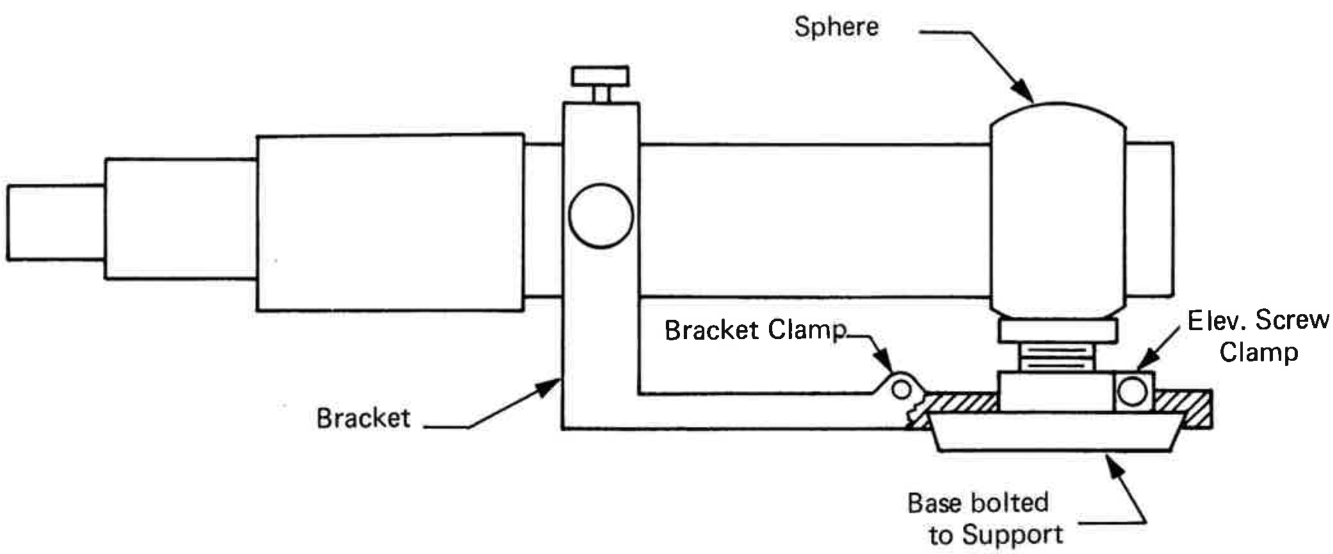


Figure 3-3. A cup mount, spherical adapter, bracket, and a schematic assembly with the telescope in the sphere. The height of the cup is adjustable. A cage clamp, not shown, holds telescope in cup. In the photograph of the bracket Fig. 3-4, the upper left-hand knob is a spring plunger, the upper right-hand knob is a tangent screw which aims the telescope left and right, the lower knob is a tangent screw which aims it up and down.

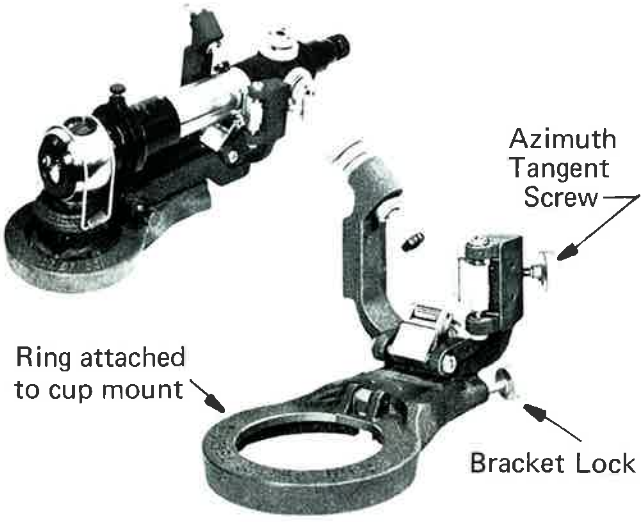


Figure 3-4. Alignment telescope bracket 71 5170.

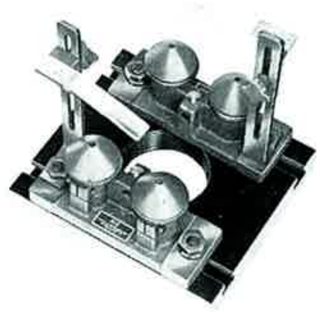


Figure 3-5. A cone-type V-block. This particular one is called the Base Line Telescope Bracket 71 5190. The four cones are separately adjustable in height and can be locked in position. The telescope rests on the cones.

control of the telescope. In Fig. 3-6 assume that screws 1 and 2 are forward. In the table below, the numbers refer to the screws turned. All screws are turned equal amounts for each operation. Note Fig. 3-7.

Operation	Turn Screws Right (Clockwise)	Turn Screws Left (Counter Clockwise)
Raise		1,2,3,4
Lower	1,2,3,4	
Move right	2,4	1,3
Move left	1,3	2,4
Aim up	3,4	1,2
Aim down	1,2	3,4
Aim right	2,3	1,4
Aim left	1,4	2,3

With the four-screw type, measurement is made to the telescope cylinder itself.

The target is placed in a cup mount. The line of sight is positioned as with the cup mount. It is clear that if the devices are removed from the mounts they can be replaced so that the reference line of sight will be in its original position.

3-7. **Other Types of Support.** The many types of telescope support equipment are described in Catalog 9. These may be mounted on the work, on an instrument stand or on a tooling bar.

OPERATION OF ALIGNMENT TELESCOPE

3-8. **To Ready the Alignment Telescope for Use.** To use the instrument after it is mounted, set the micrometers at zero (see Sect. 3-9). Focus the eyepiece by turning knob (6) in Fig. 3-1, at the end of the eyepiece, until the reticle cross lines appear sharp when the telescope is aimed at a well illuminated white surface. It is well to note the resulting setting on the scale (the diopter setting) in front of the knob for future use. This setting is often different for different observers and sometimes for different instruments, but is the same for sights of different lengths.

Place a cross level (71 3205) on the telescope by fitting the stud at the bottom of the cross level into the locating hole in the telescope near the front end (Fig. 3-1) and rotate the telescope so that the bubble is centered. This orients the reticle pattern and the optical micrometer movements with respect to gravity. Focus on the target and aim the telescope at the target with the tangent screws or by regulating the cones, whichever are used.

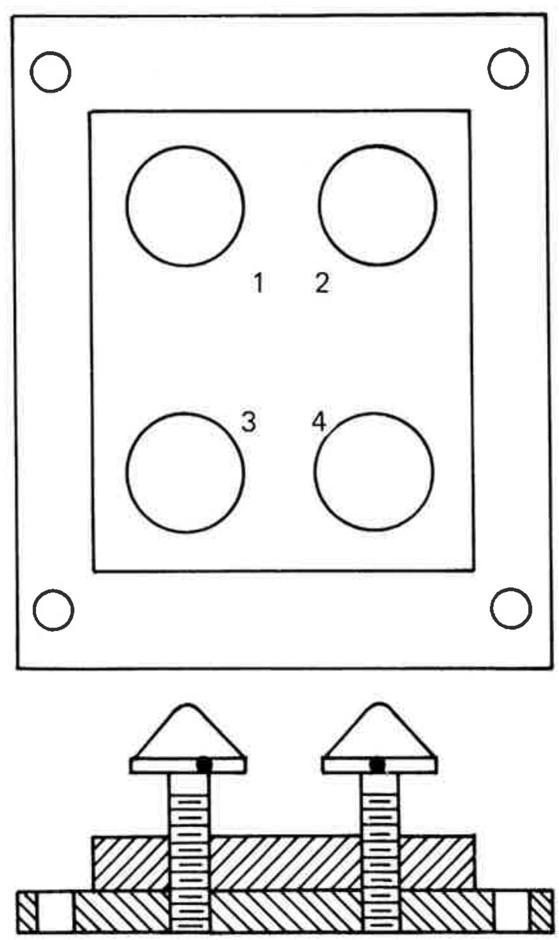


Figure 3-6. Schematic cone-type V-block. When the cylindrical telescope is held on these adjustable cones by springs, its height, position left and right, or its aim can be regulated as desired.

To measure from the line of sight, place the zero end of an optical tooling scale positioned horizontally or vertically on the object whose distance from the reference line is to be measured. Place the scale so that it intercepts the reference line of sight. Focus on the scale and use the micrometers to determine the displacement.

3-9. Control Knobs. Looking from the eyepiece end, there are three control knobs on the telescope. See Fig. 3-1. When they are right, left and on top, the right-hand knob is the focusing knob, the left-hand knob (1) moves the line of sight left and right parallel to itself, and the top knob (2) moves it up and down also parallel to itself.

Marks on a dial beside the focusing knob show the position of the knob when the focus is at infinity or at various finite distances measured in feet.

The extent of movements caused by (1) and (2) are shown by graduated dials and verniers placed next to the knobs. See Fig. 3-8. The dials are graduated in units of one thousandth (0.001) of an inch. The verniers read in units of one ten thousandth (0.0001) of an inch. The dials are numbered in both directions from zero at the center to fifty thousandths (0.050) at the ends. Black numbers are used in one direction and red in the other. When the dials are placed so that they read zero, the line of sight is on the axis of the cylindrical part of the telescope. When the left-hand dial is turned clockwise, the face of the dial nearest the observer moves downward, the black numbers become adjacent to the vernier index, and the line of sight moves to the right. Similarly, when the top dial is turned clockwise, the nearest face of the dial moves left, the black numbers become adjacent to the vernier index and the line of sight moves up. See Fig. 3-8. Thus:

Rule 1: Black = Right or Up.

The dials and verniers are read in the usual way.

Since the scale increases in both directions from zero, there must be verniers that do the same. Always read the vernier whose values increase in the same direction as those of the dial. Another way of saying this is: switch (don't reverse) at the index.

Thus, to read the left-hand dial in the lower part of Fig. 3-8, go up the dial to the index at about 0.014 thousandths and switch (continue upward) on the vernier to coincidence at five ten thousandths. Hence the reading, 0.0145.

3-10. To Read the Dials. Since K&E Wyteface® optical tooling scales are marked only in units of tenths of an inch (0.1) and the dial graduations extend only to half tenths (0.050) it is necessary to measure sometimes backward and sometimes forward from a tenth of an inch mark. This introduces certain considerations.

Two kinds of measurements are made: measurements to objects already in place, and measurements to place an object in a required position. In the first kind, the color of the graduation need not be considered. The procedure is as follows: set the micrometer at zero. Note between what two marks on the optical tooling scale the line of sight falls. Assume it falls between 8.6 and 8.7. Turn the dial until one or the other can be reached. If this is found to be the larger of the two (8.7), subtract the micrometer reading (assume 0.0145) hence, 8.6855. If the smaller (8.6), add the micrometer reading, hence 8.6145. The rule is as follows:

Rule 2: Tenth larger subtract Mike.

When measuring to place an object, it is necessary to choose the correct color. It is just necessary to note which tenth inch is nearest the desired value. For example, if the desired value were 5.3927, the nearest would be 5.4 (tenth larger). If the desired setting were 5.3073, the nearest would be 5.3 (tenth smaller).

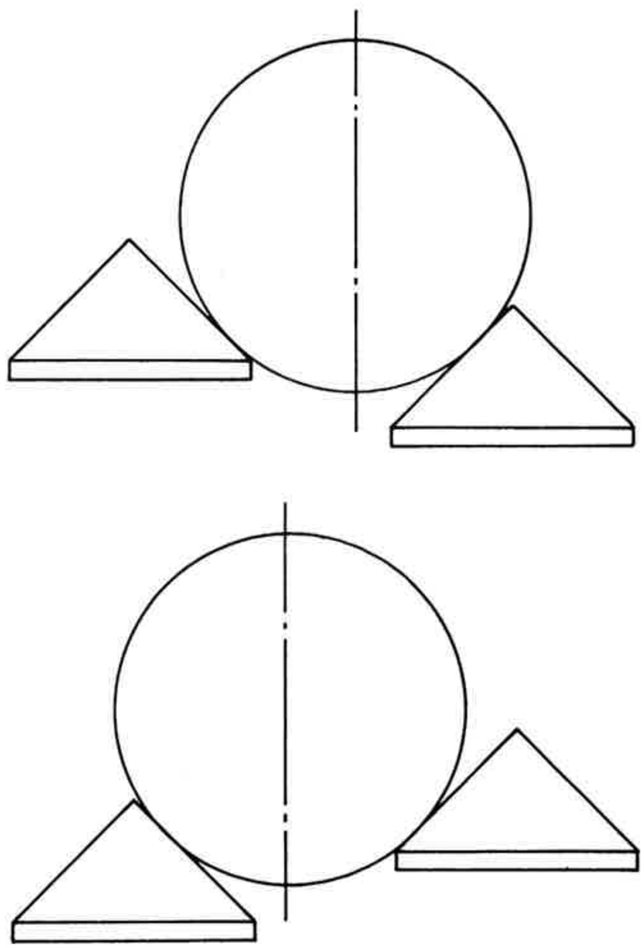
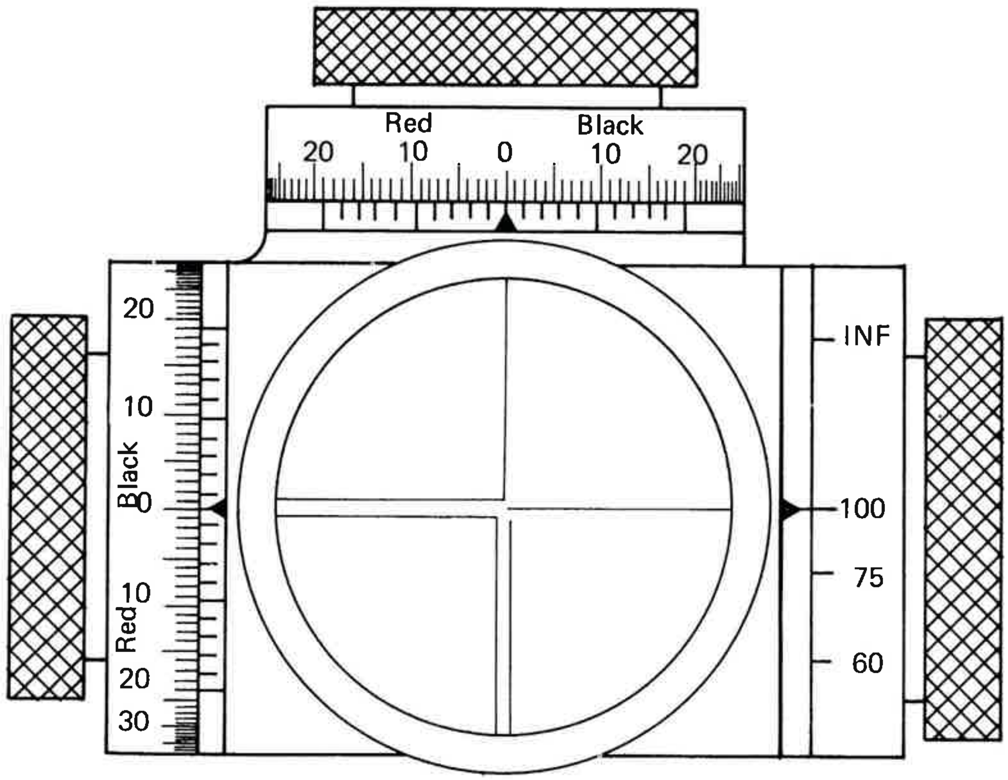
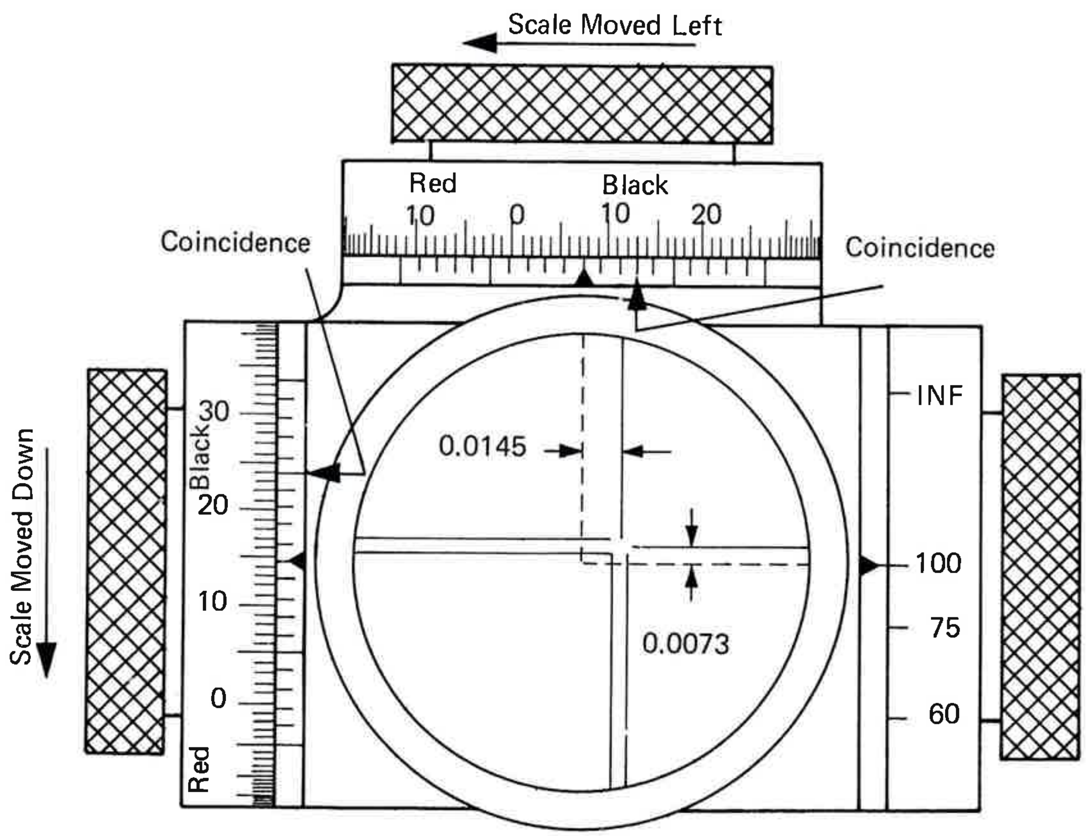


Figure 3-7. To change the aim left or right, two adjacent cones are turned equal amounts in opposite directions.



Set at Zero



Right 0.0145 Up 0.0073

Figure 3-8. The operation of the optical micrometers. Black scale for right or up. Red for left or down.

To find the micrometer setting use Rule 2, hence:

Larger	Smaller
5.4	5.3
- Mike	+ Mike
5.3927	5.3073
Set Mike 0.0073	Set Mike 0.0073

Figure 3-9 shows the four combinations that require black numbers. There are four opposite combinations that require red. Here is the best rule.

Rule 3: Black when L L.

When L = object Left, or tenth Larger.

If one L is changed to Smaller or Right, red must be used. If both L's are changed, black must be used. Hence the eight possibilities can be shown as follows:

For horizontal measurements:

	Object	Tenth
Black	L	L
	R	S
Red	L	S
	R	L

For vertical measurements by Rule 1,

Right = Up

	Object	Tenth
Black	D	L
	U	S
Red	D	S
	U	L

It is well to memorize the three rules:

1. Black = Right or Up.
2. Tenth larger subtract Mike.
3. Use black when LL (left or tenth larger).

3-11. Other Operations. In addition to establishing a reference line, an alignment telescope can be used to:

1. Establish a plane perpendicular to a reference line at a given station.
2. Establish a sloping plane which contains the reference line.
3. Establish a level reference line.
4. Establish a vertical plumb line.

3-12. To Establish a Plane Perpendicular to a Reference Line. A perpendicular plane is established with one of two types of optical squares, known as Optical Square 71 2410 (Figs. 3-10 and 3-11) and Double Sphere Optical Square 71 2412 (Fig. 3-12). Both provide a line of sight that passes straight through them and, by means of a pentaprism, a line of sight which is turned 90° (±1 Sec. arc) from its entering direction. The desired line can be selected by covering the line not wanted by a cap attached to the square.

When mounted on the alignment telescope, the 90° line can be turned in the direction needed by rotating the telescope and thus rotating the square. Only the double sphere optical square can establish the 90° line in every direction. The 90° line of the single sphere type can be established in every direction except where the 90° line is obstructed by the mount and the bracket.

To mount either square on the telescope, remove the locating screw and clean the inside bearing rings of the square. Have an assistant hold the telescope so that the front end extends over the edge of a table or surface plate, carefully slide the square over the end of the telescope, and match the locating hole with the one on the telescope. Insert and tighten the locating screw. Since the square may slightly affect the line of sight, it is well to check Adjustment 2. (See Adjustments.)

Mount the telescope with the square on a bracket. The rear sphere of the double sphere square is placed on the cup mount. Cover the 90° opening with the attached cap. Adjust the bracket so that when the alignment telescope is aimed at the center of the objective of the reference telescope the center of the opening in the square is on the reference line. Set infinity focus on both instruments and aim the cross lines of the alignment telescope at the cross lines of the reference telescope using the bracket tangent screws.

Remove the cap from the 90° opening and place it on the through opening, and aim the 90° line where desired.

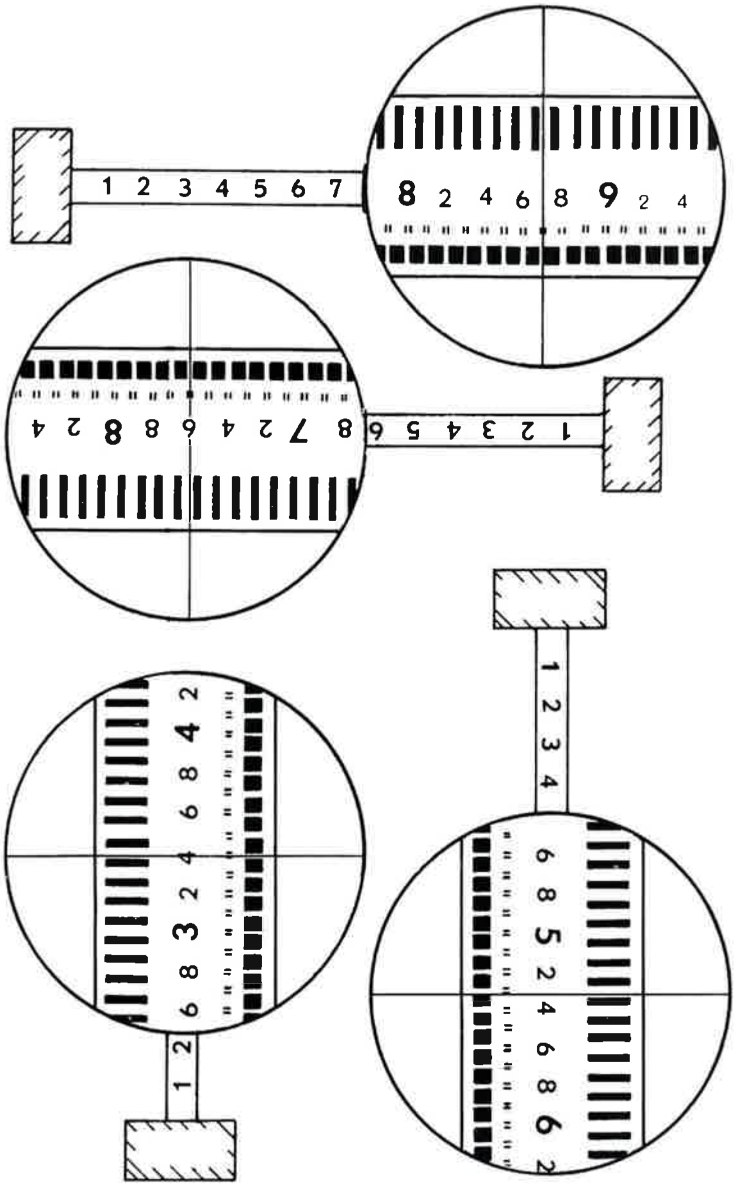
If it is not possible to aim the 90° where desired accurately enough by hand, the optical square must be removed and tangent ring 71 2420 slid over the end of the square. The ring provides a clamp and tangent screw by which the desired direction can be precisely established.

The ring requires bracket 71 5170 (Fig. 3-4) with extension arm 71 5175, or bracket 71 5180. See Catalog 9 for descriptions.

3-13. To Place the Perpendicular Plane at a Given Station. The plane swept by the 90° line can be placed at the station desired by aiming the 90° line at a scale or steel measuring tape properly indexed to the work. This procedure is best accomplished with a metrological bar.

3-14. To Establish a Sloping Plane that Contains the Reference Line. See Fig. 3-13. There is only one optical tooling device available that will establish a line of sight which will sweep a plane that both slopes and contains the reference line. It is the Planing Prism (71 2430) when attached to an alignment telescope. See Fig. 3-14.

The prism assembly slides on the objective end of the telescope and is secured with a thumb screw. A target is placed on the desired sloping plane and line of sight is aimed at the target. Rotating the telescope raises or lowers the line of sight and turning the prism swings it backward and forward. See Figs. 3-15 and 3-16. The knurled ring



Object	Left
Desired Setting	8.6855
Nearest .100	8.7 (Larger)
Color	L + L = Black
Set Mike	0.0145

Object	Right
Desired Setting	7.6145
Nearest .100	7.6 (Smaller)
Color	R + S = Black
Set Mike	0.0145

Object	Down = L
Desired Setting	3.3927
Nearest .100	3.4 (Larger)
Color	L + L = Black
Set Mike	0.0073

Object	Up = R
Desired Setting	5.3073
Nearest .100	5.3 (Smaller)
Color	R + S = Black
Set Mike	0.0073

Figure 3-9. The four conditions when the black scale is used. Use red for the other four possible conditions. Micrometer setting shown in Figure 3-8. In every case the object is placed so that the "nearest tenth" is on cross line.

Figure 3-10. An optical square. It contains a pentaprism. Mounted on an alignment telescope, it will establish a plane perpendicular to the line of sight of the alignment telescope. The illustration at right shows a ring with a clamp and tangent screw (the index level) to control the slope of the right-angle line of sight.

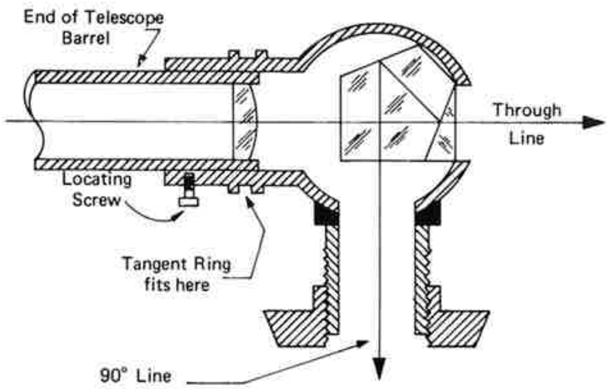


Figure 3-11. Schematic view of the optical square. Not shown is the cap that can be placed over either of the two openings in the sphere so that the line of sight passes straight through or is turned 90°, as required. The whole telescope with the square can be rotated around the telescope axis so that the line of sight sweeps a plane. It is shown pointing downward.

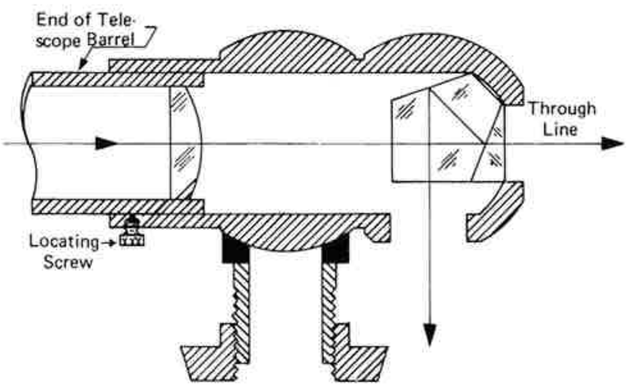


Figure 3-12. Schematic view of the double-sphere optical square. The 90° line can be turned in any direction without being obstructed by the mount.

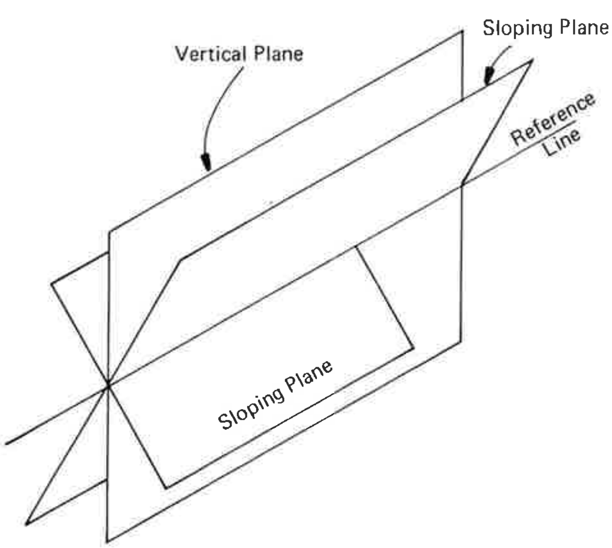


Figure 3-13. Planes at different slopes that contain the reference line.

Figure 3-14. The planing prism. When the prism is rotated, the line of sight sweeps a plane. By rotating the telescope, the slope of the plane can be changed.

near the top of the device is used to turn the prism. Reflections in the double mirror at the top aid in aiming at the target. Thereafter aim with the cross lines.

3-15. To Establish a Vertical Plumb Line. The alignment telescope can be mounted in a Plumb Aligner Bracket 71 5160. This holds the telescope so that the line of sight is vertical, pointed either up or down. See Fig. 3-17.

3-16. To Mount the Plumb Aligner and Telescope. The plumb aligner is shown schematically in Fig. 3-18. To mount the telescope for a downward sight, slide the collar of the level on as far as possible but not touching the enlarged part of the telescope. The coincidence level should be turned parallel to one of the telescope cross lines. It is locked in place with three socket-head set screws around the circumference of its lower end. The azimuth collar, which holds the azimuth tangent screws and clamp, and the handles, is slid on close to the levels collar but free of contact with it. The three socket-head set screws around its lower end are tightened.

The base plate, with the attached leveling plate and telescope collar, is bolted in place on a stand with a large enough hole to admit the telescope collar, i.e., 4 inches in diameter. There are three holes around the circumference of the base plate, each of which extends through a small foot plate for bolting.

The telescope with its two attachments is lowered into the telescope collar until the bottom of the azimuth collar rests on three bosses at the top of the telescope collar. The two large slot-headed friction plugs shown in the side of the sleeve are now tightened. The screws should only be tightened enough to assure proper three-point contact; tightening too much may result in deforming the telescope barrel or prevent the operation of the tangent motion. The tangent movement is accomplished by means of two opposing screws, hence no spring and plunger is used.

3-17. To Level and Position the Telescope. Center the circular bubble with the leveling screws. The bubble will move in the direction of any screw turned clockwise.

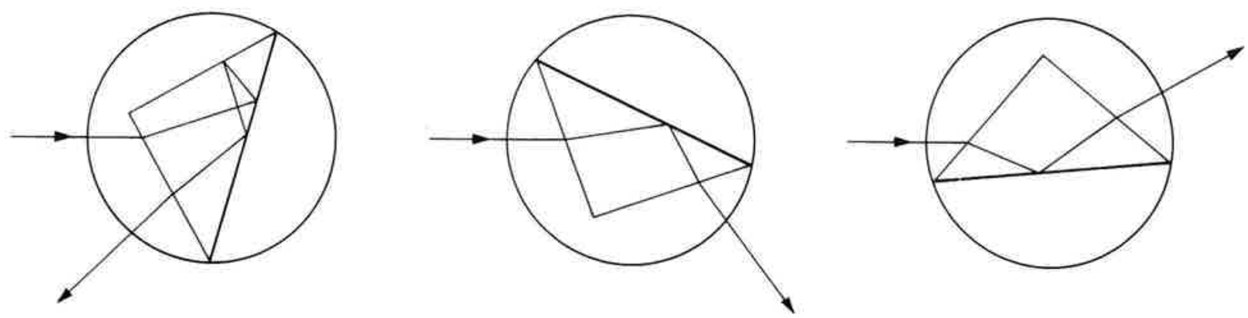


Figure 3-15. Diagram showing how the planing prism can cause the line of sight to sweep in every direction except where the body of the device interferes. The hypotenuse is silvered.

Focus on the point over which the plumb line is to be established. Use the four locating screws to bring the cross lines on the point. Use them in pairs. They are in tension. While loosening one, tighten the one opposite. The cross lines will move toward the one tightened. Leave them firm. It may be necessary to loosen one or both of the other pair before the telescope will move.

With the handles, turn the telescope so that the coincidence level is in line with any two of the leveling screws. See Fig. 3-19, Position 1. Turn screws "A" and "B" simultaneously in opposite directions until the ends of the bubble coincide. Turn the telescope 90°, i.e., to Position 2. Obtain coincidence by turning screw "C". Reposition the cross lines with leveling screws "A" and "B". Check the coincidence level. Repeat if necessary.

3-18. To Mount the Telescope for an Upward Sight. (See Fig. 18 for nomenclature). Mount the base on the stand. Slide the telescope upward through the telescope collar as far as possible without allowing the enlarged part of the telescope to come in contact with the bottom of the collar. Support it in that position. Place the azimuth collar in position on the telescope. Remove the socket-head plug screw located in the azimuth collar. See Fig. 3-18A. Rotate the azimuth clamp until the hole is in line with the hole in the azimuth collar, then tighten the azimuth lock screw. Now rotate the combination until aligned with the locating hole in the telescope barrel. Screw in the pin screw. The pin screw is to be found in an envelope or bag with other accessories. It must be removed when the telescope is to be mounted pointing down.

Replace the socket-head screw on top of pin screw.

Remove the supports from the telescope. Tighten the three set screws in the azimuth collar. Install the level housing as before.

To sight through the telescope, it may be necessary to install a right angle eyepiece (71 2230).

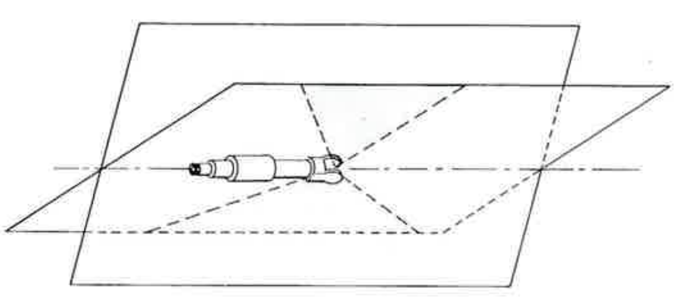


Figure 3-16. A planing prism sweeping a sloping plane.

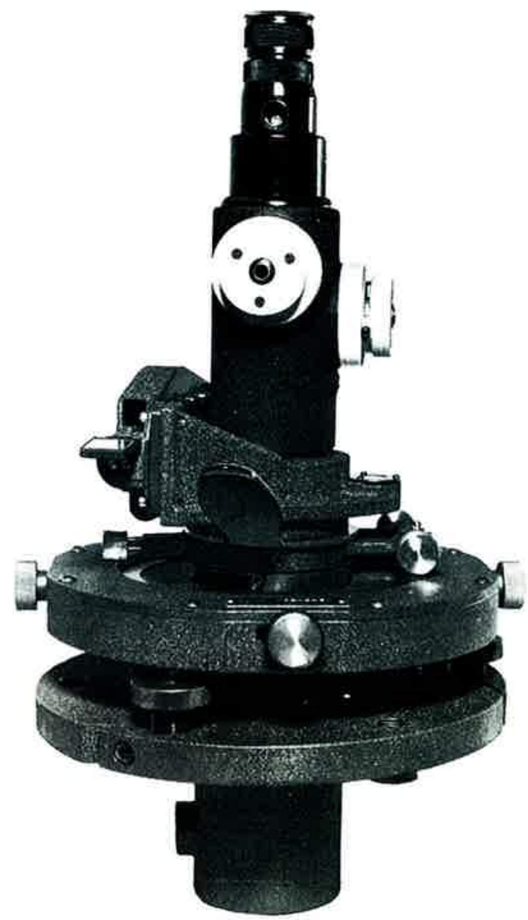


Figure 3-17. A Plumb Aligner Bracket 71 5160 with an alignment telescope mounted for downward sighting.

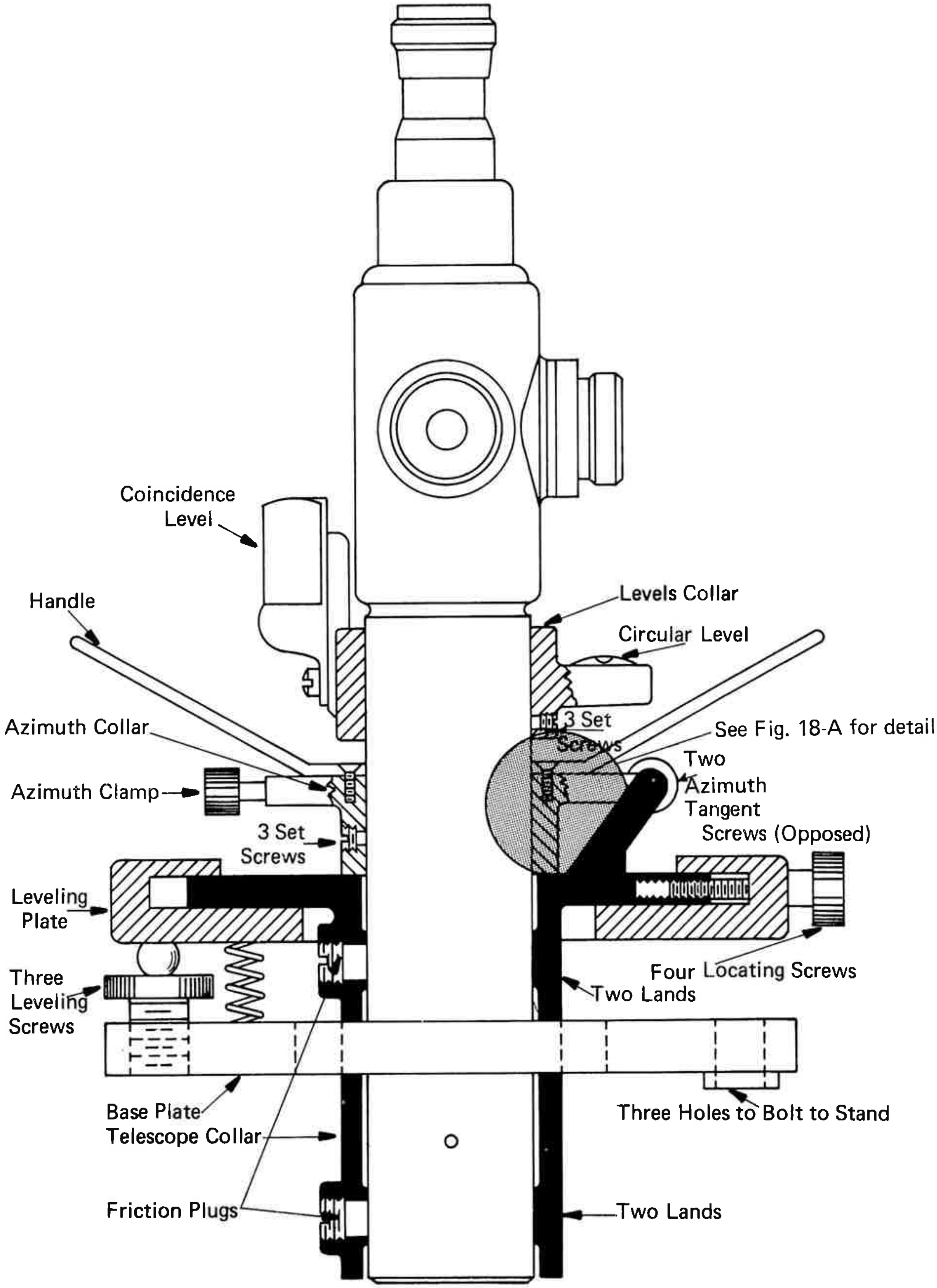


Figure 3-18. Schematic view of Plumb Aligner Bracket 71 5160 with alignment telescope in place. The spring at each leveling screw is in tension.

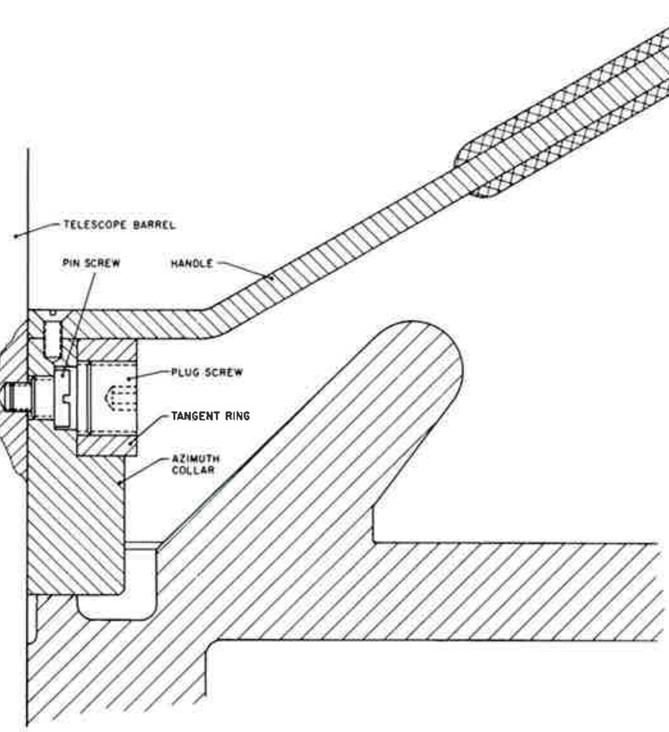


Fig. 3-18A. Detail Plumb Aligner Bracket.

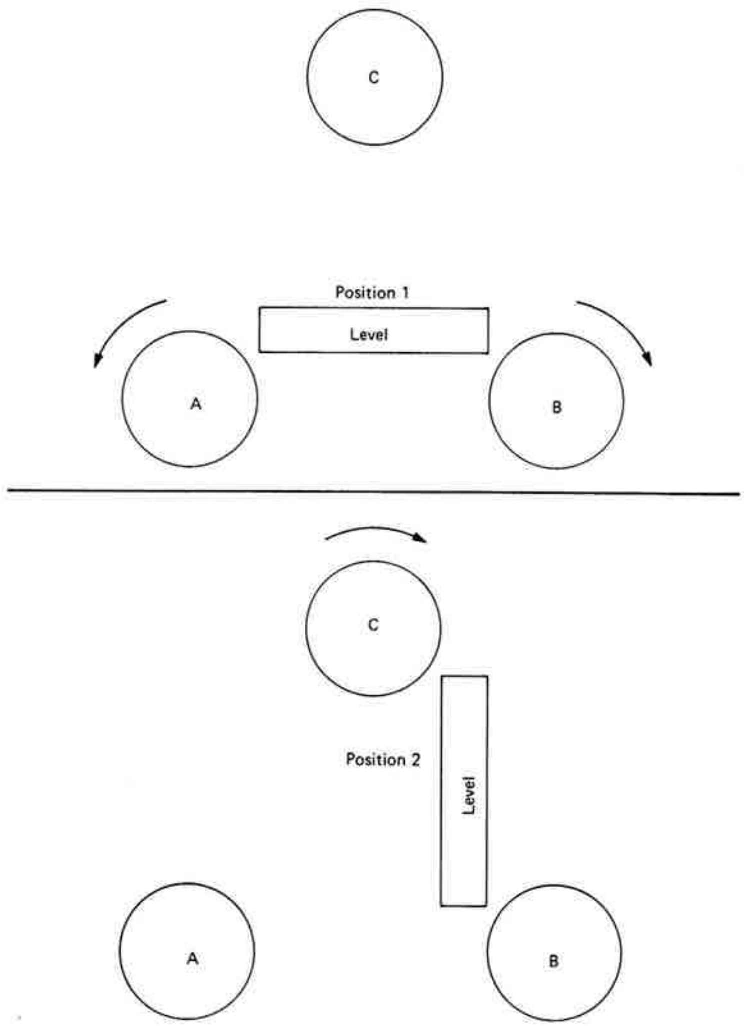


Figure 3-19. Method of leveling with three leveling screws.

3-19. Adjustments

Telescope Adjustments

Object 1. To orient the vertical cross line of the reticle so that it lies in a vertical plane when the cross level bubble is in adjustment and centered. This adjustment destroys Adjustment 2.

This adjustment is divided into two parts. Adjustment 1a and Adjustment 1b.

Object 1a. To make the cross level bubble center when the level is mounted on the telescope and also center when the level is remounted reversed, i.e., turned end for end.

Test 1a.

(a). Suspend a plumb bob by a thin monofilament line. Immerse the plumb bob in oil.

(b). Mount the alignment telescope in V-blocks arranged so that the telescope can be leveled longitudinally and aimed at the thread.

(c). Level the telescope barrel with a striding level.

(d). Mount a cross level (71 3205) on the telescope (see Catalog 9).

(e). Rotate the telescope in the V-blocks until the cross level bubble is centered.

(f). Reverse the level. The bubble should center.

Adjustment 1a.

Rotate the telescope until the bubble moves half-way toward the center.

Center the bubble with the adjusting screw at one end.

Repeat test.

Object 1b. To make the vertical cross line lie in a vertical plane when the adjusted cross level bubble is centered. This destroys Adjustments 2 and 3.

Test 1b.

Rotate the telescope until the adjusted cross level bubble is centered. The vertical cross line should coincide with, or lie parallel to, the thread.

Adjustment 1b. See Figs. 3-1 and 3-20.

(a). Unscrew the eyepiece (5) and cover (4), replace eyepiece.

(b). Four capstan-headed screws are now exposed. Loosen two adjacent screws. Tap the screws gently to make them slide around the telescope until the cross line coincides with, or lies parallel to, the thread.

(c). Tighten the screws that were loosened.

Repeat test.

Object 2. To make the line of sight parallel with the longitudinal axis of rotation of the alignment telescope, i.e., the outside surface of the telescope barrel.

Test 2. If no sphere is to be used, support the telescope in V-blocks. If a sphere is to be used support the telescope barrel in a cone-type V-block and the sphere in a cup mount.

(a). Unscrew the eyepiece (5) and cover (4), Figs. 3-1 and 3-20. Replace the eyepiece.

(b). If the instrument is equipped with micrometers set them at zero and aim at a far distant target, preferably at a collimator reticle.

(c). Rotate the telescope 180°. The cross lines should remain on the target.

Adjustment 2.

With the reticle adjusting screw bring the horizontal and vertical lines half-way toward the target.

In using the screws, be careful to retain tension so as not to destroy Adjustment 1.

Repeat test.

Object 3. To make the line of sight coincide with the longitudinal axis of rotation of the alignment telescope, i.e., the outside surface of the telescope barrel. This is a shop adjustment for line of sight telescopes.

Test 3.

(a). Mount the instrument as in Test 2.

(b). With the micrometers set at zero, aim at a target set as close as possible to the telescope.

(c). Rotate the telescope 180°. The cross line should remain on the target.

Adjustment 3.

(a). Re-aim the instrument with the micrometers so that the cross lines are moved half-way toward the target.

(b). Loosen the three screws at the top of the drum (2) of the top micrometer. While holding the micrometer shaft stationary with the finger, carefully turn the micrometer graduations until they read zero.

(c). Tighten the three screws.

(d). Repeat the procedure for the left-side micrometer.

Repeat test.

ADJUSTMENT OF THE PLUMB ALIGNER BRACKET

Object 1. To make the coincidence level indicate level when the longitudinal telescope axis is vertical. The longitudinal axis is the axis of the surface of the cylindrical section of the telescope. This affects no other adjustment.

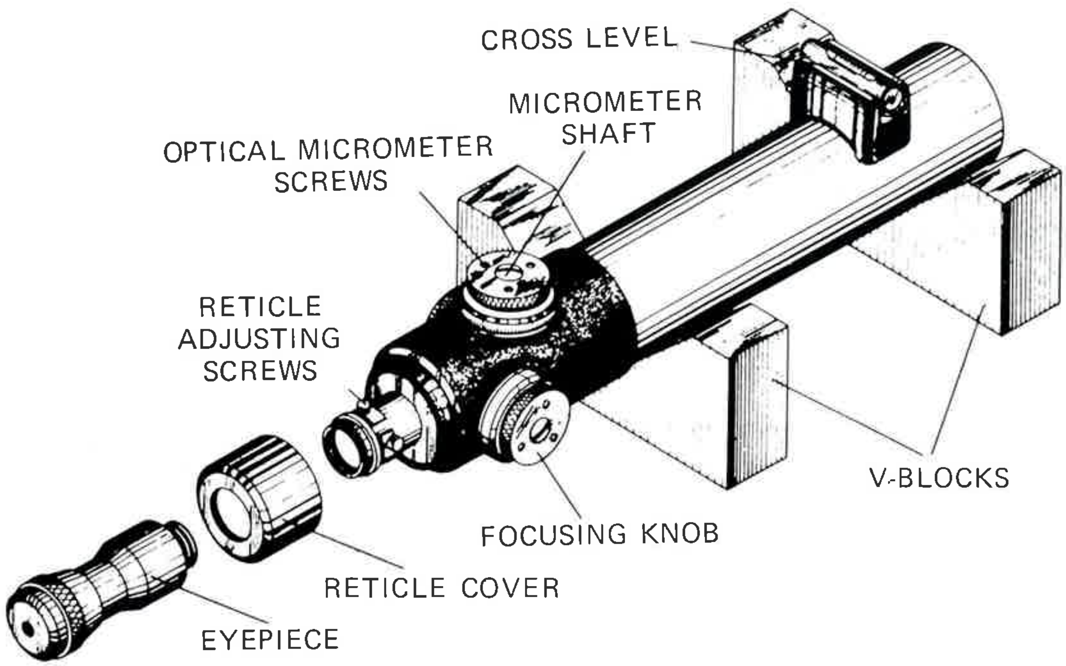


Figure 3-20. An alignment telescope prepared for adjustment.

Test 1. Mount the telescope in the bracket pointing up or down depending on the direction in which it will be used.

Level the instrument with the leveling screws. Rotate the telescope 180° in azimuth.

The bubble ends should remain in coincidence.

Adjustment 1. Eliminate half the error as follows:

Behind the level, between it and the telescope barrel are three capstan heads strung out in a horizontal line. The two end heads are screw clamps. Free these. The center head turns an eccentric which moves the mirrors forward and back and thus regulates the position of coincidence. By turning the head, eliminate half the error. If this movement is sufficient, set the two end clamps.

Repeat test.

If the movement is not sufficient, mark with a pencil the limits of the movement of the adjusting pin when turning the eccentric as far as possible in each direction. Move the pin to the half-way point between these marks.

Remove the screws on the top and bottom near the viewing end of the cover of the level. The two socket-head screws, thus exposed, bear against the top and bottom respectively of one end of the bubble-vial tube. Loosen one screw and tighten the other by small increments until, when the test is made, the coincidence very nearly occurs. When finished the screws should be firm.

Complete the adjustments with the eccentric capstan head just described.

Replace the plug screws and tighten the end capstan clamps.

Repeat test.

4. The Level and Its Accessories

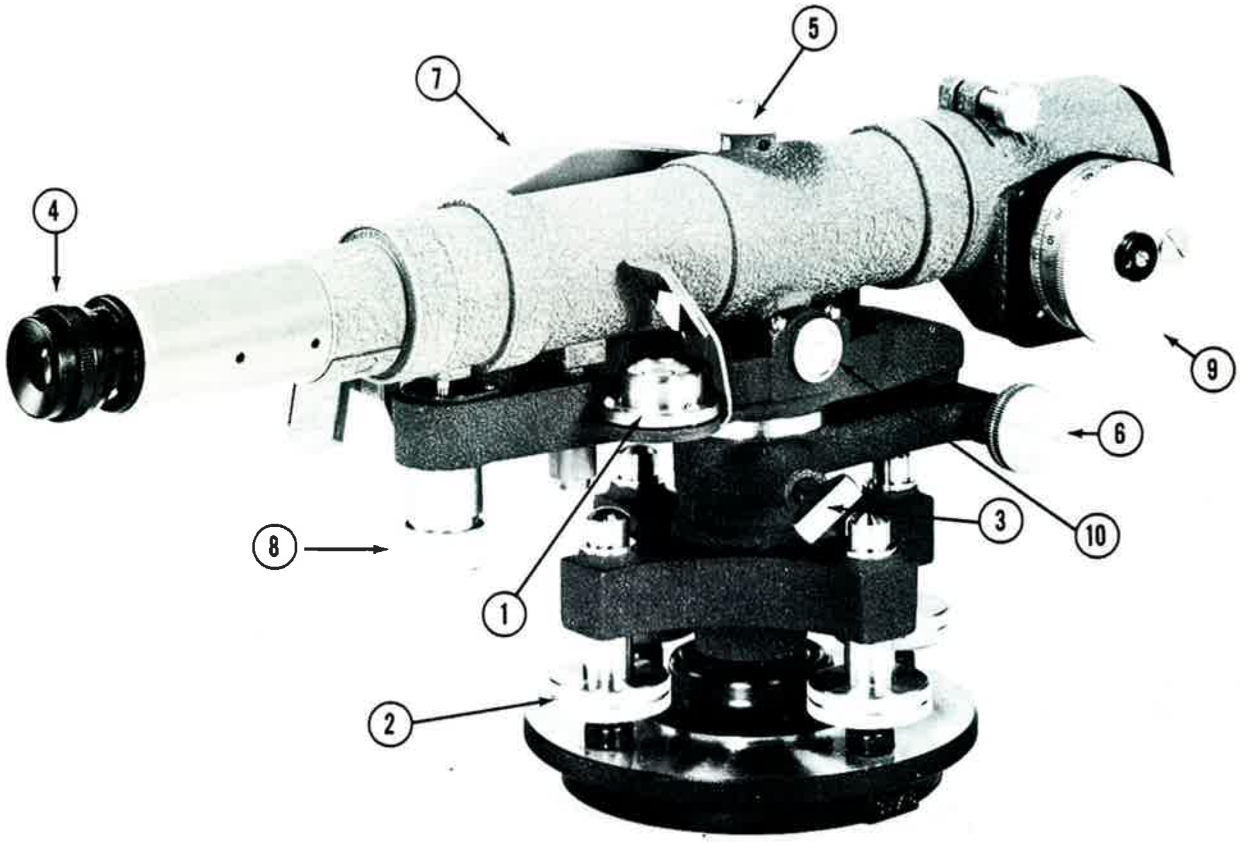


Figure 4-1. A Tilting Level.

1. Circular level
2. Leveling screws
3. Azimuth clamp
4. Eyepiece focusing ring
5. Focusing knob
6. Azimuth tangent screw
7. Cover of coincidence level
8. Tilting screw (two-speed)
9. Micrometer drum and scale
10. Tilt axle

4-1. Level Instruments. There are two level instruments. These have slightly different characteristics as given below.

Catalog Number	Characteristics
71 3010*	Minimum Focus – 4 inches Field of View – 55 minutes at infinity Should be equipped with Optical Micrometer 71 1111. Two-speed tilting screw. Should be equipped with auto-collimation eyepiece.
71 3001*	Minimum Focus – 72 inches Field of View – 52 minutes at infinity Should be equipped with Optical Micrometer 71 3101.

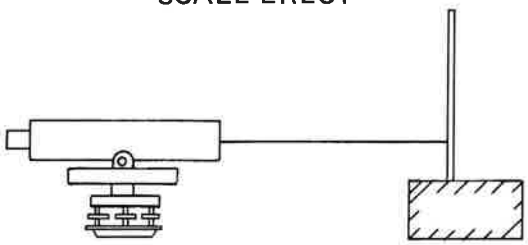
*Also available are complete leveling kits that provide the basic equipment required for precise optical leveling and alignment.

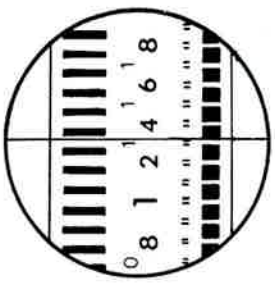
4-2. Basic Principle. Levels of this type are called spirit levels. They consist of a telescopic sight to which is attached a very sensitive spirit level. They are adjusted so that when the spirit level indicates level, the line of sight is perpendicular to gravity (i.e., horizontal).

4-3. To Take a Sight. Note Fig. 4-1. To set up the instrument, screw the base onto a support with a 3½ inch by 8 thread. Center the bubble of the circular level (1) with the four leveling screws (2). (See also Sect. 1-14.) This aligns the azimuth axis very nearly in the direction of gravity.

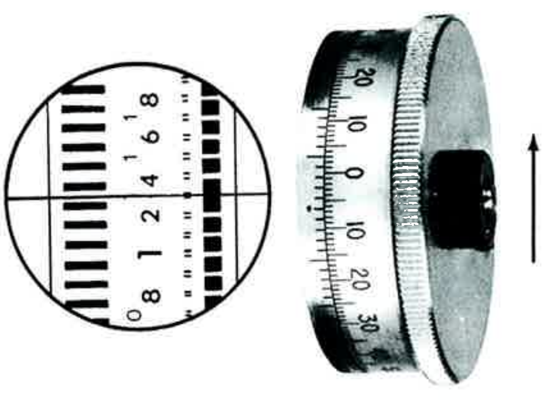
Free the azimuth clamp (3) and sight the telescope at a white or light-colored object. Look through the telescope and turn the eyepiece focusing ring (4) until the reticle pattern is sharp. Note the setting of the diopter scale for future use. The diopter scale is engraved on the eyepiece focusing ring. The setting may be different for different

SCALE ERECT



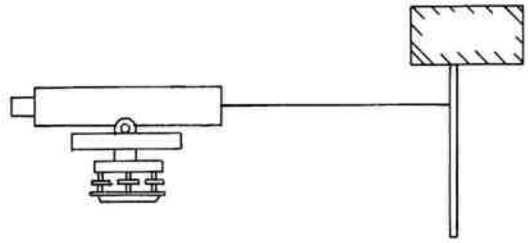


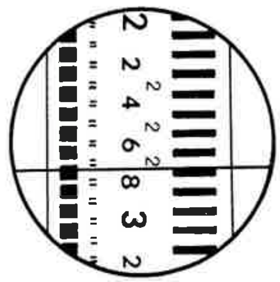
Step 1. Set micrometer scale at zero, and read optical tooling scale at crossline. Reading shown is between 1.3 and 1.4.



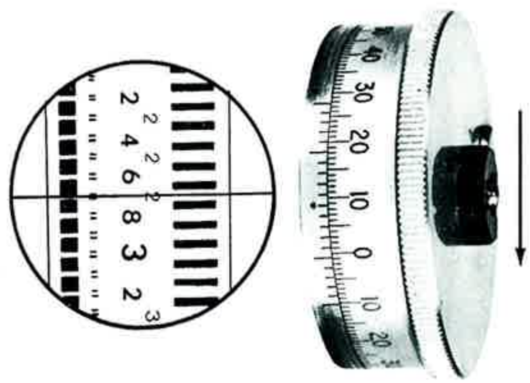
Step 2. Move crossline to least tenth, add micrometer reading (red numbers). Final reading shown is 1.3065 inches.

SCALE REVERSED





Step 1. Set micrometer scale at zero, and read optical tooling scale at crossline. Reading shown is between 2.7 and 2.8



Step 2. Move crossline to least tenth, add micrometer reading (black numbers). Final reading shown is 2.7087 inches.

Figure 4-2. Procedure for reading the scale.

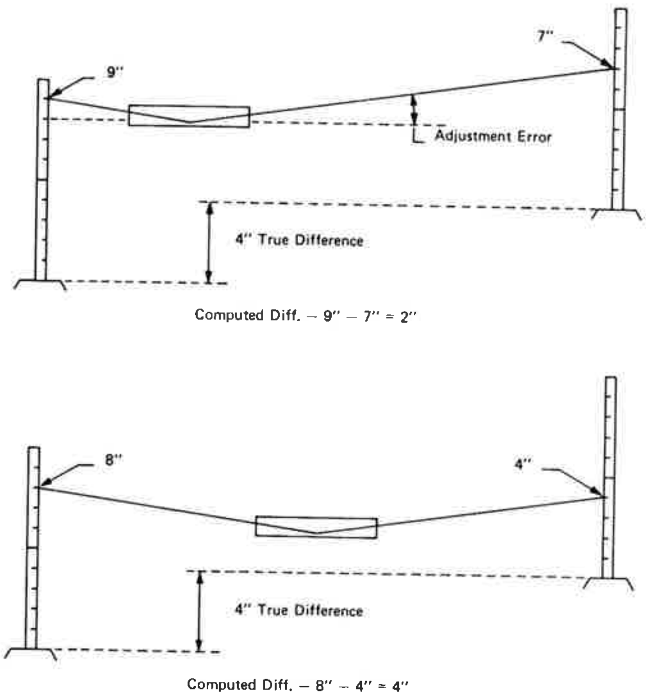


Figure 4-3. To find the difference in height between two objects with great precision, make the horizontal distances from the instrument to the objects equal.

observers and sometimes for different instruments but it is the same for sights of different lengths.

Position a K&E optical tooling scale vertically with the zero end on a fixed object. By looking over the telescope, direct it toward the scale. Sight through the telescope, bring the scale into the field of view. Focus on the scale with the focusing knob (5).

Lock the azimuth clamp (3) and bring the vertical line of the reticle on the scale with the azimuth tangent screw (6). Adjust the two ends of the coincidence bubble (7) (see Sect. 1-8) with the tilting screw (8) so that they coincide. Set the micrometer (9) at zero. Observe where the horizontal cross line falls on the scale and turn the optical micrometer so that the cross line moves to the nearest lower tenth of an inch. Assume, for example, the line falls between 9.3 and 9.4. Move it to 9.3, add the micrometer reading to 9.3. As soon as the line is properly set, check the bubble coincidence.

The tilting screw on Level 71 3010 is a two-speed screw. Within the knurled head of the screw are two stops, one-third of a turn apart. Between stops the screw operates in "low gear" at a ratio of 8:1. Beyond stops it operates in "high gear" at a ratio of 1:1. To use the screw, turn it in either direction until just past the desired point. Then reverse its direction. "Low gear" then starts to function, and continues to function in either direction until final setting is made.

The micrometer is graduated from zero at the middle to 100 thousandths at each end. The scale and the numbers are black in one direction and red in the other. When reading an optical tooling scale that is upright (above the object to be located) the line of sight must be lowered and the red numbers are used. When the optical tooling scale is below the object the black numbers are used. A double vernier makes it possible to estimate to 0.0001 inch in whichever direction the drum has moved. Use that part of the vernier where the numbers increase in the same direction as those of the micrometer drum. See Fig. 4-2.

4-4. Procedure. The instrument is used to determine differences in height. It is well to establish one point from which the differences in height to all other points are measured. Measurements are made upward from top surfaces or downward from bottom surfaces.

When high accuracy is required, place the instrument so that the horizontal lengths of the sights to the two objects are approximately equal. This eliminates the effect of slight errors in instrument adjustment. See Fig. 4-3.

4-5. Adjustments

Object 1. To make the bubble of the circular level center when the azimuth axis is vertical.

Test 1. Center the circular bubble with the leveling screws. Turn the telescope 180° in azimuth. The bubble should center.

Adjustment 1. While the telescope is in the final test position, bring the bubble half way toward the center with the leveling screws. Then center it with the adjusting screws.

There are three adjusting screws around the vial which can be turned with a jeweler's screw driver. They pull the level down against a spherical base. Slightly loosen the screw toward which the bubble should move and tighten the one in the opposite direction. Continue alternately so as not to lose tension. It is usually necessary to use two screws.

Repeat test.

Object 2. To make the horizontal cross line lie in a plane that is perpendicular to the azimuth axis. This destroys Adjustment 2.

Test 2. Aim at a well-defined point and, using the tangent screw, turn the telescope in azimuth left and right. The horizontal cross line should remain on the point.

Adjustment 2. (See Sect. 1-13) Loosen two adjusting screws. Tap one screw so that the four screws slide around the telescope until the cross line remains on the point. Tighten the same screws.

Repeat test.

Object 3. To make the split-bubble ends coincide when the line of sight is level.

Test. 3. This requires the Peg Adjustment. See Sect. 1-13.

5. Metrological Bars

5-1. Metrological Bars. Horizontal metrological bars provide a means of quickly and easily placing jig transits or alignment telescopes (equipped with optical squares) where they can sweep precise vertical planes located at exact horizontal dimensions. Vertical bars provide a means of locating tilting levels at exact heights where they can establish precise horizontal planes. Linear distance measurements to accuracies of 0.001 inch can be obtained.

Figure 5-1 illustrates the use of two horizontal bars at right angles to each other and a vertical bar near them. Carriages which support the instruments ride tracks formed on the bars. By merely operating hand screws, the instruments can be clamped in position, leveled, and aimed. See Figures 5-2, 5-3, 5-4, 5-5, 5-8, and 5-11.

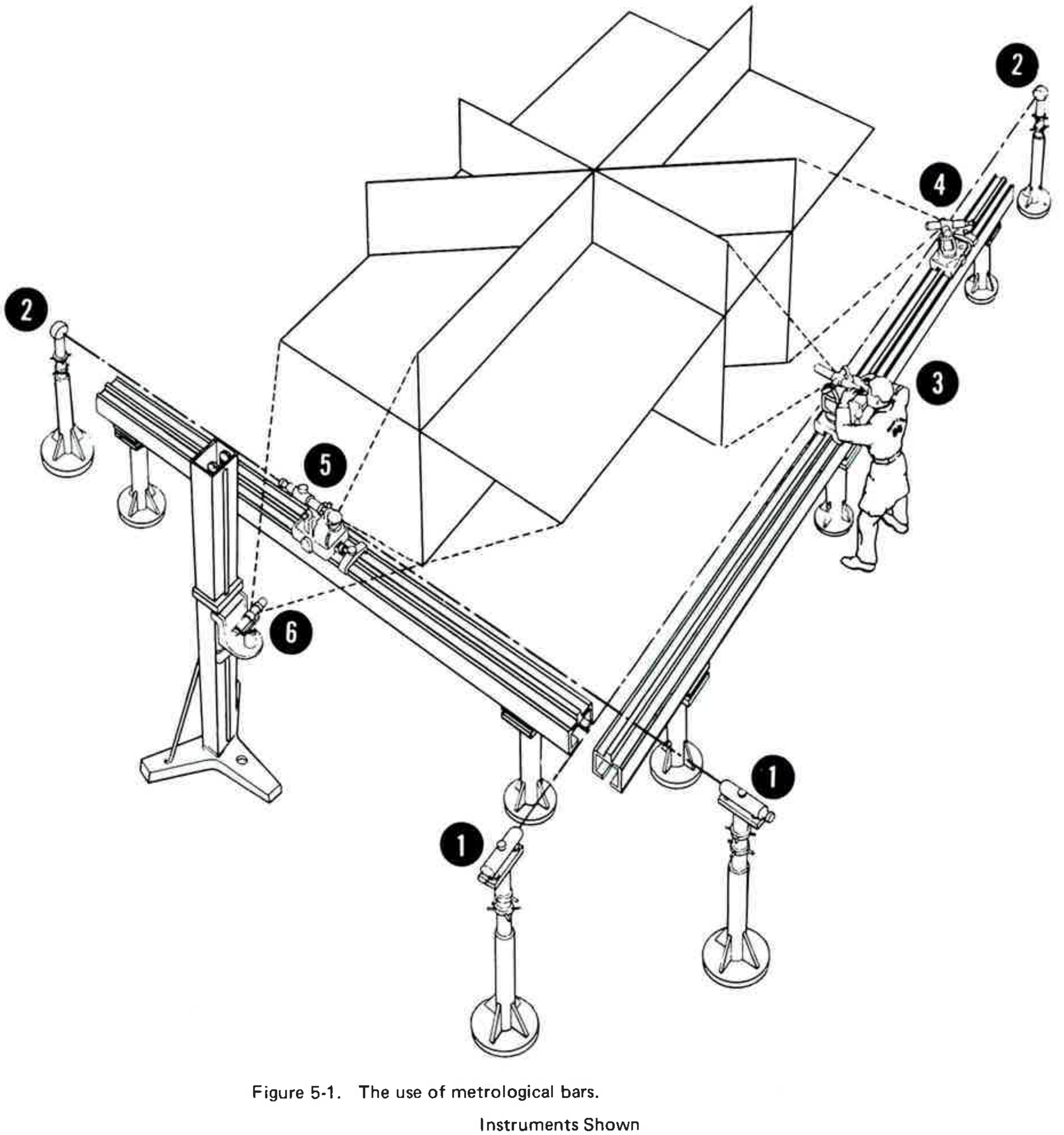


Figure 5-1. The use of metrological bars.

Instruments Shown

(1) Any type of telescopic sight (preferably a collimator)
(2) Targets
(3) Jig transit square 71 1020
(4) Any type of jig transit
(5) Alignment telescope with optical square
(6) Level instrument

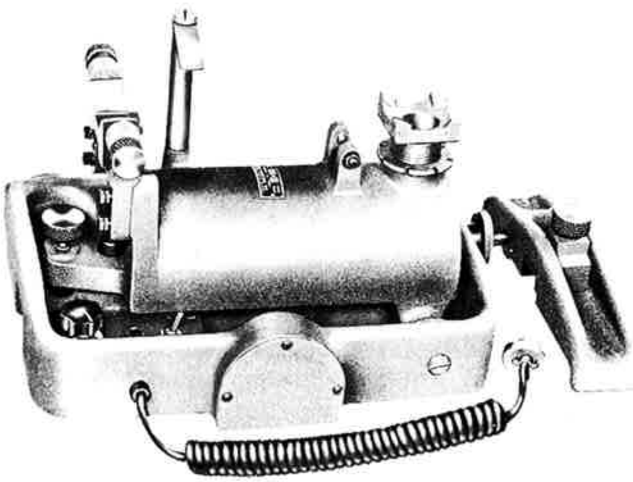


Figure 5-2. The carriage (71 5640) for an alignment telescope.

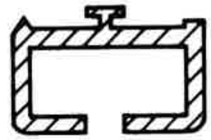


Figure 5-4.
Cross section of box track.

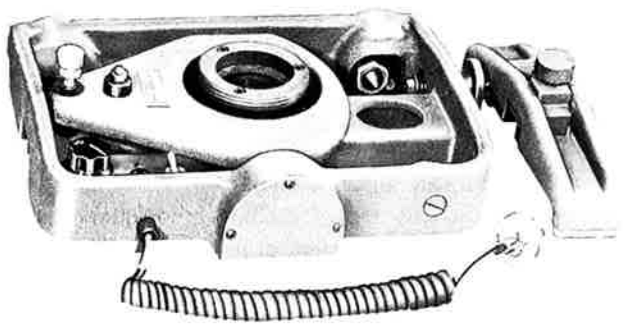


Figure 5-3. The carriage (71 5642) for a jig transit.

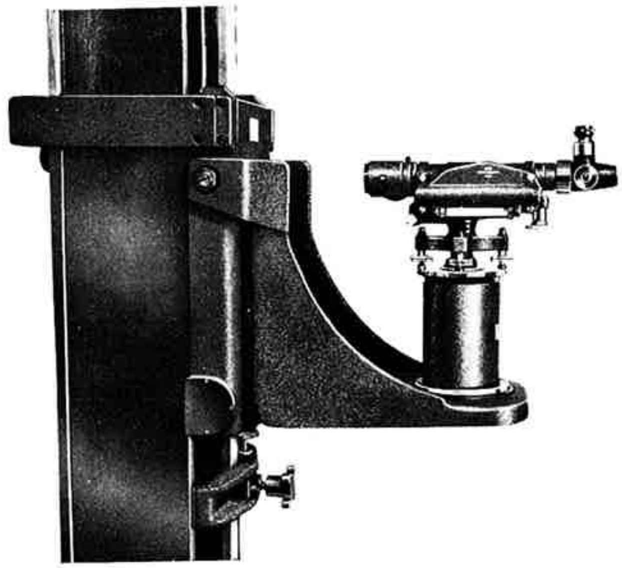


Figure 5-6. Carriage and level for a vertical bar (71 5646).

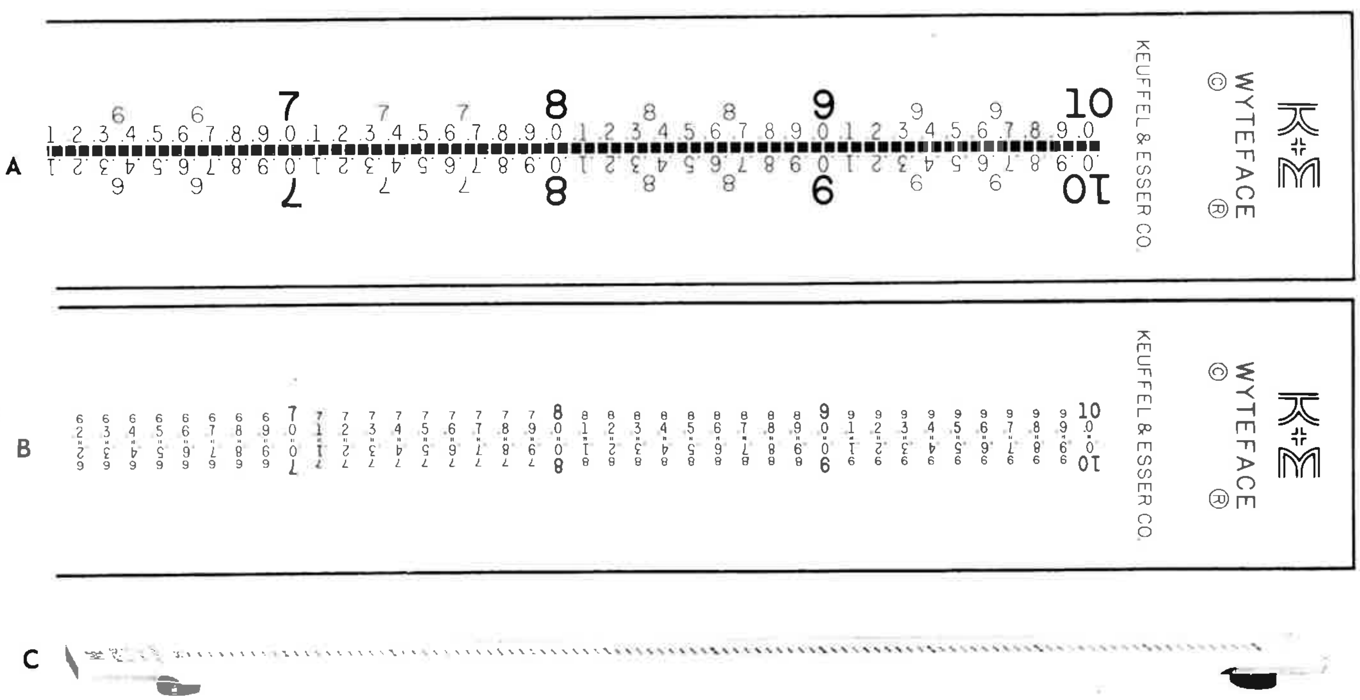


Figure 5-5. Metrological bar scales.

A. Scale 71 6050 divided every half-tenth of an inch, for use with alignment telescopes.

B. Scale 71 6055 divided every tenth of an inch, for use with jig transits.

C. Side view showing locating dowel pins.

Figure 5-4 shows the cross section of the box track. Two V-grooved rollers under each instrument carriage ride on the V-rail guide, and a single flat roller rides on the flat at the opposite side of the bar. The central T-rail supports an index bar. The underside of the T-rail provides surfaces which give purchase for the carriage clamps and the fasteners which hold the index bar in position on the top of the T-rail.

The index bar is a 1¼ in. by ½ in. rectangular, jig-bored steel bar with precision bushings located at precisely 10 in. intervals. The fasteners allow the index bar to elongate or shorten with temperature changes. Index Bar 71 5620 is 10 ft. long and 71 5621 is 5 ft. long. The end design is such that successive sections can be easily joined together. A spacing gauge, with dowel pins very precisely spaced 10 inches apart, is used to establish proper spacing between bars.

A K&E precision alignment scale is used with the index bars. See Figure 5-5. On the underside of the scale is a dowel at each end, one dowel is spring-loaded. The dowels are spaced precisely 10 inches apart to fit the holes in the index bars. The zero graduation of the scale pattern is centered to the first dowel so that wherever they are placed a continuous measurement can be made.

The scales are read through the carriage with the instrument telescope and optical micrometer. This is accomplished with the jig transit by sighting through the hollow vertical center (71 1002 cannot be used), and with the alignment telescope and optical square by sighting downward. A 6-volt electrical system is built into each carriage for illuminating the scales.

The carriages can be tilted lengthwise in the direction of the bar, through a few degrees, by operating a tilting screw. The tilt axis is tangent to the graduated surface of the scale so that changing the tilt of the carriage does not change the scale reading.

In front of the carriage is a small bracket which can be clamped to the bar. Once it is clamped, the position of the carriage along the bar can be set to a tooling scale by turning a hand screw which connects the carriage and the bracket.

The vertical bar carriage is spring-loaded against the track. It, and the tilting level mounted on it, are approximately counterbalanced by a weight inside the vertical bar. See Figures 5-6 and 5-11.

5-2. To Set Up a Single Horizontal Metrological Bar. When there are no finished surfaces and no fixtures already positioned on the work, the simplest method of placing the bar is as follows.

Procedure.

1. After the work piece is leveled, locate the bar by measurements with an ordinary steel tape and a shop level. Position the bar so that it is nearly parallel to the longest centerline on the work and approximately level.

2. Mount the instrument on an instrument stand equipped with a mechanical lateral adjuster. Level the instrument and place it in line with the bar. The instrument usually used is a tilting level, but a jig transit or any line-of-sight instrument will do. This instrument is called the *reference* instrument or the *base line* instrument. It should be carefully leveled when pointing along the bar.

3. Mount and level a jig transit, on a carriage, at the far end of the bar. An alignment telescope equipped with an optical square can be used also. Aim and center it along the line of holes in the index bar.

4. Collimate the two instruments. This is accomplished by raising the aim of the first instrument until the telescope is level, and moving the base line instrument up or down with the stand mechanism and left or right with the lateral adjuster. Check the level of the base line instrument after each movement. Relevel if necessary and check collimation.

The bar is now ready for use. Heights are established as described in Section 4-4.

If there are finished surfaces or parts already located on the work it is best to zero-in the index bar as described in Section 5-4.

5-3. To Set Up Two Horizontal Bars at Right Angles. There are many methods of using metrological bars. The simplest use and procedure are described in Section 5-2. The most complete method is described here in Section 5-3. The user should work out a procedure best suited to his work based on the methods described.

Procedure.

1. *To level the work.* Mount a tilting level on a stand or vertical metrological bar placed as near the center of the work as possible. Observe an optical alignment scale positioned on finished surfaces which are as far apart as possible and as close as possible to the jacks or other supports. Adjust the supports until the readings on the scale indicate that the dimension plane is level.

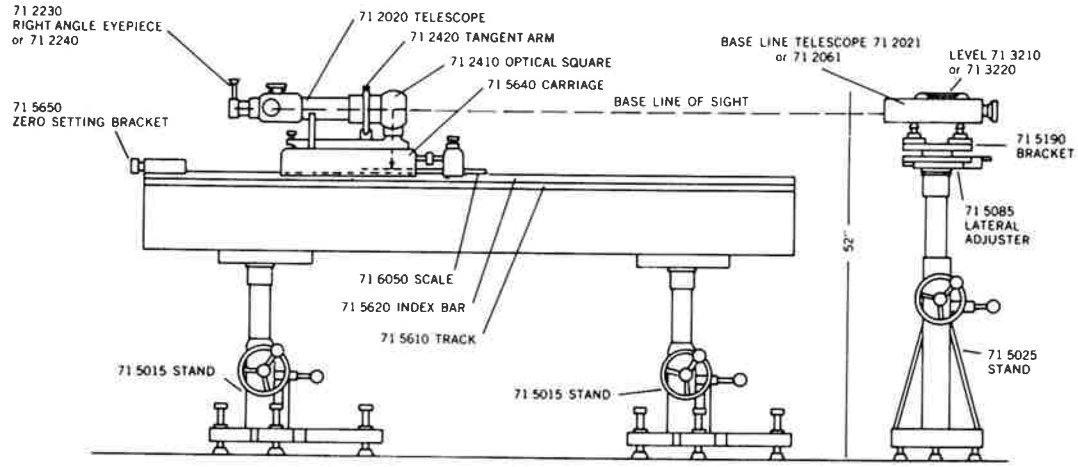


Figure 5-7. Horizontal bar system using alignment telescope with optical square.

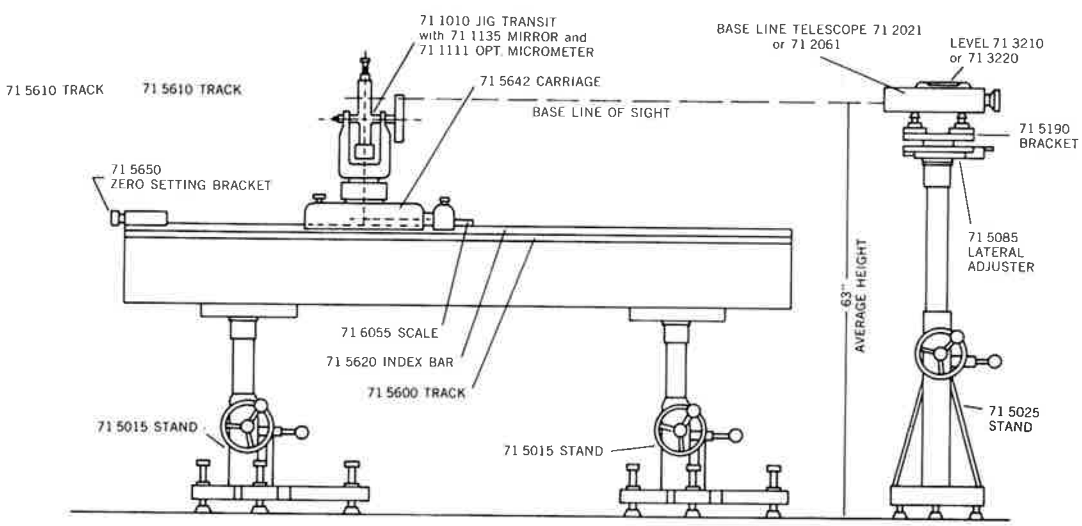


Figure 5-8. Horizontal bar system using jig transit.

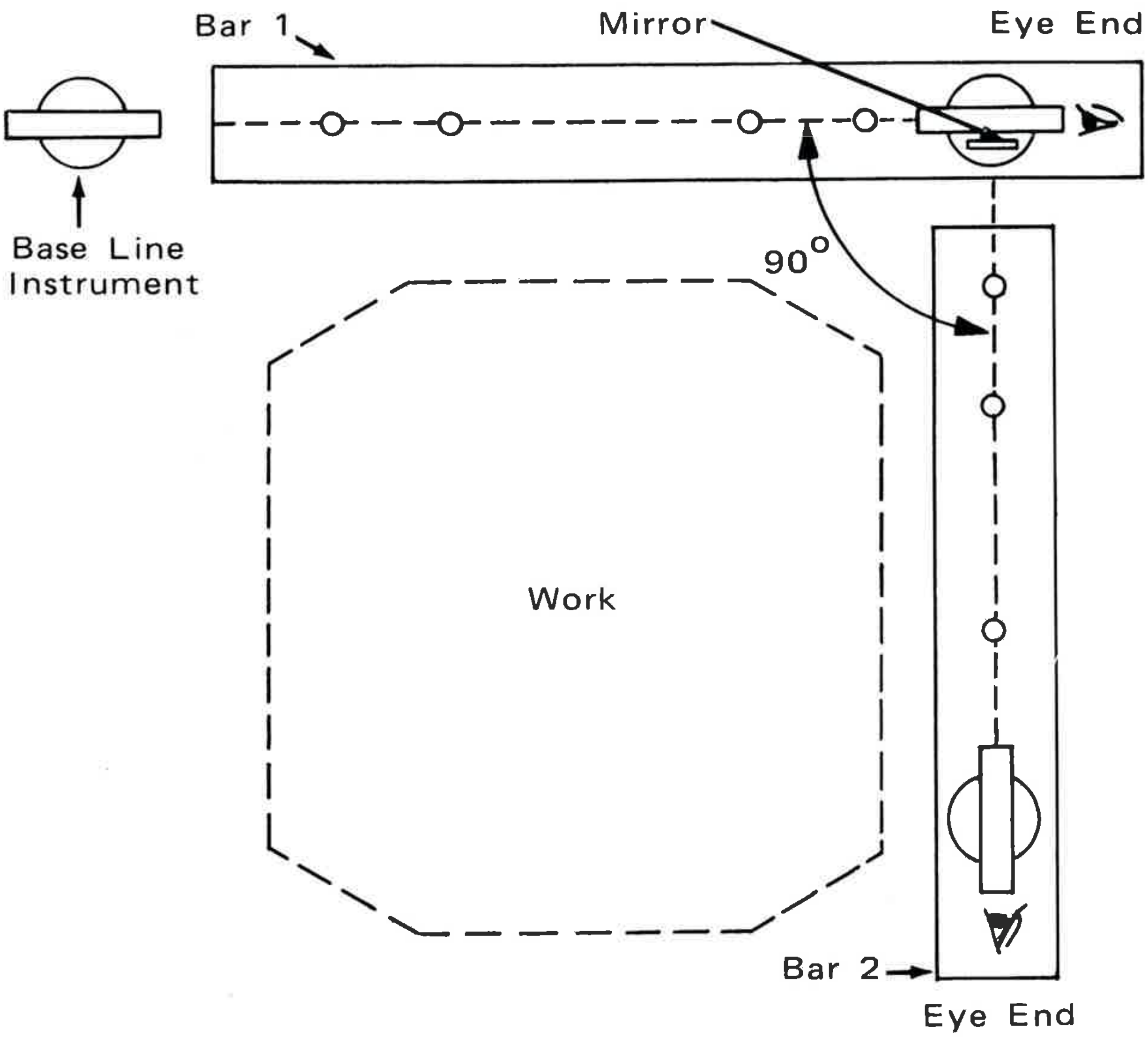


Figure 5-9. Arrangement of two metrological bars.

2. *To place the first bar.* Install the longer bar, as described in Section 5-2, parallel to the longest dimension of the work. One end must extend beyond the work to provide a support for the instrument used to align the second bar. The second bar is placed at right angles to the first bar for width measurements. See Figure 5-9.

3. *To place the second bar.* Install the second bar so that it is at right angles, at the same height, and level with the first bar. To establish the right angle, proceed as follows:

   a. Check collimation of base line instrument and instrument at end of first bar.

   b. Mount a jig transit or an alignment telescope with optical square at end of second bar, as nearly as possible at the intersection of the lines of the index bar holes. Aim and center telescope along index bar holes.

   c. Sight telescope of instrument on second bar so that it is auto-collimated to mirror positioned at right angle to instrument on first bar. A 90° angle is now established.

For important work the stands that support the bars should be grouted in place.

Although the bars should be carefully aligned and leveled, their positions have a negligible effect on the accuracy of the work. Careful placement of the bars materially affects only the convenience and speed of operations.

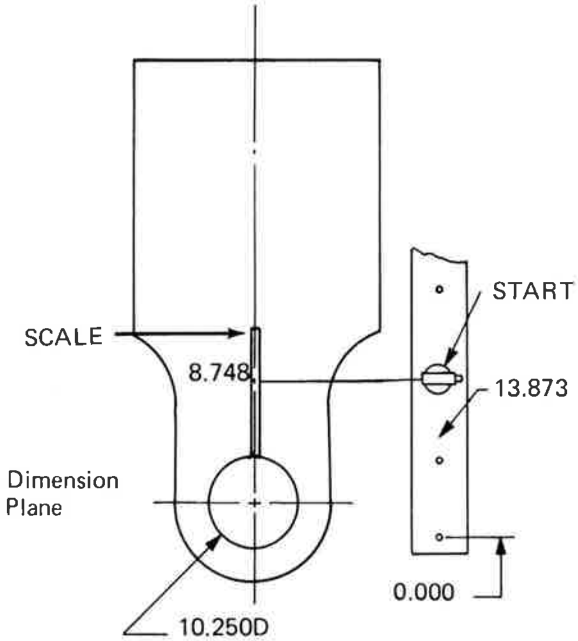


Figure 5-10. Procedure for zeroing-in the horizontal bar scale.

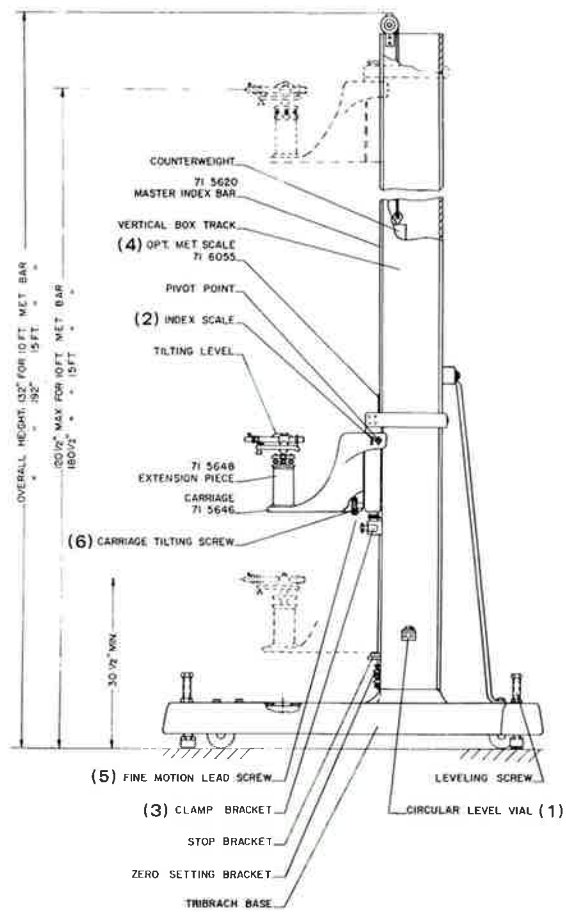


Figure 5-11. A vertical bar system.

Operation.

1. *To establish points on work piece.* Place an alignment bar scale in the proper pair of index holes. Slide the carriage to the approximate desired reading on the alignment bar scale. Sight the jig transit telescope downward to observe the scale. Clamp the carriage bracket. With the slow-motion screw move the carriage until the cross line is on the correct reading. Level the plate bubble on the jig transit. Collimate or auto-collimate on the reference instrument. Sight the telescope so that it points at an optical alignment scale on the work. Take reading and if necessary adjust the work until the correct reading is attained.

   Move carriage to the next point to be measured and repeat above procedure.

   With an alignment telescope the same procedure is followed except that the optical square replaces the telescope.

2. *To measure distance between points.* Proceed as in 1 above but read the optical alignment scales positioned on the work.

3. *To zero-in a reference line.* Place the reference line at a certain number of whole inches from the dimension plane. To accomplish this, sight the reference instrument so that readings on optical alignment scales positioned at points on the work indicate that its line of sight is parallel to and at the desired distance from the reference plane. See Fig. 5-10.

5-4. To Zero-In the Index Bar. A zero-setting bracket 71 5650 is mounted at the end of the metrological bar. A tooling bar scale is mounted on the index bar opposite a scale held on a finished surface of the work piece whose distance from the dimension plane is known. Figure 5-10 shows a shaft whose surface is 5.125 inches from the dimension plane. The jig transit is mounted on its carriage and moved along the bar until it is approximately over the bar scale. Tilt the instrument and turn with the azimuth motion so that the vertical cross line of the reference instrument auto-collimates in the telescope axle mirror of the jig transit. For an alignment telescope with optical square or a jig transit square, the procedure is the same except that you collimate to the reference instrument. Read the scale positioned on the work. Assume the reading is 8.748. This point on the scale is 8.748 + 5.125 = 13.873 inches from the dimension plane. Hence, the tooling bar scale should read 13.873. With the zero setting bracket, adjust the index bar so that the tooling bar scale reads 13.873. The index bar is now set so that all readings will agree with the plan. Check to be sure the instrument is still in auto-collimation.

5-5. To Set Up the Vertical Tooling Bar. Place the vertical metrological bar as near as possible to the center of the work.

Procedure, see Figure 5-11.

1. Plumb vertical tooling bar with leveling screws in tribrach base while observing circular level vial (1). Level optical instrument roughly with circular level on instrument.

2. Move carriage to approximate elevation as indicated by the index line on index scale (2) and lock clamp bracket (3).

3. Aim telescope on index scale (2) with instrument tilting screw, then focus on scale (4).

4. Final adjustment of line of sight to proper scale station point is achieved by turning fine motion lead screw (5) while observing scale with the telescope.

5. Level telescope with carriage tilting screw (6). This leveling operation pivots line of sight about station point and will not disturb station setting. Do not use instrument tilting screw.

6. The instrument is now ready to sweep a horizontal plane. Turn instrument in azimuth and aim telescope at the desired target point. Re-level telescope with the level instrument's tilting screw.

   You are now ready to take readings with the optical micrometer.

7. All readings should be made using the center of the telescope reticle.

Caution. Always level the instrument and take sights as directed in Chapter 4. Never use the carriage tilting screw, once the bar is set up.

Operation.

1. *To determine a height.* Aim at the bar scale. Perfect the leveling. Read the bar scale. Aim at the scale on the work. Perfect the leveling. Read the work scale. Check the bubble. When the scale is upward (on top of the work surface) subtract the work scale reading from the reading on the bar scale and vice versa. The result is the height sought.

2. *To establish additional planes from a reference point.* Set the tooling bar scale so that it is within the range of the point to be set. Free the clamp bracket screw and move carriage so that instrument can be aimed at the scale on the work. Level the instrument. With the carriage fine motion lead screw, move carriage until the desired reading is obtained on the tooling bar scale. Check the coincidence bubble. Aim at the scale on the work. Check the coincidence bubble. Raise or lower the work until the scale on the work gives the desired reading. The same procedure can be followed for establishing additional planes.