WHAT IS OPTICAL ALIGNMENT?

by

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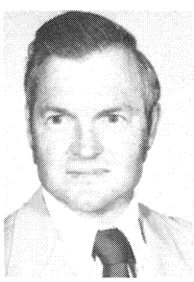


Born and educated in Kansas. He worked with Boeing-Wichita from 1953 to 1970 primarily in the jig and fixture erection department. Five years of his employment with Boeing he worked with their training center teaching the use and care of optical alignment instrumentation to new employees. He also served as a Jig Erection Supervisor for four years. He has been with the Keuffel & Esser Company since 1970 as a Technical Representative in Optical Alignment and Surveying Instrumentation.

ABSTRACT:

Optical alignment as we know it today was borne out of the aircraft construction industry. With the advent of necessity to maintain a straight line within closer tolerances and over greater distances, precision instrument companies stepped in to meet the need. Working closely with aeronautic engineers and other design people in the industry, the present state of the art phase of alignment equipment evolved by answering specific needs of the aircraft industry.

With the equipment already designed and proven, other industries were quick to accept this new method, and applied the basic techniques to their own needs. As a result, optical alignment methods can be found in use at paper mills, shipbuilding yards and in machine installation on all levels of sophistication.

In essence optical tooling assures the engineer the ability to maintain straightness, flatness, plumb and squareness at any given installation. The very nature of light as opposed to (wire) allows set-up such that work is not interrupted. The reference scopes are set up in positions where the workmen can pass within the optical line to make adjustments. With some modifications, the same instruments can be used for a wide variety of alignment tasks.

Contrary to a still too popular belief, optical alignment is not a mysterious, complicated method used only to align huge machines and totally replace mechanical alignment systems.

In fact, optical alignment is remarkably simple in concept, even easier to learn and put to use, and far more accurate than some of the old standbys involving piano wires and the like.

It has been said it's time to put the piano wire back in the piano, a euphemistic way of saying that mechanical alignment is passe. This is an exaggeration. For example, if you need to level a 12-inch square sole plate, a precise spirit level will work fine. However, if you need to set a second plate 25 feet away that is not only level, but precisely on the same horizontal plane, optical alignment is far and away the best, most accurate method.

The reason is that optical procedures span space very precisely. The optical reference planes are easy and quick to establish and can be precisely re-established to make periodic alignment checks.

Debunking the mystique

Like a carpenter or mason building a residential home, the erector of industrial machinery is concerned with the same fundamentals; is it straight, flat, plumb or square? The big difference is that those responsible for industrial alignment are working to infinitely closer tolerances than the carpenter. Often the principles involved are the same and, truly, quite simple. The optics within the tools are the only complicated aspect of optical alignment and they needn't concern the user of these tools.

Ever evolving systems

No one person invented optical alignment procedures. In fact, its applications are virtually unlimited and, as has happened in the past, new instruments and procedures will be developed to meet new and varied alignment needs. Optical alignment, as we know it today, evolved from other methods throughout the years.

The British used optics during World War II to align the main shaft bearings of many of the ships built at that time. In the U.S. it was the aircraft industry that first recognized the method's advantages and gave optical alignment a great shot in the arm, developing various systems. Unlike the holes in a bridge girder, which only have to be drilled close enough for the steelworker to get a bolt through, the holes for the rivets in an airframe must be precise.

The paper, chemical, petroleum and printing industries quickly followed the aircraft producers' lead, as did machine manufacturers, recognizing that one of their biggest problems was the alignment of high-speed rotating equipment, such as in the field of turbomachinery.

Instrumentation

The fact that light travels in a straight line makes the telescope, a very precisely manufactured telescope, the heart of an optical alignment system. As we focus the telescope from minimum to maximum focal distances, we establish an optical straight line known as the instrument's "line of sight."

Given this line of sight, the next question is how to control the position of this line in order to take precise displacement readings. There are three instruments that

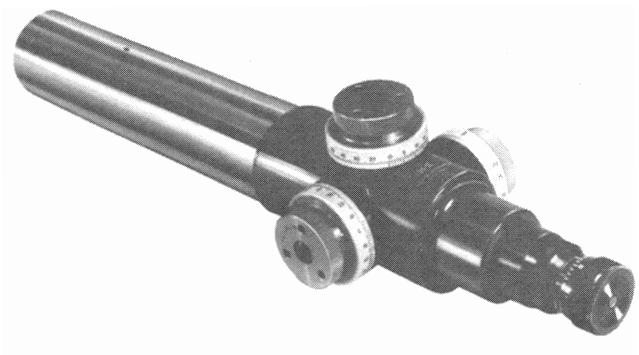


Figure 1. Alignment Telescope Equipped with two micrometers to measure displacement in all four directions.

will provide the control required:

1. The alignment telescope (Figure 1)
2. The precise level (Figure 2)
3. The jig transit (Figures 3 and 4)

Exactly what instrument or combination of instruments is needed depends on the application, which calls for a quick review of the four basic parameters discussed earlier.

Is it straight?

The alignment telescope creates a line of sight from eye to target that is optically straight. Weightless, it cannot sag. It is equipped with two micrometers that allow you to take displacements readings to 0.001 of an inch in all four directions from its optical center line.

The accessories now become the key factor in positioning this fixed line of sight. To level the line of sight you use a striding level. The plumb alignment bracket positions it in a true vertical plane. The optical square (Figure 5) produces two lines of sight that are precisely 90 degrees to each other. Should you need, for example, a line of sight on true center of a power unit in order to set shaft bearings, you would use a spindle mirror target, as shown in Figure 6.

Is it flat?

A tilting level establishes a line of sight that is a true horizontal plane. By equipping the level with a microm-

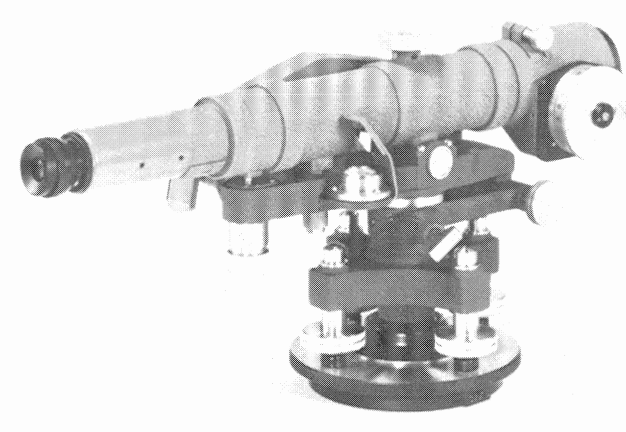


Figure 2. Precise Tilting Level—used to measure vertical displacement from a horizontal plane.

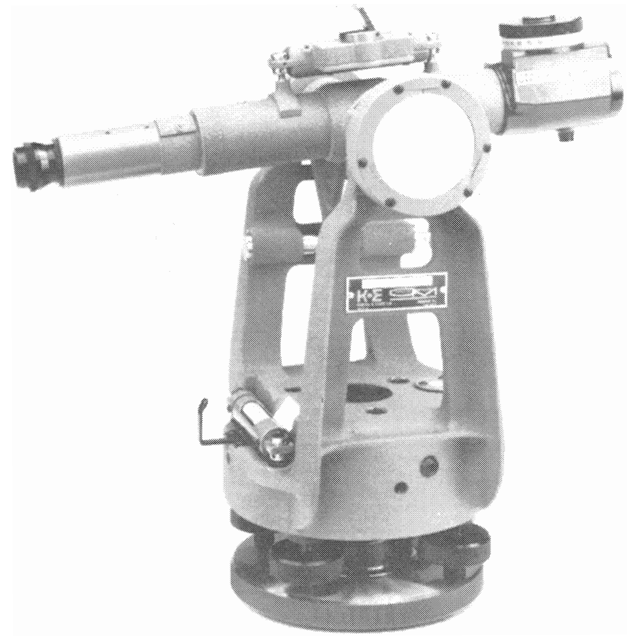


Figure 3. Jig Transit with mirror, micrometer coincidence level. Instrument used to measure horizontal displacement from a vertical plane.

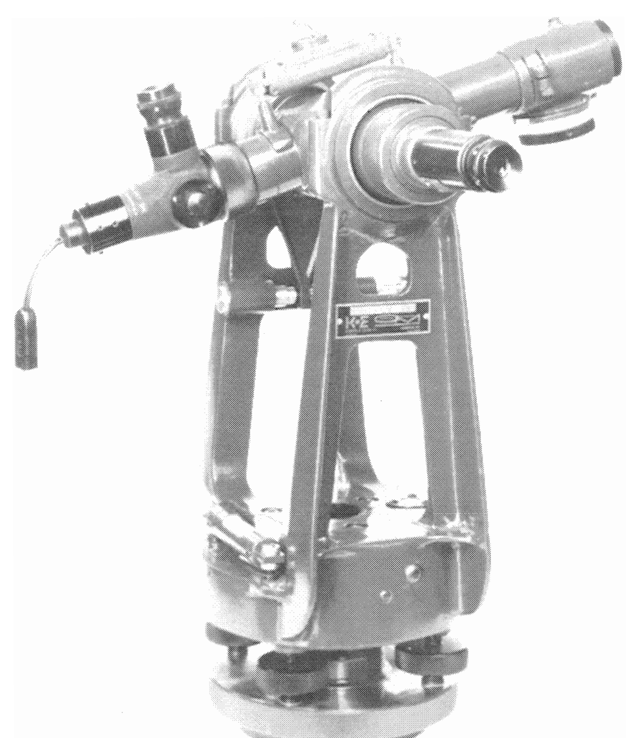


Figure 4. Cross-Axis Jig Transit with micrometer coincidence level and 90% projection, A/c eye piece. The cross axis telescope permits one man to establish two optical reference planes 90° to each other.

Figure 5. Optical square—used in conjunction with an alignment telescope.

eter and using Wyteface tooling scales, it is possible to measure vertical displacement from this precise, invisible horizontal plane. Figure 7 shows the principle used in most optical micrometers. Figure 8 is a close up of the scale used. The procedure for reading this scale is shown in Figure 9. Figures 10 and 11 are photographs of actual micrometer readings.

Is it plumb?

The jig transit establishes a line of sight that will sweep a vertical plane from which precise horizontal displacement readings can be taken. Again, you would use a micrometer and Wyteface tooling scales.

Is it square?

Before discussing this fourth fundamental, a fairly thorough understanding of the three basic methods of

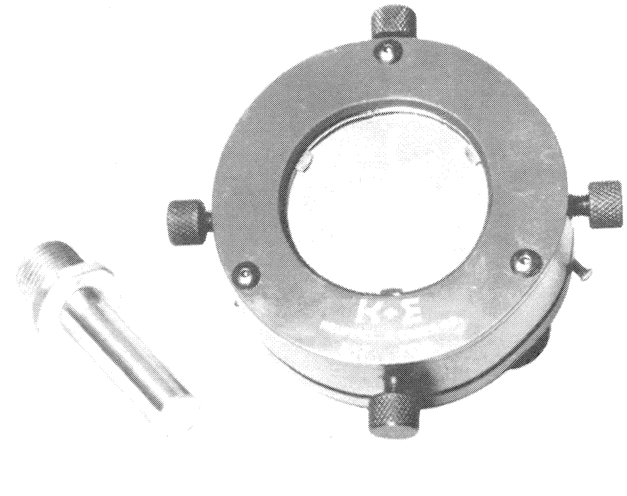


Figure 6. Spindle Mirror Target—used to establish L.O.S. on true center line of shaft rotation.

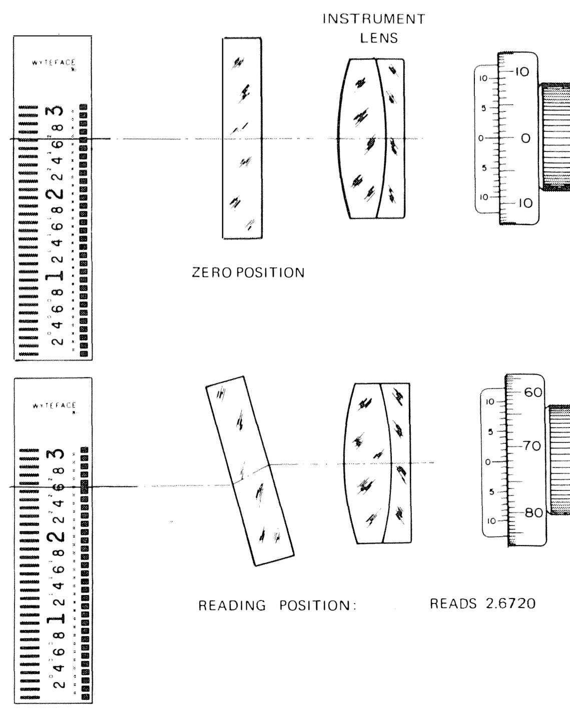


Figure 7. The principle of an optical micrometer.

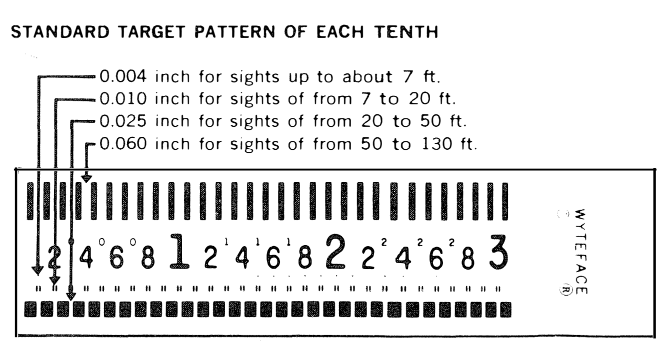


Figure 8. Pattern used on a typical scale.

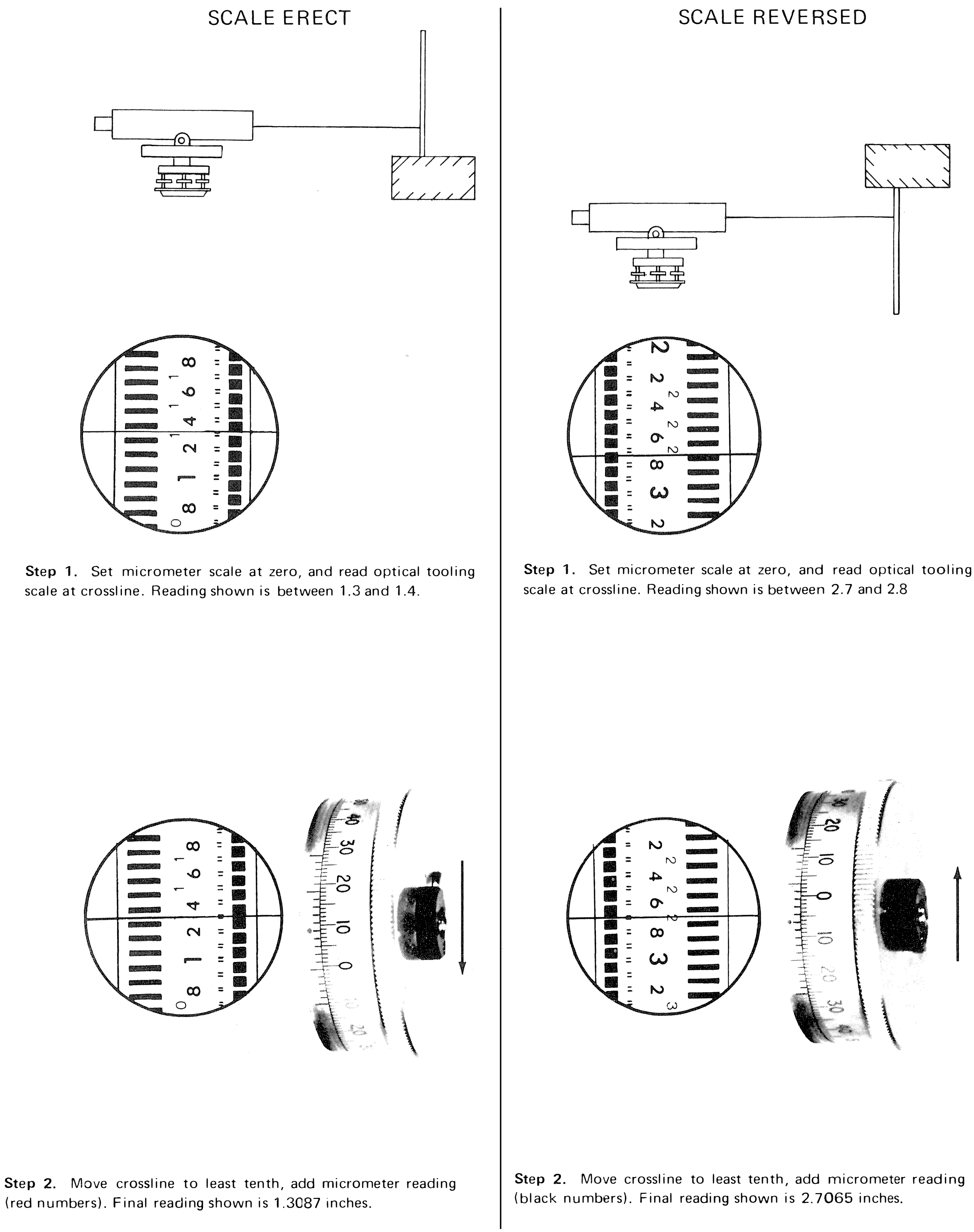


Figure 9. Procedures for reading the scale.

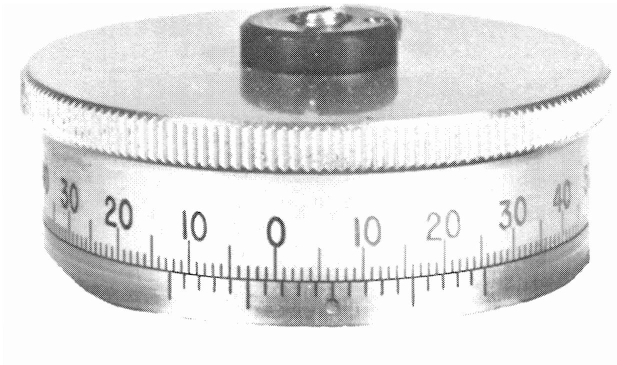


Figure 10. Close-up view of optical micrometer reading is .0065 inch.

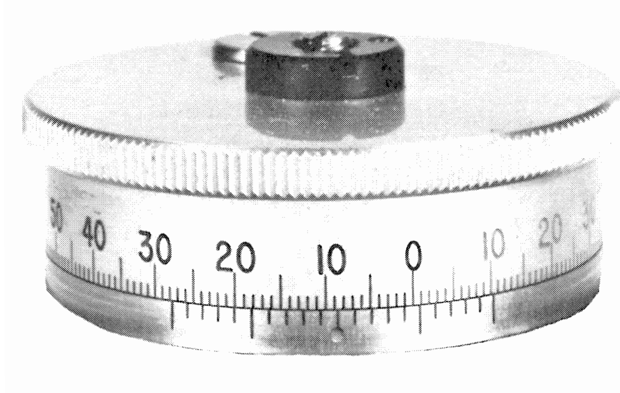


Figure 11. Close-up view of optical micrometer reading is .0087 inch.

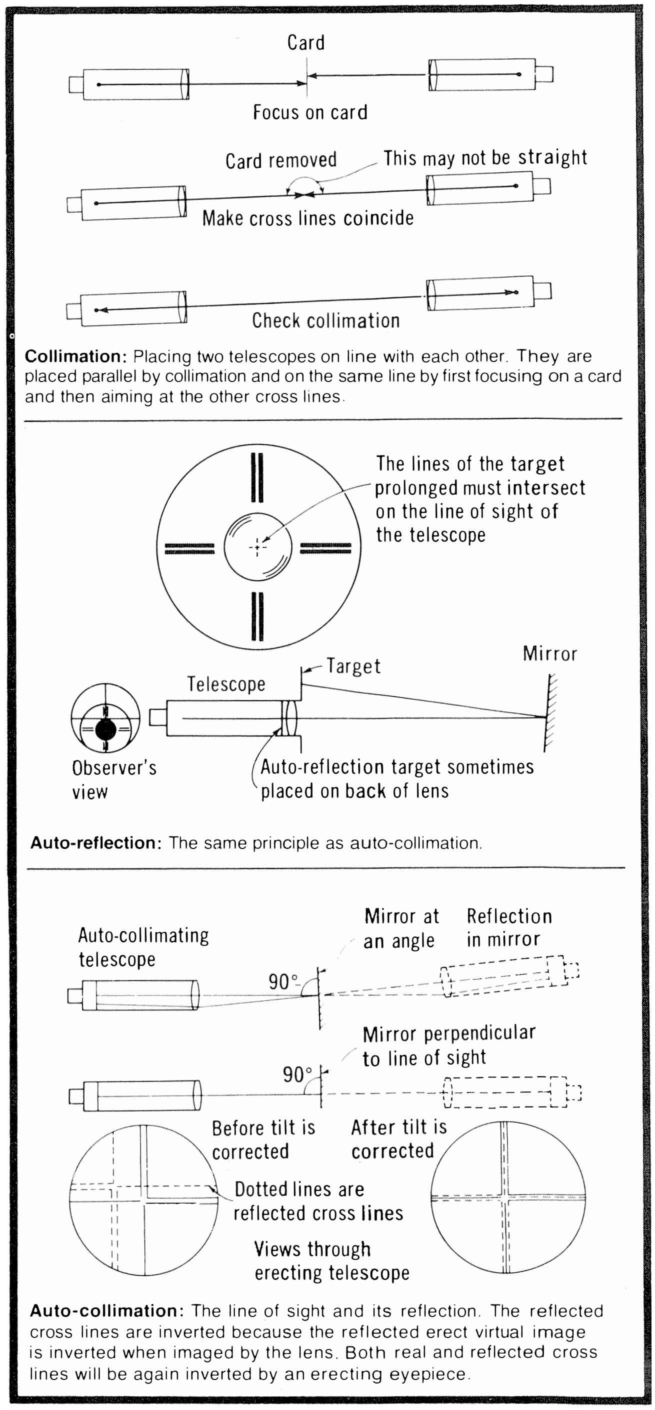
optical alignment is a must. The only things which you as a user must understand are these three methods of alignment in order to fully exploit the optical instruments being discussed. The three techniques are (1) collimation, (2) auto-reflection, and (3) auto-collimation. Figure 12 indicates the basic principles involved in these techniques. With the knowledge, you can easily outline an optical alignment procedure that will allow your people to align any given machine both quickly and easily.

The first method is collimation. Parallel light rays are said to be collimated. When any telescope is focused at infinity, it focuses collimated light rays on the reticle of the instrument. Conversely, when the reticle is illuminated, it projects collimated rays.

When collimated rays are viewed with a second telescope set at infinity focus, an image of the illuminated cross lines appears on its reticle. When the second telescope is aimed so that cross-line image coincides with the actual cross lines, the lines of sight of the two telescopes are parallel.

The second basic alignment method is called auto-reflection. When precise angular accuracy is necessary, an optically flat mirror is mounted on the part to be positioned so that its reflecting surface is parallel to the proper reference plane on the part and where it will be in the line of sight of the alignment telescope.

The part is positioned by placing the mirror on line and then turning and tilting the part until the cross lines



Collimation: Placing two telescopes on line with each other. They are placed parallel by collimation and on the same line by first focusing on a card and then aiming at the other cross lines.

Auto-reflection: The same principle as auto-collimation.

Auto-collimation: The line of sight and its reflection. The reflected cross lines are inverted because the reflected erect virtual image is inverted when imaged by the lens. Both real and reflected cross lines will be again inverted by an erecting eyepiece.

Figure 12. Pictorial Description of three methods of alignment.

in the alignment telescope appear to coincide with the image of the auto-reflection which is located at the objective end of the telescope.

When several points must be set at some distance off the line of sight, an optical reference plane must be established at a known station at right angles to the line of sight. This is accomplished by auto-reflection using a jig transit or a device based on the pentaprism principle (Figure 13) called an optical square.

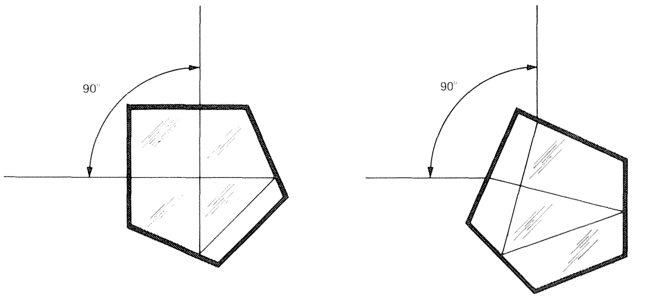


Figure 13. A pentaprism turns a line of sight 90° independent of its orientation.

The third and most sophisticated method is known as auto-collimation. It is similar to auto-reflection but more accurate. While in auto-reflection the line of sight is aimed at the reflection of a target, in auto-collimation the line of sight is aimed at the reflection of the cross lines of the telescope itself. as shown in Figure 14.

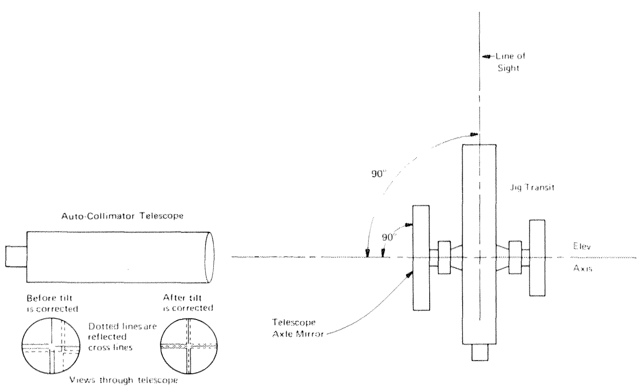


Figure 14. A right angle by auto-collimation. A jig transit has a telescopic sight mounted to turn on an elevation (horizontal) axis. At the end of the axis is a front surface mirror perpendicular to the axis and therefore parallel to the plane swept by the line of sight.

To use an instrument in this way, only a small amount of light need be directed on the cross lines. The telescope is focused at infinity, which means its reflection is really a collimator and the cross lines of this collimator are in focus. When the mirror is adjusted so the reflection of the cross lines falls on the cross lines themselves, the mirror's surface is precisely perpendicular to the line of sight.

Using auto-reflection, there is always the possibility that the target mirror had been exactly centered on the line of sight and this can introduce a slight error. Also, as auto-reflection is used to establish a series of parallel planes, a slight error may be introduced if there is any curvature in the line of sight of the sighting telescope when it is focused at different distances. The auto-collimation system has the sighting telescope focused at infinity and hence there can be no curvature in the line of sight due to focusing.

Now, is it square?

With this brief cram course on aligning methods out of the way, let's address the fourth fundamental question: Is it square? Determining this can be done several ways, three of which are outlined.

1. By simply mounting an optical square on the barrel of an alignment telescope, you create two lines of sight which are precisely 90 degrees to each other.

2. For more complex applications, a jig transit is aligned parallel to a known reference plane using either Wyteface scales or known floor points on an offset centerline. Then, a titling level is set up at approximately the same height as the jig transit and in line with it.

Next, the line of sight of the level is collimated parallel to the line of sight of the jig transit. The line of sight of the level is now parallel to the reference plane. All that has to be done now is to rotate the transit 90 degrees to the level, so the mirror, attached to the transit axle, can be auto-collimated to the line of sight of the level. The line of sight of the transit is now 90 degrees to the reference plane.

3. The third procedure is similar to the one just described except that two jig transits are used. The first one is set up and aligned parallel to the reference plane. The second jig transit is then positioned in line with the line of sight just established. Next, auto-collimate or auto-reflect the mirror on the second jig transit axle 90 degrees to the first line of sight.

The advantage of this procedure is that you can sweep two vertical planes at one, which are precisely 90 degrees to each other. Add a titling level to this setup and you can control X, Y and Z planes simultaneously and precisely locate any point in space.

In conclusion, it obviously was not my intent to specifically describe the application of optical alignment to turbomachinery installation, but there are some very specific advantages to the method.

If we could eliminate all pipe strain, foundation settlement and could control climatic conditions at all times, our problems would be few. But since these variables can't be controlled, we must monitor the movements created by them.

With optics you can not only precisely align the machine, but you can check for temperature growth, foundation settlement and misalignment caused by pipe strain. So-called "hot" alignment can be done without shutting down the machine. The optical alignment technique can mean, for you, less down time and greater bearing life.

Aligning machinery with this optical technique is limited only by the user's imagination. The use of the laser in this type of work has, so far, been somewhat limited because of the lack of accessories, but research and development groups have recently engineered several new items, such as see-through targets and two-plane micrometers. Work is being done on several other accessories that will make the laser a practical instrument for many new applications.