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RETICLES AND THEIR USES

PROJECT NO. 9039

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EDMUND SCIENTIFIC CO.
Barrington, New Jersey

A reticle is a system of lines or wires situated in the focus of the eyepiece of an optical instrument. Perhaps the best known group of reticles are the cross-hairs of a telescope gunsight or surveying instrument. However, the most prevalent use of reticles occurs in the field of science, particularly microscopy, where extremely accurate measurements must be made.

RETICLE MANUFACTURE

The actual manufacture of a reticle might seem, at first, to be an easy job but actually the requirements are extremely rigid and the process considerably complex. The requirements demanded of a good reticle, such as those sold by EDMUND SCIENTIFIC CORPORATION, are outlined as follows:

1. It must be free from major blemishes - that is, the glass surfaces must not be scratched or marked in any way and the glass itself must be of optical quality.

2. The pattern lines must be fine enough for the requirement and, at the same time, be sufficiently visible. The finest lines on the highest quality reticles have a width of approximately one micron (1 micron = 0.000039 inches).

3. The dimensional accuracy must also be within the desired limits. For the majority of engineering instruments, an accuracy of 0.005mm is satisfactory. However, in special circumstances with a protractor reticle, the scale pattern should have a tolerance within 0.001mm.

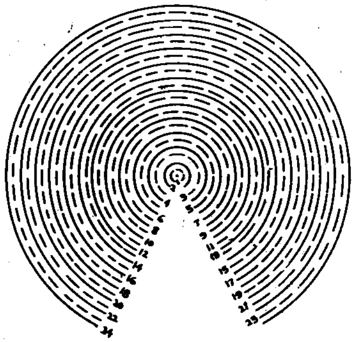
4. Since, in some cases, the reticle must appear as a bright pattern on a dark background, the background should be uniform in density.

5. Finally, the pattern must be durable. In most cases, the reticle pattern is protected by another clear piece of optical glass cemented over the surface of the reticle pattern.

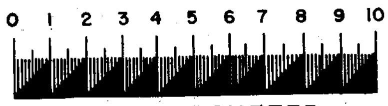
In general, reticles may be classified either according to their manufacturing process, or by their specific uses. Manufacturing processes vary to some extent, although the actual methods employed may be listed as follows:

MECHANICAL RULING - A diamond stylus used with an accurate ruling machine will produce line widths of about 0.0025mm. The lines so produced are generally filled with graphite or other fine pigment to make them visible. Lines of fine width usually cannot be made to hold the pigment satisfactorily, and the line widths are limited to about 0.005mm. With mechanical ruling, quantity production is limited by the considerable amount of wear produced on the diamond stylus.

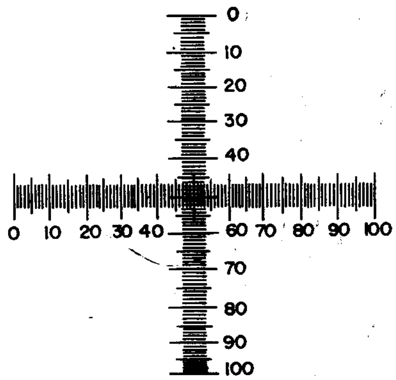
ETCHED RULINGS - With this process, the surface of the reticle blank is coated with a thin film of wax or other acid resisting compound and the reticle pattern traced through it. The clear areas are then exposed to hydrofluoric acid which eats into the glass and produces etched lines as



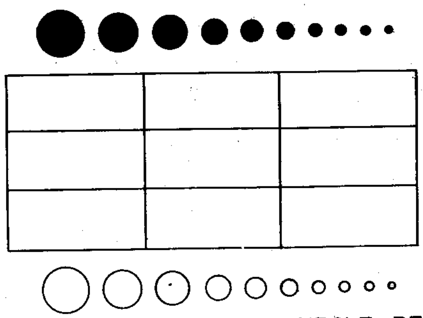
(A) CONCENTRIC CIRCLES
0.5mm TO 12mm



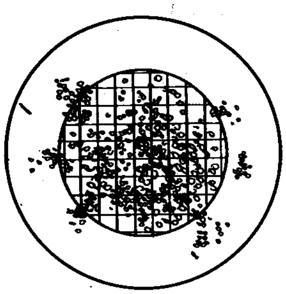
(B) STEP MICROMETER
100mm IN 100 PARTS



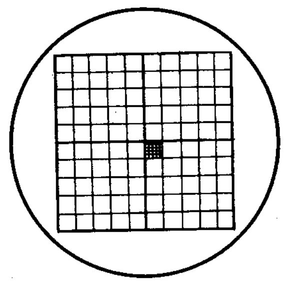
(C) CROSSED SCALES
100mm IN 100 PARTS



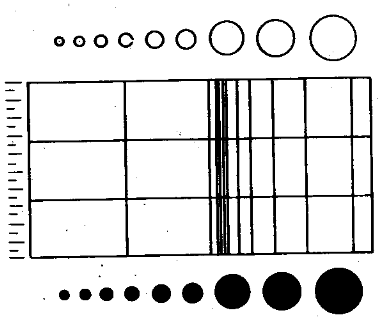
(E) THE PATTERSON GLOBE AND CIRCLE RETICLE



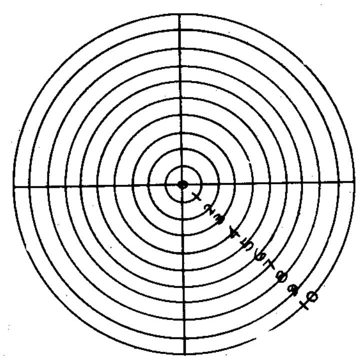
(D) THE HOWARD RETICLE



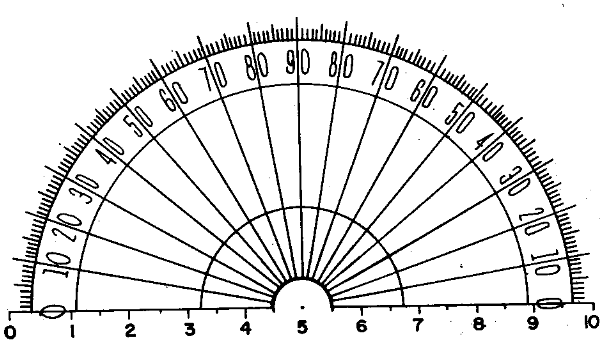
(F) THE WHIPPLE RETICLE



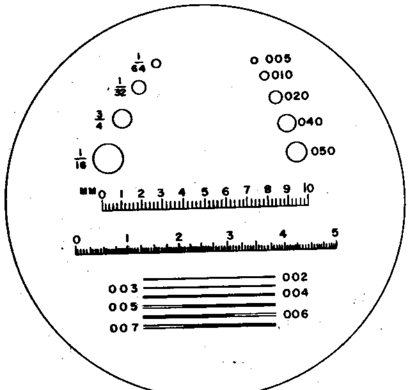
(G) THE PORTON RETICLE



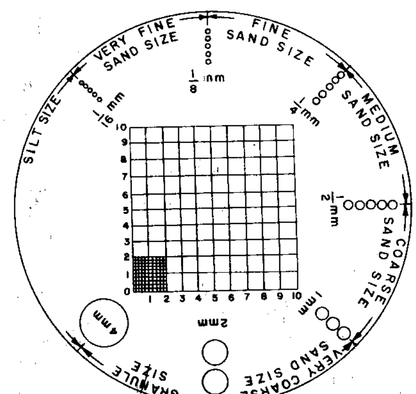
(I) THE FINDER RETICLE



(H) PROTRACTER HALF CIRCLE



(K) EDSCORP JR. COMPARATOR RETICLE



(J) EDSCORP GEOLOGICAL RETICLE

FIGURE 1 — TYPES OF RETICLES

fine as 0.005mm. After the etching process, the lines are generally filled with an opaque pigment to make them visible. Unpigmented etched lines, on the other hand, are mainly used when the pattern is to be illuminated from the edge of the reticle, giving the effect of bright lines on a dark background. Many of the reticles found in war surplus instruments are of this variety.

PHOTOGRAPHIC COPY - All ruling methods suffer from two defects, (1) each reticle must be ruled separately, and (2) only a limited number of pattern varieties are possible with a given ruling machine. Therefore, to obtain quantity production and higher precision, photographic methods of producing reticle scales are more generally used. An accurate large-scale drawing of the final reticle pattern is first made and then reduced to the desired size on transparent film. The final transparency is then mounted between two pieces of optical glass for protection. Methods of photo-etching have also been used with varying degrees of success. By photographic process, reticle-scale line widths as fine as one micron have been produced with a spacing of less than five microns, although the average line width runs about 0.001mm.

The specific uses of reticles are just as varied as is their manufactoring processes. They are used in many scientific fields such as Medicine, Textiles, Engineering and Nucleonics. In most cases, they are used as an aid in the measurement of an unknown distance by means of an optical instrument such as a microscope, or in a direct-measuring instrument such as a comparator. For example, in the Medical field, microscope reticles are used for blood count and bacteria count operations. In Textiles, they are used for checking fiber diameter and size graduation, while in Engineering, reticles are used for measuring small objects or as pointers in theodolites and transit levels. Reticles are also used in optical tooling instruments, such as an alignment telescope, for checking point-to-point alignment within 0.001 inch accuracy at distances up to 150 feet. Of course, the armed forces use reticles in their Ordnance equipment for fire control, such as range finders, gun sights and field binoculars.

TYPES OF RETICLES

As mentioned previously, the main use of reticles for scientific applications is in conjunction with microscopic instruments. These reticles are important since it would be impossible, or at least very difficult to measure the exact size of a minute object without them. The usual eyepiece reticle measures an average of 21mm. in diameter, and is designed to be placed directly in the microscope ocular. Such reticles may be classified as either "measuring" or "counting" discs - some of which are illustrated in figure 1.

Pure measuring discs such as the CONCENTRIC CIRCLES pattern, the STEP MICROMETER, the CROSSED SCALES pattern, and the PROTRACTOR HALF-CIRCLE pattern all have uses which are fairly obvious. The step micrometer is graduated with small, opaque "steps" or triangles for visual convenience, while the others are straight-forward line patterns.

On the other hand, the HOWARD reticle (figure 1D) is used for mold counting and, therefore, is a typical "counting" disc. It is ruled in squares for use with a standard 10X Huygen's ocular. Each ruled square has an area equal to one-sixth the diameter of the ocular field of view. The Howard reticle is used in conjunction with the Howard mold-counting chamber, and is generally employed for taking a mold count of food products.

The PATTERSON GLOBE AND CIRCLE reticle (figure 1E) is generally used for counting and measuring abrasives and dust particles. The PORTON reticle (figure 1G) is used for the same purpose, the only difference being the width of the counting rectangles on the left. These rectangles are varied in width in a non-linear fashion, as are the circle diameters, in order to be more discernible to the eye than the linear variations found with the Patterson reticle.

The WHIPPLE reticle (figure 1F) is mostly used for counting bacteria and dust particles. Such a reticle consists of a large square subdivided into four smaller ones as illustrated. In turn, each of the four squares is again subdivided into twenty-five additional squares. Two other counting discs (not illustrated) are the "Milk Smear" reticle and the "Net" reticle. The milk smear reticle, as the name implies, is used for counting the bacteria in milk. It has an 8.0mm. diameter circle which is divided into equal quadrants by a pair of cross lines. The net reticle usually consists of a 5mm. square which is further divided into millimeter or 0.5mm. squares. It is used for counting large materials such as coarse abrasives or the larger organisms.

The FINDER reticle, illustrated in figure 1I, is numbered from the center out with each division equally spaced. The main use for this type of reticle is to mark off a particular part of the field under observation for another person's attention. Used in this fashion, either the specimen is moved or the ocular rotated until the section in question is directly under one of the numbers.

Most of the above reticle types are, of course, not limited for use within a microscope ocular only, but may be used in an instrument when the need arises. Astronomical telescopes, for instance, would have a definite use for a "Crossed Scales" reticle when the relative position of celestial bodies must be determined. In general, however, telescopic reticles are primarily used as centering devices or finders, and as such, many variations are possible.

MOUNTING RETICLES

As mentioned previously, each standard microscope reticle is approximately 21mm. in diameter and designed to fit directly within the ocular. Figure 2 illustrates the method used to accomplish this. Figure 2A shows a reticle mounted in a standard Huygen's ocular, while figure 2B illustrates a reticle mounted in a Ramsden ocular.

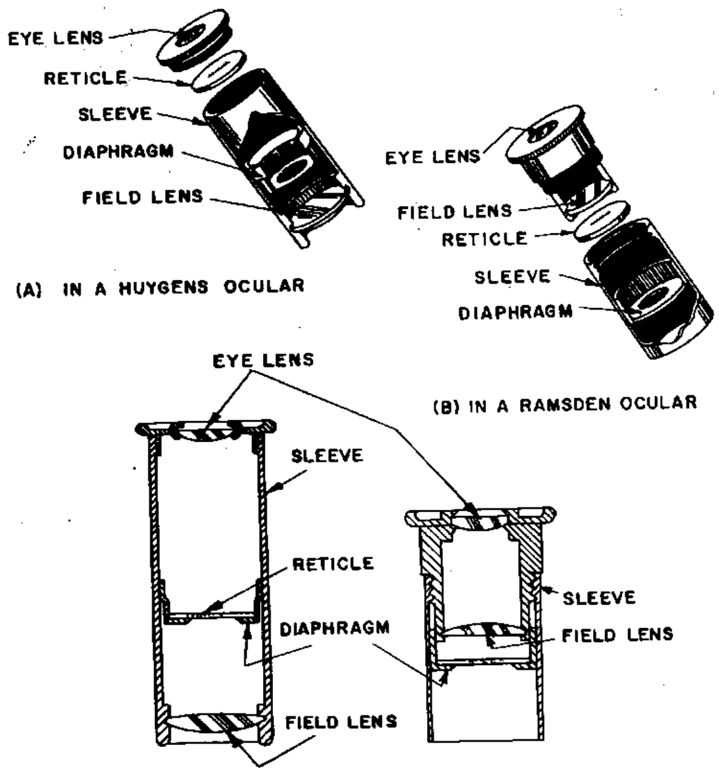


FIGURE 2 — MOUNTING RETICLES

In a Huygen's ocular, the focal plane lies within the ocular housing between the two lenses. Therefore, in order for the reticle to be in focus along with the object viewed by the microscope, the reticle must also be placed within the ocular as shown. The correct position is quite easily found, since with all oculars a diaphragm or field stop is always located at the ocular focal plane. In order to insert the reticle, simply remove the eye lens from the main ocular housing and place the reticle so that it rests directly on the diaphragm. With some microscope oculars, however, the reticle will not fit within the diaphragm as shown in figure 2 because its diameter may be too great. In this case, the diaphragm must be removed and inserted upside down and the reticle placed on top of the diaphragm cell.

With a Ramsden ocular, the focal plane lies just beyond the ocular field lens, and thus a reticle must be placed at the same location. With this type of ocular, the eye lens and the field lens are generally mounted together in a removable cell, just above the diaphragm location. To insert the reticle, remove the lenses from the main ocular housing and place the reticle on the diaphragm as shown in figure 2B.

Since the normal position of a microscope is vertical, no provision is normally made to hold the reticle firmly in place. However, if the microscope is to be used in a horizontal position, the reticle must be secured with a spring-wire retaining ring.

After a reticle is placed within a microscope ocular, the next step is to see if it is inserted correctly and in focus. First, look through the ocular toward a light-colored object. If the numbers on the reticle scale read backwards, the reticle is inserted upside down. If the numbers read correctly, but are blurred, then the position of the diaphragm must be adjusted to bring the scale into focus.

The direction in which to slide the diaphragm is most easily determined by gradually unscrewing the eye lens from the ocular body while viewing the reticle scale. If the scale becomes clearer, then the diaphragm should be moved away from the eye lens; while if the scale instead becomes more blurred, the diaphragm must be moved toward the eye lens. Remember, however, if you wear glasses and make this adjustment with your glasses on, the reticle scale will not be in focus when using the instrument with your glasses off. It is generally recommended to use a microscope with your glasses off, since the exit pupil of most microscope oculars is extremely short and your eye should be placed as close as possible to the ocular eye lens.

With the higher-power oculars (12X to 20X), it may be found that the diaphragm cannot be moved into the focal plane of the eye lens if it was inserted upside down to accommodate for the diameter of the reticle. If this happens, the only alternative is to use a smaller diameter reticle (approximately 19mm. for most ocular diaphragms) and reinsert the diaphragm in an upright position as illustrated in figure 2.

Although figure 2 relates to microscope oculars, the same principle may be used for most telescopic instruments as well. In this case, the reticle diameters are even more important, since telescope eyepieces vary greatly in size from instrument to instrument. The procedure here would be to first measure the diameter of the eyepiece diaphragm cell, and then obtain a suitable reticle. Of course, with a telescope, the reticle must be held in place with a spring retaining ring. High-power telescopes containing erector systems, however, are generally designed with their reticles located at the objective focal plane. This is especially true if the erecting system adds magnification to the telescope, and a reticle placed in any other position would have to be larger in size than if placed at the focus of the objective. This, then, is a problem concerning only those telescopes used for high-power terrestrial viewing, and can be completely disregarded with astronomical telescopes.

RETICLES AND INSTRUMENTS

Since the majority of reticle types are used in conjunction with microscopic instruments, the calibration and use of these types will be discussed first.

Before any reticle is used for measuring purposes, it must be calibrated in terms of linear measurement. This is true even though the physical length (and thus the distance between divisions) of the reticle scale is known. A microscope objective magnifies the image of a specimen and projects it onto the focal plane of the ocular. Therefore, a linear distance as measured at the image plane (at the reticle position) is not the same as the actual distance between similar points on the specimen.

If the exact magnification at the image plane were known, then there would be no trouble calculating the actual distance measured on the specimen. In this case, the actual distance measured would be equal to the distance measured at the image plane DIVIDED by the magnification of the image. However, there are many factors influencing the magnification obtained at the image plane which cannot be readily calculated. For example, with a standard Huygen's ocular, the image plane is separated from the objective by the ocular field lens, which may add to or subtract from the original objective magnification. Thus, the ocular reticle scale must be calibrated by using a standard measure located in the object plane of the microscope objective.

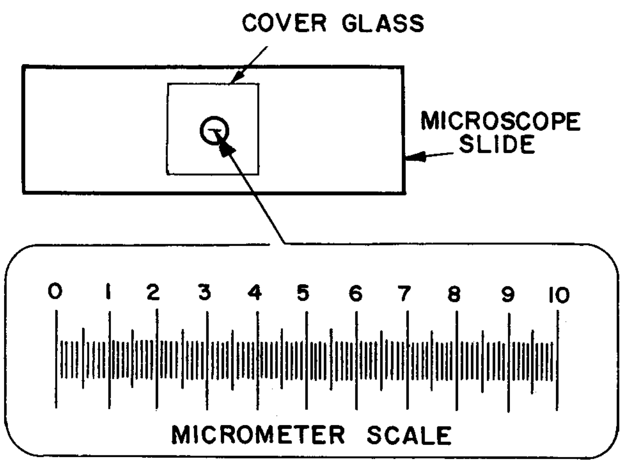


FIGURE 3 — STAGE MICROMETER

Figure 3 illustrates a typical standard measure used to calibrate an ocular reticle scale. This standard measure is called a STAGE MICROMETER, or more simply, a reticle scale mounted on a standard microscope slide and protected by a thin cover glass. The cover glass also serves another purpose - a good quality microscope objective is corrected for use with a standard cover glass, and without it, serious aberrations can be introduced.

The better stage micrometer consists of either an 0.1 inch scale divided into 100 parts (0.001 inch divisions), or a 1.0mm. scale divided into 100 parts (0.01mm. divisions). Of course, it is advantageous to have both types available, since either the English or the Metric system of measurement may then be easily used. In cases where the objective magnification is small (5X or less), a larger, more easily read reticle scale should be used. For this purpose, a stage micrometer consisting of a 10mm. scale divided into 100 parts (0.1mm. divisions) is most commonly used.

When in use, a stage micrometer is placed on the object stage of the microscope, directly in the field of the objective. The ocular containing the reticle to be calibrated is then inserted in the microscope and the scope focused on the stage micrometer. After careful focusing, a view similar to that illustrated in figure 4 should be seen. Before attempting to calibrate the ocular reticle scale, make sure the objective image is focused exactly with no parallax existing. Parallax occurs when the objective image and the ocular reticle are not exactly in the same plane, and can only be detected by moving the eye back and forth slightly in front of the eye lens. If one scale moves relative to the other, a slight focusing adjustment should be made.

When the stage micrometer scale has been into exact coincidence with the ocular reticle scale, the stage micrometer should be moved so that its zero line coincides with the ocular reticle zero line as shown in figure 4. In the illustration, the ocular reticle scale consists of 100 equal divisions, the actual physical distance between divisions being of little importance, as will be seen later. The magnified image of the stage micrometer scale is shown in the upper portion of the field of view in figure 4. For this example, the stage micrometer scale illustrated consists of a 10mm. scale divided into 100 parts, although the same principle may be used with any type of stage micrometer.

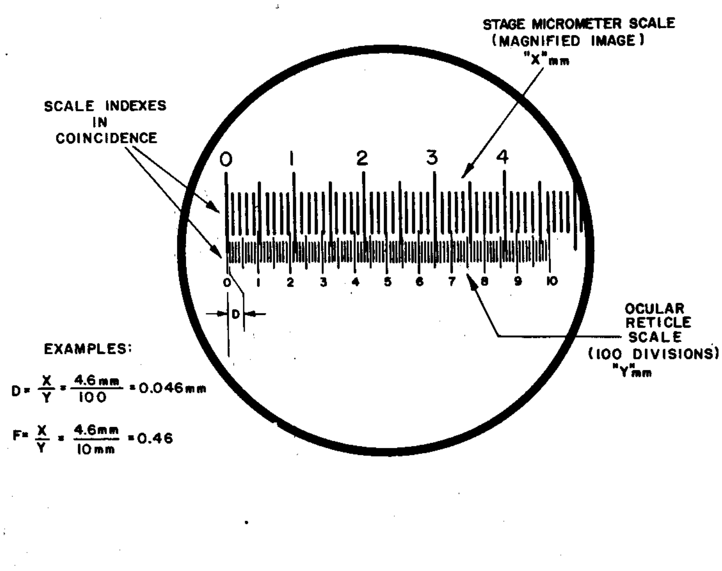


FIGURE 4 — RETICLE CALIBRATION

With the example shown in figure 4, 100 divisions of the ocular scale correspond to 46 divisions of the stage micrometer scale, or 4.6mm. Thus, the apparent distance "D" between each reticle scale division is equal to 4.6mm. divided by 100, or 0.046mm. This, then, is one method of calibrating an ocular reticle scale, and the general rule is as follows:

THE APPARENT DISTANCE "D" ON THE OCULAR RETICLE IS EQUAL TO THE STAGE MICROMETER READING (X), DIVIDED BY THE NUMBER OF DIVISIONS (Y) ON THE OCULAR RETICLE CORRESPONDING TO THE STAGE MICROMETER READING. Expressed mathematically, this rule becomes

Apparent Distance "D" = X/Y (in units of X)

In order to measure a specimen with a reticle calibrated in this fashion, simply multiply the reticle scale reading by the apparent distance "D". For example, if the apparent distance between each division of the reticle scale were equal to 0.46mm., and a certain specimen measured 51 divisions in length, the actual length of the specimen would be equal to 51x0.46mm., or 2.346mm. In actual practice, it is more convenient to adjust the position of the microscope draw tube for more or less magnification in order to make the apparent distance an easily remembered number. In the example of figure 4, the apparent distance is 0.046mm. However, by extending the microscope draw tube for more magnification, the right-hand end of the ocular scale can be made to correspond with 4.5mm. or even 4.0mm. on the stage micrometer. This extra magnification would then result in apparent distances of 0.045mm. and 0.040mm., respectively. Similarly, the draw tube could have been contracted to make the ocular scale cover a distance of 5.0mm. on the stage micrometer with a resulting apparent distance of 0.050mm.

Another method for calibrating an ocular reticle scale, and which is used mainly in the engineering field, depends upon the actual physical lengths of both the calibrating and eyepiece scales. Suppose, in our example of figure 4, that the ocular reticle scale was also 10mm. long and divided into 100 parts. Thus, a distance of 10mm. as read on the ocular scale corresponds to a distance of only 4.6mm. on the stage micrometer scale. The distance read directly from the ocular scale would then be greater than the actual distance seen, and must be multiplied by a factor of 4.6/10, or 0.46, in order to obtain the correct measurement. This, then, is the second method of calibrating an ocular reticle scale, and the general rule is as follows:

TO OBTAIN THE MULTIPLYING FACTOR (F) WHEN THE DIMENSIONS OF BOTH SCALES ARE KNOWN, DIVIDE THE DISTANCE READ ON THE STAGE MICROMETER BY THE CORRESPONDING DISTANCE READ ON THE OCULAR SCALE. Expressed mathematically, the second rule becomes:

Multiplying Factor "F" = X/Y

To measure a specimen with an ocular reticle calibrated in this fashion, read the distance directly on the ocular scale and multiply it by the factor "F". Using a value of 0.46 for "F", for example, the actual length of a specimen measuring 5.1 millimeters on the ocular scale would be equal to 5.1mm. x 0.46, or 2.346mm. It will be noticed that this is the same answer as obtained above using the first calibrating method, and thus either method is satisfactory. Here again, in order to obtain a more easily handled multiplying factor, the microscope draw tube should be adjusted as mentioned above.

It should be emphasized that each combination of ocular reticle, ocular, and objective will vary the calibration of the reticle. Thus it is recommended that the calibration of each reticle be checked before any great amount of measuring is attempted.

<u>Measuring With A Microscope</u> - A major requirement when measuring any small object with a microscope is good resolving power in the optical system used. Magnification is also important, but the necessary amount of magnification depends entirely upon the resolving power of the microscope objective. The resolving power of a microscope objective is, in turn, dependent upon its numerical aperture (NA). The numerical aperture of a given objective is a measure of the maximum cone of light which the objective can intercept and project to the eye. Thus when measuring the distance between two points of a certain specimen, there is a minimum distance between these two points below which they will appear to merge together, despite any further magnification. This minimum distance is called the resolving power of the objective. The resolving power of several EDSCORP microscope objectives is given in table I.

Table I. Resolving Power

Obj. Power	NA	Resolving Power	
5X	0.1	0.00014"	0.0035mm.
10X	0.25	0.00005"	0.0013mm.
40X	0.65	0.00002"	0.0005mm.
60X	0.85	0.00001"	0.0004mm.

For example, if it is desired to measure an object with a tolerance of 0.0005mm., then it is necessary to use an objective whose NA is equal to at least 0.65. The next step is to determine the ocular power required for the eye to be able to discern such a dimension. That is, the overall magnification must be large enough for the eye to see the finest detail resolved by the objective.

The average human eye can resolve detail subtending an angle of not less than 2 minutes of arc at the eye. This simply means that, when viewed at a distance of 10 inches, two lines 0.15mm. apart are seen as two separate lines. However,

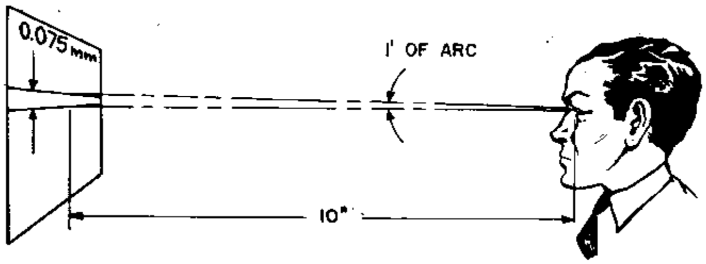


FIGURE 5 — PRACTICAL LIMIT OF RESOLUTION

a trained observer can often resolve detail smaller than this, as shown by figure 5. Thus, an angle equal to 1 minute of arc is often called the practical limit of resolution for the human eye. The microscope ocular magnification must, therefore, provide an image (of the finest detail resolved by the microscope objective) which subtends an angle of 1 minute or greater. Table II lists ocular magnifications recommended for several EDSCORP objectives.

Table II. Ocular Magnifications

Obj. Power	NA	Min. Mag.	Recommended-ed Ocular	Useful Mag.
5X	0.1	20X	5X to 12X	25X to 60X
10X	0.25	60X	8X to 20X	80X to 200X
40X	0.65	140X	5X to 10X	200X to 400X
60X	0.85	180X	5X to 15X	300X to 900X

For example, if an objective having a NA of 0.65 is used, the minimum magnification, in order that the eye may resolve the same detail as the objective, is 140X. In practice, an overall magnification of two to three times this figure is used for more comfortable vision, and the recommended oculars lie between 5X and 10X. If the magnification is increased still further, no finer detail will be seen and the image will appear to be less sharp. Thus, for each objective there is a useful range of magnifications above which and below which the visual image will suffer.

Counting - When it is desired to count the number of objects seen in the field of view of a microscope, a "counting disc" must be used. Since all counting procedures are similar, only one example will be given here - that is, the number of bacteria and cells contained in fresh milk. The actual method used for preparing the microscope slide will only be outlined generally because we are primarily interested in the method of counting.

To prepare a milk-smear slide, the following method may be used:

1. Make a drawing of a standard microscope slide with a square whose area is equal to one square centimeter drawn in its center. Place a clean glass slide over the drawing and drop over the center of the small square exactly 0.01 cc of milk. With a stiff straight needle, spread the milk over the area (one square centimeter) of the small square.

2. Dry the smear by applying gentle heat, fix and stain to a light blue by using 95% alcohol and methylen-blue stain.

For counting the number of bacteria, an ocular reticle having a circle ruled into equal quadrants is recommended, and an objective having a numerical aperture of at least 0.85 must be used. Here again, the ocular reticle must be calibrated with the use of a stage micrometer.

First, determine the apparent radius of the reticle circle and calculate its area in square millimeters. Then the factor necessary to transform the number of bacteria counted within the perimeter of the reticle circle into terms of bacteria per cubic centimeter may be found by the expression

$$\text{Conversion Factor "Y"} = 100X/A$$

where

X = The area of the milk smear in square millimeters.
A = The apparent area of the reticle circle in square millimeters.

To determine the number of bacteria per cubic centimeter of milk, count the number in one quadrant and multiply this figure by the number of quadrants. Do this for several different microscope fields by moving the specimen and observing another section of the milk smear. Obtain an average figure from the fields counted and call this the average number of bacteria counted within the perimeter of the reticle circle. Multiply this average figure by the conversion factor "F" to obtain the number of bacteria per cubic centimeter. For those who are interested, table III lists the bacteria and cells which may be found in different types of milk.

Table III. Milk Analysis Standards

Milk Quality (Grade A)	Bacteria Per Reticle Field	Bacteria Per c.c.	Tissue Cells	Cell Count Per c.c.
GOOD	NONE*	NONE	2	800,000
FAIR	5	2,000,000	1	400,000
SOURING	200	80,000,000	1	400,000
POOR	250	100,000,000	7	2,800,000

*In comparatively fresh milk, the bacteria are few, and the whole smear should be searched.

In order to "count" anything with a microscope, therefore, it will be seen from the above example that it is necessary to know the area of the specimen as well as the apparent area of the reticle circle. Likewise, the total amount of specimen within the slide area must also be known - i. e., how many cubic centimeters, ounces, or grams. Then, by using a method similar to that shown above, the total count per c. c., per ounce, or per gram may be calculated quite easily. Where the objects to be counted vary greatly in size, then a reticle such as the Porton reticle may be used to classify the different sizes, as well as to determine their number.

Up to this point, we have discussed the uses of reticles with a standard microscope - that is, with a microscope constructed in a conventional manner. However, specially designed microscopes such as Profile Microscopes, Introscopes, Comparators, and Scale-Reading Microscopes depend entirely upon the observation of a reticle scale or scales. The EDSCORP DIRECT-MEASURING MICROSCOPE is an example of this type of instrument. These instruments are used to measure items which would be rather difficult to measure in any other way, and under extremely accurate tolerances.

Reticles and Telescopes - As is commonly known, reticles are used in telescopic instruments primarily for the purpose of centering the telescope on a distant object. When used in this fashion, the type of reticle scale is not particularly important so long as it fills certain general requirements. Such requirements may be outlined as follows:

1. The scale must be easily visible against the intended target.
2. The reticle should be optically, as well as mechanically, centered within the instrument. This, of course, depends upon the centering of the optical components, which sometimes are not centered mechanically.
3. If the instrument is intended to be used by more than one person, some provision must be made to bring the reticle scale into focus to suit individual observers.

Since the above general requirements may be considered problems of initial design, they will not be discussed in this booklet. However, there are many interesting applications for telescopic instruments utilizing a reticle scale or scales. In the majority of engineering applications a telescope is used as an Optical Pointer in which the pointer (the optical axis of the telescope) is displaced a known amount. The amount of displacement is measured by another telescopic instrument known as a collimator.

An optical pointing system consists, therefore, of a telescope, a collimator, and several types of reticles. One of the reticle scales is a simple cross hair designed to be used within the telescope. The others are equipped with scales divided into inches, angles, or other patterns, and are used in the focal plane of the collimator objective. In practice, the telescope and collimator are mounted on separate fixtures and the telescope focused on the reticle scale of the collimator. In this way, a direct line of sight is provided which acts as a base line or reference line from which various fittings may be accurately positioned. Auxiliary parallel, vertical, horizontal, and angular lines may also be established from such a reference line.

Other instruments such as Scale-Reading Telescopes, Optical Micrometers, Optical Squares, and Direct-Measuring Telescopes also use reticle scales for measuring purposes. These telescopic instruments can be used at various distances, from under two to over 150 feet, with tolerances as close as 0.001 inches and about 6 seconds of arc. Therefore, it will be seen that telescopic instruments can be used with reticles in a similar manner as microscopic instruments.

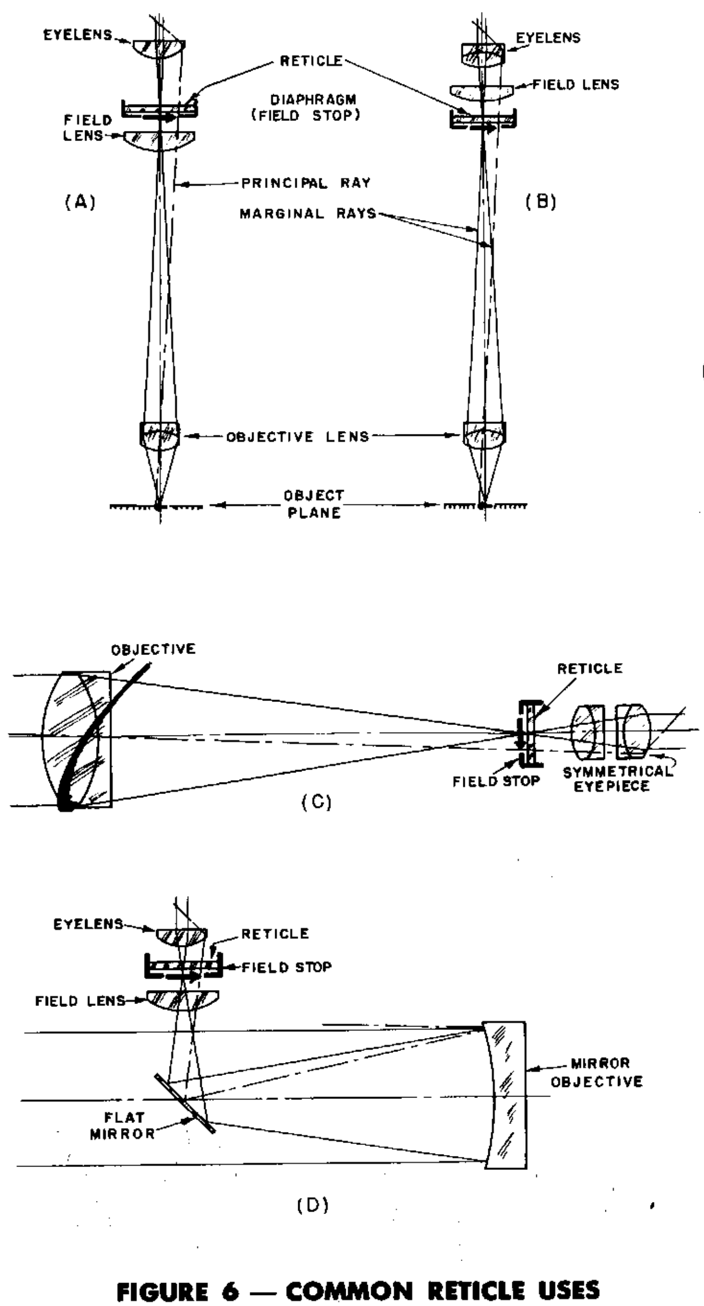


FIGURE 6 — COMMON RETICLE USES

Designing Instruments With Reticles - Figure 6 illustrates several representative optical layouts of instruments using reticles as part of their system. Figure 6A shows a standard microscope with a negative, Huygen's ocular. The correct position of the reticle is indicated on the drawing. On the other hand, a microscope using a positive, Ramsden ocular is shown in figure 6B. Note that the reticle is located on the objective side of the field lens in this case. These are the only two positions in which a reticle can be inserted within a standard microscope and, in most cases, within any microscope.

An astronomical telescope using a reticle in conjunction with a symmetrical eyepiece is shown in figure 6C, while figure 6D illustrates the correct reticle position for a reflecting telescope using a Huygen's eyepiece. In any telescope, the reticle must be located in coincidence with a real image. Thus, with a terrestrial telescope having an erecting system of lenses, there are TWO possible locations for a reticle as shown in figure 7.

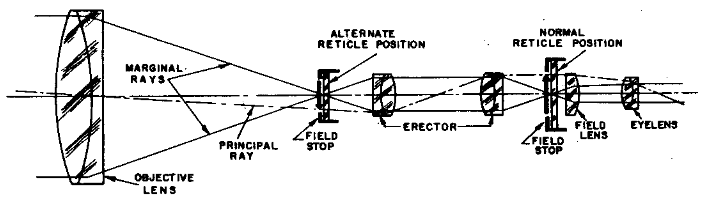


FIGURE 7 — RETICLE POSITIONS IN A TERRESTRIAL TELESCOPE

However, a reticle CANNOT be used with a Galilean telescope, since the objective does not form a real image but only a virtual image. If a prismatic erecting system is used with an astronomical telescope, the reticle must be located in the object plane of the eyepiece since, here again, only one real image will be formed.

Figures 8A through 8D illustrate some special measuring instruments used mainly for engineering purposes. A Scale-Reading Microscope is shown in comparison to a Scale-Reading Telescope in figures 8A and 8B. Direct measurement to 0.00005 inch is possible with the microscope by moving one reticle scale in relation to the other with a micrometer screw adjustment. The Scale-Reading Telescope is used when the scales to be read are inaccessible with a microscope. Readings to 0.001 inch may be obtained with this instrument at distances up to about 20 feet.

The optical layout of a collimator is shown in figure 8C. It will be seen that the reticle scale is located in the primary focus of the objective lens. Thus the objective forms an image of the reticle scale at infinity. A telescope focused at infinity and placed in line with the collimator will form an image of the collimator reticle scale in the plane of its own cross hair. The image formation is independent of the distance between the telescope objective and the collimator objective. Collimators are used as targets for optical pointers as mentioned above; to determine the field and magnification of telescopes; and to align, test, and adjust many types of optical systems.

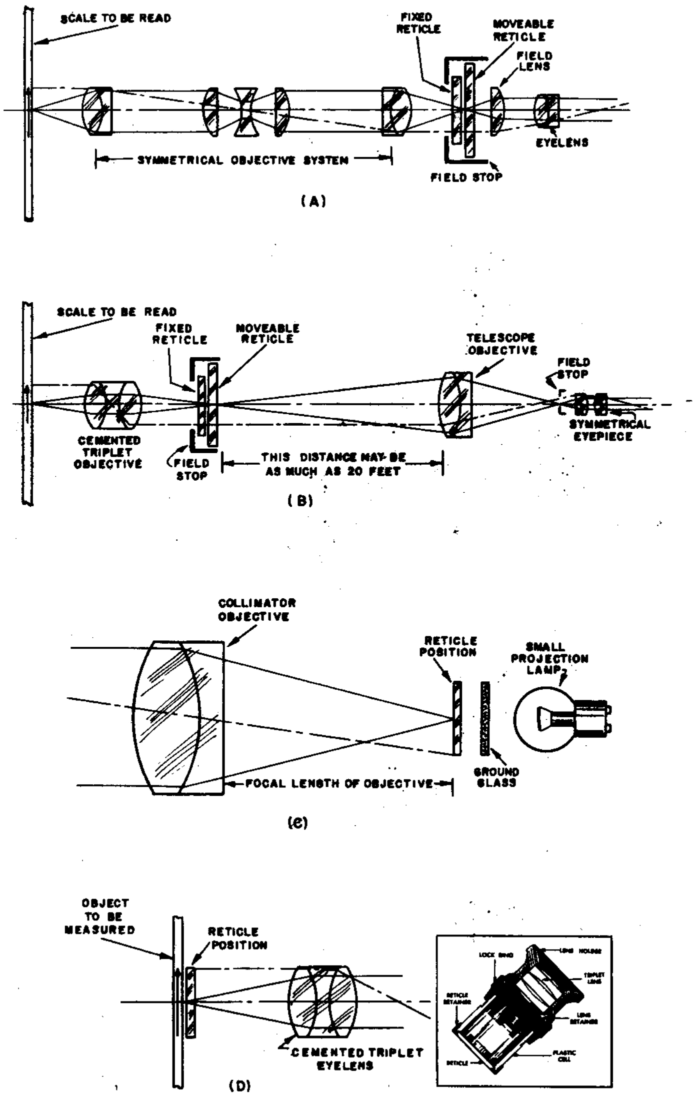


FIGURE 8 — SPECIALIZED RETICLE USES

Figure 8D illustrates the general optical system of a comparator, such as the EDSCORP POCKET COMPARATOR. Essentially, this type of measuring instrument consists of a positive eyepiece used to view a reticle scale. As shown, the reticle scale is usually placed in direct contact with the object to be measured. Direct-measuring comparators rely on the eyepiece for magnification, and therefore, the eyepiece must have exceptional optical qualities. Spherical aberration, chromatic aberration, and distortion must be held to a minimum, and the depth of field should be great enough to allow for slight differences in the reticle and object planes. Since a comparator is an adaptation of a positive ocular or eyepiece, it may be used as such in telescopic or microscopic instruments in the same fashion as a standard ocular. However, the quality of the image viewed will normally exceed the quality of the image obtained with standard oculars. At certain times, a field lens placed between the comparator scale and the objective may have to be used in order to intercept the principal rays from the edge of the objective field.

For those interested in furthering their knowledge on optical measuring instruments, the following books will be helpful:

Stock No. 9214, "Engineering Optics" by Habell & Cox. 411 pages. $7.50 postpaid.

Stock No. 9201, "Fundamentals of Optical Engineering" by D. H. Jacobs. 487 pages. $6.00 postpaid.

Stock No. 9202, "The Principles of Optics", by Hardy & Perrin. 632 pages. $8.50 postpaid.

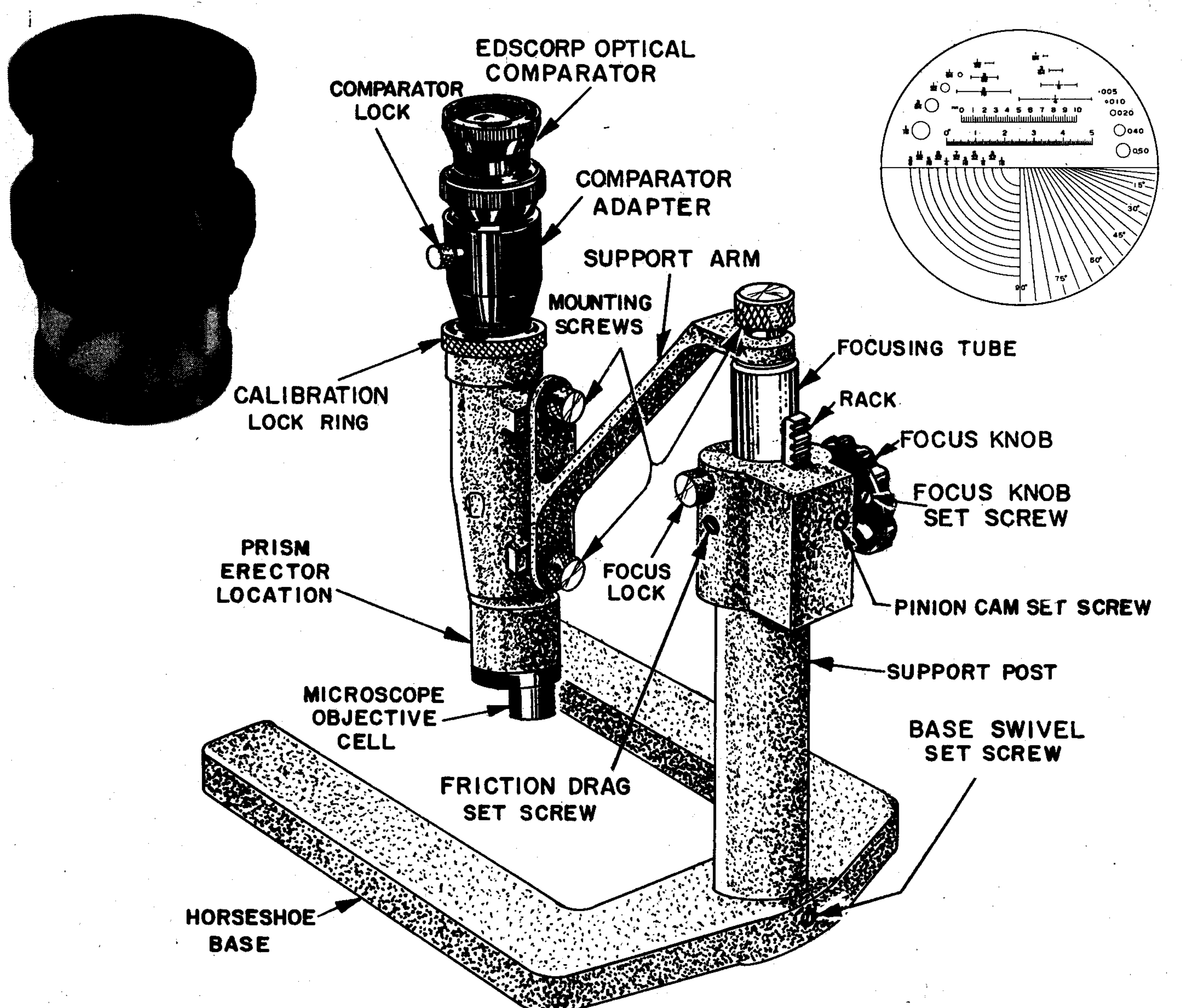


FIGURE 9 — THE EDSCORP MEASURING MICROSCOPE WITH COMPARATOR