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GEODETIC LEVEL AND ROD

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INTRODUCTION

The instruments used in geodetic leveling, while similar in general characteristics to those used for leveling of a lesser degree of accuracy, nevertheless differ considerably in the details of their design. Several things have to be considered which can be overlooked in instruments of lesser caliber, such as effects of comparatively small changes of temperature, fineness of fit of mechanical parts, quality of optics, and accuracy of calibration. The instruments described in this publication have been used by the Survey for many years, during which time various improvements have been made, but in general the essential characteristics and basic design of the original instruments have been retained. The merit of these instruments has been proven through years of use in the field, and they have been widely copied by other governments and by private organizations.

The purpose of this publication is to furnish a sufficiently comprehensive description of these instruments so that the fundamentals of their design and methods of construction may be made clear. In considering them, it is of value to appreciate the quality of work which they are called upon to perform. The bubble vial in the more common type of level is seldom more accurate than 10 seconds of arc per 0.1-inch graduation; whereas, in the Survey's geodetic level, the bubble is more than four times as sensitive, ranging from 1.7 to 1.9 seconds of arc per 2-millimeter graduation (0.08 inch). The rod used in conjunction with this level is so designed that variations of temperature have a minimum of effect, and the graduations are of a high degree of accuracy.

The Survey's lines of levels are extended to great distances, and the requirements are that the probable accidental error must not exceed ±1 millimeter per kilometer, regardless of the topographical characteristics of the country over which the operations are carried on.

GENERAL DESCRIPTION OF LEVEL

Two forms of the leveling instrument are shown in this publication. That illustrated in figure 1 shows the level as originally designed when put into service in 1900. Many of these early instruments are still giving satisfactory service; but in figure 2 is shown a more modern development of this level, which has various features which make it more convenient to use and superior in certain mechanical characteristics.

The elements which cause these levels to differ from the more customary instruments are:

1. The vertical micrometer screw adjustment of the telescope, and the mounting of the telescope on conical pivots placed directly over the vertical axis.
2. The sensitivity of the bubble, which is from 1.7 to 1.9 seconds of arc per 2-millimeter graduation.

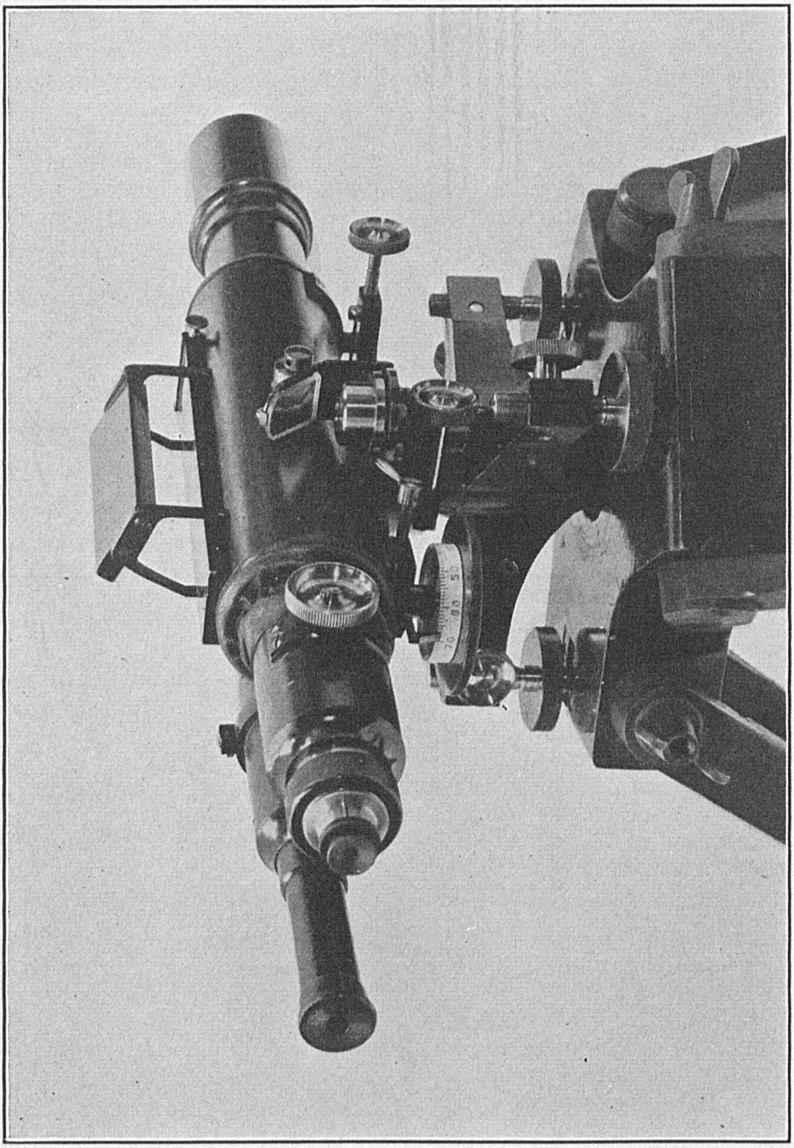

FIGURE 1.—Design of original level.

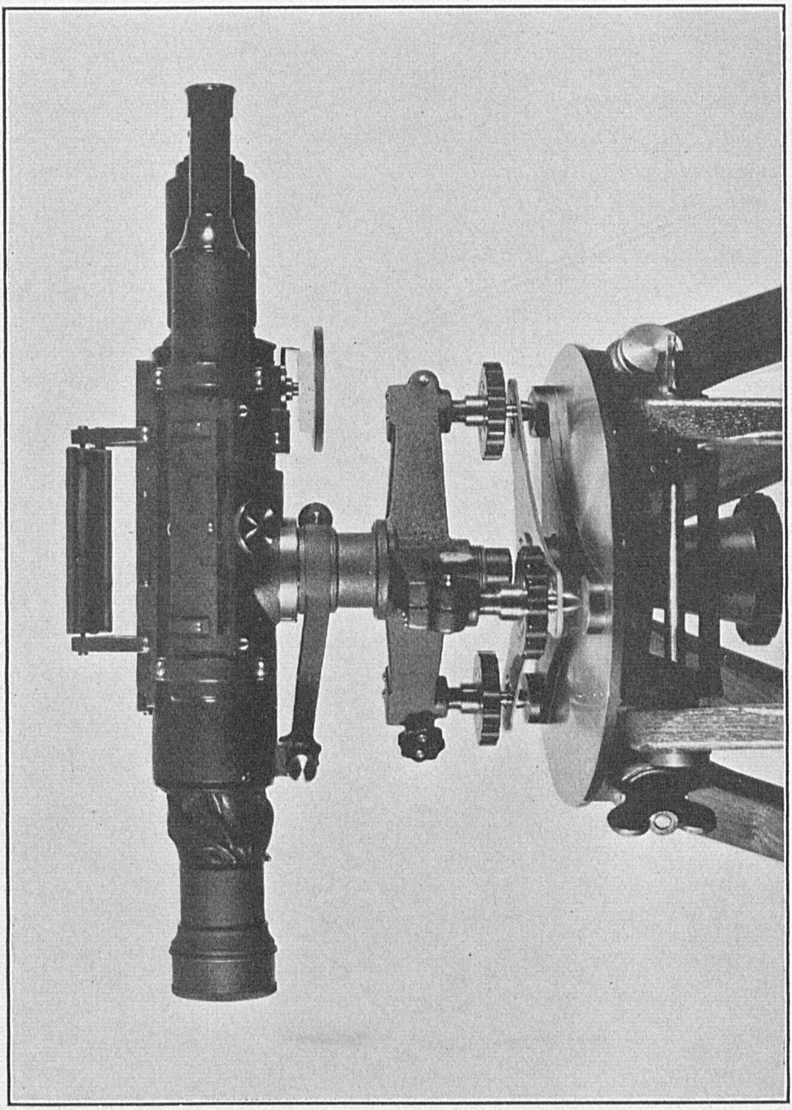

FIGURE 2.—Geodetic level—Model of 1934.

3. The construction of the telescope of a material having a low temperature coefficient of expansion, to prevent or minimize uncorrected errors due to uneven heating of the parts of the instrument.

4. Reading of the bubble from the eyepiece end, so that observations upon the bubble and the rod will be simultaneous.

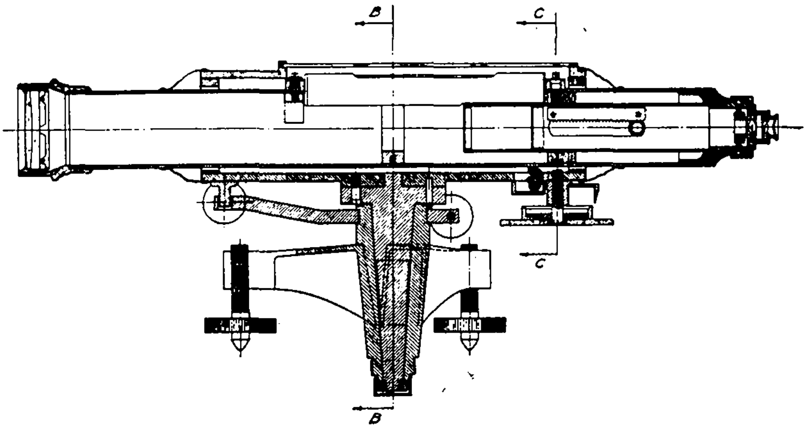

FIGURE 3.—Cross section through assembly of level.

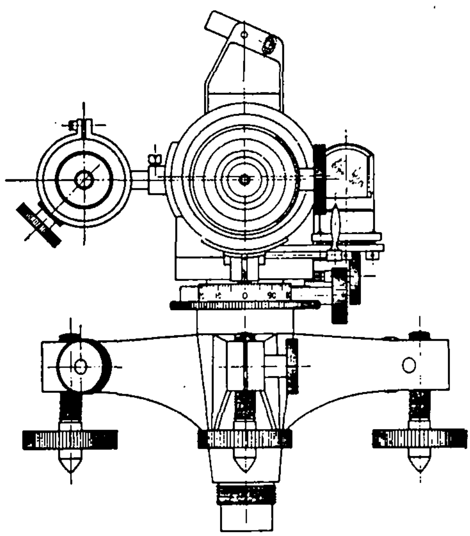

FIGURE 4.—Eyepiece view of level assembly.

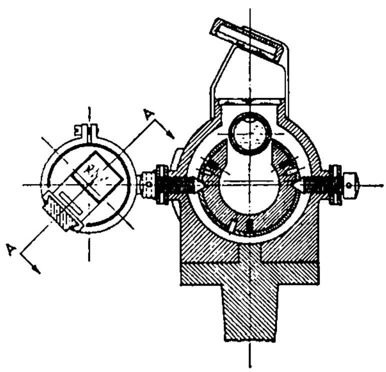

FIGURE 5.—Section of assembly at B—B (indicated in Fig. 3), showing pivot mounting of telescope.

5. A powerful telescope with large-size objective, giving better field of view, high magnification, and sharpness of image, so that long sights may be made without sacrifice of accuracy.

THE TELESCOPE

All metal parts of the telescope with the exception of the eyepiece assembly and its holder, in which variation in size due to change in temperature would affect the accuracy of the observations, are made of invar in the case of the instrument shown in figure 1, or of stainless steel in the instrument shown in figure 2. This includes the reticule ring and the bubble-vial holder, as well as the adjusting screw for the latter. It is considered desirable that the temperature coefficient of expansion be kept at approximately 0.000001 per degree centigrade.

The telescope is mounted on cone-shaped pivots placed directly over the vertical axis so that the tilting of the telescope when adjusting by the micrometer screw will not change its elevation with respect to the earth. The level-vial holder is mounted in an opening in the top of the telescope body, and placed as near to the optical axis as is possible without interfering with the vision. The body of the telescope is either ground truly cylindrical or is provided with two raised rings, one near either end, which are ground true, for the purpose of facilitating the adjustment of the optical axis to coincide with the geometrical axis. This operation is performed with the telescope dismounted from the rest of the instrument and placed in the wyes of a testing fixture, observation being made upon a suitable collimator.

The objective lens has a clear aperture of 42 millimeters and an outside over-all diameter of 44 millimeters $^{+0.0}_{-0.2}$ millimeters. The focal length is 410 millimeters ±10 millimeters. The lens is of the achromatic type with its elements cemented together with stick balsam, and its outer diameter ground true with its optical center. Two Steinheil eyepieces of 9½ and 12½ millimeters focal length are provided to give magnifications of 43 and 32 diameters, respectively.

The vial is of the chambered type to permit regulation of the length of the bubble, as temperature conditions may require. The graduation lines are 2 millimeters apart, and each division represents an arc of from 1.7 to 1.9 seconds. The vial is mounted in a tube of the same material as the telescope, and is held in place by cork rings which are sufficiently resilient to permit such slight longitudinal expansion as may occur, without setting up strains which might cause a change in its curvature.

The holder is supported at one end by two pivot screws which permit the adjustment of the axis of the vial into parallelism with the line of collimation in the horizontal plane.

A square-headed, fine-pitched screw, also of the same material as the body of the telescope, passes through the other end of the holder with a shoulder which forces the holder down against two stiff helical springs, fitting in recesses in the telescope. This screw is for the purpose of adjusting the vial so that its axis is parallel to the line of collimation in the vertical plane.

THE BODY

The housing or main body of the instrument, is a casting of any suitable material, such as cast iron, or preferably bronze. This part carries the pivots on which the telescope is supported, the bearing of the micrometer leveling screw, and the bubble-reading device. (See Figs. 5, 6, and 7.)

A polished tapered steel vertical axis is attached to this housing, rotating in a cast-iron socket cast integral with a 3-armed leveling head. It is essential that the vertical axis have a carefully ground shoulder at the top which shall bear upon the top of the socket in such a manner as to take the thrust of the weight of the rotating elements, and at the same time the tapered part must correctly fit in its bearing to serve its purpose as a guide. No other thrust bearing is required, but a nut at the bottom prevents the telescope assembly from falling out in case the instrument is inverted. This nut in the normal position must not touch the leveling head in any way. A lug is attached to the lower front end of the body to furnish a bearing for the slow-motion tangent screw.

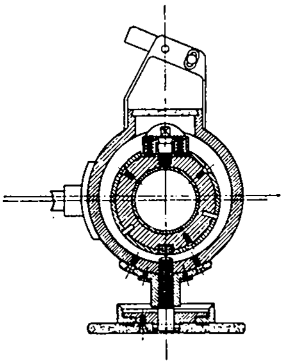

FIGURE 6.—Section of assembly at C—C (indicated in Fig. 3), showing micrometer screw.

At the rear of the body is located a small eccentric which may lift the telescope, by means of a small external lever, away from the point of the micrometer screw, forcing it against a stiff spring in the top of the housing. The eccentric bears against the lower side of the telescope, and is used to avoid damage to the point of the micrometer screw when the instrument is being transported. For the approximate leveling of the instrument, a small spherical level-bubble is attached to the side of the body with a 45° glass or metallic reflector, so that the bubble may be observed upon from the eyepiece end of the instrument. The telescope and vial are protected from dust and dirt by means of a thin flexible leather shroud held to the telescope and housing by means of thin metallic clamping bands. This leather is of fine quality and is usually made of what is known as sheepskin skivers, such as are used in the manufacture of organ bellows or similar musical instruments.

The opening over the level vial, through which it is observed upon by the reading device, is enclosed by a tight-fitting glass plate to keep out dust and dirt.

THE LEVELING HEAD

The 3-armed head is of cast iron with wide-spreading legs. On the original instruments, the radial distance is about 3⅝ inches from the center of the leveling screws. On the new instrument, as shown in figure 2, the radial distance is 3½ inches, and the size of the leveling screw has been standardized at one-half inch with a 32-pitch United States standard form thread. The ends of the legs are split with a narrow saw cut to permit clamping, and on the new instrument, the leveling screws do not extend through this leg at any position. The threaded hole is covered with a thin metal plate to keep out dust and dirt. This is attached to one side of the leg only.

The leveling screws are of steel, preferably stainless steel, and are fitted with 2-inch diameter fluted hard-rubber thumb wheels which provide adequate leverage for turning, the flutes permitting a firm grip to be obtained without undue discomfort in cold weather.

LEVEL-READING DEVICE

It is of the utmost importance that the reading of the rod be made at the instant when the level indicates horizontality of the line of sight. Accordingly, a prismatic reading device, shown in figure 7, which is a modification of that used by Berthelemy, was designed. It consists of two 45° prisms mounted upon sliding brackets connected to a knob by a linkage in such a manner that the distance between them can be varied to accommodate for variations in the length of the bubble due to temperature or barometric changes.

The faces of the prisms directed toward the eye are ground to such curvatures as will bring the images of both ends of the bubble to a common focal plane. For the benefit of the observer who may need to wear glasses, the eye cap is arranged to hold a lens which will enable him to observe without them.

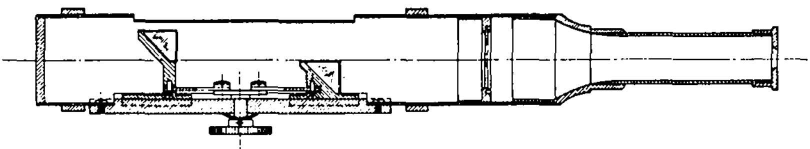

FIGURE 7.—Section of bubble-reading device at A—A, indicated in Figure 5.

The entire reading mechanism is mounted in a tube and attached to the side of the body of the instrument, and a mirror is held on brackets over the vial in such a way as to reflect the image of the bubble into the prisms.

The reading tube is adjustable for varying interocular distances to accommodate the individual observer.

THE TRIPOD

The tripod is of such height that the user can readily observe through the telescope without stooping or in any way cramping the body. This is of importance in the speedy conduct of the work.

Two styles of tripod are used, one for the older instrument and one for the new. In the old-style tripod (see fig. 1), the instrument is fastened by means of a thumb screw threading onto an extension of the center part of the leveling head. This forms a rigid clamp, but applies tension to the main body of the leveling head directly at the vertical axis with a theoretical deformation of this part. The legs, which are of second-growth white ash, are attached to the tripod head by means of bolts passing through suitable holes, and must be tightened firmly to prevent play in the bolt holes.

In the newer tripod (see fig. 2), the level is fastened to it by means of a 3-armed flat steel spring which, by means of elongated holes, slips over the enlargements on the ends of the leveling screws. The screws must be removed from the level in order to attach this spring, and when in place the spring cannot be lost off. A large thumb nut in the tripod head is attached to a threaded hub at the center of the spring and applies the necessary tension, the advantage of this newer style being that no stress is introduced into the leveling head, and there is no possibility of deformation of the bearing surfaces.

In both instruments, the leveling screws rest, one in a cup-shaped depression, a second in a radial V-shaped groove, and a third rests on a plane surface, thus eliminating any possibility of improper seating of the instrument due to differences in position of the leveling screws in different instruments.

The new tripod has a different method of attaching the legs, ball-shaped metal plates being attached to the wood which fit into similar hollows in the head, and these are pulled together by the tension of a bolt, which is similar to that used on the old tripod, the difference being, however, that the rigidity of the tripod is not dependent upon the quality of the fit of a bolt in a hole, there being instead a metal-to-metal joint.

The old-style tripod head is made of a 7-percent silicon alloy of aluminum, whereas the new style of head is made of a high tensile strength duralumin.

THE RODS

The rods are always used in pairs. One of these is shown in figures 8 and 9, and consists of a graduated metallic strip securely attached to a metal foot piece, the latter being fastened to a wooden backing which supports the strip. The wooden part of the rod is 1⅛ inches thick by 3½ inches wide. The over-all length is 10 feet 8¼ inches. The handle, for convenience of carrying, is located approximately at the center of gravity.

To insure that the rod is held in an erect position, a spherical bubble is mounted on a step at the back of the rod as far down as possible so that the rodman's line of sight is nearly vertical, and in order further to eliminate the effect of parallax a reference circle is placed on the under side of the glass which forms the top of the level vial. In order to reduce the effect of temperature changes, the graduated strip, about 3.3 meters in length, is made of invar or a nickel-iron alloy of similar characteristics, having a temperature coefficient of between 0.000001 and 0.000002 per degree centigrade. Even though the temperature coefficient is low, a thermometer is provided in the back of the rod, whose bulb rests against this metal strip, and readings are taken so that the effect of temperature changes may be computed when analyzing the observations.

This metal strip is fastened by a brass machine screw and two steel dowel pins to the steel foot piece. The strip is 1 inch wide and about 0.04 of an inch thick. The foot piece is made of a short piece of 1¼-inch steel shafting, welded to a piece of structural angle steel, and then machined to the proper dimensions. The angle-shaped step is carefully ground to form a good bearing, and its two bearing surfaces are at right angles with each other. The lower end of the foot piece is thoroughly casehardened and then ground so that this surface shall be normal to the invar strip.

The wooden portion of the rod is made of a single piece of well-seasoned straight-grained white pine, free from knots, wind-shakes, or other defects. It has been found advisable to work these approximately to size and shape and then allow them to season for several weeks before finishing, as sometimes apparently straight-grained

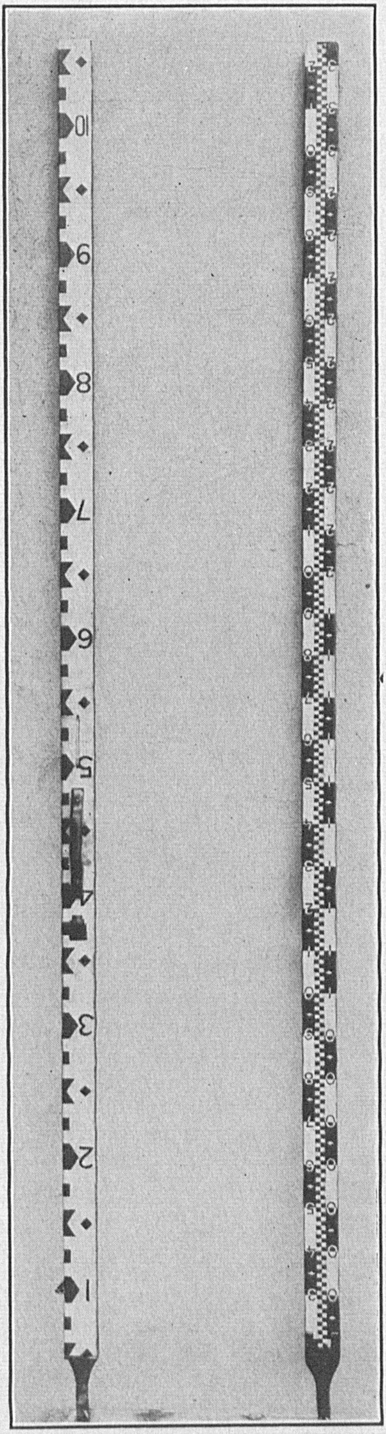

FIGURE 8.—Leveling rod, back and front views.

wood will warp considerably. This backing piece is securely fastened to the foot piece by four brass bolts passing through the foot piece and threading into a heavy brass plate at the back of the rod. A shallow groove is routed out through the entire length of the face

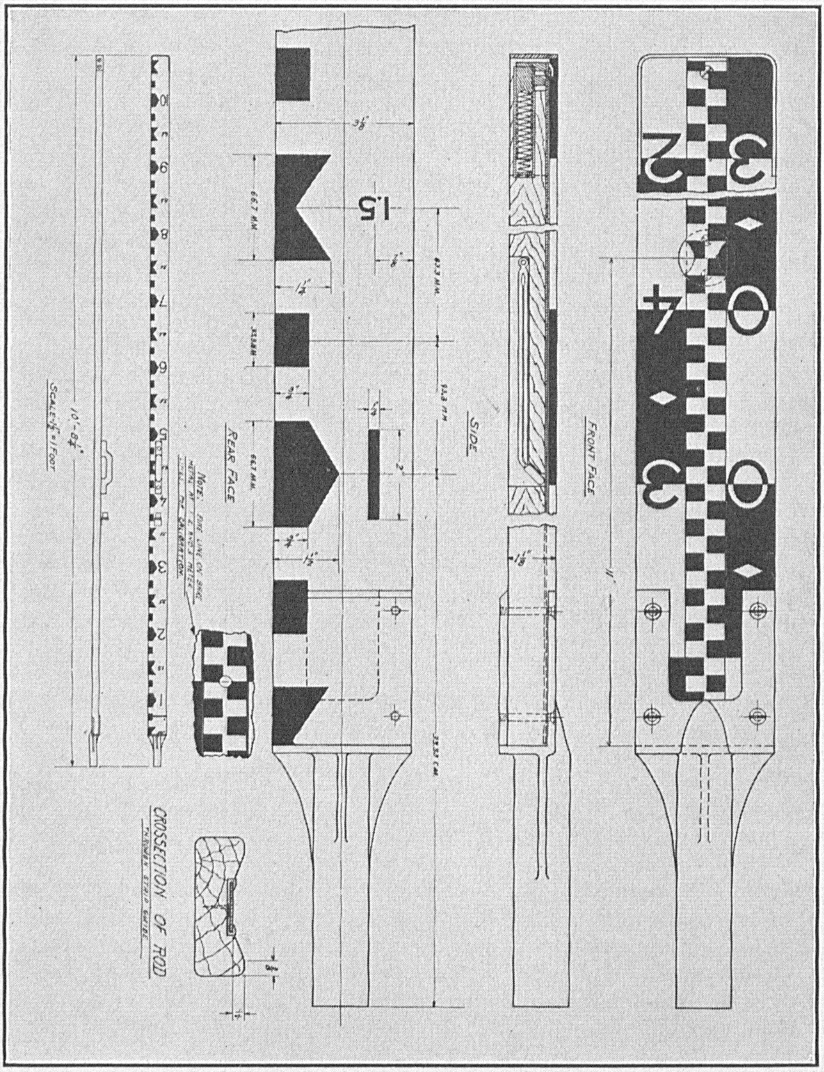

FIGURE 9.—Leveling rod, details of back, front, and cross section.

and deep enough so that the metal strip is free to move through the washer-shaped brass guides which are shown in the illustration, these guides being set into holes counterbored in the wood. The face of the rod is concaved about one-fourth of an inch, so that the rodman's hands will not bear against the metal strip and wear off the graduations. This is also an added protection against scoring of the strip if the rod comes in contact with another body.

The wood is finished with two coats of white lead and oil paint, and then given one or two coats of a white varnish enamel. The use of white baking enamel as commonly made for use on metal, but air-dried instead of baked, has been found very advanageous for this final finish, as it gives a hard, tough, very white, and glossy surface.

In order to eliminate any error which might occur due to sagging when the rod is held erect, the strip is placed under tension by a stiff spring set into the wooden portion of the rod.

The graduations on the metal strip are in the form of alternate squares of black and white. The metal is first prepared by sanding, and then given a coat of auto-body metal surfacing. It is then sprayed with automobile type of white pyroxylin lacquer, as many as six coats being applied, rubbed down between coats with pumice stone and water, the final coat also being rubbed down.

The method of graduating is as follows: A line is carefully ruled on a small polished area of the level strip, 2 decimeters from the end of the footpiece. This interval is carefully checked and calibrated, and if found to be within the allowable limit of 0.1 millimeter, three additional lines each 1 meter apart are ruled along the length of the rod and their intervals calibrated. If the error in any interval is found to exceed 0.1 millimeter, the rods are rejected and regraduated. These reference lines are then used in locating the strip in the graduating machine in order to apply the black squares in their correct position. When pairing the rods for use, the measurements of the 2-decimeter interval must be the same, for while an error as great as 0.1 millimeter is allowed, the errors must be the same amount and in the same direction. In selecting the pairs, the length of corresponding meter intervals is not permitted to differ by more than 0.1 millimeter, nor shall the accumulated errors at any point differ by more than 0.1 millimeter. The accuracy of manufacture is such that it is seldom that the position of any line is more than 0.1 millimeter from its correct position.

The back of the wooden portion of the rod is laid off, as shown in the illustration (see fig. 9), in thirtieths-of-a-meter intervals. This is to give a rough check on the reading on the face of the rod, both sides being recorded at each station. These graduations are applied by the decalcomania transfer process, which forms a quick and inexpensive method of application. The same method is used in applying the numbers and the diamond-shaped mid-section markers on the face of the rod. The black areas, however, are applied by hand, as this method has proven more economical.

THE GRADUATING MACHINE

The graduations were formerly applied by coating the strip with white paint, then placing it beside a master scale and transferring the dimensions by means of a steel square and scriber. The black squares were then filled in by hand, a most tedious process. With this method it was impossible to obtain uniformity of width, as the scriber cut a shallow groove of finite width which filled with paint causing a general tendency for the black squares to be wider than the white. Irregularity of the lines of demarcation was also unavoidable.

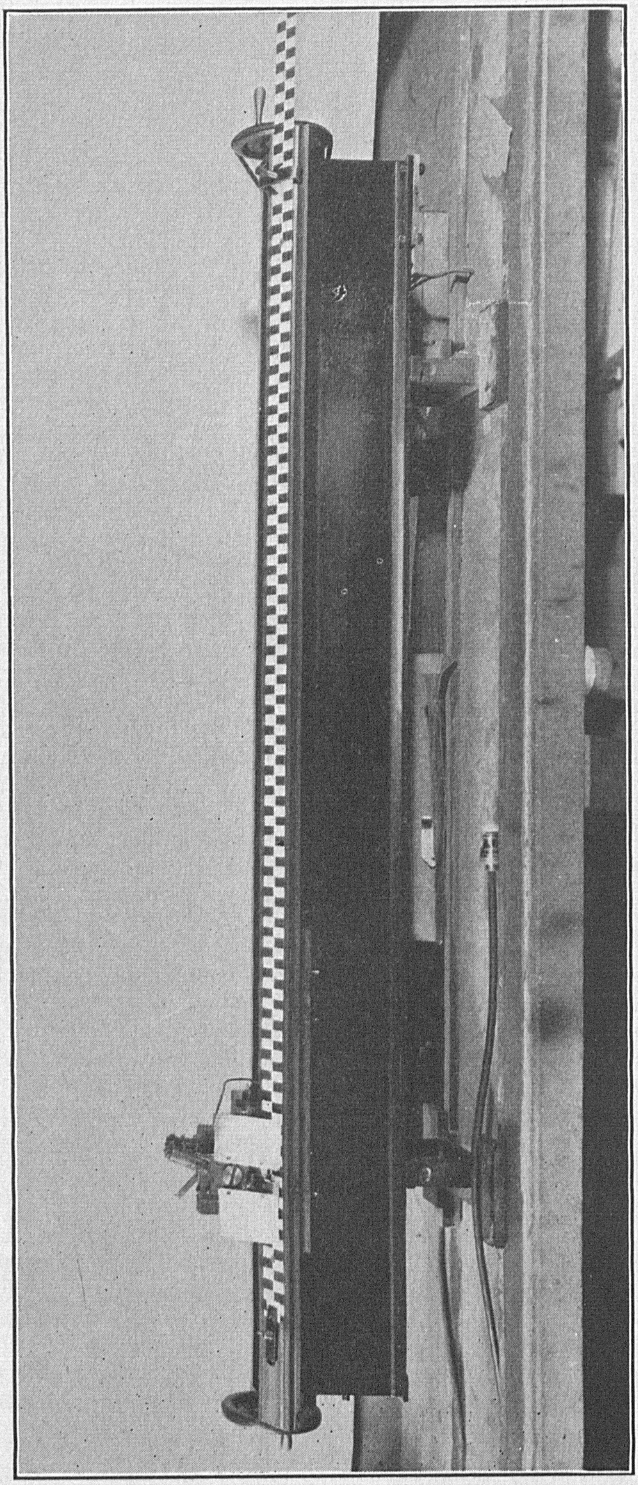

FIGURE 10.—Machine used in calibrating and graduating invar tape.

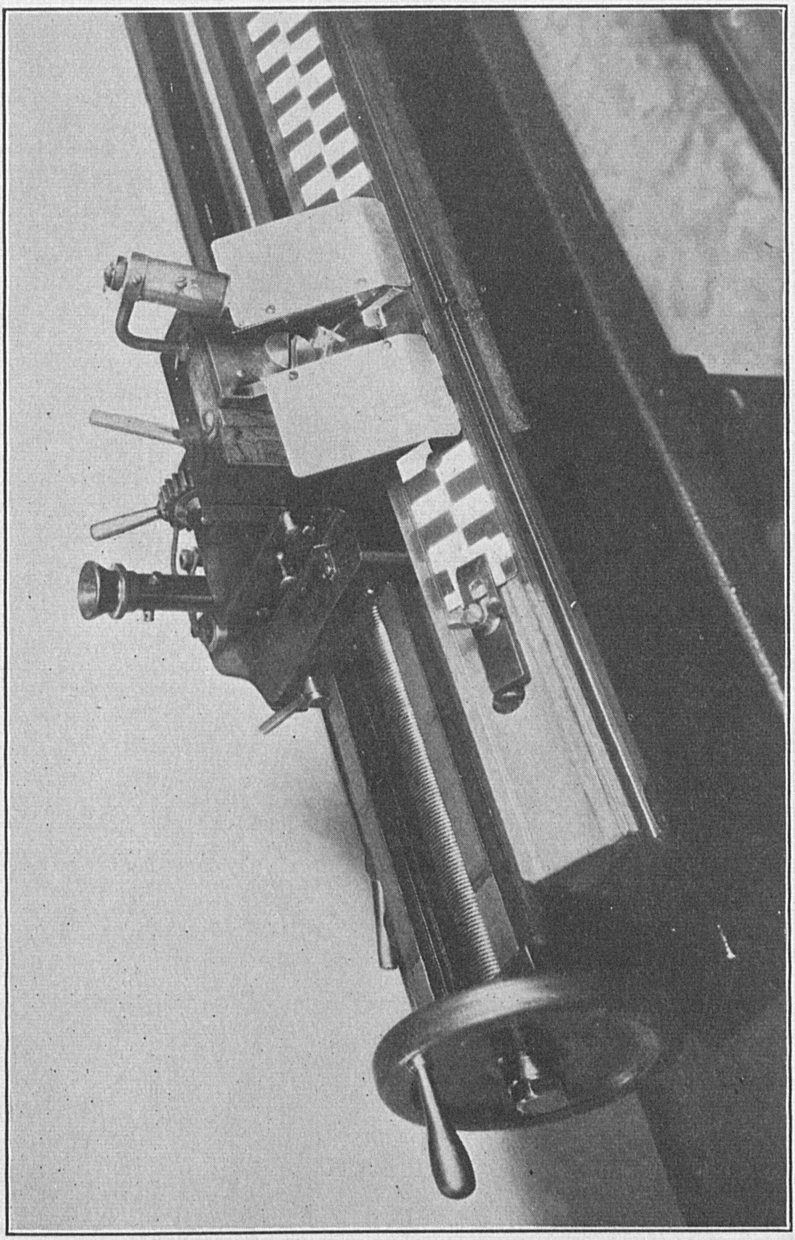

FIGURE 11.—Detailed view of traversing carriage and painting mask.

With the new machine (see figs. 10 and 11), the comparison method is used, thereby avoiding the necessity for cutting a long and accurate lead screw and for working at constant temperature. An invar bar of the same physical characteristics as the strip, accurately ruled in 1-centimeter spaces, is located in a groove at the rear of the machine. A microscope is mounted on the carriage carrying a pair of fine parallel tungsten wires in its focal plane. A small electric bulb placed beside the microscope tube illuminates the comparator bar, causing the ruled lines to stand out brilliantly. The tungsten wires show blackly against this brilliant background, and the setting of the carriage is surprisingly easy.

The cross slide of the carriage carries a vertical slide which is lowered and pressed against the work by a small eccentric and lever. This vertical slide carries a mask made of stainless steel which contains two openings 1 centimeter wide offset 1 centimeter with respect to each other to correspond to two contiguous squares on the rod. When pressed against the work, these open spaces are sprayed with a quick-drying black lacquer by means of a small air brush and, as the mask is raised vertically, no difficulty is experienced with smearing the paint, and it is not necessary to wait until it is thoroughly dry. In fact the operation can be carried forward with no delay.

As soon as the square has been painted, the mask is raised and the carriage traversed the next space, and the process repeated. To speed up the process, the traversing screw may be operated either by hand or by a small motor and a belt. A telegraph key is used for contact, and the current is applied long enough to move the carriage to approximately the correct position, the final setting being made by hand. With a little experience, the mask can be very closely registered by means of the motor drive, and only a minimum of hand setting is required.

The resulting graduations, both white and black, are all of the same width. The lines of demarcation are straight and sharp, and the sharpness is enhanced by the thinness of the film of black which does not provide a raised and shining surface to cause annoying reflections.

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