The Development of an Azimuth Beam Fire-locator

by

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INCLUSIONS

PLATE I  The Coelostat  Page 7
PLATE II  Secondary Mirror  "  8
PLATE III Sighting  "  9
DIAGRAM I Tilt of The Primary Axis  "  13
DIAGRAM II Rate of Speed of Clockwork  "  14
DIAGRAM III Effect of Seasonal Movement of the sun  "  16
TABLE I  Calculation of Mirror Curvature  18
DIAGRAM IV Color Zone Diagram  "  22
TABLE II  Results of Field Tests  "  31
DIAGRAM V  A Typical Lookout Setup  "  38
FOREWORD

This thesis consists of two parts. Neither part is complete in itself. The part that follows the written part, serves only one purpose, that of making the other part useful, practical, and understandable. The other part, the fire-locating apparatus itself, was first turned over to the School of Forestry a year ago. Since then it has been improved and is being returned together with this thesis which tells of its uses, its history, its theory, its limitations, as well as suggestions for improvements. The directions for the use of model IV have been added as an appendix.
THE DEVELOPMENT OF AN AZIMUTH BEAM FIRE-LOCATOR

The field of forestry is constantly broadening. The fields of silviculture, logging, and fire protection are not the same today as they were ten or 20 years ago. Constant improvement is made and our problems, one by one, are being solved. Once in a great while someone comes along with an idea of a technical nature which immensely changes the whole field. To the logging industry such an invention was the track-laying tractor. The inventor had no idea of the significance of his machine, but this one idea in 20 years of development, has profoundly changed the whole logging picture.

Like a sow and her litter, along with the occasional idea of great significance come a myriad of other technical improvements which continually shove outward the limitations of our special field. These are largely applications of scientific principles to the smaller problems we encounter. It is in such a light that the azimuth beam fire-locator should be viewed.

Need

The need for a device to guide the smokechaser to a fire has long been felt. It was brought home
clearly to the author when for three days a crew of three men hunted vainly for a lightning fire. It was on the south side of the Rogue River, and the author, who was twelve miles away on the north side could plainly see the thin wisp of smoke at least half the time. As the crew returned to their camp each evening they grew more and more disgusted. Finally on the third day they found the fire burning in the top of a snag which they had passed once before.

In the meantime, remembering some of the simpler mechanical principles of astronomy, the author drew plans for a mirror device which would keep a spot of reflected sunlight on the fire to let the firechaser know when he was in the immediate vicinity of his fire. These original plans, with minor improvements, have resulted in the model azimuth beam apparatus which accompanies this thesis.

The need of a fire-locator can be summed up as follows:

First, where the fire is hard to find it is needed to prevent the smokechaser from wasting his energy by hunting over many acres all around the fire.

Second, it is needed to automatically give the smokechaser his line of sight. Often times it is difficult to take a backsight on the
lookout with vegetation in the way. However, a strong flash of sunlight can usually be seen through the little openings that are always present in a forest canopy. Such a beam is, besides being far more accurate than a compass, never influenced by local attraction. Third, it is needed because the smokechaser, as a general rule hasn't had more than a summer or two experience. He needs any mechanical aids he can be given to get him to the fire in a fresh condition and to keep him from wasting valuable time. It would ease his mind considerably to reach a spot where he could see the flash from one, two, or three lookouts. This psychological effect is important.

Fourth, it is needed to put auxiliary landmarks on roads, trails, and ridges that can be seen from a lookout. This would save time in telling the smokechaser where he is to leave a road, trail or ridge, to save him the trouble and inaccuracy of pacing from a section-line marker.

Fifth, it is needed to automatically tell the smokechaser if he is on the right vertical angle. The smokechaser seldom carries any means for determining if he is at the right elevation.
Objectives

Any machine or apparatus built to meet these needs would have to be designed with certain characteristics to fit it to this job.

Practicability, to the sacrifice of everything else, would have to be stressed both in building the instrument and putting it to its intended use.

In designing the apparatus it was my hope that the cost of manufacture could be kept below $25. Although the completed apparatus would at present cost two to four times that much there is every reason to believe that it could be made very reasonably. To accomplish this objective the design should have few parts, especially the working parts. It should be designed so that it could be assembled from standard sizes of gears, clocks, and other parts. In machining and assembling the design would have to provide for a minimum of expensive milled or machined parts. The use of wood and metal substitutes might be possible if designed correctly.

The greatest test of whether the machine was practical would be in use. In filling the need for more efficient fire location it should be designed to be foolproof, simple to understand, reliable, automatic, strong, steady, properly powered, and to require very few field adjustments.
Although the apparatus presented with this thesis meets a few of the good characteristics in construction and several in field use, it is still a long way short of a perfected model. Its present stage of development can be compared with the first model automobile, or first model fire finder. In building this model the author was as much concerned with proving that his application of theories were correct as with making a practical field model.

Design

As can be seen by studying the accompanying photographs and drawings (or the model itself) this azimuth beam apparatus consists of three separate parts, (1) the primary mirror-and-clockwork or coelostat, (2) the secondary zoned mirror, and (3) the aiming sight.

The Mirror train

The primary mirror and clockwork or coelostat has for its main purpose that of reflecting the rays of the sun on the secondary mirror. From the secondary mirror it is again reflected, this time to the fire. In addition to this the primary mirror is geared to a clock in such a fashion that the sun's motion is completely compensated. This keeps the sun's rays centered steadily on the fire. The theory of why it works will be presented later.
The primary mirror and clockwork, or coelostat, is mounted on a base 12" wide by 17" long made of angle iron. Since the coelostat must be oriented and leveled before it will operate, two devices are mounted to this base to facilitate this adjustment. The first is a two way level mounted on the center member of the base. When both bubbles are centered by means of three adjusting screws the instrument is level. The second device consists of a pair of sight leaves. These are used to orient the coelostat for direction. These sight leaves are parallel to the axis of the main mirror. When sighted on a distant point whose azimuth is 180°00', the mirror and clockwork is properly oriented. Once oriented and leveled no further adjustments to the base need be made.

Upon this angle iron base is mounted a 12" square mirror which rotates by clockwork. The axis upon which this mirror rotates is built parallel to the earth's axis. This means that besides being in a north and south direction the axis is tilted at an angle equal to our latitude when measured from the horizontal. For the vicinity of Corvallis the apparatus is set at 44°38'15" from the horizontal.

Connected at right angles to the mirror shaft by means of a one inch worm gear is an old, battered
PLATE I

THE COELOSTAT

Consisting of the primary mirror, clockwork, sight leaves, levels, leveling screws, and frame.
alarm clock. The hour hand has been removed and the worm is connected through a rubber universal joint to the minute hand. In order to compensate for the motion of the sun the mirror must turn one revolution every two sidereal days, or one revolution for every 48 revolutions of the hour hand on the clock. For this purpose the gear ratio of the worm gear is 48 to 1.

When not in use the mirror is generally allowed to rotate freely on its shaft to prevent damaging the worm gear. However, when in use the coelostat is oriented, leveled, and the reflection from its primary mirror is centered on the secondary mirror. Then the small screw located between the gear box and the mirror is tightened to make the shaft and mirror a rigid unit. From this time on the running clock turns the mirror with an angular velocity which adjusts automatically for the sun's motion.

The secondary zoned mirror was ground to perform a very special function. Catching the parallel rays of the sun from the primary mirror it reflects them to the fire slightly altered. The mirror was ground in such a way that at five miles distance the rays would have diverged 1,000' in a vertical plane and 300' in a horizontal plane. At other distances from the mirror the divergence is of
SECONDARY MIRROR

This mirror has a double convex curvature and is shown divided into zones with yellow and red cellophane.
course proportional to this. When this flash of light is centered on the fire the approaching fireman at five miles distance would begin to see the flash at 500 feet above or below the fire or 150 feet to either side of it.

The actual grinding of this mirror was done by the author from instructions found in "Amateur Telescope Making." Additional information needed to grind a mirror having a radius of 40 feet in one plane and 21 feet in another may be gained by consulting the physics.

In addition to this the secondary mirror is zoned in colored glass in such a fashion that the upper third of the flash will be tinted yellow, and the lower third tinted red. To the fireman this means that when he sees red light flashing from the lookout he is below the fire. He would then climb until he begins to see the white flash which indicates the spot on which the mirror is centered.

To aid in adjusting the secondary mirror a fine adjustment screw such as is found on the ordinary transit is provided for vertical adjustment. None is provided for horizontal adjustment because the author was in the process of making such an adjustment when his work was halted. However, the art of centering the flash on the fire is not a difficult one without this adjustment.
CHECKING FOR MIRROR ALIGNMENT

This shows the author checking on mirror alignment as described in the instructions for operation.

LOOKING BACKWARDS THRU THE MIRROR TRAIN

This is what he sees. Secondary mirror has been purposely shifted so the sun-glare will not spoil the picture.
The third and final part of the apparatus is the sighting device which holds the front sight. It is simply a low-priced camera tripod with a swivel head on which is mounted a strip of clear plastic. Lined boldly on this plastic strip is a cross. At a distance of 10 feet this makes an excellent front sight.

Sighting

The art of setting up the three parts and centering the flash requires a moderate skill, but is not so difficult if the principles are understood. In the author's experience a few minutes teaching was all that was required before persons totally unfamiliar with the apparatus could correctly center it on any spot.

As explained previously, the primary mirror and clockwork must first be oriented and leveled, and the flash from the primary mirror must be centered upon the center of the secondary mirror. This must be accomplished without disturbing the orientation of the primary mirror, hence most of the adjustment must be made by moving the secondary mirror unit. Once accomplished, no other adjustments need be made between the two mirrors. To facilitate this adjustment a \( \frac{1}{4} \)" black spot is provided at the center of the primary mirror. This black spot shows up very well in the reflection to indicate the center of the primary mirror's
reflection. At the center of the secondary mirror a small hole has been scraped in the silvering to assist in sighting. The frame for the secondary mirror was built in such a fashion that this sighting hole came at the very center of both the axes on which the mirror turns. Because of this the sighting hole remains in a fixed position no matter how the secondary mirror is swung in sighting.

Finally, when the reflection center of the primary mirror is on the center of the secondary mirror, the front sight is placed on a line between the center of the secondary mirror and the fire. The distance that the front sight is placed from the secondary mirror is, of course, not too important. Anywhere from three to forty feet is permissible although about 10' seems to be optimum. Beyond this the center spot of the reflection becomes increasingly dim and aiming takes longer. This lining up of the center hole on the secondary mirror and the sight is a trial and error method. Usually about three trials are necessary to place the front sight exactly on line. To facilitate this adjustment the tripod legs are adjustable for length. The final adjustment is made in the swivel headed base on which plastic sight rests.
When all three parts are finally aligned the only thing left is to center the sun's reflection on the center of the cross on the plastic sight. This is best done by placing a sheet of cardboard behind the plastic sight to better see the black spot which marks the center of the reflection. When this black spot centers exactly on the cross of the front sight the reflection's center is on the fire.

It must be noted here that the operator must watch to see if he is using the correct reflection. Besides the reflection of the sun made by this train of mirrors, there is another equally bright reflection made by the secondary mirror alone. Once on a field test this second reflection was trained over the sight and the afternoon's work was wasted chasing a moving beam.

Time Required

This whole procedure of setting up the apparatus varies in time from five minutes to a half hour depending upon the circumstance. In a completely familiar place such as the rooftop on which many of the tests were made, only about five minutes were required. However, in setting up the apparatus on Alsea Mountain Lookout the first time required nearly half an hour. Ten minutes is about the average.
Theory

For those whose purpose in reading this thesis is simply a cursory knowledge of the subject this section on theory may be omitted. It was written to pass on the few things the author feels that are necessary for future work on the apparatus.

If the apparatus were designed to be used at night, any source of strong light could be used to replace the mirrors. However, in daylight no source of light that could be used on a lookout could approach the 20,000 candlepower of bright sunlight. It is only the matter of harnessing sunlight for such use that had to be thought out. The transforming of a moving source of light into a steady source, and using of this beam in the most useful way was the pith of the problem of developing an azimuth beam fire-locator.

The theory behind the coelostat, which answers the first problem, that of transforming the moving light from the sun into a steady beam, is founded on very simple astronomical and physical principles.

The first principle in designing the coelostat is to resolve the sun's apparent motion into one plane so that this motion can be compensated for by revolving the mirror on one axis only. If the mirror were mounted with a vertical axis and a horizontal
The axis of the primary mirror must be parallel to the earth's axis. As the earth revolves to the east the clock compensates for this by revolving the mirror to the west. The diagram also indicates why the angle of tilt "$A" is the same as the latitude.
axis like the tube in a transit, then not only would a motion be made on the vertical axis in following the sun from east to west, but also a horizontal motion would have to be made to follow the sun as it rose from the horizon to its position at noon and back to setting.

By tilting the axis of the mirror, however, to a position parallel to the axis of the earth the necessity of having more than one revolving axis is entirely eliminated. This can be shown in the accompanying Diagram I. In order to tilt the mirror axis parallel to the earth's axis it must be set at angle A which is equal to the latitude at which the apparatus is used. Once set in a plane parallel to the axis of the earth the only requirement for keeping the mirror pointed at the sun is that it be slowly turned at the same angular velocity that the earth revolves. The mirror can, in this position, be considered a small earth with the sun revolving around it in a plane at right angles (or nearly so) to its axis. This becomes more obvious from the diagram when it is realized that the distance of a few thousand miles between the axis of the earth and the axis of the mirror is insignificant when compared with the 93,000,000 miles distance of the sun. (1) If operated on the north pole, for instance,
Since the angle of reflection increases as fast as the angle of incidence, with each one degree movement of the sun the reflection also moves one degree. To cause the reflection to be in one place the mirror should be moved one-half degree for every degree of sun's motion. In two hours the apparent sun's motion is 30 degrees, but the primary mirror revolves only 15 degrees in this time interval.
the mirror axis would be mounted vertical and attached directly to the hour hand of a clock.

Reason for speed of revolution

There is a second principle, that "the angle of incidence is equal to the angle of reflection" (2) which determines the rate of rotation of the primary mirror. Instead of rotating the mirror once in a sidereal day (23 hours, 56 minutes, 04 seconds) the mirror actually makes one revolution in two sidereal days. If the mirror revolved at the same rate as the earth, or one revolution every day, then the angle made by the ray and its reflection would be the same all through the day. In effect this would cause the reflection to travel 15 degrees every hour when actually we desire it to remain stationary.

If the mirror revolves only half this speed or one half degree for every degree of apparent sun motion, then the reflection becomes stationary to one point. This is shown in the accompanying Diagram II where the mirror is viewed as if the observer were looking at it from the pole star. The sun's apparent motion would then be circular as shown. In two hours the sun would move through an arc of 30° while the mirror revolves 15°.

* The sun's apparent motion is actually the result of the earth revolving. However, it is easier to picture when spoken of as the sun's motion, so this terminology will be used for convenience with all due apologies to the intelligence of the reader.
These two principles are enough to know how to operate or even to construct a coelostat. There are, however, two more principles. The first will aid in understanding why the coelostat was designed as it was, and the second in operating the whole apparatus.

After the apparatus is used for some time, it is natural to wonder why one mirror could not be set up to take the place of a train of two mirrors. This subject was rather completely investigated by the author. It can be done with more complicated machinery on principles laid down by an astronomer named Silbermann. However, there are distinct disadvantages to a single mirror since a great deal less light would be reflected to fires north of lookout than to fires in a southerly direction.

Using a system such as the one presented with this thesis, the author wasted two valuable months of experimenting trying to eliminate the secondary mirror by mounting the primary mirror on another axis rotating at right angles to the polar axis. In this way the reflection of the mirror could be turned in any desirable direction. However the spot will not stay on any terrestrial object because the terrestrial plane or horizon is always different from the celestial plane in which the sun travels. As a result the sun's reflection would stay on a
This diagram shows the sun's position on June 21. The reflection from the primary mirror will fall somewhere on the line denoted as a "locus of possible reflection centers". This locus is always the same number of degrees south of the celestial equator as the sun is to the north. On September 21 the sun and the locus of reflection centers would be on the equator.
certain spot on the celestial sphere, but in relation to a certain spot on the earth such as a fire it would move north and south as the sun progressed through the day. There is no point in any other investigations into this possibility when the present method or the suggested method are both theoretically and practically correct.

The last principle in regard to the coelostat is that when the apparatus is oriented the sun's reflection will always follow a line on the celestial sphere as many degrees to the south of the celestial equator as the sun's declination happens to be that day. This is not important when setting up for any one day, but if a permanent mounting were to be made for the coelostat on a lookout, it would be necessary to move the position of the secondary mirror first southward a little each day until June 21, then northward again till December 21. This takes care of the seasonal north and south movement of the sun caused by the tilting of the earth's axis 23½ degrees. As long as the secondary mirror is anywhere on the locus of reflection centers shown in Diagram III the apparatus is correctly set up.

The secondary mirror, as previously stated, accomplishes three purposes. (1) it allows the beam from the primary mirror to be redirected at
any desirable point, (2) it diverges the beam to cover a greater area which increases the ease of locating it in the field, and (3) it is zoned into colored bands, amber above and green below, to tell the fireman his position in relation to the fire.

How the first of these purposes is accomplished has been thoroughly treated. To accomplish the second purpose, that of diverging the beam, requires a convex mirror ground to accurate specifications. May it be said here that the specifications chosen by the author were at best only an estimate of the needs. Field experiments, in their present state, indicate that for distances greater than five miles the curvature of the secondary mirror used is too much, resulting in too dim a beam, especially in the colored zones. However, the remedy is self-evident. If another mirror were to be ground a curvature of about half the present amount should be tried. It was best, perhaps, to have excess curvature on the first trial in order to prove conclusively the principle of zoning the mirror.

The specifications aimed for in this mirror were based on having a beam which would cover a spot 1,000 feet in a vertical direction and 300 feet in a horizontal direction at a distance of five miles. The formula for calculation of the radius of curvature to diverge rays is not given
TABLE I

CALCULATION OF SECONDARY MIRROR CURVATURE

Vertical Curvature

\[ \frac{.84}{500} = \frac{x}{26,400} \]

\[ x = 43.6 \text{ feet focal radius} \]
\[ 21.8 \text{ feet focal length} \]

Horizontal Curvature

\[ \frac{.58}{150} = \frac{x}{26,400} \]

\[ x = 102.6 \text{ focal radii} \]
\[ 51.3' \text{ focal length} \]
in any physics textbook but it is an easy one to derive. For the mirror which was used in this experiment the calculations of radius of curvature are presented on the accompanying sheet. The formula is based on the principle that the lines normal to the curvature of the mirror at the outer edges of the mirror will be only one-half the divergence at any distance. This is so because, again, the angle of incidence of the parallel rays will be equal to the angle of reflection. On a distance of five miles the width of the mirror is insignificant and the radius of curvature of the mirror is to its width as the total distance is to the one-half the total divergence.

The mirror which accompanies this thesis has a focal length in the vertical plane of 21 feet and in the horizontal plane of slightly over 40 feet compared to 21.8 feet and 51 feet calculated focal length. It is quite difficult with such shallow curves to measure radii of curvature of this magnitude until the final polish, and the author considers himself quite lucky to have come this close to the correct curvature. There is one correction that must be taken into account should another mirror be ground. It would seem insignificant to consider the width of the sun as influencing the
accuracy of this calculation. However, the sun's apparent diameter covers eleven minutes of the sky and while we speak of the sun's rays as being parallel, actually they are not quite parallel. This eleven minutes spreads rays over an arc of 22 minutes even from the flat surface of a plane mirror. Since a train of two mirrors are used this correction is four times 11 minutes or 44 minutes. This correction is a constant one, diverging 67.4 feet per mile or 337 feet at a distance of five miles. Actually, the spot of light from the secondary mirror can be seen over an area of 1,337 feet in the vertical direction and 637 feet in the horizontal direction at a distance of five miles.

If the reader has difficulty visualizing how a mirror ground with two different radii of curvature would look, the best example the author has seen is the outer (tread) surface of a worn auto tire. This mirror is ground with a noticeable curvature across its length and almost flat across its width.

There is not much to be written concerning the use of color zones upon the mirror. It was tried by accident, found to work in limited distances, and needs much more experimentation. However, the idea is technically sound. On a circular-curved mirror there is no intermingling of rays. Dividing
the mirror into colored zones causes the corresponding area to be colored in the spot produced in about the same proportional area. The actual results will be treated in the discussion of field tests.

A few words might be added here to clarify the point concerning the ability of the beam to be seen in dense timber or vegetation. Actually about 95 per cent of the visible light of the sun is reflected from a silvered surface, so there is no appreciable difference between looking into a plane mirror and looking into the sun. We have all had the experience of getting our bearings in the woods from the sun. There are plenty of openings through which it may be seen when it is sought. A plane mirror reflection even at ten miles is almost unbearably bright, and could not be mistaken for anything else even if it were seen filtering through the foliage of a forest. On the other hand a curved mirror such as this one spreads the rays and is considerably weaker with distance. The problem to be solved is striking the balance between spreading the rays for ease in locating the beam, and leaving the mirror perfectly plane for intensity of flash. At this point in the experimentation the author would recommend a mirror ground with a 30 foot focal length in the vertical plane and as near flat as possible in the horizontal plane. The spread
caused by the sun's parallax is almost sufficient in the horizontal plane without additional curvature. *

To better picture the type of spot which the present secondary mirror makes, the accompanying Diagram IV attempts to show the areas or zones of the flash produced at five miles distance. These have been checked in the field at approximately this distance and found to be, for practical purposes, correct. Note that banding the 300 by 1,000 foot full sunlight zone is a zone 168 feet wide in which the light tapers from full sunlight to no light at all. This is caused by the parallax, or variation from parallel of part of the sun's rays. This is actually helpful in the field. Since the center of the beam is the brightest it gives the firechaser an additional method of placing himself on the exact azimuth.

History

The azimuth beam cannot be called an invention. Rather it should be looked at as an application of an old idea to a new problem.

Even though the plans for this device were made without reference to any written work, the

* However, in grinding it is almost impossible to grind a mirror having curvature in a vertical plane without getting some curvature also in the horizontal plane.
author quite independently designed a coelostat which differed very little from models made by astronomers a century ago. It was not until three months after the construction of Model I that the author, in his research, found that the first principles were laid down almost exactly 300 years ago.

The following history, taken from the New International Encyclopaedia(3) under the caption "Heliostat" is very revealing.

"An instrument used in astronomy, physics, and engineering to reflect the light from the sun in any desired direction notwithstanding the motion of the sun. It consists essentially of a mirror mounted on an axis, which is parallel to the axis of the earth and is caused to turn by clockwork with the same angular velocity as that of the sun. The first instrument of this kind was described by s'Gravesande (1668-1742) in his Physicae Elementa (3rd ed., 1742).

"Various improved forms were invented by Fahrenheit, Boit, Foucault, Silbermann, and others."

The helioscope, or coelostat which is the simplest form has been used with the spectroscope and the horizontal astronomical telescope. Some forms have been tried successfully in making long distance observations in geodetic surveying.

Model IV which accompanies this thesis is the result of building three other models which were one by one discarded.
The first model, built on Mt. Bolivar Lookout with scarcely any tools, had a 2 x 2 with sharpened spikes driven in the ends for its principle axis. The clockwork was made by whittling out two pulleys from a sugar pine box board. The results with it were very encouraging. For an hour and twenty minutes the author kept a spot of light on Hanging Rock Lookout using this simple device.

Cost

The present model IV was built at a cost of approximately $10.00. This, of course, is for materials only, and there is no way of telling how many thousand dollars it would cost if shipyard wages were paid for labor upon it. The following itemized list is as near as can be determined complete.

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metal</td>
<td>1.25</td>
</tr>
<tr>
<td>Screws, bolts, fittings, etc.</td>
<td>3.50</td>
</tr>
<tr>
<td>Gears (48:1 ratio worm gears 1&quot; diameter) Bond Gear Co., Philadelphia</td>
<td>1.85</td>
</tr>
<tr>
<td>Mirrors</td>
<td></td>
</tr>
<tr>
<td>Primary</td>
<td>3.00</td>
</tr>
<tr>
<td>Secondary - glass and grinding materials</td>
<td>1.00</td>
</tr>
</tbody>
</table>

$10.60
Limitations

There is much to be gained from a knowledge of the limitations which are inherent with such a device. The apparatus is limited to be used when the sun is shining. This is obvious, but a knowledge of how much sunshine is required is helpful. There is an immense amount of light in the region of the sky near the sun even on a cloudy day, and once the apparatus is set up a flash of diminished intensity can be seen. Although the author has made no exact experiments upon this particular phase, he has had chance observations of the flash at two and four miles when clouds interfered. Each time the flash diminished greatly, but did not become so faint that it could not plainly be seen.

The device is naturally limited to use in the "seen area" of a lookout. However, its use may be greatly extended by taking it out into the field and setting up on the side of a road or the top of a ridge. The only problem here is orientation. If compass readings are accurate to one degree this is sufficiently close to keep the beam pointed correctly over the period of about two hours. A one degree inaccuracy in orientation means two degrees possible inaccuracy of the flash.

The length of time the beam will stay on one spot is limited only by the accuracy of adjustment.
Orientation and adjustment

in the apparatus, and also in the accuracy of orientation. Provisions are made on every adjustable part of the machine for minor adjustments. The author feels that this is one of the machine's greatest faults - too many possibilities of adjustment. There is no reason that many of these cannot be eliminated by correct design and workmanship.

Major Adjustments

Most of the adjustments are of minor importance when compared to the two major adjustments. The minor ones are obvious and can be discussed under "Directions for Operation." The major adjustments which will be presented here have to do with the coelostat only. Once this device is in adjustment and the device is set up to flash on the fire there are few conceivable things that can go wrong. These adjustments have to do with setting the primary mirror axis parallel to the earth's axis and with adjusting the clockwork to turn the mirror through 180 degrees rotation in 23 hours, 56 minutes, and 4 seconds at a uniform speed. Although the apparatus works tolerably well if the mirror axis is off two degrees and the clockwork runs 15 minutes fast in a day, there is no excuse for this much inaccuracy.
The clock, when it runs at all is reliable to within a couple of minutes of turning at the right speed. It has never given trouble. The trouble in the clockwork has come from two sources. The first of these is too much play in the gears. This is adjustable by turning the bronze eccentric bearing on the clock side of the gear box. If turned too tightly there is too much friction or bind in the worm gear and the clock will not turn it. If the gears are too loose the wind will cause the mirror to vibrate, throwing the flash back and forth over the spot. A play of about .002 inches is about right. This spot on the eccentric bearing is found when matching up the scratches going across the bronze bearing with that on the side of the gear box.

If the main shaft is out of line, the mirror will not swing freely, but gets tight in spots. The adjustment here depends upon lining in all the bearings with a line scratched on the flat surface of the middle bar of the frame. To do this the primary mirror with its frame must be removed and the instrument leveled. Then, a plumb-bob is dropped from the upper bearing. This bearing is adjusted until the center of the bob is on the center line marked in the frame. The clockwork bearings, being close to the frame may be lined-in with a machinist's square.
While the coelostat is unassembled the other important adjustment can be made. On cardboard or sheet metal a template is made with the same angle as our latitude. This is used to adjust the angle of rotation to be parallel with the earth's axis. It will be necessary to cut this template to fit the machine because the clockwork housing gets in the way of a template made in the form of a triangle. If the center shaft is removed from the gear housing, a very exact alignment of the other bearings can be made by eye once the height of the top bearing is determined with the angle template.

In passing, it may be added that the most difficult job of the whole development was the machine work in machining a play-free gear box, and in aligning all the bearings.

Outcome of the Tests

For a machine whose chief characteristic must be practicability it must be said in all frankness that the tests are too incomplete to tell, except in a general way, what the apparatus will do. This is not because the machine has not been tried a great many times, but because the author, being a tinkerer and not a machinist, was continually troubled with "bugs" of various kinds. He had no knowledge of metal craft when he started. With
each change of design he would machine as many "bugs" into the apparatus as his new design was meant to eliminate. Model II was an improvement in design over Model I, but never did run correctly when the clock was attached. This was because spur gears were used.

In order to achieve a 48:1 reduction, a fault which is inherent with spur gears showed up immediately. Each gear had to have a little play in order to run. When a line of three gears was used, the play was enough so that the mirror would swing five degrees in taking up the slack. Another fault of spur gears is that their rate of rotation is not constant. In turning past each individual tooth there is a speeding up and slowing down effect that is greatly magnified when the clock requires an hour to rotate past one tooth.

Model No. 3 was too light, besides having poor quality machine work. It was full of "bugs" and finally was abandoned after the first trial. The clock would not turn the mirror.

Model No. 4 was "finished" at least five times. Each time it was "finished" the apparatus was carried out of the machine shop and tried until it became obvious that in its "finished" condition it was not practical. Usually the fault lay in the coelostat. Poor alignment, poor machining of the
gear box, or failure of the universal joint between the clock and the worm shaft always resulted in trotting back to the machine shop for "re-finishing."

Lately when the machining of the apparatus began to compare in quality with the clock that powers it, the results have been quite good. It was not until the coelostat had reached this state of development before there was any point to making practical field tests.

Testing

The testing has been of two phases, that of the apparatus itself, and that of its performance in the field.

On the apparatus a four-day trial run to test the angular rate of velocity of the clockwork was made. The mirror should rotate through 720 degrees in four sidereal days which equals 3 days, 23 hours, 45 minutes approximately. A pointer was attached to the mirror to indicate the exact starting point. After three preliminary time adjustments the mirror came back to its starting point on the fourth day within three minutes of correct time. This time was 3 days, 23 hours, 48 minutes.

Outside test runs of the coelostat alone were then made to test the ability of the machine to reflect a flash on one point throughout the day. A true north line was establish on the author's roof top for orientation purposes. For several days during the February good weather the coelostat was
set out in the morning to run all day. In the course of eight hours the flash would vary from its starting point not more than one and one-half degrees. This variation is one that slowly and steadily accumulates. It results apparently from the use of too coarse a method of leveling. The level bubbles used were taken from an old compass and quite possibly are not accurate to more than a degree.

The above results are the present model's best, and it might be added the most recent. There have been many examples of strikingly poor results, but always the explanation was the need of improvement in the coelostat, not in any fault of the idea itself. The good results indicate what can be expected with further development.

As for field trials the results lately have been very encouraging. A lookout point from which several miles of road could be seen, was required. Alsea Pass Lookout was made available for use in field trials of five miles or less. This point was used because of its convenience and because an exact orientation was obtainable there. Two days were spent here testing the various characteristics of the flash at varying distances. The accompanying table was made up for distances of one, three, and
<table>
<thead>
<tr>
<th>Mirror regions</th>
<th>Bright white</th>
<th>Full yellow</th>
<th>Full red</th>
<th>Dull white</th>
<th>Dull yellow</th>
<th>Dull red</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dist. Miles</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 1/2 mi.</td>
<td>very bright 100' by 130'</td>
<td>bright yellow 100' by 140'</td>
<td>bright red 100' by 150'</td>
<td>moderate to bright 55' by 130'</td>
<td>dull to moderate 55' on each side. No height measure</td>
<td>dull to moderate 55' on each side. Approx. 100'</td>
</tr>
<tr>
<td>3 mi.</td>
<td>moderately bright 220' by about 280'</td>
<td>dull to moderate 220' by 300' (app.)</td>
<td>dim to moderate 220' Height not measured</td>
<td>dull to moderate approx. 90' by 260'</td>
<td>very faint approx. 90' on each side. Height not measured</td>
<td>impossible to distinguish color approx. 90' No height measure</td>
</tr>
<tr>
<td>4 mi.</td>
<td>moderately bright 280' by 330'</td>
<td>dull to moderate 280' by about 350'</td>
<td>dim to moderate approx. 150' by 300'</td>
<td>impossible to distinguish color about 150' broad - No height measure</td>
<td>impossible to distinguish color about 150' broad. No height measurement</td>
<td></td>
</tr>
</tbody>
</table>
The above figures were obtained by pacing. The horizontal distances were much more accurate than the vertical.

The conclusions shown by the accompanying table indicate:

| Conclusions of field tests | (1) That the greatest objection to the present machine is too much curvature in the secondary mirror. At four miles there is need of a more intense flash in all regions. The divergence could be cut down about half. |
| (2) That the colors can be distinguished very well. The zones are sufficiently distinct so that at four miles the border lines between the zones are less than 50 feet wide. |
| (3) That the center of the reflection can be found by the nature of the flash. The light is most intense at the very center, tapering off into a twilight at the edges of the flash. In this way it was possible to tell within a 50 foot square of where the center of the spot was at four-miles distance. |
| (4) That the mirror zones actually showed up. In crossing the spot in a horizontal direction the flash is seen for about one-fourth its distance gradually increasing in intensity. This is the zone caused |
by non-parallelism of the sun's rays. Quite markedly the next zone is apparent because the flash suddenly becomes almost full strength. This zone becomes gradually brighter toward the very center.

5. In timber the flash was seen enough so it would not be missed. In walking, it was usually seen at least once every 10 feet. Indications are that this varies greatly depending mainly on the angle at which it shines through the timber.

Recommendations for Future Development

There are two phases of further development that are now apparent to the author. The first group are the further improvements to the present machine; the second is the building of an improved model.

For the present apparatus there are a few more additions that might be added.

1. A fine adjustment needs to be made for the vertical axis of the secondary mirror. This could be made similar to the present one.

2. The clock should be more firmly attached. However, no attempt should be made to re-fasten the top strap of the clock to the gear housing. This will cause an intolerable
bind on the main shaft of the coelostat. Instead a new strap attached to the same piece as the lower strap should be made.

(3) Some transparent colored substance should be found to permanently replace the colored cellophane. Ordinary colored glass cuts out too much light. Colored celluloid may be a good substitute. Glass, stained much lighter than the samples found in the storage box would be the best answer.

(4) The one-half degree of play in the gears is very difficult to eliminate or even reduce. The author has experimented in the wind and found that there is a bit of a flutter in the flash when the wind is blowing. Two lines of research suggest themselves. One is to draw all the slack in one direction by means of a spring or rubber band attached to the mirror edge. This has been tried and is of some help. However, it is risky business and must be done with caution. The other approach would be to build a windbreak for the coelostat.

Field tests on the present model under more varied conditions. Work needs to be done to improve the quality of the colors now
that the question of whether or not they can be
used at all has been demonstrated. The azimuth
beam should be tried at greater distances. Mary's
Peak presents a splendid opportunity for this. And
at the first opportunity it should be tried on a
fire.

Suggestions

Should the results from trial tests with the
present model be encouraging enough to demand the
building of an improved model, the author wishes
the following recommendations to be considered.

(1) Decide at first whether the primary mirror
should be larger or smaller.

(2) Much machining can be saved if the clock
and the worm gears were placed above the
primary mirror instead of below it. This
would eliminate a pivoting bearing below
since the end of the primary axis could
be a point resting on a jewel, or simply
a cup with a tiny ball in it.

(3) There is no objection to the use of a
wooden frame. A frame built solidly from
five-ply veneer using glued construction
is just as rigid as the present frame. The
clockwork must be of metal.

(4) For the present size of mirror the author
believes that the primary mirror shaft and
the worm gears are too small. Gears twice
the size of the present ones and shafting one-quarter inch or three-eighths would probably be strong enough to rotate the mirror using gears even larger than this.

(5) As stated before, a new secondary mirror might be ground with less curvature to increase the intensity of light. Recommendations for this mirror may be found under "Theory" which was presented in another part of this writing.

(6) It was the author's aim to experiment using a plane mirror $1\frac{1}{2}$ inches wide and 10 inches long in conjunction with the secondary mirror. This strip of mirror was to be laid lengthwise across the very center of the secondary mirror. The anticipated effect would be that the fireman would find a greatly intensified band of light on the exact line-of-sight of the fire. There is no reason why this cannot be tried with the present secondary mirror.

(7) Since the aiming sight can be made very light, perhaps the aiming sight and the secondary mirror could be combined into one unit. Using a telescoping rod attached to the secondary mirror base, it might be
possible to make a sight steady enough, yet flexible enough to make such a unit highly feasible. Wind would give rise to the greatest problem.

Conclusion

It would be satisfaction in its highest degree to hear a smokechaser returning from his fire remark, "Find it! I just walked to the center of the beam and there it was!" For as a "gadget," even as a working model, the apparatus has no value in itself. It must find its intended use.

It is with this purpose in mind that the author wishes to present this fire locator and this thesis to the School of Forestry. Henceforth to the School of Forestry will belong all the rights as well as all the problems of development of the azimuth beam fire-locator.

Certainly it could be put in no more unselfish and capable hands to guide its development toward becoming a useful tool to the forester.
This shows the relative position of the three parts. The fire is in the southeast. The secondary mirror is placed west of the coelostat preparing for the westward movement of the sun. It is also a little south of west because the sun is north of the equator in the summertime.
APPENDIX

Directions for Operation of the Fire-locator

To set up: Remove the coelostat from box carefully. Set on solid surface. The clock may be started by probing through the arc-shaped hole in its back with a fine wire. The clock starts when the wire moves the hair spring on the balance wheel inside the clock. This sometimes requires much "tickling" with the wire inside the clock before it starts.

Wind the clock.

(1) Sight through sight-leaves upon a distant point having an azimuth of $180^00'$. 

(2) Level instrument by using the three adjusting screws in the angle iron frame.

(3) After leveling recheck to make sure the cross hair is exactly upon the distant point having an azimuth of $180^00'$.

(4) Rotate the primary mirror watching the reflection's path for the best position in which the secondary mirror may be put. The secondary mirror must be placed in such a position that the center spot in the primary mirror's reflection will lie on the center of the secondary mirror.

(5) Set the secondary mirror in this predetermined best position so that the primary mirror's reflection will center on the secondary mirror.
(6) Return to the coelostat, revolve the primary mirror to bring its reflection into this exact position and clamp tight. This is done by tightening the screw on the primary mirror shaft between the bottom of the mirror and the gear housing. If there is any adjustment to be made after tightening, move the secondary mirror. Some final adjustment of the coelostat can be made in one plane only by turning the rubber universal joint between the clock and the gears.

(7) Sighting through the small hole in the center of the secondary mirror, determine approximately the position in which to place the front sight tripod to have the cross center on the fire.

(8) After placing the tripod, adjust by trial and error method for the height and the exact position of the front sight. Any distance from 6 to 40 feet is permissible between the secondary mirror and the front sight.

(9) When the front sight-cross, the sighting hole in the secondary mirror, and the fire are all exactly in line, the reflection from the primary and secondary mirror* is centered on the cross

* There are two reflections. Be sure to use the double reflection not the single reflection.
of the front sight. A piece of cardboard placed behind the front sight, acting as a screen, is an aid in telling when the center spot is on the cross. Mirror spot is now on the fire.

(10) To check alignment of the mirror train place yourself in such a position that your eye is directly behind the cross of the front sight. Looking back at the secondary mirror you should see, after your eyes become accustomed to the glare, a large sun image and a small sun image, both centered upon the sighting hole of the secondary mirror. (It is important that only the small sun image be correctly centered.) Closer observation will reveal that the spot in the center of the primary mirror will also center in this sun's reflection indicating that the primary mirror is also aligned. This is a more accurate test for alignment than the one previously described.

(11) If any difficulty is found in the running of the clockwork, or the steadiness with which the clock remains upon the spot, there is probably an error in the shaft alignment of the coelostat. Instructions for this repair are found in the body of the thesis.
ACKNOWLEDGEMENTS

Had it not been for the extra efforts and encouragement of a number of people this gadget would have found its way into the scrap drive and this thesis would have found its way into my wastebasket.

First I wish to thank Professor George H. Schroeder and W. F. McCulloch for their continual encouragement and the many little hints for improvement of the "gadget" during the two years of tinkering with it.

Also I should like to thank Boyd Rasmussen and Robert Afterheide for the very material assistance they gave in making available the facilities of the Forest Service during the building and testing of the apparatus. Acknowledgement must be made of the very excellent technical help of Dean W. Weniger, Professors William C. Reed, James Brady, and John C. Garman of the Physics Department. The important phases of testing of the theory, the silvering of the secondary mirror, and the photography was accomplished in that department.

But it was the willing assistance of Milton Scheely of the Industrial Arts Department, who for two years acted as counselor, instructor, and
friend to a green forester with a "gadget," that turned these nebulous ideas into their metallic form.

The reward of the association and friendship of these men, gained through working on the apparatus, is something I value much more than the machine which their help produced.

Roy Silen
(1) Ingalls, Albert, Amateur Telescope Making, Scientific American Publishing Co., New York, 1933, pp. 22-26 and Chapter V.

