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Night View of the New Open-type 60 inch High-intensity Searchlight and Its 20-kw. Mobile Power Unit in Position to Ward Off an Airplane Raid

A SPECIAL ISSUE ON

SEARCHLIGHTS

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GENERAL ELECTRIC REVIEW

A MONTHLY MAGAZINE FOR ENGINEERS

Manager, M. P. RICE Editor, JOHN R. HEWETT [illegible] B. M. EOFF
In Charge [illegible]

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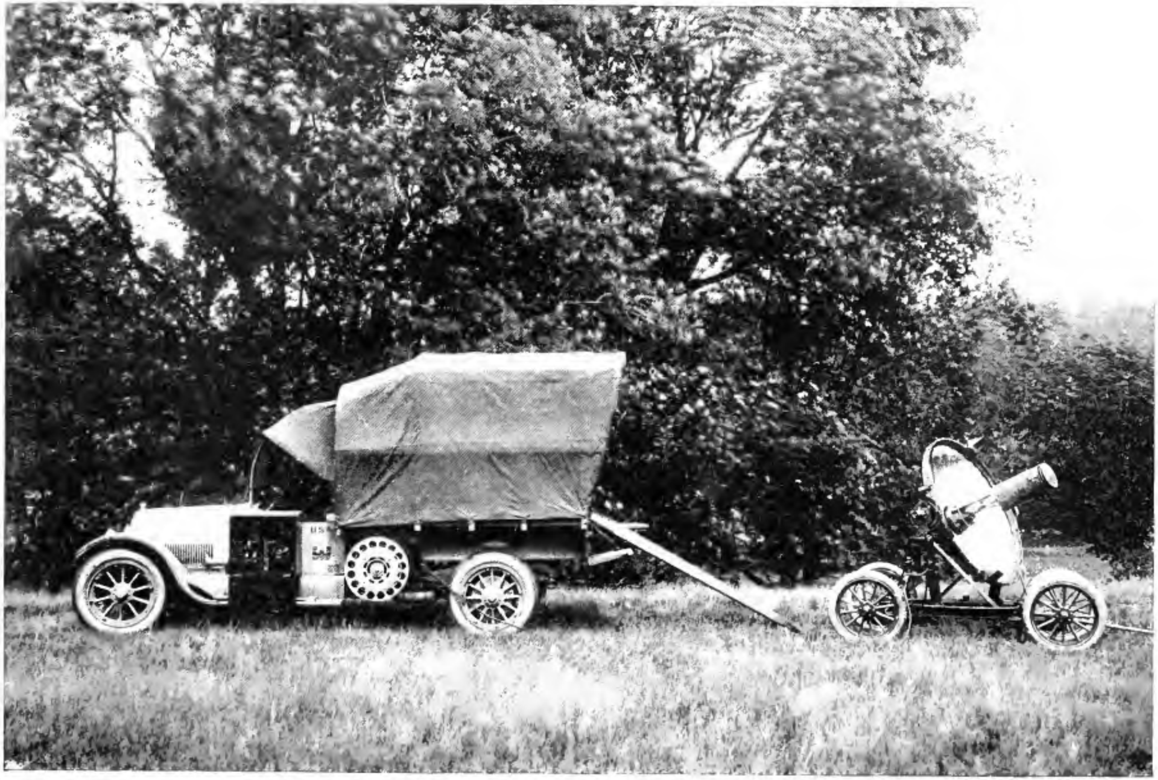


Day View of a Complete Mobile 60-in. Searchlight Outfit. When in operation, the power plant can be sheltered in the comparative safety of darkness, 300 feet from the light. When in transit, the power unit carries the searchlight and, on good roads, can attain a speed of 45 miles an hour

GENERAL ELECTRIC
REVIEW

NECESSITY'S STIMULUS

"Necessity is the Mother of Invention" and it is also the main spring of development; indeed, developments mostly consist of a multitude of minor inventions. The stimulus given development by necessity is well emphasized by the collection of articles we publish in this issue showing the many sided progress made in searchlights during the war.

Pre-war searchlights were wonderful contrivances and showed a remarkable development when we remember that, although the voltaic arc was produced by Davy in 1810 and the Jablochkoff candle invented in the early part of the last century, no substantial progress could be made in maintaining an electric arc until the invention of the Grove battery in 1836 and the Bunsen battery in 1842. The invention of the dynamo electric machine led to a host of different types of arc lamps and to the rapid extension of arc lighting as an industry. The new arc light was applied at an early date to the lighthouse to replace the comparatively feeble illuminant then in use and perhaps this might be described as the first form of electric searchlight.

The results achieved in searchlight development, owing to the war emergency, were accomplished by the co-ordinated efforts of the Army officers, the scientists, and the manufacturers. Captain Lichtenberg tells of some of these accomplishments as follows:

"One example of these points is a 60-inch searchlight which weighs only one-tenth as much as the 60-in. searchlights heretofore considered standard. It costs only one third as much as the standard, is about 10 to 15 per cent more powerful and consists only of about 100 parts, as against several thousand parts for the old design. It is very much more rugged and is so arranged that it can be produced in less than one fourth the time required for producing the old model. Its fabrication requires only ordinary machine shop equipment, no special tools being necessary.

"Another example is a 30-in. searchlight weighing only 200 lb., yet more powerful than the 4000-lb., 36-in. seacoast searchlights heretofore considered the best obtainable. The 200-lb. searchlight has a great field, particularly for foreground illumination. It is so designed that it can be readily taken apart and transported by men to points heretofore considered inaccessible for searchlights. The searchlight and its power unit require a crew of only three men for complete operation. The cost is about one fifth that of the 1915 equivalent."

This reduction in the number of parts, weight, and cost, and this increase in power and mobility, achieved in so short a space of time, bear an eloquent tribute of what can be accomplished by co-ordination of human effort when we are spurred on by necessity. It is interesting to think how many wonderful things there are in this age of machines that could be improved beyond all recognition if the necessity should arise. This thought should give a grain of comfort to those who sometimes bewail that we have reached, or are nearly reaching, our limits.

Among the articles in this issue telling of the development of different types of searchlights, complete searchlight units, and the elements entering into their construction, such as the mirrors and high intensity carbons, etc., is an article dealing with the testing of the finished product, and we wish to call particular attention to this contribution and to the illustrations of the testing range which accompanied it. This testing range played an important part in the development work; and the evolution of new apparatus and instruments for testing purposes, the building of the range itself, and its operation reflect great credit on those responsible for this work. It is seldom that we publish such a group of articles as appear in this issue, while the developments dealt with are so new and have been undertaken in such various places by different interests, so it may be well to call attention to the fact that in a few cases our authors are not in entire agreement. It may also be well to state that we cannot always be responsible for the opinions of our authors, especially when their articles have such various sources of origin.

J. R. H.

Metal Mirrors for Searchlights

By R. B. Hussey

Arc Lamp Engineering Department, General Electric Company, Lynn Works

The successful production of metal mirrors as large as 60 inches in diameter for searchlights was one of the most interesting of war developments. The author describes the process used in their production and tells some of the difficulties met and how these were overcome.—**Editor.**

R. B. Hussey

When the question of developing a new type of searchlight for the use of American Forces was put up to this Company one of the important features that was brought forward was that of a metal mirror in place of the usual silvered glass mirror. Such a mirror had not been commercially manufactured up to this time. There were numerous reasons why such a development was much needed. In the first place, glass mirrors of the size under consideration, 60 inches in diameter, were very expensive articles, costing approximately $1000 each, and were manufactured by only one or two concerns in this country. Further, a glass mirror is easily cracked and ruined from the heat of the arc, particularly, where arcs of high current, 200 amperes or over, are being considered, as was the case. In war service a single bullet would ruin a glass mirror, while a metal mirror could be riddled with bullets and still be a usable device. These considerations led the officers of the Engineer Depot to request the commercial development of a metal parabolic mirror that could be used with the large arc searchlights.

A spun or pressed metal reflector was entirely out of the question as it proved to be impractical to make one with the necessary accuracy of curvature. The grinding of a parabolic curve of this size is necessarily a difficult operation requiring considerable

Fig. 1. Applying the Cement Backing to 60-in. Metal Mirrors at the Lynn Works of the General Electric Company

equipment and experience, so that any method involving the development of a paraboloidal surface seemed to be inadvisable. The idea was advanced that a glass mirror might be used as a form to obtain the desired curvature and polish, and the mirror could be removed and the form used over again. A large number of experiments were made on small glass reflectors depositing silver on the glass surface and then after backing with different materials removing the silver from the glass. This seemed to give promise of success and experiments were carried out with larger sizes of reflectors in this general manner. The limit of 150 pounds in weight for a 60-in. mirror set by the army engineers restricted the kind and amount of material that could be used and made the requirements very severe. As only the outer surface of the glass form was used it was found practical to obtain glass forms that were in the rough on the inside and only ground and polished on the outside. This left a piece of glass weighing about 200 pounds which must be silvered and handled in the different operations and carefully treated throughout so that it might be used over and over again. After several methods of experimenting were tried, involving continuous runs of 36 to 48 hours in many cases, and after the building of special tanks and equipment for handling, a process was finally developed at the Lynn Works whereby one mirror from each form could be turned out in finished condition every week.

Fig. 2. The Lacquering Operation in the Manufacture of 60-in. Metal Mirrors

Without going too far into details, the process employed is in general as follows: The glass is first placed on a movable table and carefully washed to remove every particle of foreign matter. The [illegible] on a silvering table and [illegible] ordinary mirror silvering process. When [illegible] it is removed and secured on a [illegible] like supporting frame. The form and frame are handled as a single piece and placed in silver plating solution where the silver is built up to a thickness of several ten thousandths of an inch. After rinsing the form is at once put into a copper-plating bath and copper is deposited on the silver until a thickness of about 0.030 inch is produced. Great care was necessary during this process to obtain a homogeneous copper of the greatest possible strength and toughness. The temperature of the bath, the strength and composition of the solution have to be carefully regulated through this stage of the process which requires from 30 to 40 hours. The arrangement of the anodes, the current density and the specific gravity of the solution are additional points that require close attention. After the requisite amount of copper is deposited, determined by the number of hours and the current density, the mirror is removed, washed and allowed to dry. When dry the clips supporting the mirror are removed and the mirror placed on a table for backing, see Fig. 1. A coat of adhesive material is then applied to the surface of the copper and allowed to dry thoroughly. Then a backing in the form of a plastic coating is

Fig. 3. A 60-in. Metal Mirror with Ribbed Sheet Steel Reinforced Cement Backing. Note the cement "rivet heads"

applied to a thickness of ½ in. and carefully smoothed and gauged on the edge to a uniform thickness so that when mounted the axis of the mirror will be in the correct position. As soon as the backing is completely dry and hard the mirror with back is removed from the glass and if necessary the silver surface cleaned. No polishing is required as the silver comes from the glass with a high degree of polish, in fact, polished better than it would be possible to do with any ordinary polishing means. In order to protect the silver surface from atmospheric conditions it must be coated with lacquer, see Fig. 2. The lacquer is flowed on and allowed to dry in a dust-free room. The back of the mirror is then painted and the mirror stocked ready for shipment. In order to obtain a greater strength in the back it was thought advisable to use a sheet steel support in addition to the plastic compound. This was made up in sections and welded together giving a strong reinforcement having a weight of only 35 lb. This steel was perforated with holes about ⅛ inch in diameter, allowing the plastic compound to come through and clinch all over the surface of the mirror back, see Fig. 3. This form withstands very much more abuse than any glass or ordinary mirror backing without injuring the surface, in fact this mirror seems to be so strong that it is now planned to mount the entire mirror and lamp from pivots attached to this steel backing of the mirror thereby saving a large amount of weight.

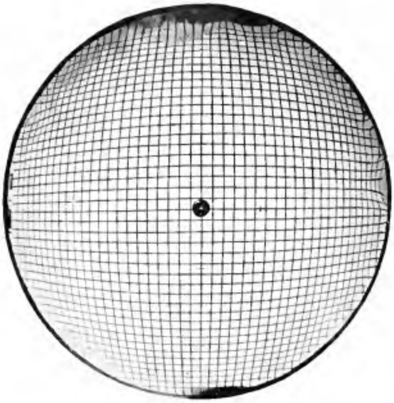


Fig 4. Line Photograph on 44-in. Metal Searchlight Mirror

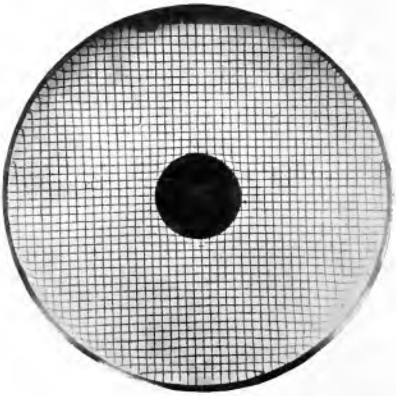


Fig. 5. Line Photograph on 60-in. Metal Mirror

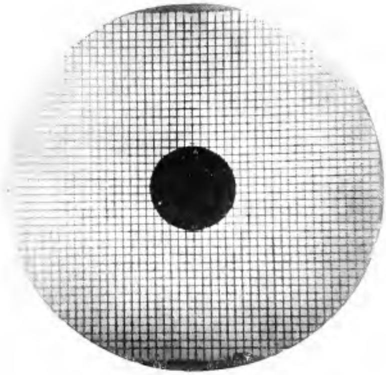


Fig. 6. Line Photograph on 60-in. Glass Mirror

The method of depositing silver and copper so as to produce a metallic layer that could be removed from the glass, the actual removing of the mirror from the glass and the handling of the heavy bulky piece throughout the processes were all problems to which much attention had to be paid, and many experiments were made before a satisfactory process was finally reached. The plastic compound used for a backing material as well as the adhesive also demanded careful attention. The backing required to be strong, light, tough and without any shrinkage or expansion on setting. It was thought at one time that the copper should be deposited with a rough surface and the backing made to adhere to this rough copper. This could be done, but it was found that the roughness tended to show on the surface of the silver mirror as very minute distortions of the curvature. Then, too, if the back is everywhere absolutely tight to the metal the unavoidable difference in thermal expansion between the two would either pull and distort the silver or crack the backing or both. Figs. 4 and 5 give some idea of the accuracy of curvature which has already been attained in the manufacture of mirrors by this method and Fig. 6 shows a similar test on a high grade glass mirror.

Adaptation of the High Intensity Arc to the Open-type 60-inch Army Searchlight

By John T. Beechlyn

Street Lighting Ddepartment, General Electric Company, Lynn Works

After pointing out the characteristics essential to the production of a high-intensity arc and describing how these are obtained in practice, the author successively deals with the mounting and connections, the ventilation system, mechanical construction, and feeding mechanism. He then discusses occultation and concludes his article with an account of the arc-viewing system and the way in which the "projection characteristics" have been improved.—Editor.

John T. Beechlyn

THE highest development in light generation for projection purposes has been attained in the so-called high intensity arc. This arc owes its characteristics to the extreme temperature of the gaseous contents of the positive crater which can be produced under certain conditions. These conditions include: high current density by employment of relatively small diameter electrodes of special composition, uniform conservation of the crater walls through rotation of the positive electrode, protective covering for the electrode near the arc to prevent excessive oxidization, and the maintenance of the arc in fixed relation to the crater of the positive electrode.

The chief advantage from this concentration of energy is found in the high penetration and small divergence of the resulting beam projected from a given reflector. This result can be obtained to a considerable extent by using a mirror of considerably greater focal length and correspondingly increased diameter with an ordinary type of arc, but on account of the lower specific brilliancy of the ordinary arc, a large mirror combination will not equal a high intensity, except by using a greater amount of energy and, of course, the large mirror would involve a great increase in weight and cost of the whole equipment.

The automatic lamp has been found satisfactory for naval and coast defense applications. The simple and more rugged hand-operated lamp is more suitable for open warfare field conditions.

In other respects the design of the present lamp unit was governed by the inherent requirements in regard to means of occultation, arc viewing system and facilities for arc control under all degrees of elevation that are characteristic of the open-type mounting. In addition certain dimensional restrictions were imposed by the "breach loading" feature of mounting which had already been developed in connection with the medium intensity lamp unit with which ready interchangeability must be maintained.

The aim has therefore been to meet these requirements and to obtain the greatest facility for efficiently operating, trimming and handling the lamp that is consistent with the fundamental simplicity that has characterized the whole equipment.

This has resulted in the production of a lamp in which departures from existing practices have been made both as regards construction and manner of operation. In certain respects distinct improvements in the characteristics of the projected beam have been obtained. To this reference will be made later.

Mounting and Connections

A general view of the lamp in operating position in the open-type mounting is shown in Fig. 1. The lamp is placed in position by insertion from the rear through a central opening in the mirror support and is retained by a radially operative bolt which engages a square thread cut into a ring-shaped member carried by the lamp near its base. This ring can be independently rotated by means of a flanged extension serving as a hand wheel, and the lamp by this means moved axially into correct position with reference to the focus of the mirror.

Support is lent to the central portion of the lamp by a sleeve that extends forward from the breech casting to which it is fastened by insulating means. This sleeve forms the positive terminal of the lamp mounting and establishes contact with the drum-like middle portion of the lamp unit which is directly connected with the contacting means of the positive electrode.

Connection for the negative electrode is established by means of a flexible cable extending from the switch carried on the mounting to a plug socket in the base of the lamp.

In the above respects the arrangement is very similar to that employed with the medium intensity lamp.

Characteristics of Draft System

The chimney is attached to the lamp after the latter is in position and is fastened by merely being pushed into a light-tight drawer-like slide over the arc chamber.

The inclined position of the chimney relative to the lamp axis assures the vertical rise necessary for draft under all conditions of elevation of the beam.

When a target is followed across the sky the two planes of rotation in the mirror mounting are ordinarily both brought into play, the azimuth movement being used principally when the target approaches its highest elevation over the horizon. As the beam is again lowered the chimney will, under these conditions, regain its upward position in a natural way.

Fig. 1. High Intensity Arc Lamp as Adapted to Open-type 60-in. Army Searchlight

If, however, the zenith is traversed by the target, the elevation movement must be resorted to and during the subsequent lowering of the beam the lamp and its chimney will suffer inversion. Provision is therefore made whereby the lamp itself may be rotated 180 deg. within its mounting and if this is done while still under a high elevation the vertical draft rise will be constantly maintained. This turning operation can be effected by gripping the rim of the operating base of the lamp which for this purpose has been extended rearward to form a handwheel.

The focal relation is not disturbed by this operation since the aforementioned annular screw member does not partake in the rotation, being retained by the spring pressure of the lock bolt in the breach.

Mechanical Construction

A general view of the lamp removed from its mounting is shown in Fig. 2, and in Fig. 3 the lamp is shown dissected into its major component units, which include frame with operating base, arc chamber, positive and negative feed mechanisms, occulting system, arc viewing system and chimney.

The frame consists of three longitudinal steel strips joined by spotwelding to spun steel members, its general form being apparent from the illustration. By means of a heavy bakelite plate it is insulated from the cast aluminum focusing screw and the operating base. The latter is made from spun steel which is pierced on one side to allow the mounting of the arc viewing screen. In the recess within the rim of the base are located handles for operating the occulter and to adjust the electrodes. The positive feed handle which is in most constant use is normally projecting beyond the base rim. This handle may, however, be snapped into a telescoped position within the outline of the rim. This allows the lamp unit, when the occulter is closed, to be stood vertically on its base, a position that is very convenient when making adjustments on the lamp while it is removed from its mounting.

Fig. 2. View of High Intensity Arc Lamp Removed from Its Mounting

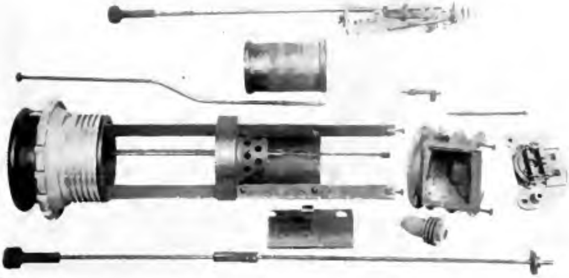


Fig. 3. Disassembled View of High Intensity Arc Lamp

The arc chamber is made from a calorized casting of boron-copper, which externally is provided with cooling flanges for keeping the temperature below that of luminous heat. The arc chamber is mounted at one extremity of the frame rods by insulating means. These consist of mica washers fitted in countersunk holes in both sides of the end flange and permanently held in position by means of spun-over steel bushings. This construction is characteristic of the insulation throughout the lamp, there being an entire absence of small loose insulation pieces when the lamp is disassembled. Similar insulating supports are provided between the arc chamber and the base of the positive feed mechanism. Electrical connection is made between this latter member and the lower frame rod by means of a copper rod passing through clearance holes in the flanges of the arc chamber.

Electrode Feed Mechanisms

The rotation and axial feed of the positive electrode is effected by means of sharp toothed double friction rollers, made from hardened steel that clamp the carbon from opposite sides. During the feeding operation these rollers are swung around the electrode axis, though being carried by a gear that receives its motion from a pinion directly mounted on an extension from the operating handle at the rear of the lamp. At the same time a slow rotation is imparted to the rollers by means of a planetary worm drive which is actuated by a star wheel that successively engages a number of stationary pins mounted around the supporting gear. By altering the number of these pins the ratio of rotation to axial feed of the electrode may be varied.

Current is supplied the electrode by means of spring-actuated silver contact brushes to which connection is made by flexible silver conductors of flat section. These contacts are situated an appreciable distance from the arc crater. Over the intervening space, to within a short distance of the crater, the electrode is protected by a calorized copper tube provided with cooling flanges.

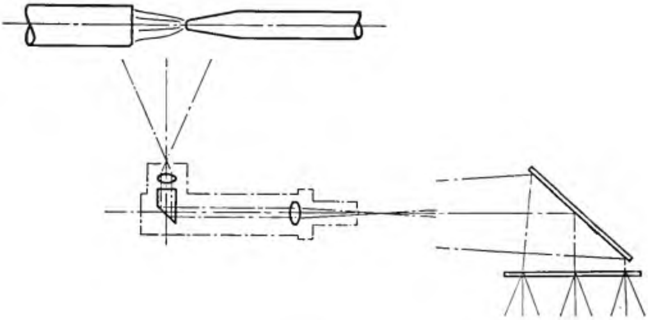


Fig. 4. Diagram of Optical System Employed with High Intensity Arc Lamp for 60-in. Open-type Army Searchlight

A somewhat similar arrangement of contacts and protection is employed for the negative electrode, but in this case the rotational feature is omitted and provision is made for axial feed only. A large diameter, double feed roller is employed and this is actuated by a simple worm drive, the worm being carried directly by the rod extending to the handle in the base of the lamp. In order to strike the arc the negative carbon may be rapidly advanced by exerting a pull on this handle. In this case the gear and worm momentarily assume the function of a rack and pinion. After the arc has been established the handle and electrode are returned to their normal position by means of a spring. The burning length is 8 inches for the negative electrode and 15 inches for the positive electrode, the diameters being $\frac{7}{16}$ in. and $\frac{5}{8}$ in. respectively. With an arc potential of 80 volts and normal current of 150-160 amperes continuous operation for fully one hour is obtained.

Occultation

The established practice in connection with arc searchlights of providing means whereby the arc may be started and tried out without externally visible evidence of this taking place had been followed in the case of the open field light. In the closed type the practice has been to effect this occultation by arresting the beam after it leaves the mirror by means of a suitable shutter mechanism, which obviously must be of large dimensions.

The necessity of employing different means in the case of the open type is the cause of one of the fundamental differences between the two types.

Occultation in the open type is best effected by means of a cylindrical shutter which intercepts the light between the source and the mirror. The closer to the source this cut-off is effected the smaller will be the required dimensions of the shutter and the range of axial movement it must cover.

In the present lamp this dimensional advantage has been carried as far as provision for efficient ventilation will permit, the shutter when closed serving as a duct which provides all the air entering the arc chamber and chimney.

Arc Viewing System

Closely associated with and largely conditioned by this manner of occultation is the special arc viewing system that has been developed for this lamp.

To prevent the escape of light when the lamp is occulted and at the same time obtain the best possible conditions for the operator who is situated behind the lamp and normally operating the controls with his right hand, an image of the arc and its immediate surroundings is projected back through the lamp to a screen on the left side of the operating base. The disposition of the electrodes in this image appear exactly as if viewed a few feet farther forward abreast the arc; and the location of the image within a few inches of the controlling handles and corelative to the movements of these is a distinct advantage in controlling the conditions of the arc and crater.

The optical elements employed are shown in a horizontal section in Fig. 4 and consist of a two-lens system into which is inserted a small reflecting prism for turning the light at right angles. The tube containing these members is held in a ball socket clamp on the side of the arc chamber and is readily removable. The image is projected back through the lamp outside the occulting shutter and is again turned through 90 deg. by means of a mirror and brought to a focus in natural scale on a ground glass screen on which a fixed black line serves to indicate the correct position of the crater edge.

A distinct advantage of this arrangement is found in the fact that the whole system is carried by the lamp unit which allows the position of the arc to be altered with respect to the mirror by axial adjustment of the lamp's position without disturbing the location of the arc on the viewing screen, a point of much importance when it is considered that the arc to obtain the best operation must be situated in a very definite relation to its immediate surroundings.

The arrangement of a lens within a few inches of a source of about 13 kw. of energy is rendered feasible by the relatively low illumination required in the image when compared with the intensity of the light source. This allows the use of a very small objective a few millimeters in diameter, which readily endures the conditions that would cause fracture or fusing with a larger piece of glass.

Improved Projection Characteristics

An objectional feature in the beam from a high intensity arc searchlight is present in the projected inverted image of the arc flame that surmounts the positive crater and which causes the appearance of a luminous mantle beneath the beam proper. This appended projection serves no useful purpose, while by its diffusion in the atmosphere it lowers the visibility of the target from points near the searchlight and may cause undesired illumination of objects in the foreground. It also imparts a flickering aspect to the beam.

In the present lamp it has been found possible to practically eliminate this objectionable feature by means of a screen which prevents the light from the arc tongue from reaching the mirror. To be effective this screen must be placed very near to the positive crater, while still providing egress for the arc flame. It must also be kept sufficiently cool to endure and not itself become a source of light through incandescence.

To this end a calorized copper apron is provided which depends from the chimney base across the arc chamber to within a fractional part of an inch above the crater, its lower edge being slightly in front of the crater edge. Being cast integral with the chimney base the heat is readily conducted up through this member and from there radiated by cooling flanges. Tests made with this arrangement show a very distinct improvement in the definition of the beam, the luminous mantle being practically eliminated, and also a marked increase in its apparent stability and this gain appears to be unaccompanied by any loss of light in the beam itself or any impairment of operation.

Glass Searchlight Mirrors

By Dr. Howard D. Minchin

Optical Engineer, Engineer Corps U. S. Army

This article and the one by Mr. R. B. Hussey are of especial interest in that together they cover the only practical searchlight reflectors, viz.: glass mirrors and metal mirrors. Dr. Minchin outlines the general requisites of a searchlight mirror, states the characteristics of the glass mirror, and describes some of the difficulties surmounted in producing this type. The remainder of the article he devotes to a brief statement of the detailed steps in manufacturing and testing a glass searchlight mirror.—Editor.

Dr. Howard D. Minchin

THE use of a mirror in the searchlight work of the army is of vital importance. The target to be illuminated is of necessity at a considerable distance from the source of light. In order that sufficient light be impinged upon this target for observation purposes there is needed some means of gathering and reflecting to it a large part of the light emitted by the source. For this purpose a reflector is used. This reflector must possess the ability to collect as large a part of the emitted beam as possible and then to reflect it to the target. To accomplish the latter, the beam must be reflected as a parallel beam. In addition to this requirement, the reflector must stand up under rather severe strains when in operation.

1. Strain due to the great heat from the source of light.
2. Strain due to transportation and handling.
3. Strain due to shell fire in the field.

The shape of the reflector to give high gathering power and proper reflecting power is a surface in the form of a paraboloid and is termed a parabolic mirror.

Metal mirrors were used at first. These stood the strain but failed in the reflecting power. A polished metal surface corrodes very readily and is easily scratched and the reflecting power very rapidly falls off. Glass, on the other hand, readily takes on a very high polish and a silvered glass has high reflecting power. Glass is easily moulded into any desired shape and to produce a paraboloid is relatively easy. The glass mirror now used is a paraboloid silvered on the convex side and backed by a suitable backing. However, to produce a good parabolic glass mirror has taxed the skill of the manufacturer.

Practice proves that a true parabolic mirror will not produce a reflected parallel beam; first, because a parallel beam results only when the source of light is a point; and, second, the thickness of the glass results in a refraction that interferes with the parallelism of the beam. It has been found necessary to give the convex surface a curve somewhat different from a parabola so that the refraction produced combined with the effect resulting from the size of the source will co-operate to produce a parallel beam.

One of the principal difficulties in the manufacture of the glass parabolic mirror has been the zones which result when the curve has once been produced.

Fig. 1 is a photograph made of a mirror having a good curve but showing zones in the surface. Fig. 2 is a photograph of a mirror with good reflecting power and free from zones. This mirror gives a parallel beam free from ghosts.

To withstand the strains, a glass has been produced that with proper annealing is very tough. It is remarkably free from stones, striæ, bubbles, fish-eyes, comets, etc., and has a good color and a low absorption coefficient. When the mirror is silvered and properly backed it withstands all ordinary strains as well as a mirror of metal. The glass serves as a supporter for the silver reflecting surface and also serves as a protector of this surface. The backing protects the reflecting surface on the other side and serves to hold the glass together in case of breakage due to shell fire or other cause.

At present, tests are being made with a view of producing a backing that will possess good protective qualities and a higher supporting property and at the same time keep the weight low. It is also proposed that a thinner glass be used. A thinner glass will reduce the weight and make handling easier. It can be annealed more efficiently than the thick glass and thus will be tougher. It will absorb less heat from the source of light and therefore will reduce the breakage due to temperature effects.

The method now being used in silvering and the method of attaching the backing that is proposed will produce a mirror which is held, as it were, in a solid cup that protects the reflecting surface against all foreign action.

Manufacture of the Mirror

The manufacture of the searchlight mirror is covered briefly in the following. The different steps are given with a short statement of each step.

Mixing the Ingredients for the Glass. The ingredients in the proper proportion and of the proper purity are very carefully mixed. The ingredients chosen are determined by the kind and the quality of the glass desired.

Melting. When thoroughly mixed, the mix is fed into a large glass pot and placed in the furnace where it is melted and kept at a given temperature a sufficient time to assure its being thoroughly fluid and that all the material is melted.

Pouring. When the melt is ready, the pot is taken from the kiln by large mechanically operated tongs. It is skimmed and the outside cleaned from all dirt particles. The glass is then poured upon a large steel table that is water-cooled. The glass mass is then rolled out to the desired thickness by a water-cooled roller. The rolled sheet is trimmed and then pushed into the lehr. It is passed gradually from chamber to chamber [illegible] each chamber being of a lower temperature than the one preceding. A given sheet of glass requires about one and a half hours to pass completely through the lehr and become properly annealed.

Cutting. In the last chamber of the lehr, inspectors check the sheet for flaws, after which it is passed out onto a large table and there cut into the largest pieces possible without flaws. The glass for a searchlight mirror is cut circular.

Moulding. The circular disk is placed on the mould in the oven and the temperature is gradually raised to about 1350 deg. F. When the glass becomes soft enough it falls to fit the mould.

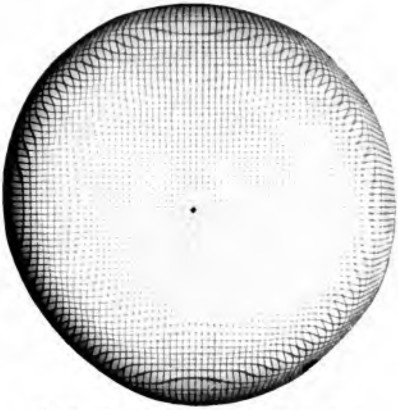


Fig. 1. Line Photograph of Mirror Having Good Curvature but Showing Zones

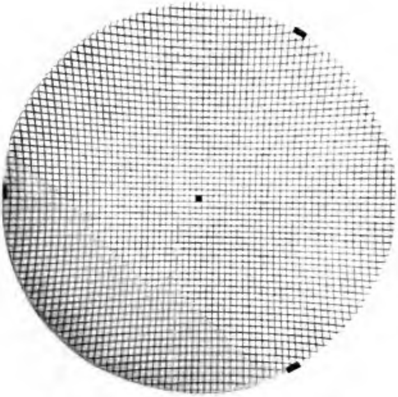


Fig. 2. Line Photograph of Mirror with Good Reflecting Power and Free from Zones

Annealing. The temperature is held at 1350 deg. F. for about 10 hours. It is then cooled to 900 deg. F. at about 10 deg. per hour. Then it is cooled to 700 deg. at the rate of 20 deg. per hour. From 700 deg. F. the kiln door is opened and the cooling goes on until room temperature is reached.

Grinding. To grind the surface to a uniform condition:

1. A wheel driven over the surface and guided by templates has been tried, the abrasive being fed to the wheel at the point of contact.
2. An abrasive wheel has been used and driven as above.
3. Different forms of laps varying from a strap to a complete shell have been tried.

Different abrasives have been used such as carborundum, emery, and sand. The best form of grinder and abrasive is still in doubt.

Smoothing. For smoothing, different forms of laps are being tried out with a fine grade of sand. The best form of lap, here also, is yet to be determined upon.

Polishing. Rouge is used for polishing but some doubt exists as to the best form of lap to be used. In polishing, the lap is driven at a higher rate of speed than in the other processes. A greater pressure is also applied to the lap.

Silvering. The surface to be silvered is thoroughly cleansed and the disk is then lowered into the silver bath and left about two and a half hours. The scheme of silvering is to allow the silver to deposit upwards. This gives a very uniform deposit and one free from all fish-eyes, dust particles, etc.

Copper Plating. The silvered mirror is then transferred to the copper plating tank and a current of 80 amperes at one half a volt is passed through the solution for one half hour. This gives a deposit of great uniformity and one free from fish-eyes.

If a thicker deposit of copper is desired, all that is necessary is to let the current pass through the solution a longer time.

Backing. When the copper plating is completed several coats of paint are applied. Wire mesh is attached when the last coat of paint is still quite tacky. The mesh is pulled tightly in place and a heavy coat of a special paint about the consistency of putty is applied. This mixture, which is waterproof, is worked well into the mesh and allowed to dry. A good coat of black paint is now applied and the mirror is placed in an oven at a temperature of 90 deg. C. and baked for 24 hours.

Testing of Glass Searchlight Mirrors

The testing of glass searchlight mirrors may be considered in two parts: First, the inspection and testing of the glass, and, second, the inspection and testing of the finished mirror.

As proper glass is an absolute necessity great care is required in its manufacture. The quality and proper proportion of the ingredients must be carefully adhered to. The temperature of the furnace and the proper length of time the melt is left in the furnace must be carefully attended to. The pouring and the annealing of the plate are very important factors.

When taken from the lehr the glass is inspected and after being polished it is again inspected. The glass must be clear white, free from stones, bubbles, striæ, fish-eyes, comets, stars, stone-cracks, smoke, etc. In the finish of the glass disk the surface must be reasonably free from fire cracks, blotches, and deep surface bubbles. The disk should be subjected to a very thorough test for toughness and a careful test for proper annealing should be given it.

Having passed all these tests satisfactorily the disk is ready for the mirror manufacturer.

There are some fifteen steps in the manufacture of the mirror. First comes the bending of the disk to the required form and the proper annealing of this form. (When this step is completed the form may be tested but this is more in the interest of the manufacturer and concerns the ease of production chiefly.) The annealing should be thoroughly tested, as upon this depends the toughness of the glass and its ability to stand up under use. Polarized light may be used for testing the annealing.

The disk is then ground, smoothed and polished and when a surface free from sleets, scratches and surface flaws is produced the convex surface is silvered. The mirror should now be inspected and tested carefully for form of curve and for focus.

Focal Point Test. A beam of light one inch in diameter is projected parallel to the axis of the mirror and moved across the mirror perpendicular to the axis. The reflected beam should pass through a point which remains fixed. When this occurs the mirror has no spherical aberration. In practice a tolerance of about three eighths of an inch is allowed.

Line Test. The reflection from the mirror of a screen, consisting of a series of lines so ruled as to form squares, is photographed. A regular series of lines will indicate that the mirror is uniform in thickness and free from irregularities caused by grinding.

Night Illumination Test. This test consists in placing at the focal point of the mirror a strong source of light and reflecting the beam. If the mirror is of the correct curve the reflected beam will be parallel and will show uniform intensity in any given cross section. It will be free from zones and free from ghosts. These ghosts are cones of light outside the parallel beam and are caused by irregularities in the surface of the mirror. The silver surface should be of uniform depth of deposit.

Backing Test. The copper plating should be uniformly applied and of the proper thickness. The paint and wire mesh must be evenly applied and firmly fixed to the mirror. The backing should not be affected when subjected to a dry heat of 90 deg. C. for a period of 24 hours. The reflecting backing should not show any discoloration after being thus heated.

In the tests of the mirror, the optical qualities must be looked for rather than the appearance of the mirror. A bubble in the mirror may look bad but it is of little importance optically. A slight defect in the curve may lessen the optical efficiency to a considerable extent and yet in no way interfere with the appearance of the mirror.

Packing. When the mirror has been accepted it is packed very carefully, each mirror being placed in a separate box. The box is made strong so that in transportation the mirror is not shaken or in any way damaged.

Searchlight Air Defense Operations

By William F. Tompkins

Major of Engineers, United States Army

Major Tompkins writes with authority on the subject of "Searchlight Air Defense," for he spent over a year with the 56th U. S. Engineers in France and took part in most effectively protecting advance bases against hostile aircraft. In his discussion he says that: "Searchlights suitably supported by carefully located night pursuit squadrons or anti-aircraft guns must be placed in bands along the entire front especially guarding * * * the prominent routes to the important objectives in the rear." After outlining the trend of the actions which led up to this situation, he describes the technique and effects of this method of defense against night raids by enemy aircraft.—Editor.

William F. Tompkins

AT the commencement of the European war, it was universally believed that radical advances in warfare would be made, especially in the new arm of aviation. This expectation began to be realized almost immediately, with the result that each year such great strides were made in the development and tactical use of aircraft that many prophesied that victory would come to the side which could obtain and maintain the supremacy in the air.

In order to win a great war it must be brought home to the entire mass of the opposing nation that it is or is certain to be defeated. This may be done in several ways, or by a combination of ways. The defeat of the Spanish Armada is an example where a great naval victory made a formidable power realize its defeat. Similar examples may be found in the history of the American nation in the Civil War, when the certainty of defeat was made known to the Southern people, primarily by the terrible losses which were felt in every home of every city, and, secondarily, by such expeditions as Sherman's march to the sea. In the recent war the Teutonic Allies attempted to obtain the same result by submarine warfare which, through starvation, would make the Allies, especially the British Isles, feel the dread of impending defeat, and also by large raiding squadrons of dirigibles and airplanes, which threatened to destroy the most important centers in England and France.

More than ever entire nations find themselves drawn into warfare. In distant and hardly accessible countries, such as America during 1917, positive attempts may not be serious, but for countries such as France, located comparatively near to the fighting line, the whole civilian population from Paris to the East found itself open to demoralizing attacks by constantly increasing numbers of powerful aircraft. A similar position was that of the British Islands, especially as regards the London area. It was soon realized that, unless immediate and effective measures were taken to counteract these attacks from the air, the people would soon begin to feel that the enemy had such strength that it was useless to attempt to continue the war to a successful conclusion.

In addition to the demoralization of the civilian population, there were other results of warfare from the air which were of still greater value, especially from the military point of view. At the beginning of the war, troop units were withdrawn from the fighting lines and brought back a few kilometers where they could rest and recuperate in security.

As time went on and aviation produced more and more bombing machines, carrying projectiles ever increasing in size, and having far greater cruising ranges, it became practically impossible to withdraw troops to billets where they could rest in safety unless the supremacy of the air, not only by day, but by night, was constantly maintained.

Fig. 1. Gotha Type of German Bombing Airplane

Before the outbreak of the war, searchlights were designed for two purposes—foreground illumination or field searchlights and water illumination or coast defense searchlights. On the entry of the United States into the struggle, it was immediately apparent to the Army that every searchlight available must be used in conjunction with the other arms to combat the night flyer. Thus lights of every type were hastily converted to meet the needs of aerial work and troops were trained with the British and French Armies according to the most modern tactics of air defense. Therefore, when the American Army, as a unit, began to take its share in the giant blows against the common adversary, there were American searchlights available, operated by American troops, which rendered great service in the offensives.

Just as with opposing infantry, it was soon found that night operations gained more and more in importance, so it was found in aviation that bombing by night was much more successful than day raiding. The day bomber has some advantages, no doubt. His route is clearly indicated and his objective is easily seen, but from the moment that he approaches his frontier he is constantly exposed to attacks from defending aircraft, which will have much greater ability to maneuver and which may be nearly half again as fast. The heavy bomber is necessarily limited to a low ceiling so that he is always within range of anti-aircraft guns and if he approaches too close to the ground is sure to be attacked by machine guns and even rifle fire. The farther he penetrates into the opposing country, the greater is apt to be the superiority in numbers against him.

The night bomber also finds many restrictions, especially the difficulty in finding his way towards his objective and in accurately locating it when once near the proper area. Night landings are more difficult and dangerous than those by day, but night landing for the slow flying, heavy bombers is comparatively simple when compared to the difficulty of landing the fast pursuit planes which must combat them. The night bomber has the great advantage of being hidden in darkness, so that, unless he is artificially illuminated, defending airplanes or anti-aircraft artillery have but a slim chance indeed of bringing down their target. In addition, night bombing has a greater demoralizing effect even among seasoned troops and this is still more apparent among civilians, particularly women and young children.

A study of the action of night bombers shows that they must follow certain clearly defined features of the ground. These may be classed in importance as follows: Large rivers and river valleys, edges of great forests, coast lines, railroad tracks when there are trains moving over them, canals, clearly defined highways and railroads. In order not to be lost, the hostile planes must then follow such a route as indicated above and consequently defenses are planned to obstruct these routes. Searchlights suitably supported by carefully located night pursuit squadrons or anti-aircraft guns must be placed in bands along the entire front especially guarding, by additional depth of the lighted area, the prominent routes to the important objectives in the rear.

It is necessary to call attention to the need of co-operation, or liaison, with other branches. Searchlights illuminate the plane when it approaches vulnerable areas and the plane should then be attacked by friendly pursuit planes or by well placed bursts of anti-aircraft fire. If the hostile plane comes close to the ground, it must be attached by machine gun and rifle fire in addition. In other words, every effort must be brought to bring down the bomber and this can be obtained only by constant and thorough liaison. This necessitates many conferences leading to joint planning of air defenses, perfect means of communication, and thorough co-operation.

The searchlights must be most carefully moved into position at night, all work of location being done under camouflage nets. The final emplacement must always be well camouflaged in order to prevent its location being spotted by the enemy's observation balloons or photographing planes. If care is not taken in locating searchlights and if the location is not constantly changed the moment that it is discovered, not only are losses in materiel and personnel are to be [illegible] from artillery fire, but also the searchlight may act as a lighthouse indicating position to the aerial flyer. If they are carefully located and constantly changed to new positions, they not only defend the objectives in the rear, but also aid in confusing the flyer. The same effect of moving searchlights may sometimes be obtained by care in exposing only those lights in actual range of the approaching target.

Correct air defenses would therefore find a band of searchlights stretching along the entire front and forming a lighted area having a depth of at least four searchlights. In addition, more materiel will be needed to protect vulnerable objectives in rear in case hostile planes should penetrate the primary defensive area or circle around its flanks. Sound locators should be employed to give close indication of the direction of the approaching bomber and to limit the field of search by the searchlight beams. The emplacements must be within supporting distance of adjacent lights and must be on high ground with the best field of view in all directions and well above ground mists. Searchlight positions are from one to three miles apart depending upon various conditions and are placed in staggered order.

The uses of searchlights may be summarized. Their primary use is to illuminate hostile planes for attack. They are so located that at least three beams can be brought on any target over the area, which makes an illuminated area most difficult for a heavy,

Fig. 2. Typical Searchlight Emplacement showing Searchlight Pipe Control and Sound Locator

Fig. 3. Captured German Searchlight Truck, Unloading Lamp

Fig. 5. Captured German Searchlight Power Plant, Unloaded

Fig. 4. Dugout for Searchlight Stationary Power Plant and Quarters

Fig. 6. 60-in. "Dishpan" and 60-in. Sperry Searchlights in Operation

slow flying, low flying bomber to escape from. In addition, they dazzle and mislead hostile aviators and, by contrast, hide objectives. By skillful location, they may be used to create effective camouflage of real objectives. The psychological effect upon an aviator when illuminated may easily be imagined. Far from his own airdrome, flying at night, necessarily at a comparatively low altitude, in a slow machine most difficult to maneuver quickly and more or less unprotected in the rear, he realizes that he forms a huge target, especially to attacks by fast flying, easily maneuvered pursuit planes. When illuminated, he can see nothing and yet knows that he is immediately open to attack by planes, anti-aircraft artillery and machine guns. His only idea is to get out of the searchlight beams into the friendly darkness again. He is dazzled and becomes confused in his route, frequently losing his way in his efforts to escape. He may attempt to fly high at the risk of losing his way, but he cannot go above a certain level which is within the range of illumination and within easy range for attack. The higher he flies, the more difficult he finds it to follow his routes of approach and to locate his objective and the greater is his inaccuracy in dropping aerial torpedoes on the desired spot. If he attempts to circle around the lighted area, he must travel a great distance, with a correspondingly greater chance of becoming lost, of being attacked, or of meeting some accident which forces him to land in hostile territory.

Air defense is a problem which requires much future thought and is a subject of absorbing interest. In future wars, it is believed that searchlights will find their principal use in combating airplanes. Bombing attacks must be expected on a still greater scale, employing larger and larger planes, carrying projectiles containing thousands of pounds of explosives. There is reason to believe that fast pursuit planes will work in conjunction with the bombers so as to fight off attacks by friendly planes and to attack and confuse air defenses such as searchlights. It should be borne in mind that materiel objectives for aircraft are usually large, impossible to move, and difficult to conceal. Also air reconnaissance and "strafing" by night will be correspondingly increased in value.

The need for development may therefore be seen. Searchlights must be made as cheaply and as simple in construction as possible. They must be exceedingly rugged and possess a maximum of mobility. Their range should be increased to meet future needs, and the area of their beams must be greater in order to facilitate the picking up of aerial targets and to hold them more easily when once illuminated. The co-operation of American manufacturers, who successfully improved searchlight materiel as the needs of field conditions required, has caused American lights to reach a high stage in development. By their continued patriotic aid a state of searchlight efficiency, which will be the first step towards night protection, may soon be reached and their industry and skill will be relied upon to meet future difficulties, which must be overcome. In order to be brief, this article has been limited to searchlights for air defense, but searchlights employed for field and water foreground illumination have a great future and developments made for one purpose are, nearly always, applicable to the others.

Fig 7. Searchlight Power Plant Emplacement

Searchlight Testing

By F. A. Benford

Illuminating Engineering Laboratory, General Electric Company

The results which the war necessity produced in the direction of obtaining more powerful, lighter, and mobile searchlight units are told by the other authors in this issue. Mr. Benford tells of the testing which was such a factor in accomplishing these results. The large testing ground which he describes and the instruments involved for testing purposes reflect credit on all those responsible for this work.—Editor.

F. A. Benford

UPON the entrance of the United States into the world war, our military authorities saw the need of a greatly altered type of searchlight to meet the demand for protection against bombing planes which at that time were having things pretty much their own way. The anti-aircraft gun, whatever it may have done later, was of little aid, and many a proud and ancient city was reduced to seeking a precarious safety in darkness and the suppression of visible signs of life. Every night saw the blaze of bombed ammunition dumps, the breaking of communication, and the interruption of supplies, but above all, was the nervous tension of the soldiers and civilians waiting for the hovering Boche to drop his bombs or pass on. Sitting in a trench listening to the whistle of a descending bomb has been described as the most nerve-racking experience of the war. The man on the ground could always tell by the sound that the bomb was directly over his head, and as the force of gravity is a straight up and down affair, it didn't take a long train of reasoning to bring him to the conclusion that it was his own personal bomb that he heard. Of all the tactics employed by the Germans, few came closer to success than night bombing, and the call for help was clear and insistent. The only promising aid in sight was a powerful, mobile searchlight that would reveal the enemy to the ground and air defenses and, if not able to turn him back, at least drive him so high that accurate bombing would be impossible.

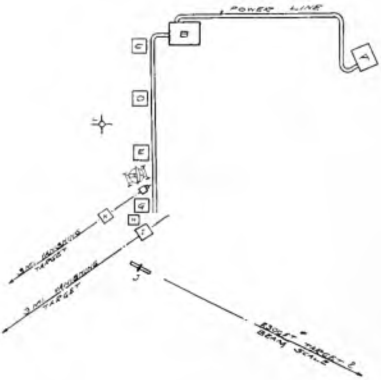


Fig. 1. General Ground Plan of Searchlight Station

A—Power House
B—General Test House
C—60-in. High Intensity Drum Type Projector
D—60-in. Low Intensity Drum Type Projector
E—60-in. High Intensity Drum Type Projector
F—60-in. Medium Intensity Army Open Type Projector
G—Incandescent Projector
H—Wireless Telephone Station
I—Sectored Disc (Visibility Test)
J—6-in. Telephotometer
K—15-in. Telephotometer
L—Antenna of Wireless Telephone.

The characteristics required of an anti-aircraft searchlight are: Mobility, durability under rough usage, reliability under all circumstances, ability to operate at any elevation of axis or even upside down, good luminous efficiency, and quietness of operation. When to this list is added the fact that the positive electrode is often at a blazing white heat for its entire length and many parts of the lamp are red hot during a protracted run, it is seen that the design of an operating projector is not a simple matter. Several of these requirements were entirely new, and some idea of the radical changes in the new projector may be gained by a glance at the illustration of the old fortification-type searchlight, Fig. 3, and the army open-type searchlight, Fig. 4. During the tests that accompanied the development of the new type searchlight, every part of the projector had to be kept under constant observation and the interested engineers kept posted. The scheme and scope of the testing was laid out by Mr. W. D'A. Ryan, and all actual test work was done by members of the Illuminating Engineering Laboratory of the General Electric Co. Following each test, technical reports were made to the General

Fig. 2. General View of Searchlight Station. From left to right, there are shown: (1) 6-in. telephotometer tube, (2) lens of 15-in. telephotometer on pier, (3) sectored disc housing, (4) wireless telephone house, (5) 15-in. incandescent projector, (6) 30-in. incandescent projector, (7) 60-in. medium intensity open type projector, (8) 60-in. high intensity projector, (9) mast of wireless telephone, (10) 60-in. low intensity projector (in high intensity drum), (11) 60-in. high intensity projector, (12) test house.

Engineer Depot, U. S. Army, covering first, fairly complete original test data and notes on operation; second, a summary and comparison of the data; and third, a judgment on the thing tested.

The principal source of information was the outdoor searchlight range on the Schenectady-Duanesburg road. Here was equipment for operating and testing the numerous types of searchlight, singly or in groups. The test work fell into three classes: first, a mechanical or operation test of the searchlight or carbons; second, a test of the relative revealing power of the searchlights; and third, a photometric analysis of the beams of light. The last class of testing took up the greater part of the time, but the three classes were always more or less interwoven and proceeded simultaneously. To the uninitiated, the amount and scale of testing apparatus is amazing, and the labor involved in choosing between two identically appearing carbons seems beyond all reason. The explanation is simple enough for sheer difficulty—searchlight photometry stands in a class by itself. There are several factors, such as current and voltage, that are under control; several others, such as crater formation and steadiness of burning, that can be observed but only slightly controlled; and finally, there is the action of the atmosphere, which cannot be controlled, and until this station was built was probably never before measured as a regular part of the photometric testing of a searchlight.

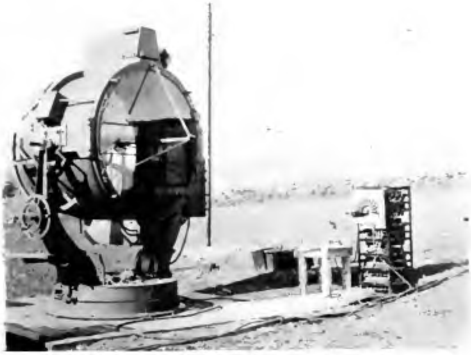


Fig. 3. Full Automatic High Intensity Lamp in Coast Fortification Type Drum. On account of its bulk and weight, this searchlight was not suitable for mobile service.

The country around Schenectady was thoroughly examined before a suitable location was found on the Schenectady-Duanesburg road about five miles from Schenectady. This location is entirely free from smoke and river fog. The power station and searchlight are located on a hillside having a free view across a wide shallow valley. A high point of ground 2300 feet away was selected for the station at which photometric readings were to be taken. A mile and a half away an airplane silhouette was erected, and three miles across the valley was located the big "vanishing" target mounted on the brow of a hill so that the sky formed the background. The searchlight station, powerhouse, and photometric station were connected by a telephone line, while communication between the searchlights and vanishing target depended on a wireless telephone outfit similar to those used by the airplanes spotting for the artillery.

Fig. 4. An early model of the 60-in. Type Medium Intensity Searchlight adopted for army use

The beam of light reflected from a parabolic mirror has several peculiar features, the most important being the great distance to the point where the light in the beam has assumed an approximately final distribution. The light that strikes the center of the mirror has the greatest spread and forms the outside of the beam, and the light that strikes the rim of the mirror is most abundant in the center of the beam. Theoretically this crossing over process never ceases, but practically the light is in its final position at from one hundred to four hundred times the diameter of the mirror, depending upon the type of arc. These distances allow considerable atmospheric interference and also necessitate some means of constant communication between the two parts of the testing squad which is composed of five active members, as follows:

(1). Lamp operator, who also records arc voltage and current at half-minute intervals.

(2). Beam trainer, who sees that the arc is properly focused and who directs the beam on the target and, by watching the arc, helps the operator in maintaining a normal crater.

(3). Communication man, at searchlight, who in addition to keeping up communications, records the degree of flicker in the beam, the kind and time of hissing arc, and the outages.

(4). Photometer reader and communication man.

(5). Data recorder, for photometer only.

In addition to the above, there is the engineer of the power station and from one to six observers, depending on the type of the test.

Fig. 5. A close-up view of the Beam Scale and Photometer House. Note the size as compared with the man standing near the middle

The electrodes of the open-type searchlight are kept in the correct burning position by occasionally rotating both positive and negative. Any slight movement of the crater on the positive carbon is accompanied by a movement of the beam and there is no provision on the searchlight itself for keeping the arc as sharply in focus as is required in test work. For this reason, the beam scale shown in Figs. 5 and 6 was used as both a guide for the beam and as a means for observing and checking the beam width. The photometer was placed with its head at a hole in the center of the large white square near the right end of the scale. This zero mark on the scale was really a six-foot square hut with full equipment and accommodations for the photometer reader and the data man. The trainer would direct the beam so that the part in which measurements were required would come at the zero mark. The points of measurement were usually 0.2 of a degree apart, or two small divisions on the scale. The trainer watched one edge of the beam as he moved it across the target. The edges of the beam are more clearly defined than the center and as only one edge can be seen plainly at a time, the target was placed near the extreme right end of the scale. The left edge of the beam could then be moved over four and a half degrees, if the beam were that wide. In general, the testing was done across the horizontal centerline of the beam, but a vertical scale was built so that occasional special tests in a vertical plane could be carried out.

The photometers were of the Weber portable type with a working range of one hundred thousand to one, which is more than sufficient to cover the variations in intensity encountered. Thus, the ratio of the greatest intensity of the high-intensity arc to the lowest measured intensities of some of the smaller arcs was about one thousand to one. The readings were in foot-candles at the face of the target, normal illumination, and the apparent intensity of the searchlight in candles was found by multiplying the illumination by the square of the distance, or 5,290,000.

It was realized from the first that the handicap of not knowing the atmospheric transmission would be fatal to much of the testing orginally planned. Consequently, two instruments were designed and assembled at the Laboratory for the measurement of this transmission. The smaller one, 6-in. diameter and 18-ft. focal length, was used during photometric work on the 2300-ft. target; and the larger one, 15-in. diameter and 30-ft. focal length, was used during the visibility tests on the three-mile target. These telephotometers each consisted of a simple double convex lens which formed an image of the target in the center of the Lummer-Brodhun cube of a portable photometer. To make a 15-inch diameter telescope lens of good figure is a matter of several thousand dollars and a year's

LAMP—Open Type   TEST NO. 3062
MIRROR—B & L 456.   DATE—10—25, 1918
ELECTRODES Pos. G.E. 161.
           Neg. G.E.
AMPERES—

Time	Hiss	Low Hiss	Quiet Operation	Steady Beam	Remarks
12:07	Start		2 min.		Smoking small
12:09	1 min.			2 flare	Good, steady in 7 minutes
12:10			3 min.		
12:13	1 min.			1 flare	
12:14			50½ min.		Reading begun
1:04½	Current off				
	2	0	55½		

FLARES—3.
HISS—4 per cent.
LOW HISS—0 per cent.
QUIET OPERATION—96 per cent.
STEADY BEAM—100 per cent.
CONCLUSIONS Good operating electrode. Hissing and flares only at start.

Fig. 6. The 2300-ft. Target and Beam Scale, as viewed from the searchlight station. The long stubs are one degree apart. The horizontal scale is five and one half degrees long and the vertical scale is one and one half degrees high

time. The degree of accuracy required for the telephotometer lens, very fortunately, may be almost anything when the size and distance of the target are known. With an achromatic lens, the losses of light may be calculated and the exit pupil determined beforehand. A simple, uncorrected lens gives a blurred image that wastes light at the ocular, and in both telephotometers the loss of light was determined by direct experiment, using an exit pupil smaller than called for by the calculations.

The instruments were first set up in the Laboratory and directed against a block of magnesium of such size as to give an image similar in size to that of the target on the outdoor range. The brightness of the magnesium was then measured through the telescope and compared with measurements made directly at a few feet distance. This ratio gave a figure for the relative brightness of the image in the photometer field. When used on the range, the zero section of the beam scale was illuminated by an incandescent searchlight that was carefully adjusted and maintained constant during the test. At a given signal, the man at the telephotometer would take readings and the men at the target, who had an extra photometer for the purpose, would take brightness readings on the same surface. A comparison of the two figures for brightness so obtained would give the loss of light in the atmosphere from the target back to the telephotometer, and the photometric data of the searchlight on test could be corrected accordingly.

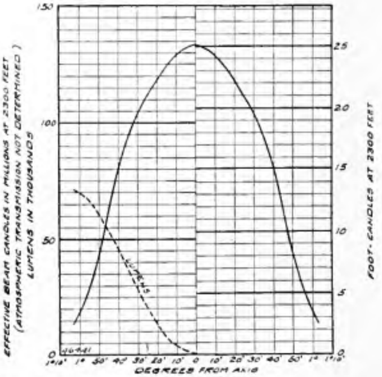
Telephotometer readings were usually taken at the beginning of each night's work, at 11 o'clock, and at 2 a.m. just before quitting. A curve of time against transmission was drawn for each night, and the various tests were then located on this curve and given the proper correction.

The selection of electrodes for the open-type searchlight involved testing a large number of makes and mixtures before the final choice could be made. Three companies, the Speer Carbon Company, the National Carbon Company, and the General Electric Company were actively engaged in making experimental mixtures that were tested out and reported on so that the chemists of the three companies were kept posted on both their own electrodes and those of the other two. Frequent meetings of the three chemists were held at the Laboratory, where the test data and carbon stubs were inspected and these led to an extremely rapid development in the art of making better electrodes. It was this part of the work with which Mr. Ryan identified himself most closely, and it was his original specifications for sizes and currents that gave the development of carbons its flying start toward success.

Fig. 8 gives the total data of the tests on eight carbons of the same mixture, including curves of the beam characteristics as determined by seventeen separate traverses of the beam.

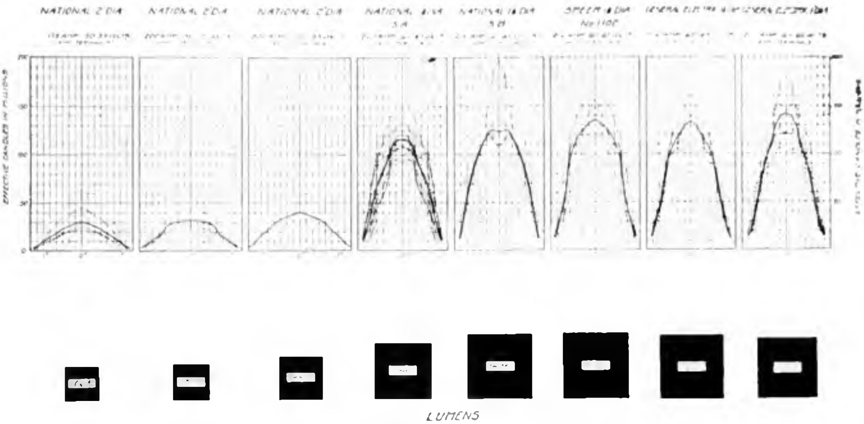
There are three prime requirements to be met by carbons for anti-aircraft searchlights. These are: High luminous efficiency, steadiness and uniformity of burning, and quietness. The first is the easiest to meet and the last is the hardest. Luminous efficiency and quietness (that is, freedom from hissing) seem to be opposite characteristics, and to obtain one without sacrificing the other is often difficult. The electrodes now made surpass the best pre-war carbons in all three features; and the development of carbons for greatly increased currents is still under way and holds great promise for the future.

The so-called disappearing target consisted of a strip of canvas thirteen feet wide and three hundred feet long. This was wound on two spools leaving exposed a section thirteen feet long. This thirteen-foot section constituted the target on which visibility tests were made. The canvas was held high in the air so that the sky formed its background, and to this extent at least it resembled an airplane,



W. D'A. Ryan, Illuminating Engineer

Fig. 7. These Curves show the beam intensities and flux values obtained with a certain group of similar electrodes

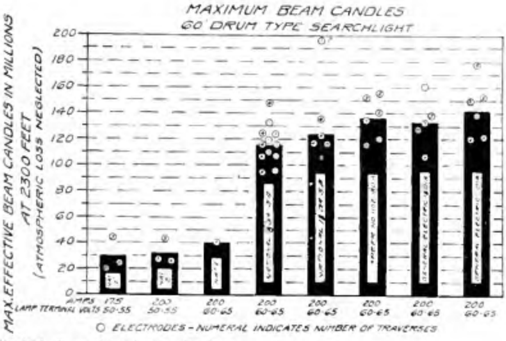


W. D'A. Ryan, Illuminating Engineer

Fig. 8. The three Curves at the left show the pre-war intensities from a 60-in. searchlight. The five Curves on the right show preliminary results with five of the most promising electrodes developed during the war. Later tests were restricted to the three best out of these five. These curves and those on the following seven sheets were hand-colored in the reports sent out from the laboratory. The same color was used throughout for each make of electrode, and this expedient was very successful in getting the information to people who had only a limited experience in photometry, besides being a great convenience to the more experienced. The scattering of the individual curves is a good index to the steadiness and uniformity of burning

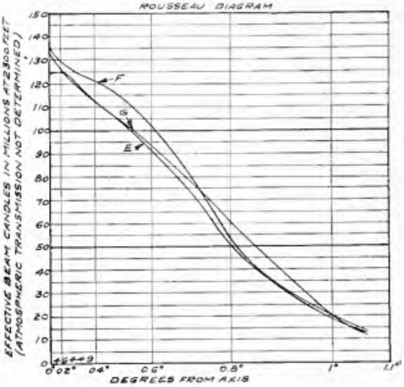
and its distance from the searchlight, three miles, represents a common "pick up" distance for airplanes. One end section of the canvas was painted with a good white diffusing paint having a reflection coefficient of 0.670. The second section was white with a number of fine black stripes, reducing the average coefficient to 0.532. The third section had wider black stripes and a coefficient of 0.423. The fourth had a coefficient of 0.335 or just one half that of the first section. This geometric series, which reduces the coefficient by half every three steps, was continued until the last target was entirely black. The black and white markings were not visible at three miles, and to the observer the target grew dimmer and dimmer as it was moved toward the black end.

The target was used both as a disappearing and as a reappearing object. Starting with a white target, the canvas was rolled toward the black end. To the observers the target became gradually dimmer and dimmer until it finally disappeared. The disappearing point is not sharply defined, principally on account of the normal variations in the intensity of the beam. While the target was still fairly bright and distinct it would momentarily disappear during a period of low crater brilliancy. These periods of invisibility became longer as the target became a darker gray, until finally the target could be seen only during short periods of high crater brilliancy, and then came total invisibility.



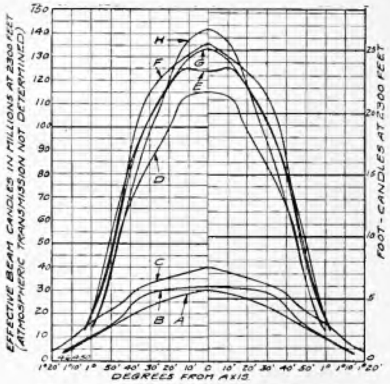
W. D'A. Ryan, Illuminating Engineer

Fig. 9. A graphical study of the maximum intensities given by different electrodes. The scattering of the spots indicates the variation encountered between individual electrodes of the same mix



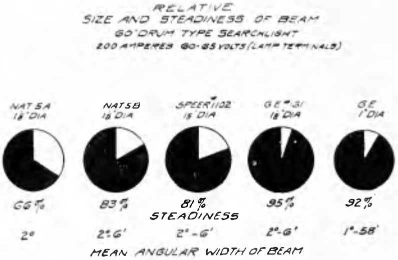
W. D'A. Ryan, Illuminating Engineer

Fig. 10. The Rousseau Diagram is useful in studying the effect of the distribution of light within a searchlight beam



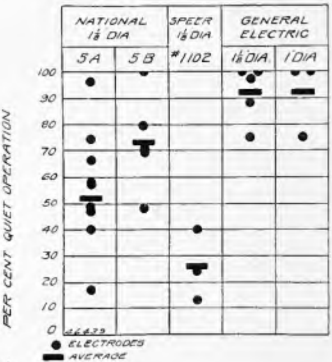
W. D'A. Ryan, Illuminating Engineer

Fig. 11. These Curves of Beam Intensities illustrate the great improvement realized in efficiency through using a better designed and manufactured electrode



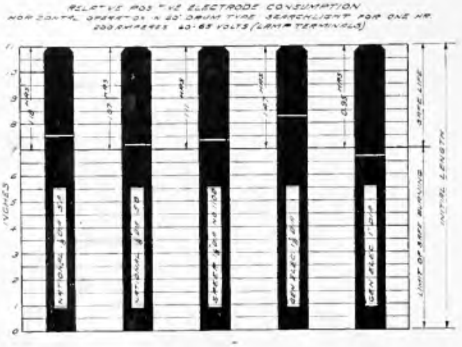
W. D'A. Ryan, Illuminating Engineer

Fig. 12. Holding a Searchlight Beam on a swiftly maneuvering plane requires alertness and quick action. A wide, steady beam is a great help, and the shaded areas above are a measure of the beam's holding power



W. D'A. Ryan, Illuminating Engineer

Fig. 13. Quietness of operation was an essential feature where the operator had to listen for shouted orders. Many electrodes of good efficiency were discarded on account of hissing. Arc noises interfered greatly with the listening devices that formed a part of the searchlight division equipment



W. D'A. Ryan, Illuminating Engineer

Fig. 14. On account of the high current densities employed, the length of stub left after an hour's run was quite important. A short stub might cause overheating of the lamp

The observers, who occupied various positions about the searchlight and whose watches had previously been set to agree with that of the target operator, recorded

(a) The time of first momentary disappearance,

(b) The time of disappearance half the time,

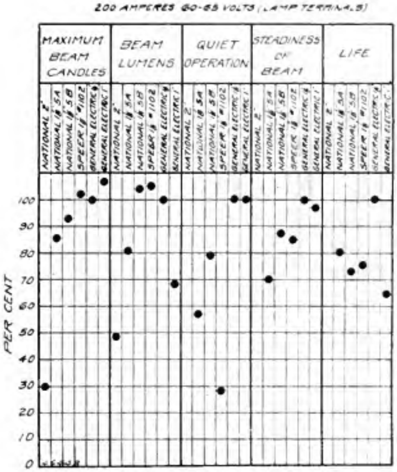
(c) The time of final disappearance.

The curtain was then wound in the opposite direction and the observers recorded

(d) The time of first appearance,

(e) The time of visibility half the time,

(f) The time of permanent visibility.



W. D'A. Ryan, Illuminating Engineer

Fig. 15. A General Summary Sheet in Graphic Form. As in all engineering, the final result is a compromise, and this form of chart is a great help in getting a properly balanced view of all the factors

These records were then compared with the log of the target and the various sections identified. This test repeated with different searchlights gives a means of comparing their revealing power. It is worthy of notice that the revealing power, or working range under fixed conditions, increases much less rapidly than the beam intensity, and the relation between intensity and range is controlled by several factors of which the transparency of the atmosphere is the most important.

It is one of the unfortunate peculiarities of the searchlight that the beam itself often forms the most effective concealment for the target. The beam appears as a bright blue-tinted shaft of light, and this illuminated space forms a curtain in front of the objects under observation. In the vanishing target tests the beam maintained its brightness and the target grew dimmer. At the vanishing point it may have had a fair degree of brightness, but not enough to make it visible in the body of the beam. This condition made it highly desirable to have another means of controlling the disappearing point of the target. An obvious way of doing this would be to decrease the intensity of the searchlight until the target was lost. It is not practicable to alter the intensity of a searchlight without altering its color or beam width. The same result may be obtained by cutting down the light from target and beam as it enters the observer's eye. This was done at the range by having the observer look through the blades of a rapidly rotating sectored disc. The eye slit slid along a scale that told the degree to which the light was diminished. Thus if the target was found to be just visible at 0.20 on the transmission scale of the disc, it indicated that a projector of one fifth the intensity would show the target under the given conditions of test.

Among the numerous questions that called for settlement early in the war was the effect of the blue light of the high-intensity arc and the relative merits of gold and silver backed mirrors. The blue tinted light of the Beck type arc was in disfavor in some quarters, and the French army was definitely committed to the use of the gold mirror with its brown tinged beam. The experiments conducted by the Laboratory failed to reveal the supposed superiority of yellow light. On the contrary the blue beam was found to have less screening effect and the seeing conditions were almost uniformly better. Later news from Europe was to the effect that the French had abandoned the gold mirror and that the German aviators, after several sad experiences, had learned to hurriedly change their plans and retire when a high-intensity beam swung in their direction.

Distant Control of Projectors for Sea Coast Defense

By J. L. Hall

Searchlight Engineering Department, General Electric Company

The element of distance does not in itself present the only serious problem in designing a system for the remote control of a group of searchlights employed in seacoast defense. The speed and accuracy of directing the light beam by a remote control mechanism at the lamp must involve no sacrifice over hand control. The manner in which remote control is effected and the equipment for its performance are ably described in the following article.—Editor.

J. L. Hall

IN any Sea Coast Defense System projectors are installed at widely separated points where, with reference to the batteries, they will best serve their purpose. For the efficient and systematic tactical control of the various beams, it is necessary, where possible, to group the controls at one point. In the majority of installations the radius of control may be several hundred feet.

The target is normally a moving ship. At the different ranges and with variations in speed and course it has a small and variable angular velocity which, combined with the necessity of a more rapid movement for changing targets as well as for airplane defense, requires a wide range of speed control of the projector.

A ship at a range of 15,000 yards with a speed of 15 knots has an angular velocity of about two minutes of arc per second of time when steaming on a course normal to the axis of the beam. This velocity varies as the cosine of the angle of the course, becoming zero when the course coincides with the axis of the beam. This will illustrate the variation due to variation in course; the variation due to range and speed being apparent.

For use with the old type of 60-in. coast defense searchlights using 2-in. carbons with a large crater, and therefore a large beam, minimum steps of 15 minutes of arc were considered satisfactory, but with the high intensity searchlight with a beam of small diameter and with the maximum intensity confined to a still smaller diameter, the Army selected 2 minutes of arc as a minimum step and 360 deg. per minute as the maximum speed.

The system of control adopted is of the synchronous type, the angular movements of the beam being a function of the rotation of two handwheels at the controller, one for each plane of control.

Since the control in both planes is similar, the detail description will be confined to but one, the horizontal. At the controller the horizontal control handwheel rotates a commutator which commutates the direct-current supply to currents having three-phase relation. The frequency of alternations depends on the speed of rotation of the handwheel. Through three of the wires in the controller cable the commutator is connected to the stationary armature of a pilot motor at the projector.

The pilot motor is a simple form of a three-phase synchronous motor having a Y-connected, six-pole, stationary armature or stator and a four-pole rotating field. All its coils are stationary, including those for the field excitation. This design permits of the connections being made directly to the coils, the omission of the usual slip rings, and the reduction of the inertia of the rotating parts.

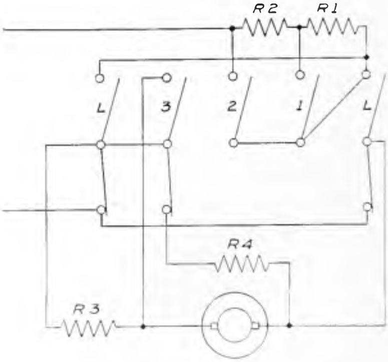


Fig. 1. Diagram of Connections of Contactors Controlling Power Motor

Each of the four poles of the rotor is of the same width as a stator pole and in addition is slotted, the width of the slot being equal to the space between the stator poles. By this arrangement twelve equally spaced positions of the rotor per revolution are obtained, each being assumed with a high degree of accuracy.

A direct-current separately-excited power motor is geared to the turntable through two electro-magnetic clutches which provide two gear ratios, one being 7.5 times that of the other. This change in gearing is necessary for the wide range of speed and the small unit angle of motion required. With the fast gear ratio a maximum speed of 360 degrees per minute and a minimum angle of movement of 15 minutes of arc are obtained. With the slow gear ratio a minimum angle of 2 minutes of arc is obtained with a corresponding reduction in the maximum speed.

An azimuth dial with 30-minute graduations is geared to the horizontal control handwheel shaft at the controller through a similar arrangement of clutches. The clutches in both the projector and controller are operated together from a common clutch control switch at the controller to insure the synchronous rotation of the projector and dial.

The shaft of the pilot motor rotor, Fig. 2, has a spur pinion (*1*) secured to it. Loosely mounted upon it in addition is a cam cylinder (*2*) which operates contact fingers for the operation of the contactors that control the power motor. The cam cylinder is rotatable both by the pilot motor and by the mechanism driven by the power motor, being one form of a hunting controller.

On the cam cylinder is a stud carrying a spur pinion (*3*) which meshes with the rotor shaft pinion and also with an internal spur gear (*4*) inside of which it rotates. The internal gear is driven by the projector training mechanism. The gearing is proportioned for a movement of six degrees of the cam cylinder for each unit movement of 30 degrees of the pilot motor, and corresponds to a movement of the projector of 15 or 2 minutes of arc depending on the gear ratio employed.

To move the beam one unit step, the commutator at the controller is rotated by hand 60 degrees or ${}^1{}_6$ of a turn, rotating the pilot motor one unit step of 30 degrees. The rotation of the rotor and its pinion (*1*) causes the cam cylinder pinion (*3*) to roll around on the interior of the internal gear (*4*) thus rotating the cam cylinder 6 degrees, dropping one of the fingers into contact, and starting the

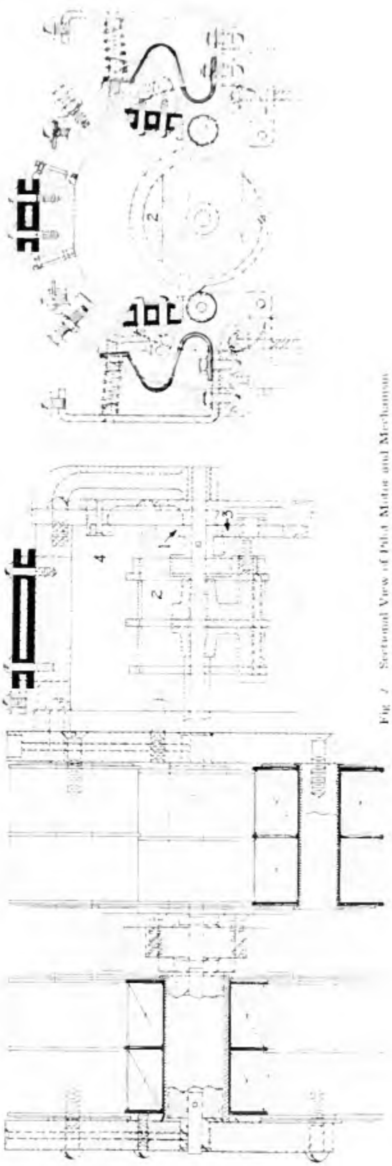


Fig. 2 Sectional View of Pilot Motor and Mechanism

power motor. The projector, in moving through the prescribed angle, rotates the cam cylinder back to its normal or stop position by the action of the internal gear (*4*) which is the reverse of the action from the pilot motor.

Continuous rotation of the projector is obtained by continuously rotating the controller handwheel. An increase in the speed of rotating the handwheel increases the training speed. The cam cylinder remains stationary at any angle of displacement from the normal or stop position when the relative speeds of the pilot motor and projector are alike, and any change in the speed of either will cause the cam cylinder to assume a new position.

At the higher speeds the projector will be slightly behind the controller dial in the ratio of the displacement of the cam cylinder from its normal or stop position. In coming to rest, the displacement is taken up and the projector stops on the proper azimuth.

When roughly handled, or stopped suddenly, the projector may over-run on account of inertia; in which case, the cam cylinder also over-runs reversing the power motor and returning the projector to the proper azimuth. The weight of the rotating parts prohibits a severe braking effort.

Five contactors (three double-throw and two single-throw) are used for the control of the power motor operated by the five fingers of the cam cylinder. The connections of the contactors are shown in Fig. 1. Two of the double-throw contactors marked *L* determine the direction of rotation depending upon which is used, and also provide the first speed step. When both of the contactors (*L*) are open, i.e., closed on the lower contact, the dynamic brake is in operation, the armature being short circuited on one side of the line through the resistance (*R-3*).

Contactors (*1*) and (*2*) form the second and third speed steps by cutting out the resistance (*R-1*) and (*R-2*).

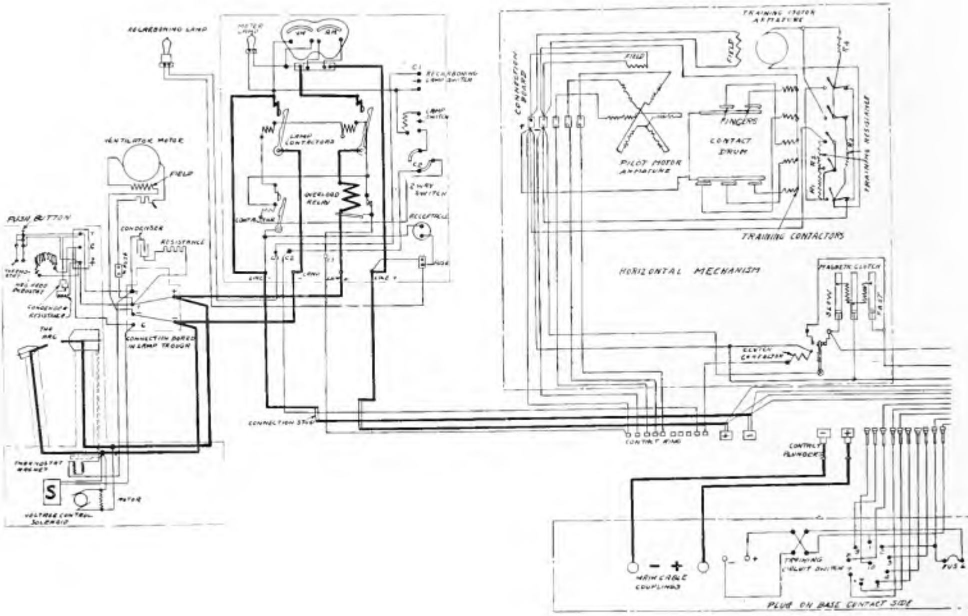


Fig. 3. Complete Diagram of

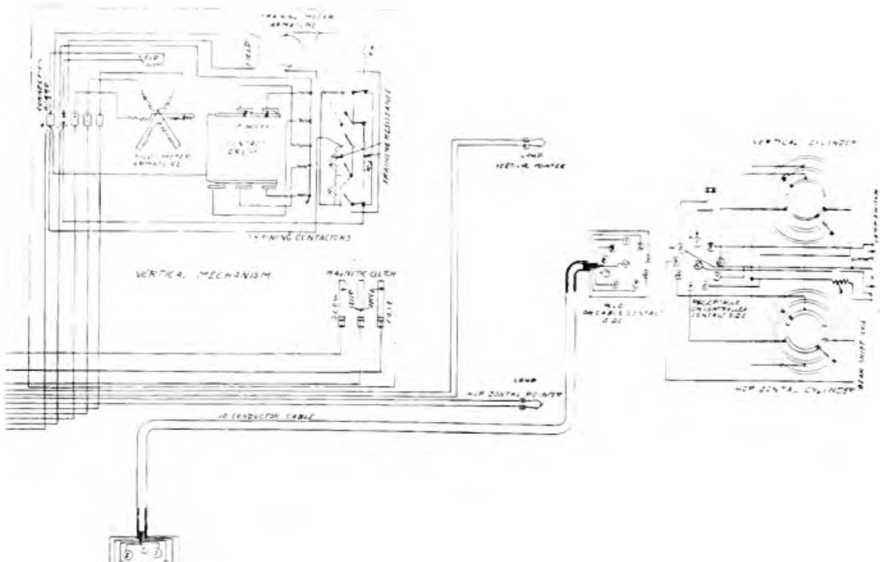
Contactor (5) forms the fourth speed step by opening the shunt resistance (*R-4*) and short circuiting the resistance (*R-3*). Resistance (*R-3*), in addition to its speed control function, is adjusted to give the proper dynamic braking effect. The shunt (*R-4*) is of special value in retardation.

In addition to the control of the direction of the beam in azimuth and altitude, the control of the arc circuit is required for occulting or putting the projector "in" or "out of action" at will from the controller.

This may be accomplished either at the projector or controller where switches are located which control the arc as follows: Upon closing either switch, the circuit to an operating relay is completed and the relay in turn closes the circuit to two main arc contactors which, in closing, complete the arc circuit and start the lamp. A magnet at either switch, in series with it and with the main contactor operating relay coil, holds the switch closed but does not prevent manual operation.

A second or overload relay [illegible] operating coil in series with [illegible] normally closes the circuit [illegible] relay coil but upon passage of [illegible] opens the circuit to the operating [illegible] to the magnets of the switches [illegible] jector and the controller. The operating relay, in opening, disconnects the coil [illegible] main arc contactors interrupting the [illegible] circuit. The switch-holding magnet [illegible] the controlling switch is also opened, allowing the switch to snap to the "off" position.

It will be seen that the starting and interruption of the arc, the wide range of speed control, and incidentally the shifting of the gear changing clutches, as well as the exact synchronous movement between the projector and the azimuth dial of the controller, may be accomplished by an operator at the controller two miles distant from the projector, the movement of the beam being accomplished in two directions in both planes and the movement in each plane being entirely independent of that in the other.



Connections and Equipment

Thirty-inch Open Type Searchlight with Tripod Mount

By E. J. Murphy

Engineer Schenectady Searchlight Department, General Electric Company

The need for an exceptionally light weight but powerful searchlight of moderate size resulted in the development described in this article. As pointed out by the author the outfit fulfills its purpose admirably. A complete description is given of the high-intensity lamp used, its control mechanism, and operation. The illustrations are very graphic in revealing the design and construction of this searchlight unit.—Editor.

E. J. Murphy

THIS searchlight was designed for use in military operations under severe conditions, such as exist in tropical jungles and in mountainous countries. For this service it was desirable to reduce the size and weight to the limit but to still retain high illumination and to make the construction simple and rugged. The complete searchlight, with tripod mount, weighs only 250 lb.

In its construction the question of the most suitable materials was of prime importance and the relative merits of a light steel structure and a design using aluminum sheet and alloys were carefully considered.

The steel structure would require the assembling by riveting or welding of numerous small pieces as it would be necessary to use standard sheets and sections; needless to say, steel castings could not be used to any appreciable extent, and while a light steel structure would be sufficiently strong to stand rough handling, it would be questionable if it would support the mirror and other parts in their proper relation.

The aluminum alloys were investigated and it was found that many competent engineers were prejudiced against these materials, due to unsatisfactory service in the past. We found, however, that certain of these alloys have been vastly improved in recent years and are now widely used in automobile engines by many first-class makers. Many other applications, where the parts are subjected to very severe shocks and vibrations, might be mentioned, one of which is the famous Lewis machine gun where practically all the exposed parts are made of aluminum alloy. We found that the successful casting of these alloys was made entirely possible by special foundry knowledge, the lack of which in some foundries resulted in inferior castings and accounts for certain manufacturers refusing to adopt these alloys or discarding them.

The 30-in. open-type searchlight has a high intensity 150-ampere arc with a voltage of 75, and it should be noted that the light flux in this 30-in. searchlight is practically equal to the light flux of the standard 60-in. drum type projectors that were used in France during the war. The 30-in. mirror will produce a less concentrated beam, on account of greater

Fig. 1. Front View of 30-in. Open Type Projector Mounted on Tripod

dispersion due to its shorter focal length, and for this reason is inferior to a similar searchlight equipped with a 60-in. mirror. Where it is desirable, however, to illuminate larger fields at lower intensity, this increased dispersion is not objectionable, and a searchlight with the smaller mirror will make a much lighter and less bulky equipment.

The complete searchlight is shown in Fig. 1. The tripod can be folded, and the mirror and lamp readily removed with the chimney extension. These separate parts can be easily carried over the roughest country and afterwards reassembled in very short order. The illustrations show practically all the important features of the searchlight, so a lengthy description will be unnecessary.

Fig. 2. Side View of 30-in. Open Type Projector

The searchlight is of the open type, without the usual drum and glass front door.

The lamp, shown in Fig. 5, is hand-operated without any automatic control. It is of the high intensity type. The negative carbon is controlled through a control feed by a small knurled handwheel which projects through the hollow trunnion pin of the searchlight. The arc is struck and the arc length controlled by manipulating this wheel. The positive carbon is rotated and fed by means of the small crank which projects through the trunnion support forward of the trunnion pin.

Fig. 3. 30-in. Open Type Projector Showing Method of Feeding and Rotating Carbons

Both the positive and negative carbons can be readily controlled by a man standing beside the lamp as shown in Fig. 3, regardless of the elevation of the searchlight.

The positive feeding mechanism can be seen in Fig. 5. The crater end of the carbon projects through a head which is equipped with a metal baffle or obdurator, a radiator and a plunger type contact. The opposite end of the carbon is held in a clamp which is carried by a revolving frame and fed forward by means of a screw. The carbon is not rigidly held in line by this clamp and it is therefore possible to operate a very crooked carbon successfully. The frame carrying the carbon clamp and the feed screw have bearings at both ends and revolve by means of the bevel gear which is driven by a small bevel pinion, which in turn is controlled by the hand-operated crank. A starwheel is secured to the forward end of the screw and is arranged to engage detent while revolving. It thus can be seen that when the crank is turned in one direction the carbon is revolved and also fed forward. The carbon can be fed backward by simply reversing the motion of the crank.

Fig. 4. Removing Lamp from 30-in. Open Type Projector

The viewing screen can be seen in Fig. 1 and is located between the trunnion and the positive operating crank.

It is unnecessary to give a detailed description of the negative head. The current is fed to the carbon by means of a spring pressed plunger and the spring provided for this purpose also causes the feed rollers to grip the carbons.

The lamp is secured in the arc chamber by means of two screws attached to the large wooden handles shown. These screws also carry the line current to the lamp. Conical pins are provided for locating the lamps in the proper position. It will be noted that the lamp while hot can be readily removed from the searchlight by the operator using the wooden handles as shown in Fig. 4.

In order to remove the lamp from the searchlight, the positive and negative operating shafts can be withdrawn from the lamp couplings by simply tilting the negative operating wheel and the positive crank one fourth turn, thus disengaging the connection of the lamp. The wooden handles will then unscrew and the lamp remove as shown in Fig. 4. In replacing the lamp it is only necessary to reverse the operation.

The angular chimneys projecting from the arc chamber as shown in the illustrations are provided so that the searchlight will have sufficient ventilation at all angles of elevation. With the searchlight in the position shown in Fig. 1, the upper chimney will draw the smoke from the arc chamber. When he searchlight is pointed directly upward, both chimneys will act as ventilators, and when the searchlight is turned so as to point in the opposite direction to that shown in Fig. 1, the lower chimney, shown in Fig. 1, will then be in a reverse position and act as a ventilator.

Loosely-pivoted, gravity-operated dampers are provided in these chimneys. The damper of the chimney in the lower position will be closed while that in the upper chimney will be open. When the searchlight is pointed towards the zenith, both dampers will be open.

Locking devices are provided for holding the searchlight in any angle of train or elevation and adjustable scales are also provided for each motion.

This 30-in. searchlight has been thoroughly tested and found to operate successfully for an indefinite period at all angles of elevation. This is due to the double chimney feature.

We are at present developing a design for a 44-in. open type searchlight using much higher current, and while this searchlight will be substantially similar in design to the above described equipment, we expect to introduce a number of improvements, one of which will be to provide means of readily carrying the searchlight by means of two litter poles.

Fig. 5. Lamp for 30-in. Open Type Projector

Searchlight Production

By Langdon Gibson

Manager of Production Department, General Electric Company, Schenectady, N. Y.

Mr. Gibson gives a few interesting notes on the production of searchlights on a war basis. While the 28,000 sq. ft. was sufficient before the war, 61,500 sq. ft. were required to meet the war emergency. During this period of intense activity 2475 searchlights of high, medium and low intensity were manufactured at Schenectady Works representing approximately a total candle-power of 175 billion.—Editor.

Langdon Gibson

WITH the entry of our country into the world war, searchlight apparatus of all descriptions, as might be expected, came into heavy demand. The requirements of both the army and navy were urgent, while large industrial plants throughout the country found it expedient to install search and flood lights for protective purposes. As a result of this unprecedented demand, existing stocks of manufactured searchlights were almost immediately exhausted, and we found ourselves facing a manufacturing problem the like of which had never before been encountered. The 28,000 square feet of floor space allotted to the manufacture of searchlights, which during peace times had been found ample, was on very short notice found to be less than one half of the manufacturing space necessary to meet the requirements. Accordingly it became necessary to commandeer additional floor space in other parts of the plant, which was done, until the total floor space occupied amounted to 61,500 square feet, and the total hands employed numbered 379.

In addition to the difficulty of building up the personnel of the department in the face of a country-wide shortage of help, we found the situation still further complicated through

View in One of the Departments Manufacturing Some of the Smaller Searchlights the introduction of improvements in design, suggested as the result of experience gained in actual operation in the field with the A.E.F.

Difficulties also were encountered in securing raw material, such as carbons and mirrors. These problems were successfully met; workable schedules consistent with the manufacturing possibilities were laid out, the working organization was strengthened with the best men at hand; and, by a carefully worked out system of inspection, quantity production was secured without the sacrifice of quality. The government's needs were such that we had little or no time in which to manufacture complete sets of jigs or machining fixtures, and this in itself developed a situation which made it necessary to employ the highest degree of skilled mechanics.

During this period of intensive manufacture, the Schenectady Works produced and shipped approximately 2475 searchlights, of high, medium, and low intensity, representing approximately a total candle-power of one hundred and seventy-five billion.

While we are dealing in large figures and generous ideas, it might be stated that this regiment of searchlights, if rolled into a single projector of high intensity type, would have the following dimensions:

Diameter of mirror, 870 inches.
Diameter of carbon, 15 inches.
Current, 87,500 amperes.
Watts, 10,500,000 at terminals.

The beam would give full sunlight at a distance of one and one tenth miles (overlooking atmospheric effects and a few other considerations); ordinary outdoor daylight at about five and five tenths miles; comfortable illumination at thirty-five miles, and sufficient light for rough work at seventy-eight miles. Should we desire only full moonlight, we would find good working conditions at three hundred and fifty miles.

These staggering figures may be of interest to the layman. Of how much more interest would they have been to the student of economics, a merchant of Albany, who, less than sixty years ago, took his grandson on his knee and remarked: "My boy, there is trouble in store for you. I see by the papers that they are killing off all the whales, and the time is coming when you will have to go to bed in the dark."

A table showing the increased rate of output of searchlights from 1913 up to and including 1918, follows:

1913 produced	206	searchlights
1914 produced	609	searchlights
1915 produced	304	searchlights
1916 produced	666	searchlights
1917 produced	922	searchlights
1918 produced	1747	searchlights

Such war time results could not have been obtained but for the indomitable energy and loyal co-operation of all the employees in the Searchlight Department. They were men of many nationalities, but they all worked many hours overtime with the common end in view.

Searchlight Electrodes

By W. H. Hardman

Research Laboratory, General Electric Company

Of all the elements that go to make up the complete modern high-intensity searchlight the electrodes are perhaps the most important. The author tells of their development, stating the requirements of the finished product, describing the raw material necessary and explaining the process of manufacture. While before the war America largely confined her attention to quantity production, the author shows that she now possesses both the experience and the raw material necessary for producing any type or quality of electrode.—Editor

W. H. Hardman

ABOUT eight years ago the Research Laboratory at Schenectady took up experimental work on moulded carbon, particularly on high grade carbon brushes for railway motors. At that time, although the United States manufactured nearly ten times the total output of the European factories, the quality was of low grade and all the high grade carbons were imported from France and Germany.

The American moulded carbon industry was then in a relatively crude state. Great quantities of carbon for motor brushes, electric furnace electrodes, arc lamp electrodes etc., were manufactured and were of such quality as to meet the large quantity demand; but as an art, the work had not been highly developed. "Tonnage" was the chief consideration; and in many cases, mass production was more imperative than special quality.

With certain electric apparatus, however, such as railway motor brushes and searchlight electrodes, the highest quality attainable is of the utmost importance, regardless of cost. Therefore, "Grammage" with special quality, had to be considered above "Tonnage," and the cost of production per pound became greater than the previous cost per hundred weight.

The Research Laboratory's experimental work on searchlight electrodes covers both high and medium intensity carbons of various sizes, ranging from $\frac{5}{8}$ in. to $1\frac{3}{4}$ in. in diameter and for currents from 150 to 500 amperes.

The following specifications for the high intensity positive electrodes, for the 36-in. and 60-in. drum type projectors, give some idea of the necessary refinement of manufacture. This electrode is 1100 mm. long, 16 mm. diameter with an 8-mm. diameter core of flaming salts. The shell and core are extruded separately; the one-piece core is inserted in the shell with a minimum clearance and firmly cemented. It must be substantially straight; any curvature must be evenly distributed along entire length, and the maximum curvature must not exceed 2 mm.

In addition to being straight, good electrodes should have a maximum burning life of two and one half hours, with proper crater depth and without excessive spindling, so as to give the maximum beam candle-power at the

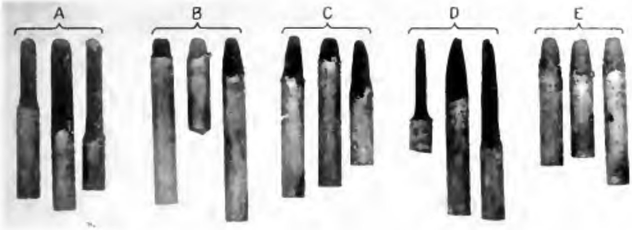


Fig. 1. 200 Ampere Negative Electrodes

(a) (b) (c) (d) Electrodes of various manufacture. (e) Electrodes manufactured by the General Electric Company

Fig. 2. Mixer

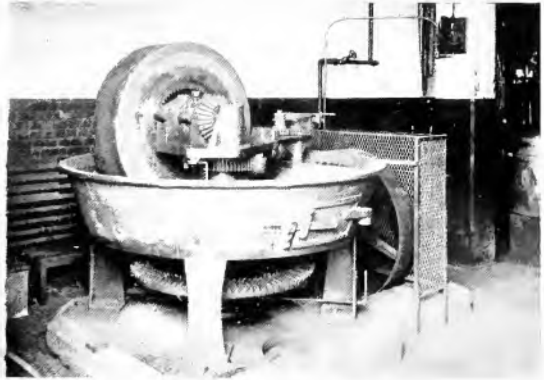


Fig. 3. Chaser-Mill

Fig. 4. Extension Press

Fig 5. Baking Muffles

Apparatus Used in the Manufacture of Carbon Electrodes for Searchlights required current and arc voltage. Of course, the resistance affects the operation and should be controlled.

One of the first essential requirements of successful electrode manufacture is the selection of the raw materials. The various allotropic forms of carbon have quite different characteristics, and offer quite a wide field from which to choose. Experience, covering the development and manufacture of many types of high grade carbons, such as brushes, special moulded carbons, etc., gave us an intimate knowledge of the various grades of carbon materials available for electrode work, and permitted the introduction into the manufacture of electrodes of certain refinements in materials not common in general carbon manufacture. For instance, good calcined lampblack, because of its extreme fineness and purity, lends itself admirably to the manufacture of high grade electrodes. Calcined petroleum coke, gas retort carbon and dehydrated coal-tar are also used extensively. Coal-tar pitch can be used and is easy to handle, but tar lends itself more readily to the extrusion process.

Fig. 6. 200 Ampere Medium Intensity Electrodes

The manufacturing of electrodes can be divided, in general, into five parts, viz., mixing and kneading, forming, extrusion, firing and coring.

The carbon powder, reduced to the desired degree of fineness, is placed in the mixer with the bonding material. The mixer is equipped with blades having a progressive and retrograde motion which squeezes and kneads the mixture and coats the carbon particles with the binder. After this process, additional kneading is effected in the chaser mill until the whole mass becomes a very stiff, worked putty. Fig. 1 and 2 respectively show the mixer and chaser-mill.

Fig. 7. 500 Ampere Medium Intensity Electrodes

The material is then formed into pellets which are put into the steam cylinder of the extrusion press and squirted out through a die of the desired size. Good extrusion depends upon the fineness of the materials, amount of binder, temperature of mixture, rate of extrusion and the pressure used. Fig. 3 shows a standard type of hydraulic extrusion press.

The next step in the process is known as the curing, baking or firing, and is the most important of all. The furnace used for the carbonization of the electrodes is of the utmost importance, and has caused more failures than anything else. Good materials are, of course, essential for good electrodes, but if the furnace for carbonization is not adapted to the requirements, the electrodes will be of low grade. Temperature control is necessary, because the electrodes must be baked very slowly on account of their poor heat conductivity in the green state. A special electric muffle type of kiln has been developed, which is capable of regulating the temperature rise to 10 deg. C. per hour, up to a red heat. A row of such muffles is shown in Fig. 4.

After the baking or firing the electrodes are ready to core. Too much stress cannot be placed upon the necessity of care in this operation, as the steady operation of the electrode depends to a great extent upon the manner in which the electrodes have been cored. Poor coring causes sputtering; this is due to the coring paste being too thin, which leads to spongy, fired mixture.

electrodes, but at first with little success. It was their contention that it was of so special a type that its field of application would be very limited. Hence it did not warrant the time necessary for its development. By close co-operation, however, the development of an electrode of this type was accomplished, and it is believed that at least two well-known American concerns are today producing high intensity electrodes of a quality comparable with the best foreign works.

For the army open-type projector, operated at 200 amperes, there have been developed electrodes $1\frac{1}{8}$ in. in diameter, which give very satisfactory operation. Such a high electrode current density as 200 amperes per sq. in. had never been used before. The old Army and Navy 60-in. drum-type projector operates at 175 amperes with a 2-in. diameter electrode. This comparatively low electrode current density, with its accompanying low efficiency, was determined on the basis of steadiness, quiet operation and long carbon life, without any apparent reference to the candle-power or lumen performance. Under this condition, its operation in respect to maximum beam candle-power, quietness of operation and steadiness of beam, is greatly inferior to the $1\frac{1}{8}$-in. diameter electrode, operated at 200 amperes.

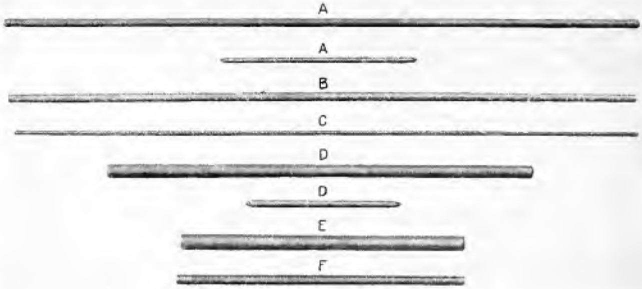


Fig. 8. **High Intensity Electrodes**

(a) 150-ampere positive and negative high intensity electrodes
(b) 150-ampere positive and shell high intensisy electrodes
(c) 150-ampere positive and core high intensity electrodes
(d) 200-ampere positive and negative high intensity electrodes
(e) 200-ampere positive and shell high intensity electrodes
(f) 200-ampere positive and core high intensity electrodes

The chief test to which an electrode must be subjected is, of course, its operation in a lamp. However, a general knowledge of the characteristics can be obtained by certain electrical and mechanical tests. The electrical resistance is measured; the tensile strength, density and hardness, on each batch of electrode is also measured, as in this way the uniformity of the product can be better assured, and the necessary information for future improvement may also be secured.

As a result of this research work on electrodes we have been able to successfully manufacture on a small production basis high intensity electrodes for operation at 150 to 500 amperes. Prior to this development of the high intensity electrode, the best known electrodes were operated at a current density of 150 amperes, and these were only obtainable from Germany.

The war shut off this supply, so that American manufacturers had to be appealed to for

From this work it is apparent that any type or quality of electrode can be produced from American raw materials.

The author wishes to express his appreciation of the help given by M. F. Girvin in the preparation of this article.

Searchlight Tower Units

By R. S. Hood, Jr.

First Lieutenant of Engineers, United States Army

The author gives a brief description of the several types of searchlight tower units. Some of the most important dimensions relative to size and power, etc., and other interesting data are given concerning the telescopic, Bascule bridge and counterbalanced types of unit. The different means of making these units mobile are also described.—Editor.

R. S. Hood, Jr.

General

In the design of large searchlights, as used by the Corps of Engineers, U. S. Army, among the first problems are the diameter and intensity of the beam and the maximum effective range for the particular work to be accomplished. The range is, under ordinary conditions, anywhere from 12,000 to 45,000 feet. These figures vary in accordance with the prevailing atmospheric conditions and the nature of the terrain over which the beam will be projected.

In the case of field operations, the searchlight may be mounted on an automobile truck and its position may be limited to such an extent that it is behind a hill, or that a wooded area stands in front of it. It then becomes necessary to elevate the light enough to clear the obstacle, since otherwise its position on the ground or the truck will enable it to be effective only at angles varying from 30 deg. to 90 deg. and *then* only against airplanes. The uses made of the light, however, are not entirely confined to anti-aircraft work. Should the searchlight be used on the seacoast and the beam be projected across the water from the ground line on the coast, the curvature of the earth and ocean seriously limits the range. This being from eight to nine inches per mile, it again becomes necessary to elevate the light. Special study has been given this phase of searchlight development and the following types of elevating towers have been the result:

Types

(a) The Telescopic Tower Unit.
(b) The Bascule Bridge Tower Unit
(c) The Counterbalanced Tower Unit.

(a) The Telescopic Tower

The telescopic tower was the first successful design adopted by the Engineer Corps. Many modifications have been made, owing to the fact that careful thought and workmanship indicated improvements during the developmental stages. To elevate and lower a telescopic tower with a searchlight mounted on the top, requires the use of well designed sheaves, bearing surfaces, locking devices and the elimination of all surplus weight.

Fig. 1. 24-in. Sperry-Brill Caisson Tower Type Searchlight

The 24-in. Limber-caisson Tower Unit

This is a horse-drawn field outfit consisting of a limber, which is the power unit; and a caisson which carries the semi-telescopic tower and a 24-in. drum type searchlight. See Figs. 1 and 2.

(a) *The Limber Power Unit*—A 5-kilowatt gas engine generating set and a suitable switchboard are mounted on springs that are bolted to the axle of the limber unit. It is only necessary to set the proper voltage of the generator for continuous power to the searchlight. See Fig. 1.

(b) *The Caisson (Tower Unit)*—A 24-in. drum type searchlight is mounted on an 18-foot semi-telescopic tower. There are two movements to be made before the tower is extended to its final and highest position. See Fig. 2.

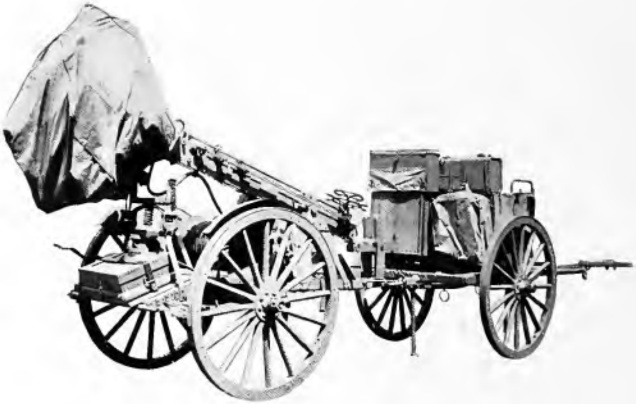


Fig. 2. 24-in. Sperry-Brill Limber Caisson Searchlight Tower Unit Complete

A cable drum operated by two men hoists the telescoped tower and light to the vertical position. One man then raises the telescoping section with a hand hoist to the final eighteen foot position.

The light is remote controlled, and the proper regulation is secured with a thermostat. Extra cable is provided so that the caisson can be separated from the limber, when this is necessary.

60-Foot Tower Caterpillar Tractor Unit

At the present time, there is in the course of construction a tower 60 feet high, mounted on an eight-wheel caterpillar tractor. This will accommodate a 60-in. diameter searchlight and with the tower in its extended position will withstand a direct wind pressure of 100 miles per hour, with or without the use of outriggers. The tower is made up of telescopic sections and when telescoped and mounted on tractor, can pass through any average railroad tunnel. A suitable ladder up the side of this tower is provided for the convenience of the operator, who is in position at the lamp when the arc is burning. A flexible cable, carrying the power from an electric generator on the vehicle up to the searchlight is suspended alongside the tower when in the elevated position. When the tower is lowered, the cable is wound automatically on a drum. The generator referred to receives its initial mechanical power directly from the gasolene engine of the propelling unit.

This tower can be elevated in approximately four minutes and lowered in approximately the same time, using an electric motor and hoist.

The versatility of this unit is evident, when it is known that it can be used either for seacoast or field work. Metals not affected by salt-ladened air have been employed. A "ball and socket" effect has been introduced to take care of the position and stability of the tower when the nature of the ground prohibits the proper leveling of the supporting vehicle, and many other obstacles have been met and overcome, with the result that the telescopic tower has been made a success.

(b) The Bascule Bridge Tower Unit

This unit employes the "jackknife" tower principle and is designed for field use. A 36-in diameter drum-type searchlight is mounted on the tower, which is in turn mounted on an automobile truck. See Fig. 3.

The tower is raised by means of ropes and sheaves wound on a cable drum. The drum receives mechanical power from the motor truck engine. The electric power for the searchlight is obtained from a separate power unit, which is carried along for this purpose.

(c) Counterbalanced Tower Unit

Where *extreme* stability is desired and where remote control of the searchlight beam is considered necessary, the counterbalanced tower is most successful. Its application is confined to seacoast defense work, however, for the reason that with the employment of counterweights, the weight factor presents itself and the result is necessarily a slow moving unit, which is undesirable for field service.

A remarkable step was made when the 60-in. railway counterbalanced tower type searchlight was completed. See Fig. 4.

The unit consists of one standard steel reinforced box car, 40 feet long, coupled to a standard 40-foot steel flat car.

The Flat Car Unit

On the flat car is mounted a 33-foot counterbalanced tower with a 60-in diameter drum type searchlight mounted on a platform on the end of the tower. See Fig. 4. The tower is so accurately balanced that one man can elevate or lower it easily in one minute's time. This is done through the use of a crank leading to a worm gear. Theoretically the tower could be raised or lowered by merely applying the slightest force, but the element of friction necessitates the use of man power to overcome it.

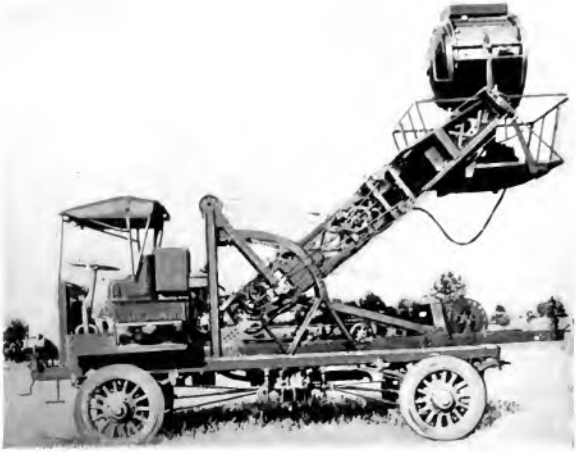


Fig. 3. 36-in. Carlisle & Finch Searchlight Mounted on Strauss Tower—Tower partly raised

The platform with the searchlight mounted thereon is kept in the horizontal position at all angles as the tower rises from the horizontal to the elevated (90 deg.) position. This is accomplished by a three fourth inch equalizing cable and gravity.

Fig. 4. 60-in. Seacoast Railway Type Searchlight. Box and Flat Car coupled together

Fig. 5. 60-inch Seacoast Railway Tower Type Searchlight. Side View of Flat Car with Tower in 45-degree Position

The searchlight is fitted with a remote control equipment, consisting of motors in its base, 1000 feet of control cable and a scaled controller box. The operator has then complete control of the light anywhere within a radius 1000 feet of the light itself.

The flat car unit is self propelling, being equipped with railway motors and control equipment. Powerful headlights are provided on the front of the car for night traveling.

The power for the searchlight, railway motors and headlight is obtained through

Fig. 6. 60-inch Seacoast Railway Tower Type Searchlight. Side View of Box Car (Power Unit) showing One of the 320-gallon Gasolene Tanks Suspended

jumpers from the box car unit, which is described below.

The Box Car Unit

The box car unit is the power unit. See Fig. 6. It is self propelling, employing a motor and control equipment which is a duplicate of that on the flat car. All of the electric power is obtained from two 25-kilowatt, 115-volt General Electric GM-12 gas-electric sets that are situated conveniently in the box car.

To propel the equipment, both generating units are put in series, giving 230 volts. Both units can be operated from one 25-kw. unit, however, obtaining a maximum speed of five miles per hour, while when using both sets in series a speed of from seven to ten miles per hour maximum is obtained.

A suitable switchboard is located in the power unit. This is the control center of all equipment. From this board a 115-volt line is led to the searchlight through a permanent ballast resistance located on the flat car, which cuts the voltage to 75 when the proper amperage is drawn by the arc (150 amperes). Other lines run to the different motors, fans and control circuits.

For the comfort of the operators, suitable sleeping cots are placed in this car. To prevent freezing and to insure the necessary warmth, two coal stoves are supplied. Each stove is enclosed in a sheet-iron compartment made tight enough so that the gases from the engine do not come in contact with the flames in the stoves. Access to the stove compartments is gained from the outside, thereby eliminating any chance of a door admitting inflammable gases.

Two tanks for gasolene are supplied, each with a capacity of 320 gallons. One tank is suspended on each side of the box car. The gasolene is supplied to the engine through individual pumps. The same gasolene level is maintained in both tanks with the use of an equalizer pipe connecting one to the other. Suspended from the ceiling of the car are four 25-gallon water tanks. A pipe arrangement equalizes this water also. If desired, water may be furnished either engine from one tank or from all. The engine mufflers are placed on the top of the car so as to get the full benefit of cool, fresh air. All power delivered from the box car to the flat car is transmitted through jumpers. It can therefore be seen that the two cars make up a complete, self-propelled tower type searchlight unit and that it is entirely independent in its operation.

Conclusion

The tower units described in this article have all been developed since the entrance of the United States into the world war; before that time the matter had scarcely been given a thought. The remarkable strides made and the success gained is due to the untiring efforts and the close, patient co-operation of manufacturing companies with the Engineer Department of the United States Army.

Mobile Searchlight Power Units for U. S. Army

By Henry S. Baldwin

Engineer Automotive Department, Lynn Works, General Electric Company

Ready mobility is a leading characteristic of the weapons which proved most effective during the war just concluded. Great difficulties were met and surmounted by the engineers when incorporating this characteristic in many of the instruments of warfare which, by reason of size or weight, had hitherto been considered to be stationary or at least only semi-portable. Such an instance was the development of the powerful light-weight army searchlight and its mobile power plant. A complete description of three units of different size is given below.—Editor.


Henry S. Baldwin

THE great conflict of the past four years may well be termed a Motor War. Except for the explosion engine, warfare of today is practically the same as it has been for centuries. The internal-combustion motor, however, has given us the airship, the artillery caterpillar tractor, the tank, the motor truck, the portable electric power plant, and also the means for propelling the submarine and patrol boat. There has been great refinement in ordnance, machine guns, and small arms but, generally speaking, except for the explosion motor, warfare has remained practically unchanged since the introduction of gun powder. Trenches, dugouts and mines, grenades and gas bombs, bayonets, and the like are the same.

The explosion engine has opened the way for the use of electricity in warfare; for the purpose of illuminating bases and dugouts; for anti-aircraft searchlights and flood-lights for landing fields; for signalling; wireless telegraphy, telephony, and many similar uses.

Not the least important of these is the searchlight, which until the Great War had been little changed since the beginning of the industry back in the '90s. The conventional searchlight consists of a large barrel containing a mirror and lamp mechanism, together with a suitable support so that it can be trained at any angle. During the past two years, however, searchlights of great size and comparatively light weight have been developed by the engineers of the Lynn Works, who have cooperated with the Engineer Corps of the U. S. Army. The delicate mechanism for controlling the carbons has been replaced by a simple hand device which passes directly through the center of the mirror. By this noteworthy improvement a searchlight having a 60-in. diameter mirror actually weighs less than a 36-in. diameter unit of the old style. The importance of this development in warfare cannot be overstated, as the use of the airship for bombing cities, towns, bases, and ammunition dumps has made it necessary to provide means to locate the ships at night so that they can be driven off or destroyed.


Fig. 1. General Electric-Cadillac, 20-kw Mobile Searchlight Power Unit showing Searchlight in Position for Action, Engineer Corps U. S. Army

Engineer officers, who have been overseas, state that enemy planes usually turn back upon encountering a searchlight barrage of any magnitude; whereas, the fire from artillery or machine guns is comparatively ineffective, except at close range, in stopping air attacks.

The great anti-aircraft searchlights are usually located well up toward the front line in order to protect the important strategic points at the rear and endeavor to stop the enemy in the air before he has an opportunity to bomb them.

The 60-in. searchlight requires the output of a 20-kw. generator, which must be available in the field far distant from the usual source of electrical supply. In other words, a self-contained and complete electric power plant, which can be moved rapidly from place to place and readily camouflaged, must be provided. In the early years of the war the necessity for this equipment was not so apparent as air warfare had not been fully developed. As time passed, however, the bombing plane and enormous Zepplin dirigible, which attack usually at night, made it necessary immediately to provide mobile power units to operate field searchlights.

It has been stated that the British used the gasolene-electric omnibuses taken from the streets of London, and that the French attached generators to the front end of Renault and Brasier trucks. Our own army in 1917 and 1918 devised power units constructed of 5-ton gasolene truck chassis. The British and American units were more or less heavy and cumbersome and, therefore, could not be moved rapidly over rough ground to meet field requirements. It was at this point in June, 1918, that the engineers of the General Electric Company were requested to develop a mobile power unit which, as was stated in a message from France, should be more like a "jack-rabbit than a road-roller."

An order was placed by the Engineer Corps, U. S. Army, on July 9, 1918, for a mobile searchlight power unit which should be as light in weight as possible and yet comply with all the military conditions specified for the earlier 5-ton truck unit, with the addition of a 60-in. searchlight and accessories in place of the 36-in. light originally called for.

After eight weeks of intensive designing and construction a complete outfit meeting every requirement was delivered to the Engineer Depot in Washington, with 60-in. lamp ready to be shipped abroad. A few hurried tests were made over the roads of Virginia. It was then driven to New York under its own power and placed on board ship, arriving in France the latter part of September. Early in October it reached Paris and from that time on to the present it has been demonstrated on American, British, and French fronts and was also taken to London for inspection by the British War Office. It is interesting to note that it was in active service with the troops on the American front for some time prior to the signing of the armistice, November 11, 1918.

Fig. 2. Map showing Itinerary of first General Electric-Cadillac Mobile Searchlight Power Unit sent to France in 1918

The following figures will indicate how this power unit differed from those which had previously been proposed for the United States Army. The overall weight was reduced more than 10,000 lb., the speed increased from 15 to 45 miles an hour; and the cost reduced nearly 40 per cent. The new machine weighed 9000 lbs., ready for field service. This included motor car and body, prime mover, an eight-cylinder gasolene engine, 20-kw. generator, fuel and lubricating oil, 300 feet of No. 00 twin cable and reel, switchboard and 60-in. diameter searchlight with carriage, together with personnel of five men to operate the unit. In addition were carried a training control, spare lamp, lamp supplies and accessories, all necessary tools, together with pick, spade, shovel, crowbar, lanterns and similar equipment.

In order to produce this result a standard Model 57, 145-in. wheel base Cadillac chassis was selected. This has an eight-cylinder engine having a maximum output of 80-brake horse-power. A General Electric automotive generator with hollow shaft and double-acting clutch was attached to the chassis, requiring very little change in the latter. The generator, clutch, governor, and other details had a total weight of about 650 lb., or somewhat less than that of the engine. The engine and generator were exactly in balance as regards capacity, and the result was a smooth-running, quiet, gas-electric set well adapted for searchlight purposes. Suitable reels were provided for the 300 feet of twin cable which, together with an extra supply of gasolene for fuel, made up what was probably the lightest unit of its capacity produced during the war. The Automotive Department of the General Electric Company at Lynn built 90 of these, and two of special design were supplied to the Bureau of Aircraft Production, U.S. Army, to be used in flood lighting landing fields. The latter, had the war continued, would have played an important part in air warfare, as the ability of our aviators to make a safe and sure landing at night, within their own lines, was a matter of vital importance. It is interesting to note that several of these searchlight power units were put to practical use at Roosevelt Field, Mineola, N.Y., when the British dirigible R-34 landed there on July 6, 1919, after completing the first successful Transatlantic voyage of a lighter than air ship.

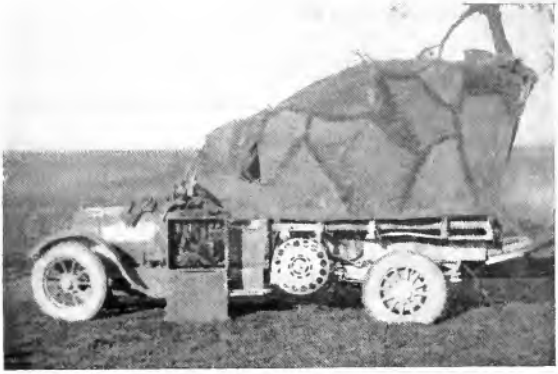


Fig. 3. General Electric-Cadillac Camouflaged on Firing Line in France

Fig. 4. General Electric-Cadillac 20-kw. Mobile Searchlight Power Unit, Engineer Corps, U. S. Army

The plans of the Engineer Corps and the Bureau of Aircraft Production, U. S. Army, contemplated the use of great numbers of these mobile power units, which, together with the 60-in. searchlight, bear about the same relation to the dreaded bombing airplane and Zepplin as the hydrophone or listening device does to the German submarine. The moral effect on the enemy of great searchlight beams tended to keep their airships away from the strategic points of the allies, thereby permitting military and civil operations to be carried on without molestation.

It might be added that one of the GE-Cadillac power units, U. S. A., No. 6051, together with searchlight, all equipment and five men, completed a road test of over 2200 miles between the West Lynn Works of the General Electric Company and Carlstrom Flying Field, Florida. Although this was made in February and March, at the worst time of the year, with mud and clay frequently up to the hubs, the unit withstood the test successfully. After a three weeks' period of field service in Florida it was returned to West Lynn over the road. The total distance covered in the round trip was 4408 miles, during which all important parts functioned correctly.

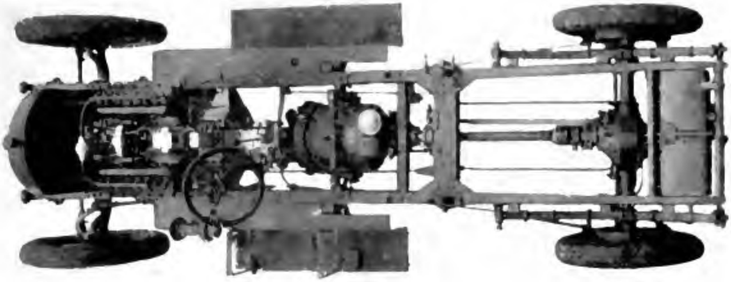


Fig. 5. General Electric-Cadillac 20-kw. Mobile Searchlight Power Unit, showing Plan View of Chassis, Engineer Corps. U. S. Army

A similar unit is now taking part in the Washington-San Francisco run, which is being conducted by the Government, to try out various motorized equipment developed during the war.

The great saving in weight, over five tons per unit, together with the marked increase in speed and reduction in cost, render this development most important and interesting from a military standpoint. Had the war continued, it is evident that the safety of European cities, and perhaps our own, together with vast supplies of munitions and military stores, would depend upon protection from night bombing. Without power units and searchlights such raids could never have been prevented.

A number of sets for special military applications are now being developed, and it is clear that a mobile electric power station of light weight can be used for many purposes both in war and in peace.

Fig. 6. General Electric-Cadillac 20-kw. Mobile Power Unit Equipped for Floodlighting Landing Fields, Bureau of Aircraft Production, U. S. Army

Owing to the success of the G.E. Cadillac power unit, the Engineer Corps of the U. S. Army has placed orders with the General Electric Company for a 50-kw. and a [illegible] power unit along similar lines.

The 50-kw. set is mounted on a La France Fire engine chassis having a motor of 125 brake horse-power. This set is now on test and will be completed in a short time. It will weigh about 17,000 lb., and will carry a full complement of 12 men, together with field equipment consisting of stove, and complete kitchen outfit, machine guns, rifles and ammunition, field telephone, reel and 300 feet of heavy cable, also a 60-in., 500-ampere medium intensity searchlight, with necessary supplies and accessories.

The Automotive Department is also supplying a 50-kw. generator of the same rating, for a 60-foot searchlight tower, to be operated on a special form of caterpillar tractor.

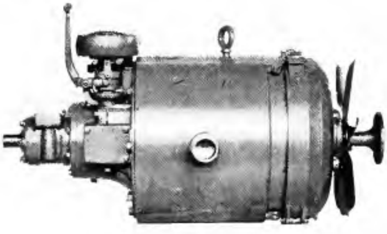


Fig. 7. General Electric 20-kw. Generator showing Clutch and Governor, Engineer Corps U. S. Army

A 6-kw. mobile set is being built on the standard Dodge chassis, which has been lengthened 20 inches. A 6-kw. generator, of quill construction, is mounted just back of the transmission. This will be provided with a clutch similar to the ones used in the machines already described. The 6-kw. unit will have a weight of about 4000 lb. fully loaded. This includes two men and a high intensity searchlight which has a 30-in. mirror and weighs about 250 lb.

It should be mentioned that the kilowatt rating in each of the foregoing cases is given on an intermittent basis, and on the assumption that the searchlight will be operated at the full capacity of the generator for fifteen minutes with a no-load interval of five minutes, the total cycle being two hours and the operation at night. This complies with actual field experience as regards night bombing attacks.

Fig. 8. Convoy General Electric-Cadillac 20-kw. Mobile Searchlight Power Unit, No. 6051, from Dorr Field, Florida, to West Lynn, Mass.

These developments have also led to the placing of an order by the Signal Corps of the

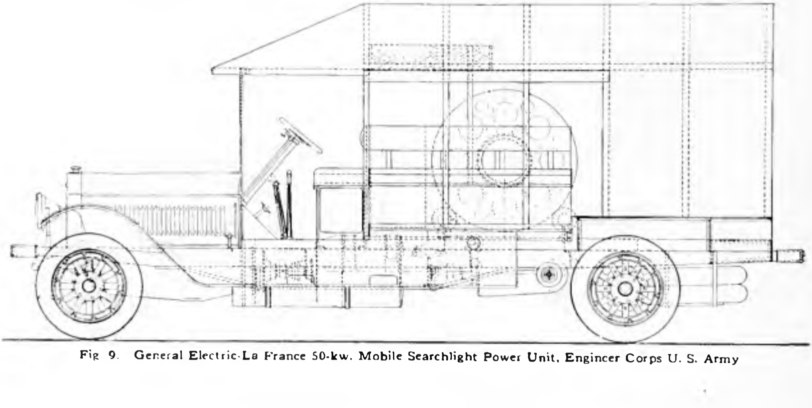


Fig 9. General Electric-La France 50-kw. Mobile Searchlight Power Unit, Engineer Corps U. S. Army

U. S. Army for 25 radio units to be built in a similar manner to those already described, but suitable for wireless telegraphy or telephony. White Army trucks of two tons capacity will be used in producing these units.

Fig. 10. Rear View Mobile Searchlight Power Unit in Mud Hole One Mile North of Gretna, Va. Engineer Corps U. S. Army

It is evident that the novel method of mounting a generator on a gasolene car, which was first used on the GE-Cadillac chassis, has opened up an interesting field of endeavor. Undoubtedly for war purposes it is of vital importance, as it is the only one which insures an efficient, quiet, direct drive, and which is free from intermediate gearing of any kind.

Another advantage is that the generator can be wholly disconnected from the car when moving from place to place, although the clutch is so made that the unit can simultaneously perform both functions under special conditions.

For peace purposes there is a demand for electric units for farm lighting, as is best indicated by the sales of the small power sets, of one to five kilowatt capacity, which appeared on the market a few years ago. Furthermore, the combination of a motor car and a generator of useful size and capacity at once affords a valuable unit for municipal and industrial purposes. It can be used by fire departments for operating searchlights, for pipe thawing, for illumination in case of accidents, and by farmers for the isolated supply of electricity, for operating motor-driven apparatus such as pumps, electric hoists, and farm appliances. In industrial fields there is electric welding, emergency work, and many uses of a similar nature. Another suggested use is for circus and pleasure resort lighting where a portable power plant would be of great assistance.

It has now been demonstrated that by the method herein described small generators can be directly applied to standard automobile chassis with slight changes, thus utilizing the engine and complete prime mover, the only addition being the generator. Undoubtedly, this idea can be carried out commercially, and the automobile will thus become available for a new purpose.

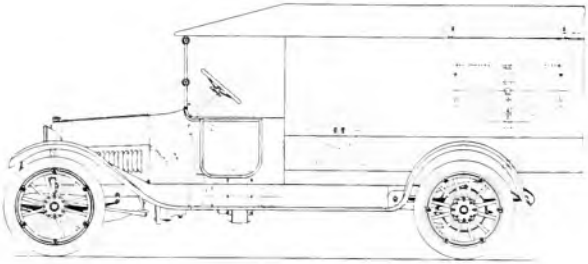


Fig. 11. General Electric-Dodge 6-kw. Mobile Searchlight Power Unit, Engineer Corps U. S. Army

Searchlight Developments of the U. S. Army

By Chester Lichtenberg

Captain of Engineers, United States Army

Captain Lichtenberg in outlining the development of the searchlight shows how the weight and number of parts have been reduced, the power and efficiency increased and the mobility vastly improved. He cites specific improvements in the power units, the mirrors and carbons, and concludes his article by showing that 293 searchlight problems were investigated during the period of 1918-1919.—Editor.

Chester Lichtenberg

Foreword

THE practice of successful commercial organizations shows that competition is stimulated, cost reduced and a better product obtained where a selected force is assigned to the development and testing of the materiel. These facts were appreciated early in the war period just closing, and were demonstrated with remarkable clarity in the wonderful improvements made in searchlight equipment by the Corps of Engineers, U. S. Army.

1914

The start of the great war of 1914-1918 found practically all searchlights in the United States Army installed in coast defense positions. A few searchlights on horse-drawn vehicles were ordered in 1907 for coast defense commands, and some experimental work was done between 1909 and 1914 on portable towers with 24-in. searchlights. These were drawn by horses or gasolene tractors and supplied with electric current by portable gasolene electric power units similarly drawn.

1914–1917

In June, 1916, a new start was made toward obtaining improved searchlights for seacoast defenses and suitable searchlights and power units for field armies. The efforts were directed toward purchasing modified or improved equipment, suggested by observations made in Germany and in Mexico. No funds, however, were available for experimental work and the equipment ordered was developed by the manufacturers without material aid from the United States.

1917–1918

The desirability of modifying searchlight designs to make them specially adaptable for the warfare conditions encountered in France was indicated by the Expeditionary Forces. Reports showed the important part taken by searchlights in combating hostile airplanes and the need for large numbers of more powerful types.

Active steps were taken to obtain scientific aid in this matter, when on November 19, 1917, General William M. Black, Chief of Engineers, U. S. Army, requested the National Research Council to undertake the development of a searchlight beam of suitable color and maximum intensity for field army service. This work was extended in December, 1917, by Colonel R. S. A. Dougherty, of the General Engineer Depot, U. S. Army, who assigned an Engineer Reserve Officer to inquire into all existing searchlight investigations and to start such new investigations as seemed desirable.

Searchlights

Intensive searchlight investigation work was started December 5, 1917. The assistance of eminent scientists, large manufacturing companies, noted engineers and experienced army officers was obtained. As a result, twenty different kinds of searchlights have been wholly or partially developed and new and previously undreamed of types contemplated. All of the designs tend towards weight reduction, simplicity, ease of operation, and diminution in cost. They are so arranged that a large production may be expected in a relatively short time with ordinary shop facilities.

One example of these points is a 60-in. searchlight which weighs only one tenth as much as the 60-in. searchlights heretofore considered standard. It costs only one third as much as the standard, is about 10 to 15 per cent more powerful and consists only of about 100 parts, as against several thousand parts for the old design. It is very much more rugged and is so arranged that it can be produced in less than one fourth the time required for producing the old model. Its fabrication requires only ordinary machine shop equipment, no special tools being necessary.

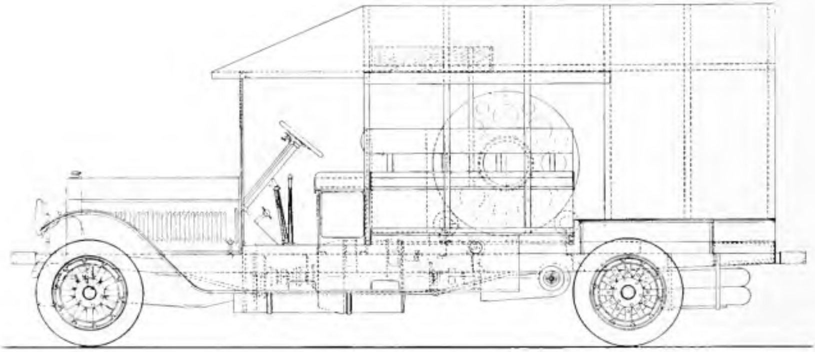
1917 Model, 60-inch Size, Mobile Searchlight Equipment

1918 Model, 60-inch Size, Mobile Searchlight Equipment

Another example is a 30-in. searchlight weighing only 200 lb., yet more powerful than the 4000-lb. 36-in. seacoast searchlights heretofore considered the best obtainable. The 200-lb. searchlight has a great field, particularly for foreground illumination. It is so designed that it can be readily taken apart and transported by men to points usually considered inaccessible for searchlights. The searchlight and its power unit require a crew of only three men for its operation. The cost is about one fifth that of the 1915 equivalent.

Power Units

A great deal of attention has been paid to the development of suitable mobile searchlight power units. Four designs have been prepared. These range in capacity from 6 to 50 kw. and from three fourths of a ton to 10 tons.



1919 Model, 60-inch Size, Mobile Searchlight Equipment

The three fourths ton, 6-kw. equipment consists essentially of a standard Dodge chassis, with a 6-kw. generator mounted on the propeller shaft, a 30-in. open type searchlight mounted in a suitable body on the chassis, and a crew of three men on the front seat. Present designs indicate that the complete equipment will weigh about 4000 lb.

Another development used in connection with the 2nd Field Army in France was the one and one half ton, 20-kw. Cadillac outfit. This uses a standard Cadillac ambulance chassis with a 20-kw. generator mounted on the propeller shaft, a 60-in. open type searchlight mounted in a suitable body on the chassis and a crew of five men. The total weight is 9000 lb. The cost, including the searchlight and repair parts, is about $8500. This development is indeed remarkable, since it has provided a mobile searchlight equipment which weighs and costs about one half as much as the fixed seacoast equipment, is equally efficient, yet extremely mobile.

Power units now being developed include a 50-kw., 500-ampere, three and one half ton mobile unit, weighing complete with searchlight and men about 18,000 lb., and a 50-kw., 500-ampere, 7-ton unit with a 60-ft. extensible tower, weighing, complete with all equipment, about 25,000 lb. and fitted to go over any kind of ground at speeds up to 15 miles per hour.

Mirrors

In 1917 there was only one concern in the United States making large glass searchlight mirrors. This organization had an output of three 60-in. glass mirrors per week. Each mirror cost about $1000. Immediately following the declaration of war, negotiations were opened with three other manufacturers who had facilities which might be developed for glass mirror manufacturing. As a result of the encouragement given these manufacturers, the production of 60-in. glass mirrors was raised to 15 per week in 1918 and the price reduced to about $900 per mirror, even with war-time conditions concerning labor and material prevailing. This is equivalent to about $700 per mirror under peace-time conditions, thus resulting in a saving of over 30 per cent in the cost and an increase in production of over 400 per cent without any impairment in quality.

Metal mirrors were subjected to extensive investigation during the war period. A preliminary survey indicated that a successful metal mirror might be produced which would weigh about the same as the standard glass mirror, but which would be very much less fragile and cost very much less than the standard glass mirror. Extensive researches, which are still progressing, indicate that successful 60-in. searchlight metal mirrors can be produced. These will cost about $100 apiece, will have a reflectivity equal to that of glass mirrors, be practically indestructible and can be fabricated in less than one fifth of the time required to produce standard 60-in. glass mirrors.

Carbons

Great strides have been made in the development of suitable searchlight carbons. The size for the 200-ampere medium intensity lamp has been reduced from two inches in diameter to one and one eighth inches in diameter, the cost halved and the amount of light given forth tripled. Developments now in progress promise carbons costing less than those previously considered standard and capable of giving more light than the best heretofore produced.

Control Systems

Distant electrical training controls for searchlights proved to be a fruitful field for experimental work prior to 1917. The systems produced, however, were complicated and not at all suitable for field service conditions, nor were they entirely satisfactory for seacoast defense requirements. Investigations now in progress indicate that an accurate and relatively simple system of distant electrical control which can be readily applied to field and seacoast searchlights will soon be produced.

Finders

Preliminary studies made in 1918 indicated that the effective range of practically all searchlights could be extended without any modifications of the lights themselves, if they were provided with suitable optical devices. Further research showed that the ordinary telescope or night glass is not suited for searchlight target finding. The aid of a number of eminent scientists was enlisted, and as a result of their suggestions, there are now in development several kinds of searchlight target finders which give promise of wonderful results. Their cost will be relatively low, but their application will at least double the range of any searchlight.

Organization

The study of these problems, the means devised for solving them, and the tests required in connection with these led to the building of an efficient organization for Searchlight Investigation. It consisted of officers and enlisted men of the emergency army with a few civilian clerks and watchmen. They had a headquarters near the office of the Chief of Engineers, U. S. Army, and splendid searchlight testing stations at Tenleytown, D. C., Schenectady, N. Y., Brooklyn, N. Y. and West Lynn, Mass. They established and maintained very cordial relations with over one hundred scientific, engineering, manufacturing and commercial organizations, and through the development contracts, which they initiated and placed on a firm foundation, they enlisted the active support and assistance of a large number of private development and investigation groups.

The large manufacturers especially aided in searchlight development. Through the patriotism of Mr. Francis C. Pratt, Vice-President of the General Electric Company, and the foresight of Mr. Elmer Sperry, President of the Sperry Gyroscope Company, large, well organized and exceptionally good designing, manufacturing and testing facilities were made immediately available for searchlight work and contributed in a large measure to the success attained.

Summary

The period from January 1, 1918, to June 1, 1919, has seen an undreamed advance in the art of searchlights. Many new types have been developed, new uses found, and a wonderful future indicated. The organization charged with searchlight investigations during this period covered the field as indicated in the summary which follows:

SUMMARY OF SEARCHLIGHT INVESTIGATIONS 1918-1919

No.	Subjects	Number [illegible]
1	Arcs	17
2	Control Systems	20
3	Convoys	10
4	Electrodes	13
5	Finders	5
6	Mirrors	24
7	Photographs	14
8	Photometry	56
9	Power Units	6
10	Searchlights	19
11	Tests	97
12	Towers	3
13	Stations	9
	Total	293

The Lynn 60-inch Open Type Army Searchlight Development

By Cromwell A. B. Halvorson, Jr.

Designing Engineer, Street Lighting Department, General Electric Company

The most impressive features in the development of the 60-inch open-type searchlight are the radical departure from conventional design, the rapidity of carrying out the experimental work, the speed with which the difficulties were overcome and the first unit completed. The object sought was to produce a powerful lightweight searchlight that would be so mobile and yet so rugged that it could withstand the severe conditions of battle service at the firing line. How this was accomplished, the author tells in the following article.—Editor.


Cromwell A. B. Halvorson, Jr.

DURING the spring of 1918 the engineers of the General Electric Company were requested to confer with the Engineer Corps, U. S. Army, at Washington with regard to certain searchlight requirements occasioned by modern warfare as initiated by the Hun. The practice of bombing at night from aerial machines of war, causing great loss of life as well as tending to a shaken morale, had to be checked; and so far as our observers with the American Expeditionary Forces could predict, large numbers of searchlights to create glare screens or to use in conjunction with pursuit planes would be eventually the most satisfactory method of combat. However, the searchlights available and those in use by the Allies at the time of our entry into the war were not particularly well adapted to the requirements of the new art of aircraft spotting. They were heavy and cumbersome, each requiring a large force of men to move and operate and a corresponding heavy auto truck unit for transportation and power purposes. The automatic lamp mechanisms in general use were far too delicate for field conditions and skill of a high order was required to maintain them in good operating condition. They were limited in beam intensity due, in part, to the relatively small mirrors used and available (48-in.) and also to the low current densities in the carbons. Very few 60-in. searchlights were in use, partly because each weighed nearly 6600 lb. Such searchlights were primarily designed for purposes of coast defence, and consequently being immobile were unsuited to field conditions. As their cost was great and labor and materials were scarce, their immediate production was limited. The light beams were more or less unsteady in the case of the medium-intensity lamps, that is, mechanisms using plain carbons, due to the relatively large diameter of the carbons used as well as to their inferior quality; and, everything considered, there was much need for improvement in searchlights for anti-aircraft purposes.

At a general conference in Washington, May 1, 1918, the army engineers outlined the possibilities of searchlight developments along radical lines to meet the new conditions. They suggested, among other things, that the arc might be maintained in the open without a surrounding barrel of the conventional design, that the front glass might be discarded, that the lamp mechanism might be greatly simplified (in fact, a rugged hand-feed device was preferred as it was always necessary to have an attendant stand by an automatic mechanism while in operation) and, last but not least, that a strong metal mirror having correct optical properties might be used instead of a glass one. In short, what was wanted was something radically new and better in every respect and it was wanted without delay as many lives could be saved if an adequate searchlight defence could be immediately assembled at the front. Finally, after a thorough discussion of modern searchlight requirements for army purposes, the following quite general specifications were evolved:

First—That the new unit was to mount at least a 60-in. mirror and was to weigh not more than 1000 lb. complete.

Second—That it was to have a hand-feed mechanism that would endure at least sixteen hours of intermittent operation. The life of a single trim of carbons need not be more than one hour, since bombing attacks were commonly of short duration.

Third—That higher beam intensities were to be obtained if possible; but due to the limitations of portable power plants, 200 amperes at about 115 volts was considered the maximum available current from one power unit. It was suggested also that a beam having a divergence of three to five degrees would be desirable as the greater width of beam would be more useful in aircraft searching, provided that at the same time intensities at least equal to those in use could be maintained.

Fourth—That it was considered necessary to develop a process for manufacturing metal mirrors in quantities for use with the new type of searchlight as the existing 60-in. glass mirrors were necessarily fragile and very expensive and their production was limited, for the skilled labor available for their manufacture was inadequate to meet the demands of both the Army and Navy and the latter obviously had to be supplied.

The general specifications as framed by the army engineers while indicating problems did not at the outset, when considered in their broader aspects, appear so formidable or impossible of fulfilment. The detail requirements, however, presented many extremely difficult problems. Operating an arc practically in the open and at the mercy of the elements did not appear to be impracticable, as in all probability methods of sheltering it from the most severe conditions could be developed. It appeared, therefore, that one of the first things to be done was to determine which type of arc seemed to offer the greatest promise. After hasty experiments along these lines, reinforced by some theory, it was decided that the medium-intensity arc using plain carbons, in which the light is emitted largely by the crater of the positive carbon, offered the best chance of immediate success. The wind certainly could not greatly disturb the crater, if the arc stream were reasonably well controlled or maintained within certain bounds, either magnetically or by other means. Just the opposite condition exists, however, in arcs of the vapor or flame types, as the Beck, for instance, in which the luminosity is largely affected by the characteristics and control of the arc which is easily affected by air currents and therefore increases many fold the problem of adapting this arc for burning in the open. Accordingly the greatest efforts at the start were directed to the development of means to control and to improve the medium-intensity arc, partly by increasing the current densities in the carbons and partly by centering the arc and stabilizing it by magnetic and mechanical means.

The lamp mechanism had to be simple, according to the specifications of the army, and yet the requirements of the arc had to be met by a mechanism which would permit of the utmost accuracy of adjustment of the crater and arc relative to the mirror. It must be capable of being quickly interchanged or retrimmed if necessary, and its operation must be such that it could be quickly assimilated by the enlisted man. It must also be of a construction rugged enough to withstand rough usage. Moreover, one of the most rigid detail requirements was that the arc be enclosed or occulted for indefinite periods while locating the "bird" by sound, with the consequence that the mechanical parts in the arc chamber had to be made to endure extreme temperatures. In fact, in order not to obstruct the output of light rays from the mirror to any appreciable extent when non-occulted, a ventilated device capable of bottling up 13 to 15 kw. of energy in an absolutely light-tight compartment was necessary and practical considerations appeared to limit it to a construction of light weight telescopic cylinders approximately 12 inches in diameter and forming a chamber 30 inches overall.

In order to feed the carbons properly, to align the arc and control it with relation to the focus of the mirror, it would be necessary to provide an arc finder screen in such a position that an image of the arc could be observed constantly by the operator, and this promised to be one of the most troublesome features of the open-type searchlight design.

Furthermore, compared to former searchlights, the device to be built was to be no less accurate or less easily manipulated in regard to such essential features as training of the beam, exact coordination of the beam with azimuth and altitude scales, and accurate mounting of the mirror, either glass or metal.

In pondering over these requirements and problems, it appeared that the older and more conventional type of searchlight had been built to prevent these very problems from ever arising. The large glass covered barrel furnished an ample compartment for the easy dissipation of heat. Obviously problems of windage did not exist, occulting the beam was easily taken care of by the iris shutter, an automatic mechanism maintained the arc at the focus of the mirror, and the arc could be conveniently viewed through an eye-piece in the barrel. The price of doing these things easily was excessive weight, high cost, and limited production.

Having these various matters in mind it seemed that the logical thing to do was to follow the methods of rifle or gun designers to a certain extent. They had started with a "muzzle loader" and had come to the breech-loading type. Why not follow this method of operation in a searchlight? Why not make the mechanism in the form of a cartridge with all the controls at the rear away from the heat of the arc, provide an opening in the mirror for the insertion of the cartridge, and devise a breech holder in the hub of the mirror supporting frame to receive the lamp and to carry the guides and occulter mechanism? All problems of perfect carbon alignment with the mirror axis, arc control, arc feeds, rapid interchange of mechanisms, and ease of trimming promised to be solved by this scheme, including that ever present and most important problem of speedy manufacture and quantity production. Accordingly a design was made and in a short time the experimental mechanism shown in Fig. 1 was in operation. This mechanism and a proposed design of mounting and carriage was exhibited to the army engineers at Lynn, on May 31, 1918, and approval was obtained with only slight modifications. The work of commercializing this design was vigorously prosecuted with the result that on June 10th, exactly one month having elapsed since the work was started, the anti-aircraft searchlight, as shown in Fig. 2, was successfully tested at Lynn. A week of tuning up followed and this searchlight, Fig. 3, complete with a 36-in. metal mirror, temporarily mounted, was formally presented to the Engineer Depot, represented by Captain Lewis and Lieut. Lichtenberg, officers in charge of Searchlight Investigations, at Schenectady on the evening of June 17th. The test was successful, the searchlight met the specifications in every particular and gave a pure white, steady and full beam of light having three to five degrees divergence.

Fig. 1. Original Cartridge Type Lamp Mechanism

Fig. 2. Lynn No. 1 Design

Although no beam intensity measurements were made on this particular combination, visual tests were made comparing it to the standard 60-in. medium-intensity searchlight operated at both 175 and 200 amperes and it was obvious to all that in spite of the fact that the new lamp was equipped with only a 36-in. mirror, and therefore produced a beam of nearly twice the divergence, much higher intensities were attained. An excellent showing was also made as compared with the 60-in. high-intensity Beck searchlight operated at 150 amperes, which heretofore was considered far outside of the medium-intensity searchlight class. However, it was seen that while the extremely concentrated beam of the Beck lamp (about one half a degree) resulted in a much higher intensity, and therefore greater pickup distance, there was some question as to its revealing power being correspondingly greater; and when the areas illuminated were compared, indicating a ratio of 1 to 36, it was plain to see that the new medium-intensity lamp was producing a remarkably large flux of light which if utilized with a 60-in. mirror would rapidly cut down the difference in maximum beam intensities and it was considered that the pure white light would place the medium-intensity lamp on at least an equal footing with the more intense Beck lamp so far as revealing power was concerned. There was a possibility, too, that continued research on carbons would further improve the new lamp as up to that time little had been done except to test various sizes for operation, and good results had been obtained with positives as small as one inch and negatives of 1/2-inch in diameter. Exhaustive photometer tests made later justified these conclusions as eventually the 1 1/8-inch positive and 5/8-inch negative carbons were standardized. This combination operating at 200 amperes and with a 60-inch mirror gave 150,000,000 apparent beam candle-power as against 45,000,000 for the old medium-intensity, using a 2-inch positive at 175 amperes.

As a result of the good showing made with the Lynn No. 1 design, the Company was authorized by the army engineers to produce another model incorporating any improvements it might be able to suggest and to continue the development of the 60-inch metal mirror. Accordingly an improved design was laid out, and on June 28th, but eleven days having elapsed, the Lynn No. 2 design, Fig. 4, complete with 60-inch metal mirror was presented to the army engineers for their approval at Schenectady.

The original of design No. 2 was later shipped to Washington and exhaustively tested with the result that the Lynn design, at least in its essential features, was adopted by the army as the standard field searchlight.

The actual device standardized on army drawings and manufactured in quantities is shown in Fig. 5. It will be observed that the principal variation from the Lynn design is in the carriage, turntable details, and mirror support. These changes in design were made by the production engineers of the army who felt that standardization of these details could be effected to good advantage with similar details of a sound-ranging apparatus which was being developed by the department for use in conjunction with the searchlight. The function of the sound-ranging device was to locate the hostile plane by sound, after which the searchlight was to be trained on the spot indicated, the occulter suddenly opened, and the "bird" revealed in the beam for target practice by anti-aircraft batteries or pursuit by swifter planes equipped with machine guns.

Fig. 3. Lynn No. 1 Design with 36-in. Metal Mirror Temporarily Mounted

Fig. 4. Lynn No. 2 Design

From the outset it was seen that the searchlight problems could be classified under the following general heads:

1. Metal Mirrors
    - a—Electro-Deposition
    - b—Backs
    - c—Lacquering

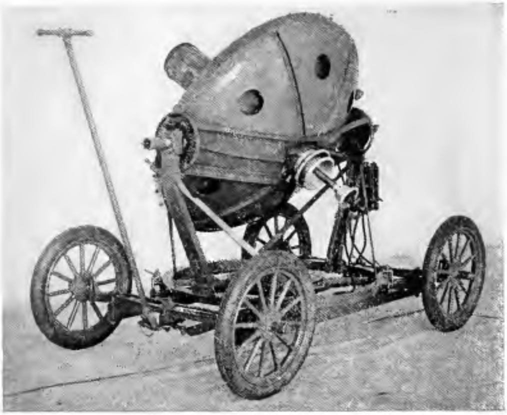


Fig. 5. Standardized Design 200-ampere Medium Intensity Lamp

2. Lamp Mechanisms and Arcs
    - a—Medium Intensity
    - b—High-Intensity Beck Adaptation
    - c—Carbons
3. Mechanical Design
4. Production; experimental

The working force was accordingly divided in such a way that these problems were attacked by engineers peculiarly fitted to cope with matters coming up under these headings.

From the start, it was obvious that the metal mirror was to be the major problem of the Lynn organization. Metal mirrors were not unknown, the French having used, in the present war, cast bronze mirrors with ground and polished surfaces plated with gold. However, such mirrors had no particular advantage over glass mirrors other than that of mechanical strength, as the process of manufacturing is equally laborious and production thus limited. The design of a metal searchlight mirror having suitable optical properties and capable of being manufactured in quantity had, so far as we knew, never been developed, although Professor Thomson made a four-inch metal mirror some twenty years previous by electro-chemical deposition and this indicated a possible line of development. Several references have since been found in the Patent Office to mirrors made in this way, and Sherard Cowper-Cowles of England evidently covered an enormous field of experimentation. However, it is sufficient to say that, independently of what other investigators may have accomplished, the Lynn Searchlight Department, with the advantage of Professor Thomson's advice, produced a 60-inch mirror having fair optical properties within five weeks after starting the initial study of the problem; and 60-inch metal mirrors were being regularly produced at the time of the signing of the armistice, while resources were practically developed capable of producing such mirrors at the rate of one hundred a week.

In addition to the problems of deposition and removal from the master form, the backing up of the deposited paraboloid so that it would hold its shape proved to be no mean problem. After making exhaustive tests on all promising cements something suitable for the purpose was found. However, this particular problem is still engaging some attention, and the most useful metal mirrors so far developed are those employing a reinforcing ribbed metal back imbedded in the cement. Such mirrors have been found to be strong enough to withstand the greatest abuse and

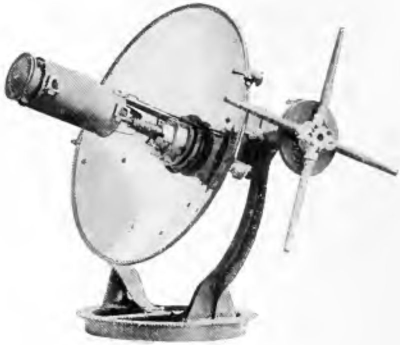


Fig. 6. 60-in. Searchlight, Lightest Weight, 300 lb., Design No. 7

a searchlight was constructed, Fig. 6, using such a mirror as the nucleus of design, in which the weight of a complete 60-inch searchlight unit is but 300 lb. In the case of this design the weight has been so reduced that even wheels are unnecessary. The details of metal mirror construction are covered in an article by Mr. Hussey elsewhere in this issue.

As stated at the outset of this article, there were several types of arcs to be considered in the new development and a brief description of each may be of interest as indicating their influence on subsequent design problems. The so-called medium-intensity arc is an arc of moderate luminous output but capable of wide development. It consists simply of a pair of carbon electrodes arranged with their axes in substantially the same straight line, Fig. 7-A. In this type of arc the light useful for projection is emitted altogether from the positive crater and the brilliancy of this crater should be as uniform as possible as the quality of the beam from the mirror depends largely on this condition. It follows, therefore, that the positive carbon should be operated at the maximum current density consistent with good operation, that is, quiet operation, fair depth of crater, minimum of oxidation (which affects the size of the carbons, life etc.). In other words, there should be an even distribution of temperature over the face of the crater so far as possible. There appears to be a fairly constant relation between the diameter of the carbon and the current density; and it was found that good results could be obtained with current densities as great as 400 amperes per square inch, depending somewhat upon the quality of the carbon. The operation of an arc depends very largely upon the character of the negative electrode and, in general, a relatively small cored negative carbon of high conductivity appears to operate best. A combination of electrodes of the following dimensions was at length standardized for a normal 200-ampere current.

Negative $\frac{5}{8}$-in. by 6-in. cored
Positive $1\frac{1}{8}$-in. by 11-in. cored

Oxidation reduces the diameter of the positive to about $\frac{7}{8}$ inches. The medium-intensity arc possibly has an advantage in color. Its spectrum is more like daylight than other artificial light sources developed for searchlight work. The steadiness of the Lynn arc is largely due to the peculiar distribution of the current through the positive head and arms, Fig. 7, which have a remarkable stabilizing effect.

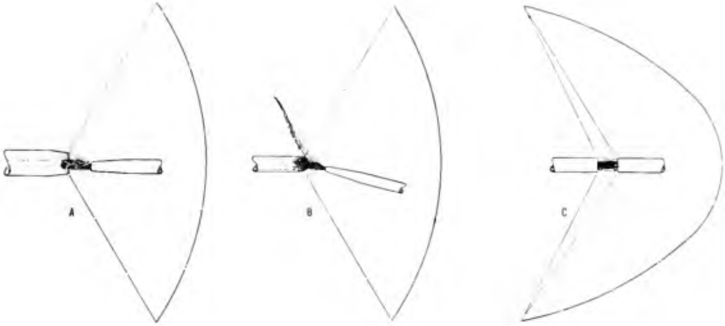


Fig. 7. Diagram of Arcs and Light Flux Distribution

While the Lynn medium-intensity mechanism appeared to be capable of operating all grades of carbons, its operation is best with the carbons specially developed for the purpose by the Research Laboratory, Schenectady, which was early called into consultation with the result that excellent carbons were being manufactured at the Schenectady plant before the signing of the armistice.

Another type of arc available at the time the Lynn development was undertaken was the Beck flame carbon arc, Fig. 7-B. This consists of a positive carbon of very small diameter ($\frac{5}{8}$ inch for 150 amperes) heavily loaded with light-giving salts which are heat evaporated into the arc stream and concentrated at the positive crater. Due partly to an angular setting of the axis of the negative electrode, relative to the axis of the positive electrode, an extremely deep crater is produced which is in effect a cup which contains the gas, so long as all of the necessary requirements are observed. Such an arc possesses very valuable characteristics where extreme intensities and maximum concentration of beam are concerned, as in marine work for instance, but its flexibility so far as current range and spread of beam are concerned had not yet been tested. Be that as it may, the lack of definite information as to the relative value of these arcs for anti-aircraft searching indicated the necessity of developing both types and accordingly the Lynn organization carried both developments along in parallel but with the productive pressure applied to the medium intensity lamp. Adapting the Beck arc to the breech-loading design searchlight was difficult but this also has been successfully accomplished and in some features there are noteworthy improvements. This development is covered in an article by Mr. Beechlyn elsewhere in this issue. Fig. 8 shows the searchlight complete and indicates how standardization of searchlight design has been maintained. This mechanism differs from the medium-intensity mechanism in appearance, mainly in the chimney required to carry away the products of combustion which are given off very profusely from the high-intensity type of arc. However, in this respect the arc is similar to those in common use in street lighting, as the magnetite, and since the lamps designed for use with these arcs employ chimneys, it was obvious that similar methods would probably apply in this case and such proved to be the case (refer to General Electric Review, Dec. 1911, page 578).

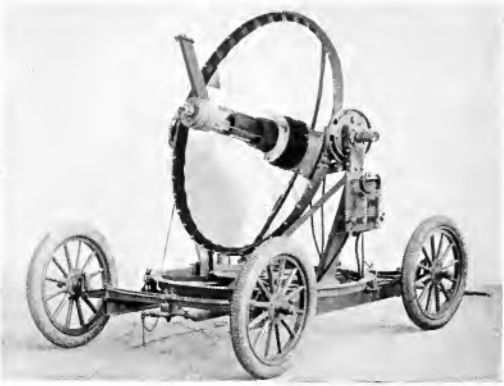


Fig. 8. High Intensity Mechanism in Place on Standard Design

Another arc considered as a possibility and partially developed was the titanium and its modified varieties on account of their high luminous efficiency in lumens per watt. The appearance of such an arc is shown in Fig. 7-C. By comparing the diagrams of the arcs and their light flux distribution, it will be seen that the light in this case is all given by the arc stream and that if such an arc is employed a much deeper parabolic mirror must be used.

The mechanical design of the mountings, turntables, trunnion arm supports, carriage, etc., was highly developed. No less than six designs were approved and built on developmental orders. Design No. 4, one of the

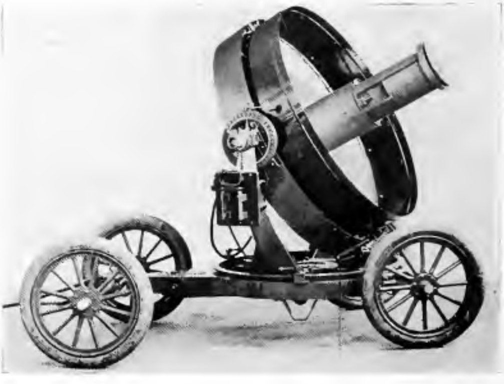


Fig. 9. Lynn Design No. 4-A

earliest but not adopted by the army production engineers, is shown in Fig. 13.

Design No. 4-A was finally standardized for future deliveries and is shown in Figs. 9 and 10. This searchlight, unlike the earlier designs, has been fitted with collector rings, Fig. 11, arc finder at the breech, improved occulter system, and other modifications and improvements, suggested in part by the criticisms of returning army searchlight experts. In fact, the development is now considered complete and represents the best knowledge on the subject of anti-aircraft searchlights up to the present time. One of these has been sent to the British Government whose searchlight commission to this country recently inspected the device on test. It was pronounced far superior to anything thus far developed for field use by our Allies. One of its several modified forms, the "litter type," is shown in Fig. 12. Figs. 14 and 15 are other views showing the high-intensity mechanism in place. Figs. 16 and 17 show how compact and easy of access are the hand-wheels and various controls for operating the arc mechanism.

Fig. 10. Lynn Design No. 4-A on Feet Without Wheels

The arc is "struck" by pushing the hand-wheel *A*, attached to the arc striker and negative carbon rod, forward against a spring until contact is made between positive and negative carbons, when the negative element is released slowly thus drawing the arc. The negative carbon is offset a small amount and even burning of the positive is assured by rotating the eccentric negative slowly or by stopping its rotation and impinging the negative blast on irregularities on the positive face. The offsetting may be augmented by flexing the negative arc striker rod which is flattened for a distance along its length.

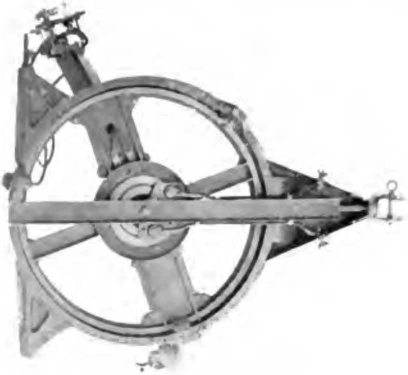


Fig. 11 Lynn Design No. 4-A View of Under-side showing Collector Rings

The negative feed is accomplished by the screw thread *B* which carries the negative structure. The positive feed is accomplished by the screw thread *C* which is engaged by a detent in the breech casting; the entire lamp is moved in this case and the focusing of the arc accomplished by the same operation.

The positive head and carbon can be rotated when desired by turning the hand-wheel *D*. Even burning of the positive may be facilitated to some extent by this operation as the convection currents can be employed to work in conjunction with the eccentric negative blast to wear away evenly a carbon which may lack uniformity in texture.

To protect the positive head supporting arms, arc shields *E* are provided; these are easily renewable and assure long life of the positive head.

The occulter is operated by the handle *F*. The arc finder screen *G*, on which is thrown a correct image of the arc, is conveniently placed for observation purposes, as the successful operation of the lamp depends on this detail of the design.

Another important phase of the Lynn searchlight development is to be found in the

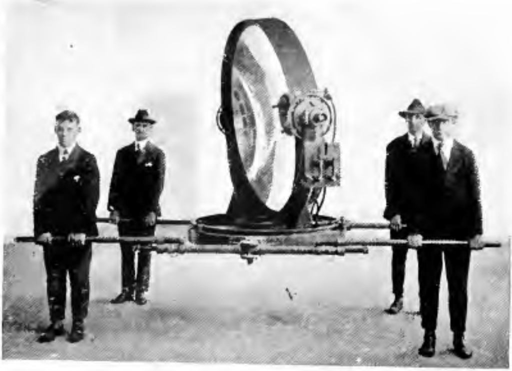


Fig. 12. Litter Type Lynn Design No. 5

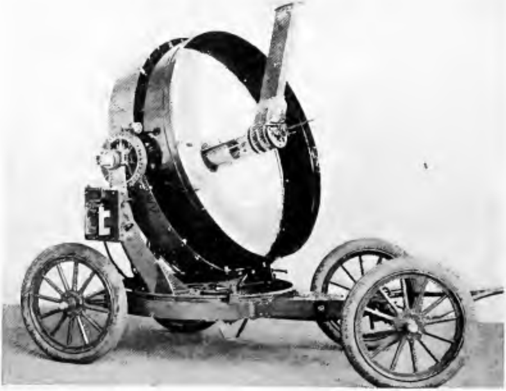


Fig. 14. High Intensity Lamp Mechanism in Place on Lynn No. 4-A Design

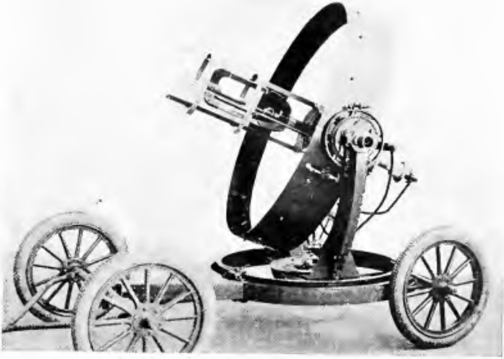


Fig. 13. 500-ampere Medium Intensity Lamp Development

Fig. 15. High Intensity Lamp Mechanism in Place on Lynn No. 4-A Design showing Lamp Mechanism and Controls

Automotive Department of the Lynn Works. At the same time that the light-weight open-type searchlight was being developed three types of correspondingly light-weight mobile power units, capable of speedy movement, were designed. A complete description of these remarkably efficient and smooth-running machines is given in an article by Mr. H. S. Baldwin elsewhere in this issue. The largest of these machines, equipped with a 50-kw. generator, is designed to operate the 500-ampere normal rating medium-intensity searchlight shown in Fig. 13. Standardization has been maintained also in this case for all three lamps—the 200-ampere medium-intensity, the 150-ampere high-intensity, and the 500-ampere medium-intensity—are interchangeable in the breech.

It is interesting to note that the characteristics of these mobile generators are such that no stabilizing resistance for the arcs is required other than the copper cables employed to connect the searchlight with the power-plant, the cable reels making possible the operation of the searchlight either on the power-plant or 300 feet distant.

Thus in a brief period of time and under the pressure of war-time exigencies, there was developed a new art, the possibilities of which in peace times can only be surmised; but it seems safe to predict that much useful knowledge has been gained which can be put into effect in the course of time. The metal mirror certainly should have a broad field of application; every "man-of-war" should carry "spares" to be used interchangeably with the more expensive glass mirrors; in performance they are about equal, the lacquer necessary to protect the silver surfaced mirror [illegible] about the same amount of light as the glass absorbs. However, there is practically no heat absorption as in the case of glass and consequently the metal mirror runs cold, whereas the glass runs hot and therefore its liability to crack is great.

Fig. 16. Medium Intensity Lamp Controls and Breech Details of Lynn No. 4-A Design

The more efficient arcs and new methods of arc control should also have a wide field of usefulness wherever highly concentrated sources of light are employed as in various projection devices.

Fig. 17. Medium Intensity Lamp Mechanism

Light Weight Barrel Searchlights

By Preston R. Bassett

Research Department, Sperry Gyroscope Company

The methods of attack and defense employed in the stupendous field and air operations of the past war necessitated that the engineers design their equipment for maximum performance with minimum weight. The airplane motor is a splendid example. Another, as described in this article, is the development of the light-weight barrel-type searchlight which is only one fifth as heavy as its predecessor. The author also describes the construction of this type of unit and briefly outlines its possible future uses.—Editor.

Preston R. Bassett

PERHAPS the most noticeable and universal effect that the four years of warfare have had on the development of military weapons and war apparatus of all sorts has been the obtaining of greater service from lighter apparatus. "Performance per pound" has been the byword of the engineer in this war, and as much emphasis has been placed on the pounds as on the performance. Up to the past few years there have always been two classes of military apparatus—the mobile or field apparatus and the permanent or fortification apparatus.

The fortification apparatus has consisted of units too large or too heavy to be portable and they have therefore been used only in permanent locations, such as coast defense fortresses. The intensity of this war, however, has been such that the demand for the superior performance of the large fortification apparatus has been imperative in the field. Permanent fortifications played so small a part in this war that all apparatus which was to take an active part had to be made portable and dragged to the shifting scenes of operation on wheels.

For many years one of the permanent residents of all forts has been the 60-in. searchlight. Although this searchlight has always been considered indispensable on permanent locations, it had never been thought of as a possible recruit to the field army. But the army found that the need for a searchlight of its power in the field was so urgent that it, in turn, was subjected to the process of redesign and emerged from the war a very different piece of apparatus from its pre-war predecessor.

This evolution was caused largely by the new use which searchlights found when night bombing from airplanes was instituted as an important method of warfare. Anti-aircraft searchlight service demanded primarily a most powerful beam. An airplane is none too good a target even under the most ideal conditions, and it was very quickly discovered that the small portable units with which the armies started the war were useless for this new and important service. Therefore, the call was issued for a light-weight searchlight of maximum power.

The development of the 60-in. light to fill this need has been accomplished by a series of steps and improvements which are worthy of recording. The 60-in. searchlight of 20 years ago was practically the same piece of apparatus as the 60-in. searchlight at the start of the war. No remarkable changes had taken place during that period. The apparatus with which this war started was a cumbersome affair, weighing anywhere from 6000 to

Fig. 1. 60-inch Heavy Type Searchlight, which was about the only type available at the begining of the war

9000 lb. Most of the structural parts were castings; the base, trunnion arms, end rings, door and mirror frames were all heavy iron or steel castings. The light was built for permanent locations and no special pains had been taken in keeping the weight down to a minimum.

Figs. 1 and 2 show typical examples of the heavy searchlights which were available at the start of the war. The equipment shown in Fig. 1 weighs approximately 9000 lb. This outfit is mounted on a small carriage with car wheels, but this does not make it, by any means, portable; the carriage and wheels were used only for pushing the searchlight in and out of its shelter over about 20 feet of track. The light shown in Fig. 2 is one of the standard 60-in. equipments with which all of the coast defenses of the United States are supplied. It weighs about 6000 lb. and has always been permanently installed on high ground or towers.

When the night raiding by aircraft became a serious menace, the immediate need for searchlights of great power was so urgent that at first even a great many of these heavy old type searchlights were dragged to new locations near the front, where they could be of considerable service in the emergency until they could be supplanted by portable equipments of at least equivalent power.

The problem which the engineers faced in designing a lighter equipment was difficult since there had never before been a demand for the 60-in. searchlight in the field and consequently the usual methods of light construction had never before been applied to the construction of the larger size searchlights. The construction of two light weight 60-in. searchlights was started at about the same time by different manufacturers. One attempt at extremely light construction was made by using aluminum wherever possible. The drum was built of sheet aluminum with cast aluminum end rings and with aluminum mirror frame and front door ring. The searchlight was mounted in light trunnion arms of structural iron, which were carried on a light carriage with rubber-tired wheels. The outfit weighed 1800 lb. complete, which immediately placed it well within the class of portables. The other attempt at light construction was made by the use of light structural iron. The drum was constructed of thin galvanized sheet iron with end rings bent from No. 8 gauge iron plate. The plate was first cut and bent into a channel section and then the channel section was rolled to make the rings of the proper diameter. This construction was found to give the greatest strength and rigidity to the cylinder with the least weight. The mirror ring and the front door frame were also formed from thin boiler plate and then bent to the proper radius. The trunnion arms and base were made entirely of light angle iron trussed to make a very rigid support for the drum. The base was mounted on a light carriage having standard Ford automobile wheels. This outfit weighed about 2000 lb. complete with the carriage.

Fig. 2. Side View of Heavy Type 60-inch Searchlight. This searchlight weighs approximately 9000 pounds

The performance and the weight of these two light equipments was very nearly the same, but when further development along these lines was considered it seemed that the latter scheme had many advantages. First, it was by far the cheaper method of construction, and was better suited for emergency production. Moreover, the structural iron method produced a searchlight which would stand much rougher treatment than the aluminum castings could withstand. The light iron drum was quite flexible and would spring or bend slightly to take up jars and jolts in rough handling, whereas large aluminum castings of small section have proved themselves very unreliable when subjected to blows or hard treatment, since instead of springing or bending they fracture and break.

The next logical step was to reduce still further the weight of the structural iron design. The first model proved to be so strong and rigid that it was considered safe to use lighter gauge throughout in the second model of this type. The limitation of decreasing the weight of the apparatus by using lighter material was that the drum reached a degree of flexibility which endangered the mirror, and which also made it difficult to hold the arc at the focus of the mirror. It was found that when the construction was too light, the mirror was very easily warped, giving a distorted beam and running the risk of breaking due to temperature changes on the mirror while in this distorted condition. It was also found to be very difficult to hold the arc in the proper location, since warping of the drum would throw the lamp mechanism out of the center line of the mirror.

Fig. 3. Light Weight 60-inch Searchlight

These two disadvantages were remedied by inserting within the drum tie rods which held an inner frame rigidly at the center of the drum by three tension members. This device, somewhat similar to a bicycle wheel with three spokes, both located the central frame rigidly and at the same time prevented the drum from warping out of shape. The lamp was designed so that it could be inserted within the inner frame at the center of the drum. The lamp mechanism was divided into two units, one, the carbon holders which could be inserted in the inner frame, and the other unit, the controlling mechanism, which was attached to the drum. The positive and negative columns, which in all standard searchlight designs connected the carbon holders to the lamp mechanism, were eliminated. The only connection between the carbon holders and the control mechanism were the feed rods which transmitted the power for feeding and rotating the carbons.

With these new features in mounting the carbon holders and strengthening the drum it was possible to construct an extremely light outfit. The base on which the drum was mounted was also simplified and its weight reduced. The base consisted of two rings of channel iron, one stationary and one movable. The rings were attached by cross braces to a center pin. Between the two rings there was mounted a spider carrying four small steel wheels on which the upper ring carrying the trunnion arms and drum rotated. A ball thrust bearing was also inserted on the center pin under the rotating section of the base. This arrangement reduced the turning friction to a much lower figure than had been reached by previous types of 60-in. searchlights. This is an important feature in that it allows much easier and more accurate training of the light, either with electric or hand control. This equipment mounted on a light carriage with Ford automobile wheels weighed, complete, less than 1400 lb. or about one fifth of the weight of its predecessors. The apparatus met all service tests very satisfactorily and was considered a very important new member to the fast growing family of 60-in. searchlights. There were, however, at the time of

Fig. 4. 60-inch Open-type Searchlight

this development, other considerations of importance. It was necessary to have the equipments take up a minimum amount of shipping space, which was the most important consideration in the days when shipping space was so precious. Furthermore, a hand-operated apparatus was desired, which could be operated by an untrained personnel. Therefore the wave of development passed over this type of light and strove to reach a design which would better comply with all the requisites. The final result was the open-type light shown in Fig. 3 which met ideally the peculiar set of conditions which the emergency demanded. The story of the open-type light is, however, told in another article.

Now that the war is over, and we can take account of the tremendous variety of war material which has been developed during the past few years, it will be found that a great many of the developments, which were never used extensively in this war, will be of great value in equipping our army for a peace-time basis of preparedness. The light weight barrel searchlights, which on account of their bulk never got to France, have many advantages over the open-type searchlight for regular service both in the field and in the forts. They are automatic and are capable of running unattended for periods of two hours or more. This is a decided advantage for all coast defense work where long watches and searches are required. Another advantage of the drum type for coast defense work is that the arc is enclosed and can operate steadily in a gale which would cause the open-type searchlight to flicker. In the field both the open-type and light weight drum will have their uses. The difference in weight and portability of the two outfits is very slight, even though this does not appear so in the photographs. The light weight drum, however, uses the barrel and the braces to obtain rigidity for mirror and lamp, and can, therefore, have a very light mirror ring and metal dome behind the mirror. The open-type light, lacking the barrel, has to be strengthened by a much heavier mirror ring and a heavy metal dome to prevent warping. The two methods of strengthening the mirror ring about offset each other as regards weight, so that the only additional weight in the light weight drum is the front door which weighs about 100 lb.

Another important use of searchlights which has developed during the war is the illumination of aviation fields. The lights are used both as beacons to locate the fields and as floods for illuminating the fields for the landing of the planes. A 36-in. light weight barrel searchlight has been developed especially for this use. It is built along the same lines as the 60-in. light weight already described. It weighs, complete with its carriage, 900 lb. and can easily be pulled around the field and operated by one man. As the arc is automatically controlled, it can be used very conveniently as an aircraft beacon burning in the vertical position for several hours without attention. Fig. 4 shows one of these equipments mounted on its carriage.

Fig. 5. Light Weight 30-inch Barrel Type Searchlight

The future army searchlights will probably be open types and light weight barrel equipments. The old coast defense searchlights are becoming obsolete, as they are being outclassed by their portable successors, which are easier to move, easier to manipulate and easier to operate. The development may be summed up by referring to the "performance per pound." The new portable searchlights are capable of giving 30 times the candlepower per pound that could be obtained from the searchlights which the army had available at the beginning of the war.

Distant Electrical Controls for Military Searchlights

By Theodore Hall
Sperry Gyroscope Company

Remote control for searchlights is essential in some of their military and naval applications. The author describes some of the different forms of control in use and discusses their relative merits.—Editor.

Theodore Hall

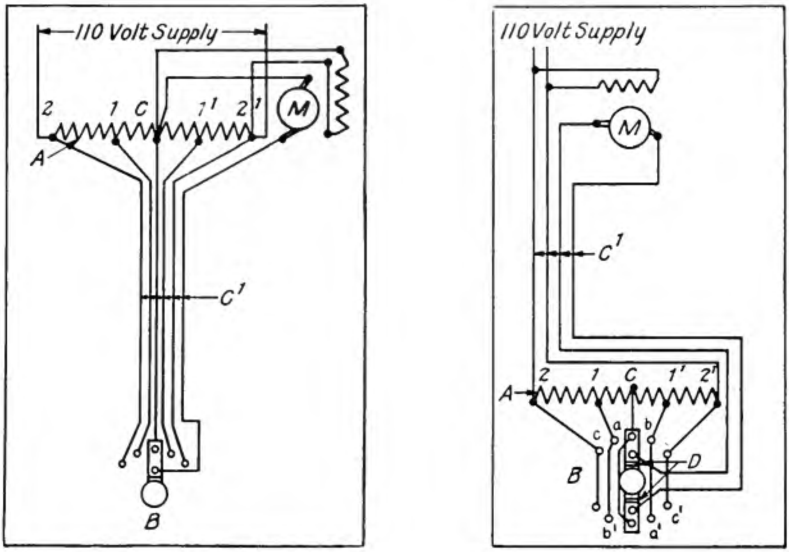
Anyone who has had occasion to be near one of the powerful army or navy searchlights when in action is aware of the fact that the closer to the source of light an observer stands the less can he see of the field illuminated by the beam. An operator stationed at the light, training it by means of the handwheels or levers, finds it very difficult to direct the comparatively narrow pencil of light to a distant object. Could he add an extension to his handwheel shafts so as to get away from the light, say a distance of ten feet or so, he would find it very much to his advantage. It has been found, by actual trials, that an observer stationed 500 feet to one side of the searchlight, can see a target at three times the range that an observer stationed at the searchlight can discern a similiar target. The reason for this is that the observer at the light is handicapped by the dazzling effect of the bright beam on the eye. He is looking at the target through a bright curtain of light, whereas, when stationed at a distance his eyes receive very much less light from the beam, and are, therefore, more sensitive to the light reflected from the target. The longer the range and the more intense the light the more difficult it is to "pick up" or follow a target. Long ago it was found necessary to devise some means of controlling searchlights from a distance. It was needed for the pre-war low intensity lights, but with the modern high intensity flaming arc searchlight, of twice the range, it is absolutely essential; for the advantage of the higher intensity light would be offset by its greater dazzling effect if controlled by handwheels located on the light. Training handwheels and levers have now come to be regarded as emergency devices only.

Distant mechanical controls of various types have been used to some extent by the army, but these, with few exceptions, have been replaced by the more compact and convenient electric controls. When the bulk and weight of the shafts, cables and pulleys, or chains, necessary to manipulate the searchlight from a distance of a few hundred feet, by purely mechanical means, are considered, it will at once become obvious why this system has fallen into disuse.

A number of distant electrical control systems have been used during the past ten or twelve years by both the Army and Navy with varied success. The earlier controllers were for the most part of the relay type, much on the order of the simpler forms of street car controls. Another form used a sensitive relay located on the searchlight and was operated by push-buttons from the distant or controller end of a cable. The relay in turn operated a plunger and solenoid contactor which in its turn closed, opened and cut in or out resistance in the training motor circuits. A number of other similar schemes could be mentioned, but a history of this subject can not be included within the limited space of this article. Great advances have been made during the past four years, but until recently the synchronous control made by the General Electric Company and supplied to both the Army and Navy, has been the only system which has successfully met the service requirements. This control was for many years the standard means of training the large military searchlights.

A recent distant electrical control system, which has made an excellent showing both in rigid laboratory tests and in the field, is one called the Potentiometer control, so named on account of the manner in which the potential across the armature of the training motor is varied. This system promises to fill the long felt want of a simple, rugged, and flexible controller for long and short distance work, both at coast fortifications and with portable searchlights in the field. This controller scheme, or at least the application of the scheme, being new and not very widely known, I shall try to describe it somewhat in detail. The description will be better understood by the aid of wiring diagrams, Figs. 1, 2 and 3, which have been made as simple as possible for the sake of clarity. Only one motor has been shown where two are used in practice, one for training in azimuth and one for elevation. Only two speeds in each direction are shown, whereas at least four are actually used.

Referring to Fig. 1, *A* is a rheostat located in a convenient place on the searchlight base. It is connected directly across a line delivering direct current at a pressure of 90 to 110 volts. The fields of the training motor *M* are connected across any portion of the rheostat that will give the proper difference of potential for the excitation desired. One armature lead, of motor *M*, is connected to the center point of the rheostat; the other armature lead passes through the controller cable, C^1, and is connected to the movable contactor arm of the transmitter, *B*, at the distant end. At a number of points on the rheostat, *A*, conductors are connected and pass through cable C^1 to *B*, where they are connected to contacts in the same consecutive order as on the rheostat, that is, in such manner that point *C* on the rheostat will be joined to the center contact of *B*, and if point 1 is joined to the first contact to the left of the center on *B*, 1^1 must be connected to the first step to the right, etc. Power is transmitted from the motor *M* to the searchlight through a train of gears. A suitable handle is provided on the contactor arm on *B* so that it can be moved over the different contacts at will. A centralizing spring causes the handle and arm to always take up a neutral position when released by the operator.



Figs. 1 and 2. Simplified Wiring Diagrams of Control Systems

From the diagram it will be seen that as the contactor arm on *B* is moved to the right, or the left, of the center point to the adjacent contacts a potential, equal to the drop across the portions 1-*C* or 1^1-C, is impressed on the armature circuit of the training motor, and the first speed in one direction or the other is thus obtained, the direction of the current in the armature being dependent on which side of the neutral point the arm is moved. Moving to the next adjacent point in either direction gives us the second speeds, and so on.

The armature resistance of the training motor is made as low as possible, so that when the motor is connected across 1-*C* or 1^1-*C* of the rheostat the greater part of the current from the line may pass through the armature. This gives the necessary high starting torque so desirable, and makes it possible to run the motor at very low speeds without stalling, because of slight variations in the load.

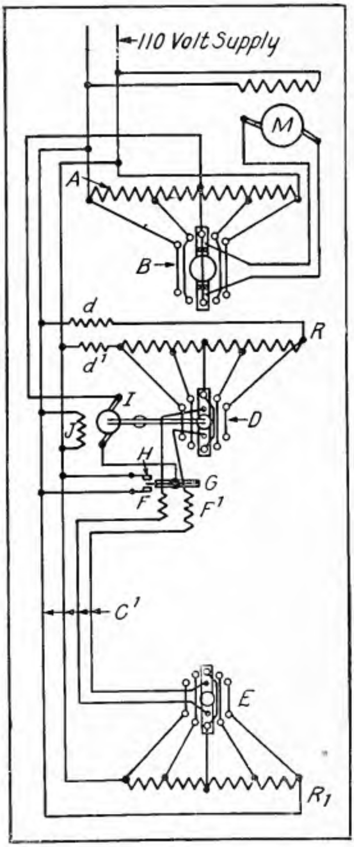


Fig. 3. Wiring Diagram of a System of Control for Both Long and Short Range Work

The first step is usually so proportioned as to give the motor a speed of 60 r.p.m. when training the searchlight and no trouble is experienced from stalling in turning the light continuously through a complete revolution.

The main advantage claimed for the potentiometer system is that it does away with the starting resistances, usually connected directly in series with the armature. The series resistance tends to keep the current constant for all loads and thus seriously reduces the starting torque and makes the motor uncertain on low speeds. It is true that this tendency is present to some extent in the potentiometer system also, but here the ill effects are hardly noticeable.

The control in Fig. 1 is used with portable field lights and is good for distances up to 800 feet when the standard No. 16 B & S Gauge copper conductor is used in the cable C^1.

Fig. 2 shows the same system of control so arranged as to use a minimum number of conductors in the cable. For obvious reasons this is of great importance, and the designing of controllers has become a problem of getting a reliable system with as great a number of speeds as possible and at the same time employing a minimum size and number of conductors. In this diagram the rheostat A is located at the distant end of the cable C^1 instead of on the searchlight. The points C, 1, 2, 1^1, and 2^1 are here connected to the contactor by means of short "jumper" wires. The 110 volt supply line is brought in to the rheostat through cable C^1. In Fig. 2 a double contactor is used, which makes it possible to impress full line voltage across the terminals of the motor in place of one half the drop across A, as was the case in Fig. 1. The movable contacts are

Fig. 4. Photograph showing Controller Mounted on Tripod with Transmitter and Indicator (cover removed)

insulated from each other and from the handle and shaft at D. It will be seen that when the arm is moved to contacts a and a^1 it gives first speed in one direction, and when moved to contacts b and b^1 first speed in the opposite direction is obtained, etc. Regenerative braking, which is of importance, is obtained as the contactor is moved from a higher to a lower speed contact and on the neutral or center contacts. This feature applies to Fig. 1 as well.

The control as connected in Fig. 2 requires four conductors in the cable C^1 for the control of one motor and two additional conductors for each additional motor controlled, as well as one contactor arm for each motor.

Fig. 3 shows a system well adapted for both short and long range work. This control has been used on ranges up to 12000 yards with excellent results. At these long ranges six speeds in each direction are generally used with a speed variation of from 5 degrees to 1080 degrees per minute of the searchlight. The late war, where air craft has played such an important part, has shown the necessity of a wide range of speeds and uniformity of each speed from the very slow, which is used for following a target or searching at extreme ranges, to the high speed used for following a plane passing directly overhead at low altitude or for rapidly swinging the beam from one portion of the sky to another when it is desired to search for a new target.

The description of the short distance controls of Figs. 1 and 2 applies to the long distance system of Fig. 3 with the exception of the method of manipulating contactor arm E, which in Figs. 1 and 2 is operated manually by means of a lever. In Fig. 3 contactor E is operated manually causing a polarized relay to close one of two contacts H. This energizes motor I which in turn moves the contactor arm on D through a train of gears. Contactor D is pinned to the same shaft with E and the two move in unison. Two high resistance rheostats, R and R_1, are connected across the same line of supply, R at the searchlight and R_1 at the distant or controller end of Cable C^1. Two resistances, d and d^1, limit the current in R so that the drop of potential per step will be the same as that in corresponding steps in R_1. The motor I is reversible by means of the two contacts at H. The armature G of the polarized relay is pivoted. It is evident that if the contactor arm at E is moved to a contact to the right or left of the center point, the arm at D being on the center point, a difference of potential is impressed across each of the coils F and F^1 of the relay. The relay now tilts in a definite direction and makes connection with the proper contact at H, causing the motor to bring contactor arm D to the same relative position as E when the potential across the relay becomes zero and the relay armature returns to neutral position. For any position of the contactor arm E, contactor arm D will take up a corresponding relative position.

Searchlight Development

By Prof. Elihu Thomson

Lynn Works, General Electric Company

Prof. Thomson in his always interesting style traces the development of the searchlight. He cites the lantern, candle flame, and concave mirror as the simplest example, and then traces the development of the light source and lens or mirror through their successive stages—Editor.

Prof. Elihu Thomson

LENSES and mirrors have been employed for a long period in more or less perfect forms to give direction to light beams from such sources as flames and incandescent solids. The lantern with its lamp or candle flame, back of which is mounted a concave reflector of polished metal or of silvered or mirror glass, is the simplest example. So far as the use of lenses for a like purpose is concerned, the familiar bull's-eye lantern and the later electric battery flashlight are crude examples. The more refined and complete forms have undergone gradual development and find their most perfect embodiments in the modern searchlight and in the elaborate Fresnel lens lanterns of the great lighthouses along our coasts. The degree of optical perfection required in the best of these is not generally realized by those who have given little attention to the subject.

Confining our attention to the case of reflection by mirrors of proper construction, such as are to be found in the searchlight of today, it is purposed herein to emphasize the requirement of accuracy in the mirror construction, so that a projected beam may be held together so to speak, for its long traverse, perhaps for miles after leaving the mirror surface. In the earlier applications of concave mirrors the light source itself, being a more or less spreadout flame covering a considerable area, it was not to be expected that even with the most perfect reflectors the beam could be held to a straight course without great divergence. The intrinsic illumination at the source being also low, the useful range was again limited to very small distances.

The invention of the Drummond light, the so-called calcium light so much used in the past for lantern projection, rendered possible the establishment of searchlight conditions to a degree comparable somewhat with the use of the electric carbon arc as the source. In the calcium light the concentrated flame of oxygen and hydrogen from an oxy-hydrogen jet, driven against one side of a small cylinder of lime, gave a small hot area the light from which might measure three hundred candles or more in intensity. The area itself heated by the flame might be about a quarter of an inch in diameter, more or less, thus fulfilling one of the conditions of accurate projection, which is that the surface or area from which the light emanates should be as small as possible and as near in character to a point source as practicable. It is interesting to note in passing that the lime light or calcium light was the first example of the employment of a solid with selective radiation heated by a mixed gas jet. The Welsbach mantle lights of today are the modern examples of illuminating agencies embodying the same principle of light production.

The mirrors used with the calcium light were, as a rule, of sheet metal spun into form, silvered, and polished. In the nature of things, such mirrors cannot possess the perfection of form or figure and the refinement of surface demanded in real searchlight work.

The calcium light projector found its application in concentrating light on scenes or objects needing a more or less spread beam or general illumination, directed it is true, but covering a considerable area at no very great distance from the reflector. It was, therefore, applied extensively to stage lighting in theatres. It has the great merit of absolute steadiness. "The gases used were generally oxygen and illuminating gas, though hydrogen sometimes replaced the latter. Drummond employed the gases mixed and compressed and invented his "safety jet" to obviate the passage of flame back into his reservoir of mixed gases, with the consequent violent explosion that would have resulted. In the middle of the last century it was general to employ two collapsible rubber bags for the gases, and to put a moderate pressure on them in use by what were called "pressboards." Each user had then to make his own oxygen and fill the gas bags, for neither oxygen nor hydrogen were at that time articles of commerce. Later the practice of compressing the gases in cylinders was begun and such cylinders were sold or kept in store for future use.

It was early seen that the electric arc, the carbon arc, would on account of its approximation to a point source and its very high intrinsic brilliancy lend itself admirably to projection of powerful beams, if used with proper reflectors or lenses. When it is remembered, however, that before the early eighties of the last century dynamos for obtaining electric energy from power were very rare machines, and that previous to that period they were, as we may say, conspicuous by their absence, and that to run an electric arc meant the setting up of from forty to sixty large cells of a Grove or Bunsen battery, using sulphuric acid and concentrated nitric acid, it can easily be understood that electric arc lights were almost as rare as dynamos. Such batteries themselves were only to be found in a few laboratories and they took days to set up in action, could only be used for a couple of hours, and then had to be taken down, cleaned of acid and stored for perhaps months before being set up again. Only an abundant youthful scientific enthusiasm, a certain unmindfulness of the highly corrosive character of the acids used, and a willingness to be "gassed" by the inevitable fumes could rob the enterprise of its terrors. The advent of the dynamo, however, changed all this. It may be interesting to note in this connection that the earliest arc dynamos were, as a rule, made to run a single arc and this arc was, as a rule, intended to be used in a projector. The first arc dynamos of the Gramme type were designed for such use.

Probably the first drum armature in the United States was in the Siemens dynamo imported by the U. S. Navy and installed at the Torpedo Station at Newport, R. I., to run an arc light for projection.

The early searchlights for naval use were of but moderate capacity, as compared with those of today. Outside the source of light, the electric carbon arc, the important feature was and is the mirror, the reflecting surface of which should be a close approximation to a paraboloid surface. The difficulties at first experienced in grinding and polishing such deep concave mirrors to a nearly true parabolic curve led to the endeavor to obtain a like effect in directing the beam by a combination of refraction and reflection from a mirror having only spherical curves. Colonel Mangin in France designed the now well-known Mangin reflector, which, like many other products of scientific investigation has in recent years been produced in great numbers for automobile headlights of certain types.

The Mangin reflector is in reality a concavo-convex lens silvered on the back or convex surface. The surfaces are spherical and the light undergoes refraction on entering, and again after reflection, which so bends the rays as to cause them to emerge in a nearly parallel beam. When, however, the diameter of the mirror is increased, the Mangin type becomes impracticable, not alone because of the great weight due to the thickness of the glass at the edge, but also on account of the risk of cracking of the mirror by unequal heating, as the thick edge absorbs much heat and also diminishes the light by its absorption. The larger mirrors for searchlights are, therefore, when of glass, made as thin as is consistent with strength and are worked by grinding and polishing machines to a near approximation to parabolic form. The rays from the source of light placed at the focus of such a mirror are reflected without aberration and leave all parts of its surface parallel; or if desired, can be made to converge or diverge regularly by slightly shifting the light source back of or in front of the true focus of the mirrors.

It is very important in searchlight work of high type that the mirror shall have a consistent curve, by which is meant that it shall at no part of its surface depart perceptibly from what the optical conditions require. When it is remembered that the light source at the focus is only a moderate distance, a few inches, from the mirror, while the reach of the light beam projected may be miles away, it is readily seen that we are, as it were, working on a very short arm of an extremely long lever, regarding the mirror surface as the fulcrum. The relation of distance from focus to mirror and from mirror to distant object may be say 1 to 5000 or more. It follows from this that in such cases, if the light source be one half inch in diameter only, the least possible spread of the rays with perfect accuracy of mirror surface will be not less than 200 feet. It follows also that any rays which are inaccurately reflected will either diverge from the main path, or converge, cross, and then diverge, a small error in the optical character of the surface leading to a highy magnified error at the distant point. Emphasis is here laid upon these conditions of accuracy to show why it is that the processes of spinning, pressing, or casting of metal mirrors, often proposed, must be neglected in the production of large searchlight mirrors. However, considerable results of promise are obtained by methods which were practiced on a small scale by the writer several years ago and independently by Sherard Cowper Cowles in England. By the use of a glass mould or matrix, which by optical methods of grinding, polishing, and figuring has been given the correct form, we may chemically deposit on it a film of silver from a solution. All mirrors are now so made, where formerly they were coated on the back with tin amalgam. This silver coating, very thin at best, is next reinforced by the deposition of more silver from an electrolytic bath. This is again followed by a heavy copper layer, or other strong metal coating. We now have what is virtually a metallic mirror with a glass front. Methods are now applied to remove this glass front or matrix, so as to use it for forming other like mirrors.

The copper-silver deposited mirror is, of course, thin and flexible, and must be given a rigid backing and framing so that it will permit of being mounted and used instead of the glass mirror. It is, of course, much less fragile and far less costly in time and labor to produce. Moreover, it will bear much more intense radiation, as it cannot crack as glass will do if subjected to too intense radiation. The silver surface is automatically obtained in the highest degree of polish and accuracy. It can be coated with a thin flowing of proper lacquer to prevent corrosion by the sulphur gases in the atmosphere. The progress recently made in lightening the equipment and increasing the facility with which it can be transported and handled will in itself form a most interesting chapter in the development of the modern high-duty searchlight apparatus.

The Development and Testing of Arc and Incandescent Searchlights

By W. D'A. Ryan

Engineer Illuminating Engineering Laboratory, General Electric Company

Mr. W. D'A. Ryan, Engineer of the Illuminating Engineering Laboratory, was requested to contribute an article to our Searchlight Issue, but Mr. Ryan let Mr. Benford prepare the article descriptive of the tests carried out by this laboratory, and therefore we are able to publish only the following short memorandum from Mr. Ryan; but at the same time we wish to state that he was responsible for the tests described.—Editor.

W. D'A. Ryan

THE active war work of the Illuminating Engineering Labortory dates from January, 1915, at which time considerable attention was given to the development and testing of searchlights for both the Army and the Navy. From this time until the United States entered the war, a great amount of work had been accomplished, especially on high power searchlights. In addition to this, the Laboratory was called upon to make lighting recommendations covering an extremely wide range of war applications, not only in the United States and Canada, but at the seat of war.

In May, 1918, arrangements were made for closer co-operation between the United States Army and the General Electric laboratories in the matter of searchlight development and testing, the actual developmental work being assigned to the respective engineers at Schenectady and Lynn in collaboration with army engineers and others interested This resulted in a working arrangement and co-operation which could not have been secured by any other means. While the Illuminating Engineering Laboratory acted as a clearing house on reports and general information pertaining to the development, its primary work was in connection with the testing of the various units and electrodes as developed.

As this number of the Review is devoted to this general subject, under various headings and by different authors, I shall not attempt to go into detail as to the range and scope of the work

The technical features of the testing were under the direction of Mr. F. A. Benford, who has been associated with the Laboratory for a number of years. Mr. Benford describes in this issue the testing equipment of the outdoor searchlight range and explains the uses to which the various apparatus was put and the nature of the different types of tests.

IN MEMORIAM

FREDERICK CHARLES TODD

Frederick Charles Todd, for many years connected with the General Electric Company, left a host of friends and warm admirers when he died on November 10, 1918, just one day before the armistice was signed.

During his long period of service with the Company the positions he occupied were many and varied. In November, 1888, he entered the Expert Course at Lynn and a year later he was an expert on "outside work." The year 1899 was one of rapid promotions for Mr. Todd; he successively became traveling inspector for the Railway Department, salesman for the Railway Department at the Home Office, and then was made Manager of the Railway Department of the Northwestern Thomson-Houston Company at St. Paul.

In March, 1892, he was appointed assistant to the First Vice-President and had his office in New York, and two years later, in 1894, he was made Manager of the Middle Atlantic District and moved his office first to Washington and afterwards to Baltimore. He held this latter position for 19 years and in 1913 he resigned as Manager and was detailed to special duty.

Mr. Todd did not enjoy robust health and in 1916 he was invalided from duty for a year by the doctor's orders.

In 1917 he was in the saddle again, but this time he was serving his country, in the Office of the Naval Intelligence, where, although we have no record, we know he did meritorious work. These activities took him as far afield as Canada and the Hawaiian Islands where he carried out valuable investigations for the Government.

The above cold record of facts tells that Mr. Todd led an active business life and that he held many positions of responsibility. What his friends love to talk about concerning the subject of our memoriam is, however, the man himself, as a lovable and faithful friend, as the charming and affable host, and as a companion never to be forgotten, and, above all, as an intense lover of nature.

Yes; Mr. Todd loved nature, revelled in it, and while he was a busy man, he strenuously refused to let business be the master of his destinies. He mastered his share of business, made a success of it, but, at the same time, he learned of "better things" through an intimate contact with nature herself. He loved flowers better than machines and congenial companionship, in his wonderful cabin home, better than dollars.

Mr. Olivier, in the *Baltimore News*, while Mr. Todd was still alive, wrote a beautiful editorial tribute to him. We might write much about Mr. Todd, but will refrain as we cannot do better in friendship's name than just quote the concluding paragraph of Mr. Olivier's article, and then leave the memory of Mr. Todd in the safekeeping of his friends' happy recollections of those hours spent with him in the presence of nature.

Mr. Olivier said: "In the workaday world we are very prone to lose our sense of proportion, and it is men like "Fred" Todd who steady us when we are about to fall and help us keep our poise. They point out the glory of the hills and valleys, the romance and the joy of the great outdoors, the hollowness and dullness and oppressive stupidity of downtown. While just as keen and just as aggressive in business as any of us, down in their hearts they laugh at all the struggle and turmoil and hot pursuit of unimaginative wealth. Dollars, after all, are such ugly things beside the first Arbutus."—J.R.H.

The General Electric Company in the Great World War

PART III. SHIP PROPULSION, ELECTRIC HEATING DEVICES AND SEARCHLIGHTS

By John R. Hewett

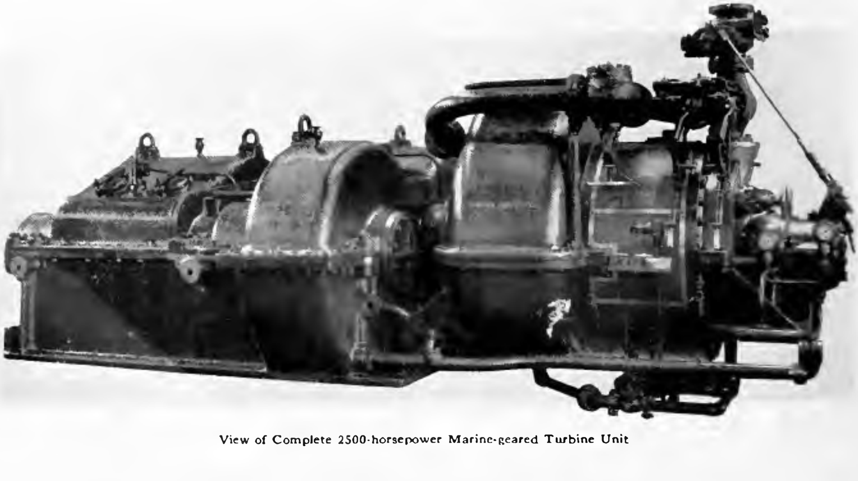
Editor General Electric Review

Part I of this story appeared in our July issue and told of some of the Company's war activities other than research and manufacture. Part II appeared in the August number and dealt with the Company's research activities, including submarine detection, X-ray work, the many-sided radio developments, electric welding, and notes on other research work. In the present issue we outline the enormous amount of work the Company did to help the Government with ship propulsion equipments for cargo boats, destroyers, and other naval vessels. Among the electric heating devices that comprise part of the Company's war work we deal with the gun shrinking and heat treating furnaces as well as the electric rivet heaters. The section on searchlights is short and unillustrated, because so much attention is paid to this subject in the other articles appearing in this issue.—Editor.

When America entered the war the whole world realized that shipping was one of the most vital factors. With the serious inroads that the unrestricted submarine warfare had made in the mercantile tonnage of both allied and neutral nations, where were the ships to come from to carry the American army, its equipment and stores, as well as to serve the enormous requirements of the allied nations?

The government's gigantic shipbuilding program, a truly American answer to the challenge of the enemy, is a matter of history and the part that the General Electric Company played to make this program effective is well worthy of permanent record.

To fulfill such gigantic orders as the Company took would have been a tremendous undertaking in normal times of peace, but to assume work of such proportions in times of war, when machine tools were almost unprocurable, when labor was scarce, and all materials hard to obtain involved more difficulties than can be described. The story of how old buildings were remodeled and fitted out as machine shops, how new buildings were erected under the most trying of war conditions, how new machine tools were built on the spot when they could not be procured from the outside and the host of special problems that war work involved will in all probability never be told. No one individual knows it all, and those who know the special phases of this work are too busy in restoring the industry from a war to a peace basis.



View of Complete 2500-horsepower Marine-geared Turbine Unit

Cargo Boat Equipments

The reason for the Company assuming the enormous orders that they did for propelling machinery for cargo boats is interesting. The number of ships and the total tonnage of the government's shipbuilding program was absolutely fabulous, especially so when it is compared with the previous shipbuilding capacity of American yards. The amount of construction in every phase of the work was appalling to those responsible for its completion, and all this production had to be arranged to meet the emergency. Under these conditions those responsible for the shipping program judged that the propelling equipments would be the limiting feature and that it would be impossible for the country to produce the required horsepower in reciprocating engines. They therefore turned to those firms that had been producing other forms of prime movers.

The turbine was already established as a marine drive, but to secure efficient operation from a turbine with the slow propeller speeds of the boats that the Government proposed building and at the same time to secure the inherent efficiency of the turbine at high speed it was necessary to adopt a gear reduction.

The gear drive was not new, the Company having furnished a limited number of geared turbines for a matter of about two years, but they felt that the experience gained with this class of equipment was too small to warrant assuming such immense orders if commercial consideration alone were to govern their decision. Commercial considerations did not govern their decision in war time and the Company assumed the heavy responsibility of building a great number of geared turbine equipments for the Emergency Fleet Corporation at the earnest solicitation of the Government.

Before the war the Company's capacity at the outside was four 2500-horsepower units per month. When the armistice was signed they were delivering these equipments at the rate of twenty-nine per month. That is to say, that during this period they had increased the monthly production seven times.

During the years 1917 and 1918 the Company furnished the Government approximately 200 geared turbines for the propulsion of cargo boats. The majority of these were turbines of 2500-horsepower with the necessary reduction gears. They were installed mostly in ships of 7500 to 12,000-tons capacity which operated at a speed of about 10.5 to 12 knots.

View of same unit shown in Fig. 1 with upper casings removed. During the war over 200 of these sets were produced at the Schenectady Works for the various shipyards throughout the country. Three of the largest buildings in the Plant were devoted to this work

This work was all done on special rush orders and necessitated very extensive additions to plant. Buildings, tools and additional materials of all kinds were required which were difficult to obtain. The old foundry at Schenectady was remodeled, enlarged, and equipped with machine tools, a new foundry was built and other buildings taken over to fill these contracts, which the Government placed in a class ahead of practically all the other war work the Company had on hand. In addition to these increases in plant a large new shop was built for the manufacture of gears.

Gear cutting for marine purposes presents a peculiarly difficult engineering problem, and the Company being unable to purchase the necessary machine tools in the time required undertook to build these themselves. It is hard to give the reader any idea of what this work involved, but it may be interesting to state that the gears as used in these equipments have to be cut accurately to one-thousandth of an inch, and that the Company produced the huge precision machines to perform this difficult work. They also designed and built some huge horizontal boring mills to machine the cast-iron bases for the gears. Like so much of the war work, whole volumes might be easily written on the enormous amount of new work they did in this direction alone.

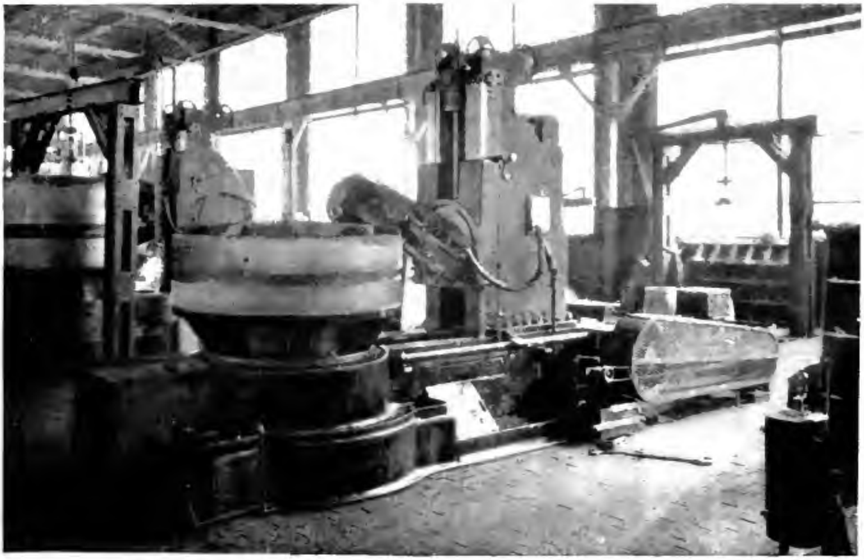
At the time the armistice was signed the Company had manufactured over 200 geared turbine equipments for cargo vessels, 105 of which were in service; and they had a total of 579 sets on order. The vessels actually in service equipped with the Company's turbine drive at the time the armistice was signed had steamed over 3,400,000 miles, equal to about 550 round trips to France, which, allowing an average of 8000 dead weight tons of cargo capacity, represents 4,400,000 tons of supplies delivered in France as the Company's contribution during the great shipping crisis. This was in addition to the multitude of other ways they were contributing to the upbuilding of the Country's shipbuilding industry.

Some of the orders for the ship propulsion sets were cancelled after the armistice was signed, in conformity with the government's general policy on all war material, but it is interesting to know that the General Electric Company had assumed the responsibility for building and had provided the necessary organization, equipment and manufacturing facilities to deliver no less than 1,776,000 horsepower of turbines for cargo vessels alone.

View of the interior of Building No. 49 at the Schenectady Plant. Before the war this was an iron foundry. To meet the war emergency for producing turbines and gears for ship propulsion, this building was enlarged and equipped with machine tools, etc.

It has been stated that the Government considered the propelling machinery as the limiting feature of their shipbuilding program. It is therefore interesting to record that the Company never hindered the completion of a boat by non-delivery of its equipment during the entire war—with one single exception—and in that particular case the boat was one

Battery of 84-in. Gear Hobbing Machines



Closer view of 84-in. gear hobbing machines, as installed in Building No. 85 at the Schenectady Plant
This large building was erected specially for this work during the war

The *S.S. Schenectady*, one of the fabricated ships built by Hog Island. This ship was equipped with one of the 2500-horsepower ship propulsion units shown in other views

month ahead of its schedule. At the time the armistice was signed the Company had propelling equipment awaiting boats in every yard they were supplying.

The need for ship propulsion equipments was so imperative that even after placing enormous orders with, practically speaking, every Company who could produce equipments, the Government was looking for yet more facilities for production and approached the General Electric Company on the subject of electric propulsion. The Company had

The Company undertook a great deal of educational work during the war. This view shows a class of officers at the Schenectady Works from the U. S. Naval School of Turbine Engineering, who were given intensive training relative to the design, care, and operation of turbines, gears, and electric apparatus as used aboard ships. Four hundred and ten engineers have graduated from the classes at these Works already had certain experience in this work and at first were asked if they could deliver 100 equipments. The Company was actually asked to build 50 electric ship propulsion equipments. This number, however, was reduced when the armistice was signed. Each of these vessels was to have a single screw driven by a 3000-horsepower motor. The operation of these electric equipments will be watched with keen interest by the shipping world, as there are many who look for a brilliant future for the electrically propelled ship.

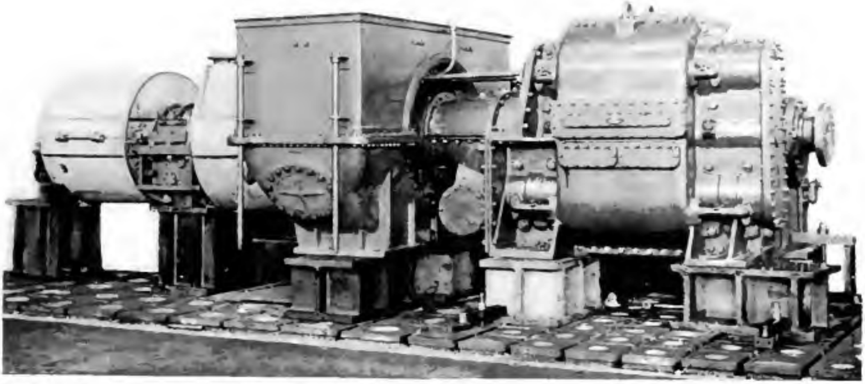
Owing to the tremendous number of new vessels placed in service during the war it was impossible to obtain a sufficient number of trained marine engineers who had had any experience with turbines to operate these boats. This, of course, often led to the equipments being operated by inexperienced men and the Company was called upon to do much work in the way of small repairs and inspections which, in normal times, might have been performed by the engineers of the boats or by the ship owners themselves. In order to deal with this phase of the work effectively and to prevent interruption in service, the Company organized and maintained a very thorough system of inspection where all vessels equipped with the Company's machinery were inspected at regular intervals.

This urgent need for trained men also led the Company to conduct two training courses for training marine engineers in the operation of their machinery. One of these courses was of a month's duration and was intended for the chief engineers of the Emergency Fleet. These men were given a course of lectures and instructions sufficient to make them familiar with all details of the operation and maintenance of the turbine equipment. The second of these courses was of two weeks' duration and was for naval officers from the U. S. Naval School of Turbine Engineering at Pittsburgh. Officers came from this school to Schenectady at the rate of 20 a week and were given one week of intensive engineering and one week was devoted to electrical subjects having particular reference to the electric propulsion of ships.

Ship Propulsion Equipment for Naval Vessels

Over and above the 1,776,000 horsepower of ship propulsion machinery that the Company was providing for cargo vessels they were either building or had built no less than 2,300,000-horsepower of ship propulsion apparatus for naval vessels. These included equipments for propelling battleships, battle cruisers, and destroyers.

Literally volumes might be written on this work, but we can only mention the most



Ninety-four of these propulsion units for the 35-knot torpedo boat destroyers were built by the General Electric Company after the United States entered the war. Each unit consists of a cruising and a main turbine of the Curtis type and a speed reduction gear of the flexible disk, Alquist type

Exterior View of Building No. 5 at Erie

important work here very briefly. The April issue of the GENERAL ELECTRIC REVIEW was devoted to a description of the battleship *New Mexico* and her equipment.

Destroyer Equipments

One of the most important contracts that the Company undertook during the war was the propelling equipments for 40 destroyers. They had already a contract for six such equipments, making a total of 46 in all. This contract was let in October, 1917, and the first equipment was delivered in August, 1918.

Each equipment consisted of two geared turbines of 13,500 horsepower each and one cruising turbine of 800 horsepower, giving a total ship horsepower of 27,800. These destroyers are approximately 300 ft. long and are of 1200 tons displacement. Their speed is 35 knots.

The building of these equipments was another rush war order on which the Government asked the Company to give first preference. The turbines were designed, new buildings were erected and equipped with tools, jigs, and dies; patterns and gauges

Interior View of Building No. 5 at Erie, showing the Testing Stands for the Torpedo Boat Destroyer Equipments

The Erie Plant was very busy on war work. At the time America entered the war the above building was only half built; it had no floors or equipment. It was completed in record time for the purpose of building equipments for torpedo boat destroyers and other ship propulsion sets were made, labor provided and housed all in record time. This work was done at Erie where no turbines had previously been built.

Other Ship Propulsion for the Navy

Of the large naval vessels that the Company was building equipments for we shall hope to write more at a later date, but it is interesting to know that each of the four battle cruisers that the Company was building electric drive for required electric motors with a total capacity of 180,000 horsepower and turbo generators with a total capacity of 142,400 kilowatts, and that each of the four battleship equipments called for electric motors of 30,000 horsepower and that the cruisers each required 90,000 horsepower geared turbines. Some of these equipments had been ordered before America entered the war.

There seems to be a brilliant future for electric propulsion for war ships. The Company designed and built the entire electrical equipment for the *New Mexico*, the most successful battleship afloat. A complete description has appeared in the REVIEW, so we shall confine our remarks here to quoting Secretary Daniels' remarks before the House of Naval Affairs Committee.

The Secretary read the following statement in connection with his discussion of electrically driven ships:

"I recently paid a visit to the battleship *New Mexico*, which is the latest dreadnought to join the fleet and the first and only one of any nation to have electrically operated propelling machinery. On this account she has been an object of surpassing interest to the officers of our own navy and to those of foreign navies as well, and to electrical engineers in general.

"When we decided to equip the capital ships of the 1916 programme with electric drive it was represented that we were making a great mistake. I did not regard it as an experiment for we were in the fortunate position of being the only nation that had had any experience with this system of propulsion, and that experience was of such a satisfactory character that it would have been unpardonable if we had not profited by it to the fullest extent possible.

"The machinery was designed to develop 26,500 horsepower at full speed, which it was expected would give the ship a speed of 21 knots. She actually developed more than 31,000 horsepower and maintained for four hours a speed of 21¼ knots, and this when running at a displacement 1000 tons greater than her design called for. If she had been tried at her designed displacement, as is customary with all new ships, she would have made 21.5 knots without any trouble, and what is still better, she could have kept up this speed as long as her fuel lasted.

"When we entered into contract for the machinery of the *New Mexico*, we stipulated that, in addition to being capable of developing the maximum power, it should also give an economy at cruising speed very much superior to that obtainable with the turbine installations that we had previously used, and I am happy to say that this stringent requirement was also met. As a matter of fact, the *New Mexico* will steam at 10 knots on about 25 per cent less fuel than the best turbine ship that preceded her.

"On the whole, I think the country has cause to be proud of this achievement in engineering, not alone because of the pronounced success in this particular instance, but because of the assurance it gives us of the superiority of our capital ships to those of foreign nations."

Electric Heating Devices

Among the numerous electric heating devices which the Company developed and which played their part in helping to win the war, some were really spectacular. They reached all the way from the gigantic electric furnaces for gun shrinking to such novelties as electrically heated suits to keep aviators warm miles up in the air; they include the electric rivet heater to help the shipbuilder and the heating units for submarines when travelling in the depths of the sea; cooking ranges for naval puposes and a host of everyday devices were produced in large quantities. Like many of the Company's war activities, we can only touch on some of the most interesting if we are to confine our remarks to reasonable limits.

Electric Furnaces for Gun Shrinking

Early in 1917 the Company sold its first large gun shrinking furnace to a munition manufacturer and was thus helping the allied cause. When America entered the war this type of furnace was endorsed by the Government and a furnace seven feet in diameter and no less than 90 feet in depth was made by the Company for the Washington Navy Yard. During the period of the war about 30 of these furnaces have been built in Schenectady and sold to the American and French Governments

Top section of furnace showing cover as used for putting liners in large guns

Views showing interior construction
Note: Heating coils and guard rods

Bottom section of furnace with door closed

Bottom section of furnace with door opened

Shrinking furnaces for assembling the hoops and liners of large guns are built up of sections. Views of the top and bottom sections are shown above. The furnace is made of any required height by stacking sections one above the other; the structural design of these sections is such they can be stacked to form a furnace 88 ft. high

Two very important operations in building guns are the proper heat treatment of the forgings and the proper shrinkage of the different layers that compose the built-up gun, and should this work be done improperly it leads to a considerable loss of time, labor and material. Formerly the furnaces used for these purposes were heated by gas or oil and it was hard to secure anything like an even distribution of heat and a constant temperature. Also it was hard to prevent the oxidation or scaling of the gun forging.

The development of the electrical heated furnace has done away with these difficulties and has eleminated the rejection of many spoiled parts.

The gun shrinking furnaces developed by the Company vary in size from a 37 kw. unit which is 42 in. in diameter and six feet in depth, used for heating breech blocks, to the great 1000 kw. furnaces which are seven feet in diameter and are 90 feet in depth. These monsters are used for assembling the huge modern rifles which have been so aptly termed the teeth of the navy.

The largest of these great furnaces weigh about 220 tons and its transportation is just one of those items that has helped to make some of the Company's war developments difficult, if interesting.

The transportation of a single furnace required nine flat cars and it was necessary to use a special routing for the shipment and to obtain guarantees from the railroad companies, as the size of some of the individual parts were greater than all the standard railroad clearances.

One of these large electric furnaces consists of 1728 heating units, and no less than 6½ miles of metallic resistance ribbon are used in its construction. The material used as heat insulation was shipped from California to Schenectady in carload lots.

The work that these furnaces performed played such an important part in speeding up war production, and there is so much interest in the fact that such work is now done on the largest scale electrically rather than by the older methods, that a few further facts about these giant furnaces and their work should interest the reader.

As is quite commonly known modern field guns and naval guns are built up by shrinking together accurately machined tubes or hoops to give the required strength and the special initial tension characteristics necessary to withstand the enormous force of the explosive charge and drive the projectile. To do this work successfully and to obtain the same result many successive times it is essential to have the temperature under perfect control. It is usual in this work to hold a uniform temperature of about 800 degrees Fahr. over the entire length of the furnace so as to heat and expand the hoops and jackets [illegible]. If these conditions are not obtained these parts will not shrink properly over the tube and it may become necessary to cut them off in a lathe because they have stuck in the wrong place. This wastes time and labor and hinders production.

Electrically heated furnaces, with their simple direct means of temperature control, offer the best known means of obtaining uniform distribution of heat over long surfaces, as the heating elements are distributed evenly over the entire inner surface. As these furnaces are built up in a cylindrical form, the tube can be placed concentrically in the furnace and heated evenly all over by direct radiation.

The efficiency of the electric furnace is astonishingly high, as there are no waste gases to be got rid of and to carry a large part of the heat away with them. There is no tendency to oxidation in an electric furnace and no baffles are needed.

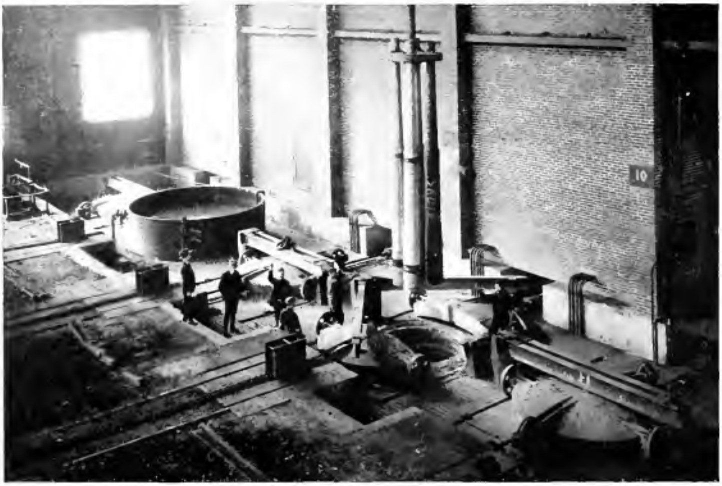
All of these electric furnaces of one given diameter are built up of interchangeable parts each complete in itself so that a furnace of any depth can be made by joining the desired number of standard units.

Each section consists of a steel frame which houses the heating elements and each of these elements is made up of a flat ribbon of a metallic resistor material wound on its insulated support. The temperature control is affected by two thermo couples, the leads from these going to the solenoid operated remote control switches.

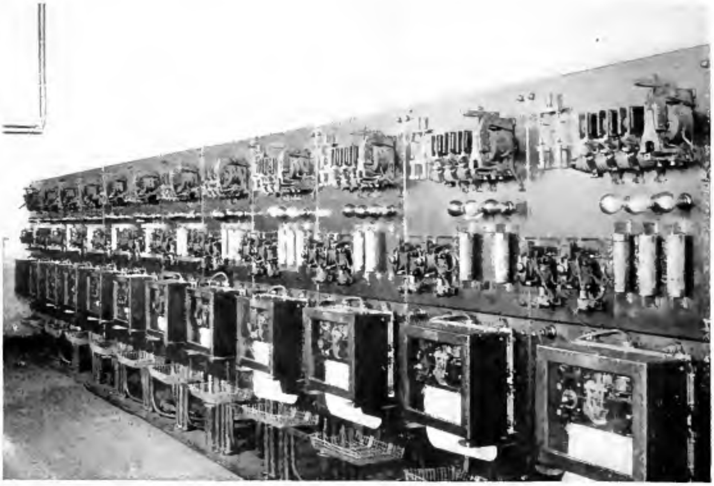
The operator sits comfortably at his central control desk with his voltmeter heat measuring instruments and switches, etc., in front of him and can control the heat in any part of his furnace without moving.

Electric Heat Treating Furnaces

The making of large guns, as may well be imagined, is a highly specialized art and the correct heat treatment of the forgings is a science in itself. These different processes are now performed electrically, the Company having developed electrically heated furnaces for this purpose. Some of these furnaces will handle as many as twelve gun tubes or jackets at one time.



Typical Installation of Four Furnaces with Quenching Tank



Automatic Control Board for Installation Shown Above

Resistance furnaces for heat-treating gun forgings. Some of the advantages of this type of furnace are the sensitive and accurate temperature control, assuring a uniform product, cleanliness, the absence of products of combustion and noise and the small amount of labor required for operation. Only one man is required to operate the installation of four furnaces shown above

As has so often been the case in other fields of industry when once the job has been done electrically, the new method has proved itself superior to all older methods, and this fact can practically always be traced to the perfect control under which electrical energy can be held.

Oil burners which were so extensively used in these processes have a very high fuel value, but the use of electrically heated furnaces had introduced refinements in manufacture which were impossible with oil or gas.

Oil furnaces can have at best only relatively few burners, while the inside of the electric furnace is covered uniformly with the heating elements all giving out an equal number of heat units and therefore assuring the uniform distribution of heat so essential in getting constant results in the finished products.

An important war-time consideration is that the labor costs for operating electric furnaces is very small, owing to the perfection of the automatic control, and the maintenance cost is practically nil as the materials used do not suffer from abrasion or deterioration.

These furnaces operate at a thermal efficiency of from 72 to 82 per cent, depending on conditions. Such an efficiency is extraordinarily high for a furnace of this nature. Furnaces of this type can be used for a variety of both war-time and peace-time purposes, the annealing of steel, brass or copper strip or tubing, the baking of porcelain and enamel and the annealing of glass all coming within their field of usefulness.

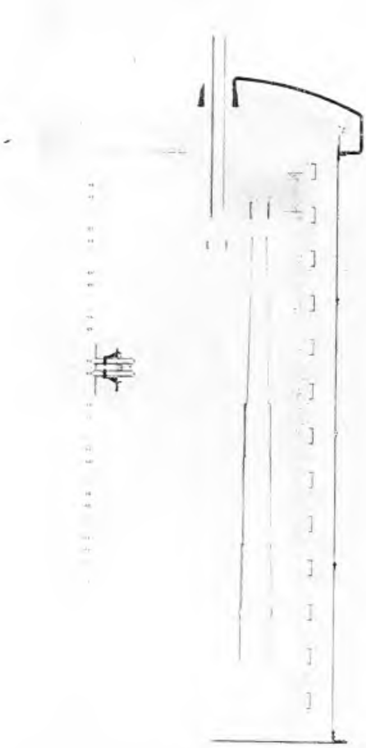
Electrically Heated Furnaces for Shells

The number of shells of all calibres made during the war is prodigious and the difficulties met in their production are legion. Early in the war many manufacturers assumed contracts for their production, only to learn later that a shell is by no means an easy thing to make or a good manufacturing proposition unless the art of making them is thoroughly understood. Many were surprised to learn that a shell to fulfill the conditions of accurate flight must be made as accurately as the parts of a watch; that the fuse which had been developed to explode at the exact instant was a most complicated, but highly developed mechanism, and that the tempering of a shell demands extraordinary care and skill.

View showing gun being quenched after removal from electric furnace

The Company developed specially electrically heated furnaces for the heat treatment or hardening of shells and as the war progressed the need for these became more imperative to the shell manufacturer, if he was to eliminate the great number of rejected shells at the proving ground and avoid the consequent waste of time, labor and material which was seriously affecting production.

How important the proper heat treatment of shells is is hard to emphasize, but it should be noted that a shell does not strike its target straight, but at an angle, and that there is a tendency for one of two things to happen: either the nose will flatten and the shell slide off, or if the nose is hard enough to pierce the object, the shell will shear off in the middle. It has been found that to make a shell more effective it should not have the same degree of hardness throughout its length, but that the nose should be more elastic. These conditions were hard to obtain, as each part of the shell had to be treated at a different temperature, ranging from 1300 degrees F. to 1650 degrees F., and not only must each section be treated at a different temperature, but each temperature must be controlled to within a few degrees very accurately.



Outline of Resistance Furnace for the heat-treating of gun forgings, showing gun in position. A number of guns can be treated simultaneously in this manner

The Company, in connection with shell manufacturers, developed an electrical furnace to meet these exacting conditions; it is divided into zones by metal diaphragms and the shell is placed in the furnace nose down, being secured by a shaft and special clamp at the butt. The diaphragms are one inch thick with a hole in the center just large enough to take the shell and to prevent the flow of heat from one zone to another. It is possible in this way to obtain a difference of temperature between adjacent zones of about 300 degrees F. Each zone has its own heat unit and automatic temperature control. The Company developed several different types of heat treating furnaces for shells, such as one zone, two zone, and three zone furnaces, and it is a satisfaction to think that this materially helped the country in the efficient production of this all-important war material.

Electric Rivet Heaters

The imperative necessity of speeding the production of ships was well recognized and the present means of heating rivets by coke, oil or gas was known to be far from satisfactory, so the Company developed electric rivet heaters which were more economical, easy to handle and more portable than the old devices. The electric heater heats the rivet uniformly which is conducive to a better upsetting of the rivet. It is interesting to note that among the electric rivet heaters supplied by the Company during the war a number were furnished to Mr. Henry Ford to be used in building the Eagle Boats.

Searchlights

Since its invention the searchlight has played an important part in every war, both for naval and military purposes. The radical difference between this and all previous wars, not only in the changed methods of field operation, but those introduced by the introduction of the submarine and the air service, have given the searchlight an importance very much greater than ever before.

The searchlight played a most important part in aerial defence. This service called for equipments designed to permit the elevation of the beam through the zenith; and the number and efficiency of the searchlights employed proved to be a direct measure of the immunity of towns from aerial bombardment.

During some of the great offensives it was found that light weight and mobility were most important factors. Many searchlights were lost owing to their immobility and the consequences were heavy casualties due to night bombing behind the lines, including hospitals.

The naval requirements were more severe in this war than ever before. Searchlights on destroyers and chasers for combating submarines must operate satisfactorily under all conditions of weather and for this service extremely accurate mechanical control was also found necessary.

Early in 1915 the Company had begun the development of the High Intensity Searchlight which was about five times as powerful as the old style light. It will surely astonish some readers to learn that the old style 60-inch searchlight gave almost 75,000,000 beam candle-power, but does it really convey much to his mind to be told that the new 60-inch searchlight gives 250,000,000 beam candle-power? It would be uninteresting to cite a list of all the searchlights that the Company produced for war purposes, but the following notes on some of the most important may be of some interest to the reader:

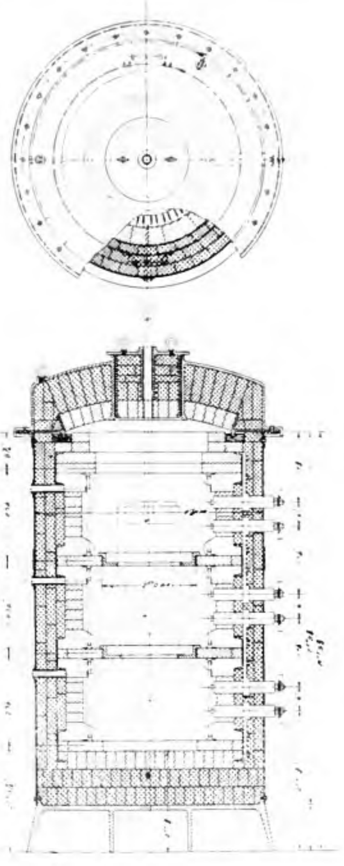
One hundred and sixty high intensity searchlights were made with parabolic glass mirrors five feet in diameter. One hundred and seventy 36-inch high intensity searchlights were made for mounting on four-wheel, rubber-tired trucks. The current for these lamps is furnished by a generator mounted on a large platformed auto truck on which the searchlight with its own small truck is transported. These portable equipments proved very effective in anti-aircraft work.

Three hundred searchlights of the 24-inch type were made for naval service, being designed especially to meet the new war conditions. Practically all these searchlights were used on destroyers.

For the Emergency Fleet Corporation the Company made 500 low intensity, 18-inch searchlights and 500 running light telltale boards, as well as 500 blinker light signal controllers, and in addition to these a large number of incandescent signalling searchlights were manufactured for naval use.

The development work done in searchlights alone was enormous and the promptness with which radically new equipments were produced reflects great credit on those responsible for this work. To cite one example of this development work:

The first 60-inch searchlight sent abroad with the American Expeditionary Force weighed nearly 6000 pounds, and the combined power plant and truck made a total weight of about 11 tons, and a large squad of men were required to handle a single searchlight equipment. It should be noted that these searchlights were originally designed and built for sea coast defense, and therefore, were intended for installation in heavy permanent emplacements. For this service, the question of weight was practically of no importance, and the use of these lights for portable duty was simply a makeshift; it was absolutely necessary to supply portable searchlights in the shortest possible time.



Outline of Resistance Furnace for heat treating shells showing diaphragm dividing furnaces into zones so different hardnesses can be obtained on different parts of the shell

Soon after America became actively engaged in the war, certain searchlight observers were sent to this country to present the facts and obtain searchlights which would meet modern warfare requirements. It was determined that a large number of extremely light, high power, mobile units would effectively check the enemy's bombing operations.

A Simple Form of Induction Device for Heating Rivets

Soon after the above requirements were known, the Company's engineers suggested that the special light weight, high power, 60-inch light be designed, using aluminum to reduce weight. It will be noted that an entirely successful 60-inch drum-type searchlight of this type was later supplied to the army, using the rather heavy four-wheel truck, originally designed for the heavy units, and this complete equipment weighed less than 1800 pounds. Severe tests proved that this design would meet all conditions of service.

After a general conference at Washington between the Engineers of the General Engineer Depot of the U. S. Army and the Engineers of the General Electric Company, when the army engineers thought that the barrel, front-door glass and many other parts could be eliminated, it was decided to develop a searchlight with a 60-inch metal mirror which would not weigh more than 1000 pounds with a very much simplified hand-feed mechanism. This development work was done at Lynn, and the work was pushed so actively that in a little over a month a complete equipment was ready for exhibition. A much smaller 30-inch, high power searchlight with a tripod mount was considered necessary by the army engineers, where extreme portability was required, and a searchlight of this type was designed and built at Schenectady, with a very simple and rugged feeding mechanism. It might be interesting to note this entire unit weighed only 225 pounds.

The difficulties encountered in development work of this nature under war conditions are hard to appreciate. The silvered glass parabolic mirror is one of the essential features of a searchlight. Such mirrors must be made of low absorption, heat resisting glass, ground with extreme accuracy and carefully silvered. The successful development of metal mirrors as large as 60 inches in diameter is not only an interesting and notable accomplishment in itself, but should lead to a distinct advance in the searchlight arts.

The Lynn factory also developed, in conjunction with the U. S. Army Engineers and the Cadillac Motor Car Company, a unit for carrying these portable searchlights. These equipments were so arranged that the same engine was used for driving both the truck and the generator, which was of 15-kw. capacity. Ninety such equipments were on order when the armistice was signed and have since been delivered. The Company had also undertaken to develop a 50-kw. equipment suitable for an American-La France chassis.

To test the mobility and strength of the newly built Cadillac unit a 6000-mile test was run between Lynn and the west coast of Florida and back. There was a good deal of road between Washington and Florida that was almost impassible and on some days less than 25 miles were covered, but no serious difficulties were encountered with any parts of the machine, and the lamp was carried over ground, which it is felt could not have been traversed by the earlier heavy weight units.

(To be Continued)