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(Paper No. 2179.)

“The Electric Lighthouses of Macquarie and of Tino.”

By JOHN HOPKINSON, M.A., D.Sc., F.R.S., M. Inst. C.E.

THE subject of the use of electric light in lighthouses was fully discussed at the Institution in 1879, when Papers by Sir James Douglass, M. Inst. C.E., and by Mr. James T. Chance, Assoc. Inst. C.E., were read.¹

The subject has been further elaborately examined by Mr. E. Allard,² and more recently in practical experiments, made at the South Foreland, exhaustively reported on by a Committee of the

¹ Minutes of Proceedings Inst. C.E. vol. lviii. pp. 77 and 168.

² Mémoire sur les Phares Électriques, 1881.

Trinity House.¹ The justification of the present communication is that, at the lighthouses of Macquarie and of Tino, the optical apparatus is on a larger scale than has hitherto been used for the electric arc in lighthouses, and presents certain novel features in the details of construction. Further, as regards the electrical apparatus, tests were made upon the machinery for Macquarie when it was in the hands of Messrs. Chance Brothers and Company, which still possess some value, although five years old; and, in the case of Tino, the machines are practically worked together in a manner not previously used otherwise than by way of experiment.

In the case of both lighthouses, Messrs. Chance Brothers and Company, of Birmingham, entered into a contract for the supply of all the apparatus required, including engines, machines, conductors, lamps, optical apparatus, and lanterns; and Sir James Douglass, Engineer-in-Chief of the Trinity House, acted as Inspecting Engineer to the respective Colonial and Foreign Governments.

As these two lighthouses present many features in common, it may be most convenient to give a full description of the earlier lighthouse, and then limit the description of Tino to those points in which it differs from Macquarie.

MACQUARIE.

This lighthouse is situated on South Head, near Sydney, the precise position being shown in a copy from the chart, Plate 9, Fig. 1. A lighthouse was first placed at this important landfall in 1817. The focal plane is 346 feet above the sea, and the distance of the sea-horizon is therefore 21·6 nautical miles, and the range about 27 nautical miles for an observer 15 feet above the sea.

Optical Apparatus.—The light is a revolving one, giving a single flash of eight seconds duration every minute. On account of the considerable altitude of the lighthouse, it was necessary to secure that a substantial quantity of light should be directed to the nearer sea; but it was also essential, on account of the exceptional power of the apparatus, that this dipping light should only be a small fraction of that sent to the horizon, otherwise its effect would be excessively dazzling. Many years ago, Mr. James T. Chance urged that it was not wise to make use of very small apparatus for the electric arc, because a larger apparatus renders it possible for the optical engineer to effect with greater precision the distribution of light which is most desirable, and

¹ Report into the relative merits of Electricity, Gas, and Oil as Lighthouse Illuminants. Parts 1 and 2. PP. 1885.

because any trifling error which may occur in the position of the electric arc has, with the larger apparatus, a less marked effect on the light as seen from the sea. In the lighthouses of Souther Point, the South Foreland, and the Lizard, the third-order apparatus of 500-millimetre focal length was adopted. Optically, the larger the apparatus used the better, but there might be some question whether, on purely optical grounds, the advantage of going beyond the third order is sufficient to justify the additional expense, but in the case of a revolving apparatus, the third order is a very inconvenient size for the service of the lamp; it is too large to be conveniently served from the outside, and too small to admit the attendant within it with comfort. With the large currents, which are now easily obtained and are likely to be used in lighthouses, a first or second order apparatus has the further advantage that it is less liable to injury from particles thrown off from the heated carbons. In the case of Macquarie, it was decided to adopt an apparatus of the first order, 920-millimetre focal length; it was further decided that the optical apparatus should produce its condensing effect by means of a single agent; that is to say, the vertical straight prisms which were used in Souther Point and other revolving electric lighthouses should be dispensed with. The condensation and distribution of light necessary may be obtained by means of a single agent, with apparatus such as has been proposed by Mr. Alan Brebner, jun., Assoc. M. Inst. C.E.;¹ but this construction is open to the objections that it is somewhat costly, and that it increases the length of the path of the rays through the glass, and consequent absorption. A practically better plan is to adopt forms not differing very greatly from those introduced by Fresnel; to specially arrange them for the purpose in hand, and to accept certain consequent minute deviations from a mathematically accurate solution for the sake of advantages of greater importance, when all the actual conditions are taken into account. Plate 9, Fig. 2, shows the optical apparatus in vertical section; the upper and the lower totally-reflecting prisms are, as is usual in revolving lights, forms of revolutions about a horizontal axis; they direct the light incident upon them to the horizon and the distant sea from 10' above the horizon to 30' below; they are specially adjusted to distribute the light in azimuth over the arc of 3° necessary for a proper duration of flash.

The refracting portion of the apparatus has the profile so calculated that the central lens, and the three rings next to the

¹ Minutes of Proceedings Inst. C.E. vol. lxx. p. 386.

lens above and below, direct their light to the horizon without vertical divergence, except what is due to the size of the arc; the light for the nearer sea is obtained from the remaining ten lens-segments, Nos. 5 to 9 inclusive, above and below the centre, counting the centre as No. 1, the distribution being according to the following Table, in which the first column gives the denomination of the elements of the lens in accordance

I.				II.			III.		
				°	'	"	°	'	"
9 top				—10	0		2	30	59
8 „				2	30	59	5	8	52
7 „				—10	0		2	37	30
6 „				—10	0		1	30	0
5 „				—10	0		1	0	0
5 bottom				—10	0		1	0	0
6 „				—10	0		1	30	0
7 „				1	30	0	3	44	27
8 „				3	44	27	5	50	41
9 „				5	50	41	7	46	57

with the numbers marked upon the section; the second, the angle between the direction of the sea-horizon and the ray emerging from the upper limit of the element; the third, the angle between the direction of the sea-horizon and the ray from the lower limit of the element, the negative sign denoting that the emerging ray is above the horizon. This practise, of appropriating certain elements of the apparatus to different distances on the sea, was first introduced by Mr. James T. Chance, in the lights of the South Foreland exhibited in January 1872.

The ray, dipping at an angle of $7^{\circ} 46' 57''$ below the horizon, will strike the sea at $\frac{1}{2}$ mile, while $5^{\circ} 8' 52''$ corresponds to $\frac{3}{4}$ mile, $2^{\circ} 37' 30''$ to $1\frac{1}{4}$ mile, $1^{\circ} 30'$ to 2 miles, 1° to $2\frac{1}{2}$ miles, and $30'$ to about 4 miles. Thus the direct light begins at about $\frac{1}{2}$ mile from the lighthouse. From $\frac{1}{2}$ mile to $\frac{3}{4}$ mile the sea receives light from one element of the apparatus, from $\frac{3}{4}$ to $1\frac{1}{4}$ mile from two elements, from $1\frac{1}{4}$ mile to 2 miles from three elements, from 2 to $2\frac{1}{2}$ miles from four elements, and beyond $2\frac{1}{2}$ miles from six elements; the upper and lower totally reflecting prisms come in aid at about 5 miles. The main power of the apparatus is hardly attained till a distance of 8 or 10 miles. Fig. 3 is a sectional plan of the apparatus by a horizontal plane through the focus. It will be seen that a dioptric mirror is placed on the landward side of the arc. This mirror is arranged to form the image of the arc at one side of the carbons, so avoiding the interception of light

which would result if the mirror were used in the ordinary way, and contributing to the horizontal divergence necessary. Further horizontal divergence is given by the form of the lens. In the ordinary revolving light the inner face of the lens is plane; here it is cylindrical, the axis of the cylinder being vertical. This method of obtaining horizontal divergence is a modification of a proposal of Mr. Thomas Stevenson,¹ M. Inst. C.E.; it is not mathematically accurate, inasmuch as the cylindrical form of the inner face of the lens not only displaces the emergent ray horizontally, but also in the case of rays not in the vertical nor horizontal plane through the focus, to a small extent vertically, but the error is easily calculable, and is unimportant, provided the lens is narrow, and the horizontal divergence of the beam moderate. Plate 9, Fig. 4, shows a complete panel in elevation with revolving carriage. Fig. 5 shows the plan of the service-table of the pedestal and lamp-table. A new construction was adopted for the gun-metal framework of the optical apparatus to reduce the interception of light by the frame to a minimum. The metal segment A, Fig. 6, forms part of the lower prism-frame, B part of the upper frame, whilst C and D are parts of the frame for the refracting portion of the apparatus; uprights E support the upper prism-frames without throwing weight on the lens-frames. With the ordinary constructions of frame, Figs. 7 and 8, the equivalent of these ring segments A and B would intercept about double as much light as in this new construction.

Mechanism for Rotation.—The pedestal is similar to those designed by Sir James Douglass to permit the light-keeper to obtain access from below to the interior of the apparatus without in any way interfering with its rotation. The clock-work is fitted with the governor, and maintaining power used by Messrs. Chance Brothers and Company for the last twelve years. The roller-ring may be mentioned as of an improved type, for although it has been used for some years in all Messrs. Chance's lights, it has not been described before. The rollers and roller-paths which carry the whole weight of the optical apparatus have long been made conical, so that the surfaces roll upon each other without twisting. There is consequently a very considerable radial force on each roller tending to force it outwards, the reaction against this force causes a very important part of the total frictional resistance. Plate 9, Fig. 9, shows a portion of the roller-ring and one of the conical rollers, according to the old construction, Figs. 10, 11, according

¹ "Lighthouse Construction and Illumination," p. 186.

to the improved construction; in the former it will be observed that the thrust of the roller is received on a collar; in the latter, on the end of a pin. The reduction of friction is practically very considerable, and although of small importance in a slow-moving apparatus like Macquarie, is of great importance in heavier and quicker apparatus; for example, the triple-flashing light at Bull Point, in Devonshire.

Lamps.—These are of the Serrin type, and were supplied by Baron De Meritens.

Lamp-Table.—The arrangements for rapidly changing electric lamps, and for substituting gas or oil when desired, are shown in Figs. 12, 13, 14, 15.

The intention was to use a gas-lamp in clear weather, and half-power or full-power electric light in thick weather, according to the opacity of the atmosphere; but the Author understands that in practice the electric arc is always used. The paraffin oil-lamp is intended as a resource in case of failure of the supply of gas.

Focussing the Arc.—Two approximately rectangular prisms are fixed upon the mirror frame at about 90° from each other, the longer face of each is plane, the other two faces convex, of such curvature as to form a good image of the arc upon the service-table, as shown in Fig. 16. During daylight, a pointed sight or focimeter is placed at the position of the image formed by the lens of an object on the horizon; this then is the position which the arc should occupy. A sight is next taken over the focimeter into one of the adjusting prisms, and a bright object such as a threepenny piece placed on the service-table, is moved about until its centre is seen in the prism, exactly upon the point of the focimeter; a mark is made in the then position of the object. When the arc is correctly adjusted, its image on the service-table will be at the point where the mark is made. Two prisms are used in order to secure that the arc shall be in the centre of the apparatus as well as at the correct level.

Lantern.—The lantern is of the well known Douglass type.¹

Dynamo-electric Machines.—Two alternate-current machines, with permanent magnets manufactured by De Meritens, were supplied. Each machine has five rings in its armature, and in each ring there are sixteen segments. In supplying one arc for a lighthouse the machine runs about 830 revolutions per minute, and gives a current of 55 amperes when half the coils are used, and of 110 when the whole of the machine is in action, the internal resistance

¹ Minutes of Proceedings Inst. C.E. vol. lvi. p. 77.

in the two cases being 0·062 and 0·031 ohm. It is unnecessary to give a description of the machine as its general construction and dimensions are well known, but some numerical details are given below.

Engines.—Each machine is driven by an 8 HP. Crossley gas-engine through a belt without countershafting.

Tests.—Whilst the dynamo machines were at the works of Messrs. Chance Brothers and Company, a series of experiments was made in March 1881 to determine their properties. The time is long passed when it would be profitable to give the details of these experiments, but the general conclusions drawn at the time are still interesting. When the external resistance was a metallic conductor with small self-induction, it was found that with varying resistance and speed the currents observed agreed

A
fairly well with calculation from the formula $\sqrt{R^2 + \left(\frac{2\pi\gamma}{T}\right)^2},^1$

in which R is the total resistance of the circuit, γ the self-induction, and T the periodic time. When the machine was running 830

revolutions per minute $A = 67$ volts and $\left(\frac{2\pi\gamma}{T}\right)^2 = 0\cdot197$ in

ohm squared, hence $\gamma = 6\cdot4 \times 10^5$ centimetres. The eighty sections of the machine are arranged four in series, twenty parallel. For a single section the value of γ would be 32×10^5 centimetres. The maximum induction in the core, which has an area of 5 square centimetres, is 24,600 or 4,920 per square centimetre. The loss of power was greater when the machine was doing little or no external work than when that work was great. This is clearly seen in the following Table :—

Current amperes	7·70	73·60
Electrical work HP.	0·69	5·66
Mechanical work applied	3·09	6·55
Loss	2·40	0·89

Photometric experiments were made upon the arc, and simultaneous measurements of effective power applied and of current passing. The red light was measured through bright copper ruby glass, and the blue through a solution of sulphate of copper and ammonia. The HP. was measured by a transmission dynamometer; but the results must be accepted with some reserve, on account of the difficulty of ascertaining the mean tension in a strap which

¹ Lectures on the "Practical Application of Electricity." Session 1882-83. "Some points in Electric Lighting." By Dr. John Hopkinson. p. 88.

is constantly varying. The oscillations of the dynamometer were damped by a dashpot containing tar.

	Half Power.	Full Power.
Red candles	1,988	4,708
Blue „	4,079	11,382
Current (amperes)	54.5	105
Mechanical power applied (HP.)	4.5	6.9
Power expended in heating conducting wires } (HP.) }	0.24	0.95

The results illustrate the fact that, as the current increases, the total light increases in a higher ratio, red light in a slightly higher ratio, and blue in a considerably higher.

The machinery for this lighthouse was sent out to New South Wales in November 1881, and was put up and started under the superintendence of Mr. J. Barnett, the Architect of the Colony, to whom is mainly due the success of the whole from the first start. The glare of the light upon the sky is said to have been seen at a distance of over 60 miles, far beyond the distance at which it would cease to be directly visible. The only criticism from mariners has been that when somewhat near the lighthouse the flashes are so bright as to dazzle the eye. This is an excellent proof of the power of the light, as a much smaller proportion of the light is directed upon the nearer sea than in any previous lighthouse. The lesson is that with powerful electric lighthouses almost all the light should, in ordinary weather at least, be directed to the horizon, and that the quantity thrown upon the nearer sea must be strictly limited. This is only possible when the focal length of the apparatus is large.

TINO.

This station is on a small island at the mouth of the Gulf of Spezia. Fig. 17, Plate 9, is copied from the chart of the neighbourhood. The focus is 386 feet above sea-level. The distance of the sea-horizon is 22.7 nautical miles, and the range practically 28 miles. The conditions, therefore, were very similar to those of Macquarie, with the exception that it was required to throw some light down into the channel between Palmaria and Tino. The lighthouse itself presents some interesting historical features. The buildings were originally a place of defence against the pirates who occasionally made descents upon the coast. Subsequently a coal-fire lighthouse was established, and in the spring of 1885 part of the stock of lignite was still found to be in some of the buildings, where it had been lying for fifty years. In 1839 a dioptric light was established, one of the earliest of

Fresnel's types, the lens-ring being replaced by short straight prisms, which formed by no means a bad approximation, and could be ground without special machinery. The present electric lighthouse has been in contemplation for several years.

Optical apparatus.—The distinctive character of the light is a triple flash every half minute. The apparatus for producing this effect is of the general form introduced by the Author in 1874. In October of that year he issued a pamphlet pointing out the several advantages of group-flashing lights, showing for the first time a simple dioptric apparatus suitable to their production, and also pointing out how easy it is to give the group-flashing effect with catoptric apparatus. Since that time a large number of dioptric group-flashing lights have been made by Messrs. Chance Brothers and Company, and some also in France, and Mr. Allard has incorporated group-flashing lights in the system of distinctions he recommends; also a considerable proportion of the light-vessels on the English coasts have been converted into group-flashing lights of the catoptric system. On the ground of economy the second-order apparatus of 700-millimetre focus was adopted in the case of Tino. It is just large enough for tolerably convenient service of the lamp by an attendant entering within the apparatus. The apparatus, shown in vertical section in Fig. 18, and in horizontal section through the focus in Fig. 19, has twenty-four sides, eight groups of three; one group of three is shown in elevation in Fig. 20. The horizontal divergence is obtained in exactly the same way as at Macquarie, excepting that no mirror is used. The metal framework, however, approximates to the ordinary type, as the type used at Macquarie would have been costly when applied to a triple-flash light. The distribution of light vertically is as follows: upper and lower prisms, and the central lens, with the two lens-rings next adjoining it, all to the horizon and most distant sea. The lens and lens-rings direct their rays according to the following Table, which is arranged in exactly the same way as the Table already given for Macquarie—

I.	II.			III.		
	°	'	"	°	'	"
7 top	0	31	35	3	16	0
6 "	..			2	0	0
5 "	..			1	30	0
4 "	..			1	0	0
4 bottom	..			0	45	0
5 "	..			0	30	0
6 "	..			0	30	0
7 "	all to the horizon.					

No. 7 bottom was directed wholly to the horizon, in order to avoid the horizontal bar of the lantern. It will be observed that the quantity of light thrown upon the nearer sea is much less in the case of Tino than in that of Macquarie, and that greater reliance is placed upon the accuracy with which the arc can be kept in focus; experience has justified these changes, as improvements of a perfectly safe nature.

A small part of each flash is bent downwards and distributed over the channel between Tino and Palmaria, by means of subsidiary prisms fixed upon the lantern, shown at X, Fig. 18. These subsidiary prisms are really superfluous, as the scattered light from the beams overhead is found to be as effective at this short distance. Fig. 21 shows the plan of lamp shunting-table and service-table.

Engines.—As there is no water upon the island, the practice of the Trinity House was followed, and two of the Brown hot-air engines were supplied, each driving through a countershaft one of the machines. The countershafts could be connected by means of a Mather and Platt friction-coupling, so that the two machines could be driven together, or either machine from either engine. Drawings of the Brown engines are given in Sir James Douglass's Paper.¹ The accompanying indicator-diagrams were taken from the compressing- and working-cylinders. Whilst these diagrams were taken, the effective power developed was measured by a friction-brake on the driving-pulley, and was found to be 9·1 HP. Thus of 33·1 HP. indicated in the working-cylinder, 17·7 HP. is employed in compressing the air, 6·3 HP. is wasted in friction in various parts of the machine, and only 9·1 HP. is effective upon the brake. The engines consume about 4 lbs. of coke per effective HP. per hour. In future lighthouses, when a steam-engine cannot be employed, it would be preferable on every ground to use gas-engines, and manufacture on the spot either Dowson gas or ordinary gas, according to the character of the fuel available.

Dynamo Machines.—There are two machines of exactly the same type as those supplied for Macquarie, the only novelty lying in the method of using them. In 1868 Mr. Wilde discovered, by experiment, that two alternate-current dynamos, independently driven at the same speed, would, if electrically connected, so control each other's motions that they would add their currents. The Author subsequently arrived at the same conclusion independently, on theoretical grounds, and gave a thorough explanation of the

¹ Minutes of Proceedings Inst. C.E. vol. lviii. Plate 6.²

fact.¹ The result has been put to a practical application at Tino. The machines are connected to a single switchboard, so that each half of the two machines can at pleasure be connected to, or disconnected from, the main conductors. Thus a current can be supplied from either machine at half power, 55 amperes, or full power, 110 amperes, or from the two machines of double power, or about 200 amperes. Further, a change can be made without

Compressor pump-cylinder, 24 inches in diameter. Stroke, 22 inches. Indicated HP., 17.7.

Working-cylinder, 32 inches in diameter. Stroke, 20 inches. Indicated HP., 33.1. Revolutions per minute, 64. Power on brake on fly-wheel, 9.12 HP. Pressure in reservoir, 19 to 24 lbs.

extinction of the light from one dynamo and engine to the other. Thus, suppose one machine is working full power, clutch the countershafts gradually together, so starting the second engine; throw on the band of the second machine, cut out half the first machine, and connect half the second machine at the switchboard;

¹ Lectures on the "Practical Applications of Electricity." Session 1882-83. "Some Points in Electric Lighting." By Dr. John Hopkinson. And Journal of Society of Telegraph-Engineers and Electricians, vol. xiii. p. 496.

the two machines at once synchronize, without affecting the light. Disconnect the remaining half of the first machine, and connect the remaining half of the second, unclutch the countershafts, and stop the first engine. One man can effect the change, with no more disturbance of the light than a change from full to half power for about one second. A further conclusion, deduced from theoretical considerations, was that of two alternate-current machines of equal potential, one could be used as a generator of electricity, the other as a motor converting the current generated back into mechanical power. It was found impossible to verify this conclusion with such intermittent driving as that of a hot-air engine. But Professor W. G. Adams effected the verification without difficulty at the South Foreland, the motive-power being steam.

Lamps.—These are the improved Serrin of Mr. Berjot. One of the three lamps supplied is of larger size, for the double-power current from the two machines. This lamp was said to be suitable for a still greater current, but with about 200 amperes it soon became dangerously heated; a simple modification rendered the lamp equal to the actual work it had to do. It is, however, probable that for the occasional circumstances when it is necessary to use so great a current as 200 amperes in a lighthouse, a lamp worked partly by hand would be preferable to a regulator entirely automatic.

The apparatus was delivered in November 1884, and was put up by workmen from Messrs. Chance's workshops, under the supervision of Mr. L. Luiggi, of Genoa, to whose ability and energy the complete success of the lighthouse is largely due. A complete test of the performance of the light, as seen from the sea in all grades of its power, was made in April 1885 by a Commission, consisting of Professor Garibaldi, of Genoa; Mr. Giaccone, Engineer-in-Chief for Italian Lighthouses; Captain Sartoris, and Mr. Luiggi, the Author attending on behalf of Messrs. Chance. The light was well observed through rain, when distant 32 nautical miles, and although below the horizon, the position was precisely localized, and the triple-flash distinction unmistakable. At 18 miles distant the illumination of the flash upon white paper was sufficient to make out letters marked in pencil $1\frac{1}{4}$ inch high, and when 14 miles distant it was easy to ascertain the time from a watch. The light is frequently seen at a distance of 50 miles, near to Genoa.

A review of work which has been carried out naturally suggests many questions as to what conclusions experience has established,

and what indications it gives of the probable direction for future developments. In the use of electric light in lighthouses, there are many questions upon which there is wide difference of opinion, questions both as to when and where electric light should be adopted, and questions as to the best way of employing it. It may not be unprofitable to allude to some of them. Although English engineers are now well agreed that a large optical apparatus should be used for electric light, this opinion is not universally accepted. The advantages of a large apparatus have already been mentioned. To balance them, there is nothing on the other side but the less prime cost of the smaller apparatus. Although the difference of cost appears considerable when attention is confined to the optical apparatus, it is unimportant when the whole outlay on the lighthouse is brought into account. Cases are, however, conceivable in which a small optical apparatus such as a fourth-order, having a focal distance of 250 millimetres, would be properly preferred; such, for example, as a harbour light which could be supplied with current from machinery also used for other purposes, but such cases are likely to be exceptional.

When a flame from oil or gas is the source of light, there is of necessity a considerable divergence vertically; and the distribution of the light through the angle of vertical divergence is not at disposal, except to a very limited extent in some cases, but is determined by the size and character of the flame. With the electric arc and a large optical apparatus it can be determined in considerable measure how the light shall be distributed—how much shall be sent to the distant sea, how much to the various distances between the foot of the tower and a distance of some miles. It becomes then a question what use is to be made of this facility. The experience at Macquarie and at Tino is emphatic, that it is in every way advantageous to direct much the greater part of the light to the horizon with a very small divergence, and to distribute the comparatively small remainder over the nearer sea with intensity increasing with the distance.

A question allied to the last is this: Whether it be desirable to provide means of directing the strongest light downwards on to the nearer sea in time of fog? The answer must depend upon the circumstances of the particular locality. Take the case of a lighthouse on an isolated rock, the purpose of which is primarily to be a beacon to keep ships off that rock; a lighthouse which would not exist were it not more practical or cheaper to build and maintain the lighthouse rather than remove the rock. Here surely it is of the greatest use to provide means whereby, if the light cannot

penetrate 2 miles, it shall if possible be visible at 1 mile. But other cases occur in which the lighthouse has to cover a long length of coast, and has almost as much to do with points of the coast 10 miles distant as with the point upon which it is placed, cases in which the lighthouse is far more useful in guiding the regular traffic passing within a radius of 20 miles or more than in preventing vessels running ashore within a mile of the tower. Such a light fails of its purpose if it can only be seen at a distance of a mile, covering less than $\frac{1}{400}$ part of its normal area of illumination; it becomes comparatively useless unless it penetrates to something like its normal range, and its efficiency must be measured by the fewness of the occasions when it fails to do this. It is a grave question whether it be prudent in such cases to place upon the light-keeper the responsibility of judging when the light should be dipped on to the nearer sea, the fact being that, if his judgment errs, he may actually diminish the range of the light, and cause unnecessarily the lighthouse to fail of fulfilling its most important function. It is easy for him to be misled if the fog is local and does not extend to any great distance from the lighthouse. Another element enters into the consideration—the height above the sea. If the focus be 100 feet above the sea-level, the dip of the sea-horizon is $9' 45''$, and a ray dipping $9' 45''$ below the sea-horizon will meet the sea at a distance of 3.1 nautical miles from the tower. Even with a first-order apparatus, if the arc be a powerful one, it is very difficult to render the light directed to the horizon from an elevation of 100 feet more powerful than that directed to a point distant 4 miles from the tower. Unavoidable divergence will render the two intensities practically equal.

Passing to questions of another class, what are the relative advantages in an electric lighthouse of continuous and alternating currents? Present practice tends altogether in favour of alternate currents, but this practice largely results from unfavourable experience of the older continuous-current machines. These machines have in many respects been greatly improved in the last two or three years. The continuous current presents the advantage of greater economy of power in producing the current, less floor-space required by the machine, and a smaller prime cost. The alternate-current magneto machine, on the other hand, has the advantage that it may be driven with a defectively governed prime mover, with an indifferent lamp, and may suffer neglect with impunity; whereas the more compact and efficient continuous-current machine would be in serious peril of destruction. Optical apparatus can

be constructed suitable to make the most of either form of arc. Hot-air engines have found favour for electric lighthouses, because in many cases there is no available supply of fresh water. The engines of which the Author has experience are open to the objection that they take a great deal of room, are not economical of fuel, and do not govern so quickly as is desirable; the wear and tear also, when they are worked to anything like their full power, is very serious. A gas-engine, with Dowson or other gas made on the spot, could be used with greater advantage.

Antecedent to all considerations as to the best apparatus and machinery to be used, is the question, under what circumstances, if at all, should electric light be used in a lighthouse? The Trinity House experiments at the South Foreland showed to demonstration that, where the issue to be decided was how to produce a light which should be capable of penetrating the furthest in all weathers, electric light could do that which could be done in no other way, and that it was the cheapest light of all when the price is estimated per unit of light. But the conclusion was also reached that an electric light must inevitably cost a large sum, both in first outlay and in maintenance; therefore that electric light is extravagant unless very extraordinary power is a necessity. This conclusion is doubtless a fair consequence of experience, but it is not an inherent property of electric light. Both the capital outlay and the cost of maintenance are greatly increased by the practice of so arranging the machinery as to provide, at all times, a light of very great power: whence follows that the machinery must be placed at some distance from the lantern, and two men must always be on duty; one man in the lantern, and another with the machinery.

The essentials for a cheap electric lighthouse are, that for ordinary states of the atmosphere there shall be provided a plant under the easy control of the light-keeper himself, which shall be precisely adapted to produce that amount of light which is wanted in ordinary states of the atmosphere; but for thick weather there shall be provided a much more powerful engine and dynamo, available also as a reserve in case the smaller machinery from any cause breaks down. The occasional machinery may be more remote from the lantern, as it is a small matter to require a second man to work on the comparatively rare occasions when the maximum power is needed. A small gas-engine and a dynamo machine can be placed without any crowding in the room immediately below the lantern, and arrangements can be made whereby the light-keeper, whether he is in the lantern or in the engine-room, can ascertain at a glance

whether the arc is in its proper position, with an error of less than 1 millimetre. The attendance on the lamp, rotating apparatus of the lens (if a revolving light), engine and dynamo, would be easy when the whole is brought together, so as to be under observation at once; in fact the gas-engine, dynamo, and lamp constitute together a gas-burner which, though consisting of many parts, is automatic throughout, and requires nothing but the constant presence of a custodian, exactly as the gas-lamp in a lighthouse requires a custodian, as a guarantee against failure. The same end, viz., the concentration of the whole mechanical and electrical apparatus under one pair of eyes, could be attained, of course, in other ways. Accumulators could be used, or a petroleum-engine.

In order to give definiteness and afford facilities for criticism, the better course will be to describe a suitable machinery; state what it will do, what attendance it will require, and what it will cost. The Author proposes, then, for an electric lighthouse where small outlay is essential, the following:—A Dowson gas-producing apparatus and gas-holder, the generator and superheater being in duplicate, each capable of making 1,200 feet of gas per hour, the gas-holder having a capacity of 3,000 cubic feet.

An 8-HP. nominal Otto gas-engine and series-wound dynamo-machine, placed in a room near the base of the tower, and copper conductors to the lantern, the dynamo having magnet coils, divided into sections so as to supply a small current when required.

A 1-HP. nominal Otto gas-engine and dynamo machine, placed in the room immediately beneath the lantern floor, with gas-pipe from the gas-holder; three electric lamps, to receive either carbons 25 millimetres in diameter or any lesser size, with complete adjustments for accurate focussing; one paraffin lamp as a substitute; an optical apparatus of the second order of 70-centimetre focal distance. The cost of this apparatus would depend upon the character of the light it was intended to exhibit. To fix ideas, let it be assumed that the light is to be a half-minute revolving light, showing all round the lighthouse. There could then be supplied a sixteen-sided apparatus with pedestal and revolving machinery. Provision would be made in the optical apparatus for giving the horizontal and vertical divergence desired by the same methods successfully used in the lighthouses of Macquarie and of Tino.

Two focussing prisms would be fixed to form magnified images of the arc, on pieces of obscured glass let into the pedestal floor, so that the keeper, whether in the lantern or in the engine-room, could see at a glance the state of the arc, and observe whether it

is of proper length with the carbons in line, whether it is exactly at the right height and in the centre of the apparatus. An error of 1 millimetre would be glaringly apparent, and call for immediate adjustment, although its effect would be only a displacement of the beam 5' of angle.

The lantern would be 10 feet diameter, with bent plate-glass.

The cost of the whole above described would be materially less than the cost of a first-order light and lantern with oil-lamp and large burners.

Now what result would be obtained? In fine weather the small engine would be used. Its effective power on the brake is fully $1\frac{1}{2}$ HP.; from this $1\frac{1}{2}$ HP. the dynamo machine produces considerably over 800 watts, say 800 watts in the arc itself, or 20 amperes through a fairly long arc of 40 volts. Of course the value of this in candles depends upon the colour in which it is measured, and the direction in relation to the axis of the carbons. In red light the mean over the sphere would certainly exceed 1,200 candles. In clear weather or in slight haze or rain, the beam of this light through the lenses would be much more powerful at the horizon and on the more distant sea than any single-focus light with oil or gas as the illuminant, and would at least be fairly comparable with anything yet exhibited with oil or gas whether triform or quadri-form. But on the nearer sea the illumination would be reduced, so that no annoyance would be caused by dazzling flashes. In thick weather or indeed in any weather when there was a doubt as to the visibility at the horizon of the lower power, the large engine would be used under the superintendence of the second keeper. This engine will give 10 HP. on the brake, and there is no difficulty in obtaining 85 per cent. of this as useful electrical energy outside the machine, that is, 6,340 watts. From this deduct 10 per cent. for the leads and the lamp and for steadying the arc, leaving 5,710 watts in the arc itself, or 114 amperes, with a difference of potential of 50 volts. Having regard to the fact that the optical apparatus here proposed acts upon a larger portion of the sphere than that used in the South Foreland experiments, that the vertical divergence is less, and that the potential difference is greater and the current continuous, although less in quantity, it may safely be assumed that the power of the resulting beam would not be inferior. It hence follows, from the South Foreland experiments, that in any fog the flashes would penetrate farther than those of any existing gas or oil light. The increased size of crater, compared with that produced by the current of 20 amperes, will give increased vertical divergence, and so cause the maximum illumination to be attained at a less distance

from the lighthouse. The attendance of two men would suffice for all the duties of the lighthouse, because under ordinary circumstances one man only need be on duty excepting for two to three hours whilst gas is being made. The consumption of coal would be 4 lbs. per hour of lighting, of water about $\frac{1}{2}$ gallon, of carbons about 4 inches. The whole cost of maintaining the light would differ little from that of an ordinary oil light of the first order.

Though it be the fact, that it is possible to exhibit an electric light at moderate cost, it does not follow that it is suitable for all ocean-lights. There is no room in a rock lighthouse tower for a gas-plant, and few would at present be prepared to recommend a petroleum-engine burning oil of a low flashing point. The light-keeper again must understand a gas-producer, a gas-engine, a dynamo, and an arc lamp, instead of only a paraffin lamp and burner, and arrangements must exist for repairing the more extensive machinery. Such considerations will justly weigh against the use of electric light in remote stations and in countries where the labour available is not capable of much training.

It may possibly be said that in this Paper no definite conclusions are reached as to whether electricity or some other agent is the best source of light in lighthouses generally, nor yet, if electricity be adopted, what is the best way of producing the light and optically dealing with it. The answer is that it is impossible on many points to arrive at general conclusions. Each case must be judged according to its special circumstances.

The Paper is accompanied by a lithograph and two tracings, from which Plate 9 and the Figs. in the text have been prepared.

[DISCUSSION.]

Fig. 1.

Scale, 32 Miles = 1 Inch.

Fig. 2.

Fig. 4.

Fig. 14.

Fig. 17.

Fig. 18.

Fig. 20.

Scale for Figs 2, 3, 4, 5 $\frac{1}{4}$ " = 1 Foot
D^o " " 6, 7, 8 1" = 1 Foot
D^o " " 9 to 15 $\frac{1}{2}$ " = 1 Foot

Fig. 3.

Fig. 5.

Fig. 15.

Fig. 6.

Fig. 7.

Fig. 8.

Fig. 9.

Fig. 10.

Fig. 11.

Fig. 12.

Fig. 13.

Fig. 16.

Fig. 19.

Fig. 21.

Scale for Figs. 18, 19, 20, 21. $\frac{1}{4}$ " = 1 Foot.