WATER-COOLED MERCURY LAMPS

by E. G. DORGELO.

Summary. The water-cooled mercury lamp is a very powerful light-source of high efficiency and small dimensions. In this article the properties of the new light-source are discussed, and the following are dealt with as examples of its application: film studio lighting, television, searchlights and air-port lighting.

Introduction

A year ago in this periodical [1]) a mercury lamp was described which excels because of its high efficiency and especially small dimensions. The investigations which led to its construction showed that the luminous efficiency (lumens/watt) of a high-pressure mercury vapour discharge increases steadily with the energy which is supplied per unit length of the column. By keeping the dimensions of the lamp sufficiently small, it has been possible to reach an energy dissipation of 40 W/cm with a total energy of 75 W. The vapour pressure of the mercury is about 20 atmospheres and the wall of the quartz tube assumes a temperature of the order of 1000° C.

Besides this mercury lamp, which is not artificially cooled, a water-cooled mercury lamp has been developed, which also works at very high mercury pressures and has very small dimensions, and which allows a considerably greater energy input (W/cm). Water-cooled mercury lamps are provided for various inputs from 200 W to 16 kW. We shall describe chiefly two types with inputs of 500 W and 800 W. These have been given the distinguishing symbols SP and SSP respectively. In *fig. 1* the mercury lamp SP 500 W with holder for water-cooling is reproduced.

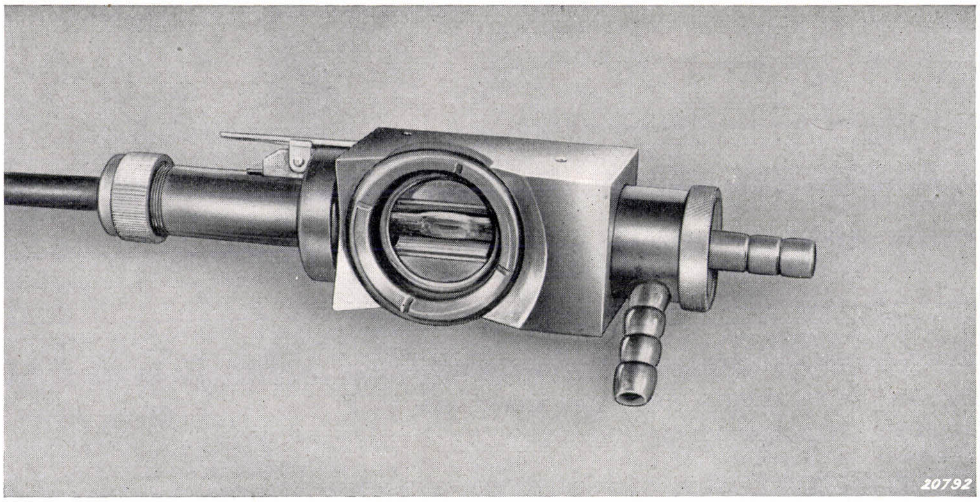

Fig. 1. The mercury lamp type SP 500 W with holder for water-cooling.

Construction of types SP and SSP

Lamps of the SP and SSP types may be used with alternating as well as with direct current. In both cases the data in the table below are valid.

Table I. Data of the super high pressure mercury lamps SP and SSP.

	SP 500 W	SSP 800 W
Length of the discharge	12.5 mm	10 mm
Internal diameter . . .	2 mm	1 mm
External diameter . .	6 mm	3 mm
Mercury pressure . . .	75 atm.	120 atm.
Input	500 W	800 W
Current (with A.C.) .	1.5 A	1.5 A
Current (with D.C.) .	1.3 A	1.3 A
Voltage	420 V	600 V
Light flux	30 000 lm	50 000 lm
Surface brightness (max)	33 000 c/cm²	91 000 c/cm²
Luminous efficiency . .	60 lm/W	62 lm/W

The SP lamp is normally mounted in a metal boat, in which also a mirror may be fastened (*fig. 2*). The whole is slid into a metal block through which cooling water is conducted. The block is

[1]) The mercury lamp HP 300, Philips techn. Rev. **1**, 129, 1936.

provided with a circular window through which the radiation is emitted.

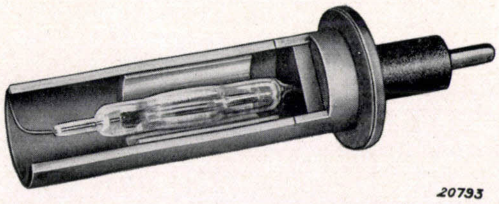

Fig. 2 Water-cooled mercury lamp (type SP 500 W) in its boat.

The SSP lamp may be used in the same holder. Usually, however, three SSP lamps are mounted close to one another on one block in order to obtain a broader light source (*fig. 3*). During the initial experiments with this method of construction it was found that the lamps quickly cracked.
The cause of this lay in the fact that each lamp absorbed a portion of the energy radiated by the other two lamps, so that the load became abnormally great. Since ultra-violet radiation in particular was absorbed, partitions were introduced between the lamps, made of a kind of glass which does not transmit ultra-violet light. In this way cracking was prevented.

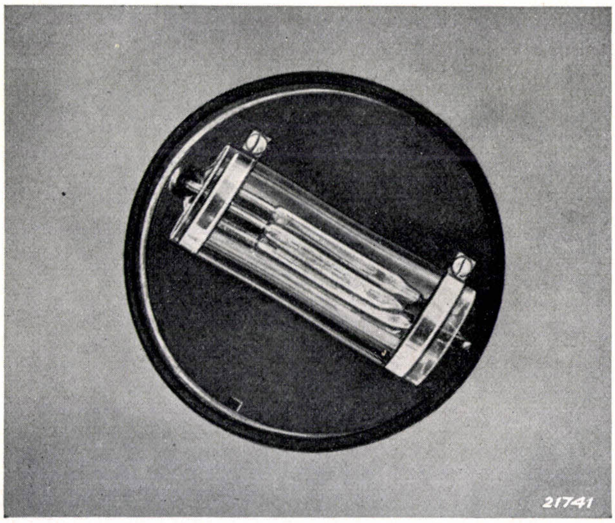

Fig. 3. Lamp holder designed for use in searchlights. Three SSP lamps are mounted on a block of "Philite". Between the lamps there is a glass partition which absorbs ultra-violet radiation. The whole is surrounded by a glass cylinder through which the cooling liquid flows.

Properties

The fact that with the lamps under discussion a large amount of energy is transformed into radiation within a small volume is apparent from the high value of the s u r f a c e b r i g h t n e s s. It may be seen from Table I that the maximum brightness (along the axis of the discharge) is 33 000 candles/cm² and 91 000 candles/cm² for the two types respectively. For the sake of comparison it may be noted that the brightness of an ordinary carbon arc is about 18 000 candles/cm². The brightness of the mercury lamps is not uniform over all parts of the luminescent surface. In *fig. 4* it may be seen that it becomes smaller toward the edges. The discharge thus does not fill the whole tube but is concentrated at the centre.

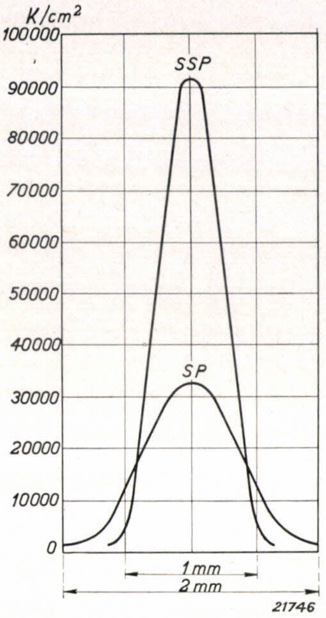

Fig. 4. Curves giving the surface brightness along a cross section of the lamp. The type SP has a maximum brightness of 33 000 candles/cm² with an internal diameter of 2 mm; with type SSP these values are 91 000 candles/cm² and 1 mm respectively.

The s p e c t r a l c o m p o s i t i o n of the light deviates from that of low pressure mercury tubes. The changes undergone in the spectrum with increasing pressure consist briefly of the following: an increase in intensity of the continuous background and a shift of the intensity maximum toward the long-wave end [2]). These facts are already clearly observable with the mercury lamp HP 300 [3]), with the water-cooled lamps they are observable to a greater degree (*fig. 5*). The modified spectral composition of the light results in considerably better colour reproduction than with ordinary mercury lamps. An idea of this may be obtained from *Table II*, in which a schematic distribution of the light intensity over a number of wavelength regions is given for several light sources.

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[2]) Refer to Philips techn. Rev. **1**, 2, 1936 for the causes of these phenomena.

[3]) See page 133 of the article cited in footnote 1.

The invisible part of the spectrum here consists mainly of ultra-violet radiation: 46 per cent of all that is radiated lies in the ultra-violet. Further 27 per cent of the light lies in the visible region and 27 per cent of the energy radiated lies in the infra-red. With the high pressures occurring here, a very strong absorption band for ultra-violet radiation appears to the long-wave side of the line 2537 Å.

Table II. Distribution of the light flux of different sources of light over four wavelength ranges of the visible spectrum in per cent of the total light flux. The regions are chosen so that, with an intensity evenly distributed over all wavelengths, they contribute the same amounts to the total light flux [1]).

Wavelength range in Å	Spectrum of constant intensity	Sun	Glow lamp	Mercury lamps		
				HP 300	SP 500 W	SSP 800 W
4000—5300	25	26	14	8	5	8
5300—5580	25	26	22	58	54	48
5580—5880	25	25	28	31	30	30
5880—7000	25	23	36	3	11	14

[1]) Cf. the table in Vol. **1**, page 134 of this periodical.

If one wishes to use the lamp for irradiation with ultra-violet light, the window must be made of quartz, or of a suitable kind of glass which transmits ultra-violet light. Very little ultra-violet light is absorbed by the water, while the opposite is true of the infra-red (heat) radiation. The light of water-cooled mercury lamps is much "colder" than, for instance, that of glow-lamps.

The luminous efficiency of the lamp is high. A new lamp gives about 60 lumens per watt. When the lamp is used the luminous efficiency falls because of the fact that the quartz does not remain completely clear. As a rule the light intensity decreases still more because of the fact that not only the luminous efficiency but also the energy taken up diminishes. This is particularly the case with alternating current supply [4]).

Cooling

The simplest way of cooling is connection with the water supply. The consumption is about 2.5 liters/min. The necessary pressure is 4 lbs per sq. inch. In cases where the water from the main is too hard, where one must economise on water or where the whole must be portable, a circulation system consisting of a pump and a radiator is suitable.

In *fig. 6* may be seen an apparatus for cooling mercury lamps up to a maximum size of 1 kW. The centrifugal pump has a "Philite" shaft bearing.

[4]) The current supplied by the source is smaller the greater the voltage of the lamp. Upon increase of voltage the product of current times voltage will initially, i.e. as long as the voltage is low, rise, and then finally fall again. With the lamp voltage used here we are on the falling branch. As the lamp becomes older, its voltage increases, and thus its input falls. When alternating current is used, the increase in the reignition voltage also plays a part when the lamp becomes older, so that in this case the energy falls more rapidly than when direct current is used. See in this connection: The Mercury lamp HP 300, Philips techn. Rev. **1**, 129, 1936; Alternating current circuits for discharge lamps, Philips techn. Rev. **2**, 103, 1937.

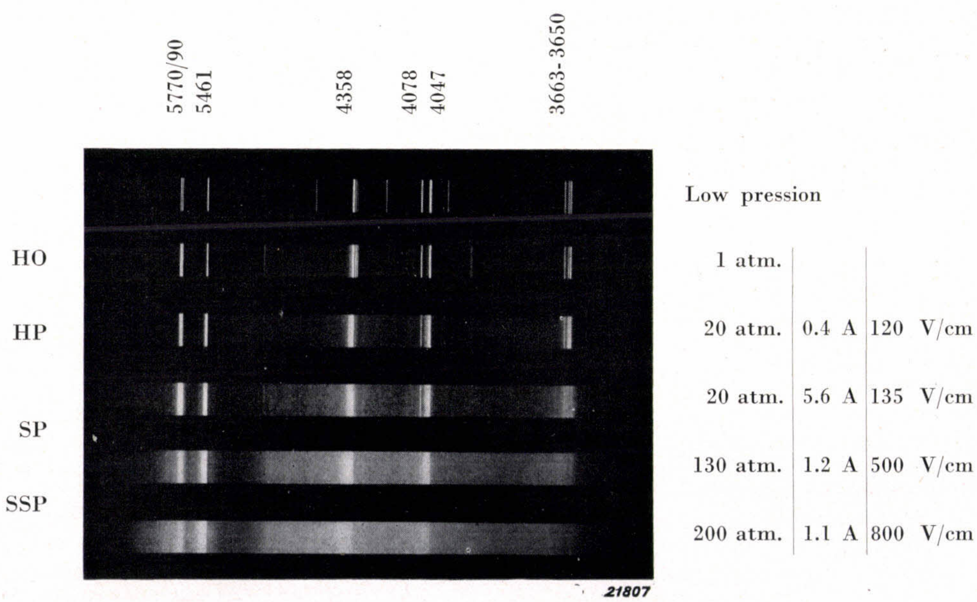

Fig. 5. Spectrum of mercury vapour at various pressures, photographed on a panchrom atic plate. With increasing pressure the lines become broader and a continuous background appears. The lines of short wavelength become weaker, those of long wavelength stronger. The accompanying figures indicate, above: wavelength in Å, to the right: technical data of the mercury lamp, to the left: approximate position of the most important types in this series. From W. Elenbaas, Physica **3**, 866, 1936.

This is lubricated with water so that contamination of the cooling liquid by oil or grease is out of the question. The capacity is 1.1 liter. If the pump must work in temperatures below the freezing

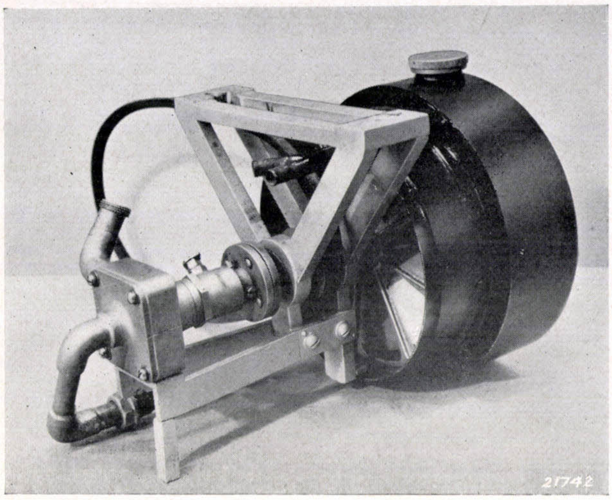

Fig. 6. Cooling unit consisting of centrifugal pump, radiator and fan. The input to the lamp(s) may be a maximum of 2 × 500 W.

point, one may use as cooling liquid a mixture of 2 parts water and one part alcohol. Since contamination of the liquid would cause a deposit on the lamp, it is desirable to use distilled water and to keep the whole system very clean. A good method of preventing the formation of a deposit is to add 0.1 % of sodium phosphate (Na_3PO_4) to the liquid.

In certain cases the noise caused by the pump and fan may be disturbing. In those cases one may use siphon cooling (*fig.* 7), where the heating due

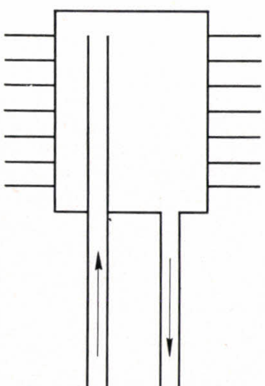

Fig. 7. Diagram of a siphon cooling apparatus. The flow of liquid is maintained by convection currents from the lamp. In the reservoir which is provided with cooling fins the liquid is cooled again.

to the lamp provides for the circulation of the liquid. The liquid cools off again in the reservoir. Because of the low circulation velocity it is impossible to prevent the formation of vapour bubbles in the cooling water. This is accompanied by a gradual decrease of clearness of the quartz tube.

Source of current

As we have already mentioned, the lamps discussed here can be used on alternating current as well as on direct current. The voltage of the supply must be higher than the working voltage of the lamp the difference being taken up by a resistance or, with alternating current supply, by a choke or a transformer with magnetic leakage. Immediately after the lamp has been switched on, while the mercury pressure has not yet reached its final value, the voltage across the lamp is very small, so that practically the whole voltage of the supply is borne by the series resistance or choke. The current then flowing (starting current) should not be too small or the lamp does not warm up at all [5]). A starting current which is too great is also harmful; a good value is 2 to 3 times the normal current.

The leakage flux transformer used with alternating current feed gives a terminal voltage for the SP and SSP lamps of 600 V and 900 V, respectively, with a short circuit current of 2.5 A. At this value of starting current, the lamps light themselves and reach their full intensity within a few seconds. For a detailed explanation of the connections we refer to the description of the mercury lamp HP 300 (footnote 1) and to the article about alternating current circuits for discharge lamps in an earlier number [6]).

Direct current can be obtained from a rectifier or a converter. With direct current one must use a series resistance and the losses are much greater than is the case with a transformer having leakage inductance. For the lamps SP and SSP one must have a source of current with no-load voltage of 500 V and 750 V respectively. As may be seen from Table I, when the SP lamp is fed with direct current, 80 V are taken up by the resistance. Since the working current is 1.3 A, the resistance must be 80/1.3 = 61.5 ohms. If the supply were connected directly to the lamp and this resistance the starting current would be almost 500/61.5 = 8.1 A. Such a high current would destroy the electrodes. In

[5]) For a detailed explanation see Philips techn. Rev. **1,** 129, 1936.

[6]) Philips techn. Rev. **2,** 103, 1937.

order to limit the starting current to a reasonable value, 4 A for example, the resistance upon closing the circuit must be 125 ohms. Only after ignition may it be brought to its final value.

In order to keep the losses in the series resistance low, it is desirable to keep the no-load voltage as small as possible. This may cause the ignition to be less reliable than is the case with alternating current. A circuit in which this disadvantage has been overcome may be seen in *fig. 8.* When the

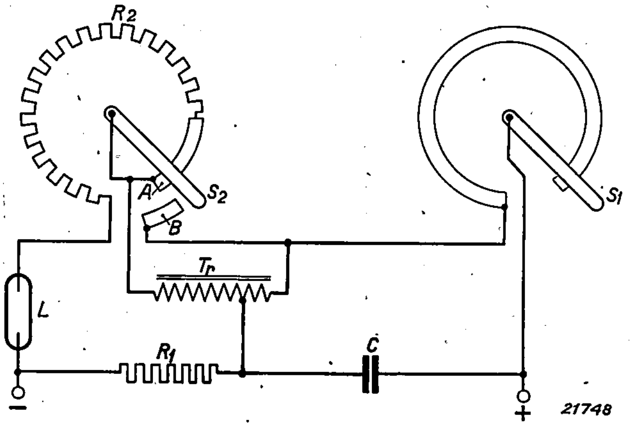

Fig. 8. Circuit for a mercury lamp with direct current. Both switches S_1 and S_2 are mounted on one spindle. S_1, however, has a certain play, so that upon moving it forward as well as backward, it remains behind S_2 by a certain angle. Upon turning the switches forward the contact between A and B is first broken and then the contact S_1 is closed, thereby connecting the lamp to the supply. At the same time the condenser C, which was previously charged, now discharges through a section of the transformer Tr. The voltage surge thus occurring causes the lamp to light. By turning farther, the resistance R_2 is decreased until the lamp takes up the correct amount of energy. Upon switching off, the resistance is first increased again. S_1, now remains so far behind S_2, that the contact between A and B is made before the circuit is broken with S_1. The inductive winding of Tr is thereby short-circuited so that upon switching off no high tension surges can occur. Upon switching on, however, A - B is again first opened.

switch S_2 is rotated the contact A - B is first broken, and then the direct current voltage is switched on by the switch S_1, which is coupled with S_2. At the same time the condenser C, which was charged previously, is discharged through a section of the transformer Tr, so that the voltage between the terminals of the lamp is temporarily raised and the lamp lights. When the knob is turned farther, the resistance R_2 is diminished gradually to the correct value. Upon switching off, R_2 is first again increased. Just before the contact S_1 is broken, the transformer is short circuited by means of the contacts A - B of the switch S_2. The occurrence of high inductive voltages upon breaking the circuit is thereby prevented.

Possibilities for application

In many cases where at present arc lamps or large glow-lamps are used, one may to advantage substitute SP or SSP lamps. It is true that the necessity of water-cooling may be considered a disadvantage, but to offset this there are great advantages, such as: small current consumption, slight heat radiation, small dimensions, absence of smoke or dirt, little upkeep, etc., while one may often be able to make use of their more special characteristics such as shape of the light-source, colour, smallness of the discharge inertia, etc.

It is still an open question which application will prove to be the most important in future. The following description of some applications, of which we already have experience, may be interesting.

Film studio lighting

Due to the high efficiency one can obtain an illumination by means of mercury lamps which is equivalent to that of existing arc lamps, but taking only about 1/3 of the power. The illumination is equivalent in the sense that it gives the same number of lux. In photography it is the actinic effect, and not the visual quantity, the lux, which is the standard. This actinic effect on panchromatic material is for mercury light about twice as high as for arc-lamp light of the same visual brightness, so that "equivalent" in the photographic sense means that one can work with 1/6 of the original energy. As is known a panchromatic emulsion has a rather low sensitivity to green light, as regards its colour reproduction in photography. The light of the water-cooled mercury lamp contains a large amount of green, so that in photography with mercury light the various colours are reproduced in a good natural relation. The reproduction of red is also satisfactory.

A very important advantage of the mercury lamp is the small amount of infra-red radiation. In order to give some impression of this, measurements were made of the increase in temperature undergone by the human skin upon irradiation, with mercury and incandescent lamps respectively, at different light intensities (*fig. 9*). The results depend of course very much on the characteristics of the skin of the person in question and on the size of the surface irradiated, and may only be considered as an illustration. In the case mentioned 4.5 times as much mercury light as incandescent lamp light could be sustained for the same increase of temperature.

Television

The SP lamp has proved suitable for fulfilling two functions in the Philips television transmitter.

Only after the installation of mercury lamps in the studio was it found possible to have sufficient illumination without the actors being too much inconvenienced by the heat. The weakness of the

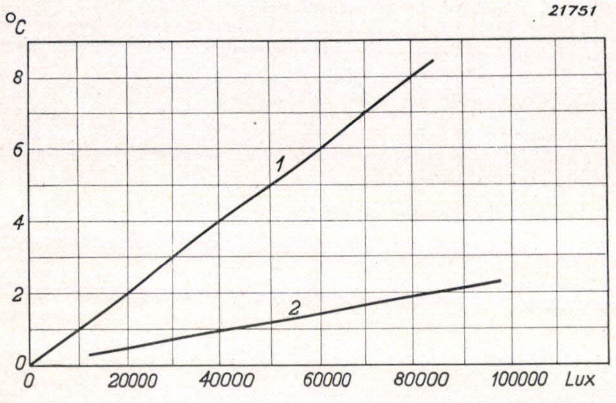

Fig. 9. Increase in temperature of a portion of the skin (lower arm) upon irradiation with light from incandescent lamps (*1*) and water-cooled mercury lamps (*2*) respectively. For equal increases in temperature $4^1/_2$ times as much mercury light can be employed as incandescent lamp light.

infra-red radiation was found to offer still another advantage. The iconoscope used for the broadcasting is very sensitive to infra-red. This is by itself no disadvantage, but the lens used was not chromatically corrected for infra-red, and therefore when mercury light was used sharper pictures were obtained. The installation contains 10 mercury lamps of 500 W and 3 of 3 kW.

Water-cooled mercury lamps were also used for scanning films in transmitters with a Nipkow disc. As explained in a previous article [7]) about this installation, the linear form and the great brightness are advantages which are lacking with other light-sources.

Searchlights

The first requirement of the light-source of searchlights is a high surface brightness. The SSP lamp, which has a surface brightness of 91000 candles/cm², is clearly suitable. By increasing the loading the surface brightness may be considerably raised. For example, with an energy of 1400 W/cm a surface brightness of 160 000 candles/cm² can be attained. The increase in energy is of course accompanied by a decrease in life. The SSP lamp offers a compromise in this respect and has a life of about 25 hours.

A difficulty in the application to searchlights is presented by the linear form of the mercury lamps. It is desirable to place the light-source in the reflector in such a way that all the light is radiated as close as possible to the focus. The extremities of the lamp give rise to strongly diverging rays, and contribute little to the intensity of the searchlight. It therefore serves no useful purpose to increase the energy by making the light-source longer. One may, however, attain greater intensity by placing several lamps next to each other, so that the light-source is made broader. A suitable holder is shown in Fig. 3. It contains three lamps with a total energy of 2.5 kW.

Air-port lighting

A very good adaptation of the reflector to the linear form of the light-source is obtained with cylindrical parabolic mirrors. These mirrors have a focal line, and by allowing the path of the discharge to coincide with the focal line a flat disc-shaped beam with an angle of divergence of 180° is obtained which is particularly suitable for the lighting of landing fields.

In this case, the length of the light source is not limited as with circularly symmetrical mirrors, so that longer tubes with higher energy may be used. The largest projector constructed in this way has a lamp 30 cm in length, with an input of 16 kW. It has, however been found that with much less energy very good results may also be obtained. With the 2.5 kW system shown in *fig. 10* completely satisfactory illumination was obtained at "Welschap", the Eindhoven air-port. By setting up such an apparatus on all four sides of the field,

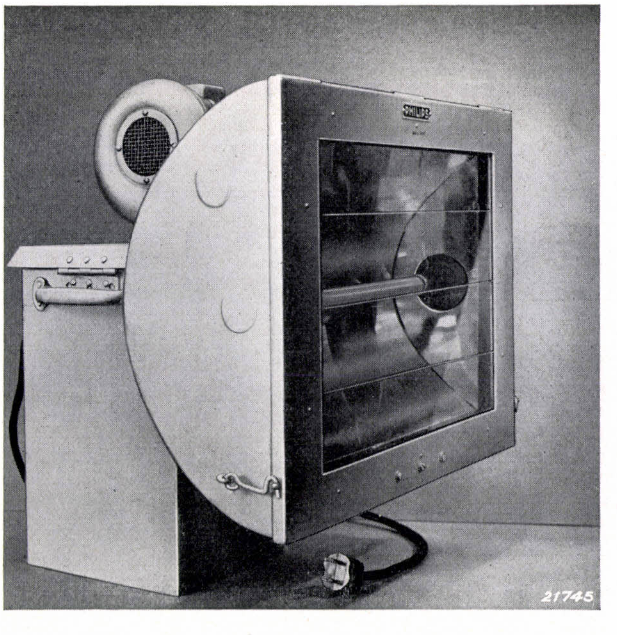

Fig. 10. Apparatus for the lighting of landing fields. The cylindrical parabolic mirror is built on to the transformer housing. Input 2.5 kW.

[7]) H. Rinia and C. Dorsman, Philips techn. Rev. **2**, 72, 1937.

the direction of radiation can be adapted to the landing course for every wind direction.

Grass reflects mercury light particularly well, this is a special advantage of the unusual intensity of the green mercury line.

This concludes our account of some applications of water-cooled mercury lamps: there are undoubtedly many more. We hope, however, that we have been able to give an impression of the possibilities offered by this new light source.

AN ULTRA SHORT WAVE TELEPHONE LINK BETWEEN EINDHOVEN AND TILBURG

by C. G. A. VON LINDERN and G. DE VRIES.

Summary. A telephone connection between Eindhoven and Tilburg is described, in which use is made of waves of about one metre in length. Triode transmitters and "autodyne-superhet" receivers are employed. Directional aerials of the Y a g i type with an amplification of 3.5 are used. The field strength was recorded during the three months that the installation has been in use.

Introduction

The results of experiments carried out in the Philips laboratory on waves of about 1 metre in length led to the attempt at a practical application in the domain of telephone communication. Thanks to the collaboration of the Dutch National Post, Telephone and Telegraph Service permission was given us to carry out an experimental wireless connection between Eindhoven and Tilburg.

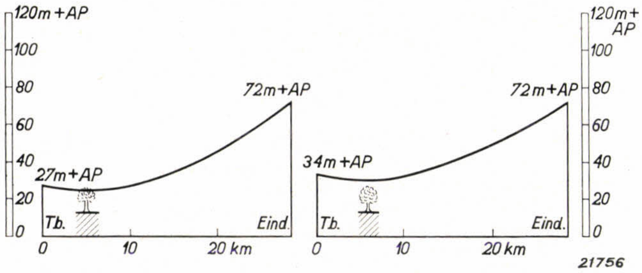

Fig. 1. The curved line represents the line of direct vision between the transmitter and the receiver in the connection between Eindhoven and Tilburg. The earth is here drawn flat, as x-axis, and represents sea-level. On the left an aerial of only 2 meters was erected on the roof of the factory building in Tilburg, while in the right-hand figure it was 9 metres high.

The first requirement of a reliable radio connection by means of ultra short waves is that the receiving aerial must be visible from the point where the sending aerial is placed. By "visible" in this case is meant that the line joining transmitting and receiving dipoles must be at least 10 metres above the tops of trees and buildings. In *fig. 1* the x-axis represents sea-level. The distance from Tilburg is set off horizontally, and the height above sea level vertically. In Eindhoven the aerial is erected at a height of 72 m on the roof tower of one of the Philips factories.

In the left-hand figure is represented the situation when the aerial in Tilburg was only 2 m above the roof of a factory building there. The curved line, which represents the line of direct vision, is found to pass through the tops of trees between the two towns. As a matter of fact very little was received on these ultra short waves with such a short aerial.

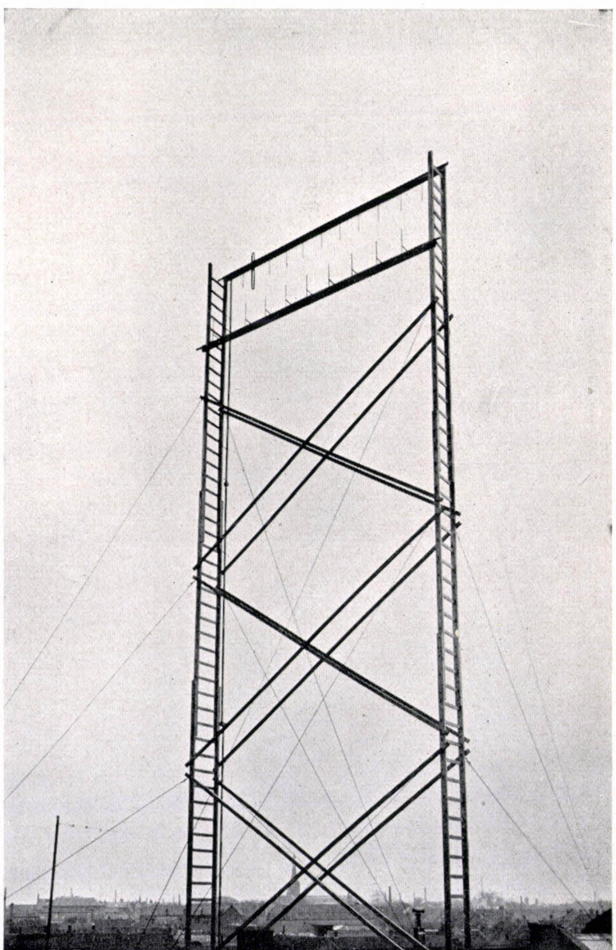

Fig. 2. The aerial arrangement in Tilburg. The aerials are mounted between two ladders; the receiving aerial is 13 m above the roof, and the transmitting aerial 15 m.