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Some Operating Characteristics of a Xenon and a Xenon-Mercury, Short-Arc Lamp Immersed in Water

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ABSTRACT

Two types of high-intensity, short-arc lamps have been operated when immersed directly in water, and some of their underwater optical and electrical operating characteristics have been measured. One lamp was filled with xenon gas and was rated at 2.2 kW dc, and the other lamp was filled with both xenon and mercury and was rated at 1 kW ac. These lamps were chosen for the very high brightness and small size of their arcs which are required for high-intensity light-beam projection in an underwater searchlight. Also, they can be flashed for signaling purposes.

During the underwater operation of the lamps, the water was in direct contact with all of their outside surfaces except for the metal electrical terminals, which were insulated. The xenon lamp had the same intensity and operated at the same power level underwater as it did in air, but the xenon-mercury lamp had a 20 times lower intensity and a 50 percent lower operating power level underwater than in air. The xenon lamp was operated for approximately 100 hours in water with no visible deleterious effects of a permanent nature to the lamp. It was seen, however, that a coating built up on the lamp envelope on continued operation in saline water. Operation of the xenon lamp was accomplished in water pressures up to 380 psi (880-ft depth). The lamp has been incorporated into a free-flooded underwater searchlight that has been operated successfully in various bodies of fresh and salt water.

PROBLEM STATUS

This is an interim report; work is continuing on the problem.

AUTHORIZATION

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SOME OPERATING CHARACTERISTICS OF A XENON AND A XENON-MERCURY, SHORT-ARC LAMP IMMERSED IN WATER

INTRODUCTION

Many light sources that are used underwater project rather broad beams of light since, in general, they are intended for the illumination of extended areas at close distances. However, for some underwater applications, it may be necessary to project a narrow beam of very intense light which can be flashed on and off for signaling purposes.

For the projection of a narrow, intense beam, a short-arc lamp has the required characteristic of emitting light from a small, intensely bright arc. The brightness of the arc can be raised or lowered by controlling the electrical current through the lamp, and, thus, a projected light beam can be flashed by controlling the current. This type of lamp has been used as a light source in signaling searchlights in air.

In addition to having characteristics required for narrow, intense light-beam projection, a short-arc lamp has some unique characteristics that especially suit it for use in water. It emits light that is rich in the blue-green spectral region where clear water is most transparent, and it is constructed strongly to withstand high pressures. Its strong construction would seem to allow its operation directly in the sea at great depths without the danger of breakage, thus eliminating the need to enclose it in a heavy, watertight housing.

In view of the several characteristics of a short-arc lamp which distinguish it for use in an underwater narrow-beam projector, two typical commercial lamps were chosen to determine some of their operating characteristics when they were completely immersed in a water bath. One lamp that was filled with xenon and rated at 2.2 kW was found to operate essentially the same underwater as it did in air. The other lamp that was filled with a small amount of mercury in addition to xenon and rated at 1 kW operated at a lower power and had a greatly reduced light output level underwater. For both lamps, the metal electrical terminals had to be insulated for operation in artificial salt water, but no insulation was required in tap water. On continued operation of the xenon lamp in salt water, a hard coating accumulated on the lamp envelope, which diffused the light emitted by the arc. The coating did not, however, cause any permanent deterioration of any of the lamp surfaces, as far as could be seen after it was scraped off.

Subsequently, the xenon lamp was incorporated into a free-flooded, high-intensity, underwater searchlight and operated successfully in bodies of both fresh and salt water and at water pressures up to 380 psi. By means of a searchlight control unit, the lamp could be operated at high or low dc levels, flashed between the two levels in Morse code fashion, or modulated at a frequency of 1 kHz.

LAMP CHARACTERISTICS IN AIR

A short-arc lamp (Fig. 1) is constructed with a quartz envelope and a metal electrical terminal at each end; in the middle the envelope is enlarged into a bulb shape. At this region within the envelope are two electrodes between which an arc is established to generate light. The arc gap varies somewhat depending on lamp power and the gas filling

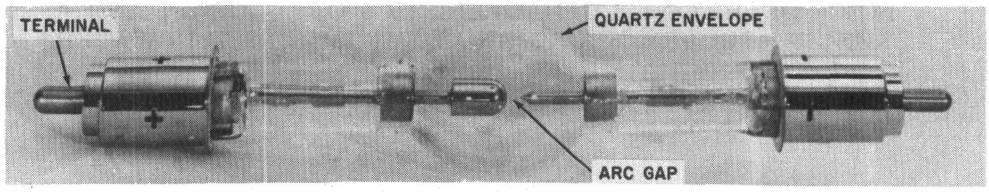


Fig. 1 - A typical short-arc lamp

among other things, but it is generally around several millimeters. In Fig. 1 is shown a typical dc lamp which has a negative and a positive electrode; ac lamps are also available. Most commercial lamps are filled with xenon, mercury, or a combination of both, and their light output is characteristic of the filling.

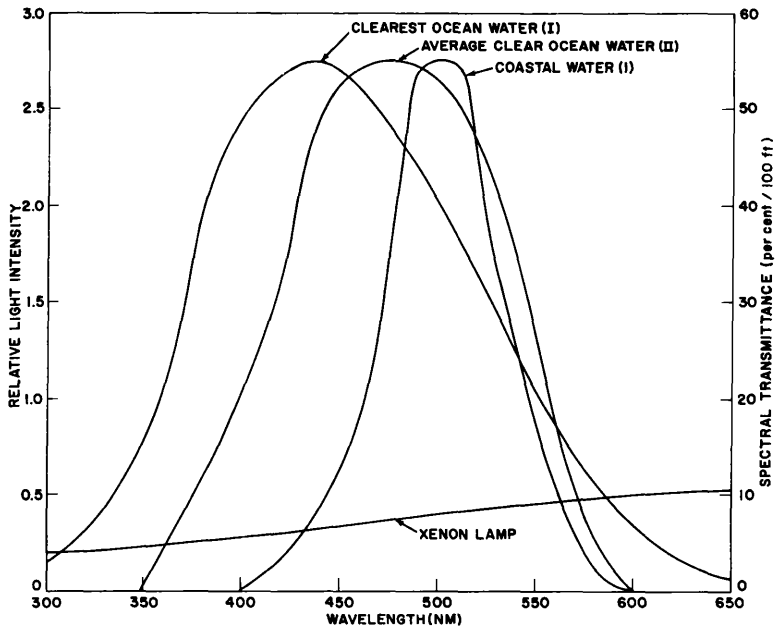
The light emitted by a short-arc lamp consists of both a continuum and lines of its gas filling as shown in Fig. 2.* The continuum is produced by the very high-temperature arc plasma that exists in the envelope at pressures in excess of 20 atmospheres. A lamp that is filled with xenon emits no significant line radiation at visible wavelengths (Fig. 2a), but a xenon-mercury lamp has strong mercury line emissions throughout the visible spectrum (Fig. 2b).

Figure 2 also shows spectral transmission curves for light transmitted through a 100-ft path of three types of seawater. The spectral transmittances given by the curves were calculated from data published by Jerlov (1). Curves I and II are representative of the clearest and the average clear ocean water, respectively, based on typing water in most ocean areas as type I, II, or III. Water found along coasts was also typed from clearest to most turbid with numbers 1 through 9; curve 1 in Fig. 2 is representative of the clearest coastal water, which is not as clear as type II ocean water. Curves II and 1 have been normalized by multiplying their spectral transmittances by factors of 1.9 and 19 respectively to bring their peaks up to the same level as the peak of curve I on the graph. Normalization aids in showing that the wavelength of maximum transmittance shifts to higher wavelengths and the spectral band of light transmitted by the water becomes more narrow as the water becomes more turbid.

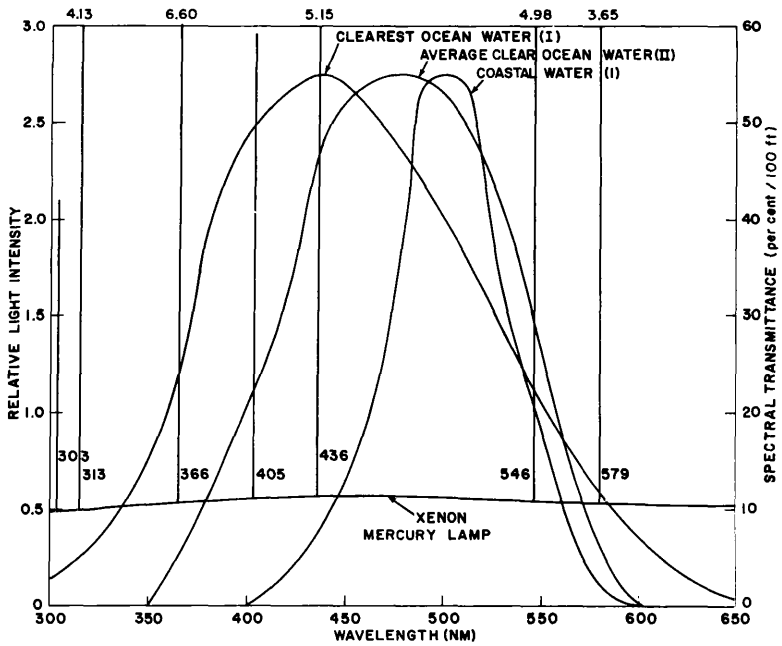
From a comparison of the spectral distribution of light curves and the spectral transmission curves shown in Fig. 2, it appears that a xenon-mercury lamp emits light that has a more desirable spectral composition for effective transmission through water than does the xenon lamp. In the first place, the continuum of the xenon-mercury lamp is relatively strong at all the wavelengths of light transmitted by water, while the continuum of the xenon lamp becomes weaker as the wavelength decreases, which is especially undesirable for light transmission in the clearest water (curve I). Secondly, some of the intense lines of mercury occur near the peaks of the transmission curves, and thus, the radiation in those lines would be transmitted effectively. In particular, the 436-nm line would be transmitted effectively by type I and II water and the 405-nm line by type I water. The 546- and 579-nm lines would be transmitted more effectively relative to the lower wavelength lines in coastal water (see curve 1) where the water is turbid.

Short-arc lamps are available in a number of different sizes; of these, a 2.2-kW, dc xenon and a 1-kW, ac xenon-mercury lamp were chosen for the underwater measurements reported herein. The in-air operating characteristics of the two lamps, according to the manufacturer's data, are shown in Table 1. Note the small arc sizes (2.5x4 mm

*Curves plotted from data published by manufacturer.



(a) Xenon lamp



(b) Xenon-mercury lamp

Fig. 2 - Spectral distribution of light from two short-arc lamps and the spectral transmission of light in three types of seawater for normalization curve II has been multiplied by 1.9; curve 1 by 19.

Table 1
In-Air Characteristics of a Xenon and a Xenon-Mercury Short-Arc Lamp

Lamp	Rated Power (kW)	Rated Voltage (V)	Rated Current (A)	Effective Arc Size (mm)	Average Arc Luminance (cd/mm^2)	Horizontal Intensity (cd)	Radiated Luminous Flux (lm)	Luminous Efficacy (lm/W)	Average Life (hr)
Xenon	2.2 dc	20-22	100	2.5 x 4	500	7000	80,000	36	1000
Xenon-Mercury	1.0 ac	60-70	18	2.5 x 5	167	5400	50,000	50	300

for the xenon lamp and 2.5 x 5 mm for the xenon-mercury lamp) and also their high intrinsic luminances (500 cd/mm^2 for the xenon lamp and 167 cd/mm^2 for the xenon-mercury lamp). The small sizes and high luminances make these lamps very suitable for use as "point" light sources in an optical system for projecting an intense, narrow light beam. In addition, the total radiated luminous flux (80,000 and 50,000 lumens for the xenon and xenon-mercury lamp, respectively) is high; therefore, these lamps may be used also to project a broad light pattern for general illumination.

UNDERWATER OPERATION

Xenon Lamp

Underwater operation of the two chosen short-arc lamps was accomplished in a laboratory water bath, where the lamps were immersed directly in water and completely surrounded by it. The lamp voltage, current, and light output were measured for both lamps as they burned in the water. The lamp ballast resistance remained the same as that established for proper in-air operation, as did the supply voltage.

Under the above conditions, the voltage, current, and light output of the bare xenon lamp in water were found to be essentially the same as they were for the lamp operated in air. Figure 3 shows the lamp burning in water. Underwater, the lamp operated at its rated 20 V and 100 A, and its light intensity was about 6500 cd. When high-voltage, rf pulses were applied across the lamp for starting, the arc ignited quickly in a normal fashion, and the lamp voltage, current, and light output immediately came up to and stabilized at their normal in-air levels.

Although the bare lamp started satisfactorily in tap water, it would not start in artificial salt water. In salt water, bubbles formed at the bare metal terminals of the lamp when voltage was applied to them, and the arc would not ignite. Figure 4 shows the extent of bubble formation when 28 V dc was applied across the terminals; in this condition, 5 A were drawn from the power supply. The artificial salt water was prepared to have a salinity close to that of ocean water.

A second attempt was made to operate the lamp in a salt water bath after the metal terminals were completely insulated from the water. Insulation was accomplished rather superficially by covering each terminal with plastic tubing and by coating any remaining exposed metal surfaces with silicone rubber cement (see Fig. 5a). Electrical leads were fed through the tubing to the terminals. With the terminals insulated from the salt water in this manner, the lamp operated normally, as in tap water.

On continued operation of the lamp in the artificial salt water bath, it was noticed that a coating gradually built up on the outside of the bulb of the envelop. After 17-1/2 hours of operation, during which the lamp was flashed between high and low intensities in Morse code fashion at a rate corresponding to about 10 words per minute, the coating appeared as shown in Fig. 5a. At this time the thickness of the coating was such that the lamp electrodes were just barely visible. Their visibility was about the same regardless of the part of the bulb through which they were viewed, indicating that the coating was approximately uniformly thick over the entire bulb. The coating transmitted light diffusely.

After the coating was removed by wiping the bulb with acetone, the lamp was found to be in good condition, and the salt water test was continued. The lamp was ignited and burned without difficulty for approximately 8 hours per day for 10 days before it was removed from the water and examined once again.

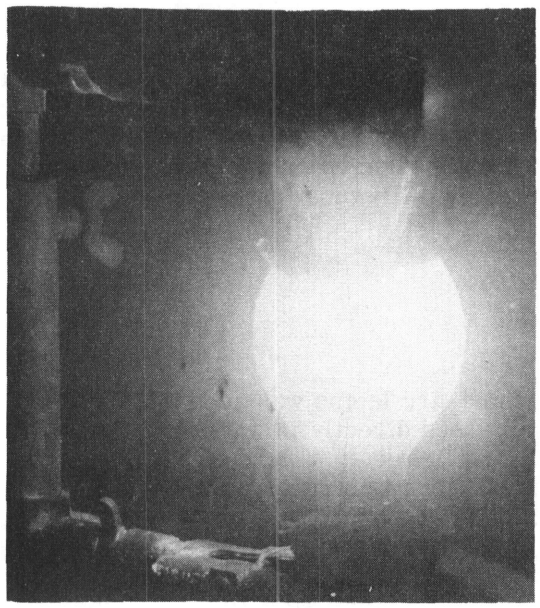


Fig. 3 - A 2.2-kW xenon lamp burning underwater

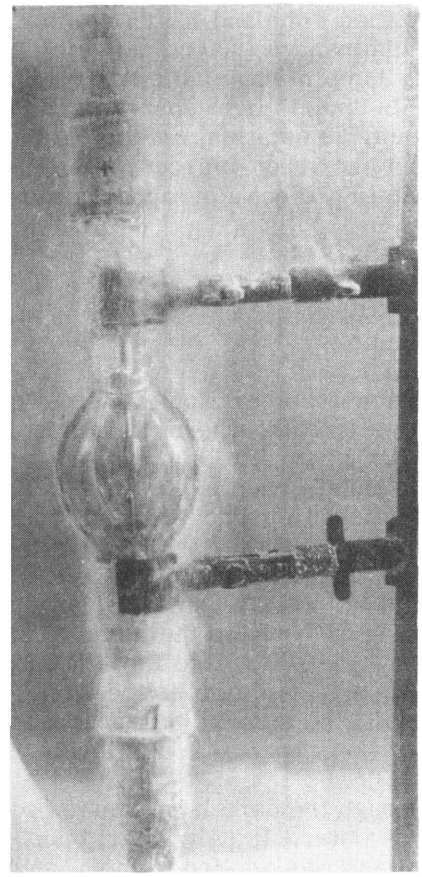
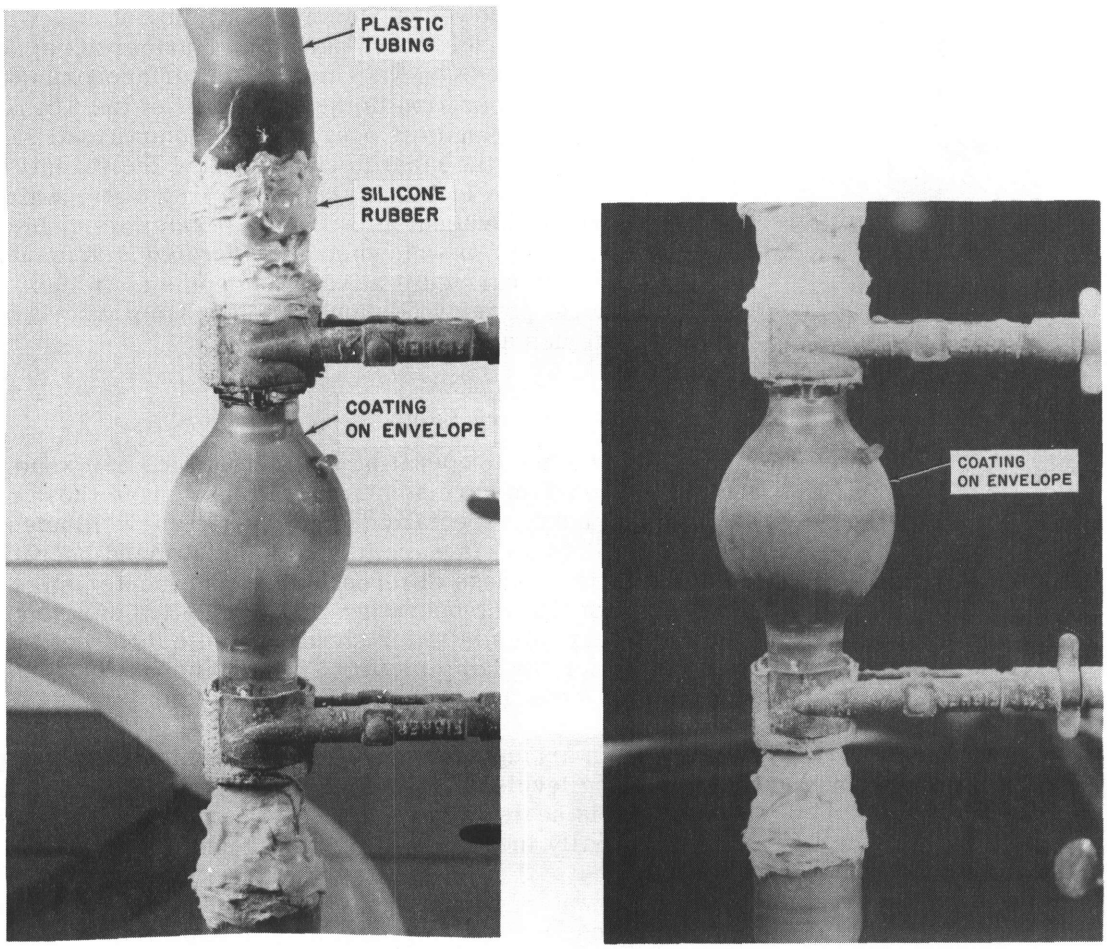


Fig. 4 - Bubbles formed at the bare terminals of a 2.2-kW xenon lamp immersed in artificial salt water

At this time a much thicker and harder coating had built up on the bulb. Attempts were made to remove it by rubbing with many different solvents, but none of the solvents were effective; it was finally removed by scraping. As before, the coating transmitted light diffusely; however, now the thickness was such that the electrodes could not be seen through it. Again, its thickness appeared to be about the same over the entire bulb. After it was scraped off, the lamp appeared to be in good condition (Fig. 6). The only observed change in the lamp was a very slight coating that could be seen covering the inside of the bulb. This was probably material sputtered off the electrodes, which occurs normally during the life of a short-arc lamp.

Subsequent to the laboratory water bath measurements, the lamp was operated successfully in a water tank at pressures up to 380 psi. During the test, the lamp was connected through 300 ft of cable to a control panel located outside the pressure tank. From the control panel, the lamp was operated at dc power levels of both 2200 and 110 W for extended times under pressure and flashed between the two levels in Morse code fashion, corresponding to a message rate of 10 words per minute. The light output was unaffected by pressure. The maximum pressure was limited to 380 psi because the lamp igniter enclosure, which was also placed within the pressure tank, began to buckle at this pressure, and thus, the test was terminated. After the lamp was removed from the tank, it was examined and found to be unaffected by the test. It is reasonable to expect satisfactory lamp operation at much higher pressures.



(a) 17-1/2 hours operating time (b) 81 hours operating time

Fig. 5 - Coatings on lamp envelop after different operating times in artificial salt water

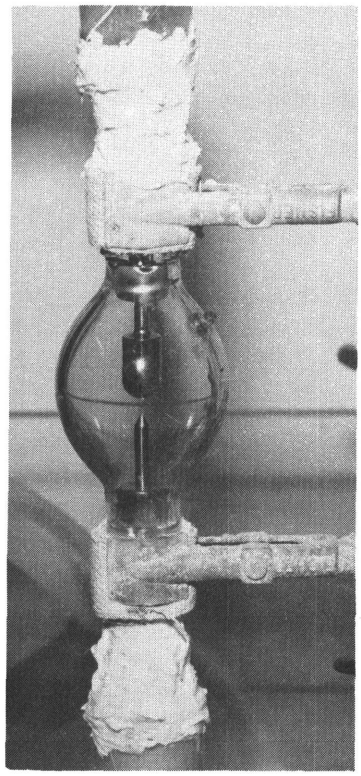


Fig. 6 - Lamp after removal of the coating shown in Fig. 5b

Following the pressure test, the lamp was incorporated into an underwater searchlight and operated for many hours in bodies of both salt and fresh water without detrimental effects. In all of the bodies of water (Patuxent River, Chesapeake Bay, and a water-filled quarry), there was a large amount of suspended material present as indicated by the low water transmissivities which were measured; they ranged between 5 and 35 percent/m. However, this material did not affect the lamp or its underwater operation. Furthermore, no coating was seen on the lamp bulb after approximately 20 hours of operation in the salt water of the Chesapeake Bay as was seen after operation in the artificial salt water bath in the laboratory. No doubt the salinity of the Bay water was less than that of the bath water which was prepared to be about as saline as ocean water. In the Bay, the lamp was mounted and operated atop a submarine, which carried it at various depths down to 60 feet. Electrical power was supplied to the lamp from a bank of batteries aboard the submarine.

Xenon-Mercury Lamp

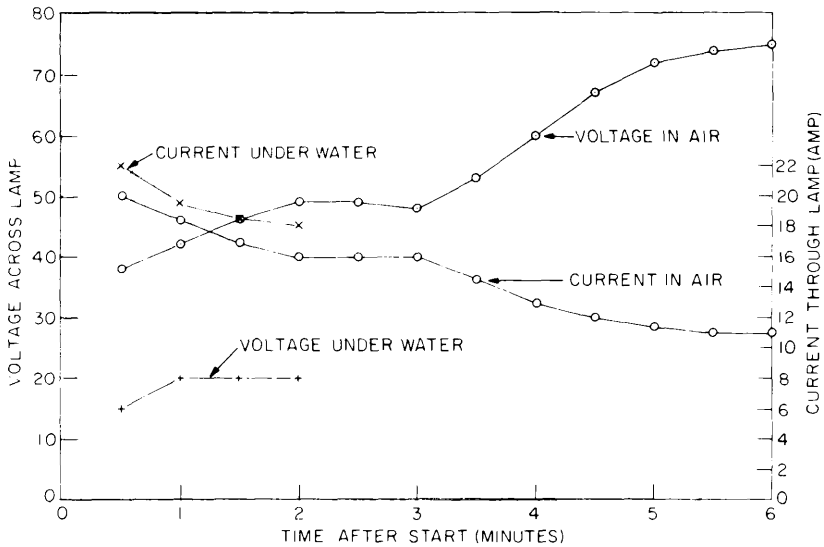
The in-air operating characteristics of a xenon-mercury lamp are somewhat different from those of a xenon lamp, especially during the first few minutes when the lamp is warming up to a stabilized operating condition. These different warmup characteristics suggest that the operating characteristics of a xenon-mercury lamp in water should be quite different from those for the lamp in air. This was borne out by underwater measurements made on a 1-kW ac lamp.

This lamp requires about a 6-min warmup period before the maximum light output and stable voltage and current operating levels are reached during normal operation in air. During the warmup, the mercury is heated and vaporized, the pressure builds up in the envelope, and the light output gradually increases to its maximum steady level.

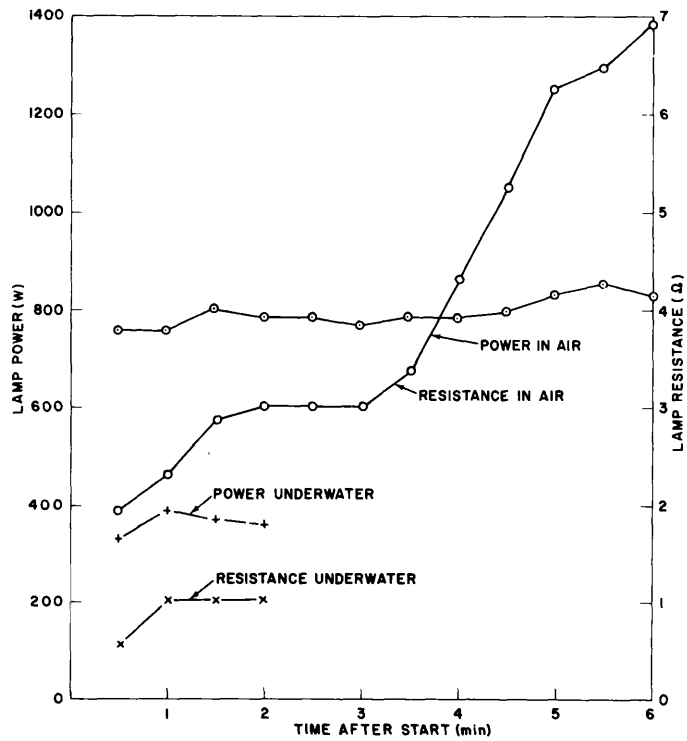
When the lamp was operated underwater, its voltage, current, and light output were measured to be quite different from those measured in air, as was expected. Figure 7a shows the underwater and in-air voltages and currents measured at different times after the lamp was started. As in air, the underwater voltage increased and the current decreased as the lamp warmed up, but the voltage and current levels were much lower and slightly higher, respectively, underwater than they were in air. Underwater, the voltage increased from 15 to 20 V and the current decreased from 22 to 18 A between 1/2 min and 2 min after start. By 2 min after start, the voltage and current became steady, which indicated that stable operation had been reached.

In contrast to the underwater voltage and current changes, the in-air voltage increased in an irregular manner from 38 V at 1/2 min after start to 75 V 6 min after start, and the in-air current decreased from 20 to 11 A during the same period. Six minutes were required for the lamp to reach stable operation in air as compared with 2 min for underwater.

In the stable operating condition, both the electrical power input to the lamp and its arc resistance were lower for underwater than for in-air operation, as shown by the



(a) Voltage and current



(b) Power and resistance

Fig. 7 - Underwater and in-air electrical operating characteristics of a 1-kW xenon-mercury lamp during startup

curves in Fig. 7b. Data for these curves were calculated from the voltages and currents shown in Fig. 7a. Underwater, the power consumed by the lamp (lamp voltage times current) reached a value close to only 400 W, whereas the in-air power consumption reached a value over twice as great (825 W). The underwater lamp resistance leveled off quickly to 1 Ω within 1 min after start. The in-air resistance, on the other hand, increased in an irregular manner from 2 to almost 7 Ω during the measurement time. The lower underwater resistance probably resulted from the cooling effect of the water on the lamp, which kept the temperature and pressure of the gas within the lamp at a low level.

Light measurements showed that the overall underwater light output from the lamp was 20 times less than its output in air. The light measurements were made at approximately the same lamp voltages and currents shown in Fig. 7a after stable underwater and in-air operating levels had been reached. The overall light output was measured by a phototube that had an S-5 spectral response and thus was relatively more sensitive to blue light than to red.

Light measurements were also made in two separate spectral bands centered on the 436- and 546-nm mercury lines. These bands were isolated by placing narrowband (approximately 10-nm bandwidth) transmission filters in front of the phototube. With this arrangement, the underwater light output from the lamp was lower than that from the lamp in air by 50 times at 436 nm and by 10 times at 546 nm. The large difference in light reduction measured in the two bands shows that the spectral distribution of the light from the lamp underwater was different from the lamp in air. It appears that the underwater lamp may not have reached a temperature high enough to fully vaporize the mercury and produce the typical mercury spectrum of light emitted during in-air operation.

CONCLUSION

From the various measurements and tests made on a 2.2-kW xenon and a 1.0-kW xenon-mercury, short-arc lamp, it has been determined that these lamps can be operated satisfactorily when immersed directly in water. Thus, they may be used as point sources of light in an underwater searchlight for projecting an intense, narrow light beam without the necessity of enclosing them in a watertight housing. The light from the lamps can be flashed between high and low levels from a remote position for signaling purposes.

The operating characteristics of the xenon lamp were about the same underwater as they were in air, but the underwater light output from the xenon-mercury lamp was much lower than its in-air output. When the xenon-mercury lamp was operated underwater, its intensity was reduced by a factor of 20 from its in-air value. Thus, the xenon lamp is more suited for incorporation into a high-intensity underwater searchlight.

No permanent deterioration of either lamp was noted as a result of underwater operation. However, on continued operation in very saline water, a coating built up on the lamp envelope although no coating was noted after operation in the Chesapeake Bay. The coating diffused the light and acted as a secondary light source of large dimensions; consequently, narrow-beam light projection would be impossible with a coating covering the envelope. The coating was removed by scraping.

Although a lamp can be operated completely exposed in fresh water, insulation of its electrical terminals is required for operation in salt water. Otherwise, the lamp cannot be started.

Underwater operation of a xenon lamp has been accomplished at pressures up to 380 psi (corresponding to a depth of 880 ft), and it can probably be operated at much greater pressures.

A xenon lamp has been incorporated into a free-flooded underwater searchlight and has operated satisfactorily for several hundred hours in various bodies of fresh and salt water and atop a submerged submarine. Its usefulness extends to applications ranging from signaling to general illumination.

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13. ABSTRACT

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Point-source illumination						
Signaling						
Underwater lamp						
Xenon short-arc lamp						
Xenon-mercury, short-arc lamp						

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