system is Gaumont-Kalee "21" dual 30-w optical reproducer equipment with the addition of a four-track magnetic stereophonic system, with 10 auditorium-effects speakers and three main speakers behind the screen. Provision has been made for future installations of multi-magnetic/optical track follower heads and interlocks. The arc lamps are Gaumont-Kalee Presidents. The projectors are interlocked for projecting three-dimensional films and unmarried prints, and allowance has been made for future developments in new film presentations as far as is possible.

At the side of the 35mm machines are two G.B-Bell & Howell Model 609 arc 16mm projectors equipped to run at sound and silent speeds and either optical or magnetic track sound reproduction.

The preview theater is served by two Gaumont-Kalee "18" 35mm projectors and dual 18-w sound-film reproducer with Universal arcs; one machine is equipped for rear projection. To provide 16mm projection facilities, a single G.B-Bell & Howell Model 630 equipment specially adapted for long running with both optical and magnetic sound systems and recording facilities on magnetic track is installed.

In determining the position of the projection room, the length of throw and angle to the main screen were the main considerations in order to allow lenses of the most advantageous focal length, which falls within the range of focal lengths of backing lenses that will give the best coverage and sharp focus over the whole picture area. It is possible that some form of television projection may be required in the future.

The angle of projection is slightly negative so that there is no distortion of the projected picture.

Design Improvements in High-Wattage Tungsten Filament Lamps for Motion-Picture and Television Studios

By LEROY G. LEIGHTON
and ALFRED MAKULEC

The development of a special-type collector grid for use in high-wattage incandescent lamps used for motion-picture studio lighting is discussed. The collector grid is designed to maintain the beam lumen output of such lamps at a high level until filament failure occurs. Causes and effects of lamp blackening are explained.

SPECIAL PROBLEMS relating to the needs of motion-picture and television studios have long been of interest to designers and manufacturers of tungsten filament lamps. Color film and wide-screen processes have created new requirements, and the advent of color television has resulted in increasingly complex lighting problems. The demands for large quantities of controllable light in compact and quiet packages have been met with a series of studio lamps of high wattage. At General Electric, more than 65% of the incandescent lamps of 2000 w or more are designed for studio lighting or related service.

Studio Performance Problems

Increased use of high-wattage lamps has brought about extensive research aimed at improving quality and performance. Recently, efforts have been directed toward two problems: (1) reducing bulb blackening, thereby improving the lamp beam lumen maintenance and reducing the tendency of bulbs to blister in service; and (2) lessening the amount of audible noise produced by studio lamps on a-c circuits.

Lamps designed for spotlight service have high-wattage, concentrated filaments in relatively small bulbs. The studio lamps are much more heavily loaded than the lamps made for general lighting purposes. In addition, color film requirements demand high filament temperatures to produce light of satisfactory color characteristics. These design parameters tend to contribute to reduced lamp performance. First of all, the rate of evaporation of a tungsten filament increases greatly as its temperature rises. The high filament wattage results in a larger filament surface from which the tungsten evaporates, and this more rapidly evaporated tungsten is deposited on the bulb wall by the convection stream of the inert gas in the lamp. Bulb blistering and depreciation in beam candlepower are caused primarily by this black deposit. The relatively small bulb sizes required for studio lamps also contribute to poor beam maintenance, first, by the concentration of blackening on the bulb decreasing the amount of light reaching the lens and the mirror, and second, by the blackening absorbing radiation from the filament and causing the already very hot bulb to get even hotter.

When the bulb is in the base down position, the gas stream rises to the top of the bulb and deposits the blackening in a region where, because of the design of the filament, relatively little filament radiation impinges, but as the bulb is tilted, the gas stream still rises vertically and deposits tungsten in an area of greater filament irradiation; the spotlight reflector redirects the energy through the blackened zone. Thus, when a spotlight is aimed down at about 45°, the gas stream in the lamp carries the blackening to an area of the bulb where it obstructs light that would ordinarily contribute to the spotlight beam. As a result, beam lumens are decreased and the bulb temperature is increased.

This increase in bulb temperature due to blackening can, and frequently does, cause a vicious cycle to begin. It is characteristic of many glasses that they will give off small amounts of moisture when heated to high temperatures. When this moisture is released inside the bulb, a "water cycle" is started, causing a more rapid rate of blackening than would occur due to normal filament evaporation. This increased blackening absorbs more radiation, which in turn causes localized bulb temperatures to increase. Soon a point is reached at which part of the glass bulb becomes sufficiently plastic that the internal gas pressure blows a "blister" on the bulb. Spotlight lamp bulbs are heated to the highest practicable temperature during manufacture to remove much of the moisture from the glass. However, after blackening begins in confining spotlights, bulb temperatures may rise high enough to initiate the so-called "water cycle." This situation is at its worst in the 10,000-w lamp. Blistering is often so severe that the bulb glass may touch the spotlight reflector,

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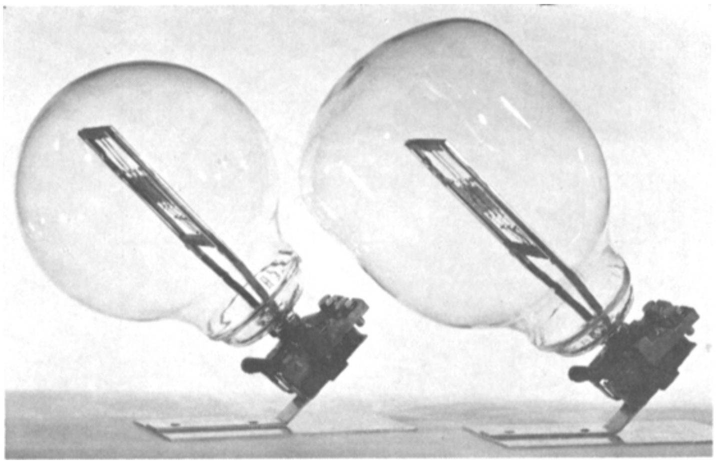

Fig. 1. Tubular bulb (right) for 5000-w lamp, designed to counteract blistering; earlier bulb at left.

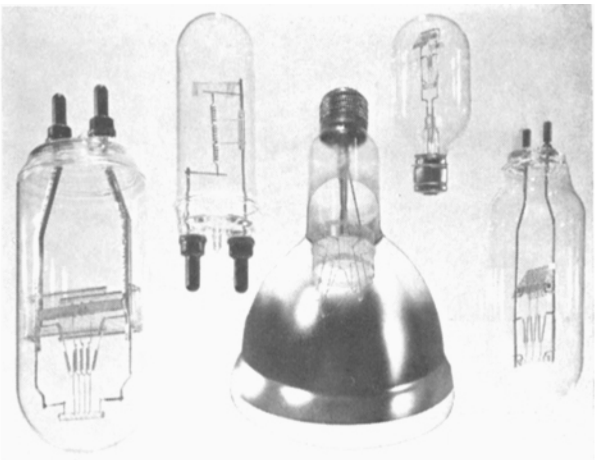

Fig. 2. Typical early collector grid lamps.

causing a crack that ends lamp life. As a result, 10,000-w lamps often must be removed prematurely from spotlight service and relegated to background floodlighting or other services that could be performed by less expensive lamps. It is estimated that 10,000-w lamps are useful in spotlights for only about 40 or 50 hr, although their filaments do not burn out until about 75 hr. In the 5000-w G-64 bulb and 2000-w G-48 bulb lamps, the problems are similar, but not so severe.

A further difficulty sometimes encountered with high-wattage studio lamps is that of noise. This problem is seldom encountered in professional motion-picture studios since d-c power is generally used. Lamp noise became a factor of importance first in TV studios, where alternating current sometimes produced sufficient noise in lamps of 1000 w or more to be picked up by sensitive microphones above the set and near the lighting equipment. This type of noise is often transitory and is not always caused by the same lamp or lighting unit.

Early Approaches to the Problems

One of the major contributions to the reduction of blackening and blistering problems was the introduction several years ago of tubular bulbs for 2000-w and 5000-w lamps. The extended contour of the tubular bulb shown in Fig. 1 is almost directly above the filament when the spotlight is aimed downward 45°. This bulb shape effectively "pre-blisters" the bulb, locating the hot spot farther from the filament. Blackening in this region interferes less with light that forms the beam. As a result, bulb temperatures are lower, blistering is greatly reduced, and bulb blackening has less effect on the spotlight beam. Unfortunately, this development is not applicable to 10,000-w lamps, since a tubular bulb of preferred contour will not fit in the vast majority of existing 10,000-w spotlights. Shortening the tubular bulb to fit these units does not improve lamp performance in proportion to the increased lamp cost.

An investigation was made to determine whether forced ventilation could sufficiently lower bulb temperatures to reduce blistering of 10,000-w lamps. The first findings were quite encouraging, as the cooling air aimed at the hot spot caused a significant drop in initial bulb temperatures. As the bulb blackened, however, the high rate of absorption of radiation nullified this good effect. Blowers of high capacity (and annoyingly high noise levels) could not remove heat fast enough to prevent blistering. In the face of limited reduction of blistering and no decrease in blackening — and considering the higher equipment cost and noise problems — it was decided to abandon the fixture-ventilation program.

An attempt was also made to reduce blackening and blistering by internal construction changes in the lamp. For many years, lamp designers have used collector grids or screens to improve lumen maintenance of their products (Fig. 2). Thomas Edison was granted three patents during the period between 1881 and 1883 on the use of various forms of collector grids to control bulb blackening. There are about 15 American patents and several foreign patents covering various configurations and arrangements of blackening control devices. Conventional grids have been tried in various studio lamps, including the 10,000-w size, with no success. Conventional grid materials had to be located too far from the filament, due to the temperatures involved, to control blackening effectively in the most critical burning positions.

The noise problem was attacked with some success in studio spotlight and floodlight lamps in the 1000-w to 5000-w range. Solutions varied for individual lamps, but they generally involved the reduction of the amount of magnetic material within the lamps and, in some cases, relocation or rearrangement of lamp parts so as to restrict magnetic effects. As a result, the lamps commonly used in television studios are now available in a "low-noise" line that significantly reduces noise effects. Some noise problems remain, but these are often due to elements external to the lamp, or else due to amplification effects caused by the acoustics of the lighting equipment.

A New Approach to Design of the 10,000-w Lamp

Several years ago, it was decided to approach design of the 10,000-w lamp with a drastic departure from conventional design. It was known that the most effective location for a collector grid is directly above the filament and close enough to the filament to intercept most of the rising gas stream. In many lamps, the screen cannot be ideally located because of construction problems or interference with an optical system.

In considering the 10,000 w lamp, it was felt that locating the grid close enough to the filament should produce favorable results that would outweigh any losses caused by the screen shading a portion of the pickup angle of the mirror. A screen located close to the filament can be much smaller to intercept the gas stream (Fig. 3) and its higher tempera-

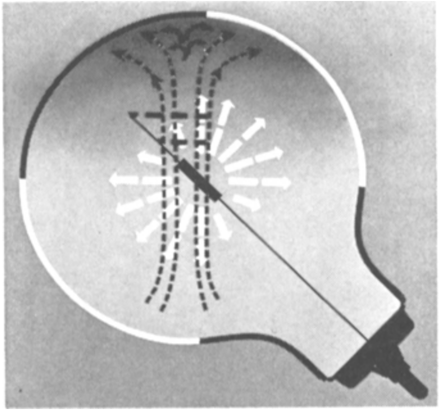

Fig. 3. Thermal gas currents; collector grid at 45° angle.

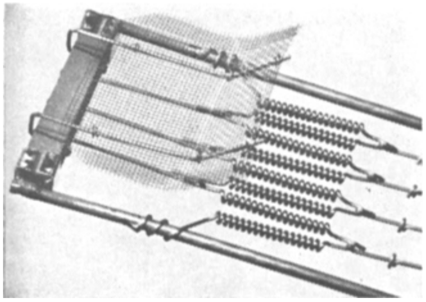

Fig. 4. Close-up of the new collector grid design.

ture improves its effectiveness. In order to withstand the temperatures involved, a special screen of woven tungsten wire was developed.

Early in our development program, practical limitations came into play. In order to obtain significant results, a relatively large number of sample designs had to be built. The resultant demand for power supplies and testing space and equipment meant that test facilities had to be greatly expanded or that the program had to be stretched out over a long period, with tests of only a few lamps at a time. Our test facilities were increased considerably, but a technique, believed to be new to the study of high-wattage lamps, proved to be the greatest timesaver. We decided to build scale models of the large lamps to test more variations in less time and at far less cost than would be incurred by using full-sized lamps. The model used for the 10,000-w lamp was a 1000-w G-30 lamp with a medium bipost base. The model gave us a 10:1 wattage reduction, with about the same bulb loading; many models were made with a variety of screen configurations.

One of the early groups of tests compared the results of burning on a-c and d-c circuits. Results confirmed the opinion that differences were insignificant. Another series of tests sought to determine if it was best to isolate the screen electrically, or to attach it to the positive or negative side of the supply (on d-c circuits). Again there was no significant difference; this was reconfirmed in later tests with full-size lamps. A further approach, that of electrically charging the grid through a third electrode at some other voltage, was dropped because of encouraging improvements made without introducing this expensive and possibly hazardous construction feature.

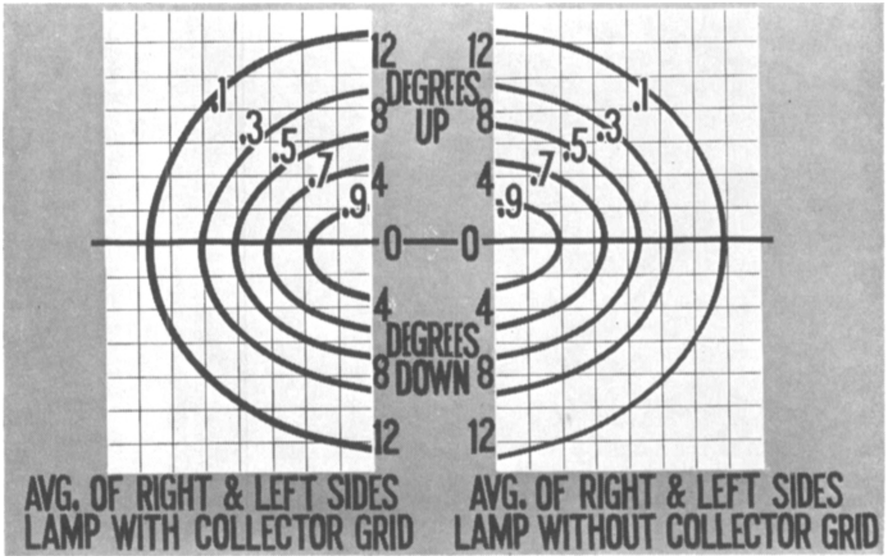

Fig. 5. Comparison of candlepower distribution from typical 10,000-w spotlight with and without grid.

Every series of tests with the model lamps was consistent in one respect. The better-located collector grid always produced an improvement of 8 to 10% in lamp lumen maintenance over lamps without grids.

When it was clear that a better lamp design had been found, tests of the full-sized 10,000-w lamp were resumed. Our feeling was that measurements of depreciation of total lamp lumens did not represent a true measure of lamp performance. Lamp users are generally interested only in the characteristics of spotlight beams. Therefore, we borrowed a scheme used previously for short-range testing of searchlight beams. A photometric hemisphere was set up and into it the beam from a spotlight was directed. Hemisphere brightness was measured by the output of two matched, color-corrected GE photovoltaic cells connected to a microammeter. Several weeks of checking and calibration were required for results accurate to within about 2%. For all tests the spotlight focus control was locked midway between the full spot and full flood positions. Subsequent tests in another laboratory using a different beam-measuring system produced nearly identical results.

With our photometric methods established, we set about life and beam lumen maintenance tests. In our life tests, we tried to duplicate service conditions as closely as possible. All lamps were tested at rated voltage on direct current in 10,000-w studio spotlights aimed 45° below the horizontal. The lamps were burned for 16-hr intervals in the life-test spotlights, then removed for measurement of relative beam lumens with the photometric hemisphere. The bulb interiors were then cleaned with tungsten powder, and the lamps were returned to the beam photometer, then replaced in the life-test spotlights for another 16-hr burning interval. In order to insure repeatability of results, two seasoned and rated 10,000-w lamps were selected to calibrate the photometric assembly at the beginning of each series of beam readings. These lamps, burned only during photometric testing, provided a guarantee of consistent comparisons over several months of testing.

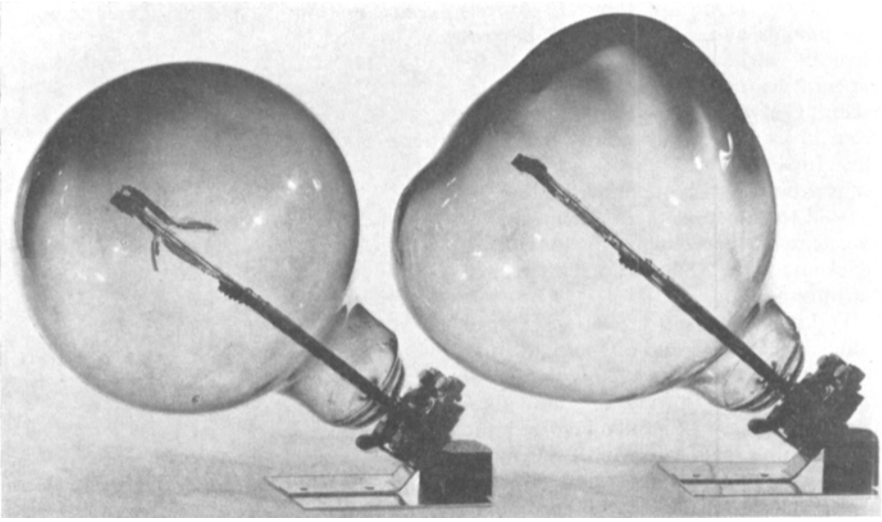

Fig. 6. Left, lamp with collector grid at end of life; right, lamp without grid.

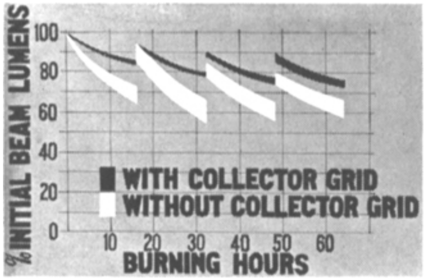

Fig. 7. Beam lumen maintenance of 10,000-w lamps in a typical spotlight.

The New 10,000-w Lamp

This relatively complex development and testing program culminated in a new lamp design incorporating a collector grid. The tungsten-wire screen is fastened to supports and electrically isolated from the filament (Fig. 4). In operation, the screen is located between the filament and the mirror, so that it is above the filament when the spotlight is aimed down. The total lamp lumens from the new design are slightly less, but the important factor, beam lumens, remains almost exactly the same. Testing of a studio spotlight on a goniometer over a projection distance of 50 ft indicates that beam patterns are essentially identical in all focus positions for new lamps with and without collector grids. Typical candlepower distribution data are shown in Fig. 5. The grid does not alter the beam because it is about 80% transparent, and it occludes only a small area of the spotlight mirror.

The most significant improvements in the new lamp are its reduced blistering and its improved beam lumen maintenance characteristics. As shown in Fig. 6, a typical collector-grid lamp burned in a spotlight to the end of filament life at 45° from base down has barely noticeable blistering. This suggests that the effective life of the lamp in spotlight service will go from the 40- to 50-hr limit now imposed by blistering to nearly the full design life of the filament, approximately 75 hr. Pre-burnout lamp replacement may still be desirable in order to avoid delays caused by a burnout during filming. Beam lumen maintenance for lamps with and without grids is shown in Fig. 7. Comparing total useful light — that is, beam-lumen-hours — from lamps with and without collector grids gives a measure of the added value provided by the grid. If we assume that the nongrid lamp is useful for about 50 hours of spotlight service, and that the collector-grid lamp is removed before burnout at 60 hours — a 20% life increase — the total beam-lumen-hour increase provided by the grid is about 37%. If the collector-grid lamp is burned to failure — at about 75 hours — then it will deliver about 68% more beam-lumen-hours than the non-grid lamp will in 50 hr of spotlight service.

Another feature has been added to the new 10,000-w lamp that improves its shipping and handling characteristics. The mogul bipost base construction (Fig. 8) supports the entire filament mount structure in two copper posts which are sealed into the glass base. Rough handling of the lamp in shipment can cause the weight of the filament and supporting structure to distort the cups at their shoulders, moving the filament off-center in the bulb. In extreme cases, distortion may move the filament enough closer to the bulb wall to affect bulb temperature. Usually, this filament distortion in shipment can be corrected easily and safely by placing the lamp in an unwired socket or similar holder and gently moving the bulb until the filament is centered. In the new 10,000-w lamp, however, two small mount braces are added to the bipost cup assembly. Extensive shipping tests indicate that these braces will minimize mount distortion caused by rough handling; hence, less time will be lost in occasionally recentering filaments.

Extension of Collector-Grids to Other Sizes

The remarkable improvements that the collector grids made in performance of 10,000-w lamps immediately suggested extension of the design to other sizes. Life and beam-lumen tests similar to those described above were made with 5000-w lamps in both the G-64 and T-64 bulbs. As expected, the collector-grid reduced blackening and blistering in the G-64 bulb. In the T-64, the improvement was barely apparent. Beam-depreciation characteristics of 5000-w spotlights make it apparent that the collector grid gives only a minor improvement over the standard lamp with the T-64 bulb. This improvement is not at all in proportion to the increased costs that inclusion of the grid would impose. Another conclusion that can be drawn from our testing is that users of G-64 lamps can gain about 10% in light over lamp life with an equivalent lamp cost increase by switching to T-64 lamps. This means that users will be able to get more light, on the average, with fewer spotlights by employing T-64 lamps.

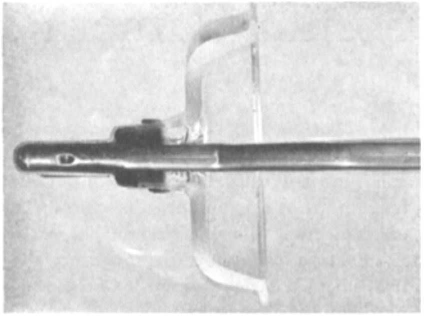

Fig. 8. Cutaway of bipost base cup.

Our tests indicate that, at the present time, conditions do not warrant the extension of the collector grid design to the 5000- and 2000-w studio lamps.

Conclusions

The recent studies made on high-wattage studio spotlight lamps have produced important results: (1) A vastly improved 10,000-w spotlight lamp is now available that holds the promise of significantly reducing production costs through its greater spotlight service life and its better beam-lumen-maintenance characteristics. (2) Comprehensive tests have confirmed that the T-48 and T-64 bulbs provide more light through life than corresponding G-bulbs for users of 2000- and 5000-w lamps. (3) During our tests, considerable emphasis was placed on the value of frequent lamp cleaning with tungsten powder as a means of further improving lighting results. (4) Low-noise construction features have been brought to the studio lamps most commonly used on alternating current in television and some motion-picture studios.

Acknowledgment

We would like to express our thanks to D. W. Prideaux, Motion-Picture Studio Engineer for the General Electric Lamp Division, for keeping our laboratory informed on the lighting needs of the motion-picture industry. His interest in, and intimate knowledge of, the subject has been a constant help to the lamp design engineers. To the several others who have aided in this development by suggestions and by furnishing test information, we would also like to express thanks.