An Electronic Ballast for Straightforward Use of Metal Halide Arc Lamps

By DENYS KLEIN

An electronic converter, called "Moduleur," for use with metal halide "daylight" lamps in production lighting is introduced. The functioning of metal halide arc lamps is summarized, and the shortcomings of conventional inductive ballasts for these lamps are pointed out in detail. The components of the Moduleur are enumerated and their functioning is outlined. A test bench for investigating residual luminous flux variations (stroboscopic effect) was set up. The residual variation was found to have a deviation of no greater than about ±1.5% from the average value. The metal halide arc striking procedure is very simple. This electronic ballast allows for the dimming of metal halide light sources without lowering their color temperature, a very useful feature.

Some twelve years ago, lamp manufacturers developed halogen arc lamps for production lighting, providing a light source very close to that of daylight. The luminous efficiency of these lamps is very high (70 to 105 lm/W), and the color rendering index reaches 90%. But power-line ac voltage to supply these lamps cannot be used directly without modification. The most well known solution is to use an inductor linked in series between the supply voltage and the lamp; this method, however, has many disadvantages. To overcome the problems, an electronic converter was specially designed for production lighting requirements. Before describing this equipment, which we call the "Moduleur" (Fig. 1), we will briefly go over the components of an arc lamp and its conventional power supply. We will also analyze the reasons for the defects inherent in these conventional power supplies.

Components of a Metal Halide Arc Lamp

In conventional metal halide arc lamps, an electric arc is struck between two tungsten electrodes in an atmosphere of a rare gas and mercury vapor. As the ambient pressure is increased, the coloring of the light resulting from the ionization of the plasma is enriched. A quartz bulb of sufficient strength is used to withstand the pressure.

For motion picture and Television lighting, an ordinary mercury vapor arc lamp is not suitable. The color distortion caused by an unnatural over- or underemphasis of certain regions of the spectrum makes it impossible to render the coloring of a face or scenery correctly. However, the addition of minute quantities of rare earths to the gases inside the bulb will produce a full spectrum. Lamps manufactured in this way, providing a high color temperature of 5000 to 6500 K, enable cinema or television filming without need for insertion of a blue filter.

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Use of a Conventional Inductive Ballast

The voltage E, which is applied across the two electrodes in order to maintain the arc, must be as constant as possible for any given model. Therefore, it is impractical to supply power directly from an ac power source. The primitive solution, some 70 years old, consists of inserting an inductive ballast acting as a buffer between the lamp and the ac power supply. This absorbs the over-voltage of the external power source magnetically and then gives back the energy during the low-power supply period in order to keep the ionized plasma charged.

Figure 2 explains the phenomenon. At the bottom is shown the wiring diagram of the arc lamp and its ballast, wired in series to a sinusoidal voltage source. Because the arc voltage can be only $+E$ or $-E$, the voltage at the inductive ballast terminals u_L is either $u + E$ or $u - E$.

At the top, graph (a) shows simultaneously the voltage of the external power source (dashed line) and the resultant inductive voltage at the terminals (solid line). As can be seen, there is a discontinuity of that voltage on each alternation. The physical explanation is as follows.

When the ac supply voltage is positive, at t_0, the ballast begins to store energy. Then, at t_1, the ballast begins to return the stored energy to the lamp. Thus, the ballast maintains the arc even though the ac supply voltage, after $T/2$, has been reversed. When the inductor's energy reserves have been exhausted, the bulb goes out but is relighted immediately, so long as the ac supply voltage is sufficiently powerful to take over when the inductor voltage is negative. The cycle then repeats.

Graph (b) shows the current wave which goes through the ballast and the lamp at the same time.

Graph (c) (solid line) gives the instantaneous power delivered to the lamp; this quantity is the product of the voltage and the current. The dashed line in graph (c) indicates the corresponding instantaneous variation of the emitted luminous flux; this quantity varies at a frequency of twice the frequency of the ac power source. Because of the thermal inertia of the plasma, the luminous flux does not fall to zero at the point where the power is zero. Let us now analyze the disadvantages of using a conventional ballast for operating metal halide lamps.

First disadvantage: The average value, I, of current during each alternation is indicated on graph (b) in Fig. 2. Its equation specifies the following parameters, which affect its value and therefore the average luminous flux: (1) the amplitude U of the ac input voltage, which is subject to ±10% fluctuation; (2) the period T of the ac input power, which is $1/60$ s in the U.S.A. and $1/50$ s in Europe; (3) the arc voltage E, which varies from one arc lamp unit to another and also varies during the life of each individual lamp; and (4) the inductance L.

Figure 3 shows the undesirable influence of the operating parameters of the lamp caused by variation in the ac power source. These parameters are arc voltage E, average current I_0, power P, luminous flux ϕ, and color temperature K.

Second disadvantage: Examination of the instantaneous value of the current reveals other difficulties (Fig. 4). A mathematical computation allows us to determine relighting conditions after each reversal. We have $\cos \omega t_0 = E\pi/2U$. Using one of the trigonometric identities we obtain $\sin \omega t_0 = [1 - (E^2\pi^2/4U^2)]^{1/2}$. Multiplication of both sides of this equation by U yields the relation $U \sin \omega t_0 = [U^2 - (E^2\pi^2/4)]^{1/2} > E$. Solving the inequality for U, we finally obtain $U > E(1 + \pi^2/4)^{1/2} = 1.86E$. This shows that the voltage U must be greater than $1.86E$, where E is the arc voltage. This explains why it is impossible to drive daylight discharge lamps from U.S. ac power lines without using a step-up transformer. This transformer is what causes the extra physical weight which makes a conventional ballast so difficult to transport.

Third disadvantage: More important and insidious is the stroboscopic effect brought about by the pulse nature of the emitted light. Figure 5 indicates how the stroboscopic effect appears with a power-source frequency of 60 Hz and a camera frequency of 25 frames/s. A beat frequency

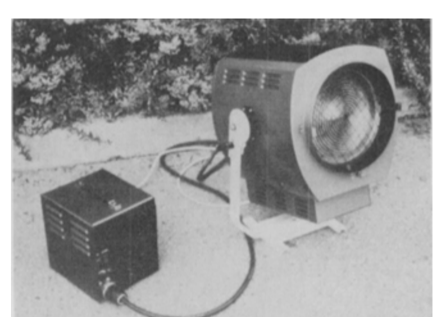

Fig. 1. Electronic ballast for HMI arc lamps, Moduleur Type 1200 W, connected to a spotlight.

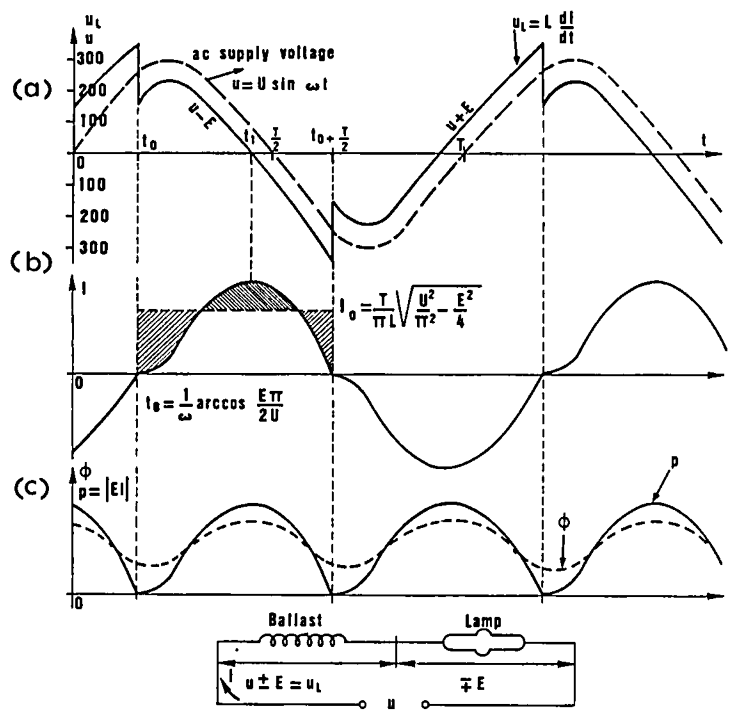

Fig. 2. Causes for the stroboscopic effect as present in conventional inductive ballasts: (a) ac supply voltage (dashed line) and inductive voltage (solid line); (b) current wave through ballast and lamp; (c) instantaneous power to lamp (solid line) and instantaneous variation of luminous flux (dashed line).

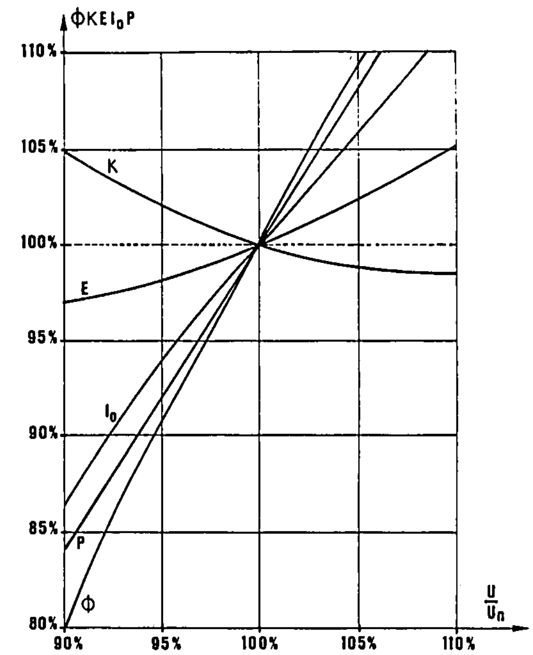

Fig. 3. Undesirable operating parameters present with an inductive ballast: (K) color temperature; (E) arc voltage; (I_0) average lamp current; (P) power; (ϕ) luminous flux. All parameters are shown as a function of ac supply voltage. The dashed line (---) indicates results with the Moduleur ballast for ϕ, K, E, I, and P.

is generated which becomes visible in projection as a disturbing flicker effect.

Different palliative solutions have been tried to correct this effect. But during outdoor filming, for example, it is difficult to synchronize a camera and a power generator. More than once, film crews have been obliged to reshoot sequences when the projected film showed stroboscopic effects, which of course could not be noticed during filming.

A New Electronic Source for "Daylight" Arc Lamps

The targets that we set for ourselves to create the Moduleur were several. We proposed to create a regulated power supply which would assure that the fluctuations in the input power would not affect the light output. It should enable the use of U.S. as well as European ac power lines. It should allow operation with both 50- and 60-Hz ac, as well as the use of dc voltage sources. It should eliminate the stroboscopic effect. It should compensate for arc voltage differences and variations. It should reduce the weight and size of the power supply in comparison with that of the inductive ballast. And finally, it should avoid a return flow of power to the ac power line and should synchronize maximum current with maximum voltage. The Moduleur, a new electronic converter, is capable of reaching all of these objectives. It will supply HMI, CID, and comparable gas discharge lamps from other manufacturers.

As shown in the layout diagram (Fig. 6), the Moduleur consists of a rectifier followed by a capacitor capable of storing much more energy than an inductive ballast of the same size. The rectifier input circuit varies, depending on the voltage of the external power source used. Next, a high frequency chopper regulator intervenes in order to eliminate over-voltage and to maintain the filter output voltage required for the lamp. This electronic chopper is a high speed switch which only becomes conductive for just the necessary fraction of time. In the filter, a smoothing inductor absorbs the alternating component of the voltage and a capacitor completes filtering of the voltage from the regulator. Because they operate at high frequency, approx.

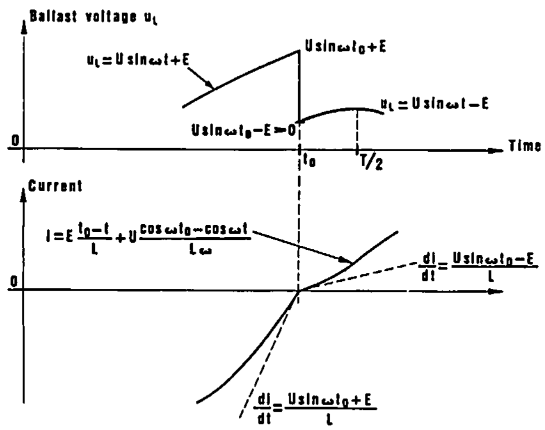

Fig. 4. Relighting characteristics of ballast voltage and current with a conventional inductive ballast.

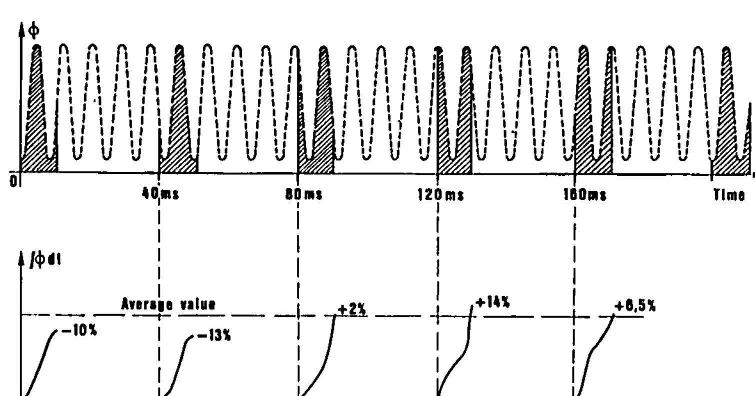

Fig. 5. Variation of luminous flux with an inductive ballast at an ac input frequency of 60 Hz, camera frequency of 25 frames/s, and a shutter angle of 94°. Film exposure is proportional to the value of the integral $\int \phi dt$.

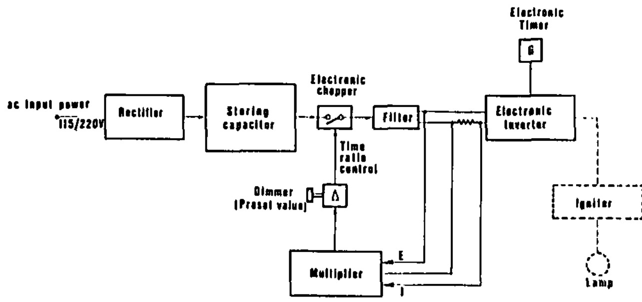

Fig. 6. Block diagram showing the components of the Moduleur.

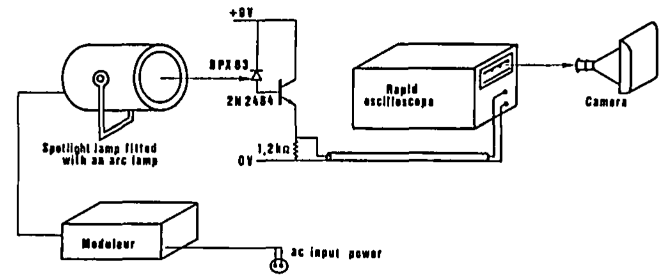

Fig. 7. Testing setup for investigating the residual stroboscopic effect using the Moduleur with an HMI arc lamp.

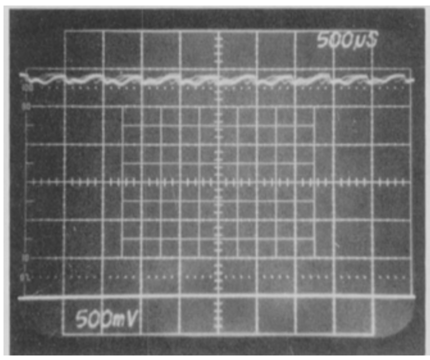

Fig. 8. Oscillogram showing the resulting minimal luminous flux variation of about ±1.5% around the average value. The upper trace corresponds to the lamp in operation; the lower trace results when the lamp is off.

25,000 Hz, the filter components are compact and light.

The circuit that follows is an inverter, the purpose of which is to alternate the polarity of the two lamp electrodes. It is driven by the electronic timer G. In fact, a dc power supply would cause damage to metal halide lamps. It would cause uneven wear of the electrodes, resulting in defocusing of the arc in relation to the optical axis of the mirror system.

To control the chopper regulator so that it will supply the lamp with the power value required to provide the desired color temperature, the lamp voltage and current are taken off at the point where they are both constant, that is, at the filter output and after the measuring shunt. An analog multiplier M calculates the product of the voltage and the current and operates the comparator Δ, which is supplied with the preset calibrated recommended power value P_0 at its other input. The comparative result, calculated between the actual power and the required power P_0, is converted into a go/no-go variable cyclic ratio signal, which is applied at the chopper transistor. If there is a drop in the absorbed power, for example, it will increase the cyclic ratio and prolong the relative conduction period of the chopper transistor in order to re-establish the required lamp consumption value. As a result, the lamp luminous flux is practically constant.

To test for residual luminous flux and residual stroboscopic effect, a special testing bench was set up (Fig. 7). Light from an HMI lamp, supplied with current from the Moduleur, was picked up by a rapid photodiode, the output of which was connected to an oscilloscope. A photograph of the oscilloscope screen (Fig. 8) shows that the residual luminous flux variation is about ±1.5% around the average value.

Procedure for Striking the Arc

Striking an arc is accomplished by means of a suitable igniter which sets up a train of high voltage and high frequency sparks. This initiates ionization throughout the argon gas contained in the bulb. After that, the Moduleur maintains ionization, vaporizing the mercury and gradually bringing the rare earths to incandescence, radiating light.

The striking process is taken into account by the Moduleur, which is programmed for the sequence that follows: (1) before striking the arc, the Moduleur acts as a voltage generator without any current consumption; (2) on command, the igniter pulses pass freely through the Moduleur, the energy of the igniter being added to that of the Moduleur; (3) once conduction is established, the regulator starts its function of delivering the highest current indicated by the lamp manufacturer as safely acceptable for bringing the lamp up to normal operating temperature in the shortest possible time. Once this condition is reached, the Moduleur will act as a regulator to deliver normal electric power.

Dimming Features

The nominal power value at which the Moduleur's regulating function is aimed may be reduced to under-supply the lamp to reduce its light output purposely. This added ability to dim gaseous discharge lights opens up new artistic, cost-saving, and convenient possibilities for production.

Surprisingly, the color temperature of these lights, when dimmed by the Moduleur, *rises* slightly, rather than dropping off as one would expect with incandescent lights. The explanation for this is interesting.

As the power decreases, the incandescence of the rare earths in the plasma becomes less efficient. This reduces the oranges and reds and increases the blue and green components of the output spectrum, so that the color temperature rises.

Conclusion

The Moduleur can be considered as the first daylight discharge lamp power supply that eliminates the well known difficulties this type of lamp may cause for the lighting technician. The stroboscopic effect caused by fluctuations in the current as supplied by inductive ballasts is completely absent. Size and weight of the power source are reduced. The voltage and frequency fluctuations of the external power source have no effect on the luminous flux. The Moduleur compensates for arc voltage variations that may be caused by aging or changing of the lamp.

In addition to eliminating all the disadvantages characteristic of inductive ballasts, the Moduleur offers the new possibility of dimming gaseous discharge lights without lowering their color temperature. This development is not only useful to the film and television industries, but will also open up new options for the lamp industry. We are currently celebrating the centenary of the filament lamp, and it is interesting to realize that with the help of the Moduleur, the non-filament lamp, which is 170 years old, can still be improved.