ELECTRONICS FOR FLICKER FREE DAYLIGHT

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The author would like to take advantage of this opportunity to thank Randall Miles for his pleasant assistance in the English translation.

Braunschweig, October 28th 2001

Contents

1. Daylight with metal-halide-lamps - general

1.1 Characteristic features of metal-halide-lamps

The light outputs of metal halogen lamps are specifically engineered to meet the requirements of film and TV lighting [1].

In the early seventies Osram in Germany has presented these special light sources.
It was the aim of the designer to develop a daylight lamp with brilliant light emission, but that could be handled safe in the film lighting business.
During the Summer Olympics in 1972 the first official presentation of the new „HMI-daylights“ took place in Munich. It was the company Arnold & Richter using the new daylight lamps in the first ARRISUN (ARRI-SONNE) fixture to illuminate the games.

Meanwhile the Metal Halide lamps are offered worldwide under different brands like HMI (Osram), MSR (Philips), KOTO, Wolfram, ILC and others.

Since the first presentation of these lamps the shortened form „HMI“ had become the most popular name for the Metal-Halide lamps in the business and will be used in the following without any valuation of that or other brands.

These characteristics have advantages for both colour film and colour TV, as follows:

- the light colour is very similar to that of average daylight; its co-related colour temperature being around 5600°K.
- the light colour changes only slightly during the entire lamp life, and these changes are normally operationally acceptable.
- good colour rendition characteristics, with the index Ra > 90
- high luminous efficiency (90 lumens per watt or better) provides economy of operation.
- compact construction and ease of handling
- trouble-free hot ignition

The excellent light quality of the HMI lamp, which is made of a high temperature quartz glass is obtained by the special fillings in the envelope of the lamp.

The lamp being basically a mercury discharge type, the few spectrum lines of mercury are supplemented by the addition of a number of rare earth’s to produce a quasi-continuous spectrum output.

Figure 1 shows the spectrum output of a 12kW HMI lamp in comparison with that of average daylight. It can be seen that overall they are in very close agreement with each other.

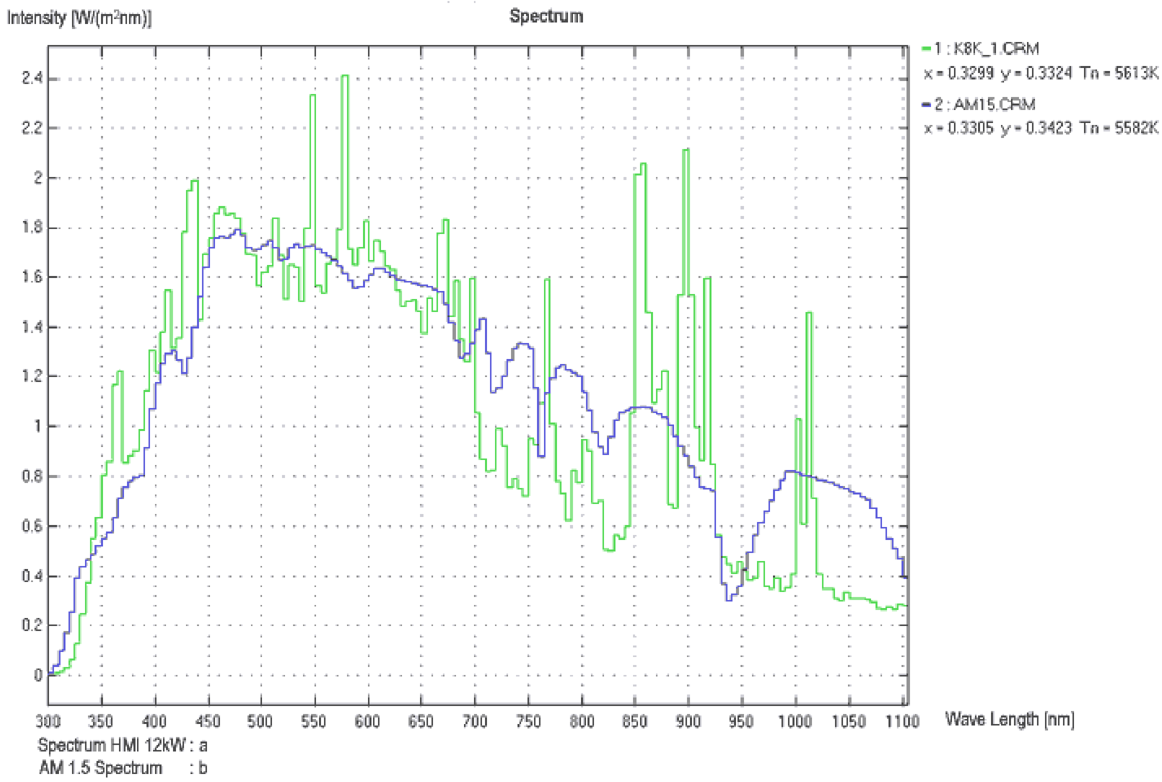

Fig. 1: AM 1.5 – spectrum

The spectrum output of the light from an HMI source, when weighted with that of the response of the average human eye, has a very similar (co-related) colour temperature of daylight (computed in accordance with DIN 5033) and is usually sufficient for most operational purposes. To better define and evaluate the light colour requires, in addition, the determination of the location of this light colour within the C.I.E. colour triangle [2].

The C.I.E colour triangle, confined within the colour spectrum locus and the imaginary purple line, encloses an area in which all really known colours are located (figure 2).

Within this locus all known colours can be determined by their colour co-ordinates of x and y.

The small downward curve within the colour triangle (Planck´s curve) is the locus of the light output from a theoretical black body radiator as its temperature (and therefore colour temperature) is varied.

The small section around the part of this `black body curve` relevant to HMI light colour is reproduced, enlarged, in Figure 3. The colour location of the standard average HMI bulb lies at co-ordinates x = 0.331 and y = 0.330. [3]

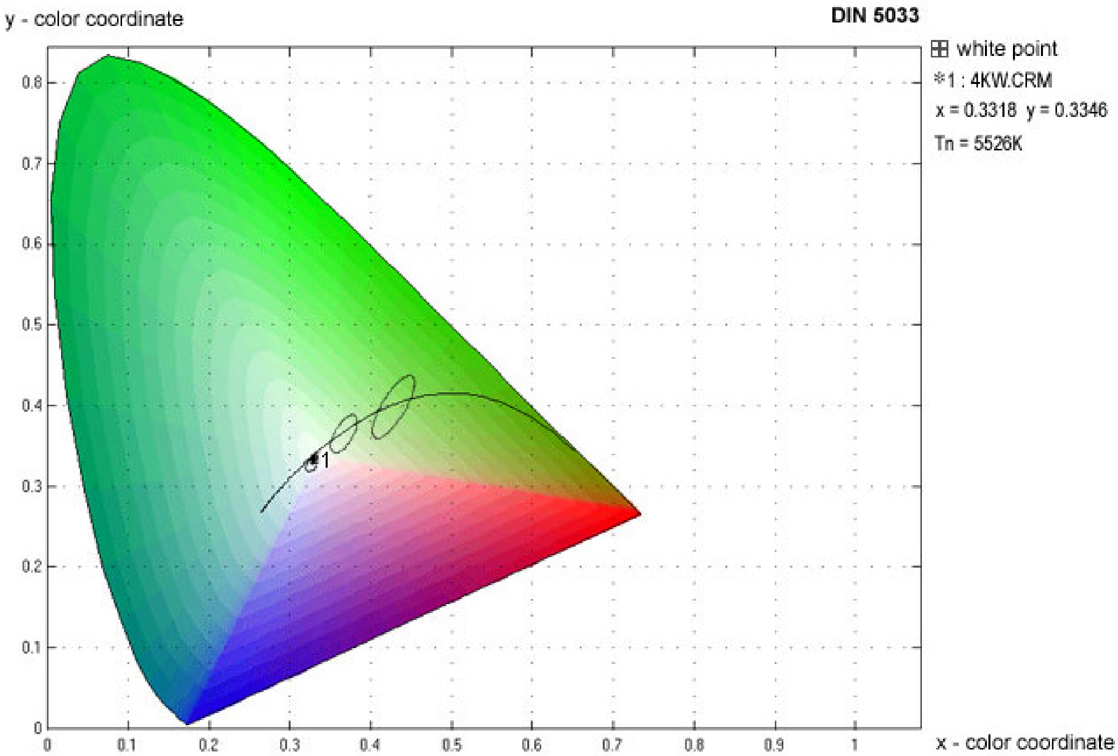

Fig. 2: Color triangle

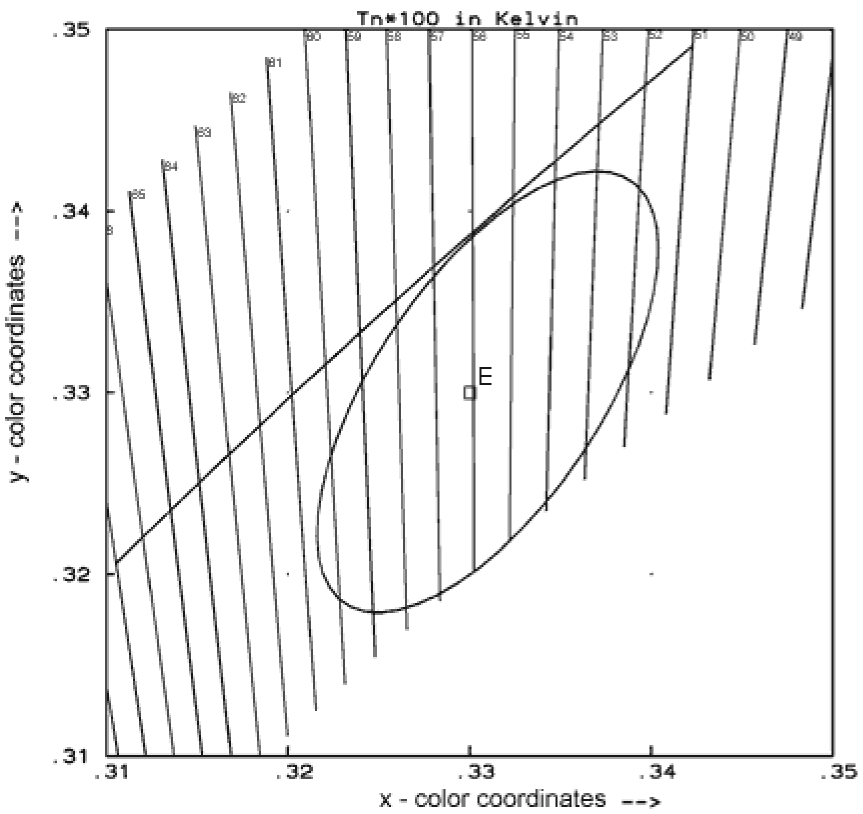

Fig. 3: Color traingle with Juddian straight lines

The nearly parallel lines (Juddian straight lines) show those points of the most similar colour temperatures to that where the particular Juddian line crosses the Planck's curve. Therefore you can see that the standard average HMI lamp has a co-related colour temperature of between 5400°K and 5500°K. The oval shape shown just under, but just touching the Planck locus line determines the limits within which the colour location of individual HMI lamps are deemed as being acceptable – any falling outside of this oval being rejected. The permissible tolerances of locations within this oval are of 5 threshold values. One threshold value is given by the distance between any two colour locations within the colour triangle where the human eye just cannot differentiate between the colour of these two points.

It should be noted that if the colour location point of the light from an HMI, perhaps due to external influences, should move directly along one of the Juddian straight lines, the co-related colour temperature does not vary but, quite obviously the colour does. This example shows that, the colour location information in addition to that of the nearest similar colour temperature is of importance when judging light quality from HMI bulbs.

Section 4.2 explains in detail the possibility of light colour control with electronic ballasts.

Standard HMI lamps currently available range in power from 20 watt to 18.000 watt. HMI lamps in common with all discharge lamps have to be powered via a ballast device, which is necessary to both stabilize and limit lamp current.

In the early years of HMI light, this problem was solved almost exclusively by a combination of HMI lamps and conventional choke ballasts. However, the application capabilities of HMI lamps with choke ballasts are considerably limited (see section 1.2).

It was the development of suitable electronic ballasts with a power range of up to 18.000 watt, which made the HMI lamp an almost universally usable light source of high quality.

1.2 Conventional operation with choke ballasts

With this method of lamp operation control of the lamp current is done with the aid of a choke ballast.

Figure 4 shows the basic circuitry (igniter, time control and safety devices are omitted).

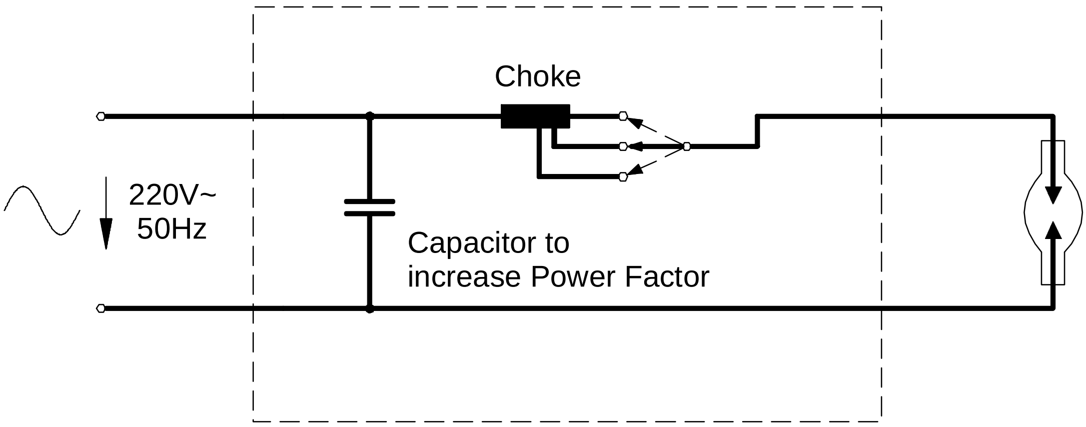

Fig. 4: Function – Choke Ballast

A choke coil is connected in series between the mains input and the HMI lamps. Its inductance can be changed, via suitable tappings, to allow for different mains voltage. Such a combination would absorb power far greater than that taken by the bulb alone. In order to recover some of this apparent power, compensating capacitors are included which increase the power factor to a figure approaching unity. In practice it is possible to obtain power factors of up to 0.98.

These comparatively simple components assembled in a suitable mechanical structure gives a robust ballast allowing virtually foolproof operation. However, being passive components there is only one definite correct operating point for each case which is determined by the individual characteristics of the mains supply and the specifications of the lamp. Therefore, the choke type ballast cannot compensate for mains voltage variations of for tolerance caused by differences of the lamp values. In addition, it is not possible to adjust the lamp voltage to compensate for the gradual aging of the lamp. Thus the quality of the HMI light output can vary considerably with the choke ballast operation.

When a lamp is started from cold the lamp current can be twice that of the normal running current due to the initial low lamp voltage (e.g. 2500 watt HMI – 20V as compared to 105V). This increases stress on the electrodes which, in turn, leads to decreased lamp life.

The main disadvantage of a choke ballast controlled HMI lamp, however, is that the light is not constant but flickers (pulses) at twice the supply frequency. This light variation is caused by the low thermal inertia of the electric arc. The light emission follows the gradient of the sinusoidal lamp current and reaches it maximum at the positive and negative current peaks and minimum when the current passes through zero. Figure 5 shows the relative light intensity of a 4.000 watt HMI lamp.

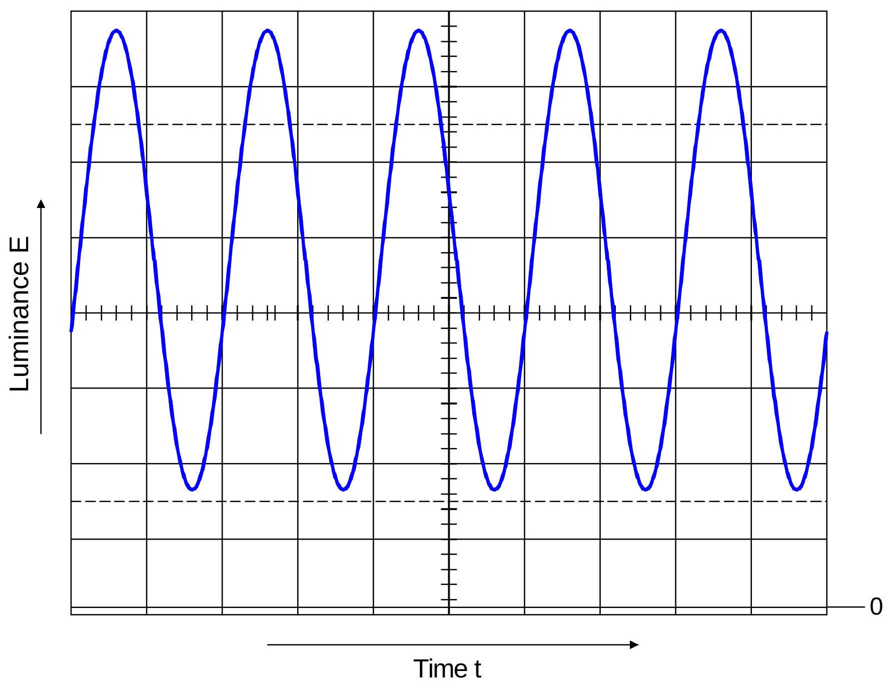

Fig 5: Sinusoidal lamp current of a 4kW HMI lamp driven by a conventional choke ballast

As mentioned above the flicker frequency is twice that of the supply and the flicker percentage (4) may be calculated as follows:

$$F = \frac{E_{max} - E_{min}}{2 \cdot E_{mean}} \cdot 100\% \qquad (1)$$

For HMI lamps F would typically be 60%.

With this flicker, the framing rate and/or the exposure time of a film camera must be precisely matched to the supply frequency. Even small deviations can result in exposure (density) variations between film frames resulting in a visible and unwelcome picture 'flickering'. A very similar effect can also occur on certain types of high shutter speed video recordings.

There are a number of possibilities to avoid this 'flickering' during filming. The most elegant solution is to ensure that the light output of an HMI lamp does not vary, enabling filming to take place at any frame rate or shutter exposure. More about this later in section2. With conventional choke ballasts one method is to synchronize the framing rate of the camera to that of the supply frequency and, at the same time, ensuring that the framing rate is equal to the frequency of the supply or a sub-multiple of it.

As almost all professional film cameras have quartz controlled motors the preferred method of eliminating film flicker is to use differing shutter angles (exposure time) with different frame rates at selected supply frequencies. The relationship between main frequency, shutter angle and camera frame rate are given by the following equations [5] :

$$\text{camera framerate} = \text{mains frequency} \cdot \frac{\text{shutter angle}}{360°} \qquad (2)$$

and correspondingly:

$$\text{mains frequency} = \text{camera framerate} \cdot \frac{360°}{\text{shutter angle}} \qquad (3)$$

or

$$\text{shutter angle} = \text{camera framerate} \cdot \frac{360°}{\text{mains frequency}} \qquad (4)$$

It can be seen from the equations (2) to (4) that it is possible to eliminate film flicker problems not only by varying shutter angles. Today's quartz control generators enable different supply frequency adjustments and thus allowing further possible variations. However, it should always be taken into account that the current, limited by the choke is therefore dependent upon frequency and, ideally, the choke should be adapted to different frequencies.

Nevertheless, even with these possible variables there are only a relatively small number of discrete filming frame rates that may be employed [5].

It cannot be stressed enough that camera frame rate and supply frequency must be accurately maintained if film exposure flicker is to be avoided. There will always remain a certain small degree of uncertainty until the results are seen.

2. Electronic circuits for flicker-free HMI light

Because of their electrode arrangement, metal vapour discharge lamps must be operated with alternating current. Permanent direct current would result in very uneven erosion of the electrodes within minutes and possibly cause the lamp to explode after a period of time. Most certainly the lamp life would be dramatically reduced.

In addition the light output from a bulb powered in such a manner would be uneven because convection, magnetic fields and the changing electrode ends would cause the electric arc to move around the electrodes resulting in a low frequency and irregular light flicker. It is therefore essential to design electronic circuits which can supply the HMI lamp with an alternating current suitable for flicker free light emission.

There are two basic methods of achieving this.

2.1. High frequency operation

The principal aim when designing an electronic ballast for HMI lights is to reduce the flicker as completely as possible. The principal behind a high frequency operation is to increase the frequency of the lamp voltage to such an extent that the thermal inertia of the arc can no longer follow the very fast change of current flow.

Tests have already been carried out above 20kHz (up to approximately 500kHz). (6), (7), (8). To avoid audio interference, the frequencies should be above the range of human hearing.

With high frequency operation all metal vapour discharge lamps have resonance points which can result in unstable arcs and even extinction. These resonances are dependent upon the shape of the envelope and the sonic speed of the arc discharge. These resonance bands may occur up to 300/400kHz. Between these resonance bands there are resonance free windows of varying width in which smooth operation of lamps are possible. However, manufacturing tolerance and the individual lamps state of age can result in these resonance free windows moving away from the frequency being applied and therefore stable and permanent operation cannot be guaranteed.

It is only well above 200 kHz that a limited degree of stability may be achieved.

Such ballasts designed for high frequencies above 200 kHz necessarily have very costly components capable of generating, handling and controlling this high frequency.

2.2. Low frequency square wave lamp current

As an alternative to the high frequency supply principal, flicker free operation may also be achieved with low frequency supply to the lamp if the supply is of a square wave form and not sinusoidal.

If the electronics are designed such that the change of current direction within the arc is less than 10 to 20 µs, the arc thermal inertia cannot follow this rapid current reversal and this results in a uniform light emission.

Figure 6 shows the light output of a 4.000 watt HMI lamp when operated with a 100 Hz square wave current.

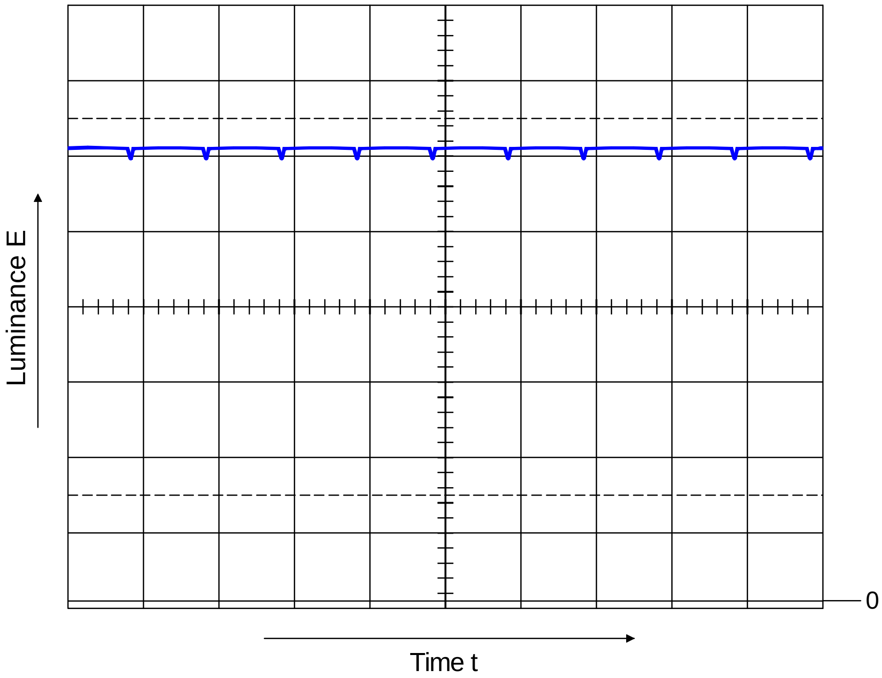

Fig.6: Sinusoidal lamp current of a 4kW HMI lamp driven by an Electronic Ballast

The 10 µs current reversals occurring at 5 ms intervals are only just discernible and the entire residual light flicker amounts to only 1% of the maximum light intensity.

This high degree of uniform light output allows for almost any camera speed to be used without visible film flicker. This has been tested up to 10.000 f.p.s. on a 16mm film format [9].

Electronic ballasts operating on this principle offer numerous advantages compared with conventional choke ballasts described in section 2.1. The low frequency electronics can be designed in such a way that they are fully compatible with choke ballasts; meaning that daylight luminaries with HMI lamps already in use may be operated without modifications.

Efficiencies of between 87% and 94% can be achieved with electronic ballasts and in addition both weight and size are considerably reduced, when compared to conventional choke ballasts. A fundamental advantage of low frequency square wave current supply is that safe electronic control of very high lamp currents (more than 120 amps) is possible. Electronic ballasts are already available up to 18.000 watts, and higher wattages (30.000 watts) are already being developed.

3. Electronic ballasts

As described in chapter 2 there are two basic approaches to the design of electronic ballasts. The advantages mentioned in chapter 2.2 have resulted in almost all manufactures of electronic ballasts using the principle of low frequency square wave power supply for metal halogen lamps. Therefore, the following chapters will deal exclusively with the principles, features and advantages of these power electronics.

3.1. Circuit principles

The main principle of these electronic ballasts is illustrated in figure 7. First a direct current voltage is generated from the single-phase mains voltage in the so-called direct current intermediate circuit. This direct current voltage lies in the range of 280 to 330V and is dependent on the kind of rectification and lamp type . The operating voltage of some HMI lamps is 200/225V so the intermediate circuit voltage should be at least 300V in order to allow sufficient reserve for the controller. In practice, conventional bridge rectifiers with smoothing choke and charging capacitors are used. The attainable power factor (cos. φ) is approximately 70%.

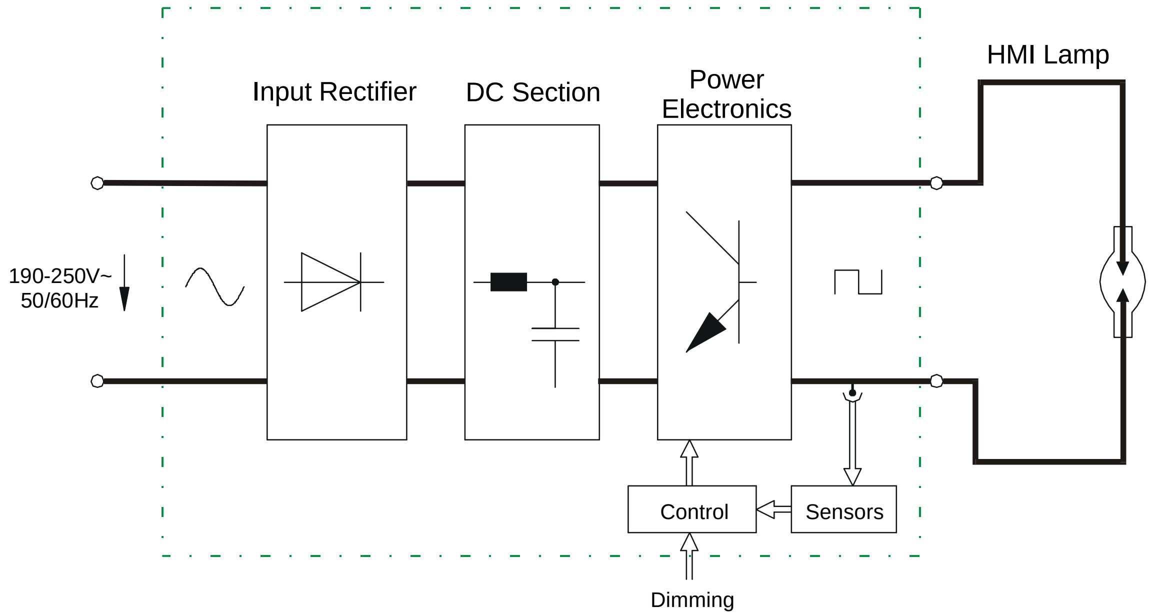

Fig. 7:Principle design of an Electronic Ballast

However reactions to the mains can be enormous with high peak loads and therefore this type of rectification is only really possible for lower wattages.

The upper section of Fig. 8 shows the basic form of this kind of rectification.

The power flows from the mains supply via the circuit breaker and earth leakage detection circuit to the RF mains filter. This filter restricts the flow of high frequency signals from the switching regulator back into the supply. After the RF-filter are the contactors K1 and K2, the start resistor, and the rectifier choke and capacitors which make up the intermediate DC circuit. Before the power electronics can be activated and the lamp ignited, it is necessary to charge the capacitors to their off-load voltage. Initially the capacitors are connected to the mains via the contactor K1 and the start resistor. When the off-load voltage is reached, K2 closes and shorts out the start resistor. The D.C. section is then ready to supply the power electronics.

A disadvantage of this circuit is that current is only taken during the peak of the sine waveform of the supply. To overcome this a power correction active filter can be used which draws current in a sinusoidal waveform. This eliminates current peaks and achieves a power factor approaching 1 (see section 3.4).

The DC voltage from the intermediate circuit supplies the electronics, which generate the square wave current that drive the HMI lamp. The power electronics consist of two frequency converters. The first is a step-down or buck converter, which draws a controlled, constant direct current from the D.C. intermediate circuit. This converter consists of the H.F. circuit and choke (fig. 8) and operates as a pulse width modulated controller. At a constant frequency of operation, typically 20 kHz, the transistor T1 can be switched on for between 5% and 95% of a cycle.

While T1 is switched on, the current flow through the HF-choke increases linearly. When T1 is switched off, the choke continues to drive current to the load via the freewheel diode D1 at a rate which decreases depending on the voltage across the lamp. By varying the duty cycle of T1 it is possible to regulate the DC mean voltage to the required value. By using a choke matched to the control frequency (approx. 20 kHz), the triangular ripple which is superimposed on the DC voltage can be kept to only a few percent (fig. 9).

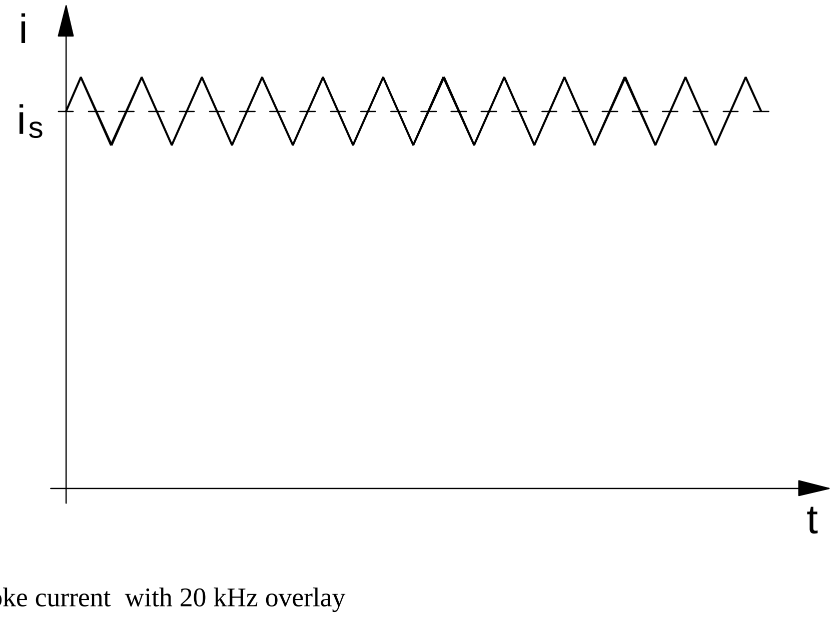

Fig. 9: HF-Choke current with 20 kHz overlay

The actual direct current flow is measured and the duty cycle of the transistor T1 is adjusted accordingly. The current flow to the lamp is thus precisely controlled.

The advantage of this type of converter is its high efficiency (better than 90%) which contributes to minimizing the losses in the ballast.

The second converter stage serves exclusively as an inverter to supply the discharge lamp with the necessary symmetrical alternating current. Transistors T2 to T5 (fig. 8) form a full H-bridge. The lamp is connected between T4-T5 and T2-T3. The transistors are switched in alternate pairs so that current from the HF choke flows through the lamp first in one direction via T4 and T3 and then in the other via T2 and T5. The switch over between the two pairs of transistors takes only a few microseconds and the frequency of operation can be selected between 50 and 200 Hz.

The ballast control receives all information about current flow and voltages in the ballast and the status of the power semiconductors. Monitor and control circuits transmit the required control signals to the power stages after comparing measured and nominal values, thus providing optimal control of the lamp arc.

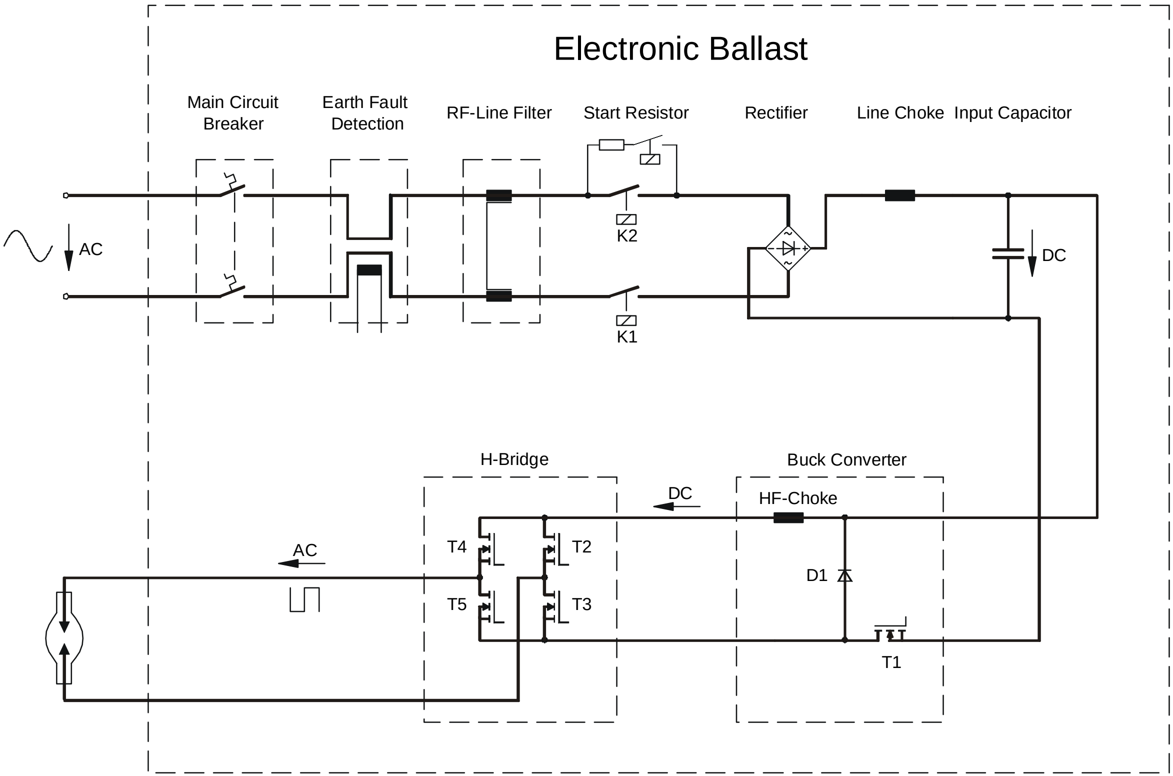

Fig. 8: Block diagram of an Electronic Ballast

3.2. Control of Lamp Power

With an electronic control system, not only current but also lamp power can be regulated. Variations due to mains supply and aging of the lamp no longer influence the energy of the arc itself. In this way, the colour of the light is held constant through its life, thus extending the time for which the lamp can be used for high quality colour reproduction.

3.3. HMI Lamp Dimming

The possibility of HMI dimming is a further advantage of the electronic over the choke ballast. Discharge lamps cannot be dimmed down indefinitely since below a certain level the arc becomes unstable and extinguishes. However, all wattages may be dimmed to 50% of their rated power without problems. Lamps should not be dimmed below this limit, especially smaller types with capacities of 1.2 kW or less. An exception is the range of single ended lamps which are matched for electronic operation and, according to the manufacturers, may be dimmed to 40% power without significantly changing the light quality.

But experiences with different „Single Ended“ lamps have shown, that by dimming the lamp down more than 70% colour changes can be seen which are not acceptable for some operations.
Dimming not only changes the lamp power but also the light colour. In general the co-related colour temperature rises when the power is reduced, but there are also differences in characteristics between different sizes of lamp and also due to luminaire design (see section 4.3).

3.4. Active Line Filter (ALF)

When operating electronic units from the mains (or line), national and international regulations for maximum permissible mains reaction should be observed. In section 3.1 it was mentioned that with a simple bridge rectifier circuit the mains is loaded with high current peaks. The capacitors in the intermediate circuit are only being charged through the rectifier diodes when the mains voltage is higher than the capacitor DC voltage. Figure 10a shows the current and voltage flow into a electronic ballast.

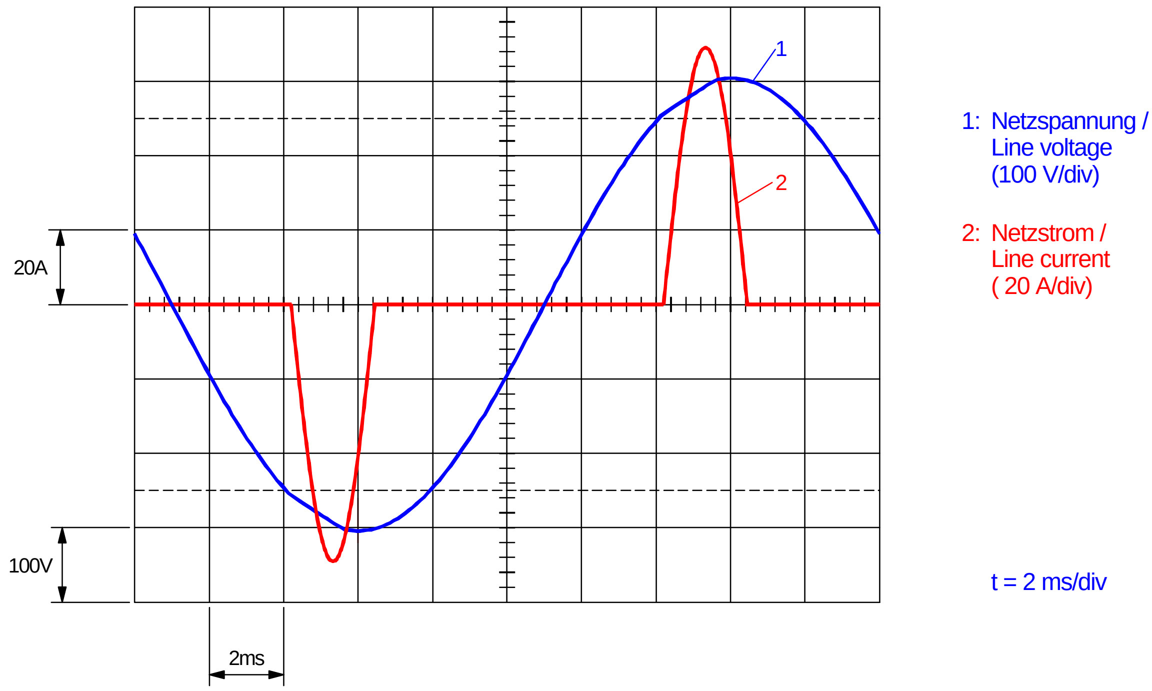

Fig.: 10a: Current and voltage flow / conventional bridge circuit

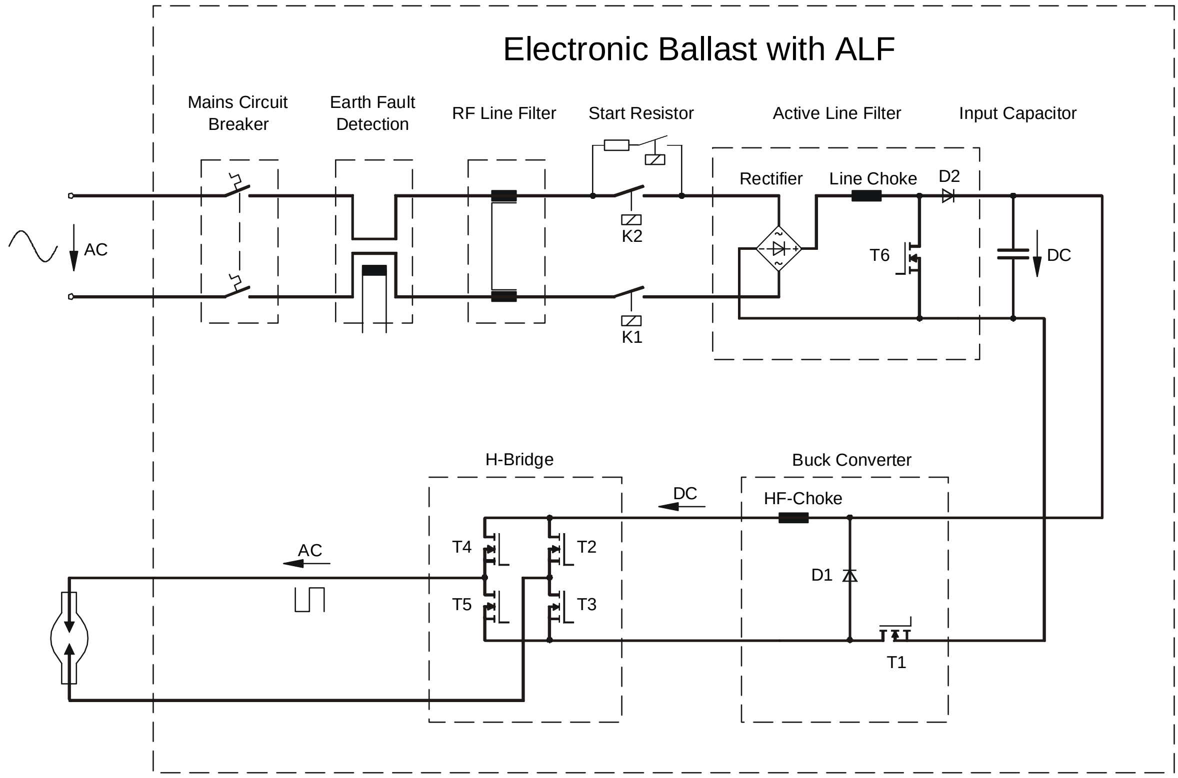

Fig. 10b: Block diagram Electronic Ballast with ALF

During the time when the rectifier is conducting, the peak current can reach 2.5 times that of an equivalent sinusoidal waveform. This results in extremely high loads on the mains or generator supply, which can seriously interfere with other units on the same supply.

The use of an active filter can overcome this problem. As mentioned in section 3.1, a step-up or boost converter is fitted between the rectifier and capacitors of the DC intermediate stage (fig. 10b). The converter consists of a choke, switching transistor T6 and diode D2. Pulse width modulation is also used to control this converter. At a fixed frequency outside the human hearing range (e.g. 25 kHz) T6 can be switched on with a duty cycle from 5% to 95%. During the on time of T6 the mains choke is charged i.e. the choke current increases linearly. When T6 is blocked, the stored magnetic energy in the choke drives the current via D2 into the capacitors. The choke voltage falls rapidly to the capacitor voltage. In this way, current is still drawn from the supply when the instantaneous supply voltage is below the capacitor voltage. The active filter control circuit ensures that the current waveform is sinusoidal and in phase with the mains waveform (fig. 10c). Therefore, besides drastically reducing the effect of the ballast on the supply, the power factor can also be optimized to approximately 1. This has the advantage of reducing the required generator capacity when on location.

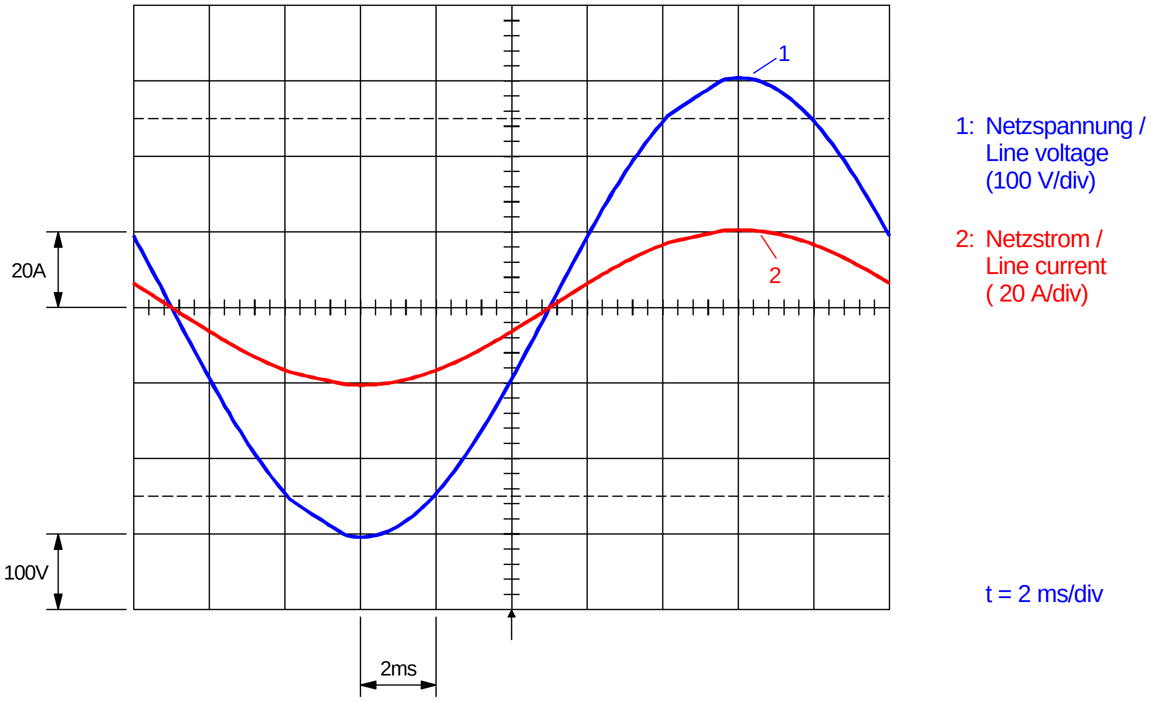

Fig. 10c: Current- and voltage flow / Active Line Filter

The apparent power which a ballast requires consists of lamp power (real power), the losses in the ballast and the reactive or imaginary power between the ballast and the generator.

Efficiency and power factor define the relationship between the lamp power and the required mains supply is given by the following equation:

$$\underset{\text{(Apparent Power)}}{\text{Mains Supply Capacity}} = \frac{\text{Lamp Power}}{\text{Efficiency} \bullet \text{Power Factor}} \qquad (5)$$

Depending on the power of the electronic ballast, the efficiency is on average 87%-94%; these being very good values.

Regarding power factor, the situation is different. Without active filtering the obtainable value is approximately 0.73.

The following example of the two 12kW electronic ballasts shows the big difference between the power requirements:

		With	Active Line Filter	Without
Lamp Power	:	12.000 W		12.000 W
Efficiency	:	87%		88%
Power Factor	:	1.0		0.73
Mains Capacity (Apparent Power)	:	$\frac{12 \text{ kW}}{0.87 \cdot 1.0}$		$\frac{12 \text{ kW}}{0.88 \cdot 0.73}$
Total	:	13.8 kVA		18.7 kVA

The result shows that without the Active Line Filter approximately 5kVA more generator power has to be made available for the same lamp wattage.

3.5 Noise Generation in the HMI lamp

One of the big disadvantages of the operating with a square wave supply is the noise that is generated in luminaire. The igniters in the lampheads were originally designed for operation with choke ballasts. The required ignition voltage that is generated is superimposed across the lamp electrodes through Tesla coils. After ignition (max. time 1 sec.) these Tesla coils carry the high currents which power the lamps. With a sinusoidal supply (e.g. with a choke ballast), the noise generated is negligible.
However, with a square wave supply (e.g. with electronic ballasts) the rapidly changing magnetic fields created when the high current reverse directions, create disturbing audio noises in associated metal components and parts.

In the lamps themselves, oscillations in the kHz. range produce high pitch whistling noises. These are due to the high frequency harmonics contained in the square wave current. Since modified igniters and matched lamps are still being developed, the electronic ballasts are fitted with a “low noise” switch for 24/25 f.p.s. operation. In this mode the HMI lamp is supplied with choke type sinusoidal current and the noise in the luminaire is drastically reduced. However, as the light now contains a mains – synchronous flicker component, it is essential to observe the same conditions of frame rate and shutter angles as is required with choke ballast operation. All other advantages such as power control, dimming, compensation of mains voltage variation and lamp tolerances are maintained.

4. Advantages of HMI Light with Electronic Ballast Operation

One of the main reasons for the development of electronic ballasts was the requirement for a uniform, flicker – free HMI light, and as described, the electronic ballasts offer a number of advantages over choke ballasts.

To summarize the main features:

- Flicker free up to 10.000 fps;
- No camera modification required;
- Luminous efficiency increased by 5%;
- Constant lamp power;
- Uniform colour temperature (4.1);
- Stable, optimal colour quality (4.2);
- Power control from 50% - 100% (Dimming);
- Mains voltage variation of ± 10% have no influence on flicker free operation;
- Mains frequency variation of ± 10% have no influence on flicker free operation;
- Lamp life approx. 20% longer;
- Smaller and lighter ballasts than choke types.

4.1 Control of the Colour Temperature

Within certain limitations the colour temperature can be controlled by dimming the lamp. This allows for a degree of colour correction. At the same time, however, the colour location could move out of the permissible area of the 5 SWE (threshold units) and the light colour may no longer be acceptable. Since HMI lamps of different size and manufacture have different characteristics, it is not possible to indicate exactly when the limit has been reached. Measuring the colour temperature with the usual three colour instruments is not sufficiently accurate because the light from an HMI has a discontinuous line structure, and not the continuous black body curve for which such instruments are calibrated.

In general, reducing the power to the lamp causes a rise in correlated colour temperature and the colour location travels parallel to Planck´s curve. Below 70 – 80% of nominal power the increase slows down and it can happen that the colour temperature then drops. Figure 12 illustrates the possible changes of colour location of an 18kW lamp. Each curve is shown in the section of the colour triangle with colour location and colour temperature details.

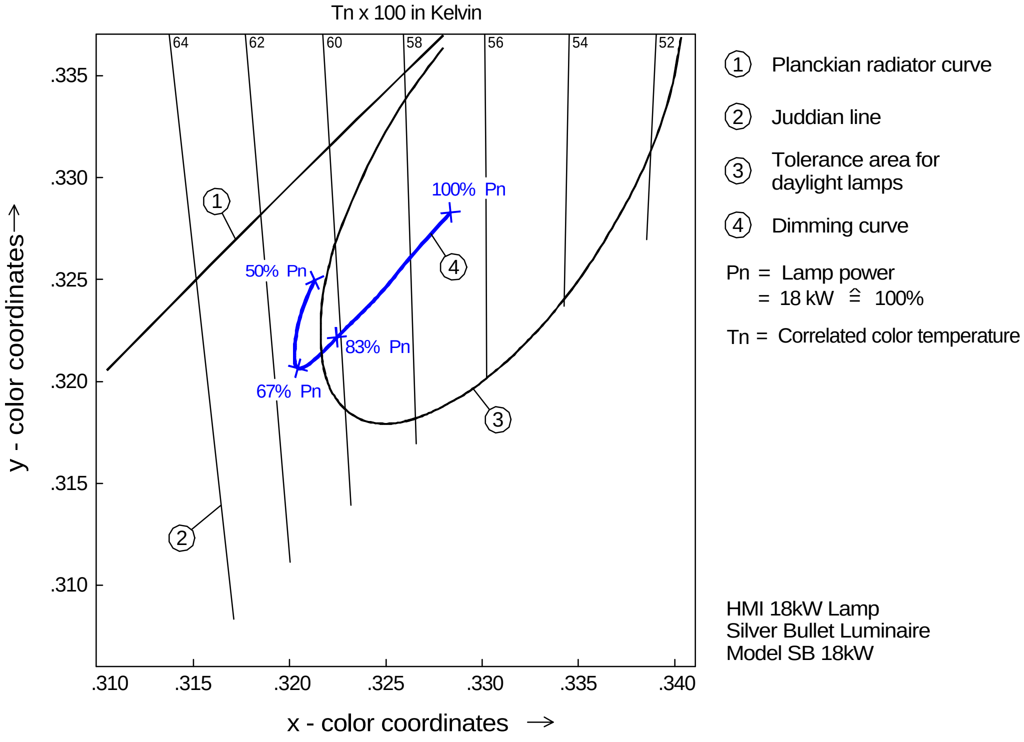

Fig 12: Color triangle 18 kW

4.2 Stabilizing the Colour Quality

One of the advantages of using an electronic ballast is the stabilization of colour quality. The constantly controlled lamp power has the result that variations of, (for example), mains voltages over a wide range (190 – 250 V) and changes of lamp voltages caused by aging are both fully compensated for and optimum light quality is maintained. Additionally, limiting the cold lamp starting currents with the electronic ballast helps to preserve the electrodes and increases in lamp life by up to 20% are normal.

5 Resume

The development of electronic ballasts for the entire available range makes it possible to fully utilize HMI light sources to their maximum. The electronic system is relatively foolproof, robust and easy to service. The operation is constantly monitored by safety circuits, which shut off the electronics if a fault condition such as excessive mains over/under voltage or a short circuit to earth occurs. The units are ideally suited for use in the often severe conditions found on location.

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