Research Note

A Dimmable Electrodeless Fluorescent Lamp

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ABSTRACT

A dimmable electrodeless fluorescent lamp (induction lamp) is introduced in this paper. The principles of the induction lamp are introduced in details. A dimming approach for the lamp is discussed in both theory and experiment. A continuous dimming range from 30%-100% can be realized with the application of the IC chip.

KEYWORDS: electrodeless fluorescent lamp, IC chip, dimming

1. Introduction

The electrodeless discharge was first discovered by Hittorf in 1884, then The first electrodeless lamp was shown by Tesla in New York in 1891. The principles of induction lamp was patented by P. C. Hewitt in 1907¹⁾. The electrodeless fluorescent lamp is fundamentally different from the traditional fluorescent lamps, which employ electrodes as electron source. The operation frequency of induction lamp can be designed in the range of hundreds of kHz to tens of MHz²⁾ which can be produced by a high frequency generator (ballast). And the electrodeless fluorescent lamp have many advantages, such as long life, high efficacy etc. With the great advance in electronics and the advent of electronic ballasts, the induction lamp got the possibilities to be introduced into commercial market for the general purpose lighting, such as Everlight and Electroless Pa-Look ball You from Matsushita, QL from Philips, Genura from GE, Endura and Icetron from OSRAM, LVD from Hongyuan and Tungda from Tungda. Here we introduce the performance of a dimmable electrodeless fluorescent lamp — a ring-type induction lamp, which employs IC chips in the ballast.

2. Principles of ring-type induction lamp

2.1 Inductive discharge

The ring-type induction lamp consists of three parts, the high frequency generator (ballast), energizing coils and the discharge tube. The schematic construction of the ring-type induction lamp is shown in Figure 1. The high frequency generator is responsible to generate high frequency current (230kHz at rated power in this design). When the high frequency current flows through

Figure 1 The schematic diagram of the lamp

the energizing coils wrapping around the ferrite cores, inductive electric field is produced to sustain the gas discharge. The two energizing coils are positioned in parallel with each other, and the turns of the coils are determined by the power of the lamp specifications. Discharge gas is composed of Mercury and Argon as the buffer gas. The pressure of Mercury is controlled by the main amalgam. Several assistant amalgams are posited close to the ferrite core to help quick ignition.

The process of energy transferring from the energizing coil to the discharge plasma can be equivalent as a model of transformer³⁾. As shown in Figure 2, the energizing coil is equivalent to the primary winding and the discharge tube is equivalent to the secondary winding. The inductively coupled discharge is maintained by high frequency voltage built in the discharge tube.

2.2 High frequency generator

The main function of the ballast is to generate high

Figure 2 The electrical lamp model

Figure 3 Block diagram of the high frequency generator

frequency current to drive the inductively coupled discharge. As shown in Figure 3, the ballast can be divided in several parts according their purposes. The first part is EMI filter which reduces the harmonics from the AC supply. The second part is the bridge rectifier where the filtered AC is converted to DC. The third part is the PFC (power factor correction) circuit which can improve the power factor to more than 0.95 and boost the DC voltage to a constant value (about 400V). The last part is the inverter, by which the boosted DC is converted to the high frequency AC.

2.3 The Dimming technology

The inverter is controlled by the IC chip: HY4501, a special designed chip for electrodeless lamp by Hongyuan company and which provides driving signals to the inverter and can decide the operation frequency. Dimming is realized by the frequency control of HY4501. The inverter circuit controlled by HY4501 is shown in Figure 4. HY4501 takes samples of the current and voltage of the lamp, and the voltage drop on the adjustable resistor. Each value of resistance is corresponding to a value of lamp power. The chip calculates the lamp power with the sampled values of voltage and current, then compares with the standard value of lamp power correspondent to the voltage drop (resistance). If the lamp power doesn't match the standard value, then the chip changes the output frequency. The output frequency of chip is the driving frequency of MOSFET inside inverter. Consequently, the operation frequency of lamp is changed. Because lamp power is inversely proportional to the operation frequency when voltage is constant, lamp power will change with the changing of operation frequency and dimming will be realized⁴. With the accurate control of HY4501,

Figure 4 The inverter circuit

Figure 5 The simplified dimming circuit

30%~100% dimming range can be achieved without negative effects on the lamp. In Figure 5, the simplified dimming circuit is shown, with which the process of dimming can be easily understood. Additionally, HY4501 also provides protection for the system, such as short circuit, and overheat. For instance, when the sampled voltage or current is too high, the chip will stop to drive the inverter then the lamp and other components will not suffer from the over current or over voltage.

3. The dimming performance

The dimming behavior of a 120W ring-type induction lamp has been surveyed. The lamp is made of boron glass tube, and the geometry of the lamp is a torus, as shown in Figure 1. The out diameter of the torus is 300mm, and the out diameter of the tube is 58mm, the thickness of the tube is 1.5mm. The buffer gas is krypton with a fill pressure c.a. 25 pa at 25°C. The DC voltage from the inverter is constant at 400V, and each of the primary coils have 17 turns. The working frequency of the ballast can vary from 150kHz to 290kHz by the IC chip, the dimming behavior of the lamp can be seen in the following figures.

3.1 Power factor

As shown in Figure 6 the dimming percentage of the lamp power is nearly linearly inverse proportional to the working frequency of the ballast. The lamp voltage nearly constant, so the lamp power is mainly decided by the current, which can be approximately described as

$$I_{\text{lamp}} \propto \frac{1}{\omega^\alpha} \quad (1)$$

Here the ω is the working frequency and α is a constant related to ballast. So the lamp can be dimmed by controlling the working frequency. In the experiments, the dimming range 30% ~ 100% is realized by the frequency changing from 150kHz to 290kHz.

Figure 6 The variation of the power percentage and factor with frequency

Figure 7 The current frequency spectrum
a) 100% power; b) 30% power

It can be seen that the power factor slowly decreases with the dimming. This can infer from the increase of the harmonics of the current. For instance, as shown in Figure 7, the current harmonics distortion increases from 6.6% to 16.4% when the lamp power dim from 100% to 30%, especially the 3rd, 5th and 9th harmonics greatly increase. But the lamp still can have a quite high power factor at lower power, the power factor remains 0.903 at the 30% of the full power.

3.2 Efficacy

Another important characteristic of the dimming is the efficacy decrease. In this dimming technology, the maintenance of lamp efficacy is quite acceptable for real application. As shown in Figure 8, the efficacy decreases very slowly when the lamp power percentage more than 60%, and it decreases greatly if the lamp power is blow 50%. The efficacy can be effected by three factors: the ballast efficacy, the couple efficacy and the energizing coil efficacy. In this case the couple efficacy changes a little, so the lamp efficacy is mainly affected by the ballast efficacy and the energizing coil efficacy. When the lamp power decreases, the working frequency is on the increase, the energy loss increases due to the components of the ballast. The energizing coil loss is very complicated, its variation is nonlinearly with the material, shape, frequency, temperature and lamp voltage. We design the lamp with the minimum core loss at normal operation²⁾, when the lamp dimming the coil loss percentage increased proportionally with frequency. Thus the electrodeless lamp efficacy will decrease when dimming.

3.3 Color performance

Figure 9 and 10 show the variation of the color temperature and rendering index during the dimming. The variation is very slim and is hardly to be detected by human eye, which give the lamp advantages in energy saving for lighting applications. The main reason is that the light emitting from the lamp is mostly decided by the phosphor coated on the inner surface of the tube and the direct emission of the visible light from the

Figure 8 The efficacy of the dimming

Figure 9 The variation of color temperature

Figure 10 The variation of CRI

plasma is very low. So the variation of the spectral power distribution of the lamp is very slim, therefore the color temperature and color rendering index not change seriously.

4. Conclusions

The working principle and dimming technology of the ring-type induction lamp has been introduced. Although there are some technology to dimming the lamp, the frequency method was applied in this IC chip technology lamp for convenience. The lamp can be a good choice for lighting and the dimming behavior can be applied for the purpose of energy-saving. Given its long life, high efficacy and dimming behavior, the lamp can be applied for the environment protecting and sustainable development.

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