Study Of Acoustic Resonance Phenomenon In High Pressure Discharge Lamps (Type Mercury Vapour And Sodium).

L. Amer[1] and M. Hamouda[1], C. Benachiba[2]
[1]*Department of material sciences, University of Adrar, Algeria*
[2]*Department of electronic engineering, University of Béchar, Algeria*

Abstract

In order to reduce the electric consumption for high pressure discharge lamps, sodium and mercury vapour type, the use of high frequencies electronic ballasts represents both a solution and many advantages such as, the decrease in the congestion, low costs and weak losses; approximately 10% however it is not regarded as perfectly reliable, this is due in a great part to the appearance of Acoustic Resonances in the plasma of electric discharges for certain functioning frequencies.
Considering the relevant relation which exists between this phenomenon and the propagation of the pressure waves in the plasma, a predictive model was established, translated into calculation program under the Matlab language through which we could determine the oscillations frequencies for the fundamental propagation modes Z axial, r axial, and φ *axial.*

The findings results will enable us to avoid acoustic resonances in lamps supplied with electronic ballasts of very reduced structures.

Keywords- *Acoustic resonance; discharge lamps electronic ballasts; pressure propagation mode.*

1. Introduction

The electric discharges play an important role in numerous applications and especially those of lighting. Among the first invented artificial luminous sources, lamps functioning with low pressure dominated the market at the time, in parallel the development of high pressure discharge lamp allowed the creation of light sources, that produce an important luminous flow beneficial for lighting wide public spaces. The principle of microscopic functioning of this discharge is identical in the two types of lamps, however the high pressure lamps presents an improvement in the volume that is very reduced in regard to that of low pressure lamps, in the photometric performances of the system, in the lamp life. And finally a better control of its functioning so as to reduce electricity consumption.

Thanks to the progress made in electronic power field, the supply at high frequencies permits to reduce the costs of manufacturing electronic ballasts by reducing the number of necessary components. Yet, at high frequencies, we remark the appearance of instabilities translated through distortion of the electronic discharge, accompanied generally by vibration of the lamp. These instabilities give rise as well to an accelerated ageing of electrodes and in certain cases the destruction of the lamp. This happen if the hot part of the electronic discharge comes into contact with the walls of the burner. This phenomenon known as "Acoustic Resonance", is due to the generation and propagation of a pressure wave in the plasma [8].

The object of this work resides in the study of the interaction between the pressure waves and the electronic discharge, sodium and mercury vapour types, functioning at high pressure, for various propagation modes with the help of numeric model translated into Matlab program.

2. Physical modelling of acoustic resonance

The proposed physical model of acoustic resonance, allows to predict excitation conditions of acoustic resonance and the arc form. This model is obtained when considering the discharge in the lamp as a plasma in Local Thermodynamic equilibrium (LTE) [3], [4].

Under these conditions all the plasma's sizes are a temperature function often very complicated. A precise measurement carried out within the laboratory to obtain the geometrical profile of the plasma temperature is necessary for the determination of the acoustic resonance frequencies. We can completely model the behaviour of the discharge by using the conservation relations of the mass, momentum and energy, coupled with electric relations and those of the radiation. Considering the loss by friction due to the plasma viscosity insignificant, which means that we can omit the terms of amortization, which leads to the following equation, characterizing the propagation of the pressure waves in the plasma [1], [7].

$$\frac{\partial^2 p}{\partial t^2} - C_s^2 \Delta p = (\gamma - 1)\frac{\partial N}{\partial t} \quad .....(1)$$

$$N = P_{ele} - U_{ray} - W_{th} \quad .....(2)$$

$$C_s = \sqrt{\gamma . \frac{R_M . T}{M}} \quad ....(3)$$

ISSN: 2278-0181
Vol. 2 Issue 6, June - 2013

3. Simplified propagation equation and its analytical solution

The equation (1) is very complex and requires the knowledge of a great number of data and its solution is extremely difficult. However, if our reasoning is limited just to the prediction of frequencies where the acoustic resonances appear, we then can omit the term source which depends only on the plasma. So we will treat the propagation of pressure wave in a hot gas but not ionized. In this context certain terms of the model may be neglected and the equation is considerably simplified. After simplification, we gets:

$$\nabla^2 p = \frac{1}{C_s^2(T)} \cdot \frac{\partial^2 p}{\partial t^2} \quad \ldots\ldots\ldots\ldots(4)$$

This simplified formulation, known as "Helmholtz equation" makes it possible to determine the acoustic resonance frequencies [12]. If, initially we consider that the temperature and the speed of propagation of sound are constant. Under these conditions this equation can be analytically solved, in a cylinder of ray R and length L, by the variables separation method:

$$P(r,\varphi,z,t) = P_A J_n\left(\frac{W_r r}{C_s}\right)\cos(n\varphi)\cos\left(\frac{W_z Z}{C_s}\right)e^{-j\omega t} \quad ..(5)$$

$$\omega_{nlm} = \sqrt{\left(\frac{a_{nm}C_s}{R}\right)^2 + \left(\frac{\pi l C_s}{L}\right)^2} \quad \ldots\ldots\ldots..(6)$$

Where:
- J_n is Bessel function of order N.
- R, φ and Z are the cylindrical coordinates of a point in the tube.
- a_{nm} indicates the root of line (m+1) of the first derived of the Bessel function Jn according to r.
- *l*, m and n, are entireties corresponding to the different modes and more precisely:
- The number l determines the periodicity along a direction parallel to the axis $\overrightarrow{OZ}$; when l=0, we speak about transverse or radial-azimuth resonances.
- The n number determines the periodicity of repetition, when the vector ray turns around $\overrightarrow{OZ}$; when n=0, we speak about radial-longitudinal resonances.
- The m number determines the number of nodal circles on which certain components of the field are cancelled; when m=0, we talk about azimuth-longitudinal resonances [6].

According to the equation (6), the acoustic resonance frequency depends then on the dimensions of the discharge tube (ray R and length L), and the celerity of the pressure propagation Cs which itself depends on the composition of gases and average temperature of the plasma.

This means that the resonance frequency may vary with the ageing of the lamp because of the change of gas compositions, and with the temperature which represents the total power injected into the discharge. Consequently, because of the manufacture tolerance, we can have light differences in acoustic resonance frequencies for lamps of the same type and manufacturer [10].

For the equation (5), terms (n,m,l) represent as well the spatial distribution of pressure in the discharge, by indicating $\omega_{nm} = \omega_r$ the transverse frequency of resonance according to (r,φ), by $\omega_l = \omega_z$ the longitudinal frequency of resonance according z, and by $\omega_{n,m,l} = \omega$ the combined resonance frequency or global. The equation (5) enables us to distinguish the following terms [11],[5]:

$$P(r,\varphi,z,t) = \overset{Amplitude}{P_A}\overset{terme\ radial}{\left[J_n\left(\frac{W_r r}{C_s}\right)\right]}\overset{terme\ Azimuthal}{\left[\cos(n\varphi)\right]}\overset{terme\ Longitudinal}{\left[\cos\left(\frac{W_z Z}{C_s}\right)\right]}\overset{Propagation}{\left[e^{-j\omega t}\right]} \quad ..(7)$$

4. Results and discussion

After having presented the numerical model used for the study of acoustic resonances in discharge lamps, as well as the equation (7) resolution, using a Matlab program, we could present the propagation of pressure according to different modes: longitudinal, radial and azimuth, relating to lamps of the following characteristics [9], [2]:

"Table 1. Lamps characteristics"

Standard lamp SHP 400W	standard lamp VMHP 400W with 70mg
R= 3,75 e^{-3} m.	R= 9,5 e^{-3} m
L= 10,7 e^{-2} m.	L= 8,2 e^{-2} m
C_s= 470,7 m/s^2	C_s= 491,71 m/s^2

The results obtained are presented below:

4.1. Sodium lamp's Results

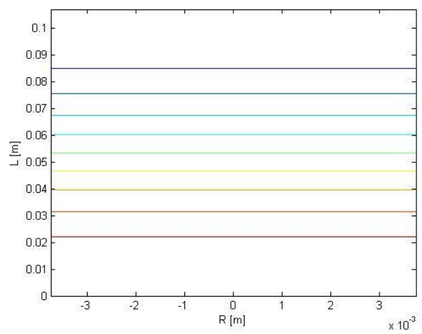

Figure. 1 Longitudinal fundamental mode (0,0,1)

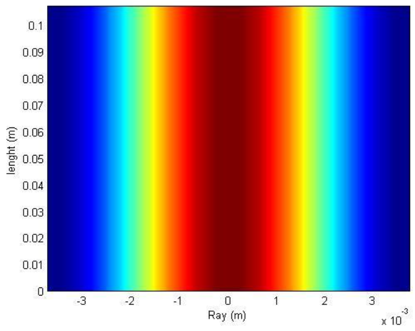

Figure. 2 Radial fundamental mode (0,1,0)

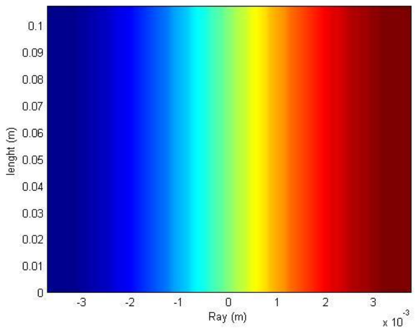

Figure. 3 Azimuth fundamental mode (1,0,0)

4.2. Mercury vapour lamp's Results

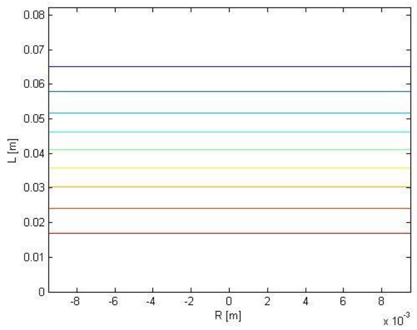

Figure 4. Longitudinal fundamental mode (0,0,1)

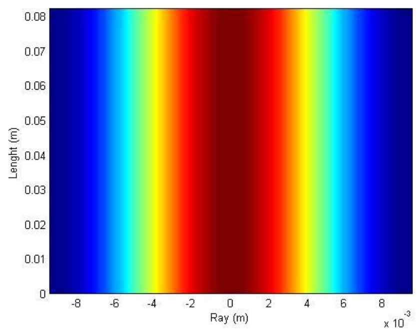

Figure. 5 Radial fundamental mode (0,1,0)

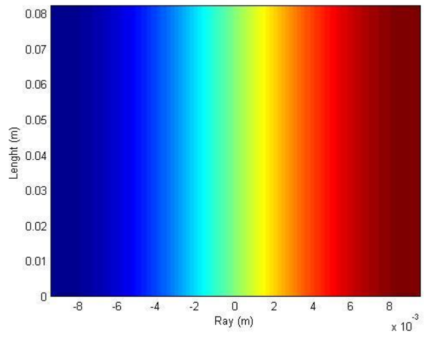

Figure. 6 Azimuth fundamental mode (1,0,0)

For all graphs: high pressure
Null pressure
Low pressure

Table. 2 Frequencies of the acoustic resonances

Mode / Lamp Type	(0,0,1)	(0,1,0)	(1,0,0)
SHP 400 W	2.1995 kHz	76.5464 kHz	36.7819 kHz
VMHP 400W	2.9982 kHz	31.5644 kHz	15.1672 kHz

According to the distribution of pressure in the arc and we note to the theory that the discharge endeavours to move through zones where the pressure is low. The arc takes the way which corresponds to the least losses.

For longitudinal mode Z axial (0,0,1) we can see clearly that the pressure begins to take important values starting from 0.045m for the HPS lamp whereas for the HPMV lamp it starts from 0.035m.

For radial longitudinal mode R axial (0,1,0), the higher pressures lies between $-0{,}8.10^{-3}$ m and $0{,}8.10^{-3}$m for HPS lamps type and between -2.10^{-3}m and 2.10^{-3} m for HPMV lamps type.

The φ axial, azimuth mode (1,0,0) the pressure starts to get important values from $2{,}5.10^{-3}$m for HPS lamp while for the HPMV this value is equal to $5{,}8.10^{-3}$m.

Concerning the two modes longitudinal Z-axial (0,0,1) and R-radial (0,1,0), we remark well that the probability to get an acoustic resonance effect is important in the case of HPMV lamps type than that of HPS ones, then it is reversed for the φ axial azimuth mode (1,0,0). In experiments this effect is translated as follow, the Acoustic resonance in longitudinal mode arises by a curved arc at the level of one of the discharge ends. In radial mode, the arc seems to segment successively to diffuse zones then narrow. Finally, the azimuth mode is an oscillation of the arc from one end to another.

The acoustic resonance affects the stability of light and the uniformity of the colour and may lead to the extinction of the discharge. In this very critical case, the acoustic resonance can damage the lamp by the deformation of the burner in permanent way, or by literally exploding it.

5. Conclusion and prospect

The excitations of acoustic resonances are linked to the propagation of pressure waves in the enclosure of the discharge with reflection on the walls from which will result a stationary wave. They appear when the harmonic powers frequencies of supply are equal to the frequencies of the lamp's own resonance and their harmonic power exceeds certain critical values.

With this occasion we could establish a physical model that allows to study the propagation of the pressure in a section of arc of two different types of lamps, high pressure sodium (HPS) and high pressure mercury vapour (HPMV).

The pressure variation constitutes a dominating factor in the appearance of the acoustic resonances phenomenon. The established model gave us the possibility to predict with good precision the propagation modes of pressure waves and their proper frequencies associated in a purely theoretical way. Thing which allows to highlight conditions of excitation of acoustic resonance, so as to determine the excitation threshold. As prospect this work will contribute to the synthetisation of detection techniques and to the realization of an adapted command in order to avoid acoustic resonances.

6. Nomenclature

p : Variation of the pressure around the average value p_0.

N(w): Electric power injected volume unit.

P_{ele}: Electric power injected in the discharge.

U_{ray}(W) : Losses radiation by volume unit.

W_{th}(W) : Heat dissipation by volume unit, due to thermal conduction.

γ : Constant defined as the ratio of the specific heats to the pressure and constant volume (respectively Cs and Cv).

R_M: Gas molar constant.

$R_M = 8{,}3144\ (j^{-1}.mol^{-1}.K^{-1})$.

M : Mass molar $(mol.g^{-1})$.

T (K): Discharge temperature.

7. References

[1] J. Correa, M. Ponce, J. Arau, J. M. Alonso , "Modeling of Low Power Metal-Halide and HPS Lamps Operated at High Frequency", Power Electronics Congress, 2002.

[2] Chun-Jen Yao; Huang-Jen Chin; Tai-Hung Wang; Shih-Jen Cheng; Yu-Kang Lo; Shann-Chyi Mou;, "A Single-Stage Full-Bridge Electronic Ballast for High-Pressure Mercury Lamps", SICE Annual Conference, 2008 , 20-22 Aug. 2008, Page(s):2705 – 2709.

[3] Attila Vagvolgyi, Agoston Boroczki, Szabolcs Gyimothy and Imre Sebestyén, "Modeling acoustic resonance in high-pressure discharge lamp arc chambers", International Journal of Applied Electromagnetics and Mechanics 2001/2002.

[4] L. Chhun; P. Maussion; S. Bhosle; G. Zissis; "Interpolation modelling of acoustic resonance in high pressure sodium lamp"Industrial Electronics, 2008. IECON 2008, 34th Annual Conference of IEEE 10-13 Nov. 2008 Page(s):1974 – 1979.

[5] J.A.J.M. van Vliet, ir, and J.J. de Groot, Dr. ir., « High-pressure sodium discharge lamps» , IEE PROC, Vol. 128, Pt. A, No. 6, SEPTEMBER 1981.

[6] Lionel Sevier, «Influence de l'alimentation par commutateur de courant sur le rayonnement des lampes sodium haute-pression », thèse doctorat en génie électrique en 1995, université paul sabatier, Toulouse, France.

[7] J.W. Denneman, Ir., « Low-pressure sodium discharge lamps », IEEPROC, Vol. 128, Pt. A, No. 6, SEPTEMBER 1981, Page(s): 397-414.

[8] Sylvain Epron, « Etudes et effets des oscillations acoustiques dans les lampes à décharge haute pression », thèse doctorat en génie électrique en 1999, université Paul Sabatier, Toulouse, France.

[9] J.W. ter Vrugt and J.K.P. Verwimp, «High pressure mercury vapour lamps » , IEEPROC, Vol. 127, Pt. A, No. 3, APRIL 1980.

[10] Sieegger, B.; Guldner, H.; Hirschmann, G.; Ignition Concepts for High Frequency Operated HID Lamps , Power Electronics Specialists Conference, 2005. PESC '05. IEEE 36th , Page(s): 1500 – 1506.

[11] J. de Groot, J. Van Vliet, "The high pressure sodium lamp", Kluwer technische boeken B.V. Deventer, 1986.

[12] S. Ben-Yaakov and M. Gulko, "Design and performance of an electronic ballast for high-pressure sodium (HPS) lamps", IEEE Transaction on Industrial Electronics, Vol.44, No.4, pp.486-491, 1997.