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Measurements of luminous flux and spectral characteristics of high pressure sodium lamps powered by high frequency voltage source

Abstract: *The article presents a comparison of the levels of luminous flux and light emission spectrum of high pressure sodium lamp powered by high frequency voltage source. The test results have been compared to measurements performed at mains frequency.*

Streszczenie. *W artykule przedstawiono porównanie wartości strumienia świetlnego oraz zmienność charakterystyk widmowych lampy sodowej wysokoprężnej przy zasilaniu napięciem o wysokiej częstotliwości. Badane parametry porównano z wynikami uzyskanymi przy zasilaniu lampy częstotliwością sieciową. (**Porównanie wartości strumienia świetlnego oraz zmienność charakterystyk widmowych lampy sodowej wysokoprężnej przy zasilaniu napięciem o wysokiej częstotliwości**)*

Keywords: high pressure sodium lamp, luminous flux, spectral characteristics, high frequency.
Słowa kluczowe: wysokoprężna lampa sodowa, strumień świetlny, charakterystyki widmowe, wysoka częstotliwość.

Introduction

The source of light of high frequency sodium lamp is ceramic filament containing sodium, mercury and xenon vapors. After lamp ignition, discharge begins in xenon and then after heating of filament a decisive luminous flux comes from sodium and mercury. The pressure inside the filament after heating equals about 2 MPa. Sodium lamps emit light of color temperature equaling about T=2000 K, whereas durability of these lamps depending on construction equals 10-24 thousand of hours of work.

Lighting efficiency ranges between 68-150 lm/W and it is one of the highest efficiencies of the currently used industrial sources of light. Because of the low Color Rendering Index (CRI) of about 20, they are mainly used for external illumination of squares, streets and crossings, etc.

Description of test station

For measurement of spectral characteristics of the tested high pressure sodium lamp, an electronic ballast with transistor bridge output was applied. The ballast allowed for regulation of voltage frequency supplying the lamp, whereas the value of power applied to the lamp was estimated by means of regulated direct voltage source to which the ballast was plugged.

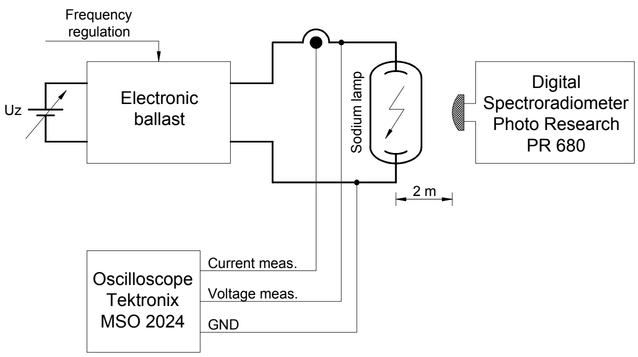

Fig. 1. Diagram of the test station for spectrum and light radiation energy

For the measurement, Tektronix oscilloscope MSO2024 type was used as well as voltage probe P5100, x100, 2,5 kV_{peak} type of baseband bandwidth up to 250 MHz and current probe TCP0030, $30A_{rms}$ (50 A_{peak}) type of baseband bandwidth from 0 to 120 MHz..

Power applied to the lamp was calculated by means of appropriate mathematical functions directly built in the oscilloscope by the producer of the device. The distance between the source of light and the spectroradiometer equaled 2 meters, therefore all the values of light radiation energy were determined for this distance. Spectral characteristics measurements and radiation energy were conducted by means of PHOTO RESEARCH digital spectroradiometer PR-680 type.

Objective and results of the research

The objective of the research was to determine variation of light radiation energy and light spectrum during supplying high pressure sodium lamp by different frequency voltage with maintaining the same power delivered to the source of light. Nominal power of the lamp was 400 W. Research results for different frequencies of supply voltage were compared to research results for the same lamp plugged to the classic coil ballast powered by mains voltage of the frequency f=50 Hz commonly applied for this type of lamps. The measurements were conducted after thermal stabilization of plasma and it was experimentally stated that the period of 20 minutes after the change of power value applied to the lamp was sufficient for performing another measurement of spectrum and light radiation energy.

Figures 2 and 3 present characteristics of light radiation energy variation with changes of frequency of power supply of the lamp and applied power.

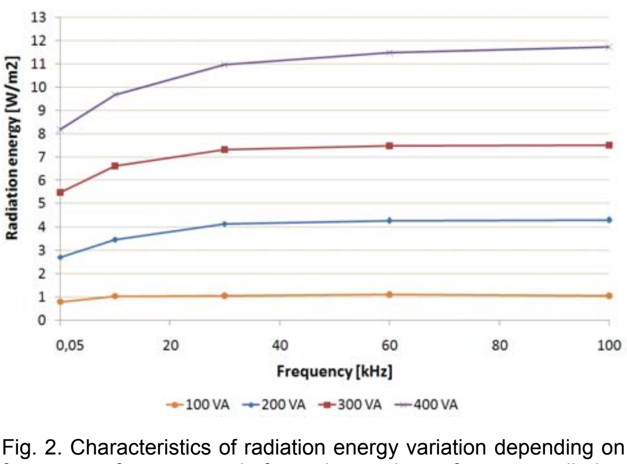

Fig. 2. Characteristics of radiation energy variation depending on frequency of power supply for various values of power applied to the sodium lamp.

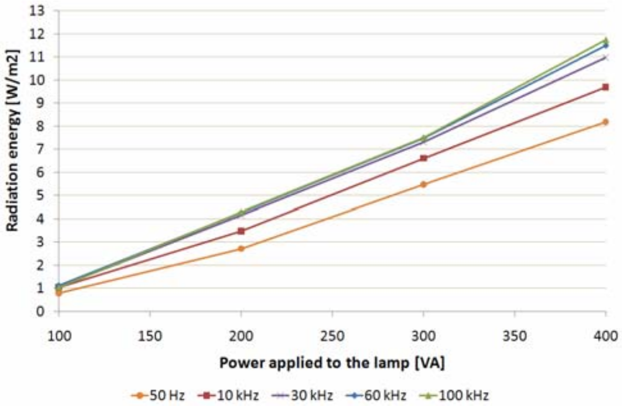

Fig. 3. Characteristics of radiation energy variation depending on power applied to the lamp for various values of frequency

Benefit obtained in the amount of radiation

Figure 4 presents the functions of benefit of radiation energy against the values of energy emitted by the lamp powered by a classic coil ballast working at the frequency of f=50 Hz. Depending on the value of power applied to the lamp, benefit of radiation energy for sodium lamp of rated power equaling S=400 VA, varies from ΔE=38,7÷43,3 %.

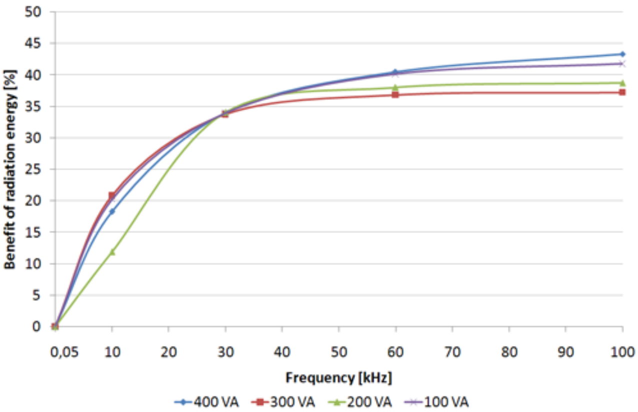

Fig. 4. Functions of benefit of radiation energy values depending on the power supply frequency of the lamp for various values of power applied to the lamp

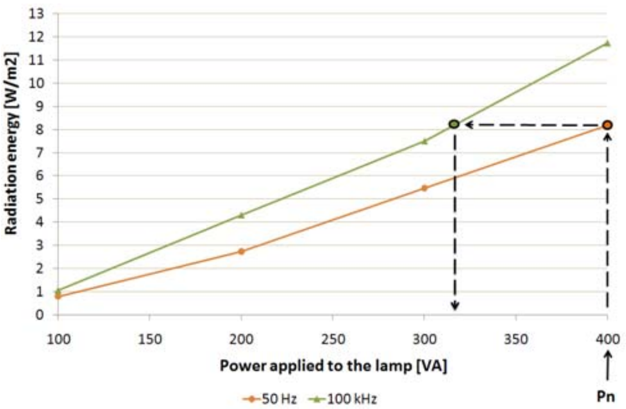

Fig. 5. Functions of radiation energy for frequencies f=50 Hz and f=100 kHz.

On the basis of the character of the function of benefit of radiation energy for the rated power and frequency of f=100 kHz, it has been stated that the curve does not have an established character, therefore it is possible to obtain even more light radiation energy at the power supply of the lamp with frequency value of over f=100 kHz.

Electric energy saving

Figure 5 presents the functions of light radiation energy measured at the frequency of f=100 kHz and f=50 Hz. In the graph a dotted line indicates the value of light radiation energy from the lamp obtained for coil ballast (f=50 Hz) with the value of rated power of S=400 VA and the corresponding to the same radiation energy value of power that should be applied to the ballast working at the frequency of f=100 kHz.

It results from researches that by supplying a tested lamp with the power of S=320 VA and at the frequency of f=100 kHz the same level of radiation energy is obtained as for the classic coil ballast supplied with the power of S=400 VA working at the frequency of f=50Hz.

Measurements of spectral characteristics

Figures 6, 7, 8 present characteristics of spectral distribution of radiation of the tested light source.

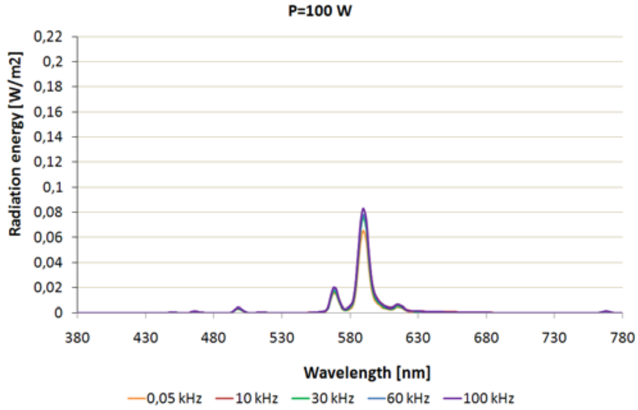

Fig. 6. Spectral characteristics of sodium lamp for S=100 VA

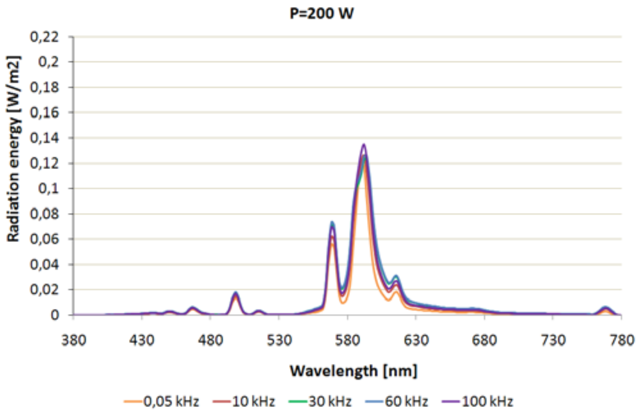

Fig. 7. Spectral characteristics of sodium lamp for S=200 VA

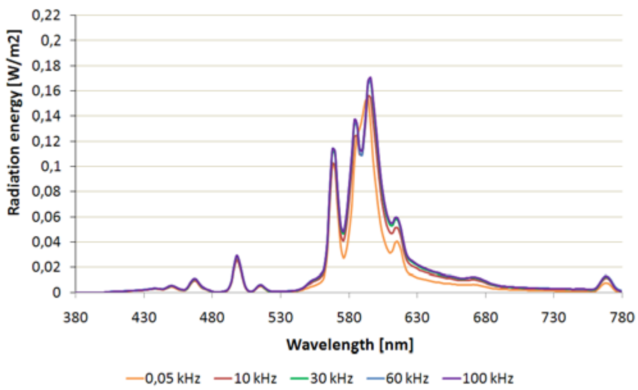

Fig. 8. Spectral characteristics of sodium lamp for S=300 VA

Researches have been conducted within the range of wavelength λ=380÷780 nm at various frequencies of lamp voltage. The power applied to the lamp varied in the range of S=100 VA to 300 VA.

Figure 9 presents characteristics of spectral distribution of radiation of the tested source of light in the range of 380÷780 nm at various frequencies of lamp voltage. For all presented functions, power applied to the lamp equaled S=400 VA.

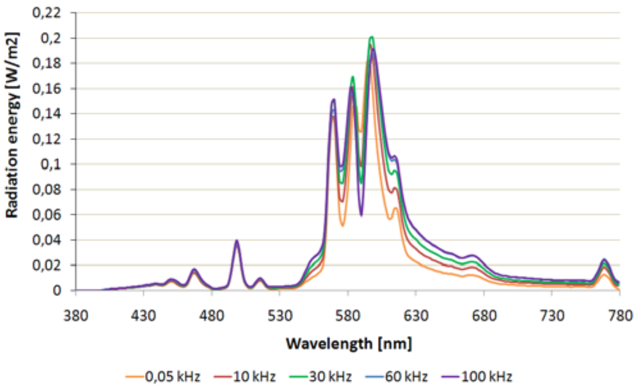

Fig. 9. Spectral characteristics of sodium lamp for S=400 VA

Light pulsation measurement

Research on light pulsation level was conducted on the basis of amplified voltage signal coming from measurement photodiode.

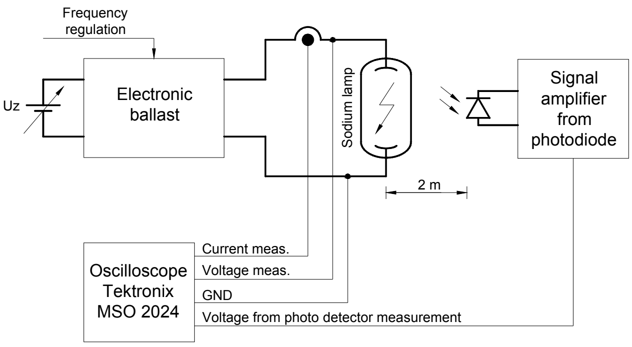

Fig. 10. Light pulsation test station diagram

Voltage output signal from detector was measured by means of oscilloscope, and its value was proportionate to the instantaneous value of luminous flux emitted by the tested source of light.

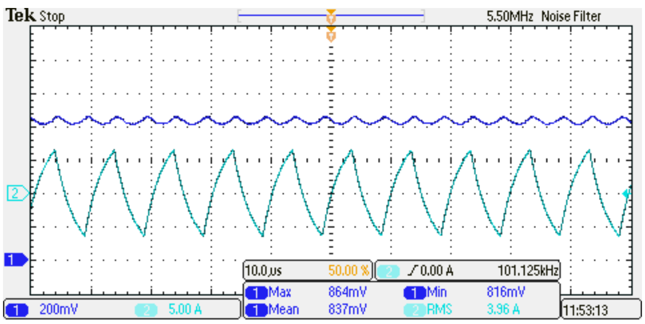

Fig. 11. Functions of luminous flux and supply current of metal halide lamp for the power of S=400 VA and f=100 kHz.Channels: CH1-voltage from photo-detector, CH2- lamp supply current

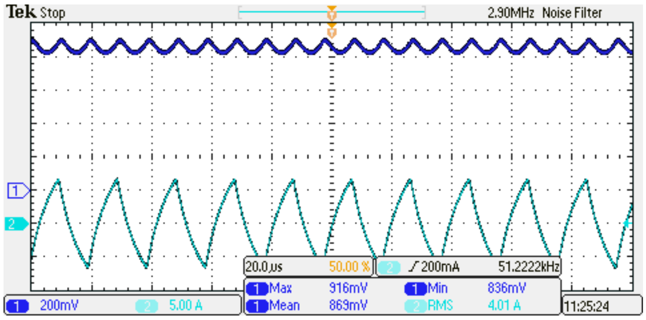

Fig. 12. Functions of luminous flux and supply current of metal halide lamp for the power of S=400 VA and f=50 kHz. Channels: CH1-voltage from photo-detector, CH2- lamp supply current

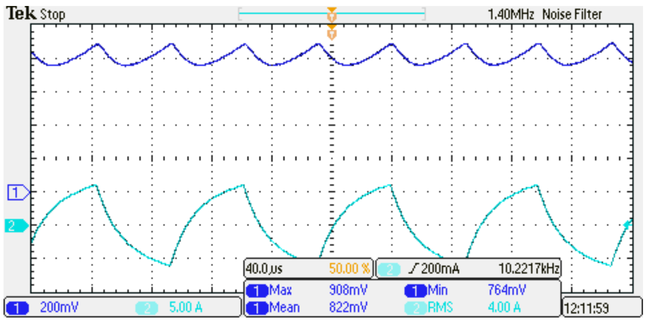

Fig. 13. Functions of luminous flux and supply current of metal halide lamp for the power of S=400 VA and f=10 kHz. Channels: CH1-voltage from photo-detector, CH2- lamp supply current

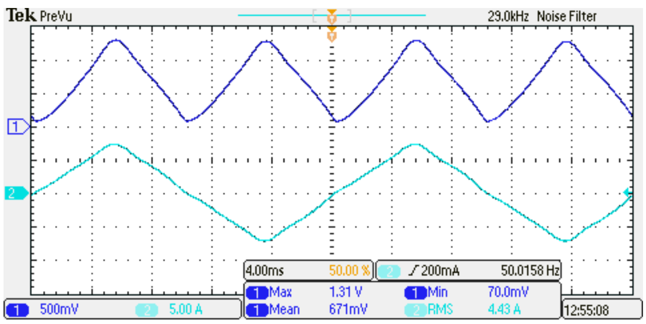

Fig. 14. Functions of luminous flux and supply current of sodium lamp for the power of S=400 VA and f=50 Hz. Channels: CH1-voltage from photo-detector, CH2- lamp supply current

Border measurement frequency of the photodiode and the applied amplifier is on the level of a few MHz, whereas, variation of signal measured on the level of maximum f=100 kHz. For calculation of light pulsation the following formula was used (1) [5].

(1) $$w = ((z_{max} - z_{min}) / z_{max}) \cdot 100\ \%$$

where: w - - luminous flux pulsation, z_{max} - maximum value of photometric parameter, z_{min} - minimum value of photometric parameter

Table 1. Comparison of the value of luminous flux pulsation

Lamp voltage frequency	Light pulsation value [%]
50 Hz	94.6
10 kHz	15.8
20 kHz	13.1
30 kHz	10.6
50 kHz	8.7
100 kHz	5.5

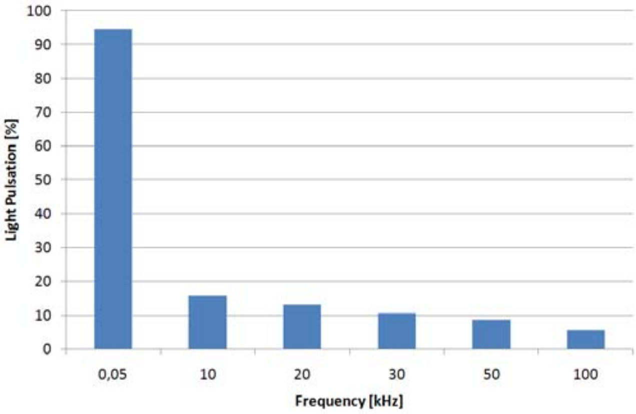

Fig. 15. Values of light pulsation when supplying sodium lamp with the power of S=400VA at various values of voltage frequency (graphic interpretation of table 1)

Researches on CRI (Color Rendering Index)

Researches on Color Rendering Index (CRI) have been conducted by means of PHOTO RESEARCH digital spectroradiometer PR-680 type.

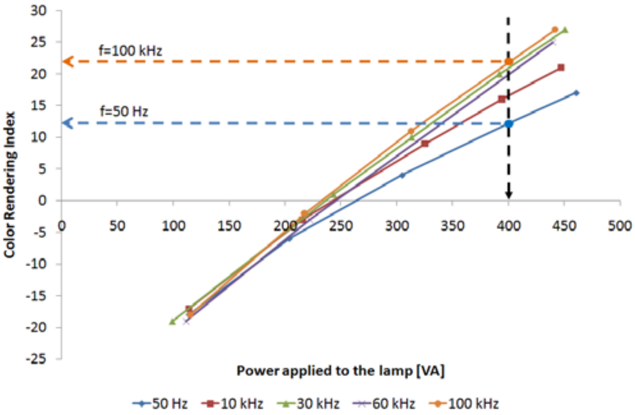

Fig. 16. Functions of CRI parameter value against power applied to the sodium lamp at various voltage frequencies of the lamp.

Figure 16 presents Color Rendering Index values for frequencies f=50 Hz and f=100 kHz. In both cases the power applied to the lamp was rated power and equaled S=400 VA.

Conclusions

After concluding the researches and conducting the analysis of results it was stated that when supplying high pressure sodium lamp with high frequency voltage, more emitted light can be obtained. The biggest light benefit was obtained for the rated power of P=400 VA and voltage frequency of f=100 kHz and equaled ΔE=43,3 %.

From the observed function of emitted energy curve (fig. 2) for the power P=400 VA, it has been stated that for the frequency f=100 kHz it does not have an established character, therefore it is possible to obtain even more radiation energy when supplying the lamp with voltage of frequency higher than f=100 kHz. In order to determine frequency at which the curve of radiation energy will have an established character, additional researches will be conducted.

Increasing the amount of generated light is connected with stabilization of illuminating plasma, which leads to minimizing light pulsation. For the frequency f=100 kHz, light pulsation equals w=5,5 %, whereas for f=50 Hz, w=94,6 %.

Supplying sodium lamps with high frequency voltage as it has already been stated, allows for generating an increased luminous flux with the same power supplied. It is possible to reverse the problem and answer the question regarding electric energy saving, at which the value of radiation energy is the same for coil ballast powered by mains voltage and for electronic ballast, therefore supplying the lamp by means of electronic ballast working at the frequency of f=100 kHz it is possible to save electric energy on the level of P=80 VA, which constitutes 20% of the apparent power supplied to the source of light.

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