Regarding the radio-technical operation mode calculation of the generator lamps

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Abstract. The variant of calculating parameters of high-power generator lamps in a dynamic mode was offered in this work. The output power of the lamp, the load on the electrodes and the efficiency of the anode circuit are determined. The calculation of experimental mode was confirmed with engineering accuracy (~10 %).

Powerful generator lamps (PGL) are one of the main types of vacuum devices [1]. It currently used in television, radio broadcasting, etc. (figure 1). By electronically lamps group refers electronic devices in which in the working volume a high vacuum is created, and the operation principle is based on the use of an electron stream, whose motion is controlled by electric fields [2, 3]. Structurally, a lamp consists of a cathode, an anode and grid electrodes to control the electron beam motion.

### Generator lamps

- **Oxide cathodes** ($T_{\text{cat}} = 850 ^\circ \text{C}$)
- **Tungsten thoriated-carbide cathodes** ($T_{\text{cat}} = 1700 ^\circ \text{C}$)

### Operating modes

| Mode | Output Power ($P_{\text{out}}$) | Heat Load ($P_{\text{heat}}$) | Grid Load ($P_{\text{grid}}$) | Frequency ($f$) |
|------|-------------------------------|-----------------------------|-----------------------------|-----------------|
| Pulsed | 5–200 kW | 0.08–8 kW | 8–1000 W | 30–800 MHz |
| Running | 10–5000 kW | 0.5–6.6 kW | 0.05–0.2 kW | 150 MHz |
| Pulsed | 2–1000 kW | 0.2–30 kW | 50–600 W | 1.6 GHz |
| Running | 0.1–15 kW | 20–200 W | 5–200 kW | 75–860 GHz |

### Grid material: W, Mo, alloys: (W + Re), (W + Mo)

### Types of antiemissive coatings:
- Au, Ti
- Ti, ZrC, ZrC + Pt, Pt/Zr, C

**Figure 1.** Technical characteristics of powerful generator lamps.
The generator lamps’ output power level varies from kilowatt to 2.5 MW in running mode and up to 5 MW in pulsed mode, and the anode voltages range varies from units to hundreds kilovolts [4]. The main areas of generator lamps improvement are an increase in the specific power per unit volume and an increase in durability with a high level of reliability. The increase in specific power is associated with an increase in the operating temperature of the grid nodes and anodes, which leads to a decrease in reliability and lifetime.

Let’s consider a variant of a dynamic mode operation of a generator lamp. First, the according parameters chosen with the maximum given permissible parameters:

- anode supply voltage \( U_a \);
- efficiency of the anode chain \( \eta \);
- residual voltage of the anode \( U_{a\text{res}} \);
- screen voltage \( U_s \).

The calculations begin with the determination of the oscillatory voltage at the anode

\[
U_{ma} = U_a - U_{a\text{res}}.
\]

The anode voltage usage factor is determined by the formula

\[
\xi = \frac{U_{ma}}{U_a}.
\]

Next step is to define the lamp operation class for the bias voltage. The concept of the operating mode is determined by the ratio of the anodic quiescent current to the magnitude of the signal current. Thus, the anode current usage factor

\[
\gamma = \frac{2\eta}{\xi}.
\]

The radio engineers use the terms angular pulse width and cut-off angle to characterize the duration of part of the half-cycle during which the anode current flows.

Finally, using the tables of the expansion of the cosine-wave pulse in a Fourier series by the Berg method, the cutoff angle of the anode current is found. The operation class for calculated lamp is C. In C operating mode the time of the anode current flow is less than the time of the positive half-wave of the input signal. The mode is characterized by much higher values of efficiency and distortion level in comparison with the used in amplifiers B operating mode [5].

The voltage on the grid 1 is determined from the graph of the anode-grid characteristic

\[
I_{a\text{max}} = \frac{I_{a1}}{\alpha}.
\]

The operating bias voltage providing the required cutoff angle of the anode current is found by graphical construction. The coordinates of the anode current pulse \( I_{a\text{max}} \) are used to determine the locking point with the residual voltage at the anode \( U_{a\text{res}} \) and half the pulse at the supply voltage of the anode \( 0.5I_{a\text{max}} \). The locking voltage is a result of intersecting two points with an axis with a straight line.

First the points \( 0.5I_{a\text{max}} \) and \( 0.5U_{ma} \) are found then a straight line through the points of the anode current pulse amplitude and the voltage on the grid 1 before crossing with the anode voltage line is drawn, a locking voltage is obtained. The bias voltage is found by the formula

\[
E_{s1} = \frac{U_{s1} - U_{a1}\cos\Theta_a}{1 - \cos\Theta_a}.
\]

The amplitude value of the excitation voltage

\[
U_{me} = U_{s1}^+ - E_{s1}.
\]

The cutoff angle of the grid 1 current is found by formula
The pulse currents according to the characteristics (for grids) are determined. Then the constant component of grid current 1 is found

\[ I_{s10} = \alpha_{01}^* I_{s1 \text{ max}}. \]  

(7)

The first harmonic of grid 1 current is determined

\[ I_{s11} = \alpha_{11}^* I_{s1 \text{ max}}. \]  

(8)

The constant component of grid 2 current is found by the formula

\[ I_{s20} = 0.8\alpha_{01}^* I_{s2 \text{ max}}. \]  

(9)

To calculate the power the currents values obtained above are used. The grid 2 dissipated power is

\[ P_{s2} = U_{s2} I_{s20}. \]  

(10)

The grid 1 dissipated power is

\[ P_{s1} = 0.5U_{ma} I_{s11} + E_{s1} I_{s10}. \]  

(11)

The anode dissipated power is

\[ P_{a} = U_{a} I_{0} - P_{\text{out}}. \]  

(12)

The grids and anode loading of the lamp do not exceed 87% of the maximum permissible powers is checking

\[ K_{s2 \text{ res}} = \frac{P_{s2}}{P_{s2 \text{ add}}}. \]  

(13)

Next the equivalent resistance of the anode circuit is found

\[ R_{\infty} = \frac{U_{am}}{I_{s11}}. \]  

(14)

Finally, the lamp power amplification factor is determined

\[ K_p = \frac{P_{\text{out}}}{0.5U_{ma} I_{s11}}. \]  

(15)

The results of the calculations are then compared with the experimentally obtained data and the deviations are determined (%):

- output power, kW;
- anode circuit efficiency factor, %;
- grid 2 loading, W;
- grid 1 loading, W;
- anode dissipated power, W.

The level of power released on the tetrode’s screen grid is determined by its operating mode and determines the output of electrons from its surface into the discharge gap. The Richard–Dashman formula [6,7] for thermionic emission:

\[ j_{\text{TEE}} = AD_0 T^2 \exp(-e\varphi / kT), \]  

(16)

where \( A = 4\pi n_e k^2 / h^3 = 1.2 \cdot 10^6 \text{ A/(m}^2\text{K}^2) \) – Richardson constant; \( D_0 \) – quantum-mechanical coefficient of electron reflection from the metal-vacuum boundary; \( k = 1.38 \cdot 10^{-23} \text{ J/K} \) – Boltzmann constant; \( \varphi \) – work function, W.

Real conditions work requires from the developers of devices to include the development of the process of applying antiemission coatings in their technological map [8–10]. The most effective
coatings used for oxide cathodes are Au-, Ti-based coatings, for tungsten cathodes these are zirconium and platinum based compounds [11, 12] are often used as anti-emission materials, which have a higher work function of the grid material.

The calculations of the dynamic mode of a powerful generator lamp were confirmed with engineering accuracy (~10%).

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