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A Graphical Evaluation of Harmonic Distortion in Valves

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The author describes a graphical method to estimate the harmonic distortion produced by valves under predefined operating conditions.

The elegant method I describe here was often used in the past and was very popular because it required no sophisticated calculations. I also provide its mathematical justification and give an example to illustrate its use.

DESCRIPTION

Consider the anode characteristics of a given valve, as shown in **Fig. 1**, on which are added:

The bias point $P(Ip_0;Vak_0)$,

The load line R_{Load} passing through the bias point,

The points A and B on the load line, defined at the maximum sine input signal amplitude: $\pm e_0$,

The points C and D on the load line, defined at the half sine input signal amplitude: $\pm\frac{e_0}{2}$,

The point M on the load line, defined as the middle of AB.

You can then estimate the harmonic distortion using the following formulas:

$$\%H_2 = 100\left|\frac{MP}{AB}\right|$$

$$\%H_3 = 50\left|\frac{AC+BD-CD}{AD+BC}\right|$$

Higher order harmonic distortion can also be estimated using additional points on the load line. But, the accuracy of the graphical method decreases rapidly with the increasing order, making the method questionable.

The graphical method also applies to push-pull configuration of valves. In this case, curves to consider are composite characteristics.

JUSTIFICATION OF THE METHOD

For a given bias point P and a load line R_{load}, the anode current is only a function of the input signal: e.
You have: $(Ip_e - Ip_0) = F(e)$. You can approximate this function by the following Taylor's expansion:

$$F(e) = a_1 e + a_2 e^2 + a_3 e^3 + \cdots$$

which, in the case of a sine input signal, e = e_0 sinωt, can be rewritten as the following Fourier's series: *see below (1)*

To evaluate the second-order harmonic distortion, you limit the Taylor's expansion to the second order:

$$\%H_2 \simeq 100\left|\frac{a_2}{2a_1}e_0\right|$$

Coefficients a_1 and a_2 of the Taylor's expansion are determined using points A and B defined in the description of the method. Some simple calculations give:

$$\%H_2 = 100\left|\frac{\left(\frac{Ip_{e_0}+Ip_{-e_0}}{2}\right)-Ip_0}{\left(Ip_{e_0}-Ip_{-e_0}\right)}\right| = 100\left|\frac{MP}{AB}\right|$$

For the evaluation of the third-order harmonic distortion, you limit the Taylor's expansion to the third order:

$$\%H_3 \simeq 100\left|\frac{\frac{a_3}{4}e_0^2}{a_1+\frac{3}{4}a_3e_0^2}\right|$$

Coefficients a_1 and a_3 of the Taylor's expansion are determined using points A, B, C, and D defined in the description of the method. Here again, some simple calculations give: *see below (2)*

ILLUSTRATIVE EXAMPLE

Consider the output power pentode type 6550 shown in **Fig. 1**.
Operating conditions for this valve are

Operation	Class A
Configuration	single stage
Anode voltage	250V

(1)

$$F(e) = \left[\frac{a_2}{2}e^2+\cdots\right]+\left[a_1e+\frac{3}{4}a_3e^2+\cdots\right]\sin\omega t+\left[-\frac{a_2}{2}e^2+\cdots\right]\cos 2\omega t+\left[-\frac{a_3}{4}e^3+\cdots\right]\sin 3\omega t\cdots$$

(2)

$$\%H_3 = 50\left|\frac{\left(Ip_{e_0}-Ip_{\frac{e_0}{2}}\right)-\left(Ip_{-e_0}-Ip_{-\frac{e_0}{2}}\right)-\left(Ip_{\frac{e_0}{2}}-Ip_{-\frac{e_0}{2}}\right)}{\left(Ip_{e_0}-Ip_{-\frac{e_0}{2}}\right)-\left(Ip_{-e_0}-Ip_{\frac{e_0}{2}}\right)}\right| = 50\left|\frac{AC+BD-CD}{AD+BC}\right|$$

Grid n° 2 voltage		250V
Grid n° 1 voltage		-14V
Load resistance		1.5k

The harmonic distortion estimation for a grid swing voltage of ±14 V peak-to-peak is determined as follows:

Bias point P		
	Grid n° 1 voltage	-14V
	Anode current	140mA
	Anode voltage	250V
Point A		
	Grid n° 1 voltage	0V
	Anode current	277mA
	Anode voltage	47V
Point B		
	Grid n° 1 voltage	-28V
	Anode current	25mA
	Anode voltage	422V
Point C		
	Grid n° 1 voltage	-7V
	Anode current	215mA
	Anode voltage	140V
Point D		
	Grid n° 1 voltage	-21V
	Anode current	71mA
	Anode voltage	355V

$$\%H2 = 100\left|\frac{\frac{(277+25)}{2} - 140}{277-25}\right| = 4.4\%$$

see below (3)

CONCLUSION

As you can see, the graphical method introduced here is simple and accurate enough to estimate the harmonic distortion produced by valves under given operating conditions. Although this method was very popular in the past, it is nowadays on the point of being completely forgotten by designers who rely too much on modern software, hiding, in most cases, the beauty and elegance of clever solutions. *aX*

REFERENCE

TUNGSRAM Memento—Roger Crespin "Guide du Radio Electricien" 1942—Tome 2—pages 28 to 30.

(3)

$$\%H_3 = 50\left|\frac{(277-215)+(71-25)-(215-71)}{(277-71)+(215-25)}\right| = 9.1\%$$

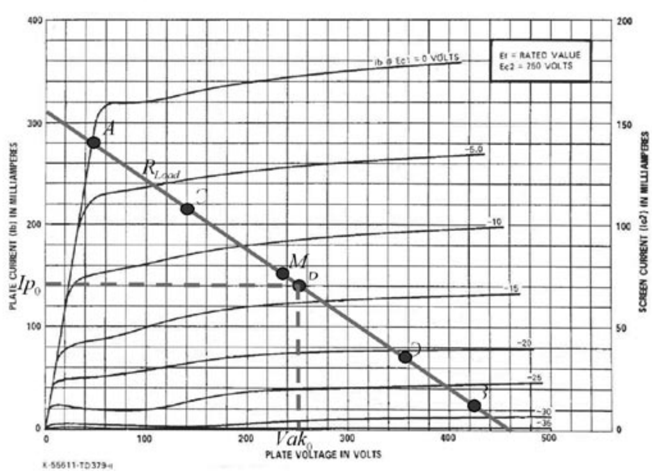

FIGURE 1: Average plate characteristics.