The Development of Designing the Deflection Yoke

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Abstract

This paper describes the development of designing the deflection yoke (DY) of CRT from the standpoint of historical view. It relates the introduction of field parameters, the deflection aberration theory, weight function, Trilemma, the birth of self-convergence color picture tube, multipole field correction theory, the calculation and measurement of deflection field, several new type DY.

Key words: DY, weight function, Trilemma, field parameters, multipoles.

Introduction

The deflection yoke (DY) is an important part of a CRT. On the one hand, it is an electron optics element. The deflection field makes the electron beam scanning the whole screen. It relates the curvature of screen and mask, the correction lens as well as the curves of the glass neck and cone. We can also understand this point from a kind of picture tubes named COTY-29 (Combined Optimum Tube and Yoke). On the other hand it is also an electrical element, it must match the circuits of TV to obtain the maximum deflection effects.

Especially the recent demands for the high definition, the large deflection angle and the flat square screen make the design of DY more and more difficult than ever. But it is interest for a designer. Hence the designers of 30AX said: " Designing deflection units is now more like playing a difficult but fascinating game of chess..."

Now we go along the historical developments and record more important achievements.

Introducing field parameters and the theory of deflection error

In black and white tube the deflection field of the line and frame coil in the DY is nearly a homogeneous field. In 1950, RCA invented the color picture tube. Its three electron guns are arranged to be Δ-type. The deflection field is near a homogeneous magnetic field also. These three electron beams are converged on the screen every where by three dynamic convergent devices. The circuits are very complicate and the adjustment knobs are more than fourteen. How to solve this question?

In the end of 1950's Haantjes J. and Lubben J.[1] introduced the field parameters Ho(z), $H_2(z)$, $H_4(z)$ for a deflection field. According to the symmetrical properties and the magnetic field should satisfy the Laplace equation, then

$$By(x,z)=H_o(z)+H_2(z)x^2+H_4(z)x^4 \quad (1)$$

Therefore the $H_o(z)$ denotes the field along the z axis (coincides with the coil center axis), $H_2(z)$ and $H_4(z)$ denote the second and fourth derivative with z.

They derived the field parameter $H_o(z)$, $H_2(z)$ analytically for a saddle coil only in single turn and the diameter is the same. They also derived the third aberration coefficients expressed by $H_o(z)$, $H_2(z)$ in a single integration. In 1968, Kaashoek J.[2] developed these works to a high level in his Ph.D. dissertation. He derived the field parameters $H_o(z)$ $H_2(z)$, $H_4(z)$ for a flare saddle coil by single turn, but expressed only by integral form in single integration. The third and fifth aberration coefficients are also derived. He also designed an instrument to measure the $H_o(z)$ $H_2(z)$ $H_4(z)$ by three in line small test coils.

1981, Shou-Qian Ding[3] derived the field parameters $H_o(z)$ $H_2(z)$ $H_4(z)$ for a single turn flare saddle coil in analytical form, and it can be expressed in following forms.

$$H_o(z) = F_{00}(z)$$

$$H_2(z) = F_{20}(z)\cos\theta+F_{23}(z)\cos3\theta \quad (2)$$

$$H_4(z) = F_{40}(z)\cos\theta+F_{43}(z)\cos3\theta+ F_{45}(z)\cos5\theta$$

here θ is the azimuthal angle of the single current line. $F_{ij}(z)$ is a function of geometrical configuration data of DY. The significances of those formulae is not only its simplicity and analysis, but also it can calculate the field parameter for the continuous distribution of current lines. The method is very simple. If a_1, a_3, a_5 denote the Fourier harmonic coefficients of the current distribution $I \cdot N(\theta)$, then let a_1, a_3, a_5... substitute the $\cos\theta$, $\cos3\theta$, $\cos5\theta$... respectively in (2), it is the field parameters for this condition. especially while $I \cdot N(\theta) = IN \cos(2n+1)\theta$, only the a_{2n+1} term exited and equal to $IN\pi/4$. The other terms vanished.

The third aberrations are determined by $H_o(z)$, $H_2(z)$ and the fifth aberrations are determined by $H_o(z)$ $H_2(z)$ $H_4(z)$.[2] The distribution of $\cos\theta$, $\cos3\theta$, $\cos5\theta$ are equivalent to a multipole field Dipoles, Sixpoles, Tenpoles respectively.[4] Therefore we can also conclude the Tenpoles through the H_4 only influence the fifth or higher aberrations and never influence the lower such as third aberrations. The sixpoles through H_2 only influences the third and higher aberrations and never influences the Gaussian deflection. It is enable the errors to be corrected systematically order by order.

In 1983, Shou-Qian Ding[5,27] improved the method of Kaashoek to measure the $H_o(z)$ $H_2(z)$ $H_4(z)$ only used two testing coils The data measured along x axis are processed by the regression method therefore it can obtain more accurate results even on H_4.

Self-convergence color tube and its DY

In 1972, under the stimulation of Sony's Trinitron, RCA invented the self-convergence tube. The principle of self-convergence has already exited in the aberration theory. If three guns are arranged in a line, then the convergence error Δx_3, Δy_3 of two side beams R and B are[6]:

$$\Delta x_3 = (A_{303}X_s^2 + A_{304}Y_s^2)\, x_s'$$
$$\Delta y_3 = B_{305}X_sY_sx_s' \tag{3}$$

If the line field parameter H_2 is positive (pincushion field) and the frame V_2 is negative (barrel field), then the astigmatism coefficients A_{303} ,A_{304} and B_{305} may be zero. It means that there are no convergence error of R and B on the screen. This is the basic principle of self-convergence.

Weight Function

Except Astigmatism errors there are Distortion and Coma errors. When we make h_2 positive and v_2 negative to diminish the Astigmatism, it can also lower the NS distortion but it would increase the EW distortion and Coma errors. When we examine the aberration coefficients there are always a multiplier factor before the h_2 or v_2. They are called "Weight Function". Summarized as follows:

$$\begin{aligned} &\text{Distortion:} && W_d = (Z_s - Z)x^2 \quad (\text{or } y^2) \\ &\text{Astigmatism:} && W_a = (Z_s - Z)^2 x \quad (\text{or } y) \\ &\text{Coma:} && W_c = (Z_s - Z)^3 \end{aligned} \tag{4}$$

Z_s is the screen distance from the gun side. Factor $(Z_s - Z)$ is the maximum on the gun side (here $Z = 0$) x (or y) is the normalized Gaussian trajectory. It is an increasing function and arrives its maximum on the screen. If we divide the DY into three areas, the near screen part is very sensitive for distortions. The near gun part is very sensitive for coma. The middle part to the end of DY is sensitive for Astigmatism. Take advantage of these properties of the Weight Functions the line H_2 must first negative and then positive in the middle parts, and the frame V_2 must first positive in the gun side and then negative. This distribution can make all these errors to minimum.

For the fifth deflection errors all the multiplier factors before the h_4 or v_4 are also called the fifth weight function. It can coordinate to diminish every kind of fifth errors when contradictions are presented.

Trilemma

In 1977 Kunio Ando et al. [7] designed the new 110° self- convergence color tube and discovered that when The B, R beans have converged in X and Y axis, the vertical direction in corner part can not be converged, or vice versa. It is called Trilemma conservation. If the top, corner, right x axis on the screen expressed by 12, 2, 3, (like the clock's positions), then.

$$Tr3 = \Delta X_{BR.3} - \Delta X_{BR.12} + \Delta Y_{BR.2} \qquad (5)$$

This situation can be explained by third order aberration theory. Instead of ΔX and ΔY in (5) by the corresponding astigmatism aberrations. The parameters h_2 and v_2 are canceled perfectly each other if $H_0(z) = V_0(z)$, and $x = y$. Therefore Tr3 is independent of h_2 and v_2, only dependent the terms h_0, x, x'.

If the above conditions are not satisfied, the Tr3 would not be constant, but it is still not sensitive for the variation of h_2 and v_2. The Tr3 can be changed by varying the h_0、v_0 and its relative distance, so it can be approached to zero.

If the fifth aberration theory are considered the Tr3 would not be constant also. Sluyterman A. A. S [8] gave the Trilemma a general definition: "An n'th-order trilemma is that linear combination of astigmatism errors (or aberration coefficients), each of them sensitive to the n'th harmonic of the magnetic field, which combination is approximately independent of the n'th and higher harmonics of the field."

It is true for Tr3. As for the fifth Trilemma, there are five astigmatism coefficients and the fifth astigmatism aberrations as follow [5]:

$$\Delta x_5 = (A_{504} X_s^2 + A_{505} X_s^2 + A_{506} Y_s^2) x_s'$$
$$\Delta y_5 = (B_{507} Y_s^3 X_s + B_{508} Y_s X_s^3) x_s' \qquad (6)$$

Every coefficient corresponds an error on the screen from (6). We can only change h_4, v_4 i.e. line tenpoles and frame tenpoles to make two aberration coefficients to be zero. The other three coefficients can be made linear combination with these two coefficients to cancel the term h_4 ,v_4. So there are three Tr5 in this condition. If we put $x = y$ and let $B_{507} = B_{508} = 0$, Then $Tr5_1$ and $Tr5_2$ are very small and $Tr5_2$ is the most significant Trilemma.

If we divide the first quadrant on the screen into four areas A, B_1, B_2, B_3 as Fig.1 and Tr_5 can be expressed by screen-read astigmatism errors.

$$Tr5_2 = 4(X_{BR.2B} - X_{BR.12B} - X_{BR.3B}) - 8(Y_{BR.2.5B} - Y_{BR.1B}) \qquad (7)$$

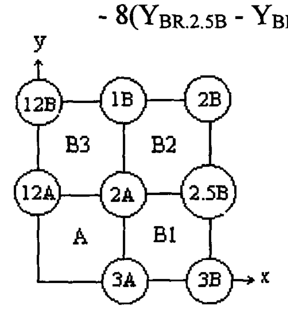

Fig. 1 Tr3 and Tr5

Changing the axial dimensions of the yoke it can be approached to zero. By means of the tenpoles and fifth weight function these fifth aberrations can be diminished.

If the deflection angle increases to 120^0, the seven aberrations and seven trilemma should be considered. [8] The figures of seven order errors are more complicate. Five Tr7 would be presented.

Multipoles and Aberrations Correction

Although the seagull distortion and the S or B type astigmatism can be qualitatively explained by the fifth distortion and astigmatism aberration, and the green beam "falling" in corner and pincushion in E W direction can be explained by fifth coma aberration, however one of the basic principles of the traditional aberration theory is based on the series expansion of the term $1/\sqrt{1+x'^2+y'^2}$ in the trajectory equation such expansion would be invalid when the deflection angle near 45° in XZ and YZ planes because x'^2 and y'^2 approach 1. Due to this limitation, Heijnemaus et al.[4] used a new method in design 30AX color picture tube.

According to the landing points on the screen they give directly the definition of

$$\begin{aligned}
&\text{Astigmatism}: Xa = (X_B - X_R)/2\,; \\
&\qquad \Delta Ya = (Y_B - Y_R)/2 \\
&\text{Coma}: \quad \Delta Xc = (X_B + X_R)/2 - X_G \\
&\qquad \Delta Yc = (Y_B + Y_R)/2 - Y_G \qquad (8) \\
&\text{Distortion}: \Delta Xd = (X_G - X_0) \\
&\qquad \Delta Yd = (Y_G - Y_0) \\
&\qquad X_0 = aI_h\,; \qquad Y_0 = bI_v
\end{aligned}$$

Where I_h , I_v are line and frame scanning current respectively; a, b are constants; X_0 Y_0: Gaussian deflection; X_B Y_B X_R Y_R are the landing coordinates of blue and red beams.

From the symmetry property we may conclude that:

$$\Delta X(-I_h, I_v, -\alpha) = -\Delta X(I_h, I_v, \alpha)$$
$$\Delta Y(-I_h, I_v, -\alpha) = \Delta Y(I_h, I_v, \alpha) \qquad (9)$$

α is the original angle with z-axis of the side beam. Following from this symmetry properties the series expansion of ΔX would contain no terms that are even degree in I_h and α together and that the expansion of ΔY no terms that are of odd degree in I_h and α together.

The deflection space field can be expand into Fourier series by angular variable θ in a cylinder coordinate system. Each term in this series forms a multipole component of the field. According to the symmetry only dipoles, sixpoles, tenpoles and so on will be excited.

As for the trajectory of the three electron beams it can be calculated by Runge Cotta method from the magnetic trajectory equation. So there is no limited on the deflection angle.

The correction of deflection errors by the multipole method has been stated as above. This method offers two major advantages. In the first place, a deflection unit can be designed in steps. The principle action of a 2n - pole is its influence on n^{th} - order error. All the subsidiary effects are always of higher order. In the second place, there is a simple relation between a multipole and the wire distribution required for it. So this method is widely applied in practical design of a DY.

As for the above correction method, multipole calculating and optimum design, Osseyran A.[10] explained more detail in his longer paper (151 pages)

Except Osseyran' method, there are many optimization methods for designing a DY. Recently M. Made et al.[11] used the conjugate gradient method with linear constraints to optimize objective function.

The curved - axis deflection aberration theory

All the above theory is based on the line axis. As the deflection angle is more and more lager, Hutter[12] firstly introduced the curved-axis optics in study the 110° deflection error. L. Zhou et al[13] build the general movement and trajectory equations in curvilinear coordinate system by Tensor analysis. Y. Tu and L. S. Tong[14] extend the second - order aberration theory with curved axis to the third aberration theory. Deflection aberrations are the same as in line axis, but a spherical aberration is presented. When the deflection angle is larger the 110°, the third curve axis aberration theory should be considered. It is equivalent the fifth aberration theory in the line axis.

Calculation the magnetic deflection field

The DY is consisted by two parts. One is the current line; the other the Toroid. The field is also produced and superposed by these two parts. The first part can be calculated by Biot-Savart law as stated above [5]. The later part can be calculated by boundary element method. It is especially suit for the flaring system such as DY. Fye's method [15] is more suitable. It is based on the use of a Green's function expansion to develop an integral equation for the equivalent magnetic charge density on the surface of the ferrite yoke core. So some times it is called surface magnetic charges method.

The space magnetic potential is produce by the induced magnetic charge on the surface of the ferrite yoke core and by the current lines. The permeability of ferrite is approach to ∞, so the magnetic charges are on the surface and the potential would be constant. By means of this condition, we can solve the charge distribution in principle. Instead of this charge distributions in the space potential equation again, the space magnetic field can be obtained.

Be careful the singularities in calculating the diagonal elements of the matrix i.e. calculating the potential on a ring produced by itself. One of the methods to avoid singularities is to use the Gauss integral. The interpolation points are the roots of Legendre's polynomials.

This method is difficult to solve the core which has several sections. X. Sheng[16] has solved this question by means of that the field normal component on each section should satisfy its boundary condition. It is not necessary to put $\mu \rightarrow \infty$.

New types of DY

There are already three types of DY: The toroid-toroid(T- T); saddle-toroid (S- T); saddle-saddle (S- S). The S- S type is always applied to the high performance DY due to its many variable factors.

In 30AX tube the coils no longer have any "flange" on the neck side and became petal shape in middle part. Matsushita has introduced the PSM (Petal Shaped Multi-section) saddle coils for the 17 inch "Pure Flat" CRT [17].

Azzi N. et al.[18] designed an NIS/coma-free 108° self-converging yoke for CRT. No magnets for NS distortion correction and no soft ferrite for the coma correction are necessary.

The self-convergence field would influence every beam's spot on the screen. Chen H. Y. et al. [19], designed a new dynamic quadrupole gun to compensate this influence.

K. Ando et al.[20] designed a flicker-free 2448 ×2048 dot color 90° CRT Display for CAD/CAE. A low-loss slot core DY is utilized. Scanning frequency H : 130kHz , V : 60 Hz. A dynamic convergence correction system is utilized.

In the new tide of digitalization and high definition the Scanning frequency higher than 100 KHz. The temperature raises over 100°C. The multiplexed Litz wire and a low - loss magnetic material suitable for high frequency should be used.

Most parts of energy are spent in DY for a color picture tubes. How to increase its deflection sensitivity is more important. One way is to use a slot core. The average inner diameter of the slot core is smaller than a commonly used core. Because of the existence of projections and therefore the deflection sensitivity is increased. 2 –2.5 times. The other way is to decrease the diameter of tube neck, but it is limited by the performances of electron gun.

Chang K.K.N. ,Tong L., Xue K.[21][22][23] invented an in-neck yoke. The yoke is made on the forward end of the electron gun. The energy is saved 1/3 and the material saved 2/3.

According to the development of HDTV. The screen aspect is from 4:3 to 16: 9. An elliptical DY is suitable It would improve the resolution and save deflection power. Dasgupta B.B[24] used the two dimension model to study this elliptical DY. Shou-Qian Ding et al.[25-26] bases on the eccentricity "e" of the elliptical yoke can be expanded to a power series the field parameters H_0, H_2, H_4 of such a DY can be easily obtained.

Recently Y. Sano et al.[26] has developed a new system of color display tube with rectangular yoke. The deflection Power has been reduced by 23% in comparison with a conventional round DY.

Conclusion

Although this paper is only a short review of the DY progress, maybe many important works have not yet been stated. We can still see these achievements are the results of many scientists and engineers cooperation. These brilliant achievements are not purely from theory nor from experiments, but from the combination of both. The "trial and error" method plays an important rule in design a new yoke. Three tools are more important. One is software of theoritical analyses; one is the instrument for measuring magnetic field[4,27]; the third is the measuring equipment with video camera which can observe and record the deflection errors in a network of point on the screen.

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