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Determination Functions of Magnetic Fields Saddle-type DY

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Introduction

The electron's beam magnetic control technique is used in scanning systems such as lithography machines, television sets or display terminals. To achieve good electronic-optical parameters (EOP) are neccessary modeling magnetic fields (MF) and electron trajectories in the deflection yoke (DY) of this devices. Sometimes these magnetic fields had been founded in using combined empirically – theoretically different methods [1-3]. On the other hand MF can be founded directly theoretically in each point of the electron trajectory [4,5]. Often to compute and optimizes the electronic-optical parameters of devices is used aberration theory [5-7]. The MF functions is given through measuring DY fields with special instrument [6] in this case. After very clear optimization procedure then can be seek good EOP without used calculation electron trajectories.

In this paper the new calculation method of the magnetic fields functions of a saddle-type DY used in the aberration theory is presented.

Magnetic fields DY distribution

The longitudinal one-half section in z, r plane of the DY combined with the coil of saddle - type and ferrite core schematically is shown in Fig.1.

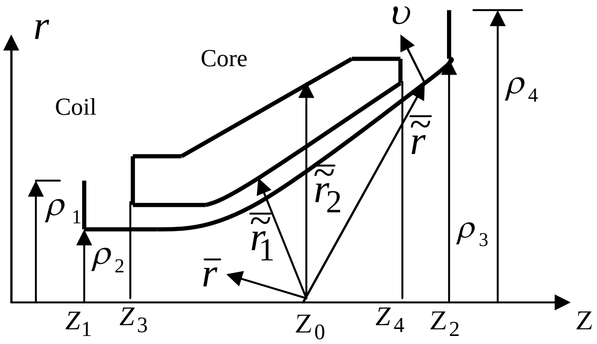

Fig. 1. Basic data of the DY

MF functions will be discovered comparing fields distributions received in two ways: applying magnetic potential double or simple sheets theory and aberration theory. First of all it will be analyzed by MF distribution of the coil. In this case according to MF theory magnetic potential at any point in space is calculated:

$$W(\bar{r}) = \frac{0.25}{\pi}\int_S \upsilon(\tilde{\bar{r}})\left[\tilde{\bar{n}}_0 \times \nabla\left(\frac{1}{\left|\tilde{\bar{r}}-\bar{r}\right|}\right)\right]d\tilde{s}, \qquad (1)$$

where $\tilde{\bar{n}}_0$ – the unit normal on the surface element $d\tilde{s}$ of the coil, $\upsilon\left(\tilde{\bar{r}}\right)$ – density of value of the magnetic dipole (MD) distribution on the surface point $\tilde{\bar{r}} = \tilde{\bar{r}}(\tilde{R},\tilde{\beta},\tilde{z})$. In the symmetrical case of a winding distribution of the coil the MD distribution can be expressed as a sum of angular harmonics:

$$\upsilon\left(\tilde{\bar{r}}\right) = \sum_m a_m \sin m\tilde{\beta}\ , \qquad (2)$$

where $a_m(\tilde{z})$ – Fourier coefficients of the coil winding distribution. Let the surface of the coil between cross sections z_1 and z_2 be expressed as function $\tilde{\bar{r}} = \tilde{\bar{r}}\left(\tilde{R}(\tilde{z}),\tilde{\beta},\tilde{z}\right)$. Then unit normal to this surface at any integration point according well-known formula

$$\tilde{\bar{n}}_0 = \frac{\tilde{\bar{r}}_{\tilde{\beta}} \times \tilde{\bar{r}}_{\tilde{z}}}{\left|\tilde{\bar{r}}_{\tilde{\beta}} \times \tilde{\bar{r}}_{\tilde{z}}\right|} \qquad (3)$$

can be written:

$$\tilde{\bar{n}}_0 = u\left(\bar{i}\cos\tilde{\beta} + \bar{j}\sin\tilde{\beta} - \bar{k}\tilde{R}^{(1)}\right), \qquad (4)$$

where $\tilde{R}^{(1)} = d\tilde{R}/d\tilde{z}$ – derivative on the point of a curve of longitudinal section, and $u = \left[1+\left(\tilde{R}^{(1)}\right)^2\right]^{-0.5}$. The distance between point on the surface of the coil and any point in space $d \equiv \left|\tilde{\bar{r}} - \bar{r}\right|$ can be described in the form:

$$d = \left[\tilde{R}^2 + R^2 + (\tilde{z} - z)^2 - 2\tilde{R}R\cos(\tilde{\beta} - \beta)\right]^{0.5}. \quad (5)$$

After calculating gradient of inverse this function, expression in the rectangular brackets of eq. (1) acquire such equality:

$$\bar{\tilde{n}}_0 \times \nabla\left(\frac{1}{d}\right) = -ud^{-3}\left[p - \tilde{R}\cos(\tilde{\beta} - \beta)\right], \quad (6)$$

where $p = \tilde{R} - \tilde{R}^{(1)}k; \quad k = \tilde{z} - z.$

First of all the MF distribution will be considered in the $\bar{r} = \bar{r}(\beta = 0^\circ, z)$ plane. After the calculating gradient eq. (1) there is only one component MF in this case :

$$H_y = -\frac{1}{R}\frac{\partial W}{\partial \beta}. \quad (7)$$

On the other hand according to well-known aberration theory MF distribution [5] in this plane can be determined by the sequence:

$$H_y = H_0(z) + H_2(z)x^2 + H_4(z)x^4 + \ldots \quad (8)$$

The functions $H_0, \ldots, H_4$ will be founded after comparing MF distribution according to this and (7) equations:

$$H_0 = \lim_{\rightarrow} \; H_y, \quad (9)$$

$$H_2 = \lim_{\rightarrow} \; \left(-x^{-3}\frac{\partial W}{\partial \beta} + x^{-2}\frac{\partial}{\partial x}\frac{\partial W}{\partial \beta} - \frac{x^{-1}}{2}\frac{\partial^2}{\partial x^2}\frac{\partial W}{\partial \beta}\right), \quad (10)$$

$$H_4 = \lim_{\rightarrow} \; \left(-x^{-5}\frac{\partial W}{\partial \beta} + x^{-4}\frac{\partial}{\partial x}\frac{\partial W}{\partial \beta} - \frac{x^{-3}}{2}\frac{\partial^2}{\partial x^2}\frac{\partial W}{\partial \beta} + \frac{x^{-2}}{3!}\frac{\partial^3}{\partial x^3}\frac{\partial W}{\partial \beta} - \frac{x^{-1}}{4!}\frac{\partial^4}{\partial x^4}\frac{\partial W}{\partial \beta}\right), \quad (11)$$

where limit is setting for $x \rightarrow 0, \beta \rightarrow 0$ .These equations after some transforms were got such forms :

$$H_0 = \frac{3}{4}\left[\int_{z_1}^{z_2} a_1\tilde{R}d_0^{-5}\left(\tilde{R}p - \frac{d_0^2}{3}\right)d\tilde{z} + \int_{\rho_1}^{\rho_2} g_0\Big|_{\tilde{z}=z_1} d\tilde{R} + \int_{\rho_3}^{\rho_4} g_0\Big|_{\tilde{z}=z_2} d\tilde{R}\right], \quad (12)$$

$$H_2 = \frac{3}{32}\left\{\int_{z_1}^{z_2} \tilde{R}d_0^{-9}\left[5(a_1 + a_3)\tilde{R}^2\left(7\tilde{R}p - 3d_0^2\right) - 4a_1d_0^2\left(5\tilde{R}p - d_0^2\right)\right]d\tilde{z} + \int_{\rho_1}^{\rho_2} g_2\Big|_{\tilde{z}=z_1} d\tilde{R} + \int_{\rho_3}^{\rho_4} g_2\Big|_{\tilde{z}=z_2} d\tilde{R}\right\}, \quad (13)$$

$$H_4 = \frac{15}{512}\left\{\int_{z_1}^{z_2} \tilde{R}d_0^{-13}\left\{33\tilde{R}^3pw - 24\tilde{R}d_0^2\left[3p(a_1 + a_3) + \frac{5}{8}\tilde{R}w\right] + 16\tilde{R}d_0^2\left[a_1p + 1.5\tilde{R}(a_1 + a_3)\right] - \frac{16}{7}a_1d_0^2\right\}d\tilde{z} + \int_{\rho_1}^{\rho_2} g_4\Big|_{\tilde{z}=z_1} d\tilde{R} + \int_{\rho_3}^{\rho_4} g_4\Big|_{\tilde{z}=z_2} d\tilde{R}\right\}, \quad (14)$$

where $d_0 = \left(\tilde{R}^2 + k^2\right)^{0.5}$; $g_0 = a_1\tilde{R}^2d_0^{-5}k$; (15)

$$g_2 = \tilde{R}^2kd_0^{-9}\left[7\tilde{R}^2(a_1 + a_3) - 4d_0^2a_1\right]; \quad (16)$$

$$w = 2a_1 + 3a_3 + a_5; \quad (17)$$

$$g_4 = \tilde{R}k\left[\tilde{R}k - 72\tilde{R}^2d_0^2(a_1 + a_3) + 16d_0^4a_1\right]. \quad (18)$$

MF distribution of DY suitable for used in the aberration theory is [5] :

$$\begin{cases} H_y = H_0 - \left(0.5H_0^{(1)} + H_2\right) + H_2x^2 + \left(1/24\,H_0^{(1)} + 1/6\,H_2^{(2)} + H_4\right)y^4 - \left(0.5H_2^{(2)} + 6H_4\right)x^2y^2 + H_4x^4 \ldots \\ H_x = 2H_2xy - \left(1/3\,H_2^{(2)} + 4H_4\right)xy^3 + 4H_4x^3y + \ldots, \\ H_z = H_0^{(1)}y - 1/3\left(0.5H_0^{(3)} + H_2^{(1)}\right)y^3 + H_2^{(1)}x^2y + \ldots. \end{cases} \quad (19)$$

To fulfill these expressions are founded derivatives of the functions (12), (13) :

$$H_0^{(1)} = \frac{3}{4}\left\{\int_{z_1}^{z_2} a_1\tilde{R}d_0^{-7}\left(5\tilde{R}kp + d_0^2p_1\right)d\tilde{z} + \int_{\rho_1}^{\rho_2} g_0^{(1)}\Big|_{\tilde{z}=z_1} d\tilde{R} + \int_{\rho_3}^{\rho_4} g_0^{(1)}\Big|_{\tilde{z}=z_2} d\tilde{R}\right\}, \quad (20)$$

$$H_0^{(2)} = \frac{15}{4}\left\{\int_{z_1}^{z_2} a_1\tilde{R}d_0^{-9}\left\{7\tilde{R}pk^2 - d_0^2\left[\tilde{R}p - k\left(p_1 + \tilde{R}\tilde{R}^{(1)}\right) + 0.2d_0^4\right]\right\}d\tilde{z} + \int_{\rho_1}^{\rho_2} g_0^{(2)}\Big|_{\tilde{z}=z_1} d\tilde{R} + \int_{\rho_3}^{\rho_4} g_0^{(2)}\Big|_{\tilde{z}=z_2} d\tilde{R}\right\}, \quad (21)$$

$$H_0^{(3)} = \frac{45}{4}\left\{\int_{z_1}^{z_2} a_1\tilde{R}d_0^{-11}\left[21\tilde{R}pk^3 - 7kd_0^2\left(\tilde{R}p - \tilde{R}\tilde{R}^{(1)}k + k^2/3\right) - d_0^4p_1\right]d\tilde{z} + \int_{\rho_1}^{\rho_2} g_0^{(3)}\Big|_{\tilde{z}=z_1} d\tilde{R} + \int_{\rho_3}^{\rho_4} g_0^{(3)}\Big|_{\tilde{z}=z_2} d\tilde{R}\right\}, \quad (22)$$

$$H_0^{(4)} = \frac{315}{4}\left\{\int_{z_1}^{z_2} a_1\tilde{R}d_0^{-13}\left[33\tilde{R}pk^4 - 3k^2d_0^2\left(6\tilde{R}p - 4\tilde{R}\tilde{R}^{(1)}k + k^2\right) - d_0^4\left(\tilde{R}\tilde{R}^{(1)}k - 2k^2 - \tilde{R}^2\right) - d_0^6/7\right]d\tilde{z} + \right.$$

$$+\int_{\rho_1}^{\rho_2} g_0^{(4)}\Big|_{\tilde z=z_1} d\tilde R+\int_{\rho_3}^{\rho_4} g_0^{(4)}\Big|_{\tilde z=z_2} d\tilde R\Bigg\}, \quad (23)$$

$$H_2^{(1)}=\frac{105}{32}\Bigg\{\int_{z_1}^{z_2}\tilde R d_0^{-9}\Big\{\tilde R^2(a_1+a_3)\big[9\tilde R pkd_0^{-2}+(p_1-2k)\big]-$$

$$-4a_1\big(\tilde R pk+d_0^2p_1\big)\Big\}d\tilde z+\int_{\rho_1}^{\rho_2} g_2^{(1)}\Big|_{\tilde z=z_1} d\tilde R+\int_{\rho_3}^{\rho_4} g_2^{(1)}\Big|_{\tilde z=z_2} d\tilde R\Bigg\}, \quad (24)$$

$$H_2^{(2)}=\frac{315}{32}\Bigg\{\int_{z_1}^{z_2}\tilde R d_0^{-11}\Big\{\tilde R^2(a_1+a_3)\big[33\tilde R pk^2d_0^{-2}+3\big(3p_1k-\tilde R^2\big)+$$

$$+d_0^2\big]-4a_1\Big[\tilde R p\big(3k^2-1/3d_0^2\big)+1/3d_0^2\big(1/7d_0^2+\tilde R^{(1)}k+kp_1\big)\Big]\Big\}d\tilde z+$$

$$+\int_{\rho_1}^{\rho_2} g_2^{(2)}\Big|_{\tilde z=z_1} d\tilde R+\int_{\rho_3}^{\rho_4} g_2^{(2)}\Big|_{\tilde z=z_2} d\tilde R\Bigg\}, \quad (25)$$

where $p_1=\tilde R\tilde R^{(1)}-k;$ (26)

$$g_0^{(1)}=a_1\tilde R^2d_0^{-7}\big(5k^2-d_0^2\big); \quad (27)$$

$$g_0^{(2)}=a_1\tilde R^2d_0^{-9}k\big(7k^2-3d_0^2\big); \quad (28)$$

$$g_0^{(3)}=a_1\tilde R^2d_0^{-11}\big(21k^4-14d_0^2k^2+d_0^4\big); \quad (29)$$

$$g_0^{(4)}=a_1\tilde R^2d_0^{-13}k\big(33k^4-30d_0^2k^2+5d_0^4\big); \quad (30)$$

$$g_2^{(1)}=\tilde R^2d_0^{-9}\big[\tilde R^2(a_1+a_3)\big(9k^2d_0^{-2}-1\big)+ +4a_1\big(1/7\,d_0^2-k^2\big)\big]; \quad (31)$$

$$g_2^{(2)}=\tilde R^2d_0^{-11}k\big[3\tilde R^2(a_1+a_3)\big(11k^2d_0^{-2}-3\big)+ +4a_1\big(d_0^2-3k^2\big)\big]. \quad (32)$$

So, description MF distribution of the DY coils is completely finished.

The same way is used to find MF from the surface charge density distribution of the DY core. In the case where ferrite core is assumed infinite permeability, charge density σ(**r**) can be find from integral Fredholm equation of the first kind [4]. Then the magnetic potential at any place of the space according to [4] would be calculated:

$$\Phi(\bar r)=\frac{0.25}{\pi}\sum_i\int_{S_i}\frac{\sigma(\tilde{\bar r}_i)}{\left|\tilde{\bar r}_i-\bar r\right|}d\tilde s, \quad (33)$$

where S_i determines the segments of the core surfaces (subscripts i=1,2 mean inside and outside segments; i=3,4- front $z=z_3$ and end $z=z_4$ segments); σ(**r**) – sourface charge density of the ferrite core.

After we have taken charge density in the analogically form as calculated (2) and made the procedures in the accordance with (7) – (11) (W→Φ; H_m →C_m) the functions $C_0,...,C_4$ would be set according to:

$$C_0=\frac{1}{4}\left(\sum_{i=1,2}\int_{z_3}^{z_4}\sigma_{1i}\tilde R_i^2d_i^{-3}t_id\tilde z+\sum_{i=3,4}\int_{\tilde R_{i1}}^{\tilde R_{i2}}\sigma_{1i}\tilde R_i^2d_i^{-3}d\tilde R\right), \quad (34)$$

$$C_2=\frac{3}{32}\left[\sum_{i=1,2}\int_{z_3}^{z_4}\big(5\tilde R_i^2q_i-\tilde R_i^2\sigma_{1i}d_i^2\big)d_i^{-7}t_id\tilde z+ +\sum_{i=3,4}\int_{\tilde R_{i1}}^{\tilde R_{i2}}\big(5\tilde R_i^2q_i-\tilde R_i^2\sigma_{1i}d_i^2\big)d_i^{-7}d\tilde R\right], \quad (35)$$

$$C_4=\frac{15}{512}\left[\sum_{i=1,2}\int_{z_3}^{z_4}d_i^{-11}\tilde R_i^2t_i\big(21\psi_i+28d_i^2q_i-2\sigma_id_i^4\big)d\tilde z+ +\sum_{i=3,4}\int_{z_3}^{z_4}d_i^{-11}\tilde R_i^2\big(21\psi_i+28d_i^2q_i-2\sigma_id_i^4\big)d\tilde R\right], \quad (36)$$

where: $d_i=\big(\tilde R_i^2+k^2\big)^{0.5};\ t_i=\Big[1+\big(\tilde R_i^{(1)}\big)^2\Big]^{0.5};$ (37)

$$\psi_i=-2\sigma_{1i}k^4+3\sigma_{3i}\tilde R_i^2\big(7d_i^2+k^2\big)-\sigma_{5i}\tilde R^4; \quad (38)$$

$$q_i=\sigma_{1i}k^2-\sigma_{3i}\tilde R_i^2; \quad (39)$$

$\tilde R_i^{(1)}=d\tilde R_i/d\tilde z$ – derivatives at the points of curves $\tilde{\bar r}_i=\tilde{\bar r}_i\big(\tilde R_i(\tilde z),\tilde\beta=const,\tilde z\big)$ in a longitudinal section of the ferrite core; $\sigma_{mi}, m=1,3,5$ – Fourier coefficients that show the charge density distribution σ(**r**) on the surface of the ferrite core.

Similar as in the case of the coil it can be founded the last functions fulfilling MF distribution (19):

$$C_0^{(1)}=\frac{3}{4}\left(\sum_{i=1,2}\int_{z_3}^{z_4}\sigma_{1i}\tilde R_i^2d_i^{-5}t_ikd\tilde z+ +\sum_{i=3,4}\int_{\tilde R_{i1}}^{\tilde R_{i2}}\sigma_{1i}\tilde R_i^2d_i^{-5}kd\tilde R\right), \quad (40)$$

$$C_0^{(2)}=\frac{3}{4}\left[\sum_{i=1,2}\int_{z_3}^{z_4}\sigma_{1i}\tilde R_i^2d_i^{-7}t_i\big(5k^2-d_i^2\big)d\tilde z+ +\sum_{i=3,4}\int_{\tilde R_{i1}}^{\tilde R_{i2}}\sigma_{1i}\tilde R_i^2d_i^{-7}\big(5k^2-d_i^2\big)d\tilde R\right], \quad (41)$$

$$C_0^{(3)}=\frac{15}{4}\left[\sum_{i=1,2}\int_{z_3}^{z_4}\sigma_{1i}\tilde R_i^2d_i^{-9}t_ik\big(7k^2-3d_i^2\big)d\tilde z+ +\sum_{i=3,4}\int_{\tilde R_{i1}}^{\tilde R_{i2}}\sigma_{1i}\tilde R_i^2d_i^{-7}k\big(7k^2-3d_i^2\big)d\tilde R\right], \quad (42)$$

$$C_0^{(4)} = \frac{45}{4}\left[\sum_{i=1,2}\int_{z_3}^{z_4}\sigma_{1i}\tilde{R}_i^2 d_i^{-11} t_i \left(21k^2 - 14k^2 d_i^2 + d_i^4\right) d\tilde{z} + \right.$$

$$\left. + \sum_{i=3,4}\int_{\tilde{R}_{i1}}^{\tilde{R}_{i2}}\sigma_{1i}\tilde{R}_i^2 d_i^{-7}\left(21k^2 - 14k^2 d_i^2 + d_i^4\right) d\tilde{R}\right], \quad (43)$$

$$C_2^{(1)} = \frac{15}{32}\left[\sum_{i=1,2}\int_{z_3}^{z_4}\left(7\tilde{R}_i^2 q_i - 3\tilde{R}_i^2\sigma_{1i} d_i^2\right) d_i^{-9} t_i k d\tilde{z} + \right.$$

$$\left. + \sum_{i=3,4}\int_{R_{i1}}^{R_{i2}}\left(7\tilde{R}_i^2 q_i - 3\tilde{R}_i^2\sigma_{1i} d_i^2\right) d_i^{-9} k d\tilde{R}\right], \quad (44)$$

$$C_2^{(2)} = \frac{15}{32}\left\{\sum_{i=1,2}\int_{z_3}^{z_4} d_i^{-9}\tilde{R}_i^2 t_i\left[7\left(9d_i^{-2}k^2 - 1\right)q_i - \left(35k^2 - \right.\right.\right.$$

$$\left.\left. - 3d_i^2\right)\sigma_{1i}\right] d\tilde{z} + \sum_{i=1,2}\int_{z_3}^{z_4} d_i^{-9}\tilde{R}_i^2\left[7\left(9d_i^{-2}k^2 - 1\right)q_i - \right.$$

$$\left.\left. - \left(35k^2 - 3d_i^2\right)\sigma_{1i}\right] d\tilde{R}\right\} \quad (45)$$

Magnetic fields description of saddle-type DY is completely finished by sumation functions H_m and C_m and its derivatives according to (19).

Conclusions

The performed investigations show the possibility to get continuity functions of MF distribution of the DY suitable for used in the aberration theory.

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The theoretical method for the determination of functions of magnetic fields are only used in the case of simple DY constructions. According to newly developed methods these magnetic field functions are needed to calculate aberrations' parameters found to saddle–type DY. Ill.1, bibl 7 (in English; summaries in English, Russian and Lithuanian).

Р. Матуляускас. Метод определения функций магнитных полей седлообразных ОС // Электроника и электротехника. – Каунас: Технология, 2008. – № 5(85). – С. 37–40.

Используются как теоретический, так и эмпирический методы определения функций магнитных полей (МП) отклоняющей системы (ОС) при оптимизации, в соответствии с теорией абераций, её конструкции. Однако применяема математическая модель ОС слишком упрощена (теряется точность), а эмпирический метод трудоёмок. Представлен новый теоретический метод определения фуикций МП ОС сложной седлообразной конструкции. Ил. 1, библ. 7 (на английском языке, рефераты на английском, русском и литовском яз.).

R. Matuliauskas. Analizinis balno tipo KS magnetinių laukų funkcijų suradimo metodas // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2008. – Nr. 5(85). P. 37–40.

Elektroninių-optinių sistemų aberacijų skaičiavimuose naudojamos magnetinių laukų (ML) funkcijos surandamos abiem galimais būdais – teoriniu ir empiriniu. Deja, matematinis kreipiamųjų sistemų (KS) modelis, apibrėžiant šias funkcijas teoriškai, naudojamas perdėm supaprastintas: kreipiamųjų sistemų ritės aproksimuojamos pavienėmis vijomis. Todėl šis metodas taikomas tik apytikrei KS konstrukcijos analizei. Tiksliau ML struktūra apibrėžiama išmatuojant jos vertes atskiruose trimačio tinklelio taškuose ir, taikant aproksimacines procedūras, surandant jas tarpiniuose taškuose. Šio metodo trūkumas būtų didelis darbų imlumas ir KS konstrukcijos tik palaipsnis – kaskart pagaminant naujus sistemos pavyzdžius – optimizavimas. Remiantis naujuoju metodu balno tipo KS magnetinių laukų funkcijos surandamos teoriškai. Il. 1, bibl. 7 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).

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