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EXACT ANALYTICAL ABERRATION THEORY OF CENTERED OPTICAL SYSTEMS CONTAINING CONIC SURFACES

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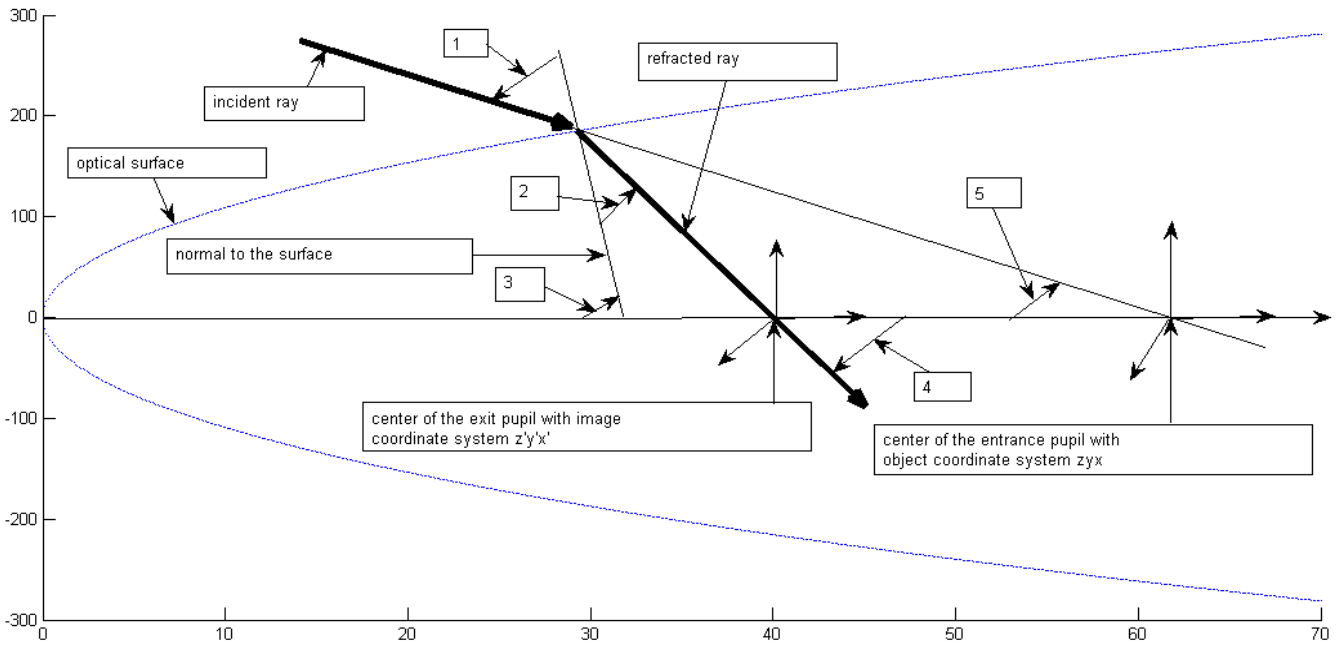
To achieve:

- **Precise** analytical correction of individual aberrations;
- **Exact** calculation of the system constructive parameters, such as surface radiuses and conic constants, axial thicknesses, etc.;
- **Correct** pictures of the aberrations space distribution in the whole object space and the whole image space of the optical system.

CONIC RADIUSES COEFFICIENT- τ_j

1 - angle of incidence (ε_j);
2 - angle of refraction or reflection (ε'_j);
3 – slope of the surface normal (φ_j) ;
4 – angle between refracted ray and z-axes (w_{j+1}) ;
5 – angle between incident ray and z-axes (w_j).

$$r_{tj} = \frac{r_{sj}^3}{r_{0j}^2}; \quad r_{0j} = \tau_j r_{sj}; \quad r_t = \frac{r_{sj}}{\tau_j^2} = \frac{r_{0j}}{\tau_j^3}; \quad \tau_j = \frac{}{\sqrt{1 + \mathrm{K_j} \sin^2 \varphi_j}}$$



EXACT TRANSFORMATIONS FROM THE OBJECT TO THE IMAGE SPACE IN A SINGLE CONIC SURFACE

In the sagittal planes: $z'_{sj} = \frac{r_{sj}p_j z_{sj} + r_{sj}^2 Q_j}{m_j z_{sj} + r_{sj}\mu_j} = r_{sj}\frac{a_j z_{sj} + b_j}{c_j z_{sj} + d_j}, \quad Q_j \equiv 0,$

$G_j = \begin{matrix} a_j & 0 \\ c_j & d_j \end{matrix} = \begin{matrix} r_{sj}p_j & 0 \\ m_j & r_{sj}\mu_j \end{matrix}$. Here p_j, μ_j, m_j are exact functions depending on the real values of the following parameters: $n_j, n_{j+1}, \varepsilon_j, \varphi_j, w_{j+1}$ and w_j.

In the tangential planes: $z'_{tj} = \frac{r_{sj}p_j^t z_{sj} + r_{sj}^2 Q_j^t}{\tau_j^2 m_j z_{tj} + r_{sj}\mu_j^t} = r_{sj}\frac{a_j^t z_{tj} + b_j^t}{c_j^t z_{tj} + d_j^t}$,

$G_j^t = \begin{matrix} a_j^t & b_j^t \\ c_j^t & d_j^t \end{matrix} = \begin{matrix} r_{sj}p_j^t & Q_j^t \\ \tau_j^2 m_j & r_{sj}\mu_j^t \end{matrix}$. Here p_j^t, $\mu_{j_j}^t$, $Q_{j,}^t$ and m_j are exact functions depending on the real values of parameters: $n_j, n_{j+1}, \varepsilon_j, \varphi_j, w_j$, τ_j^2, and w_{j+1}.

In the paraxial region: $z'_{0j} = \frac{r_{sj}p_j^0 z_{0j} + r_{sj}^2 Q_j^0}{\tau_j^2 m_j^0 z_{0j} + r_j\mu_j} = r_{sj}\frac{a_j^0 z_{0j} + b_j^0}{c_j^0 z_{0j} + d_j^0}$,

$G_j^0 = \begin{matrix} a_j^0 & b_j^0 \\ c_j^0 & d_j^0 \end{matrix} = \begin{matrix} r_{sj}p_j^0 & Q_j^0 \\ m_j^0 & r_{sj}\mu_j^0 \end{matrix}$. Here p_j^0, $\mu_{j_j}^0$, $Q_{j,}^0 m_j^0$ are exact functions depending on t he real values of parameters: $n_j, n_{j+1}, \varepsilon_j, \varphi_j, w_j, \tau_j$, and w_{j+1}.

$Q_j^0 = \frac{q_{j3}\tau_j^3 + q_{j2}\tau_j^2 + q_{j1}\tau + q_{j0}}{(\tau_j + \cos\varphi_j)^2}$.

EXACT TRANSFORMATIONS FROM THE OBJECT TO THE IMAGE SPACE IN AN OPTICAL SYSTEM OF "*K*" CENTERED CONIC SURFACES

$$g_k = G_k G_{k-1} \dots G_j \dots G_2 G_1 = \begin{matrix} a_k & 0 \\ c_k & d_k \end{matrix}$$ – sagittal matrix;

$\boldsymbol{a_k}$, $\boldsymbol{c_k}$, $\boldsymbol{d_k}$ - sagittal matrix coefficients of the whole system;

$$g_k^t = G_k^t G_{k-1}^t, \dots, G_j^t \dots G_2^t G_1^t = \begin{matrix} a_k^t & b_k^t \\ c_k^t & d_k^t \end{matrix}$$ - tangential matrix;

$\boldsymbol{a_t^t, b_k^t, c_k^t, d_k^t}$ tangential matrix coefficients of the whole system;

$$g_k^0 = G_k^0 G_{k-1}^0, \dots, G_j^0, \dots, G_2^0 G_1^0 = \begin{matrix} a_k^0 & b_k^0 \\ c_k^0 & d_k^0 \end{matrix}$$ - paraxial matrix;

$\boldsymbol{a_k^0, b_k^0, c_k^0, d_k^0}$ paraxial matrix coefficients of the whole system;

RELATIVE PARAMETERS (x_j) AND RELATIVE MATRIX COEFFICIENTS:

$x_j = {}^{r_{sj}}/_{r_{s(j+1)}}$;

A_k , B_k , C_k , D_k: - sagittal relative matrix coefficients;

$A_k^t , B_k^t , C_k^t , D_k^t$: - tangential relative matrix coefficients;

$A_k^0 , B_k^0 , C_k^0 , D_k^0$: - paraxial relative matrix coefficients;

$a_k = r_{sk} A_k \prod_{j=2}^{k} r_{sj}$;

$b_k = r_{s1} r_{sk} B_k \prod_{j=2}^{k} r_{sj}$;

$c_k = r_{sk} C_k \prod_{j=2}^{k} r_{sj}$;

$d_k = r_{s1} D_k \prod_{j=2}^{k} r_{sj}$.

EXACT ABERRATION FUNCTIONS AND SPACE DISTRIBUTION

Field aberrations: astigmatism, sagittal curvature, tangential curvature, field curvature, distortion, sagittal coma, tangential coma).

On-axes aberrations: paraxial chromatism, spherical aberration, OPD or wave aberration and Abbe's sine condition)

$\frac{\Delta z'_k}{r_{sk}} = \frac{U_1\frac{z_0}{r_{s1}} + U_0}{V_1\frac{z_0}{r_{s1}} + V_0}$ - bilinear function to z_0 for: the distortion, on-axes spherical aberration, OPD and Abbe's sine condition; Here U_1 , U_0 are linear functions to every x_j and cubic functions to every τ_j;

$\frac{\Delta z'_k}{r_{sk}} = \frac{U_2\frac{z_0^2}{r_{s1}^2} + U_1\frac{z_0}{r_{s1}} + U_0}{V_2\frac{z_0^2}{r_{s1}^2} + V_1\frac{z_0}{r_{s1}} + V_0}$ - quadratic-fractional function to z_0 for: the image astigmatism, sagittal curvature, tangential curvature and paraxial chromatism; Here U_2 , U_1 and U_0 are quadratic functions to every x_j and cubic functions to every τ_j;

$\frac{\Delta z'_k}{r_{sk}} = \frac{U_3\frac{z_0^3}{r_{s1}^3} + U_2\frac{z_0^2}{r_{s1}^2} + U_1\frac{z_0}{r_{s1}} + U_0}{V_3\frac{z_0^3}{r_{s1}^3} + V_2\frac{z_0^2}{r_{s1}^2} + V_1\frac{z_0}{r_{s1}} + V_0}$ - cubic fractional function for: the field curvature, tangential coma and sagittal coma; Here U_3 , U_2 , U_1 , U_0 are cubic functions to every x_j and τ_j;

Space distribution: zero points and zero surfaces; vertical and horizontal asymptotes

GENERAL ABERRATION THEOREMS FOR A CENTERED OPTICAL SYSTEM CONTAINING CONIC SURFACES

Discriminants of aberrations: $D_{ast} = U_1^2 - 4U_2U_0$; Theorem for the paraxial achromatic points:

In every centered optical system containing conic surfaces for every two wavelengths on the optical axis: a) there are two paraxial achromatic points if the paraxial chromatic discriminant is greater than zero; b) there is one achromatic point if the paraxial chromatic discriminant is zero; c) there is no achromatic point if the paraxial chromatic discriminant is less than zero; d) there is an endless set of achromatic points if all the three paraxial chromatic coefficients, U_2, U_1, U_0 are zero.

(Ref: HRISTOV, B. Exact Analytical Theory of Aberrations of Centered Optical Systems. OPTICAL REVIEW Vol. 20, No. 5 (2013) 395–419).

Theorems for the field aberrations: distortion, astigmatism, sagittal curvature, tangential curvature, field curvature, sagittal coma and tangential coma.

General theorem:

When the object space and image space are homogeneous and the object space is aberration-free, no more than one surface in general can be perfectly imaged by a centered optical system containing conic surfaces.

(Ref: HRISTOV, B. Development Of Optical Design Algorithms On The Base Of The Exact (All Orders) Geometrical Aberration Theory, Proc. SPIE 8167 (2011) 12.)

EXACT ANALYTICAL CORRECTION OF INDIVIDUAL ABERRATIONS AND SIMULTANEOUS CORRECTION

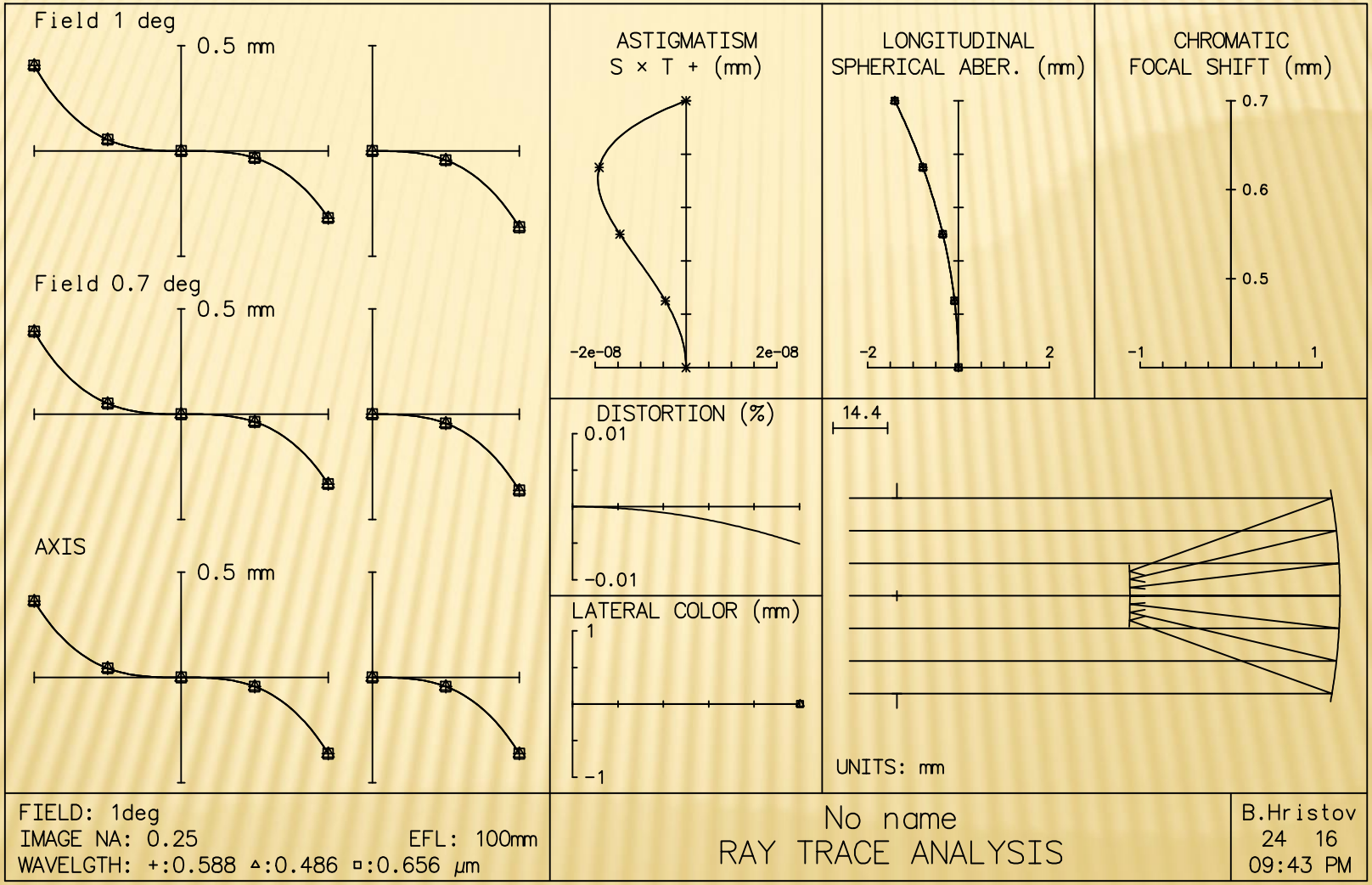
By solving one linear equation to the arbitrary chosen relative parameter (x_j), or **one cubic** equation to the arbitrary chosen conic radius coefficient (τ_j) on-axes spherical aberration, distortion, OPD, or satisfaction of Abbe's sine condition **become corrected each one separately.**

By solving one quadratic equation to the arbitrary chosen relative parameter (x_j), or **one cubic** equation to the arbitrary chosen conic radius coefficient (τ_j) **astigmatism, or sagittal curvature, or tangential curvature, or paraxial chromatism become corrected each one separately.**

By solving one cubic equation to the arbitrary chosen relative parameter (x_j), or **one cubic** equation to the arbitrary chosen conic radius coefficient (τ_j) **field curvature, or tangential coma, or sagittal coma become corrected each one separately**

For simultaneous correction of aberrations we use **Sylvester**'s matrices by excluding unknown parameters to find exactly all existing solutions.

EXAMPLE


Field 1 deg
0.5 mm
Field 0.7 deg
0.5 mm
AXIS
0.5 mm
ASTIGMATISM
S × T + (mm)
-2e-08
2e-08
LONGITUDINAL
SPHERICAL ABER. (mm)
-2
2
CHROMATIC
FOCAL SHIFT (mm)
0.7
0.6
0.5
-1
1
DISTORTION (%)
0.01
-0.01
LATERAL COLOR (mm)
1
-1
14.4
UNITS: mm
FIELD: 1deg
IMAGE NA: 0.25
EFL: 100mm
WAVELGTH: +:0.588 ▵:0.486 ▫:0.656 μm
No name
RAY TRACE ANALYSIS
B.Hristov
24 16
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THANK YOU

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