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[56] **References Cited**
UNITED STATES PATENTS
 2,975,324 3/1961 Cook..... 315/5.31
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[54] **CORRECTION OF IMAGE DEFECTS CAUSED BY
 PERTURBATIONS OF THE ROTATIONAL
 SYMMETRY WITH ANNULAR APERTURES**
8 Claims, 4 Drawing Figs.

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313/85, 315/31
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H01j 29/56

ABSTRACT: A stigmator for the electrical compensation of image defects in electron optical systems working with hollow beams and annular apertures in which a cylindrically shaped middle electrode, limited at its front faces by two metallic annular diaphragms, is closely arranged behind the aperture diaphragms within the lens field free space in the path of the beam, the middle electrode being of varying diameter and being surrounded by two sector shaped electrode ring system.

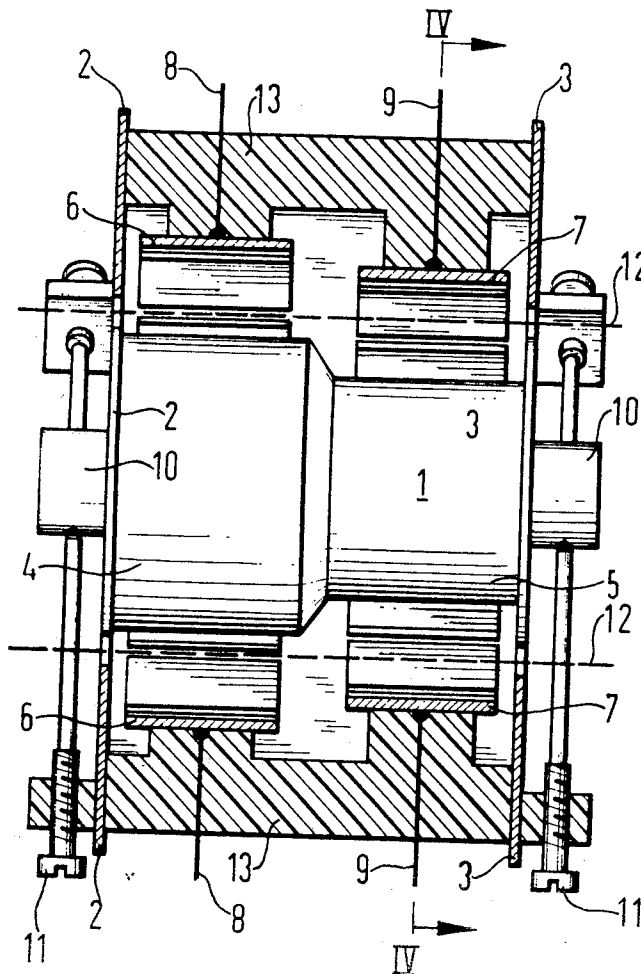


Fig. 1

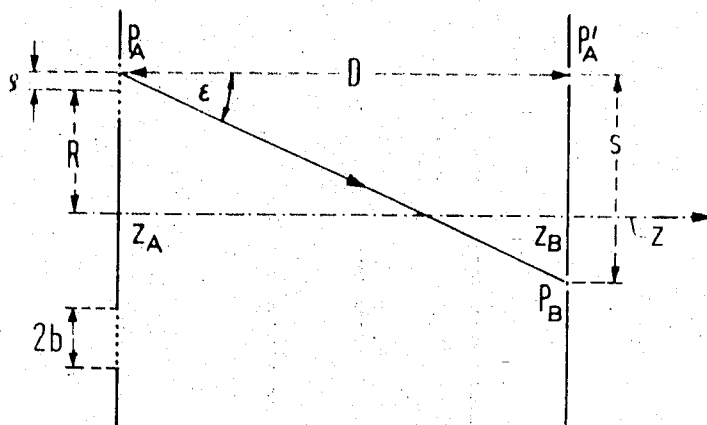
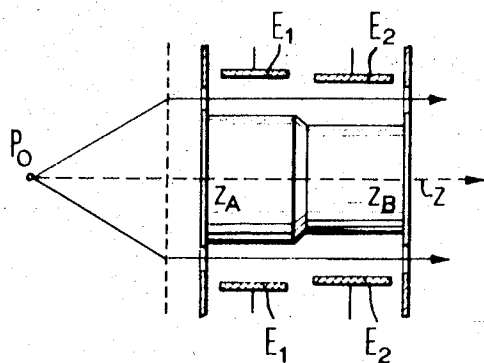
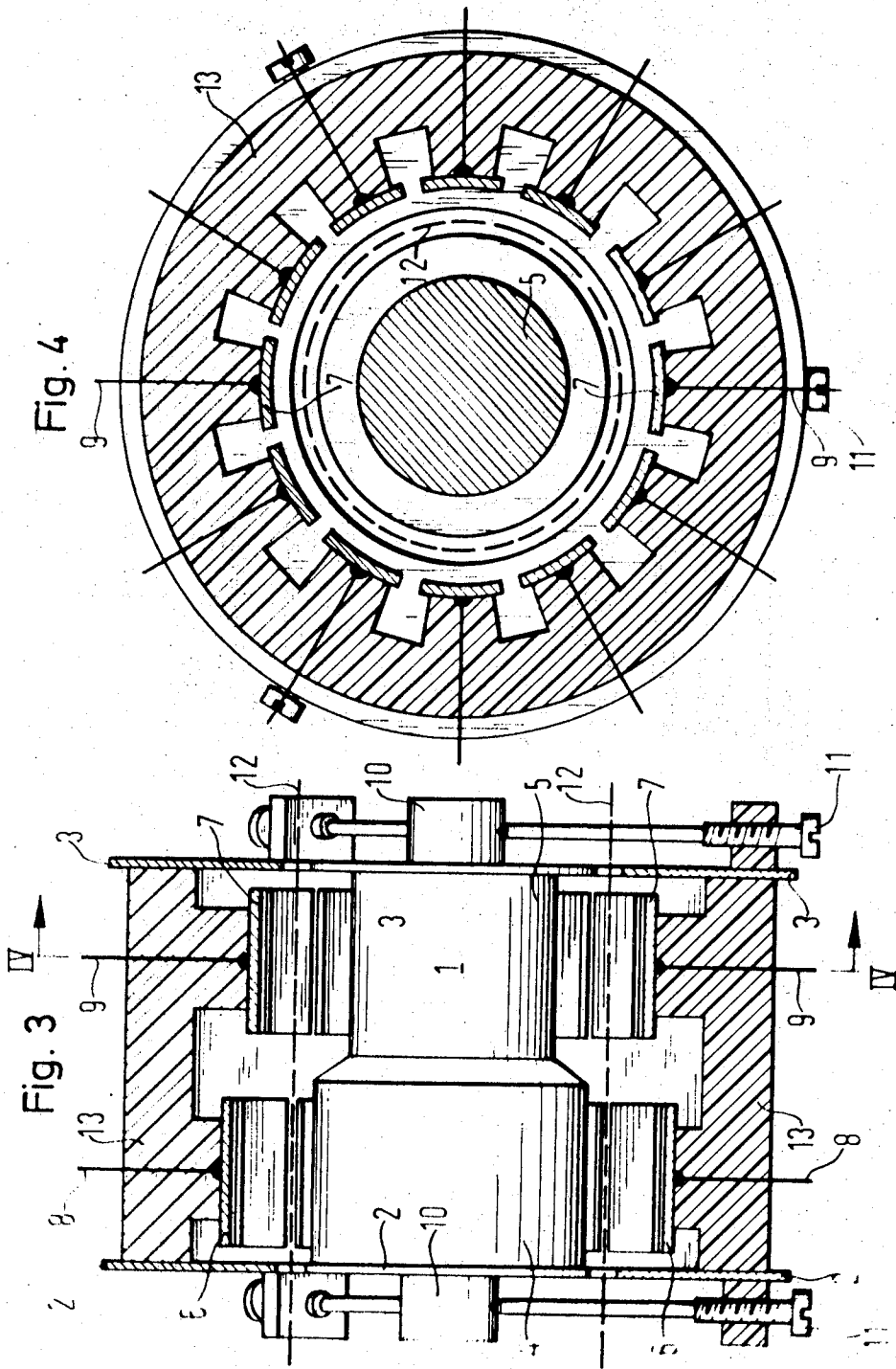


Fig. 2



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CORRECTION OF IMAGE DEFECTS CAUSED BY PERTURBATIONS OF THE ROTATIONAL SYMMETRY WITH ANNULAR APERTURES

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention concerns a stigmator for the electrical compensation of image defects in electronoptical systems working with hollow beams and annular apertures.

2. Description of the Prior Art

Electronoptical focusing systems using annular apertures may, with respect to their imaging or focusing properties, be superior to those with simple circular apertures. It is only essential that a hollow cone bundle of electrons is used, but it is not of importance, whether a metallic diaphragm with an annular aperture is brought into the beam or not. H. Noven (Zeitschrift für angewandte Physik 18, 4, Seite 329, 1965) has experimentally realized a hollow cone focusing system which produces a larger current density in the focus than can be reached with the usual technique of focusing by rotational symmetric lenses. F. Lenz and A. P. Wilska (Optik 24, Seite 383, 1966) have proposed a system using an annular aperture for the correction of the spherical aberration of magnetic lenses, this system being designed to increase the resolving power of the electron microscope (K. J. Hanszen, K. J. Rosenbruch and F. A. Sunder-Plassmann, Zeitschrift für angewandte Physik 18, 4 Seite 345, 1965). Systems with a larger number of annular apertures are zone lenses (A. Boivin, Theorie et calcul des figures de diffraction de revolution, 1964, Gauthiers-Villars, Paris, page 405) and Hoppe-plates, designed for the correction of the spherical aberration of lenses (W. Hoppe: Optik 20, Seite 599, 1963) W. D. Riecke: Z. Naturforschung 19a, 10, Seite 1228, 1964).

The focusing properties of all these systems are only optimal under the condition that deviations from the rotational symmetry of the electromagnetic focusing field are so small that, according to Rayleigh's $\lambda/4$ rule, the wave aberration at the exit of the system is smaller than a quarter of the wavelength. Arising from this demand there may be circumstances which may then cause considerable technical problems, since aberrations caused by perturbations of the rotational symmetry of the system will greatly increase with the distances of the electron paths from the axis, thus being much stronger than in systems with paraxial focusing.

SUMMARY OF THE INVENTION

An object of the present invention is to provide a stigmator permitting avoidance of image defects in electronoptical systems working with hollow beams and annular apertures, the defects to be avoided being especially those caused by the unroundness of the electron lenses.

In the stigmator of the kind cited herebefore there is provided for the accomplishment of the above object that a middle electrode of cylindrical form which is limited at its front surfaces by two metallic ringlike diaphragms having outer potential, is arranged closely behind the aperture diaphragm in the beam path of the electronoptical system within the lens field free space; that the front portion of the middle electrode has a larger diameter than the back portion; that the middle electrode is surrounded by at least two sector shaped electrode ring systems of different diameters arranged in a distance one from the other; that each of both electrode ring systems is divided into several sectors provided with contacts and having different potentials; that the electrode ring system of the larger diameter surrounds the front portion of the middle electrode and the electrode ring system of the smaller diameter surrounds the back portion of the middle electrode; and that both front surfaces of the cylindric middle form the central portion of the two ring diaphragms.

Further features and details of the invention result from the following statements made in connection with the FIGS. 1 and

2, as well as from the description of an embodiment represented in FIGS. 3 and 4.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows a schematic representation of the geometrical relation in the picture space.

FIG. 2 shows in a rough schematic axial section the construction principal of a stigmator according to the invention.

FIG. 3 shows an axial section of a stigmator according to the invention.

FIG. 4 is a section along the line IV/IV of the stigmator represented in FIG. 3.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Since deviations from rotational symmetry in lens systems used for focusing are not generally known, it is only possible to obtain general statements from the existence of regular wave surfaces in the field free image space behind the lens system.

It is supposed that the aperture plane of the system may be located in the field free image space. The aperture may have the mean radius R and the ring width $2b$, its distance from the image plane being D , as is presented in FIG. 1. The object, respectively the cathode and the lens system, are omitted in the drawing. For each center P_o of paths starting in the object plane and for every point P_A in the aperture plane a regular eikonal function must exist, which is given by

$$(1) \quad W(P_o, P_A) = \int_{P_o}^{P_A} n ds.$$

This integral is to be evaluated for a trajectory connecting P_o and P_A . The electronoptical index of refraction, which is constant in the image space may there be normalized to unity, the normalization thus being uniquely defined in whole space.

In the image space the geometric trajectories of the electrons are straight lines and orthogonally intersect the wave surfaces. From this fact the following relationship between the coordinates (x_A, y_A, z_A) of an arbitrary point P_A in the aperture plane and the coordinates $(x_B, y_B, z_B = z_A + D)$ of the intersection P_B between the image plane and the electron trajectory passing through P_o and P_A can be derived:

$$(2) \quad \begin{cases} x_B = x_A + \sqrt{D^2 + s^2} \frac{\partial W}{\partial x_A}, \\ y_B = y_A + \sqrt{D^2 + s^2} \frac{\partial W}{\partial y_A}. \end{cases}$$

The quantities D and s are defined by $D = \overline{P_o P_A} = z_B - z_A$, $s = \overline{P_B P_A} = ((x_B - x_A)^2 + (y_B - y_A)^2)^{1/2} = D \tan \epsilon$, as is also presented in FIG. 1. The triangle $P_o P_A P_B$ may not necessarily be located in the same plane with the axis of the system, as is assumed in FIG. 1 for reasons of simplicity. In the following way the eikonal function can be separated into two parts:

$$(3) \quad W(P_o, P_A) = W^{(o)}(P_o, P_A) + \delta W(P, P_A),$$

$$(4) \quad W^{(o)}(P_o, P_A) = W^{(o)}(P_o, P_B^{(o)}) - \overline{P_A P_B^{(o)}}$$

The term $W^{(o)}(P_o, P_A)$ is the eikonal of an electron bundle exactly focused into the ideal image point conjugate to P_o . For reasons of clearness this is not presented in FIG. 1. If the coordinates (x_B, y_B) in $W^{(o)}$ are replaced by the coordinates $(x_B^{(o)}, y_B^{(o)})$ of $P_B^{(o)}$ and with $z_B^{(o)} = z_B$ the function $W^{(o)}(P_o, P_A)$ exactly fulfills equation 2). The quantity $W^{(o)}(P_o, P_B^{(o)})$ is a constant. The quantities s_o, ϵ_o , used in the following have a meaning quite analogous to that of s, ϵ , but they refer to the point $P_B^{(o)}$.

The term $\delta W(P_o, P_A)$ is the wave aberration in the aperture plane. This aberration which is caused by the image defects of the system, may be regarded as a small perturbation. It causes P_B to be slightly different from $P_B^{(o)}$. With $\delta x_B, \delta y_B, \delta s$ as small quantities the following expansions can be made:

$$(5) \quad x_B = x_B^{(o)} + \delta x_B, y_B = y_B^{(o)} + \delta y_B, s = s_o + \delta s, \delta z_B = 0.$$

With restriction to linear expressions one obtains

$$(6) \quad \begin{cases} x_B = \delta s \sin \epsilon_o \cdot \frac{\partial W^{(o)}}{\partial x_A} + \frac{D}{\cos \epsilon_o} \frac{\partial}{\partial x_A} \delta W, \\ y_B = \delta s \sin \epsilon_o \cdot \frac{\partial W^{(o)}}{\partial y_A} + \frac{D}{\cos \epsilon_o} \frac{\partial}{\partial y_A} \delta W. \end{cases}$$

Now δs is of the same order of magnitude as δx_B and δy_B and it is

$$\left[\left(\frac{\partial W^{(o)}}{\partial x_A} \right)^2 + \left(\frac{\partial W^{(o)}}{\partial y_A} \right)^2 \right]^{1/2} = \sin \epsilon_o.$$

Therefore in (6) all terms containing the factor δs are of the order of $\delta x_B \sin^2 \epsilon_o$ or $\delta y_B \sin^2 \epsilon_o$. Though the aperture angle ϵ_o in the image space may be much larger than in paraxial systems, one may still assume $\sin^2 \epsilon_o \ll 1$. Then all terms with δs are small in a higher order of magnitude and may thus be neglected. Furthermore, it is reasonable to use $\cos \epsilon_o \approx 1$ in the remaining expressions. After these simplifications one obtains:

$$(7) \quad \delta x_B = D \frac{\partial}{\partial x_A} \delta W, \quad \delta y_B = D \frac{\partial}{\partial y_A} \delta W.$$

It is useful to introduce polar coordinates δ, ψ in the aperture plane, given by

$$(8) \quad x_A = (R + \delta) \cos \psi, \quad y_A = (R + \delta) \sin \psi, \quad (-b \leq \delta \leq b),$$

and to define a complex geometrical aberration

$$(9) \quad \delta u_B = \delta x_B + i \delta y_B = D e^{i\psi} \left(\frac{\partial}{\partial \zeta} \delta W + \frac{i}{R + \zeta} \frac{\partial}{\partial \psi} \delta W \right).$$

The following investigations shall be restricted to the special case that the point P_o is located on the axis of the system. Then the ideal image point $P_B^{(o)}$ will also be located on the axis, that is $x_B^{(o)} = y_B^{(o)} = 0$. It is always possible to expand the wave aberration $\delta W(\zeta, \psi)$ into a Fourier series:

$$(10) \quad \delta W(\zeta, \psi) = \sum_{\nu=-\infty}^{\infty} F_\nu(\zeta) e^{i\nu\psi}.$$

Since δW is a real function, it is:

$$(11) \quad F_{-\nu}(\zeta) = F_\nu^*(\zeta).$$

Then with (9) and (10) the geometrical aberration in the image plane is given by:

$$(12) \quad \delta u_B(\zeta, \psi) = D \sum_{\nu=-\infty}^{\infty} \left(\frac{dF_\nu(\zeta)}{d\zeta} - \frac{\nu F_\nu(\zeta)}{R + \zeta} \right) e^{i(\nu+1)\psi}$$

In the following section this expression will be studied in more detail.

In the expression (12) for the geometrical aberrations the explicit dependence on the angle ψ , is essential. A consequence of this is that even in the case of vanishing ring width $2b$ (or $\zeta = 0$) there exists a finite aberration which may eventually make the focusing system useless. This is a disadvantage of systems with annular apertures compared to systems with circular apertures in which through contraction of the aperture the purely geometrical aberrations can be made infinitely small.

The terms resulting from rotational symmetric wave aberrations ($\nu = 0$) are here of no interest, since their reduction is already investigated in detail. The terms depending on the azimuth ψ in the lowest order are those with $\nu = \pm 1$.

$$(13) \quad \delta u_1 = D \left(F_1'(\zeta) + \frac{F_1^*(\zeta)}{R + \zeta} \right) + D \left(F_1'(\zeta) - \frac{F_1(\zeta)}{R + \zeta} \right) e^{2i\psi}$$

For each constant value of ζ between $-b$ and $+b$ the aberration figure is a circle with the radius $r(\zeta) = D |F_1'(\zeta) - F_1(\zeta)/(R + \zeta)|$; its center has the lateral distance $\rho(\zeta) = D |F_1'(\zeta) + F_1(\zeta)/(R + \zeta)|$ from the axis. If the point P_A moves once

round a circle of the radius $R + \zeta$ in the aperture plane, the corresponding point in the image plane moves twice round its circle. The whole aberration figure is a coma which differs from the usual coma figure in that way that even for $\zeta = 0$ an aberration circle of finite radius and finite lateral shift may exist. The coma figure may therefore not necessarily have a tip; also the line on which all centers of aberration circles are located may be curved.

The terms with an m -fold symmetry ($\nu = \pm m$) in the expression for $\delta W(\zeta, \psi)$ cause a geometrical aberration

$$(14) \quad \delta u_m = a_m^{(-)}(\zeta) e^{i(1+m)\psi} + a_m^{(+)*}(\zeta) e^{i(1-m)\psi},$$

The following abbreviations being used:

$$(15) \quad a_m^{(\pm)}(\zeta) = D \left(F_m'(\zeta) \pm \frac{m F_m(\zeta)}{R + \zeta} \right), \quad m > 1.$$

If again the variable ζ is kept constant, the curves of aberration derived from the dependence on ψ have some simple features. For $a_m^{(+)}(\zeta) = 0$ respectively $a_m^{(-)}(\zeta) = 0$ one gets a circle. If the point P_A in the aperture plane moves once clockwise round the circle of the radius $R + \zeta$ the corresponding point in the image plane moves $(m + 1)$ times clockwise, respectively $(m - 1)$ times counterclockwise round its circle of aberration. Apart from these special cases one finds that for each circulation in the aperture plane the aberration curves are passed twice if m is odd and once if m is even. A consequence of this fact and of the relationship

$$(16) \quad \delta u_m \left(\zeta, \psi + \frac{n\pi}{m} \right) = (-1)^n \exp \left(\frac{in\pi}{m} \right) \delta u_m(\zeta, \psi),$$

valid for all integers n is, that for odd m the aberration figure has an m -fold symmetry and for even m a $(2m)$ -fold one. Equation (14) furthermore yields:

$$(17) \quad |\delta u_m(\zeta, \psi)|^2 = |a_m^{(+)}|^2 + |a_m^{(-)}|^2 + 2|a_m^{(+)}| |a_m^{(-)}| \cos(2m\psi + \gamma_m),$$

γ_m being the phase of $a_m^{(+)} + i a_m^{(-)}$. The absolute value of δu_m oscillates between the extreme values

$$||a_m^{(+)}| \pm |a_m^{(-)}||.$$

If in one special case it is

$$|a_m^{(+)}| = |a_m^{(-)}|$$

the aberration curve passes through the origin of coordinates in the image plane and it thus a rosette curve. If in another interesting case

$$|a_m^{(+)}| : |a_m^{(-)}| = (m + 1) : (m - 1)$$

is valid, then points or the curve exist in which

$$\frac{\partial}{\partial \psi} (\delta u_m)$$

vanishes. These points are then tips of the curve. In the general case the aberration curve will neither pass through the origin nor have any tips.

Practically it cannot be expected that one might observe such simple curves. Due to the dependence of all curve parameters on the radial coordinate ζ , at a finite width of the annular aperture a continuous superposition of such types of curves is to be expected which differ in shape, size and orientation in the image plane. In addition to this, aberrations of different types of symmetry may superpose linearly. The intensity distribution of the radiation emitted from one single object point P_o may therefore have a very complicated shape.

Closely behind the aperture, in the space free from the lens field, a suitable electrostatic stigmator shall be built into the electronoptical system. This is shown in FIG. 2. As is evident, only systems with one single annular aperture can be used here. In the following section conditions on the construction

of such a stigmator shall be discussed. It is assumed that the electrical field of the stigmator has only a short extension in the direction of the z -coordinate; it shall only be nonzero in the interval $z_A \leq z \leq z_E$. This can be practically realized by use of metallic screens with sufficiently narrow apertures, their potential being that of the image space. These metallic diaphragms will confine the electrostatic field being inside the stigmator. The left diaphragm may be that also presented in FIG. 1. Along their very short path through the stigmator the electron trajectories may be regarded as practically parallel to the z -axis, that is, changes of the values of the coordinates ζ and ψ along every trajectory may be neglected.

Since the wave aberration δW is to be regarded as a small perturbation, one can expect that only small voltages $V(\zeta, \psi, z)$ in the stigmator are necessary to correct this aberration; therefore $|V(\zeta, \psi, z)| \ll \Phi^* = \Phi(1 + \eta\Phi)$ may be valid. Here Φ is the accelerating voltage of the electrons and $\eta = e/(2mc^2)$. With the normalization $n(\Phi^*) = 1$ the following rate of change in the electron optical index of refraction is obtained:

$$(18) \quad \delta\eta(\zeta, \psi, z) = \eta - 1 = \frac{1}{u} V(\zeta, \psi, z),$$

the constant U being a voltage defined by:

$$(19) \quad u = \frac{2\Phi(1 + \eta\Phi)}{1 + 2\eta\Phi}.$$

From (18) one finds the additional wave aberration in the exit plane $z = z_E$ of the stigmator which is caused by the electrostatic correction field:

$$(20) \quad \delta W_s(\zeta, \psi) = \int_{z_A}^{z_E} \delta\eta dz = U^{-1} \int_{z_A}^{z_E} V(\zeta, \psi, z) dz.$$

The problem is to adjust the field in the stigmator such that $\delta W + \delta W_s$ is minimized. In order to find the conditions for this, the correction voltage $V(\zeta, \psi, z)$ is expanded into a Fourier series with respect to ψ and into a power series with respect to ζ in the proximity of the value $\zeta = 0$:

$$(21) \quad V(\zeta, \psi, z) = \sum_{\nu=-\infty}^{\infty} \sum_{k=0}^{\infty} e^{i\nu\psi} \cdot \frac{1}{k!} \zeta^k V_{\nu}^{(k)}(z), \quad (V_{-\nu}^{(k)} \equiv V_{\nu}^{(k)*}(z)).$$

This is to be introduced into Laplace's equation $\Delta V = 0$, then for each term $e^{i\nu\psi}$ a comparison of different powers of ζ is to be performed. The coefficients $V_{\nu}^{(0)}(z)$ and $V_{\nu}^{(1)}(z)$ may be arbitrary functions of z ; for all coefficients of higher order, $V_{\nu}^{(k)}(z)$ with $k > 1$, one finds recursive formulae. By the choice of the functions $V_{\nu}^{(0)}(z)$ and $V_{\nu}^{(1)}(z)$ for each value of ν the whole potential field is determined uniquely. Especially one obtains:

$$(22) \quad V_{\nu}^{(2)}(z) = \frac{\nu^2}{R^2} V_{\nu}^{(0)}(z) - V_{\nu}^{(0)''}(z) - \frac{1}{R} V_{\nu}^{(1)}(z),$$

$$(23) \quad V_{\nu}^{(3)}(z) = -\frac{3\nu^2}{R^3} V_{\nu}^{(0)}(z) + \frac{1}{R} V_{\nu}^{(0)'''}(z) + \frac{\nu^2 + 2}{R^2} V_{\nu}^{(1)'}(z) - V_{\nu}^{(1)''}(z).$$

At the boundaries of the field, $z = z_A$, $z = z_E$, all coefficients $V_{\nu}^{(k)}$ and their derivatives may vanish. If the abbreviations:

$$(24) \quad A_{\nu} = \int_{z_A}^{z_E} V_{\nu}^{(0)}(z) dz, \quad B_{\nu} = \int_{z_A}^{z_E} V_{\nu}^{(1)}(z) dz$$

are introduced, it is found that

$$(25) \quad \int_{z_A}^{z_E} V(\zeta, \psi, z) dz = \sum_{\nu=-\infty}^{\infty} e^{i\nu\psi} \left[A_{\nu} \left(1 + \frac{\nu^2 \zeta^2}{2R^2} - \frac{\nu^3 \zeta^3}{2R^3} \pm \dots \right) + B_{\nu} \left(\zeta - \frac{\zeta^2}{2P} + \frac{\nu^2 + 2}{6R^2} \zeta \right) \right]$$

is valid. After consideration of the reality of V one has for each

couple of indices, $\nu = \pm m$, two arbitrarily variable field parameters A_m and B_m available. With the proper choice of these parameters one can reach that for each value of ν the lowest two terms in the series expansion of the wave aberration δW with respect to ζ are compensated. In order to show this, the series expansion (10) is completed:

$$(25) \quad \delta W(\zeta, \psi) = \sum_{\nu=-\infty}^{\infty} \sum_{k=0}^{\infty} \frac{1}{k!} F_{\nu}^{(k)}(o) \zeta^k e^{i\nu\psi},$$

the coefficients $F_{\nu}^{(k)}(o)$ being the derivatives of the function $F_{\nu}(\zeta)$ at the point $\zeta=0$. Comparison of (20), (25), (26) yields the conditions for the compensation with respect to the coefficients $F_{\nu}(o)$ and $F'_{\nu}(o)$. These are:

$$(27) \quad A_{\nu} = U F_{\nu}(o), \quad B_{\nu} = -U F'_{\nu}(o).$$

Finally one finds the remaining uncorrectable aberration:

$$(28) \quad \delta W + \delta W_s = \sum_{\nu=-\infty}^{\infty} e^{i\nu\psi} \left[\frac{\zeta^2}{2} (F_{\nu}''(o) + \frac{F_{\nu}'(o)}{R} - \frac{\nu^2 F_{\nu}(o)}{R^2}) + \frac{\zeta^3}{6} \left(F_{\nu}'''(o) - \frac{\nu^2 + 2}{R^2} F_{\nu}''(o) + \frac{3\nu^2}{R^3} F_{\nu}'(o) \right) + O(\zeta^4) \right].$$

This expression does not depend on the special shape of the stigmator field, that is, if a compensation of the terms with ζ^2 and ζ^3 is obtained, a further correction by changing the shape of the electric field distribution is impossible. One has to choose the ring width $2b$ so that according to Rayleigh's $\lambda/4$ rule

$$|\delta W + \delta W_s| \leq \frac{\lambda}{4}$$

is valid. With restriction to the essential terms, those of the second power of ζ , the ring width b must fulfill the condition:

$$(29) \quad 6 \leq \text{Min} \sqrt{\frac{\lambda}{2}} \left(\left| F_{\nu}''(o) + \frac{F_{\nu}'(b)}{R} - \frac{\nu^2}{R^2} F_{\nu}(o) \right| \right)^{-\frac{1}{2}}$$

which is valid if one type of aberrations is dominant.

A consequence of the fact that for each symmetry number $\nu = |m|$ two variable field parameters are necessary is, that the stigmator has to contain at least two systems of electrode rings, which make it possible to approximate fields of arbitrary dependence on the azimuth ψ with sufficient accuracy. For this purpose each electrode ring should be subdivided into a sufficiently large number of sectors which can be put on different potentials. This is presented in FIG. 2. If one wants to correct an aberration with the symmetry number $m = \nu$, one has to put such potentials on the sectors that approximate the distributions:

$$(30) \quad V_j^{(m)}(\psi) = \Phi_j^m e^{im\psi} + \Phi_j^{m*} e^{-im\psi}$$

are built up in the two electrode rings; of course $\Phi_j^{-m} = \Phi_j^{m*}$ is valid. Since the relation between the potential distribution in space and the values Φ_j^{ν} at the boundaries is linear, there are also relations of the kind:

$$(31) \quad \begin{aligned} A_{\nu} &= \alpha_{11}^{\nu} \Phi_1^{\nu} + \alpha_{12}^{\nu} \Phi_2^{\nu}, \\ B_{\nu} &= \alpha_{21}^{\nu} \Phi_1^{\nu} + \alpha_{22}^{\nu} \Phi_2^{\nu}. \end{aligned}$$

One has to take care that the determinant $\text{Det}(\alpha_{ik}^{\nu})$ of the coefficients must not vanish. Then this system of equations can be solved for Φ_1^{ν} and Φ_2^{ν} . This means that in the region in which it is allowed to assume weak correction fields, there are for each ν always exactly two boundary values $\Phi_1^{\nu}, \Phi_2^{\nu}$ which make the correction possible.

In order to guarantee Det

$$(\alpha_{ik}^{\nu}) \neq 0$$

it is necessary to make the radii of the two electrode rings dif-

ferent and also to vary the diameter of the inner electrode having the potential of the image space. If the radii of both outer electrode rings are values and the radius of the inner electrode is constant, the space between the electrodes being sufficiently narrow, then along the electron paths the electrical potential will be approximately proportional to the electrical field strength. Then as a consequence of this, there is a linear relation between both equations (31). In systems with a larger space between the electrodes this is not necessarily true, but still a too small nonvanishing determinant is unfavorable. If the value of the determinant is sufficiently large, then items of the shape of the electrode rings are unimportant, they only determine the actual values of the matrix elements α_{ik} . For the adjustment of the stigmator it is only essential that always values of Φ_1, Φ_2 exist which fulfill (31) and which lie in a reasonable region. As is pointed out above, the remaining uncorrected aberration does not depend on the geometrical shape of the stigmator.

In the preceding sections only such aberrations are studied which are produced by a system of rays or waves starting from an object point P_o on the axis. This is, however, no essential restriction. The electrode potentials Φ_j can always be adjusted in such a manner that for object points distant from the axis the additional coma and Seidel's astigmatism can be compensated. Thus it is always possible to obtain a sharp image of a sufficiently small part of the object. Of course the diameter of this object region will be smaller than in systems with paraxial focusing, because, due to the larger aperture angles, the coma will have a larger magnitude. For purposes of highly magnifying imaging of very small object details or for producing of focuses of very small diameters systems with annular apertures may be superior to usual ones after aberrations caused by perturbations of the rotational symmetry have been minimized.

In FIG. 3 a stigmator according to the invention is shown in an axial section and FIG. 4 shows a section along the line IV/IV of this stigmator. In these two FIGS. like parts are designated by like reference numerals.

The stigmator comprises a cylindrical middle electrode 1 having outer potential, the middle electrode consisting preferably of V2A steel. The middle electrode is limited at its front surfaces by two ring diaphragms 2, 3. The two central portions of the ring diaphragms 2, 3 form thereby the two front surfaces of the cylindrical middle electrode 1. The front portion 4 of the middle electrode 1 has a larger diameter than the back portion 5 thereof, as can be seen from FIG. 3. The middle electrode 1 is surrounded by two sector shaped electrode ring systems 6, 7 which are arranged at a distance one from the other, and which have different diameters. The electrode ring system 6 of the larger diameter surrounds the front portion 4 of the middle electrode 1, whereas the electrode ring system 7 of the smaller diameter surrounds the back portion 5 of the middle electrode 1. In order to apply the different voltages, the different sectors of the electrode ring systems are provided with electric contacts 8 and the different sectors of the electrode ring system 7 have electric contacts 9.

In order to fix and to adjust the middle electrode in the beam path of the electron optical system, suspension arrangement 10, 11 is fixed to both front surfaces 2, 3 of the middle electrode 1. The suspension is usefully made in the represented manner by three metallic rods 11, which are adjustable from the outside and which are shifted by 120° , the rods 11 being arranged in the field free space before each

front surface 2, 3 of the middle electrode 1 so that the middle electrode 1 is well adjustable. Because the metallic rods 11, contacting the front surfaces 2, 3 of the middle electrode 1 through the metallic piece 10, represent at the same time an electric connection, it is warranted that the middle electrode 1 of the stigmator is at outer potential.

Each electrode ring system 6, 7 preferably comprises 12 sectors (as shown) so that a compensation of the especially detrimental astigmatisms of the second, third and fourth order can be achieved.

The diameter of the hollow electron beam shown by dotted lines 12 in the FIGS. 3 and 4 is 20 mm. Of course, other dimensions can be used in case of need, e.g. 5 mm. as diameter for the hollow electron beam.

For the electric insulation of the electrode ring system 6, 7 a synthetic layer, preferably a Teflon layer 13 as shown in FIG. 3, is usefully utilized.

As a material for suspension devices 10, 11, the annular two diaphragms 2, 3 and the electrode ring systems 6, 7 V2A steel is preferably suited.

I claim:

1. A stigmator for the electrical compensation of image defects in electron optical systems working with hollow beams and annular apertures, characterized in that a cylindrically shaped middle electrode which is limited at its front faces by two metallic annular diaphragms having outer potential, is closely arranged behind the aperture diaphragms within the lens field free space in the path of the beam of the electron optical system, that the front portion of the middle electrode has a greater diameter than the back portion, that the middle electrode is surrounded by at least two sector shaped electrode ring systems arranged in a distance one from the other and of different diameter, that each of the electrode ring systems is divided into several sectors provided with contacts and having different potentials, that the electrode ring system of the greater diameter surrounds the front portion of the middle electrode and the electrode ring system of the smaller diameter surrounds the back portion of the middle electrode in a distance and that the two front surfaces of the cylindrical middle electrode form the central portions of the two annular diaphragms.

2. The stigmator according to claim 1, characterized in that for the suspension and adjustment of the middle electrode in the beam path of electron optical system, the suspension devices are fixed to the front surfaces of the middle electrode.

3. The stigmator according to claim 1, characterized in that the suspension device consists of a central metallic portion which is engaged by three metallic rods which are offset by 120° and which are adjustable from the outside.

4. The stigmator according to claim 1, characterized in that each electrode ring system comprises 12 sectors.

5. The stigmator according to claim 1, characterized in that a synthetic material is used for the mutual insulation of the electrode ring systems.

6. The stigmator according to claim 1, characterized in that Teflon is used as synthetic material for the mutual insulation of the electrode ring systems.

7. The stigmator according to claim 1, characterized in that the middle electrode and the two annular diaphragms consist of V2A steel.

8. The stigmator according to claim 1, characterized in that the electrodes of the two electrode systems consist of V2A steel.