Analysis of Possible Substitution of the Aspheric Surface of the Corrector Annulus by the Shape With Simpler Production Technology.

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Abstract

In this note we study the possibility to substitute the aspherical profile of the corrector annulus by a circlular shape.

Introduction

During the last meeting at Karlsruhe we have presented the results of our analysis of the surfaces shapes of the corrector annulus which should increase the optical power of the Schmidt camera of the Fluorescence Detector (FD). Simultaneously the other optical properties, namely the maximum spot size in the plane of the photodetector should remain conserved. This presentation is currently prepared for publication as a GAP note. We have designed two possible profiles of the front surface of the annulus and the rear surface has been left planar for sake of simplicity. The shape of the front surface of the corrector annulus is aspheric and it is defined by the equation:

$$\mathbf{Z = A\,y^2 + B\,y^4 + C\,y^6} \quad .$$

This shape is sketched in Fig. 1 together with the scheme of the Schmidt camera.

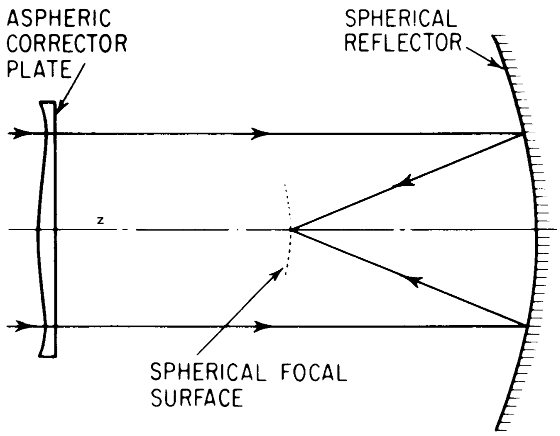

Fig. 1 : Scheme of the Schmidt camera.

In the picture is shown the whole corrector plate. In our case the plate is cut out and what remains is only the outer rim with the annular shape. Only part of the profile described by the above mentioned equation remains therefore functional but its profile is still an aspheric curve.

It would be quite useful to substitute this curve by technologically more convenient shape and in the following we shall study this option.

Methodic Approach .

We have used the simplex downhill method for curve fitting to substitute the aspheric profile. To achieve fast convergence of the solution we employed parameters of the osculatory circle – i.e. the curve, which has common with the aspheric curve at least tangent in the chosen point. The radius of this circle is in each point of the aspheric curve different. The osculatory circles in the end points of the aspheric curves are shown in Fig. 2.

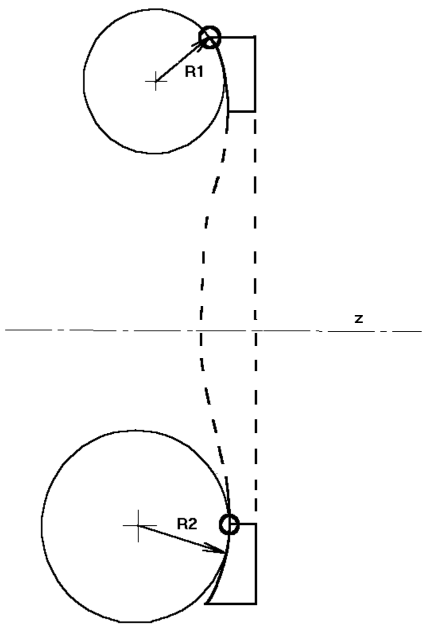

Fig. 2 : Osculatory circles in the end points of the annulus profile.

The end points correspond to the inner and outer radius of the annulus. These points are marked by small circles. The scale of the profile depth is exaggerated to illustrate it. To obtain the radii values we have used the following parameters of the profile equation. They have been obtained in our previous study.

$$A = 9.9481644 \ 10^{-6}$$
$$B = -8.9382619 \ 10^{-12}$$
$$C = -1.3472051 \ 10^{-18}$$

The radius of the osculatory circle varies in the case between the values:
R1 ~ 6300 mm a R2 ~ 11700 mm .
This is quite large range.
It is evident that the exact substitution of even a part of the aspheric profile by a circle is impossible. If we inlay the aspheric curve by circle of a given radius we may get information on local differences of both two curves and from these we can infer the possibility of substitution of one curve by another. We are looking for the solution illustrated in Fig. 3.

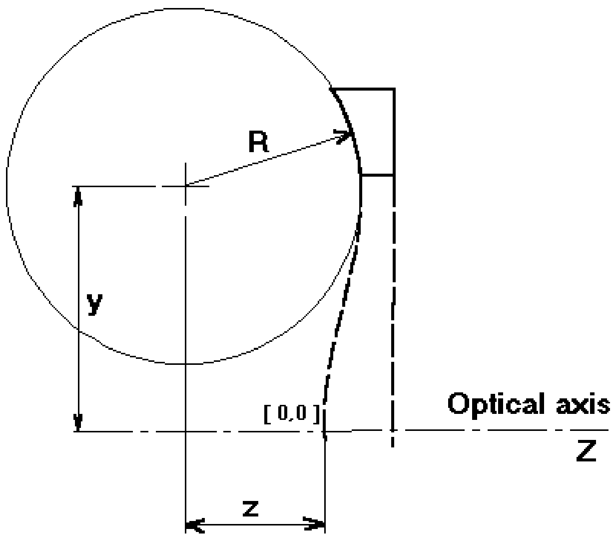

Fig. 3: Interleaving of the aspheric curve by a circle in the region of annulus.

To find the parameters R, y, z of the circle we have employed the simplex method. In our case we have found the following values:

Radius of curvature	R = 8383 mm,
Distance from the optical axis	y = 795.27 mm,
Distance from the apex of the aspheric surface	z = 8380.9 mm .

The best confirmation of this result would be calculation of the spot diagrams of the system with the aspheric element replaced by this approximation. However, this is technical problem. All programs describing passing of rays through optical systems suppose the position of the centers of curvature of all surfaces to be on the optical axis of the system. The above

described approximation by circle leads generally to infinite number of centers of curvature laying on the circle around the optical axis **z** with the radius given by the value **y** (Fig. 3).
We tried to find some other way allowing us to judge the quality of the substitution. One can use the following reasoning: If we divide the corrector plate or its part (annulus) into narrow annular parts (zones) along the **y** axis, on can approximate each zone by thin optical wedge. Fig. 4 illustrates the light transmission through optical wedge.

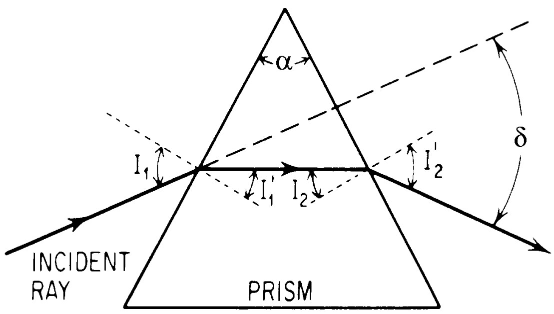

Fig. 4: Light transmission through optical wedge.

α is the wedge angle and δ is the deviation of the passing ray. In the case of small α one can approximate the deviation:

$$\delta = (\mathbf{n} - \mathbf{1})\,\alpha\ ,$$

where **n** is the refraction index of the wedge.

The refraction index is about **1.5** in our case. Therefore the deviation between incoming and outgoing ray equals approximately to half of the wedge angle α.
For each zone we can determine from 1st derivative the slope of the basic aspheric curve and the same we can do in case of circle approximation. The difference of these two values is tangent of the angular change of the original aspheric surface. We place inside each zone an imaginary thin wedge with the angle equal to arctangent of the calculated difference. As follows from the above mentioned equation one half of this angle then equals to δ by which the original direction of the ray changed due to substitution of the aspheric curve by a circle.
Thus by substitution of aspheric curve of the corrector plate profile by a circle, the intersection of the ray in the picture plane is shifted by certain value. The value of such shift compared to maximum allowed radius of the spot size (15 mm) is a good criterion to evaluate approximation of the original aspheric curve by circle. The spot size radius in the picture plane might increase at most just by this value. We denote this shift Δy.
The correction plate is placed in the center of curvature of the main mirror with diameter 3400 mm. The photodetector camera is located in the distance of approximately 1700 mm from the mirror. We have derived the approximate formula for the size of the shift Δy with the help of Fig. 5.

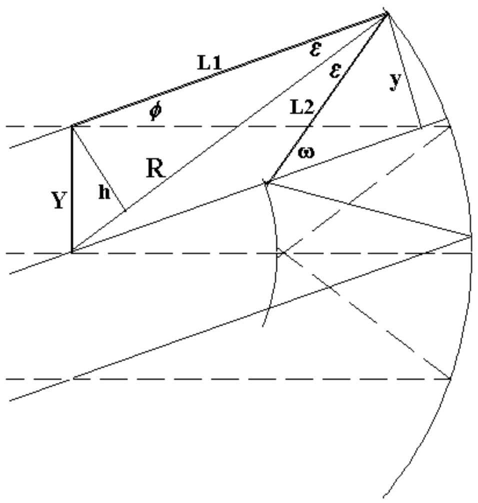

Fig. 5: Optical path of the ray between the corrector annulus and the plane of photodetectors.

By substitution of the aspheric curve of the annulus profile by circle, the ray intersection in the picture plane shifts by value (in millimeters):

$$\Delta y = \mathrm{TAN}\ (\ \delta\ )\ \ (L1 - L2)\ ,$$

where

$$L1 = R \sin(90 - \varepsilon - \varphi) / \sin(90 + \varphi),$$
$$L2 = Y \cos \varphi / \sin \omega\ .$$

In the above mentioned case of substitute circle with radius R = 8383 mm we have found the maximum value TAN (δ) = 0.001, which corresponds to the shift in the picture plane by about 1.5 mm. The edge of the original light spot shifts by this value. Thus without optical calculations we can asses the influence of the substitution of aspheric curve on the original size of the light spot in the picture plane. In our case the original diameter increases from 15 mm to about 18 mm.

One can use the above-mentioned relation also in general considerations concerning the allowed production tolerances of the correction annulus surface shape. We can consider the shift Δy as the source of aberration. The size of this aberration is function of the local change of inclination of the corrector ring optical surface. If we choose the maximum allowed value of this transversal aberration we can inversely determine the maximum allowed local error of the inclination of the refraction surface of the correction annulus.

Earlier we have stated that it is impossible to use the discussed approximation of aspheric profile in optical calculation program because generally we have to deal with the surface defined by infinitely many centers of curvature laying on a circle. We have searched for a solution circumventing this obstacle and such that it would allow to perform optical calculation of the light rays paths with usual output in the form of spot diagrams. We have started from the fact that in our optical system with corrector annulus the functional part is only the outer surface in the form of annulus. Hence we have searched for generally aspheric

rotational surface, the outer part of which might be easily substituted by an arc with the diameter given by earlier determined diameter. In our case it is R = 8383 mm. The central part of the surface has been screened during the calculation. Finally we have found satisfactory solution of the shape of the aspheric surface described by polynomial of 12th order. On the next page we list two spot diagrams. The Fig. 6 shows the spot diagram of the Schmidt camera with the original profile of the 1st surface of the corrector annulus, i.e. with the aspheric shape. The equation of the profile curve and its coefficients has been listed earlier in this paper. The following Fig. 7 shows for comparison spot diagram of the Schmidt system with the correction annulus the 1st surface of which is approximated in meridian cut by the circular arc with diameter R = 8383 mm.
Both two spot diagrams are very similar. The approximation by the arc leads to slight changes in the shapes of light spots. The middle column shows the light spots in the picture plane of the system. The spot in the top center is slightly enlarged to about 18 mm. This enlargement is in good agreement with the transversal shift Δy determined with the help of the above listed relations.

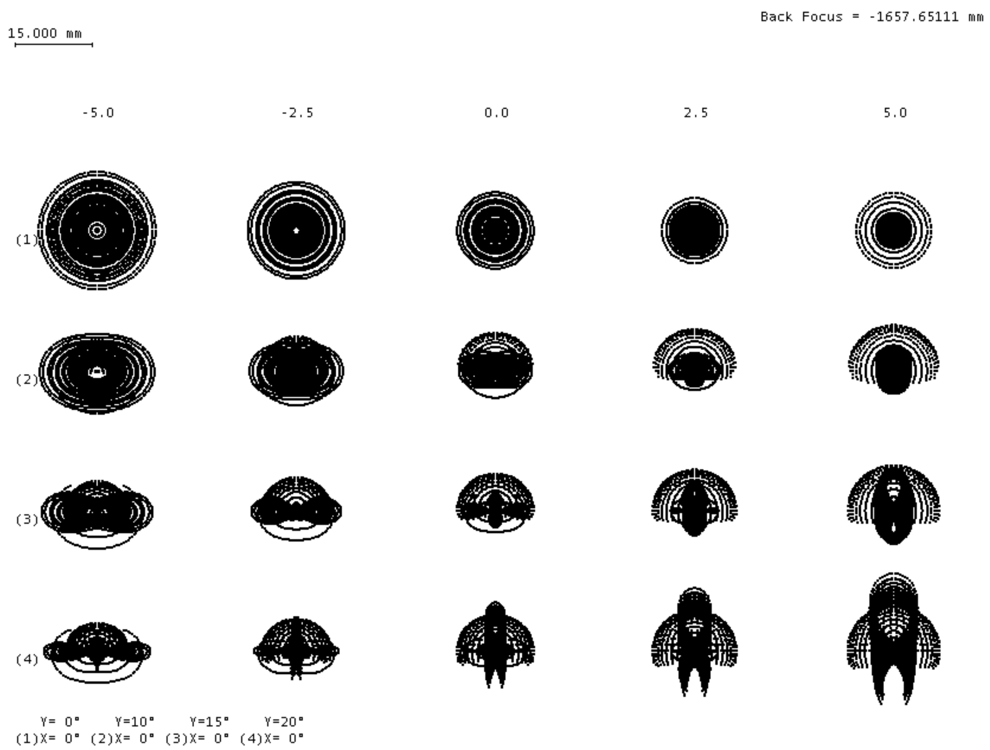

Fig. 6: Spot diagram of the Schmidt camera with correction annulus. The profile of the 1st surface is described by the aspheric curve.

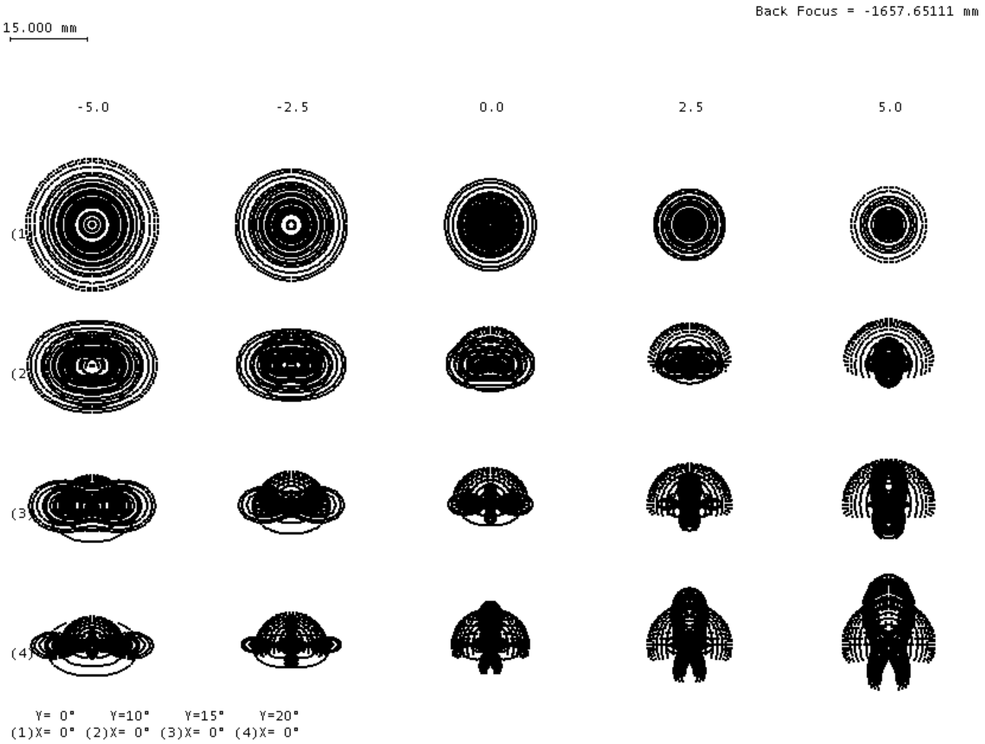

Fig. 7: Spot diagram of the Schmidt camera with correction annulus. The profile of the 1st surface is approximated by the circular arc.

Conclusions:

In this paper we have analyzed the possibility to substitute the aspheric curve describing the profile of the 1st surface of the correction annulus by a simpler shape – the circular arc. The analysis was based on the assumption that the approximation might simplify the production and subsequent control of this optical element or of the form used for its production.

As supposed, the approximation by circular arc leads to local changes of the inclination of the original surface. This results in changes of the shapes and sizes of the light spots in the picture plane of the optical system. The size of these changes is apparent from the listed spot diagrams and according to our opinion it should not have serious influence on the function of the whole optical system.

The usage of the results of this paper depends on the final choice of the technology employed for the correction annulus production and the method of its shape control. Of course the final decision will be given by the degree to which the production would be simplified by this approximation. This we leave open to further discussion of the parties involved and to the progress in search for appropriate technology.

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