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Optical design of a focal reducer

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Abstract. Optical design of a f/2.8 focal reducer having 90 arcsec field of view for the 2.3 meter f/13 telescope is described. The parameters of the design have been optimized for a medium resolution spectrograph to be used for studying the faint extragalactic sources at the cassegrain focus of the Vainu Bappu Telescope. The design was carried out with Code V optical design software package.

Key words : optical instruments—spectrograph

1. Introduction

An imaging faint object spectrograph (IFOS), as a cassegrain focal plane instrument of 2.3 m Vainu Bappu telescope is a powerful tool for observing extended emission line regions (EELR) around active galaxies. Therefore, a feasibility study for designing IFOS was undertaken. The study includes optical design, choice of a dispersing element, designing the slit system and choice of a suitable detector for recording the spectrum—which can be found in a report by Debi Prasad and S. N. Tandon. The optical design of a focal reducer is presented in this paper. The objective of IFOS is to obtain the observations of typical EELR with a spectral resolution of 0.3 nm over a field of view of 90 arcsec. The detectors with pixel size of 15 micron can provide the desired spatial and spectral resolution with a focal reduction of 2.8.

The focal reducers with all transmission optics have been designed and successfully used with many telescopes (Aldering & Bothun 1991; Geyer *et al.* 1979). Such designs are specific to a given telescope and provide aberration free full field and high degree of spatial consistency for imaging spectroscopy. A focal reducer consists of a collimator and a camera. The reduction in focal ratio of the telescope is decided by the required spatial resolution and detector pixel size. The collimator provides the parallel beam through the pupil, which is accessible to place filters and dispersing elements. Usually a grism (transmission grating-prism) or a Fabry-Perot is used as the dispersing element. This paper gives a brief account of the design considerations of a 2.8 focal reducer to be used at the cassegrain focus of the Vainu Bappu telescope, followed by the details of its components.

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2. The design considerations

It may be quick and less expensive to design a focal reducer with commercial optics (Meinel 1956), however, these devices cannot correct the coma, field curvature and chromatic aberration to the required accuracy. Courtes (1972) and Geyer *et al.* (1979) pioneered in designing focal reducer by employing customized optics. Further, it is more economical and flexible when a system is designed by its user, rather than by industry. This motivates to undertake such a task.

A focal reducer can be designed with refractive or reflective optics. Reflective optics has the advantage of using the instrument across entire spectral range to which the detector is sensitive. Apart from its fabrication difficulties, such an optics would also introduce instrumental polarization, which may lead to limit its use in imaging polarimetry study. Eventhough, the present considerations for the instrument is not making an imaging polarimeter, it is desirable to keep such an option for future. However, the fabrication difficulties are the dominating factors for choosing an all refractive focal reducer design. The choice of wavelength window is limited by the availability of glasses and anti-reflection coatings. The available glasses have poor transmission and high spectral dispersion in the wavelength shortward of 400 nm. Good antireflection coatings are available in the range of 400-1000 nm. Therefore, the design was optimized for the wavelength range 400-1000 nm. Further, since in this spectral range there are a number of interesting lines and also the sensitivity of modern detectors like CCDs are high, the choice is justified.

Computer-aided design being the normal procedure and most efficient for designing optical systems, we adopted Code V optical design and optimization package, which have been used previously to design focal reducers. This commercial package uses damped linear least-square minimization to optimize an initial design, subject to user-imposed constraints. The modulation transfer function or the root mean square spot size is used for obtaining optimal solution. Surface shapes, filter and off-axis elements are supported by this package. Transmitting optical elements are initially represented as having refractive indices n and Abbe number V which vary in a continuous manner within a user-designed region of the nV plane. Partial dispersion follows a parameterized curve representing the locus of partial dispersions for 'normal' glasses. Real glasses can be substituted from an on-line catalogue, which contains useful properties of the real glasses such as refractive index, transmission with wavelength, coefficient of thermal expansion etc. Table 1 gives the refractive index at 1014, 486.10 and 365 mm of glasses used in the present design from this catalogue. More details can be found from the Code V manuals.

3. The collimator

The collimator of an ideal focal reducer provides an accessible pupil where a filter wheel and dispersing element can be placed. From the geometrical optics point of view, the rays from any point of the object must be parallel and pass through the same area at the pupil. Consequently, the light from every point of the object is treated identically by the disperser. In practice, these conditions are realized through computer optimization by fixing the necessary marginal and chief rays. Geyer *et al.* (1979) have shown that an ideal collimator in terms of image quality and spectral range can be designed by using a dual element field lens and three element collimator configuration. This system was manufactured by Jenoptiks, Jena,

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Table 1. Refractive indices of glasses

Glass code	Refractive index at		
	1014 00	486.10	365.00
PKS3-SCOTT	1.542186	1.558358	1.573427
FK54-SCOTT	1 431427	1.440340	1 448556
UBK7-SCOTT	1.507340	1.522370	1 536233

Germany and has been successfully used (Debi Prasad *et al.* 1991). However, there exists degeneracy of the solutions by altering the combination of optical elements in the final lens configuration (Aldering & Bothum 1991). We have used the Geyer *et al.* (1979) solution for the present design.

The collimator has a dual element field lens placed at 89.6 mm from the telescope focus and the three element collimating lens at an appropriate distance for compensating the aberrations and fixing the aperture stop at 87 mm from its last optical surface. Table 2 gives the solutions obtained for various surfaces of the collimator. Figure 1 gives the schematic of the collimator lens system.

4. Camera

The normal camera lenses use a symmetrical system in which the aperture stop is placed inside the system, so that the aberration can be easily balanced. In the present case however, the stop must coincide with the pupil of the collimator, hence lies in front of the camera where the filter and dispersing elements are placed. In addition to this, the requirement of f/2.8 focal ratio makes this design difficult. We have chosen a three element configuration suggested by Morbey (1992), which consists of a collecting element followed by a field lens and an image flattener. It has been shown that in such a configuration, the back reflected light from the detector may contribute as the uniform enhancement in the background, however, the problem of producing ghost images is not serous. Table 2 gives the details of optical elements. Figure 2 shows the schematic of the camera system.

5. Summary

The design of the focal reducer optics for Vainu Bappu telescope is made for using the system along with the dispersing elements such as grism or Fabry-Perot. The system can also be used as a polarimeter with slight modification. As a first step the collimator optics,

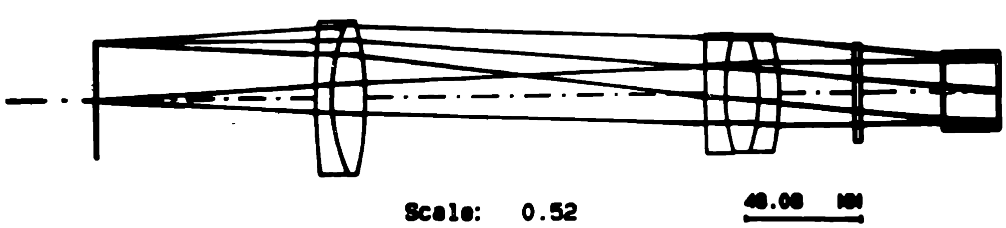

Figure 1. The collimator. The first and last surfaces are the telescope focus and the dispersing element (which is represented by a 34 mm block of UBK7 glass) respectively.

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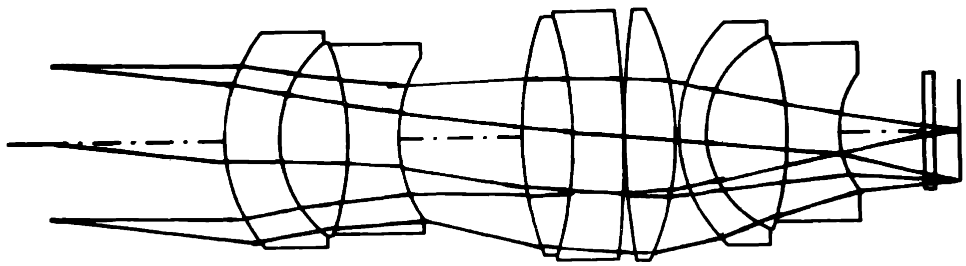

Figure 2. The camera. The first and last surfaces are the exit pupil of the collimator and image plane respectively

Table 2.

Optical surface	Radius of curvature	Thickness	Glass
Object	Infinite	89 550875	
1	282.90179	6.667662	PSK3
2	74 25812	14 102500	PSK4
3	−128.98711	142 203969	
4	1106.16061	8.472782	PSK3
5	90.03600	14.102500	Fk54
6	−69.94840	8.461500	PSK3
7	−103 53491	31.172166	
8	Infinite	2 820500	UBK7
9	Infinite	33.84600	
10	Infinite	22.564000	UBK7
11 (Stop)	Infinite	28.205000	
12	28 20500	9 018267	PSK3
	cc*	−0.15646	
13	20.92247	11 311333	FK54
14	−47.70030	8.461500	PSK3
15	25.33937	20.264164	
16	59.37717	8 461500	FK54
17	−69 86943	8.461500	PSK3
18	−175.28843	0.112820	PSK3
19	134.09785	8.461500	FK54
20	−49.29670	0 564100	
21	25 42399	4.512800	PSK3
	cc[1]	−0.14	
22	17.58864	13.183017	FK54
23	−50.61105	8 461500	PSK3
24	16.74249	13 538400	
25	Infinite	1.692300	UBK7
26	Infinite	3 948700	
27 (Image)	Infinite	0 0	

*Higher conic constants (cc) are set to zero

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along with 40 mm and 5 mm UBK 7 glass representing disperser and filter respectively, were optimized to produce a pupil at the position of the dispersor. Colour of the rays at the centre and edge of the field of view for an aperture height of 23.6 mm at the pupil was made to be coincident at the pupil. Finally the care was taken so that the rays from each object point were effectively parallel through the disperser. The second step was to optimize the camera optics while keeping the collimator optics fixed.

The summary of the dimensions of the focal reducer is given in table 3. Figure 3 gives the full ray diagram of the focal reducer from the telescope focal plane to the detector of the system. Aberration plots and spot diagram are given in figures 4 and 5. Figure 6 represents the encircled energy levels as a function of the off axis distance. It can be seen that the encircled energy levels of 80% are within 15 micron size at the full field over the entire wavelength range.

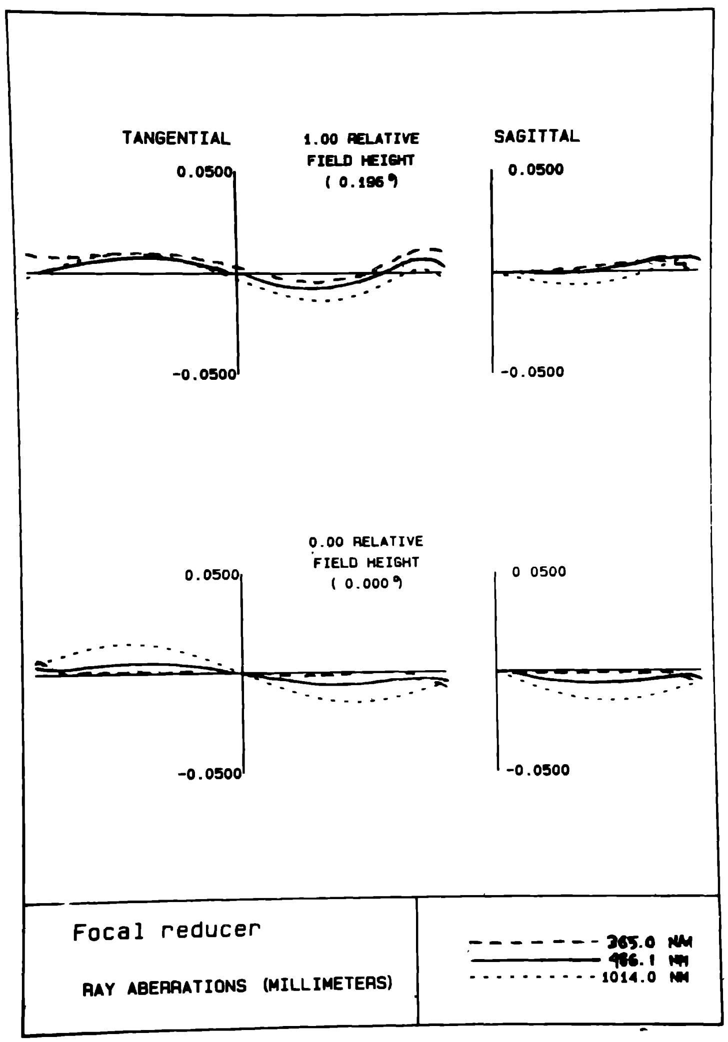

Figure 3. Aberration plot for the focal reducer

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Table 3. Summary of the dimensions

Reduction factor	0.3472
Final f-number	2.8
Object distance	89.5509 mm
Full length of the system	522 6229 mm
Image distance	3.9787 mm
Length of the optics	429.1233 mm

The object and image distances are from the first and last optical surfaces respectively.

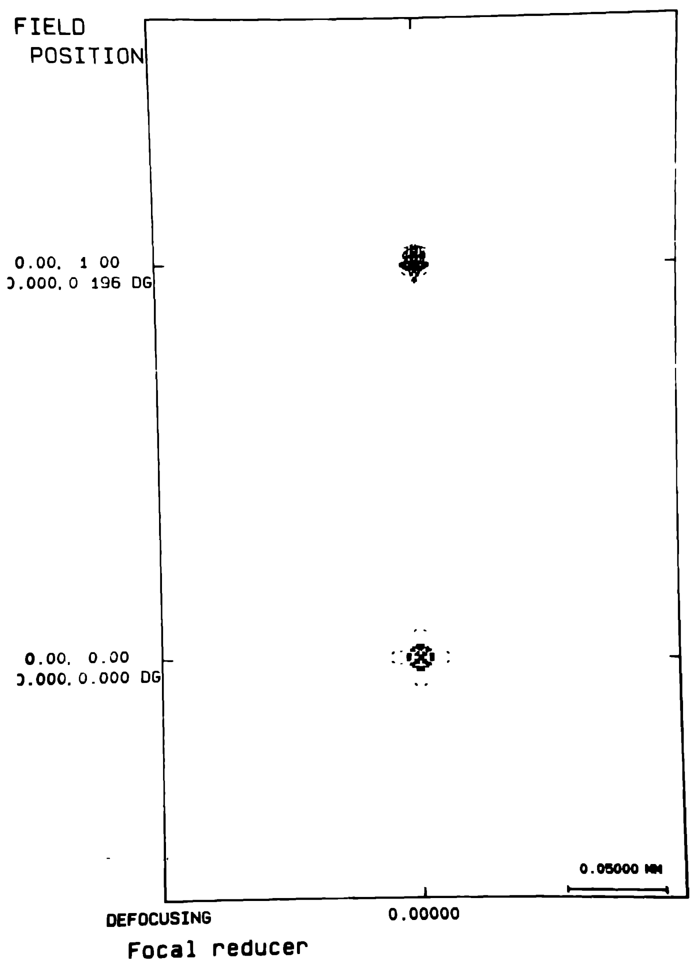

Figure 4. Spot diagram for the focal reducer.

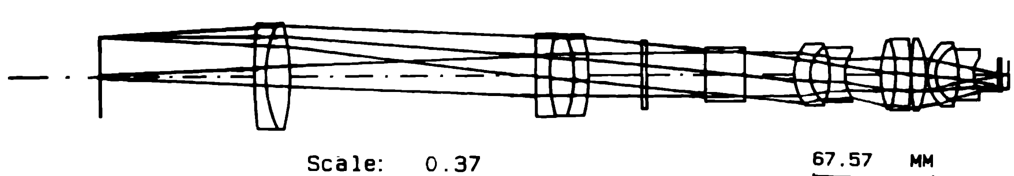

Figure 5. Full diagram for the focal reducer from the telescope focal plane to the imaging detector.

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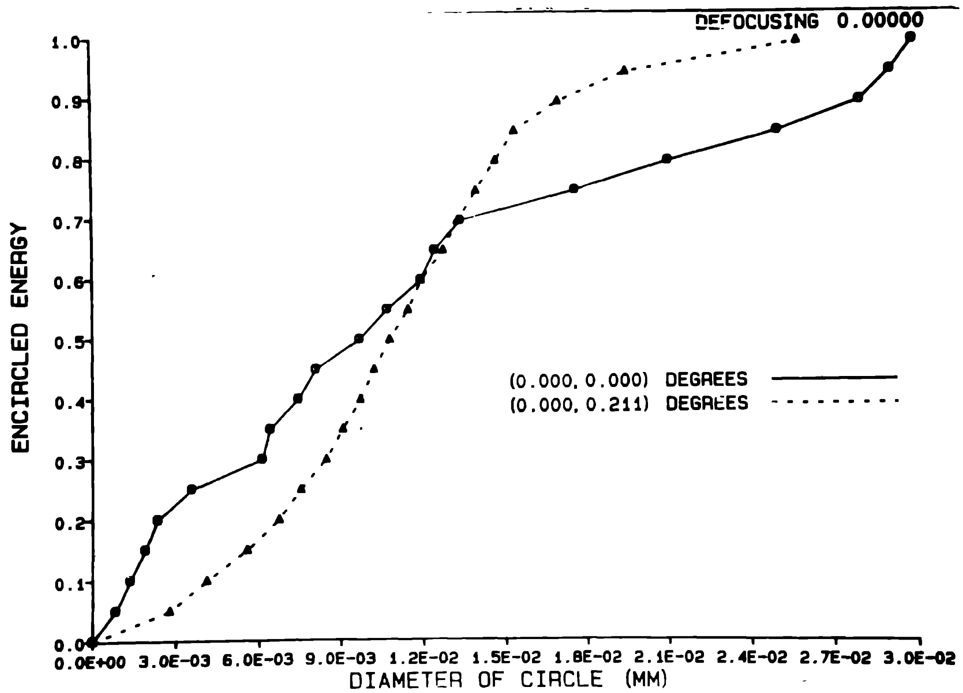

Figure 6. The encircled energy as a function of field angle.

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References

Aldering G. S., Bothum G. D., 1991, PASP, 103, 1296.

Courtes G , 1972, Vistas Astr , 14, 81.

Debi Prasad C., Tandon S N , 1992, Imaging Faint Object Spectrograph (IFOS), A proposal for observing the extended emission line region (EELR) around active galaxies with 2.3 m Vainu Bappu telescope, (unpublished)

Debi Prasad C., Jockers K , Geyer E. H., 1992, Icarus, 95, 211.

Geyer E. H , Hoffmann M , Nelles B., 1979, A&A, 80, 248.

Meinel A. B., 1956, ApJ, 124, 652.

Morbey C. L., 1992, Appl. Opt., 31, 2291.

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