The Edinburgh Automatic Star Follower

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SUMMARY

The automatic star follower or autoguider described in this paper was designed for the Edinburgh 40/60 cm Schmidt camera. The stellar image in the focal plane of the 15 cm f/18 guide telescope is split optically to produce four stationary images which are sampled by a single image dissector tube, whose sequential output signals are proportional to the intensity of illumination in each quadrant. These signals are compared to produce error signals which are a measure of the radial displacement of the star. Guiding corrections in both right ascension and declination are applied to the fine motions of the Schmidt drive mechanism.

Measurements made on a typical plate given an exposure time of 30 min, and using guide stars down to magnitude 8.5 indicate a guiding accuracy of better than 0.14 arcsec or 2 μm at the focus of the guide telescope.

1. *INTRODUCTION*

Before describing the autoguider used on the Schmidt camera here in Edinburgh, it may be of interest to mention briefly some of the designs that have been traditionally used. Perhaps the most popular are those that employ mechanical chopping techniques, where either[3, 5, 7] a chopping disc is rotated in the image plane, or[4, 12] the light beam is caused to rotate so that the star image describes a circular path on a fixed chopping disc. In either case, the modulated light beam is sensed by a single photomultiplier. In some of the earlier static systems[1, 6] the star image is divided optically to form four beams of light which are directed into four separate photomultipliers. More recently, the quadrant photomultiplier[9] and the image dissector[8, 10, 11, 13, 14] have enabled the designer to utilize electronic scanning techniques.

Although the many existing systems have proved satisfactory in their particular application it was felt that the high resolution and stability demanded by the Schmidt requires an automatic guider that contrives to combine the advantages of several systems.

2. *THE SCHMIDT AUTOGUIDER*

2.1 *The Autoguider Head*

The detecting element chosen for the Schmidt autoguider is a Bendix Channeltron Image Dissector illustrated together with the conventional type of tube in Figure 1. The image dissector is a type of photomultiplier in which an electrostatic focussing arrangement allows photoelectrons emitted from only a small selected area of the photocathode to pass into the multiplier section. Deflection coils mounted over the electron lens are used to deflect the electron image and hence position the effective photocathode area.

The Bendix tube differs from the conventional image dissector in that the dynode assembly is replaced by the simplified structure of the channel electron multiplier.

Several scan patterns were considered for finding the star image position directly on the photocathode of the image dissector. However it was considered that although the effective area of the photocathode can be reasonably well determined, it would be better to impose the burden of positional accuracy on an optical reference, and use the image dissector only to detect the amount of light received. Consequently, the star image is split optically into four parts before being applied to the dissector tube.

Figure 2 shows two biprisms mounted with their roof edges together and at right angles to one another such that they lie along the right ascension and declination axes of the telescope. The biprisms divide the star image into four parts, while a Fabry lens cemented on the exit face of the second prism images the telescope of objective on the face of the dissector tube. The four objective images remain fixed in position despite star movement, which causes only a variation in their light intensity.

It is necessary only for the effective area of the photocathode to cover the smaller optical image

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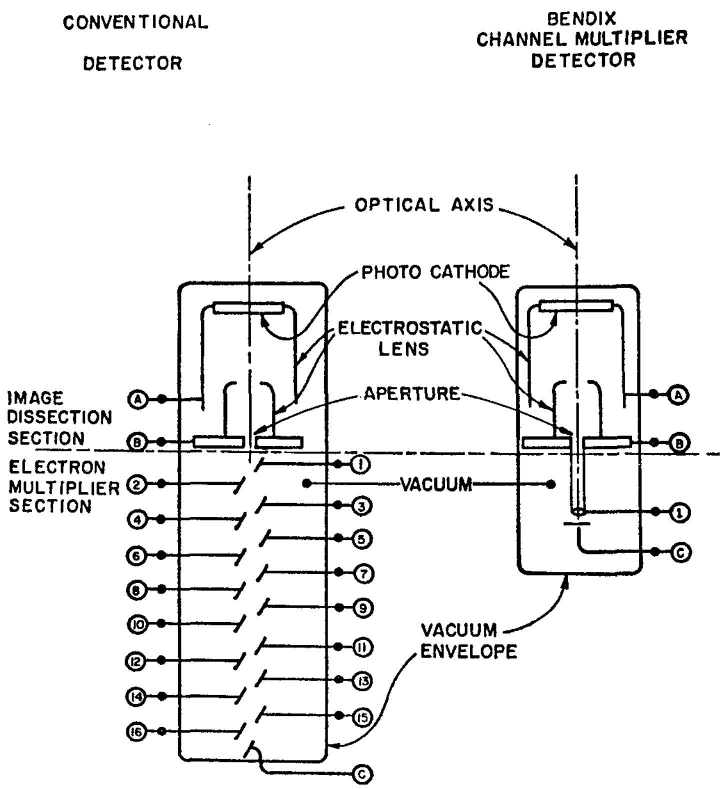
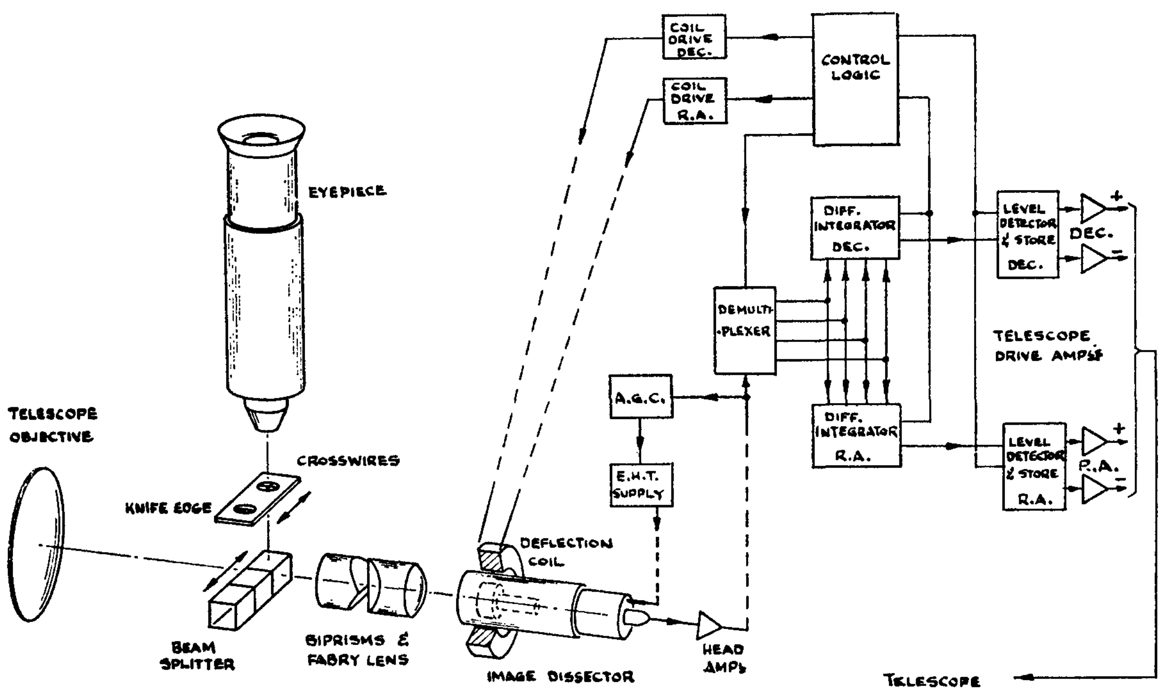


Fig. 1



AUTOGUIDER ~ 16/24 inch SCHMIDT CAMERA
ROYAL OBSERVATORY EDINBURGH

Fig. 2

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areas, therefore slight lateral instability of the electron image is unimportant. The four signals share the common path provided by the multiplier section of the image dissector and the head amplifier.

Guiding on the Schmidt is effected using a 15 cm f/18 refractor rigidly mounted on the main Schmidt tube. The autoguider is carried on a crosshead that allows the selection of a guide star in a 2° field concentric with the 4° field of the Schmidt camera. The acquisition field of the autoguider can be set in the range $\frac{3}{4}$–10 arcmin by an adjustable stop (not shown in Fig. 2).

A reflex viewing facility enables the observer to intercept the light falling on the biprism assembly so that he may manually bring the guide star into the acquisition field of the autoguider. Alternatively he may use this facility for manual guiding.

Figure 3 shows the autoguider on its crosshead mounted on the Schmidt's guide telescope.

2.2 *Electronic Circuitry*

Each deflection coil is energized by an amplifier operating as a constant current source. Two positive and two negative preset voltage levels for each axis are gated into the inputs of the deflection coil drive amplifiers. These set the four current levels required to deflect the electron image so that the effective photocathode area is stepped from one optical image to the next. To eliminate the effect of head amplifier drift, a.c. coupling is used between the head amplifier and the integrator and A.G.C. circuits which follow it. For this reason, the deflection coils are momentarily de-energized between steps so that the effective photocathode area falls on a darkened spot and signals referred to zero are produced.

In the control console the signals are distributed, in a sequence synchronized with that of the deflection coil drive, to two differential integrator circuits, one for each axis of the telescope.

The four signal inputs are applied in such a manner that the output of the integrator is proportional to the difference between the sum of the light intensity of the images produced on one side of a biprism and the sum of those produced on the other side. As the inputs arrive at different points in time, the integrator gives a true difference output only after every complete scan cycle. At the end of the integration period, the integrators are reset to a zero initial condition.

Immediately before resetting, the integrator outputs correspond to the lateral displacement of the star. The proportional error signals present at this time could be used to drive a telescope, but it was decided, in the case of the Schmidt, to make use of the very satisfactory add-and-subtract mechanism already used for manual guiding in right ascension, and a specially developed fine tangent arm drive in declination. The ON-OFF control required by both these devices is obtained from level detectors gated into the integrators just before the reset period.

3. *TEST RESULTS*

The composite plate shown in Figure 4 comprises two exposures of 30 min each. In both cases the telescope drive was set to run at 1 per cent below sidereal rate. One exposure shows the trail produced without guiding, while the other shows the circular images obtained by the autoguider working against the sidereal variation.

Figure 5 is of a region near η Orionis which, being at a zenith distance of about 58° from Edinburgh, is subject to considerable refraction effects. The two exposures were made over successive 30 min periods. Figure 5(a) was obtained using the autoguider on an 8.5 magnitude guide star, while for Figure 5(b) no guiding was employed. Measurements made on the original Schmidt plate from which Figure 5(a) is taken, using a microdensitometer with a resolution of 1 μm, have revealed no measurable asymmetry of star images. This corresponds to 0.14 arcsec or 2 μm at the focus of the guide telescope.

The circularity of the photographic images does not in itself indicate the quality of guiding, for it could be argued that random shifting of the telescope could form large circular images on the photographic plate. This is thought not to be the case because of the different response characteristics in the telescope's two coordinates. Furthermore, the appearance of the close apparent double supports this.

On short exposures (2 min) when errors in the sidereal drive are insignificant and guiding is not required, the smallest images formed on a Schmidt plate are about 1.5–2 arcsec in diameter. When manual guiding is used for longer exposures, the smallest images obtained are rarely less than 4 arcsec. Figure 6 which is taken from the same plate as that used in Figure 5(a) shows a 3 arcsec and a 2.5 arcsec image obtained over the 30 min exposure using the autoguider. By concentrating the light from faint stars, the autoguider has extended the plate limit over that obtained even with manual guiding.

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The prototype model of the autoguider has given unfailing service over the past two observing seasons, and has resulted in an increased number of plates from the Schmidt camera with consistent high quality guiding.

4. *FUTURE DEVELOPMENTS*

As an alternative to the analogue processing of the image dissector output used in this specific application, a digital method employing either a current to frequency converter or photoelectron counting techniques could be used.

Although the autoguider performance satisfies the requirements of the Schmidt, the disadvantage of using an image dissector, or any other sampling or scanning system, is that all the available light is not used. Because the channel multiplier is shared by the four separate photoelectron streams, only one quarter of the amount of light averaged over a complete scan cycle is used. Notwithstanding the benefits of the serial method of signal processing, it is felt that the combination of the optical image splitting principle used in the present system with one of the multiple photomultiplier tubes now available would result in an improved automatic guider. By using a four channel photomultiplier, the four images could be continuously monitored in parallel, and because the four sections share the environment within a common envelope, differential sensitivity and gain variations should be minimal. Furthermore, if photon counting techniques are employed, the system would be insensitive to moderate differential gain variations in the electron multipliers.

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DISCUSSION

R. E. NATHER: The Bendix channeltron tube is available with a quadrant-divided photocathode with separate multipliers for each section. Was this considered, and, if so, why was it rejected?

G. R. ADAM: It was not available when the star-follower was designed; I have considered it since.

A. ARDEBERG: What is the limiting magnitude of guide star for the accuracy that you mentioned? Relative to the desired plate centre, how far off-centre can you go to find a guide star?

G. R. ADAM: About magnitude 9.

V. C. REDDISH: We have no difficulty in guiding on stars offset up to the mechanical limit of one arc-degree from the field centre.

A. BEHR: How does the limiting magnitude depend on the telescope aperture and on the spectral type of the guide star?

G. R. ADAM: The limit of about 9th magnitude is for a 15 cm telescope. The tube has an S-20 photocathode, which provides high quantum efficiency in the blue together with a good red response.

E. W. DENNISON: At what point is the stellar image formed? What is the size of this image relative to the dissector aperture? What is the system time-constant?

G. R. ADAM: The focal point of the telescope is at the biprism junction, where the star image is divided. There are four fixed images of the objective on the photocathode, each being about half the effective photocathode diameter. The total integration time used is 1 sec, but this can be varied; a longer value might allow fainter stars to be used, but we have reached the design goal.

C. N. W. REECE: You said that you were not certain to what extent instability in the servo might generate enlarged star images that were still circular. By switching the drive off and measuring the trail width on a photograph, you would have some indication of the true image size.

V. C. REDDISH: The photographic resolution is not good enough to enable us directly to detect guiding errors of one or two microns; we can only detect a difference in right ascension and declination by looking for image elongation.

J TINBERGEN: What is the cost of the complete guider with electronics?

G. R. ADAM: About £2000.