

CONSTRUCTION AND TESTS OF AN EBERT-FASTIE SPECTROGRAPH WITH OPTICAL FIBERS.

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RESUMEN. Se presenta el desarrollo, construcción, pruebas de laboratorio y observacionales de un espectrógrafo tipo Ebert-Fastie fuera del plano con fibras ópticas. También se dan algunos resultados observacionales.

ABSTRACT. We present the development, laboratory and observational tests of an spectrograph of the off-plane Ebert-Fastie type with optical fibers, we also give some observational results.

Key words: INSTRUMENTS – SPECTROSCOPY – RADIAL VELOCITIES

I INTRODUCTION

We started a cooperation program between CHARA of Georgia State University and INAOE to design and build an efficient spectrograph, for the 2.1-m INAOE telescope in Cananea, Sonora, México, to be used together with the CCD system of same INAOE. One of the first aim of this equipment is to measure radial velocities with high precision; for this reason one needs a very stable spectrograph in the long term. The type of spectrograph chosen was of the off-plane Ebert-Fastie configuration, fed by a 10 meter fiber bundle. The spectrograph box is set on a table top and thermally isolated in order to accomplish the above objectives. Here we present the construction of the actual instrument and the tests in the laboratory and telescope.

II. DESIGN

As we mention above, the spectrograph is of the off-plane Ebert-Fastie type (Ebert 1989; Fastie 1952; Welford 1964), chosen because of its simplicity and that it produces images of good optical quality (Furenlid et al. 1988). This design includes basically a paraboloidal mirror of 300 mm diameter and a plane grating (Figure 1). The spectrograph is fed by a ten meter fiber bundle with circular configuration in the input at the exit of the telescope and a linear array in the output, that acts as the entrance slit of the spectrograph. Because of the symmetric arrangement of the entrance slit and detector, the magnification is unity. The slit and detector are opposite to each other with respect to the optical axis of the paraboloidal mirror at 103 mm from the axis and both are 1000 mm from the vertex of the mirror. The plane grating is placed at 850 mm from the paraboloidal mirror. This mirror eliminates spherical aberration and produces images on axis virtually free from point aberrations. Placing the grating at the above mentioned position produce practically (Mielenz 1964) a field free of curvature along the dispersion for the size of our CCD (8 x 16 mm) and bigger. It should be mentioned that other fiber can be used, with the only restriction that an f/8 beam should be provided to the spectrograph.

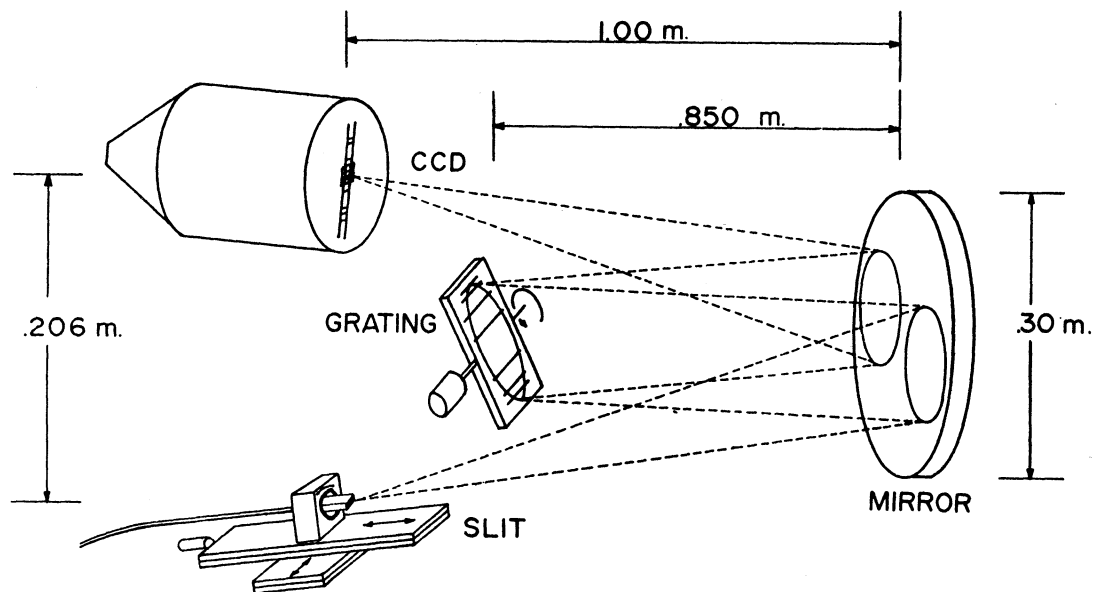


Figure 1.- The design of the spectrograph.

II. CONSTRUCTION

We constructed two paraboloidal mirrors with 300 mm diameter and focal length of 1000 mm. The support structure and the box for isolation and protection were made of aluminum with dimension 1000 x 450 x 450 mm plus the external support to the aluminum box that holds the fiber head and the CCD detector, to surround all of the above we made a wooden box lined with terefoam. Around 200 mechanical pieces were made to hold the mountings, to support the main mirror cell and the movements of the grating and the fiber head, together with four cells for the gratings and the mounting of the grating cells (see Figures 2 and 3).

A connector-guider box (Figures 3 and 4) for the telescope was made to maintain the star image in the right position on the fiber bundle. The box is made of aluminum and carries two interchangeable motorized filter wheels of four made, with seven filters each. Inside the box has also a system of plane transparent plates and a mirror to set the star on the entrance of the fiber and to maintain it in position. In the same box we have the system to project the comparison (Th) and flat field lamps. Most of the functions of the spectrograph are remotely controlled. The electronics to control two step motors and four DC motors was constructed to move the gratings, the fiber head or focusing and for the filter wheels and mirrors to redirect the light of the lamps. We acquired commercially the gratings, the fiber bundle, the mirror cell, the movements of the gratings and fiber head support, and a hose to carry the fiber bundle from the connector-guider box to the spectrograph.

V. LABORATORY TESTS

Firstly the mechanical mountings were fitted to the gratings and paraboloidal mirror, the mirror was set in the center of the box and oriented in such a way to define the optical axis in the center of the box. The center of the grating was set to coincide with the optical axis at 850 mm from the mirror. The exit of the optical fiber bundle is the slit of the spectrograph, and was located at 103 mm from the optical axis, in the opposite side of the slit with respect to the optical axis and oriented with its longest side in direction perpendicular (direction of dispersion) to the plane defined by the

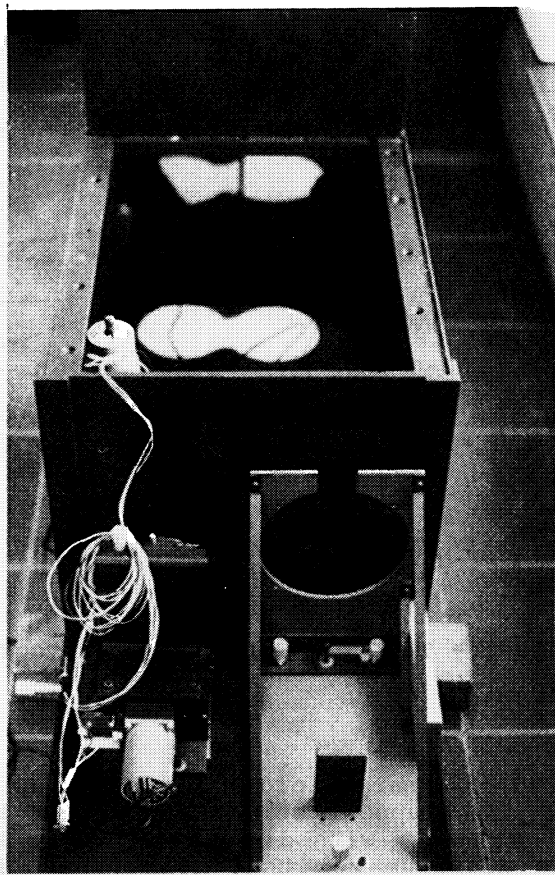


Figure 2.- General view of the spectrograph. The mirror is facing front.

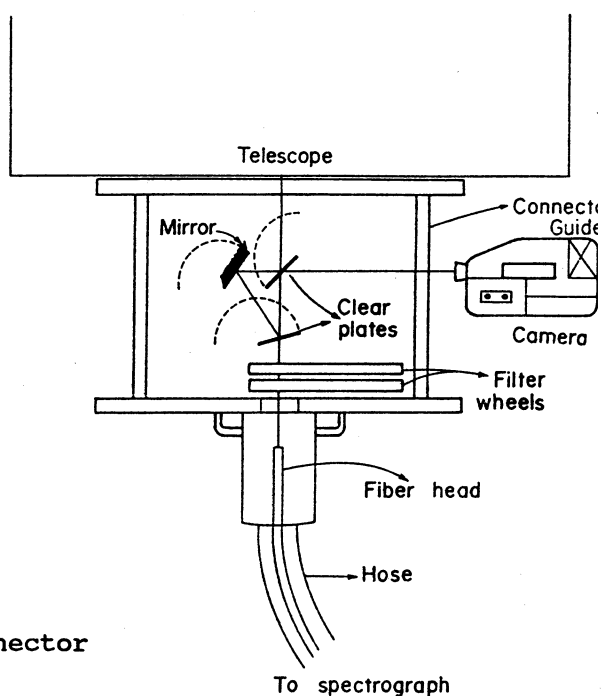


Figure 3.- A diagram of the connector guider of the fiber head.

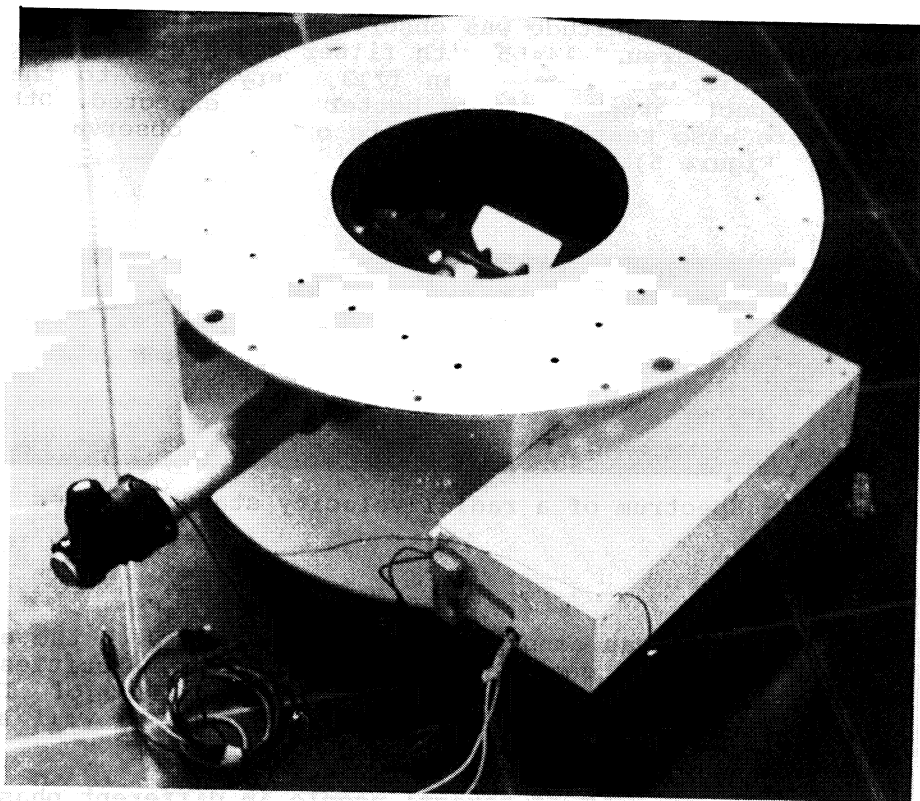


Figure 4.- A view of the connector guider with the comparison (Th) and flat field lamps.

slit, optical axis and detector (the meridional plane). The detector and slit were located at 1000 mm from the mirror. The grating in the zeroth order was rotated in the meridional plane until the image of the slit on the detector was in the center. The focusing is made with fine movements. With a sodium lamp and with an optical set up to send an $f/12$ beam we could prove that the plate factor for the 1200 l/mm grating is of 2.9 \AA/mm (Figure 5). The lines appear inclined (Welford 1964) and it is possible to correct for this effect by rotating the slit. The images were of very good quality as was predicted (slight veiling is noted in red side of the lines, we do not know exactly the reason).

7. TELESCOPE TESTS

A series of direct observational tests in the 1-m telescope of UNAM at Tonantzintla were carried out by L. Terranegra, J.M. Alcala and O. Cardona in January and February. For the first tests we used diffuse solar light and He-Ne lamps. The solar spectra obtained around $H\alpha$ are of very good quality compared with a high resolution solar atlas (Kurucz et al. 1984). Also we observed the stars Arcturus and Vega showing good image quality of the spectra. The $f/15$ telescope produces an f/∞ beam in the spectrograph that does not fill the corresponding half of the mirror, giving longer exposures than expected.

Other series of tests were also carried out in the 1-m telescope of San Diego State University at Mount Laguna Observatory from the 12 to 21 of September by I. Furenlid and J.M. Alcala. 30 late type radial velocity standard stars were observed with the 1200 l/mm grating, plus Vega and Alpha

Arietis. A star of the 6th magnitude was observed in 30 minutes with a signal to noise of 150, centered around $\lambda 4455$ with filter width of 1000 Å giving the expected efficiency. This telescope is an f/13, very close to the required f/12, therefore the spectrograph performs better than expected. Other fibers produced by I. F. were also tested. The results of these observations will be published elsewhere (Figure 5).

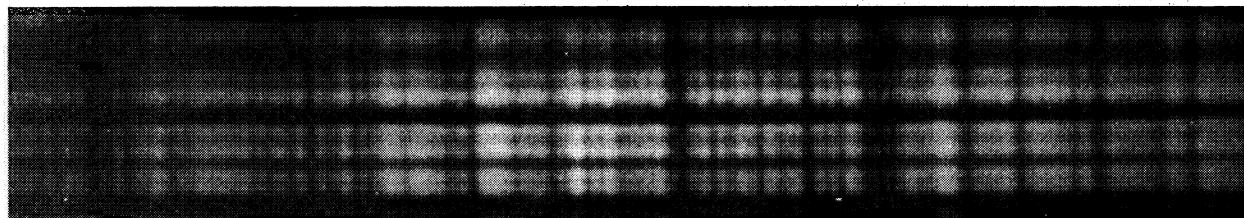


Figure 5.- Spectrum of a radial velocity standard star.

VI. CONCLUSIONS

The spectrograph was constructed in accordance with the efficiency and stability in the long range desired, to measure radial velocities of great precision as main objective in the telescope of 2.1-m of INAOE. We corroborated the quality of the design in the laboratory as well as in the direct observational work.

We appreciate the work of several people in different phases of the project. Jose Luis Ruiz in the mechanical construction of the whole spectrograph. The optical parts were made by S. Quechol y M.L. Tecuatl, Santiago Dominguez for the electronics design and construction and for observational work J.M. Alcala and L. Terranegra. We are also grateful to Universidad Nacional Autonoma de Mexico and to San Diego State University for allocation of time in their 1-m telescopes. The typing of Diana Azeneth is greatly appreciated.

BIBLIOGRAPHY

- Ebert, H. 1989, Wiedemann/sannanalen 38, 489.
 Fastie, W.G. 1952, J. Opt. Soc. Am. 42, 641.
 Furenlid, I. and Cardona, O. 1988, Publ. Astron. Soc. Pac. 100, 1001.
 Kurucz, R., Furenlid, I., Brault, J., Testermann, L. 1984, Solar Flux Atlas from 296 to 1300 nm, National Solar Observatory.
 Mielenz, K.D. 1964, J. Res. Nat. Bur. Stand., Vol. 686, Vol. 4, 205.
 Welford, W.J. 1965, Progress in Optics, Vol. IV, ED. E. Wilf, North-Holland Pub. Co., Amsterdam p.p. 241.

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