APPLIED PHOTOPHYSICS LTD.

Fast Grating Spectrograph

The optical design of this precision grating spectrograph is based on the asymmetric Czerny-Turner optical configuration employing all reflecting optics. This provides exceptional performance for spectral measurements in the 200-900 nm range.

Computer-optimisation techniques have been employed to minimise aberrations as well as to produce an extremely flat field over a large image area (62 x 6 mm).

Manual wavelength scanning is provided with a digital readout of the central wavelength of the spectral display. The spectral coverage occurs in overlapping steps of 92, 185 or 370 nm depending on the grating. Precision variable slits are fitted as standard and provide a resolution of better than 0.3 nm with a 1200 grooves/mm diffraction grating.

A detachable film-back is fitted which holds either Polaroid or cut film but any light detector, including photodiode arrays and vidicon tubes can also be used. Simultaneous spectral analysis of up to 50 separate wavelengths is possible using fibre optic light guides and separate detectors.

A flexible UV and visible light-transmitting light guide is available to collect light from a remote source and direct this to the entrance slit of the spectrograph. Since the instrument is a very sensitive and portable spectral analyser, it can be readily taken to the site of an experiment and used to record required spectra. The spectra of diverse transient events, such as firefly luminescence or an electrical discharge can be recorded often with a certainty that a single shot is sufficient. Further spectra can be taken in seconds, the time required to move the camera back to a new position. Other applications include solar radiation monitoring, picosecond and laser techniques (e.g. wavelength determination), dermatology, analytical chemistry, transient luminescence phenomena, lighting research, colour measurements and quality control in numerous industrial processes.

SPECIFICATIONS

Optical design

The instrument is based on the asymmetric Czerny-Turner optical configuration employing coated and all-reflecting optics. The resolution of conventional high aperture spectrographs of this type is limited by aberrations introduced by an optical layout using optical components off-axis. By using computer-optimisation techniques, the off-axis aberrations have been reduced in a manner consistent with the elimination of multiple diffracted light at all wavelengths. The most significant off-axis aberration, coma, has been eliminated for the plate centre at 450 nm and consequently reduced for the remaining spectral range over the entire image area. The position of the diffraction grating has been optimised to give an extremely flat field over the entire image area of 62 x 6 mm (without vignetting) and hence sharp imaging over the spectral display.

Spectral range

200 to 900nm.

Spectral coverage

370 nm with 600 grooves/mm grating. 185 and 92.5 nm with 1200 and 2400 grooves/mm gratings, respectively.

Diffraction gratings

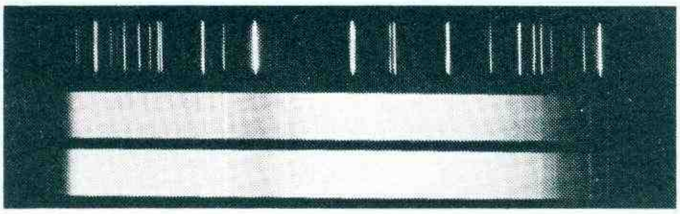
Standard grating fitted has 600 grooves/mm and is blazed at 300 nm. 25 mm ruled area. Other gratings available are as follows:–

Grating type	Blaze wavelength (nm)	Model
Holographic	250 (peak efficiency)	9005
Ruled, 600 grooves/mm	500	9015
Ruled, 1200 grooves/mm	300	9020
Ruled, 1200 grooves/mm	500	9025
Ruled, 2400 grooves/mm	300	9030
Ruled, 2400 grooves/mm	500	9035

The grating mount is specially designed to allow easy interchange of diffraction gratings without loss of optical alignment. The holographic grating is best used for studies below 350 nm or where stray light could be a problem. A grating with a 300 nm blaze has a useful working range from 200 to 600 nm and with a 500 nm blaze from 330 to 900 nm. The instrument will accommodate larger gratings (up to 50 mm square) but a grating mask must be used to restrict the usable area to 25 x 25 mm.

Wavelength scanning

The grating mount forms part of a precision sine drive controlled through a lead screw by an external knob. Rotation of this knob moves the spectral band of interest and the central wavelength of this band is displayed in nm on a three-digit readout. The scanning is accurate and reproducible to 1 nm.



Typical spectral trace showing the emission spectrum of a xenon flash lamp with reference spectral lines from a Hg-Ne spectral lamp.

Entrance slit

Spectral lines recorded are a 1.5 times magnified image of the entrance slit and considerable care is taken to fit straight, parallel slit blades. Bilateral, stainless-steel blades are fitted and the slit width (in 1/100 ths of a millimetre) is displayed on a connecting multiturn dial. The slit width is adjustable from 0.04 to 3 mm. The dispersion at the photographic plate is 6.0 nm/mm (nominally) with a 600 grooves/mm grating (3.0 nm/mm with a 1200 grooves/mm grating).

Entrance shutter

A camera shutter with a remote control lead is fitted as standard. Exposure times are 1/25 and 1/75 s and manual control (B).

Photographic film-back

A Polaroid film-back accommodating either flat-pack Polaroid film or conventional cut-film is fitted. The film-back has a precise racking mechanism allowing eight equally-spaced exposures to be placed on each film. An indexing number is provided on the body of the spectrograph.

Image area

An image area of 62 x 6 mm is produced at the film-back position. The field is flat to ± 0.5 mm and no vignetting is apparent. The maximum image area is 93 X 6 mm (with vignetting).

Mechanical construction

The optical system is mounted on a rigid U-frame assembly with a detachable sheet metal cover. The two parts are firmly secured together to avoid light leaks.

Size

33 x 30 x18 cm (WDH)

Weight

8 kg.

ACCESSORIES

Light guide

A flexible, 1 m length, 5 mm active diameter light guide which will transmit UV and visible radiation to at least 280 nm is available with optical fittings to match the spectrograph entrance aperture. This allows the spectrograph to collect light from remote or inaccessible locations (model 9050).

Spectral lamp

Low pressure mercury-neon lamp, 4 W rating for spectral calibration purposes. 240 V operation. Model 9055.

Image area plate

The film-back is detachable and may be replaced by a light-tight metal plate covering the whole image area. Virtually any electro-optic detector including separate photomultiplier tubes, photodiode arrays, vidicon detectors, CCD cameras etc. can be mounted to this plate for electro-optic studies in place of photographic film. Up to 50 separate light guides or individual fibre optics can also be attached to the image area plate for subsequent connection to individual detectors. Simultaneous spectral analysis at a number of pre-selected wavelengths is thus possible. If necessary, our engineering staff would be pleased to attach any detector to this plate at a nominal cost. Image area plate, model 9060.

RELATED EQUIPMENT

Leaflets are available describing our range of glass and plastic fibre optic light guides, an f/3.4 grating monochromator and stepping motor control unit, optical interference and bandpass filters, and high intensity xenon and mercury light sources.

APPLIED PHOTOPHYSICS LTD
20 Albemarle Street,
London W1X 3HA, England

Telephone: 01-493 4194
Telex: 263641 (Photon G)
Cables: Photophys, LDN W1

JOURNAL OF THE OPTICAL SOCIETY OF AMERICA VOLUME 59, NUMBER 9 SEPTEMBER 1969

Optimizing Czerny–Turner Spectrographs: A Comparison between Analytic Theory and Ray Tracing

JOSEPH READER
National Bureau of Standards, Washington, D. C. 20234

(Received 13 March 1969)

The analytic theory of aberrations has been used to derive an expression for the magnitude of the coma width of the image in the meridional plane in a Czerny–Turner spectrograph with unequal mirror radii. The calculated properties of a 4-m spectrograph with equal radii and a recently constructed 3.34-m spectrograph with unequal radii are compared with the results obtained by tracing individual rays. The agreement is excellent, in contrast to the results of Chandler [J. Opt. Soc. Am. 58, 895 (1968)]. The lateral position of the grating for complete elimination of coma found experimentally with the 3.34-m instrument is in fair agreement with the theory. A correction to the $\sqrt{3}$ longitudinal grating position is given for a Czerny–Turner spectrograph which results in a flatter focal surface.

INDEX HEADINGS: Aberrations; Geometrical optics; Grating; Ray tracing; Spectrograph.

The design of plane-grating spectrographs has undergone considerable development since Czerny and Turner's demonstration of the superiority of a two-mirror system over a one-mirror system.[1] In general, the design problem may be summarized by the question: Where should the grating be placed in a two-mirror spectrograph so that the aberrations in the final slit images will be minimized and so that the final focal surface will be as flat as possible? In the past, most workers have dealt with this problem by applying classical geometrical optics. More recently Chandler[2] used a high-speed computer to trace a number of rays through a 4-m focal-length system to determine the image quality, and by iteration determined the optimum lateral position of the grating. The optimum position found by Chandler was significantly different from the position calculated from the known analytical expressions.

At the time Chandler's paper was published I was aligning a newly constructed 3.34-m Czerny–Turner spectrograph designed for minimum coma according to analytic theory, and I was stimulated to look into this reported difference between the analytic theory and ray tracing. In the present paper, the results of this investigation are given. The results disagree with those of Chandler. Some brief extensions of the theory will also be given, as well as the calculated characteristics of the 3.34-m Czerny–Turner spectrograph, now in use in our laboratory.

CALCULATIONS

Coma Width of Image

We present here a calculation of the image width in the meridional plane in a two-mirror plane-grating spectrograph with mirror radii R_1 and R_2. This is an extension of the work of Shafer, Megill, and Droppleman.[3] We first calculate the angular aberration in the parallel beam generated by the collimating mirror. Following Shafer, Megill, and Droppleman, we start with Beutler's[4] light-path function for a spherical mirror reduced to two dimensions. To terms of order w^3/r^2, the light-path function F for rays travelling from an object point at r to an image point at r' is

$$F=r+r'-w(\sin\alpha+\sin\alpha')$$
$$+\frac{w^2}{2}\left[\left(\frac{\cos^2\alpha}{r}-\frac{\cos\alpha}{R_1}\right)+\left(\frac{\cos^2\alpha'}{r'}-\frac{\cos\alpha'}{R_1}\right)\right]$$
$$+\tfrac{1}{2}w^3\left[\frac{\sin\alpha}{r}\left(\frac{\cos^2\alpha}{r}-\frac{\cos\alpha}{R_1}\right)+\frac{\sin\alpha'}{r'}\left(\frac{\cos^2\alpha'}{r'}-\frac{\cos\alpha'}{R_1}\right)\right].$$

The symbols are explained in Fig. 1. If we express F in terms of w', the perpendicular distance to the principal ray, according to $w=w'/\cos\alpha'$ and apply Fermat's principle with $r'=\infty$ to indicate a plane wave after reflection, we have

$$\frac{\partial F}{\partial w'}(\text{for } r'=\infty)=-\frac{1}{\cos\alpha'}(\sin\alpha+\sin\alpha')$$
$$+\frac{w'}{\cos^2\alpha'}\left[\frac{\cos^2\alpha}{r}-\frac{\cos\alpha}{R_1}-\frac{\cos\alpha'}{R_1}\right]$$
$$+\frac{3w'^2}{2\cos^3\alpha'}\left[\frac{\sin\alpha}{r}\left(\frac{\cos^2\alpha}{r}-\frac{\cos\alpha}{R_1}\right)\right]\overset{?}{=}0.$$

The first term is made zero by letting $\alpha'=-\alpha$, which is just the usual law of reflection. The linear term in w' is made zero by letting $r=\frac{1}{2}R_1\cos\alpha$, which is the well-known meridional focal distance for off-axis points. The quadratic term in w' contains no other parameters which may be varied and thus represents the residual two-dimensional aberration referred to as coma. Evaluating this for an aperture corresponding to the projected

---

[1] M. Czerny and A. F. Turner, Z. Physik **61**, 792 (1930).

[2] G. Chandler, J. Opt. Soc. Am. **58**, 895 (1968).

[3] A. Shafer, L. Megill, and L. Droppleman, J. Opt. Soc. Am. **54**, 879 (1964).

[4] H. G. Beutler, J. Opt. Soc. Am. **35**, 311 (1945).