SIMULATION AND ANALYSIS OF CZERNY TURNER MONOCHROMATOR FOR MEDICAL IMAGING

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Abstract - Spectral resolution is the important aspect in determining the image quality. This is obtained by adjusting the monochromators like Czerny turners, thereby achieving the required image quality. This turner has advantages like flexible focal length imaging, minimizes the image aberrations, astigmatism etc. This paper focuses on the simulation of Czerny turner using COMSOL Multiphysics modeling software and analysis of its corresponding results for different spectral ranges and numerical aperture values. These results help to understand the optical interfaces and positioning of incident rays on the detector, from which the instrument spectral resolution can be derived.

Keywords - COMSO Multiphysics, Czerny-Turner, Imagining, Monochromator.

I. INTRODUCTION

It is possible to determine the wavelength calibration as well as the spectral resolution of the instrument for the given optical component arrangement and its corresponding detector properties. One such device that is widely used in many imaging instruments is the Czerny turner as represented in the figure 1. This turner has significant importance in medical imaging and diagnostic instruments as it provides good multitrack spectroscopy capabilities, good sample image and is considered as the basis for many imaging spectrometer optical layouts.

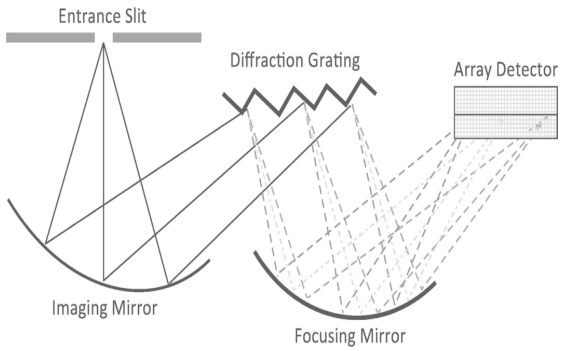


Fig. 1: Czerny-Turner monochromator structure.

II. THEORY OF OPERATION

Czerny turner spatially separates polychromatic light into a series of monochromatic rays. This consists of a slit source, a spherical collimating mirror, a planar diffraction grating, a spherical imagining mirror and an array charge coupled device (CCD) detector as shown in the figure 3. The rays are released from the front focal point of the collimating mirror. This is titled with an angle θc to direct the light towards the grating. Then the diffraction rays are directed towards the focusing mirror, where rays of different frequencies arrive at this mirror. These rays are positioned in different places and are with different angles of incidence.

II. MODEL DESIGN

A Czerny turner monochromator is designed using COMSOL Multiphysics modelling, simulation and analysis software V 5.3. Ray optics module is used from the model library. This is designed with F number greater than three to avoid large aberrations of the image at the detector. In this model, the polychromatic light source releases rays with F number equal to ten. Here the rectangle bounded by x = 0, x = 40 mm, y = −32 mm, and y = −15 mm is chosen because it encloses the CCD as shown in the figure 2.

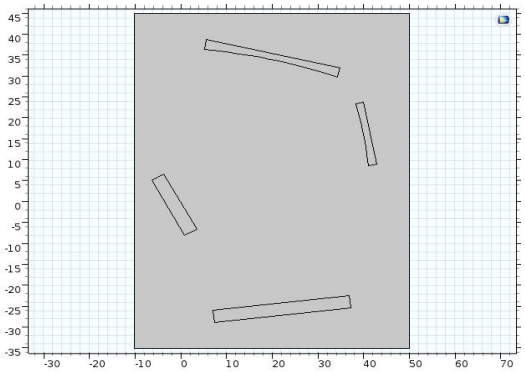


Fig. 2: Typical crossed Czerny-Turner configuration.

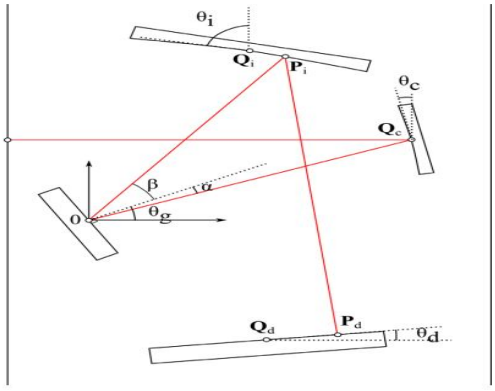


Fig. 3: Typical crossed Czerny-Turner configuration.

Table .1: Definition of the design parameters.

PARAMETERS	VALUE	DESCRIPTION
θg (deg)	28.76	Grating's angle
θc (deg)	11.0	Collimating mirror's angle
θi (deg)	77	Imaging mirror's angle
θd (deg)	6.76	Detector's angle
Qi (mm)	(20.0, 34.0)	Coordinates, imaging mirror
Qc (mm)	(40, 16.161)	Coordinates, collimating mirror
Qd (mm)	(22.08, -24.12)	Coordinates, detector
Ri (mm)	130	Radius of curvature, imaging mirror
Rc (mm)	100	Radius of curvature, collimating mirror

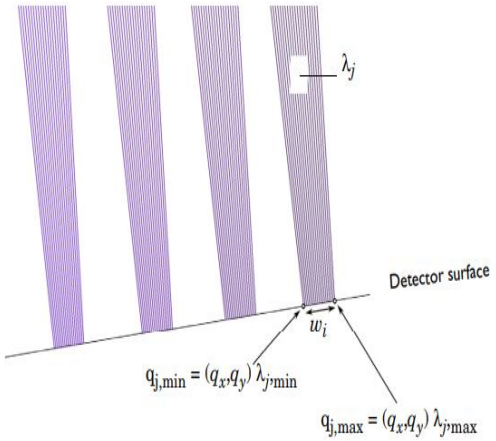


Fig. 4: Determination of the image width for a given wavelength.

The knowledge of the image width on the detector is given by the distance between the two rays delimiting a pencil of rays of uniform wavelength on the detector. Figure 4 represents how this distance is evaluated.

Table .2: Definition of the design parameters.

Name	Expression	Value	Description
lam	600[nm]	6E-7 m	Beam mean wavelength
N	3648	3648	Number of pixels
wp	8[um]	8E-6 m	Pixel width
Fnum	10	10	F-number
NA	1/(2*Fnum)	0.05	Numerical aperture
Srange	650[nm]	6.5E-7 m	Spectral range

III. SIMULATION & RESULTS

Simulation are carried out for the designed model, for about twenty frequency values, that are sampled from a uniform distribution. Where the corresponding free space wavelength distribution has a minimum of 451 nm and a maximum of 894 nm.

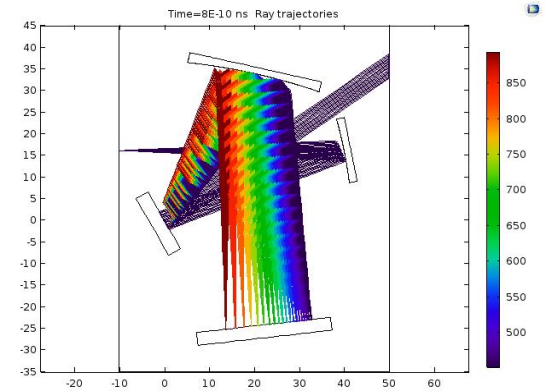


Fig. 5: Wavelength separation on the CCD detector for 8□m pixel width.

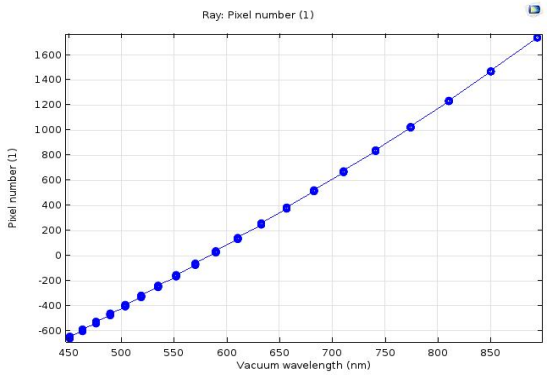


Fig. 6: Wavelength calibration.

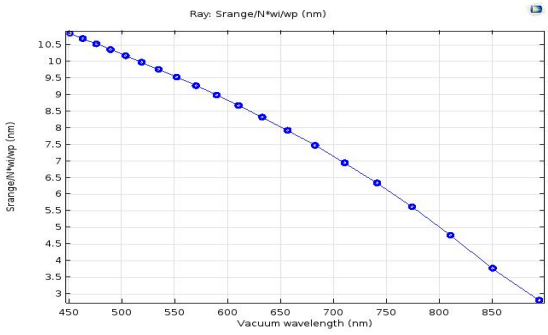


Fig. 7: Spectral resolution as a function of the wavelength.

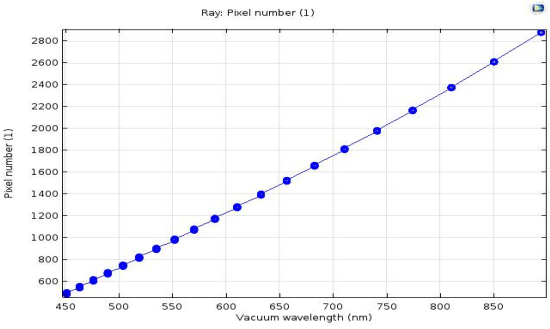


Fig. 8: Wavelength calibration for base model.

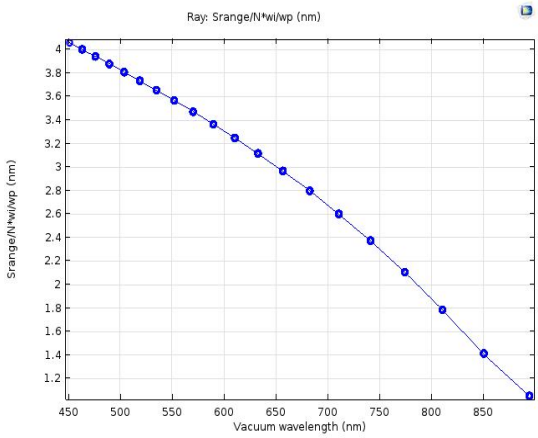


Fig. 9: Spectral resolution as a function of the wavelength for base model.

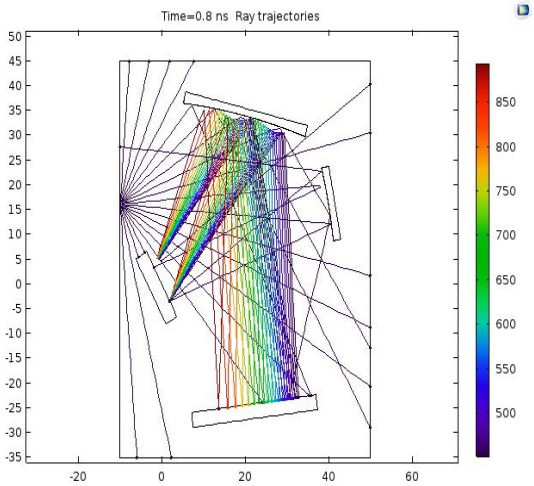


Fig. 10: Wavelength separation on the CCD detector for 4□m pixel width.

IV. ANALYSIS

Czerny turner is modeled for different numerical aperture values like 0.05, 0.1, 0.5, 1, 1.5 respectively. Figures 6, 7 represents the wavelength calibration and spectral resolution for the numerical aperture value 1 and figure 8, 9 represents the wavelength calibration and spectral resolution for the numerical aperture value 0.05 respectively. Whereas figure 10 represents the wavelength separation for the pixel width 4□m, when the numerical aperture value is 1.

In this case, as the pixel width is decreased, the detector is not capable of creating complete photon wells. On the other hand, figure 11 represents the wavelength calibration for numerical aperture 1 and pixel width 7□m. In this case, the pixel number is increased but the calibration is not liner.

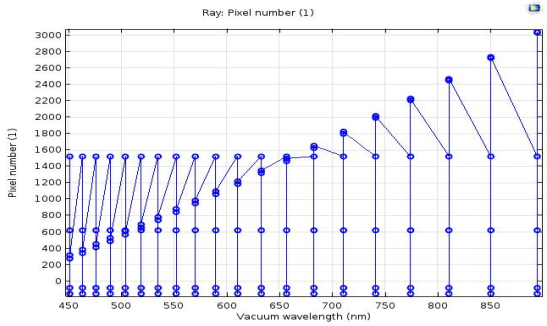


Fig. 11: Wavelength separation on the CCD detector for 7□m pixel width.

CONCLUSION

Czerny turner is simulated and analyzed for various key optical parameters using COMSOL Multiphysics software. Results help to properly choose the design parameters before manufacturing these devices and mainly helps to understand the ray optics and spectrum observed at the detector. By carefully choosing the parameters like pixel width, numerical aperture, spectral range, grating angles etc., helps to easily design the instrument and thereby resulting in determination of spectral resolution. This study helps to understand various aspects of the Czerny turner as it shows advantages like low stray light, simplicity, high F number, flat efficiency curve, aberration correction etc., and is widely used in optical instruments, especially in medical industry.

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