Adjustable High-Resolution Spectrograph Design for Celestron CPC Series Telescopes: An Engineering Approach

M Viveganandam[1,2*], J Adassuriya[2], K P S C Jayaratne[2]

[1] Department of Mechanical Engineering, The Open University of Sri Lanka
[2] Astronomy and Space Science Unit, Department of Physics, University of Colombo, Sri Lanka
janaka@phys.cmb.ac.lk

Abstract. Spectroscopy is crucial in astronomy, offering a deeper understanding of celestial bodies by dissecting light into its component wavelengths. High-resolution spectrographs reveal the intricate characteristics of atoms and molecules within celestial objects. Integrating standard spectrographs with alt-azimuth mount telescopes poses mechanical coupling challenges due to limited space between the telescope and the mount. This paper details the design and construction of a compact, high-resolution spectrograph for the Celestron CPC series telescopes, specifically the CPC 800, CPC 925, and CPC 1100 models. The spectrograph is engineered to fit each telescope's parameters, such as aperture size (8", 9.25", and 11") and focal length (2032 mm, 2350 mm, and 2800 mm, respectively), ensuring compatibility with their optical specifications. A custom-designed mounting system, developed through advanced mechanical engineering principles, ensures precise alignment and stability, accommodating various focal lengths and optical configurations. Key features include an adjustable slit mechanism, collimating mirror, diffraction grating, and focusing lenses and CCD camera. This design facilitates easy adjustment across different CPC telescopes without compromising performance. The research employs mechanical design principles and manufacturing processes to ensure precision and reliability for telescope balance. This pioneering work in adjustable spectrographs for CPC telescopes enhances observational capabilities, providing a valuable tool for education and research with broad marketability.

Keywords: Spectrograph, Telescopes, Mechanical Design, Alt-azimuth Mount, CPC Series.

1 Introduction

1.1 Background

Spectrographs are fundamental analytical tools in astronomy, used to analyze the properties of light emitted from celestial objects. Typically, spectrographs are attached to telescopes, which capture incoming light from stellar objects and direct it to the spectrograph. The spectrograph then splits this light into a spectrum according to its constituent wavelengths or frequencies, allowing astronomers to record the resulting spectrum and study the properties of distant cosmic bodies. High-resolution spectrographs are especially important for revealing the intricate properties of molecules and atoms present in these celestial objects [1].

1.2 Development and Optimization of a New Spectrograph

Traditional fiber-fed spectrographs are effective with telescopes that have equatorial mounts and focal arrangements like the Cassegrain focus [5]. However, they cannot be easily attached to telescopes with Alt-Azimuth mounts, because of limited space between the telescope and the mount. This limited space (Fig.1) does not enough to couple even a compact designed spectrograph posing a significant challenge for astronomers using the small scale Alt-Azimuth telescopes for spectroscopy.

To address this issue and provide astronomers with a powerful tool for studying stellar phenomena using compact telescopes, this research focuses on developing a new, compact high-resolution spectrograph specifically designed for the Celestron CPC series, including the CPC 800, CPC 925, and CPC 1100 models. The spectrograph is engineered to fit precisely according to each telescope's parameters, such as aperture size (8", 9.25", and 11") and focal length (2032 mm, 2350 mm, and 2800 mm, respectively). The primary aim of this project to first design and optimize the spectrograph for the 11-inch model and then create a universal design that can be applied to all CPC series telescopes.

Fig. 1. Light path layout for CPC1100

The development process involves meticulous design and optimization of the optical system using software Solidworks to ensure precise alignment and compatibility with the telescopes. This step is crucial for overcoming the unique challenges posed by Alt-Azimuth mounts and Cassegrain focal arrangements, enabling seamless integration of the spectrograph with the telescope. As shown in figure 1, the gap between the telescope and the mount differs in all three models of telescopes. The smallest gap is 124 mm for the CPC 800, and the largest is 182 mm for the CPC 925, as both the CPC 925 and CPC 1100 have the same mount. Using the gap measurements, the general spectrograph design for all three CPC telescopes is being proceeded.

2 Objectives

- Design and optimize the optical system.
- Determine the suitable collimator mirror, grating and diffraction angle.
- Construct the spectrograph and design coupling mechanism
- Determine stellar parameters of various stellar objects.

3 Methodology

- Design and optimize the optical system for a small 11-inch telescope using Solidworks, focusing on integration with the spectrograph.
- Employ mechanical design principles to develop coupling mechanisms for integrating the spectrograph with Cassegrain telescopes.
- Optimize fabrication techniques to ensure high precision and reliability, taking into account material selection and manufacturing processes.

4 Calculations

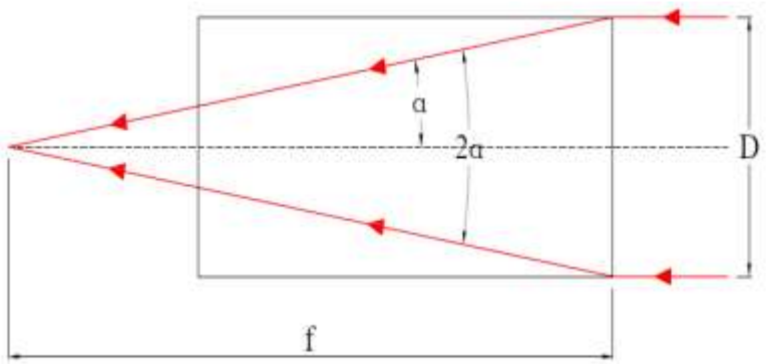

Fig. 2. General light path diagram of CPC telescopes

$$\text{f number} = \frac{f}{D} = 10$$

$$\tan = \frac{D/2}{f} = \frac{D}{2f} = \frac{1}{2}\left(\frac{D}{f}\right)$$

From the f number is given as 10 for the all three type of telescope [2], we could find the tan α remains the same for all three telescopes. Therefore, the focal point of all the types of CPC series telescopes.

The present study started the design for the CPC1100 as the Astronomical and space science unit of University of Colombo has one. We manually measured the focal length by focusing the telescopes to a distant object. From the above calculator we concluded the focal point of all the types of CPC series telescopes. The manually measured focal length was 8mm from the outer edge of the telescope.

The steps followed in the design process included modifying the star diagonal using a plane mirror for 90° light bending and positioning the slit accurately at the bent light's focal point. The collimator mirror was chosen, taking into account the beam diameter and the optical tube diameter. Using the focal point of 80mm from the telescope's outer edge as a starting point, the other dimensions required for the design were finalized.

4.1 Collimator Mirror Calculation

Fig. 3. Optical tube of CPC 1100

Here,

D out, optical tube = 312 mm

Slit distance from central axis = 62.9 mm

At 156 mm,

Distance from the slit = 93.1 mm

The formed light cone diameter = 13.33 mm

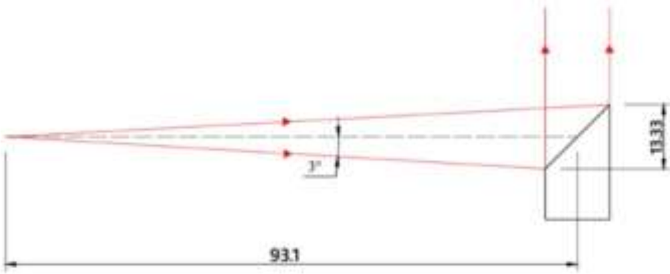

Fig. 4. Minimum size of collimator mirror needed

Considering the beam diameter and the length at the outer surface of the optical tube, a collimator mirror with a focal length of 101.4 mm and a diameter of 25.4 mm was selected which was available in the market [6].

As shown in the Fig. 5, the design was done using AutoCAD using the findings and it resulted in a parallel beam from the collimator mirror that was 10.7 mm diameter. That was quite small to achieve the high resolution spectrum as the light beam size is proportional to the resolution [4]. Also the design cannot be modified to the other CPC series telescope as it was challenging the do adjustments with the optical components alignment. Therefore, the CONCAVE LENS was introduced to the design.

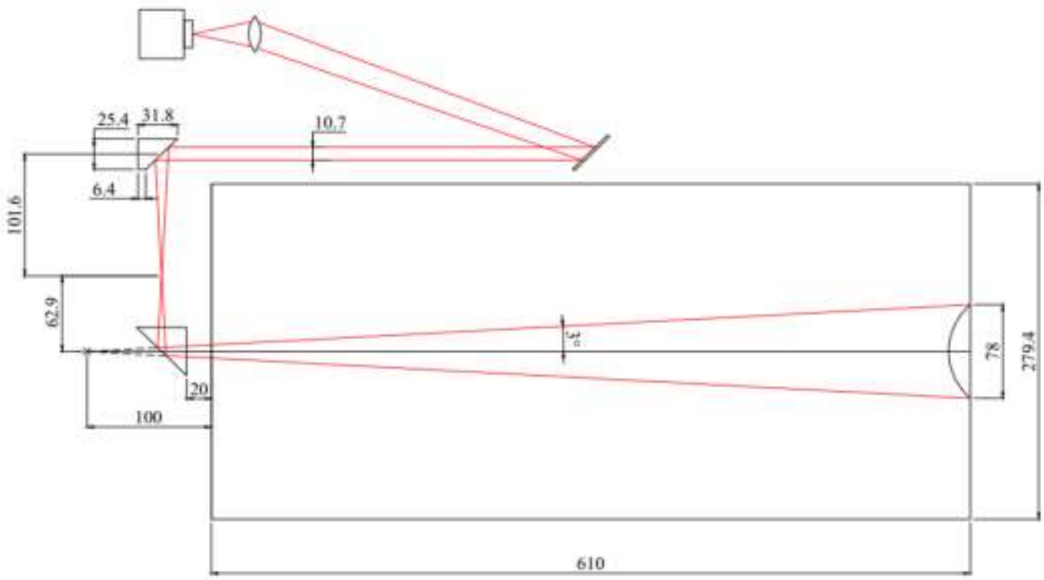

Fig. 5. General light path diagram of CPC telescopes

4.3 Concave Lens Calculation

Concave lens was selected as follows.

f = 25 mm

u = 46.6 mm

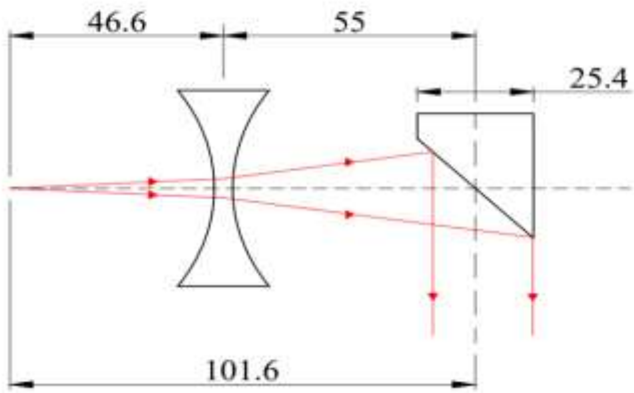

Fig. 6. Light path diagram for concave lens selection

Using lens equation, v = 16.27 mm

4.4 Grating Calculation

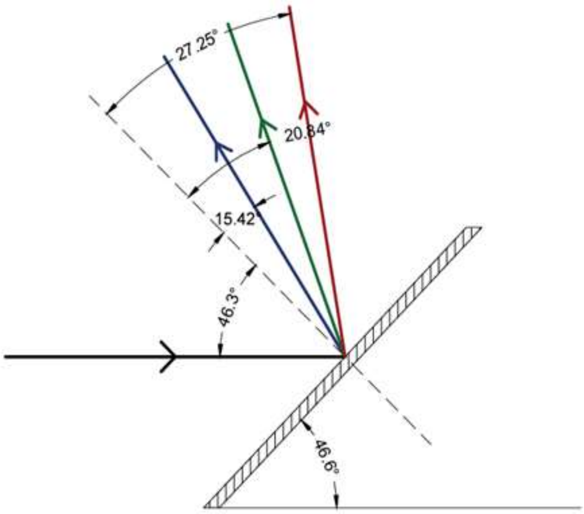

Fig 7. Light path diagram of grating

Choosing a diffraction angle:

α – incident angle on the grating

β – diffracted angle

m = 1

g = 600 lines/mm

Centre of the visible region (color green, λ_g = 5500 A°) was chosen as the reference wavelength.

$$\alpha + \beta = 90°$$

$$m\, \lambda_g = d\,(\sin\alpha + \sin\beta)$$

$$1\times(550\times10^{-9}) = (1.667\times10^{-6})\times[\sin 43.3° + \sin\beta]$$

$$\alpha_g = 43.30°$$

$$\beta_g = 20.84°$$

As illustrated in Fig.7, the minimum diffracted angle for blue light is 15.42°, and the maximum diffracted angle for red light is 27.25° for the first-order diffraction of the grating

5 Results and Discussion

Despite the challenge of not having exact internal component dimensions, we determined the telescope's focal point by assessing its outer dimensions, which allowed us to progress with our design. To achieve the desired light path, we introduced modifications to the star diagonal, incorporating a plane mirror to facilitate a 90° light deflection within the setup. Subsequently, the slit was accurately positioned at the focal point. The collimator mirror was carefully selected, considering parameters such as beam diameter and optical tube diameter, since the spectrograph is intended to be mounted atop the telescope. Using the focal point of 80mm from the telescope's outer edge as a starting point, the other dimensions required for the design were finalized.

Specifically, the modified star diagonal with the plane mirror was positioned 20mm from the outer edge of the telescope. As depicted in the Fig. 8, the beam was bent 90° and focused vertically on a slit at a distance of 61.7mm from the axis. To increase the resultant size of the light beam, a concave lens was placed at a distance of 13.3mm from the slit for the CPC1100 telescope. The focal point of the lens was determined using the lens equation.

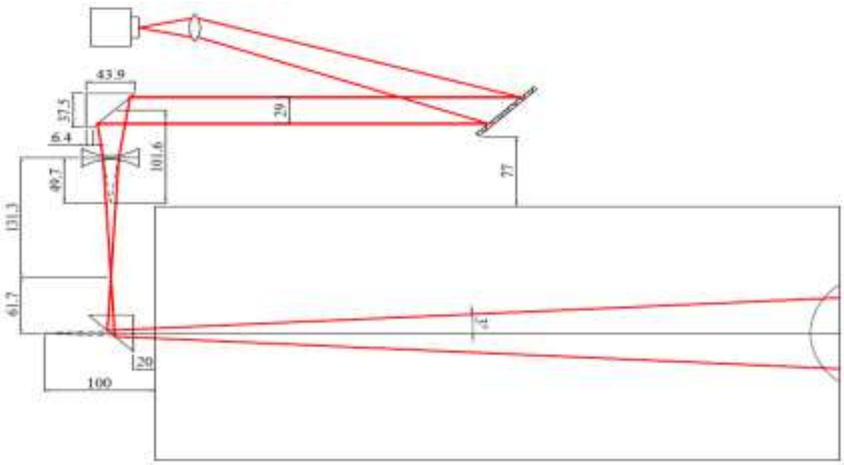

Fig. 8. Light path layout for CPC1100

Considering the beam diameter and the length at the outer surface of the optical tube, a collimator mirror with a focal length of 101.6mm and a diameter of 37.5mm was selected. This choice ensures the production of a parallel beam measuring 21.8mm in size. Consequently, an ideal 50 x 50 grating will be suitable for this design.

Embedding a concave lens is beneficial for obtaining a larger beam to the grating from the collimator mirror, resulting in higher resolution of the resulting spectrum. Additionally, we can adjust the lens placement to make suitable changes in the design for other two CPC series telescopes (CPC 925 and CPC 800).

A universal spectrograph design for all three CPC series telescopes is achieved by introducing a concave lens to the design, with minor adjustments. As shown in Fig.9, the spectrograph design for the CPC800 was drawn and proved to produce a diameter of the light beam from the collimator of 37mm by changing the placement of the concave lens. Similarly, for the CPC925, a 29mm diameter light beam was obtained by adjusting the design by 22mm which is shown in Fig.10. This demonstrates how the universal spectrograph design for all three telescopes was achieved.

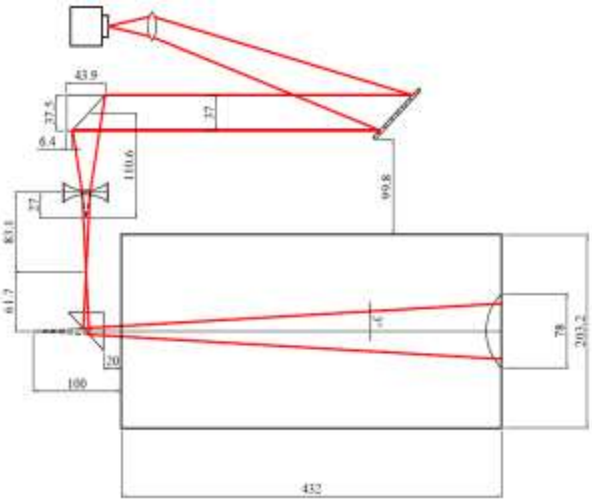

Fig. 9. Light path layout for CPC800

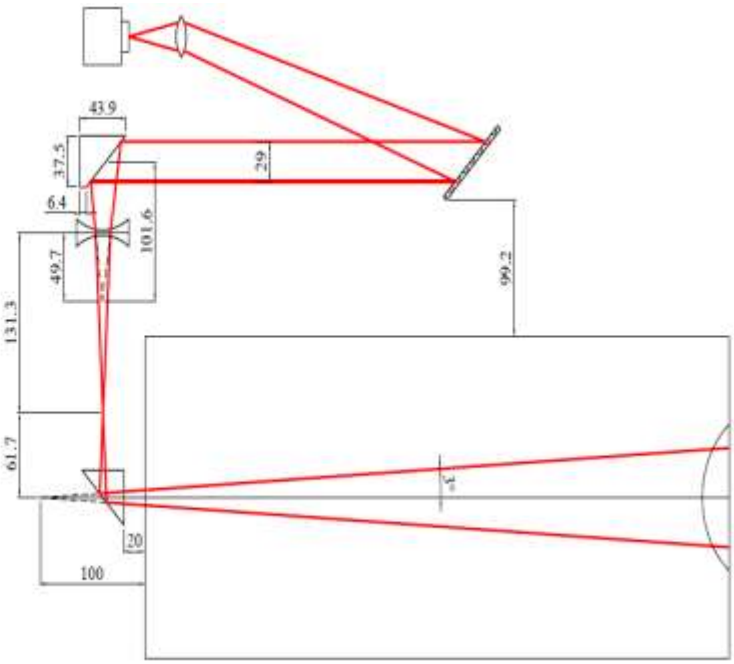

Fig. 10. Light path layout for CPC925

Based on the size and dimensions of the selected optical components, a comprehensive CAD design was created using Solidworks. Fig.11 illustrates a compact spectrograph with all necessary components integrated for seamless mounting onto the telescope. The engineering drawing of the spectrograph is depicted in Fig.12.

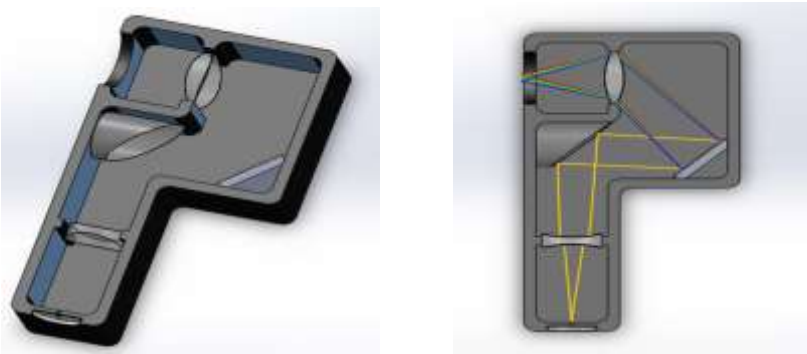

Fig. 11. CAD of the Spectrograph

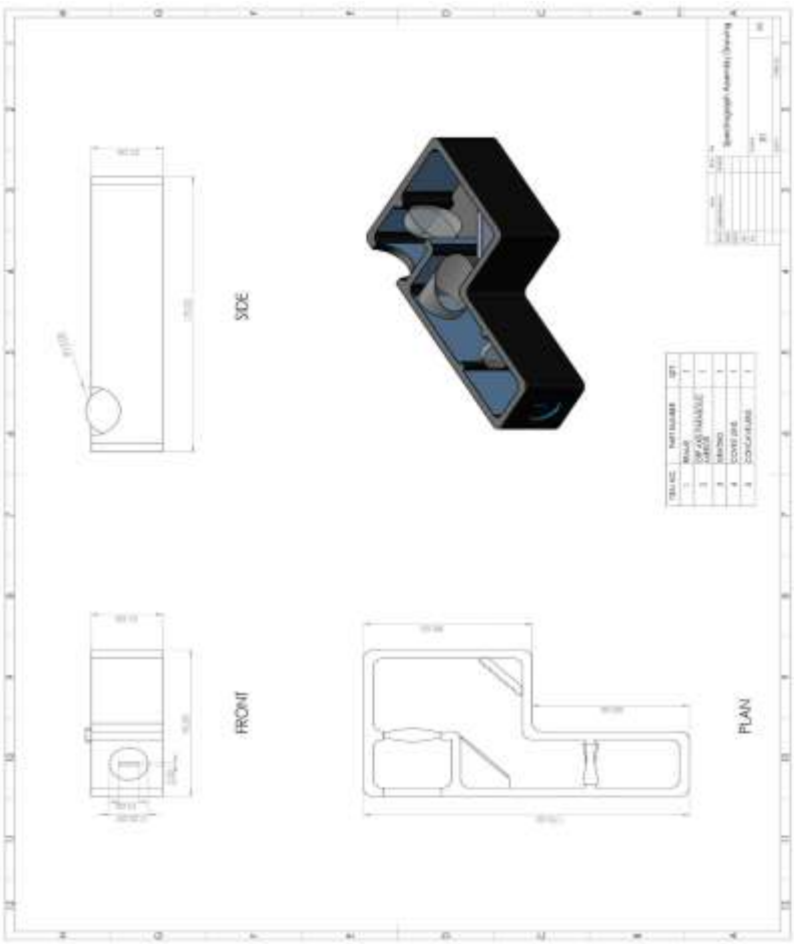

Fig. 12. 2D Drawing of Spectrograph

6 Conclusion

The research has made significant progress in developing the light path layout and CAD design for the spectrograph. Despite the initial challenges posed by the lack of exact internal component dimensions, we successfully developed an innovative light path layout for the spectrograph. By determining the telescope's focal point through its outer dimensions, we were able to advance our design effectively.

The modifications introduced to the star diagonal, including the incorporation of a plane mirror for 90° light reflections, and the precise positioning of the slit at the focal point, were key steps in achieving the desired light path. The careful selection of the collimator mirror, based on beam diameter and optical tube diameter, ensured compatibility with the telescope mount. The use of an 80mm focal point from the telescope's outer edge as a reference allowed us to finalize the necessary dimensions.

The placement of a concave lens for the CPC1100 telescope increased the resultant light beam size, which, in turn, improved the resolution of the resulting spectrum. By selecting a collimator mirror with a focal length of 101.6mm and a diameter of 37.5mm, we obtained a parallel beam with large in diameter in order to achieve the high resolution for the spectrograph.

Furthermore, the inclusion of a concave lens facilitated a universal spectrograph design applicable to all three CPC series telescopes with minor adjustments. This was demonstrated by achieving a 37mm diameter light beam for the CPC800 and a 29mm diameter light beam for the CPC925 through strategic lens placement adjustments. The values we obtained for the resulting light beam of the collimator mirror is also enough to achieve a high resolution spectrograph.

This research successfully developed a versatile and high-resolution spectrograph design for the Celestron CPC series telescopes, enhancing their observational capabilities and providing a valuable tool for both education and research.

References

1. James, J., Spectrograph Design Fundamentals. Cambridge University Press. https://doi.org/10.1017/CBO9780511534799 (2007).
2. Instruction Manual, Celestron CPC series, Celestron (2009).
3. Celestron LLC, CPC 1100 GPS, Product dimensional drawing. https://celestron-site-support-files.s3.us-east-1.amazonaws.com/support_files/CPC%201100%20GPS.pdf (2022).
4. Xian-Yong Bai, Zhi-Yong Zhang, Zhi-Wei Feng, Solar observation with the Fourier transform spectrometer I: Preliminary results of the visible and near-infrared solar spectrum, Research in Astronomy and Astrophysics, Volume 21, Number 10, National Astronomical Observatories (2021).
5. Astrosurf, Theoretical Parameters for the Design of a “Classical” Spectrograph (2023). http://www.astrosurf.com/buil/us/stage/calcul/design_us.htm, last accessed, 2024/06/04
6. Edmund Optics, Available sizes and dimensions of optical mirrors, lenses and gratings. https://www.edmundoptics.com/, last accessed, 2024/05/10