Design of a derotator for the 4 m DAG telescope

Jérémie Baudet[a], Laurent Jolissaint[a], Onur Keskin[b], Cahit Yesilyaprak[c,d], and Sinan K. Yerli[e]

[a]University of Applied Sciences Western Switzerland, Yverdon-les-Bains, Switzerland
[b]FMV Işik Univ., Engineering Faculty, Dept. of Mechanical Eng., Istanbul, Turkey
[c]Ataturk Univ., Astrophysics Research and Application Center (ATASAM), Erzurum, Turkey
[d]Ataturk Univ. Science Faculty, Dept. of Astronomy and Astrophysics, Erzurum, Turkey
[e]Orta Dogu Teknik Universitesi (METU), Physics Department, Ankara, Turkey

ABSTRACT

This paper summarize our work on the design of a field derotator for the adaptive optics instruments Nasmyth platform of DAG (Dogu Anadolu Gozlemevi), a new 4 m telescope for astronomical observations near the city of Erzurum, Turkey. While the telescope follows an astronomical object, its pupil sees a rotation of the object around the optical axis which depends on the telescope geographic coordinate and the object sky coordinate. This effect is called the field rotation. This rotation needs to be compensated during the astronomical object data acquisition. In this report we demonstrate the feasibility of placing the derotator (a K-mirror design) in the telescope fork central hole and propose a preliminary design, considering flexures.

Keywords: Field derotator, field rotation, alt-az mount, Ritchey-Chretien, Nasmyth, K-mirror, Dove prism

1. INTRODUCTION

1.1 Background

Since 2007, astronomical observations have been conducted by the science faculty of Ataturk University in the area of the Palandoken mountain range, near the city of Erzurum, Turkey (fig. 1). The first project has been the development of a 50 cm telescope. Having been a success, through the observations, the ambition to built a bigger telescope appeared, and this is how the DAG (Dogu Anadolu Gozlemevi) project was born. Since February 2010, seeing measurements have been made on site (Karakaya Tepeleri) and in January 2012, the DAG Project has been accepted by the Turkish government.

FIGURE 1. Location of DAG observatory.

During 2014 the optical design has been entrusted to the optical laboratory of the engineering school of Yverdon-les-Bains (HEIG-VD), in Switzerland. HEIG-VD will work with AMOS *, a Belgian company specialized in large optomechanical instruments. AMOS will built the telescope.

1.2 The telescope

To avoid spherical and coma aberrations, the telescope optical configuration is a Ritchey-Chretien (Bely[1]). That is to say primary (M_1) and secondary (M_2) mirrors are hyperbolic. Its conception is relatively compact and its off-axis performance is excellent. However, this type of telescope is relatively rare due to the high manufacturing cost of the primary mirror. The Ritchey-Chretien conception is mostly used within professional observatories like Keck, VLT, Gemini or spatial telescopes like Hubble or Herschel. The telescope mount is an alt-azimutal : the telescope has two degree-of-freedom (DOF), one is horizontal (azimuth) the other is vertical (altitude) (fig. 2).

Further author information: e-mail: laurent.jolissaint@heig-vd.ch
*Advanced Mechanical and Optical Systems, Liège, Belgium

Ground-based and Airborne Instrumentation for Astronomy VI, edited by Christopher J. Evans, Luc Simard, Hideki Takami
Proc. of SPIE Vol. 9908, 99085L · © 2016 SPIE · CCC code: 0277-786X/16/$18 · doi: 10.1117/12.2234392

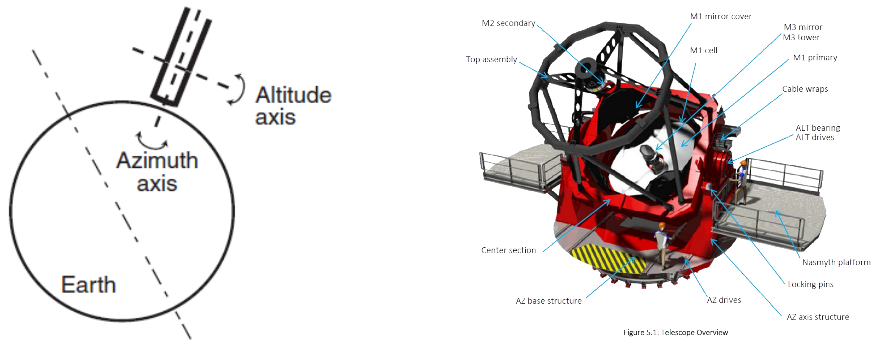

FIGURE 2. Left : alt-azimuthal mount concept. Right : DAG.

1.3 Problem formulation and requirements

Due to its alt-azimutal mount, while the DAG telescope follows an astronomical object, its pupil sees a rotation of the object around the optical axis, determined by the location of the observatory (latitude), the azimuth and the elevation of the observed object. This effect is called the field rotation. The speed of the field rotation is the derivative of the parallactic angle with respect to time which is

$$\frac{dq}{dt} = -\omega_E \cos(Lat)\,\frac{\cos(Az)}{\cos(Alt)} \quad [\mathrm{rad/s}] \tag{1}$$

where q is the parallactic angle, the orientation of the astronomical observed object, ω_E is Earth's rotation speed, Lat is the latitude of the telescope, Az is the azimuth and Alt is the elevation of the observed object.

Getting high signal-to-noise observations requires long integration times (minutes to hours), so it is mandatory to compensate the rotation of the optical field due to the earth's rotation. The device which is used to compensate the optical field rotation is called a (field) derotator. In view of the telescope's configuration (Ritchey-Chretien, Nasmyth), it is required to place this instrument between M3 mirror and the science instruments. The type of derotator has been selected for its anastigmatic and anachromatic characteristics. The K-mirror design offers this features (fig. 3). According to the parallactic angle max speed for an elevation of 89.9°, the maximum derotation speed of the K-mirror mount is about 1.8 deg/s.

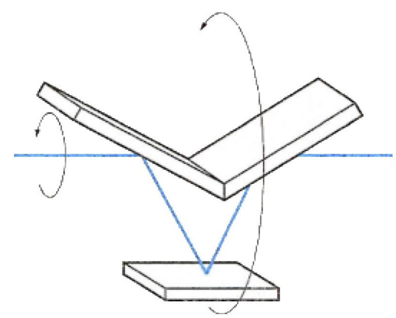

FIGURE 3. K-mirror operating principle.

1.4 Scope

The main task of this study has been the evaluation of the possibility to place the derotator in the telescope fork central hole and the evaluation of the mechanical/optical characteristics of the model. This paper is a first step in the realization of a derotator for the DAG telescope.

2. OPTICAL DESIGN

There are many ways to compensate the field rotation, divided in three main categories (Runciman & Madec[2]). First, it is possible to numerically rotate the integrated light on the detector. The main problem with this solution is that there is a significant loss of precision during the interpolation of the image - and numerical derotation is not possible in spectrography. Therefore the derotation must be optical and not numerical, because the compensation must be done before the scientific instruments.

Another solution is to compensate the rotation with a prism mount like Dove prism, Schmidt prism, Rantsch prism or Pechan prism (fig. 4, left). The concept is to built a structure which make an elbow to the optical path and turn it to counter the rotation. With this technique it is required to counter rotate the mount at half the speed of field rotation, because of the reflections.

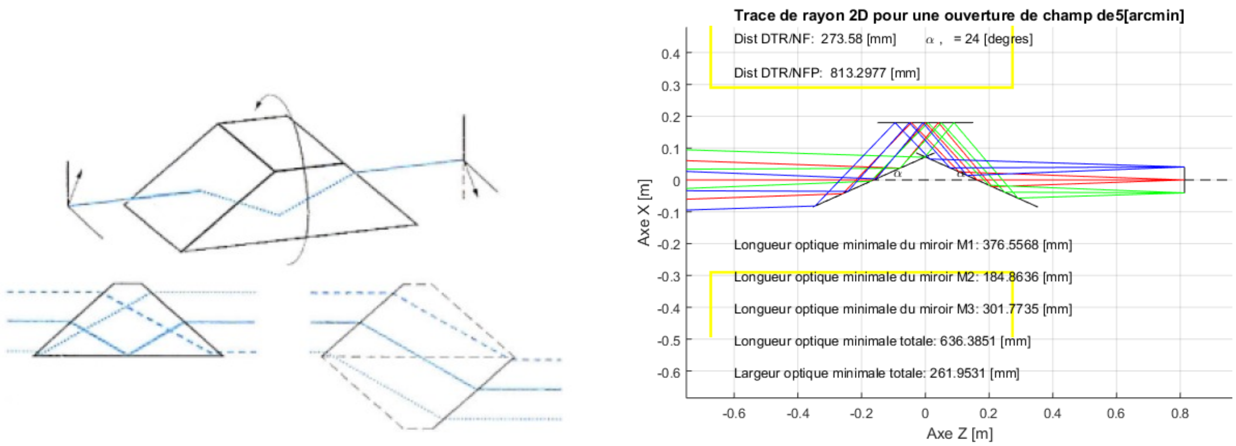

FIGURE 4. Left : Dove and other derotator-prism principle ; Right : `matlab` ray tracing model.

However the weakness of this solution is that, except if the beam is collimated, the astigmatism is severe. The third possibility is to built an optical mount like the first solution but with a mirror instead of prisms. The advantage is that there is no astigmatism. On the other hand, the rigidity and the positioning precision will be the main challenge. This is the K-mirror derotator design, and this is our choice.

Mirrors positioning

In order to set the mirrors position and check if it is possible to place the derotator in the fork central hole, a ray tracing (`matlab` model) has been realized according to the considered field aperture which is 5 arcmin. The concept is to model the three mirrors represented by straight lines and set their positions to optimize the congestion (fig. 4, right).

As the size of the optical field is known, with this model it has been possible to compute the mirrors size according to the position of the derotator compared to the Nasmyth flange. α is the angle between the lower mirrors and the optical axis. α is an important variable to set the derotator diameter and its optimal value is 24°.

3. MECHANICAL DESIGN

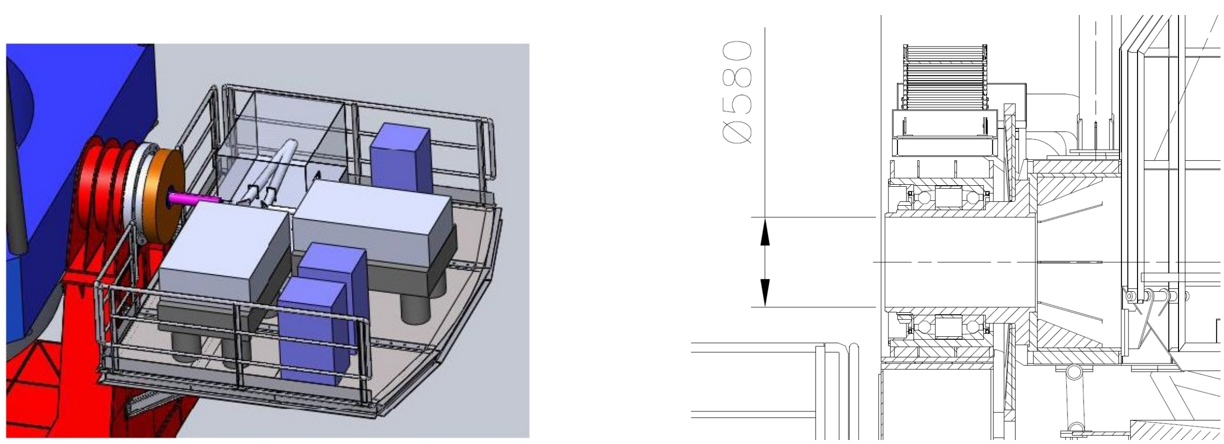

FIGURE 5. Left : Nasmyth platform. Right : central fork drawing.

The task here is to integrate the derotator in the current telescope design. The provided housing for the derotator is the hole in the alt fork next to the Nasmyth platform (fig. 5). The diameter of the allocated space is 580 mm and is approximately 800 mm deep.

3.1 Mechanical concept

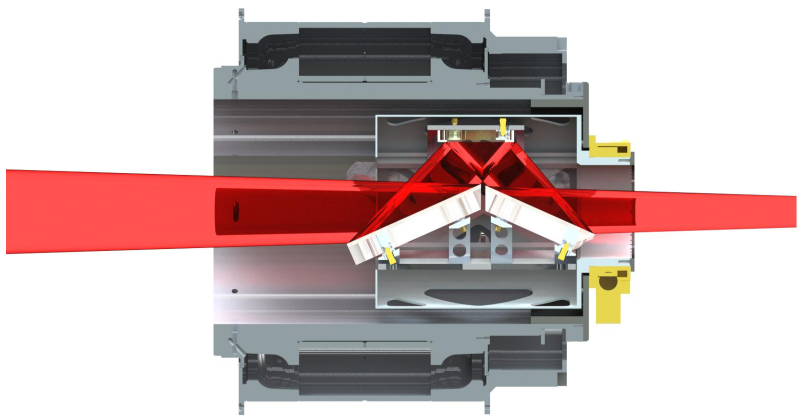

FIGURE 6. Cut-view of the derotator mounted into the telescope fork.

The derotator will be divided in four different parts, the shell that will envelop the mirror, a module that will include the two inclined lower mirror (M1 and M3), a module that will include the upper mirror (M2) and a module that will drive the derotator. In order to avoid hyperstatism the derotator will be mounted on a single bearing.

The shell will support the mirrors mount. It must be really rigid to avoid static deformations. This is the reason why this part will be built in carbon fiber. The mirrors supports will be built in aluminum to lightweight the structure (the thermal effect will have to be evaluated). Our design, integrated in the telescope fork, is shown in fig. 6.

3.2 Mirrors design

In order to avoid to add optical aberrations, the mirrors must keep their rigidity and planarity. The way to do it is to maximize the light-weighting of the mirrors and use a rigid optical glass, like ZERODUR. At this point of the study, the mirrors and the structure will be manually aligned. In the future the idea is to regulate the position of the structure and the mirrors alignment, especially the rotation axis on the telescope optical axis.

Like most of the optical mirrors, derotator mirrors will be light weighted to avoid gravity effects. In the scope of this study, an evaluation of mirrors deformations due to gravity has been realized with the finite elements tool from `Solidworks` (fig. 7).

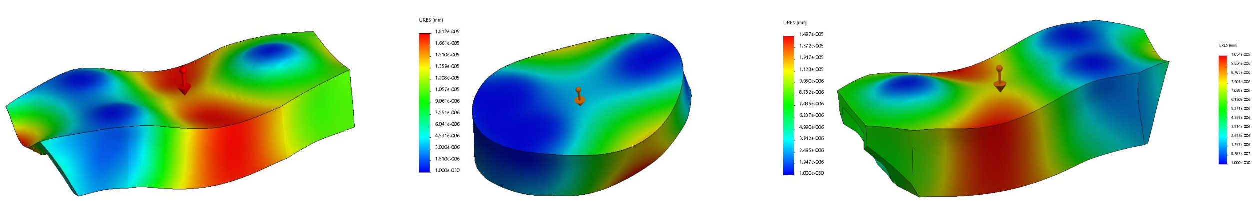

FIGURE 7. Mirrors deformations. From left to right : M1, M2, M3. Maximum deflexion is respectively 18, 15 and 11 nm peak-to-valley.

3.3 Rotation drive

Newport, a company that is specialized in optical systems offers a simple and ready to use solution : high performance precision rotation stages. The model RV350HAHLT has been chosen (table 1, and fig. 8).

TABLE 1. Newport RV350HAHLT rotation drive characteristics.

Angular Range	± 170	[$^\circ$]
Minimum Incremental Motion	0.0002	[$^\circ$]
Uni-directional Repeatability, Guaranteed	0.0002	[$^\circ$]
Uni-directional Repeatability, Guaranteed	± 0.0006	[$^\circ$]
Absolute Accuracy, Guaranteed	0.005 or ± 0.0025	[$^\circ$]
Maximum speed	80	[$\circ/s$]
Wobble	16 or ± 8	[μrad]
Eccentricity, Guaranteed	4 or ± 2	[μm]

FIGURE 8. Newport RV350HAHLT rotation drive.

4. ANALYSIS

An important point is that the derotation system should not add significant aberrations to the science image. To evaluate these errors, the mechanical structure deformation has been evaluated with a finite element tool (`Solidworks`) with the proper load plus mounts and mirrors load (fig. 9). It is found that the mechanical deformation is not constant for the different angle positions of the derotator. Apparently, the shell needs to be optimized .

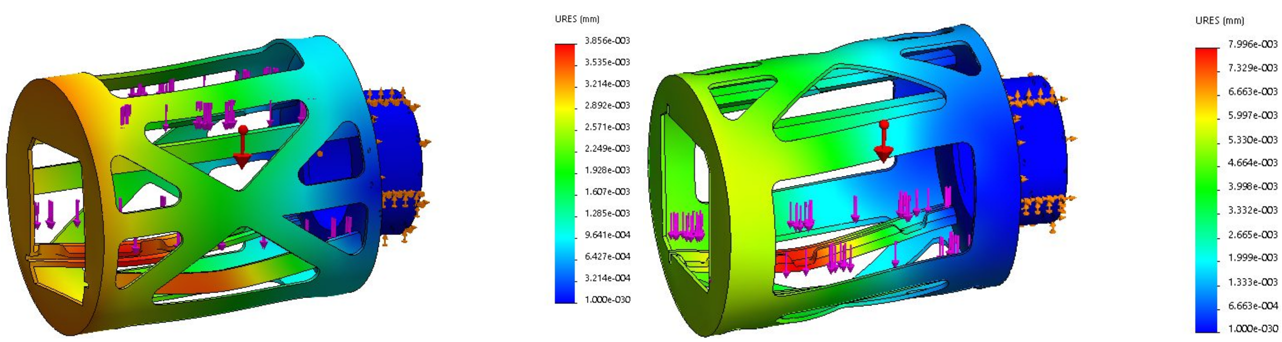

FIGURE 9. Gravity effect on the carbon fiber structure, when the derotator is in a vertical position (left, maximum deflexion 3.8 μm) and in an horizontal position (right, maximum deflexion 8 μm).

Then the computed results has been used in a 3D ray trace model (`matlab`) to evaluate the tilt error and the defocus on the telescope focal plane. In figure 10, the asterisk represents the central ray on the focal plane without structure deformation and the circle represents the same ray with the computed deformation. It is possible to see that the error is about 13 μm in vertical position and 2 μm in horizontal position.

In first approximation (in this model), the positioning errors between mirrors have been ignored. Given that, the computed defocus error is only about 10^{-5} μm and is only affecting the off-axis observation.

The worse case is when the derotator suffers from the gravity, in vertical position, the eccentricity and the angle position errors are equal to the motor characteristics. In this case the maximal shift error is about 27 μm. Given that a CCD sensor pixel is about 7 μm, the maximal error on the image is of the order of four pixels.

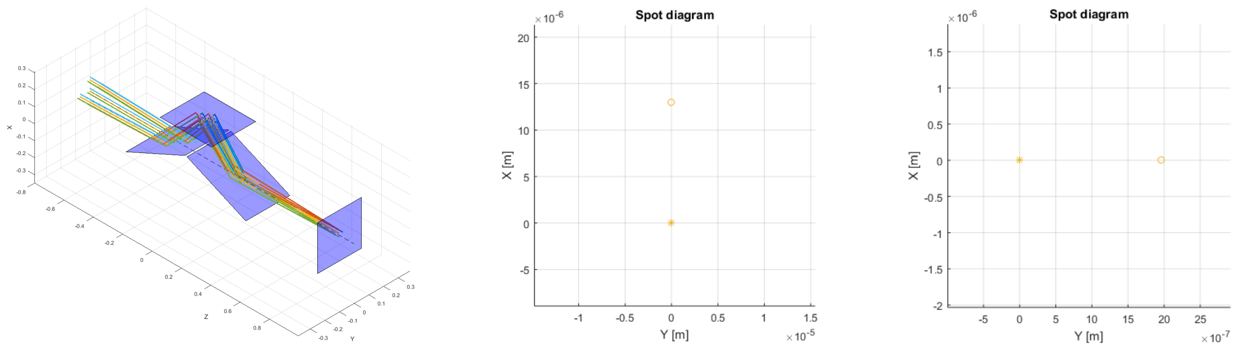

FIGURE 10. Left : 3D ray tracing (`matlab` model) ; Right : drift in the focal plane.

5. CONCLUSION

During this work, it has been possible to identify the main elements that interfere in the derotator development. The mechanical design will be enhanced to improve the rigidity. According to the considered parameters (no derotator mirrors deformations), the defocus error is not significant.

It is demonstrated that it is possible to place the derotator in the telescope fork central hole. Moreover, the precision of the presented mechanical design seems to be acceptable to carry on the development.

However there is still a lot of challenges before the first prototype. One of the first step will be development of a system to align the derotator axis with the telescope optical axis. Then the choice of mirrors coating, the development of the driving system, and the evaluation of the image aberration due to the mirrors deformations.

ACKNOWLEDGMENTS

The authors would like to thank Ataturk University, Erzurum/Turkey, Astrophysics Research and Application Center (ATASAM), Erzurum/Turkey ; Republic of Turkey, Ministry of Development ; Orta Dogu Teknik University, Ankara/Turkey (Project No : 2016K121380) ; FMV Isik University, Center of Optomechatronics Application and Research (OPAM), Istanbul/Turkey ; and the Haute Ecole d'Ingénierie et de Gestion du Canton de Vaud (HEIG-VD), Yverdon-les-Bains/Switzerland, for their support throughout the DAG project.

REFERENCES

[1] Bely, P. Y., [*The Design and Construction of Large Optical Telescopes*], Springer, New York (2003).
[2] Herbert Runciman, P.-Y. M., "Réflexion, réfraction, diffraction," tech. rep. (1990).