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Optical design of a rotating eyepiece telescope

M. Siddique, F. Nasim, A. N. Khan and A. Gul
Institute of Industrial Control Systems, P. O. Box 1398, Rawalpindi, Pakistan

E-mail: drsiddikbit@gmail.com

Abstract. Flexible eyepiece telescope has been designed and verified. The rotating eyepiece of telescope will facilitate viewing of objects in a remote or out of sight target. Eyepiece arm of telescope can be rotated upto 360^o keeping objective and reticule unchanged and ensuring zero deviation in reticule inclination. Main application of this scope is off axis viewing of objects. Image inversion has been carried out by using pair of mirrors and length of telescope is controlled by using relay lenses. The optical design, simulation and image analysis has been carried out by using ZEMAX®. Magnification of telescope is between 10~12 times with FOV of 6^0. Experiment has been carried out using uncoated Edmund Optics and optical tool box of Micro Series Kit, NEWPORT.

1. Introduction

A periscope is an optical instrument that facilitates viewing of objects which are beyond line of sight [1]. It is an optical instrument that facilitates visual imagery through bent geometries and can be described as a telescope having a bent optical path and a limited field of view [2]. The requirement of brightness, proper image orientation, field of view and maneuverability has led the periscope optics to consist of several image forming, image rotating and image scanning elements.

Periscope is an important tool of submarines. It is a necessity in searching and identifying the targets before attack. Due to the powerful and vital threat, submarine technologies such as periscope design, sonar sensors, engines, communications, and weaponry are confidential by designers. A complete periscope design includes the head piece, the relay optics in the mast, and the observation eyepiece.

An endoscope is a miniature periscope used to examine the inside of a cavity through a small orifice; they are widely used in medical applications. The size of the optics in a medical endoscope is on the order of 2 or 3mm in diameter. In an endoscope or periscope, the number of relay stages is determined by the length of the instrument. The relay lenses are typically made as cemented doublets, with the flint (negative) element made thick enough to fill the space. The outer surface of the flint is made convex so that it functions as the field lens. This is often referred to as a rod-lens endoscope. The reduction in the number of relay components both reduces the cost of the endoscope and improves the image quality (especially by reducing the secondary spectrum and the Petzval field curvature) [3].

Design presented can also be utilized in these applications when realized at miniature scale. Further CCD cameras can also be used directly to view image on mounts.

2. Design parameters
The eyepiece of rotating eyepiece telescope is rotated up to 360^o keeping objective and reticule unchanged and ensuring zero deviation in reticule inclination. The design parameters are listed below:

I.	Total length of the telescope :	470mm
II.	Magnification:	12^x
III.	Field of view :	6.1°
IV.	Viewing object scan:	360°
V.	Exit pupil diameter:	5mm
VI.	Exit pupil position:	25mm
VII.	Objective diameter:	65mm

3. Optical design
The basic design concept is to image the object field by an objective lens and then to relay this image to the eye-piece at the required distance by a set of relay lenses. The object field is scanned by rotating the entire rotating eyepiece about the optical axis. The overall design ensures that the image is finally seen in a proper perspective and no lateral inversion is introduced.
Taking 1arc-min as the angular resolution of the human eye [4], the minimum magnification needed is 6^x. The clear aperture of the objective is 65mm limiting the maximum useful magnification to 12^x. Our system is designed with a maximum magnification of 12^x.

The first order Gauss optics parameters can be determined from the design specification of FOV and angular magnification of the telescope system as shown in Figure 1. Firstly, according to the need of high slope angle and long eye-relief, the Erfle-type of eyepiece is chosen. While the focal length of the eyepiece is about 25mm and the magnification of telescope is set as 12^x, the focal length of objective is 340mm.

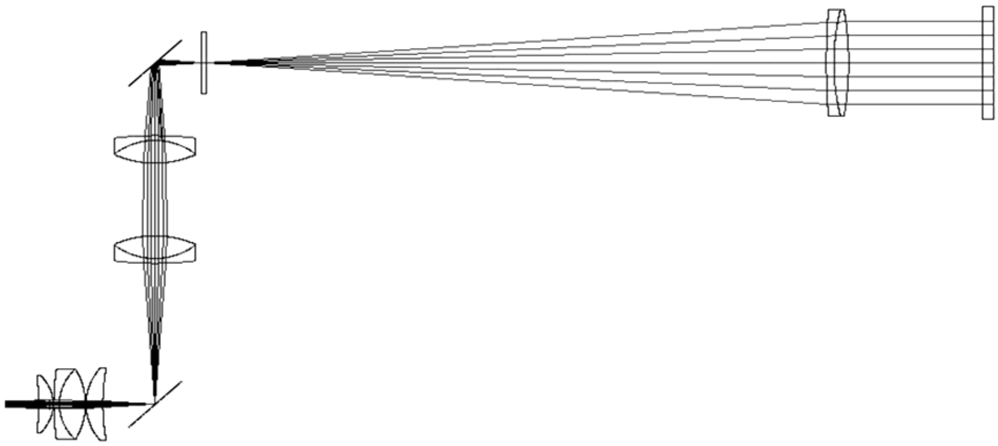

Figure 1. The 3D Optical Layout of Telescope

In order to control light for the sake of brighter illumination on the observer's eye, the exit pupil diameter of telescope can be set at 4mm and the diameter of the objective at 65mm. The full field-of-view (FOV) at the pressure window of the telescope is approximately 6^o as usually required, and the full FOV exit angle to the observer's eye will be 72^o. Secondly, the overall length is often (often more than one hundred times greater) than its diameter. This can be implemented by adding more than two sets of relay lenses. We use the achromatic doublet with a focal length of 97mm, and diameter of 43mm. In this report, we use one pair of relay to represent the image forming system. Finally, a set of mirrors with the size of 50mm X 50mm at the top and button of the mast are used to redirect the sight line.

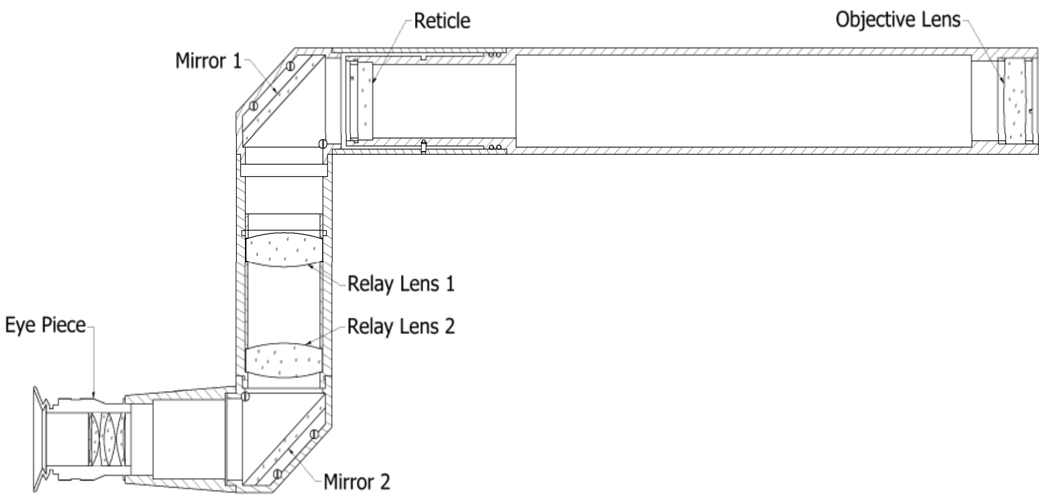

Figure 2. Cross-sectional View of Opto-mechanical Assembly of Telescope

The telescope is comprised by components as shown in Figure 2, W: pressure window, O: objective lens, R:Reticle, M_1 and M_2 are mirrors; L_1 and L_2 are relay lenses, Erfle: Eye-relief eyepiece.

3.1 Paraxial working layouts

The basic layout of the system was worked using paraxial ray tracing [5]. An axial ray is traced through the system for determining the lens positions for the required image positions in the system. A principal paraxial ray is traced for determining the clear apertures needed.

The periscopes are formed by relay lenses to transfer the image from one plane to the next with a magnification equal to one, and field lenses located at the image planes, to form the image of the exit pupil of the preceding system, on the entrance pupil of the next system (Hopkins, 1949, 1962b) [6]. A good aberration correction may be obtained if each relay systems formed by a pair of doublets in a symmetrical configuration.

The primary image is formed by the objective at the fixed reticule. Then this image is shifted on the pair of relay lenses. This is relayed in the relay module and focused at the final image plane in the eyepiece module.

The relay system is designed with images forming at the focal planes of the lenses so that beams are parallel between the lenses. The total number of reflections in the system is two with one reflection at mirror M_1 and second reflection at mirror M_2 is not laterally inverted at the eye-piece.

The prescription of rotating eyepiece telescopic system and general lens data editor are given in Table 1 and Table 2.

Table 1. The Prescription of the Rotating Eye-piece Periscopic Telescope

Lens Data Editor

Edit Solves Options Help

	Surf:Type	Comment	Radius	Thickness	Glass	Semi-Diameter
OBJ	Standard		Infinity	Infinity		Infinity
1*	Standard	PRESSURE WINDOW	Infinity	6.000000	F_SILICA	35.000000
2*	Standard		Infinity	72.000000		35.000000
3*	Standard	OBJECTIVE LENS	214.800000	8.000000	H-BAK2	32.750000
4*	Standard		-153.460000	4.000000	ZF2	32.750000
5*	Standard		-515.450000	333.000000		32.750000
6*	Standard	RETICLE	Infinity	3.000000	H-K9L	18.990000
7*	Standard		Infinity	24.960000		18.990000
8	Coordinate B..	Element Tilt		0.000000	-	0.000000
9*	Standard		Infinity	0.000000	MIRROR	20.000000
10	Coordinate B..	Element Tilt		-45.000000	-	0.000000
STO*	Standard	RELAY LENS 1	-162.930000	-3.000000	ZF5	21.750000
12*	Standard		-32.500000	-14.000000	BAK4	21.750000
13*	Standard		47.420000	-45.000000		21.750000
14*	Standard	RELAY LENS 2	-47.420000	-14.000000	BAK4	21.750000
15*	Standard		32.500000	-3.000000	ZF5	21.750000
16*	Standard		162.930000	-87.250000		21.750000
17	Coordinate B..	Element Tilt		0.000000	-	0.000000
18*	Standard		Infinity	0.000000	MIRROR	20.000000
19	Coordinate B..	Element Tilt		28.050000	-	0.000000
20*	Standard	EYE-PIECE LENS	-134.000000	9.000000	H-BAK3	22.500000
21*	Standard		-36.980000	0.300000		22.500000
22*	Standard		47.420000	14.000000	H-BAK3	21.750000
23*	Standard		-32.500000	3.000000	ZF5	21.750000
24*	Standard		-162.930000	0.300000		21.750000
25*	Standard		26.300000	8.000000	H-K9L	17.500000
26*	Standard		267.900000	26.800000		17.500000
27	Standard		Infinity	-33.000000		2.000000
IMA	Standard		Infinity	-		3.000000

Table 2. The general lens data of Rotating Eye-piece Periscopic Telescope

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GENERAL LENS DATA:

Surfaces                    :               28
Stop                        :               11
System Aperture             : Entrance Pupil Diameter = 70
Glass Catalogs              : SCHOTT SUMITA INFRARED CHENGDU
Ray Aiming                  : Off
Apodization                 : Uniform, factor =   0.00000E+000
Temperature (C)             :    2.00000E+001
Pressure (ATM)              :    1.00000E+000
Effective Focal Length      :        831.1741 (in air at system temperature and pressure)
Effective Focal Length      :        831.1741 (in image space)
Back Focal Length           :        76.82691
Total Track                 :             451
Image Space F/#             :        11.87392
Paraxial Working F/#        :        11.87392
Working F/#                 :          13.318
Image Space NA              :      0.04207183
Object Space NA             :   3.500001e-009
Stop Radius                 :       -7.310051
Paraxial Image Height       :        44.28735
Paraxial Magnification      :               0
Entrance Pupil Diameter     :              70
Entrance Pupil Position     :       -1888.753
Exit Pupil Diameter         :        4.852227
Exit Pupil Position         :        25.41197
Field Type                  : Angle in degrees
Maximum Field               :            3.05
Primary Wave                :       0.5875618
Lens Units                  :    Millimeters
Angular Magnification       :        14.42636
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3.2 Objective of telescope

An objective lens of achromatic doublet of 340mm focal length is used as shown in Figure 3. An achromatic lens reduces the achromatic aberrations. An achromatic can be bent like a singlet; this means that the system power is maintained during the bending as shown in Figure 4. Color correction is also maintained since this depends only on the power of the individual elements [7]. At the focal plane of objective lens a cross reticule with circle at centre is fixed for aiming purpose. The general data of objective and eyepiece lenses are shown in Tables 3 and 4.

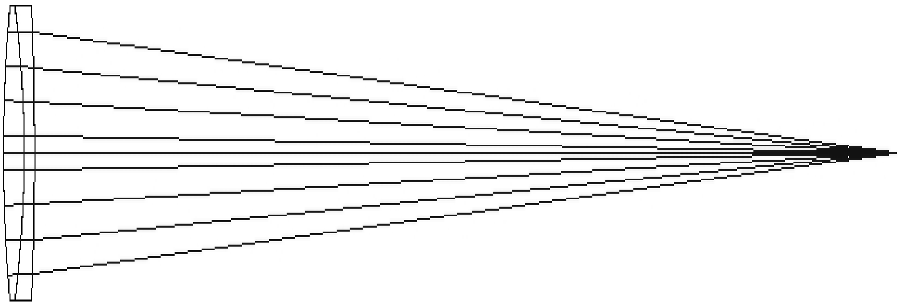

Figure 3. The Objective lens 3D layout

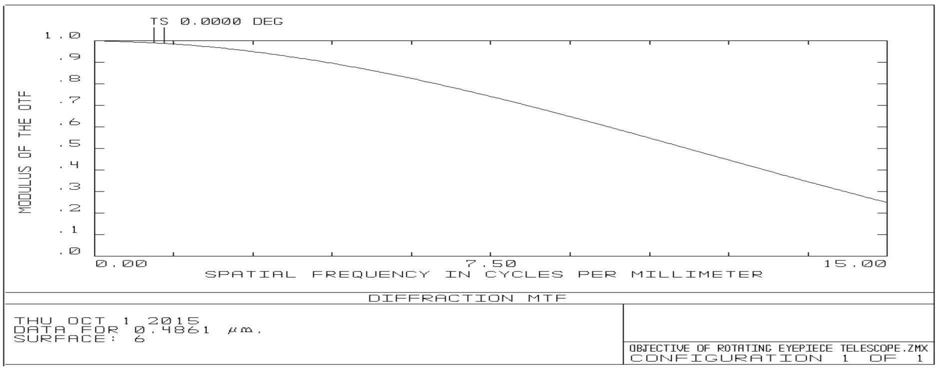

Figure 4. The MTF of Objective lens of Rotating Eyepiece Telescope

Table 3. The general Lens data of the Objective lens of Rotating Eyepiece Telescope

Lens Data Editor

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Surf:Type		Comment	Radius	Thickness		Glass		Semi-Diameter	
OBJ	Standard		Infinity	Infinity				Infinity	
1*	Standard		Infinity	6.000000		F_SILICA		35.000000	U
STO*	Standard		Infinity	72.000000				35.000000	U
3*	Standard		214.800000	8.000000		H-BAK2		32.750000	U
4*	Standard		-153.460000	4.000000		ZF2		32.750000	U
5*	Standard		-515.450000	334.008735	M			32.750000	U
IMA	Standard		Infinity	-				0.000000	U

3.3 Erfle eyepiece of telescope

A rotating eyepiece of Erfle type has been used in our telescope. It consists of three optical elements including one doublet lens, which is used to reduce the chromatic aberrations. The eyepiece collects the image made by the objective lens of the telescope and provides parallel rays for viewing directly through the eye. The eyepiece is assembled in such a way that the focal planes of objective lens and eyepiece are coincident. The optical lenses lay out, shaded view of eyepiece lenses, general lens data and MTF are shown in Figures 5-6.

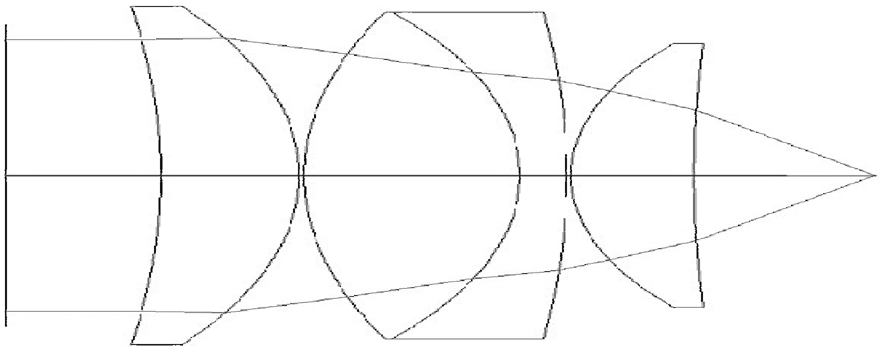

Figure 5. The Eyepiece lenses layout

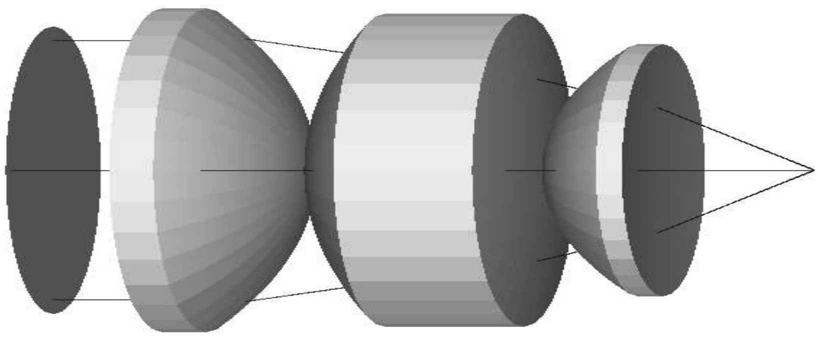

Figure 6. The 3D shaded view of Eyepiece lenses layout

Table 4. The general lens data of Rotating Eye-piece Periscopic Telescope

Lens Data Editor

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Surf	Type	Radius	Thickness	Glass	Semi-Diameter	
OBJ	Standard	Infinity	Infinity		0.000000	
1	Standard	Infinity	10.000000		20.000000	U
STO*	Standard	-134.000000	9.000000	H-BAK3	22.500000	U
3*	Standard	-36.980000	0.300000		22.500000	U
4*	Standard	47.420000	14.000000	H-BAK3	21.750000	U
5*	Standard	-32.500000	3.000000	ZF5	21.750000	U
6*	Standard	-162.930000	0.300000		21.750000	U
7*	Standard	26.300000	8.000000	H-K9L	17.500000	U
8*	Standard	267.900000	11.750000		17.500000	U
IMA	Standard	Infinity	-		0.061329	

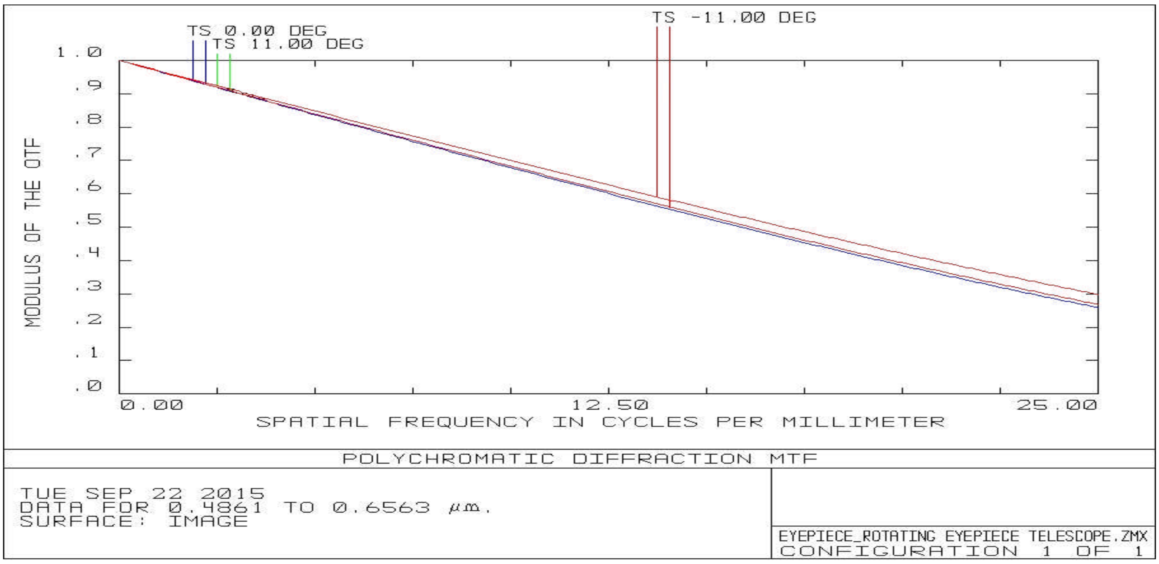

Figure 6. The MTF of Eyepiece of Telescope

4 Conclusions

I. The applications of such type of telescopes are found in military and civil projects. Main application of this telescope is in submarines for off axis viewing of objects.

II. Aberrations are balanced by adding a pair of doublets as relay lenses in a symmetrical configuration.

III. Image inversion has been carried out by using pair of mirrors and relay lens system systems and also the length of telescope is extended by using relay lenses.

IV. It is concluded that the MTF of objective and eyepiece lenses of the telescope is good enough to see the target clearly up to 4km. The image is shifted from focal plane of objective lens to focal plane of eyepiece by using a set of relay lenses of focal length 98mm.

V. The rotating eyepiece will facilitate viewing of objects in a remote or out of sight objects. Eyepiece arm of periscope can be rotated up to 360^0 keeping objective and reticule unchanged and ensuring zero deviation in reticule inclination.

VI. The optical design simulation and image analysis has been carried out by using ZEMAX® software. Magnification of telescope has been achieved between 10^x~12^x with FOV of 6^0.

VII. Prototype telescope was fabricated by using uncoated Edmund optics and optical tool box of Micro Series Kit, NEWPORT.

5 References

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