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Design of Medical Laser Detector Optical System

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Abstract

In order to satisfy the functional request of medical laser detector, the system theory of laser medical detector is analyzed. The gradual correction method is used in the design of laser transmitting and receiving optical system. The variable beam lens system is adopted in the transmitting system, and the Galileo telescope system is used in the receiving system. The software Zemax is used to simulate and macro language ZPL to write program, and the spot diagram and the structure chart of the transmitting and receiving optical system are get. In this design, the transmitting and receiving optical system is non-coaxial. There is a certain distance between two optical axes. So in order to ensure the two coaxial, splitting prisms are used to connect the transmitter optical system and the receiving optical system, forming combined optical system.

Keyword: *medical detector; optical system; transmitting; receiving*

1. Introduction

The main task of medical laser detector optical system is used to measure space distance and angle goal of target, which is calculated into space three-dimensional coordinate to reflect the spatial location, shape and other information of the target.

Medical laser detector optical system is the main part of medical detector measuring system. The range scope of laser detector in this design is 2m-18m. The function of optical system is to make the laser beam emitted from the laser transmitter into illumination beam used in laser detector. It transmits the laser energy to space and gathers much laser energy from the target return. The laser energy emitted from the laser transmitter should be used reasonable and fully, to meet the requirements of medical laser detector system for the shape, size and direction of the laser beam, and can be controlled. The optical system enables the receiver to collect the effective laser energy reflected back from the targets much as possible, and also minimizes the interference of background light and stray light.

Laser tracking medical detector optical system includes transmitting optical system and receiving optical system. In the typical medical laser detector, the transmitting and receiving optical systems are not coaxial, and there is a certain distance between two optical axes. So the combined laser transmitter and receiver have become a research hotspot in recent years.

2. The Principle of Transmitting and Receiving Optical System

2. 1 Transmitting Optical System

The transmitting optical system is used in the accurate measurement of the medical laser detector and needed to change the angel size of the laser beam from the laser into milliradian level. Through ideal lens system, the divergence, beam width and cross-sectional area of the emitted light beam can be changed. The total power remains to increase the density of light radiation.

The variable beam lens system is used in the system, and its functions are:

①It change the transmitting beam width, increase or decrease the illumination of the target, in order to adjust the laser power received by the receiver to increase the effective

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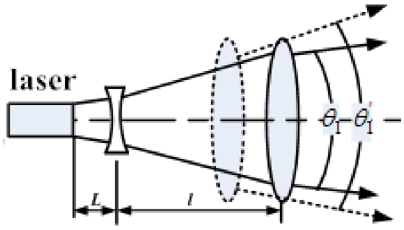
range of the medical detector or avoid the signal over-saturated in the receiver, which can ensure the normal operation of the medical laser detector;

②It change the beam width, to adapt to the requirements of the detecting distance of the system.

As is shown in Figure 2. 1.



θ_1 -beam angel before lens shift
θ_1' -beam angel after lens shift

Figure 2.1 The Variable Beam Lens System

In the laser tracking ranging medical laser detector, under fixed divergence angle condition, with the change of the target distance, the target scattering power received by the laser receiver is reflected in the equation(2.1), can be changed nearly in ten orders of magnitude. Sometimes the received power is too large, the receiver is in supersaturated state, and can not work normally. In order to enable the receiver to work properly, the variable beam optical system is used in the laser transmitter. When the target distance is near, the divergence angle of the laser beam becomes large to reduce the laser irradiation brightness of the target; when the target distance is far, the divergence angle of the laser beam becomes small, and the power density of the laser beam is increased, so that the target has sufficient irradiation brightness.

$$P_r = \frac{P_t A_e \sigma S_t S_r e^{-2R\alpha}}{4\pi R^4 \theta^2} \tag{2.1}$$

In which, P_t is the transmit power of the transmitter, P_r is the received power of the receiver, S_t is the optical efficiency of transmitting system, S_r is the optical efficiency of receiving system, □□ is the target reflection coefficient, R is the target distance, □□is the beam angle of the laser transmitter, A_e is the received aperture area of the receiver, $e^{-2R□}$ is the laser transmission in the atmosphere, □□ is the laser attenuation coefficient.

2. 2 Receiving Optical System

A receiving optical system is needed to be added in the front of the receiver, the aim is:

①converge the laser energy, reflected back from the target, to the detector as much as possible

②restrict the receiving field properly, reduce the interference of stray light and improve receiver sensitivity and signal-to-noise ratio.

The receiving optical system in this paper adopts telescope type. Figure 2.2 is its functional diagram. In the system an universal "objective" is used to generate the target scattering image, and then deliver the target scattering energy to the detector by a convergence element. The detector is placed at the exit pupil of the telescope and receives the laser energy reflected from the target. The angular density of the laser radiation is increased by the objective in the optical system, so that the detector can be filled with the laser energy.

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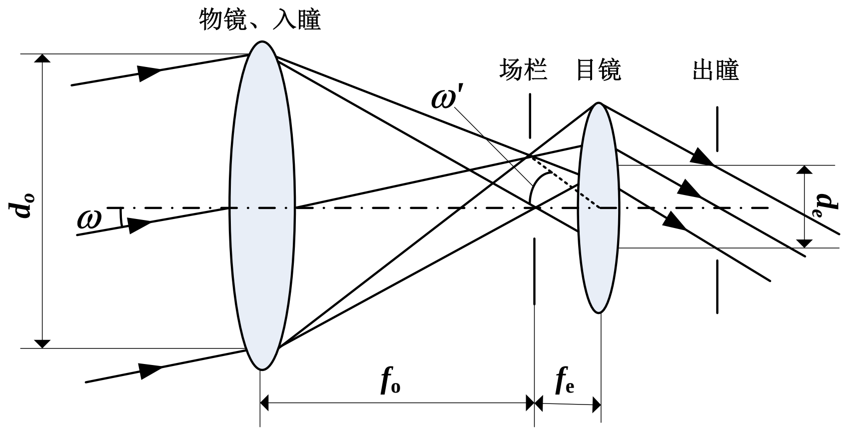


Figure 2.2 Telescope System

The angle magnification formula is

$$\Gamma = \frac{tg\omega}{tg\omega'} = \frac{d_o}{d_e} = \frac{f_o}{f_e} \quad (2.2)$$

The telescope of the laser medical detector receiver has two types: transmission and reflection type. The transmission receiving optical system is used in the simple receiver that has more light concentration and small volume. So in this paper, the Galileo telescope is chosen.

3 Design of Transmitting / Receiving Optical System

3.1 Design of Transmitting Optical System

In order to avoid over-saturation of the receiving system and meet the requirement of the detection distance of 2 ~ 18mm, the gradual correction method is used in this system to design the optical system. Its structural parameters are shown in Table 3-1.

Table 3-1. The Structure Design Parameters of Transmitting Optical System

Surface #	Surface Type	Z Radius	Thickness	Glass	Refract Mode	Z Semi-Aperture
Object	Standard	Infinity	Infinity		Refract	0. 000
1	Standard	Infinity	20. 000		Refract	4. 000
Stop	Standard	-111. 492	2. 000	BK7	Refract	4. 000
3	Standard	14. 131	28. 203		Refract	4. 031
4	Standard	-253. 587	5. 000	BK7	Refract	8. 808
5	Standard	-45. 064	5. 000		Refract	9. 398
6*	Standard	Infinity	12. 000	BK7	Refract	12. 000
7*	Tilted		0. 000	BK7		12. 000
8	Coordinate Breaks		0. 000			0. 000
9*	Tilted		12. 000	BK7		12. 000
Image	Standard	Infinity	-		Refract	6.822×10^{-4}

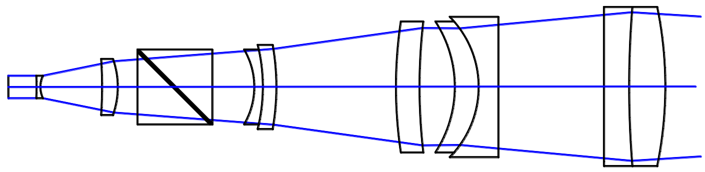
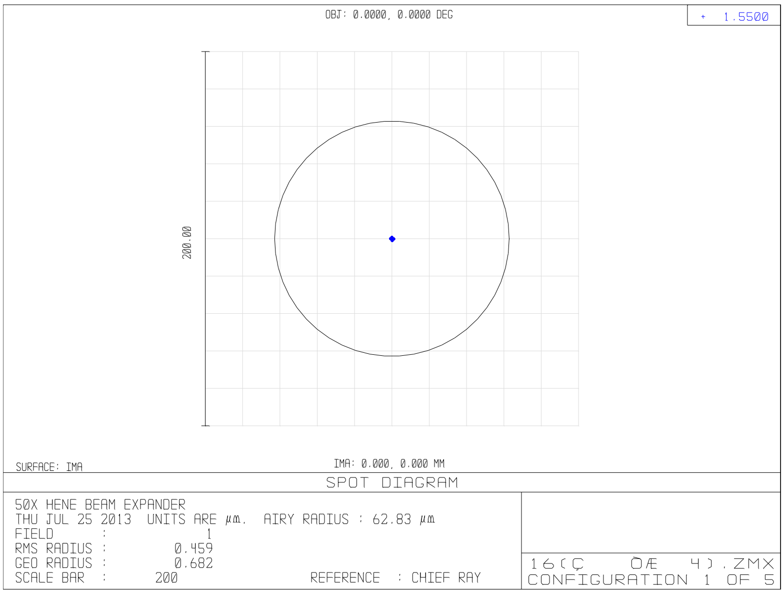


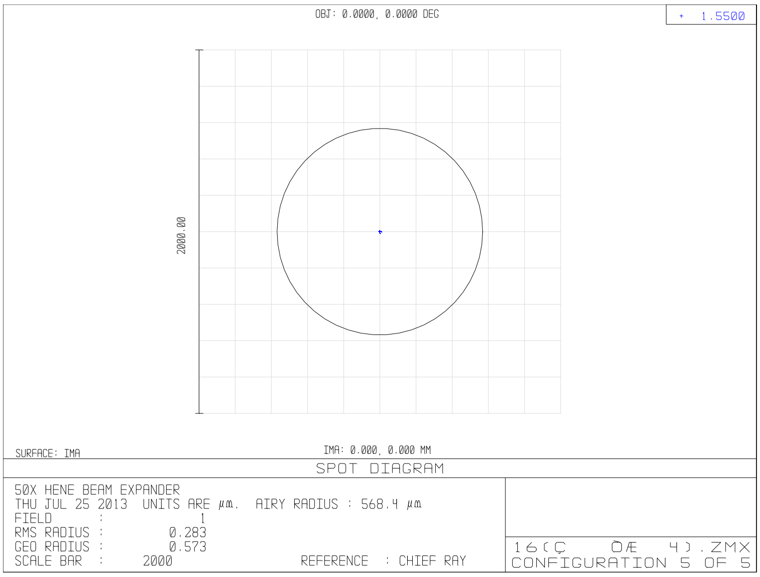
Figure 3.1 The Design of Transmitting Optical System

The design of transmitting optical system is shown in Figure 3.1. In order to obtain a small spot of high power density, the design uses three-time beam expanding collimation, reaching more than eight times of beam expanding ratio. Over the entire measurement range, the overall dimensions of the Z-axis direction of all system configurations are less than 280mm, and the instrument can be miniaturized.

The optical spot diagram is used in optical evaluation result, as shown in Figure 3.2.



(a)2m



(b)18m

Figure 3.2 The Optical Spot Diagram of Transmitting Optical System

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As is displayed in Figure 3.2, Airy spot is 568. 4 m. Root mean square radius(RMS) is much smaller than the Airy spot radius, which can make the spot small, bright and uniform.

3. 2 Design of Receiving Optical System

In order to meet the requirements of energy concentration and small volume of the receiving system, transmissive converging system is used in the design. It is designed with optical design software ZEMAX. The structural parameter of the system is listed in Table 3-2, and Figure 3.2 is the structure plane graph corresponding to Table 3-2.

Table 3-2. The Structural Design Parameters of Receiving Optical System

Surface #	Surface Type	Y Radius	Thickness	Glass	Refract Mode	Y Semi-Aperture
Object	Standard	Infinity	25. 354		Refract	4. 000×10^{-3}
Stop	Standard	Infinity	2. 000	BK7	Refract	3. 193
2	Standard	Infinity	10. 000		Refract	3. 361
3	Standard	-41. 654	4. 000	BK7	Refract	4. 592
4	Standard	-18. 722	4. 000	SF8	Refract	5. 024
5	Standard	-39. 237	30. 000		Refract	5. 603
6	Standard	207. 743	5. 000	BK7	Refract	9. 582
7	Standard	141. 924	5. 000	SF8	Refract	9. 941
8	Standard	-71. 413	10. 000		Refract	10. 164
9	Non-Sequential	Infinity	-			12. 000
Image	Standard	Infinity	-		Refract	0. 033

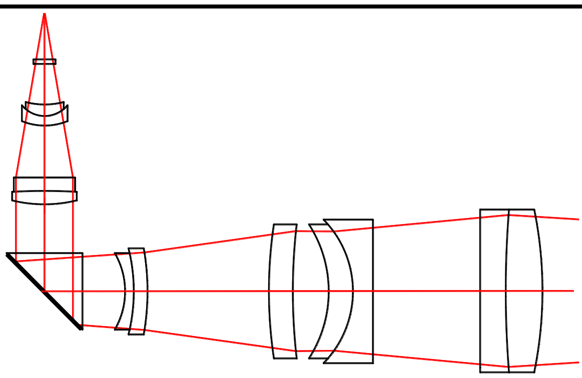
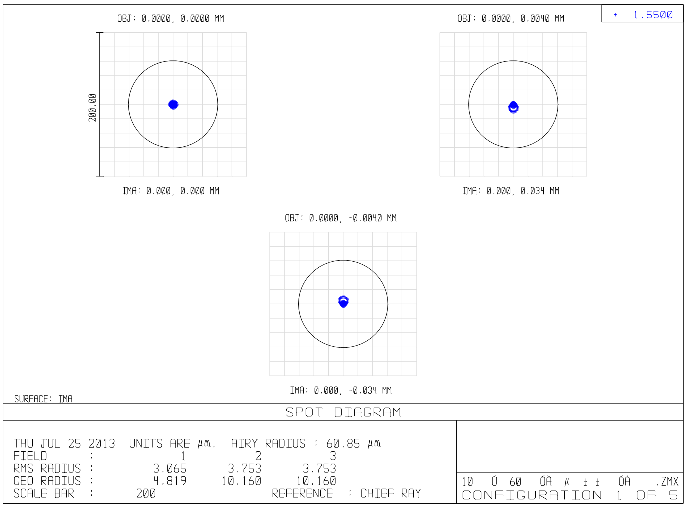


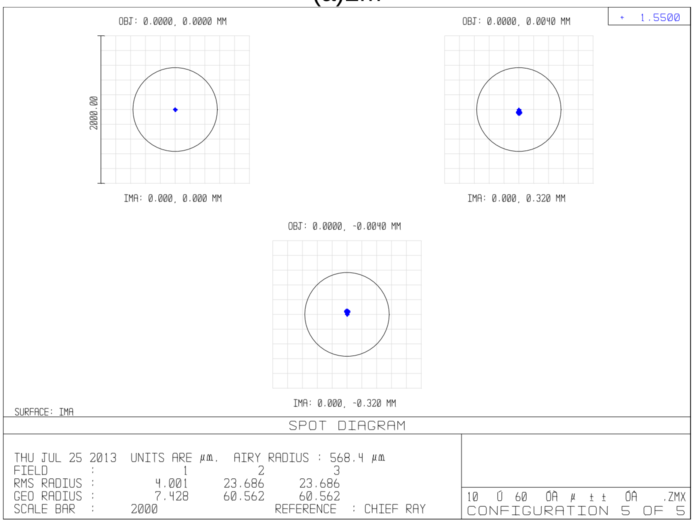
Figure 3.3 The Structure Design of Receiving Optical System

As shown in Figure 3.3, the transmitting and receiving common path as mentioned above is realized by beam splitter. The overall size of the system in the Y-axis direction is less than 105mm, combined transmitting optical system Z-axis direction size of less than 245mm, the entire optical system is smaller than 280mm×105mm.

The optical spot diagram is also used in optical evaluation result, as shown in Figure 3.4.



(a)2m



(b)18m

Figure 3.4 The Optical Spot Diagram of Receiving Optical System

As is displayed in Figure 3.4, Airy spot is 568. 4 □m..Root mean square radius(RMS) of six field in 2~18mm detection is much smaller than the Airy spot. The value is consistent with the transmitting optical system.

3. 3 Coaxial Design

In this paper, transmitting and receiving optical system of the medical laser detector are not coaxial. There is a certain distance between two optical axes. Therefore, this design uses the combined laser transmitting and receiving optical system. The transmitting optical system is connected with the receiving optical system by the splitting prism, which can guarantee both of optical axes are coaxial.

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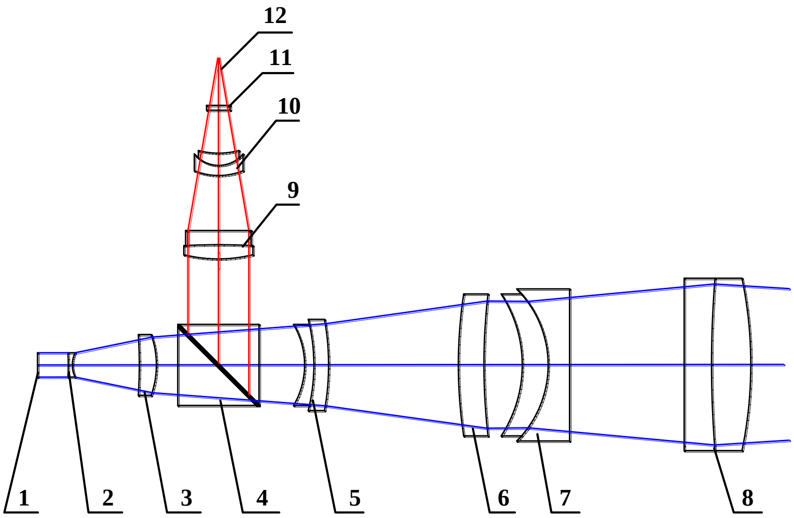

Figure 3.5 Design of Integrated Optical System

As shown in Figure 3.5, the lens 5~8 are sharing parts of the transmitting and receiving optical system.

Transmitting optical system is a beam expanding collimation system. Light from the first lens 2 to the last piece of lens, after three times of beam spread collimation, through the lens 8, converges to the target surface through scanning mirror. Then reflected by the target surface, from the lens 8 to the lens 5, after the direct-vision prism 4, the light comes into the red receiving optical system.

The receiving optical system is a convergent optical system, and takes shape into a spot in the image plane 12. In order to realize the measurement in the range of 2~18 m, the lens 2 needs to be moved to focus. Within the measuring range, the spot is got with the most concentrated energy to ensure the measuring accuracy.

4. Conclusions

The medical laser detector transmitting and receiving optical system is designed for the ranging laser detector. For the transmitting optical system, the formula for calculating the scattering power of the target is derived. Based on the theory of Gaussian optics, software ZEMAX is used to simulate and macro language ZPL to write program, and the spot diagram of the transmitting optical system is got. In order to meet the requirements of energy concentration and small volume of the receiving system, transmissive converging system is used in the design. The medical laser detector receiving optical system is simulated with the scattering characteristics of laser target. Because the transmitting and receiving optical system are not coaxial, there is a certain distance between two optical axes. Therefore, the combined laser transmitting and receiving optical system is used in this design. The transmitting optical system is connected with the receiving optical system by the splitting prism, which can guarantee both of optical axes are coaxial.

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