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Design and Simulation of Solar Animated Simulator for Functional Testing Of Spatial Systems and Design Analysis in Zemax Software

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--***ABSTRACT***--
In order to test the performance of solar sensors that are installed with a particular layout on the satellite body, laboratory testing is required. Therefore, facilities and hospitalization should be provided so that in the presence of physical agents, such as sunlight, they can actually see the results. The solar simulator is a device used in space laboratories to test solar sensors. In this paper, the optical system and light source of the solar mobile simulator are designed according to the requirements of the test conditions. This optical system consists of a halogen light source, a parallel lens, a flat mirror and a meter that has a surface level of three degrees of freedom of the satellite's location in the test bed. The results of the optical system analysis in the Zemaxsoftware show the proper performance of the system, including the intensity of light, the diameter of the stain and the uniformity of the received light at the level of the data.
KEYWORDS – *Sun light simulator- The satellite- Optical light source- Parallel lens- Detector- Zemax software.*

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I. INTRODUCTION

The solar simulator is a device used in space laboratories to test solar sensors. The performance of solar sensors that are installed with a particular layout on the satellite body is affected by the angle of the sun's radiation. Since the sun is sensitive to sunlight, it provides an information to the processor, and the processor analyzes the information to determine the current state of the satellite relative to the sun. Therefore, it is very important that the light produced by the solar simulator has the characteristics of sunlight (J. Oliviéri. 1998).

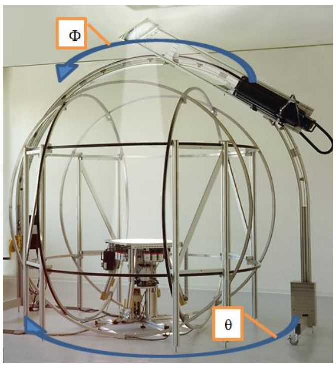

figure1. The structure of Solar Simulator Model (Raschke,C.,Roemer,S.,&Grossekatthoefer,K. 2011)

The construction and design of solar simulators have been very much considered in recent years. A sample of sun simulator has been shown in figure 2. In this model, sun’s movement was simulated to the orbital coordinates of the satellite and was implemented by a mechanism for a particular circuit. In this model, mirror is not used, instead the light shines directly from the light source to the table. In this simulator model, changes in the angular elevation and azimuth are modeled by a particular mechanism (Kermanshahi, F., Mohajerani, M. H., Babini, M. H., & Mortazavi, M. 2012).

Figure 2: Sample simulator of the sun with a quarter scale (Kermanshahi, F., Mohajerani, M. H., Babini, M. H., & Mortazavi, M. 2012).

The schematic of another sun's simulator is shown in figure3. The sun's angles are steady and, they do not have a spotlight or a mirror during the test. The illumination used in this simulator is fixed on a base that can change elevation in the range from 1300 to 2800 mm. The mirror of the simulator is mounted on the aluminum structure. The limitation in this simulator is that the position of the mirror and the source of light does not change during the test and has a constant coordinate. To solve this problem, the solution is to select the coordinate system of the airplane plate so that the sun can be seen fixedly (Dumke, M. 2011). The structure of this kind of simulator is shown in figure4.

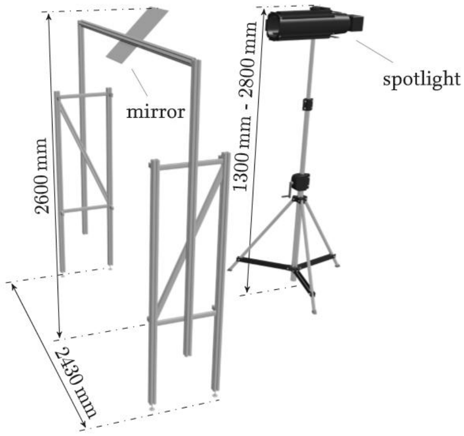

Figure 3. Solar simulator model of the second type (Dumke, M. 2011)

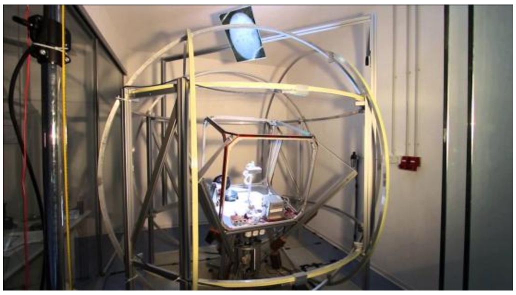

Figure 4: A view of the second type simulator along with other testing components and status control (Dumke, M. 2011)

As shown in Figure 5, the mirror can move on the semicircular path, and the light source shines light from outside and on a base that has the ability to adjust the height. The semi-circular rails, also is mounted on the mirror, can rotate 180 degrees around the perpendicular axis. The advantage of this mechanism is that different angles of the sun can be simulated with this simulator of the sun. Another noteworthy point is that the light angle of the light during the test is constant. The structure on which the mirror is mounted, can displace and rotate around a 360 degree perpendicular axis. To get different angles, it is necessary to coordinate between the light source and the mirror, which is done prior to the start of the test and carried out automatically (HSFL Overvie. 2017 & https://www.hsfl.hawaii.edu/facilities/adcs/)

Figure 5: View of the solar simulator of the third type model (HSFL Overvie. 2017 & https://www.hsfl.hawaii.edu/facilities/adcs/)

In the example shown in Figure. 6, the light source shines directly towards the table so it does not need a mirror. The light source in this sample is connected to the aluminum structure by two arms. The two arms are connected to the spotlight by a pin with a degree of freedom, and the other end of the arms is connected to a degree of freedom and pin-to-aluminum connection. An electric motor is used to rotate the spotlights and aluminum rails around the axis perpendicular to the ground to form different elevation angles. Another important point in this sample is the distance between the light cargo and the table. This point is important in designing the features of the spotlight, as well as the dimensions of the structure, because spotlight approached the table space is limited motion, and no mechanism can be used to satisfy the desired movement.

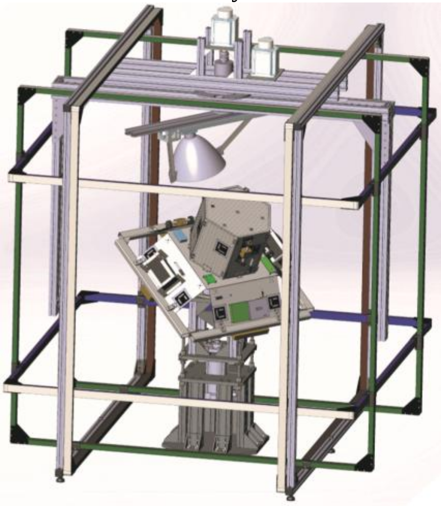

Figure 6 Sample 4 simulator along with other parts of the test table

The requirements and system requirements are to be considered in order to select the structure and option. So, in the next section, we will discuss the requirements of the system.

II. OPTICAL REQUIREMENTS FOR THE SOLAR SIMULATOR

According to the announcement of the required project, the requirements for the solar simulator are described below. Spectrum: As far as possible, it's similar to the sun's spectrum. (At least in the HMI vapor discharge lamp or new technologies such as LEDs)

- Light intensity at the satellite location: 50,000 lux
- Circle diameter with uniform light in center: 50 cm
- Motion radius: 450 cm
- Angular positioning of the solar simulator (degree): 0.1

Based on requirements and our studies, the structure of Figure (2) is considered as a suitable model for design in this paper. The advantages, similarities and differences of the samples with the chosen structure are as follows:

1. This aluminum mirror design is used.
2. The mirror is capable of moving on a semicircular path. However, in the other model in which the mirrors are not used, and the light is directly transmitted to the surface of the optical table or the mirrors are fixed.
3. The mirror has a 180-degree rotation around the axis perpendicular to the ground.
4. In the previous model, the light source is considered on a fixed base that has the ability to change the height. But in this design, the light source can move on a semicircular path.
5. The highest level of brightness at the table surface is 41,000 lux, which is a closest to the brightness of the sun's surface.
6. Another advantage is the parallelization of light output from the source by a lens designed with the highest percentage of parallelism.
7. Because of the parallel light received at the optical table surface, all angles measured by the solar sensors will be the same.

Therefore, in this paper, the preliminary and minor design of the optics section will be carried out in such a way that the requirements stated in Section (2) are met. For this purpose, the principles and relations prevailing on the optics, lens and mirror sections are first described and then designed and analyzed using Zemax software. In the section of designing the optics, the light released from the source is parallel, and to ensure the results are achieved, the design is done in two sequential and non-sequential structures. In order to consider manufacturing and implementation considerations, error sources and error analyzes are identified for each of the elements, and the constraints of each of the influential factors in the field of optics will be extracted.

III. INTRODUCING THE CONSIDERED SIMULATION STRUCTURE

The structure of this simulator consists of two optical and mechanical parts. The goal of this paper is to design an optical section that uses an electric discharge steam lamp (HMI) as a light source. The released light passes through a designed lens and with the highest percentage is parallel (Eugene Hecht. 2017 & C. Frohlich.2006), then hits a mirror and eventually reflects the surface of the optic table. This structure is shown in Figure2. These elements are as follows:

1. Light source: The electric discharge steam lamp MSHR HMI has a radiant intensity of 49,000 lumens. Which has the ability to move 180 degrees around the perpendicular to the earth's axis and satellite location.
2. There are a pre-made collimator lens made of BK7 is not available and is designed for this project.
3. The mirror is flat and made of aluminum with the highest reflectivity, capable of moving 180 degrees around the perpendicular to the earth's axis and satellite location.
4. Optical table with 3 degrees of freedom.

In the following, according to the proposed structure, we will design the optical section.

IV. DESIGN OF THE OPTICAL PART

The design is done in two preliminary and partial sections. We will go through each of these sections**.**

4-1. Preliminary design:

The first part includes the study of principles and relations governing the optical sector as well as design in the software environment.

4-1-1. Study Principles and Relationships Governing the Optical Division.

In accordance with the requirements, the light intensity level on the table should be equalize to the intensity of the sun's brightness. Also, the radius of the sun's simulator arches that optics devices are placed on it is 25.2 m. According to the inverse square law (Alma E. F. Taylor.1990 & Bukshtab, Michael. 2012):

$$E_t = \frac{I}{d^2} \qquad (1)$$

Where:

$E_t = 50000$ lux, table level illumination and d = 2.25 m. Distance between the table and the light source, which reflects the light from the mirror. As a result:

$$I = E_t \times d^2 = 253152\left(\frac{lum}{sr}\right) \qquad (2)$$

Now we use the following equation to find the space angle:

$$\Omega = \frac{2\pi dh}{d^2} = \frac{2\pi h}{d} \quad \text{(sr)} \qquad (3)$$

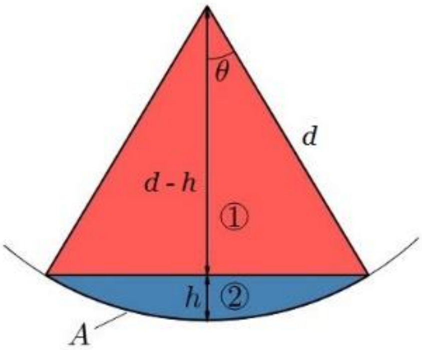

Figure 7. Components of a butter sector with spatial angles

And on the other hand (Alma E. F. Taylor. 1990):

$$h = d - \sqrt{d^2 - \frac{c^2}{4}} \qquad (4)$$

In this case, C is the diameter of the circle of light that should be placed on the table that equal to 0.5 meters. Consequently:

$$h = 0.013932(m)$$

Therefore, the angle of the space will be calculated as follows:

$$\Omega = 0.03890 \ \text{sr}$$

For the light intensity units, we used equation 5 (Alma E. F. Taylor. 1990):

$$I = \frac{F}{\Omega} \to F = I \times \Omega = 9846.5 \ \text{(lum)} \qquad (5)$$

As a result, 9846.5 lum is the amount of light flux emitted from the mirror at the table level. We are now discussing the connection between the lamp and the mirror. With regard to Figure8, it can be said that with a lamp with Optical flux of 49,000 lumens, at 1 meter distance, at a level of 1 sq. M, we will have a brightness of 49,000 lux. Hence, by placing a surface area of 0.5 × 0.5, there is a need for a less optical flux to reach 50,000 lux. In terms of fit, we find that the optical flux for this mode will be 12250 lumens.

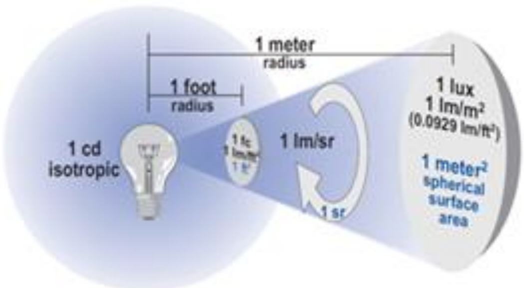

Figure 8. Lighting

Given the Figure9 and the following equation which is known as the Cosine Lambert equation, we have constant surface area (Alma E. F. Taylor. 1990):

$$E_\theta = E.\cos\theta \qquad (6)$$

$$F_\theta = F\cos\theta \to \theta = \cos^{-1}\left(\frac{L_\theta}{L}\right) = 36^\circ$$

As a result, the angle of the beams sent to the mirror with the vertical line of the mirror will be 36 degrees and finally, the angle of the mirror to the structure should be complementary to that angle of 54 degrees.

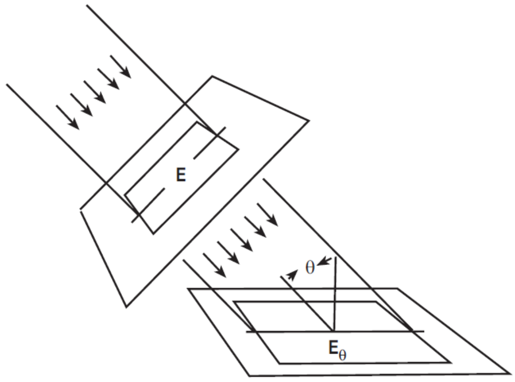

Figure 9. The Law of Cusinos Lambert

To validate this item, using the Digimizer software, the mirror angle is calculated in the simulator Astr-und Feinwerktechnik, which is in accordance with Figure10.

Figure 10: Validation of the calculations done with the sample

4-1-2. Preliminary design verification using Zemax software.

Considering the research done and considering the desired goals, we examined the available optical software and finally, ZIMEX software was used to simulate it. ZIMEX is software based on beam tracing and beam diffusion modeling in the optical system. This software can simulate the effect of optical elements such as simple lenses, aspherical lens, gradient-index, mirrors, and optic refractive and diffusion elements. ZIMEX also creates standard analytical charts. This software has two different sequential and non-sequential environments (Sequential or Mixed Sequential/ Non-Sequential and Non-Sequential) for design. The ordering environment, as its name implies, is used for designing cases where light passes through the designed elements, respectively (the light path is specified) and eventually reaches the image page. But in a non-Sequential environment, the light path is uncertain and the light randomly selects a path to reach the detector plate. This environment has features such as viewing the heat of the light and the amount of luxury and lumens on the level of the detector and etc. In this design, in order to ensure the results obtained from the processing and analysis of optical design in both environments, the results are compared in both environments and the same output obtained confirms design accuracy.

In the following, with respect to selected elements, software design is provided in both sequential and non-vertical environments.

4-1-2-1. Design in a sequential environment:

In Figure 11, a three dimensional design of this design is shown.

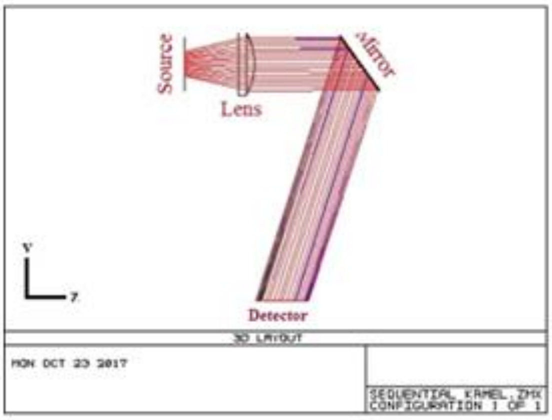

Figure 11. 3D Design View

According to the selected lamp and the information contained in the lamp catalog and the optimization of the calculations performed in the design of the optical structure, first, in a sequential environment with the following design conditions:

- The selected light source has a divergence percentage of 22 centimeters. (Divergence percentage is specified in the lamp catalog).
- The distance of the light source output from the lens page is 52 cm in the direction of the z-axis that optimized.
- The lens is 15 cm thick in the z-axis direction.
- The distance of the output light parallel from the lens to the mirror is 100 cm in the z-axis direction.
- The mirror is located at the angle of 36 degrees relative to the z axis.
- The detector plate is located 225 cm from the mirror in the direction of the Y axis and 73 cm in the direction of the X axis.

These distances and sizes are shown in Figure 12:

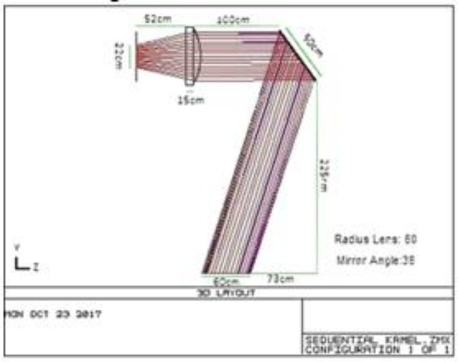

Figure 12. Showing the calculated and optimized distances

In this design optimization of distances is done by the software. So that the calculated distances from the formulas, for example, the distance obtained between the parallel light and the mirror, or the mirror distance to the level of the detector (the optical table surface), are fixed and the intervals such as the thickness of the lens or the distance from the light source to the lens are variable is considered and the software optimizes the distance of variables.

In the table 1, a summary of these results, the area and gender of the elements are presented.

In optical systems, each deviation occurs from the full image under the name of aberration, which is a deviation for single light including spherical aberration, coma aberration, field curvature, distortion, and astigmatism. The composite light will have a colorful aberration in addition to the aberrations. The software has

Table 1. Designed and selected components and elements

Elements	Model	Type	Components
Light source	MSRHR	HMI	Lumens = 49000 Average lamp life =750 hour Color temperature = 6000 K Voltage Start-up < 5Kv Running = 95v Current Start-up = 7.7 A Running = 7 A Percent Divergence = 22 %
Lens	-	BK7	Thickness = 15 cm Radius = 30 cm
Mirror	Flat	Aluminum	Area = 50×50 cm Angle = 36°
Output surface	Optical table	-	Area = 50×50 cm

an analysis called Spot Diagram (Outburst). The analysis shown in Figure13 specifies the following options:
1. The light output from the center of the light source or the center of the lens is considered as the center or axis, indicating that 80% of the light output from the source and the light received at the surface of the detector is at the radius of that axis.
2. Specifies the radius and precise size of the output blemish.
3. Indicates whether there is aberration, and if it is positive, the type of aberration can be detected.

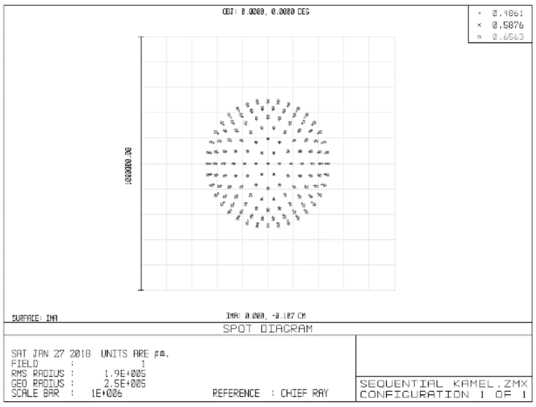

Figure 13 Spot Diagram output

The analysis output and the numbers in Figure13 show that 80% of the output light from the source and the received light at the detector surface (RMS Radius = 1.9 E + 500 µm) are in a radial size of 19 cm that centered axis is considered. It also shows that the output is completely circular GEO Radius = 2.5E + 005µm and 25 cm in radius. Confluence and Convergence the triple symbols (Multi plication summation, and squares) shown in Figure 13 indicate the absence of an aberration in the received light at the surface of the data plate.

4-1-2-2. Design in non-sequential environment:

The three-dimensional design output in this environment is quite similar to the sequential environment. The reason for designing in this environment is the amount of intensity, power, luxury and flux of the system output designed at the surface of the detector because of the greater accuracy of the analysis in this case. In this mode, the software is first implemented, the analysis is performed, and then the output of the same form (14) will be displayed.

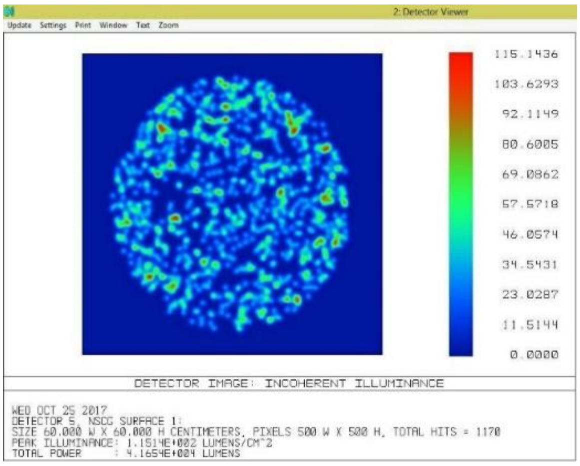

Figure 14 Display the output of the detector

Given the output shape and the numbers presented in it, the result is that the surface of the detector plate is 60x60 cm, with an entirely illuminated page of 41,000 lumens.

4-2. Optical component design

In the partial design, first consider the tolerance and then analyze the tolerances.

4-2-1. Calculation of tolerance

Calculation of tolerance and percentage error of selected elements are the major challenges of any design. Tolerance measurement in the designed simulator is done by selecting the elements and their technical specifications using the software. The result is determines the effect of each element on the simulator's ultimate goal and can be selected based on it or decide to change the elements. The Zemax software reviews and compares the tolerance of the selected elements by which it can be concluded which element is the most and which element has the least positive and negative effect in achieving the desired goal. We will continue to analyze the aforementioned analyzes.

4-2-2. Graphing Analysis of Tolerances

The main purpose of the design is to have the intensity of sunlight at the surface of the optic table at a radius of 25 centimeters. Considering that the selective light source has the greatest effect on the radiation intensity at the table surface, As a result, the analysis of the graphs of other elements is based on the diameter of the output stain.

With respect to the selected elements, it is observed in the calculation of the tolerance and the result of the tolerances that the lens's distance from the mirror's surface, the mirror thickness, the vertical distance of the mirror to the surface of the optical table, and the half of the light source openings have a smooth slope of zero. As a result, they have no effect on the size of the diameter of the stain of the output. However, the initial surface thickness charts, the source distance to the lens plate, and the lens thickness have a negative slope output relative to the diameter of the stain and therefore have a negative effect on the diameter of the stain. Finally, by observing all the graphs examined, it is concluded that the curvature angle of the lens has the most positive effect on the diameter of the output blemish. The following four charts are shown in the following figures:

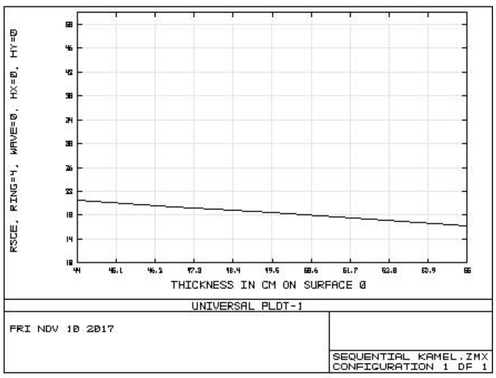

Fig. 15. Strip diameter diagram. Thickness of zero surface with slope of -0.39

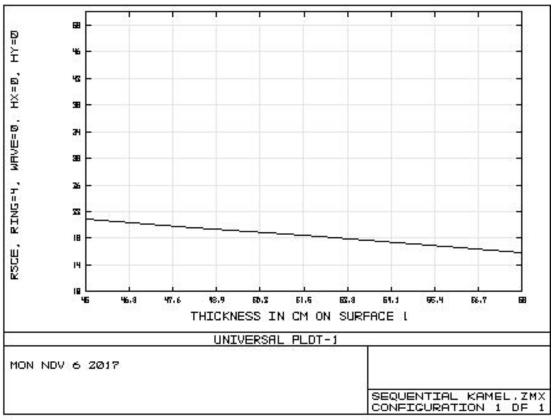

Figure 16 Spacing diagonal chart - Source distance to lens plate with -0.38

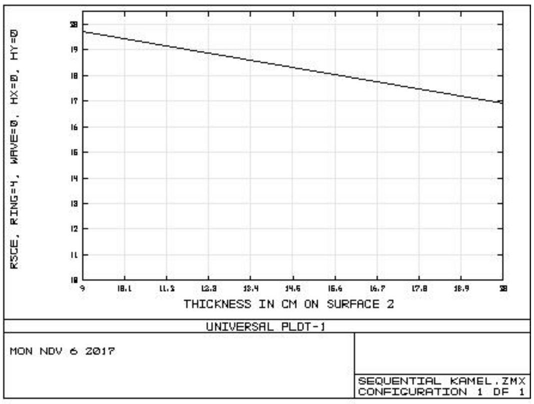

Fig. 17. Diagram of the diameter of the stain-thickness of the lens with a gradient of -0.25

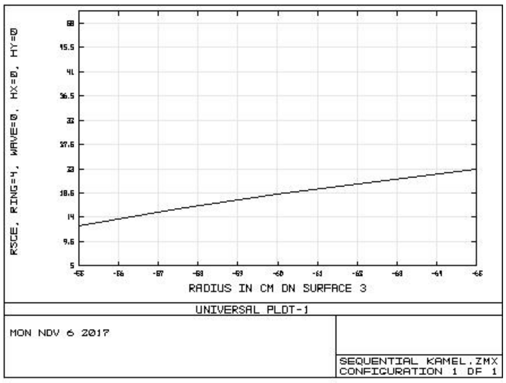

Figure 18 Spacing diagonal curve-curve angle lens with gradient 1.06

According to the above diagrams, the diameter of the elements used does not have any effect on the diameter and size of the output blemish on the surface of the detector (optical table surface). The only effective elements of this size, which are very important in this design, are the angle and thickness of the lens designed, the distance from the source to the lens, which is observed with respect to the gradient of the related diagrams, where the angle of the lens (Lens Radius) has the greatest impact on the diameter has a stain.

I. RESULT

The purpose of this design i**s** to create an intensity light equal to the intensity of sunlight at the optical desk surface and at angles similar to the various angles of solar radiation in a spot with a radius of $50 \times 50 cm^2$. According to the requirements, the characteristics of the selected elements and the results of the Tolerance measurement and analyzes carried out are favorable results compared to the calculations performed. The following table shows the effect of each element as a result of the output.

Table 2. The results of analysis of the tolerance of the elements in the size of the stain of the output

The elements of the analysis of the tolerance	Chart gradient
Thickness of the elementary level of the source	-0.38
Source distance to lens screen	-0.39
Lens thickness	-0.25
Angle of curvature of the lens	1.06
Lens Distance to Mirror surface	Fixed
Mirror thickness	Fixed
Mirror vertical distance to optic table surface	Fixed

According to the results, from the light source, the type of lens and the mirror of the bed, the type and conditions of the lens design, such as the angle of curvature and thickness, the calculated and optimized distances, the most positive effect is the angle of curvature of the lens and the greatest negative impact on the distance of the source Up to the lens plate on the diameter of the output blemish on the surface of the detector. Other elements and options will not have any effect due to the large distances between them. Also, according to the calculations, a spot with a 50x50 cm2 radius should be created, an extremely high-intensity 50,000 lux at a detector surface, in which the light received will be visible in a spot with the same radius, which is 80% of the incoming light in the radius of 19 Centimeters with an intensity equal to 41,000 lumens.

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