CZECH TECHNICAL UNIVERSITY IN PRAGUE

FACULTY OF MECHANICAL ENGINEERING

Instrumentation and Control Engineering

Master Thesis

Design of a Safety Shutter for Laser Beam

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Prague, 2021

Annotation

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Title : Design of a Safety Shutter for Laser Beam

Academic Year : 2020/2021

Programme : Master of Instrumentation and Control Engineering

Major : Applied Optics

Supervisor : Ing. Jiří Čáp, Ph.D.

Abstract : This thesis examines the absorption of a laser beam whose parameters such as wavelength, stroke, pulse duration, operation time have been defined before. The size limits of the safety shutter to be used for the absorption process are predetermined and yield improvements were made without exceeding the size limits. The cooling of the heat generated by the laser was provided by water. This thesis also has 3D drawings, material information and dimensions of all these applications. In addition, it includes other designs and scenarios that can be used for cooling. Solidworks software of SolidWorks Corporation were used for 3D designs and thermal analysis.

Keywords : Lasers, Safety Shutter, Applied Optics, Water Cooled Laser, Thermal Analysis

Number of Pages : 47

Number of Figures : 46

Number of Tables : 5

Declaration

I hereby declare that the thesis ‘Design of a Safety Shutter for Laser Beam’ is based on my own work. All ideas, major views and data from different resources by other authors were only used as a reference and/or research purpose. I am the sole author of the thesis and that neither any part of this thesis nor the whole of the thesis has been submitted for a degree to any other University or Institution.

In Prague ………… Ebrar Yücel Odabaş

Acknowledgements

I would like to thanks to my thesis advisor Mr. Jiri Cap for his guidance, patience, cooperation and everything he contributed to me. He always gave me valuable advice and our communication was very good at every stage of the thesis. I would also like to thank him for helping me find my thesis subject .

Special thanks for Mr. Vladimír Hlaváč who answered all my questions and helped me during my education life in Czech Technical University in Prague.

Finally, my special thanks belong to my family for their existence, love and their belief to me.

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1. Introduction

General Overview to Safety Shutters

Safety shutters are optical locks that block the beam path in the event of unauthorized access and thus prevent laser radiation from leaving the laser environment uncontrolled. The laser shutters either absorb the entire laser power or direct it into an external beam dump using a mirror. The heat energy created by the laser beam is absorbed by water or air. The shutter can be manually operated and integrated into the safety circuit of an interlock control system.

In this thesis, the design and optimization of a water-cooled safety shutter with predefined limits will be examined.

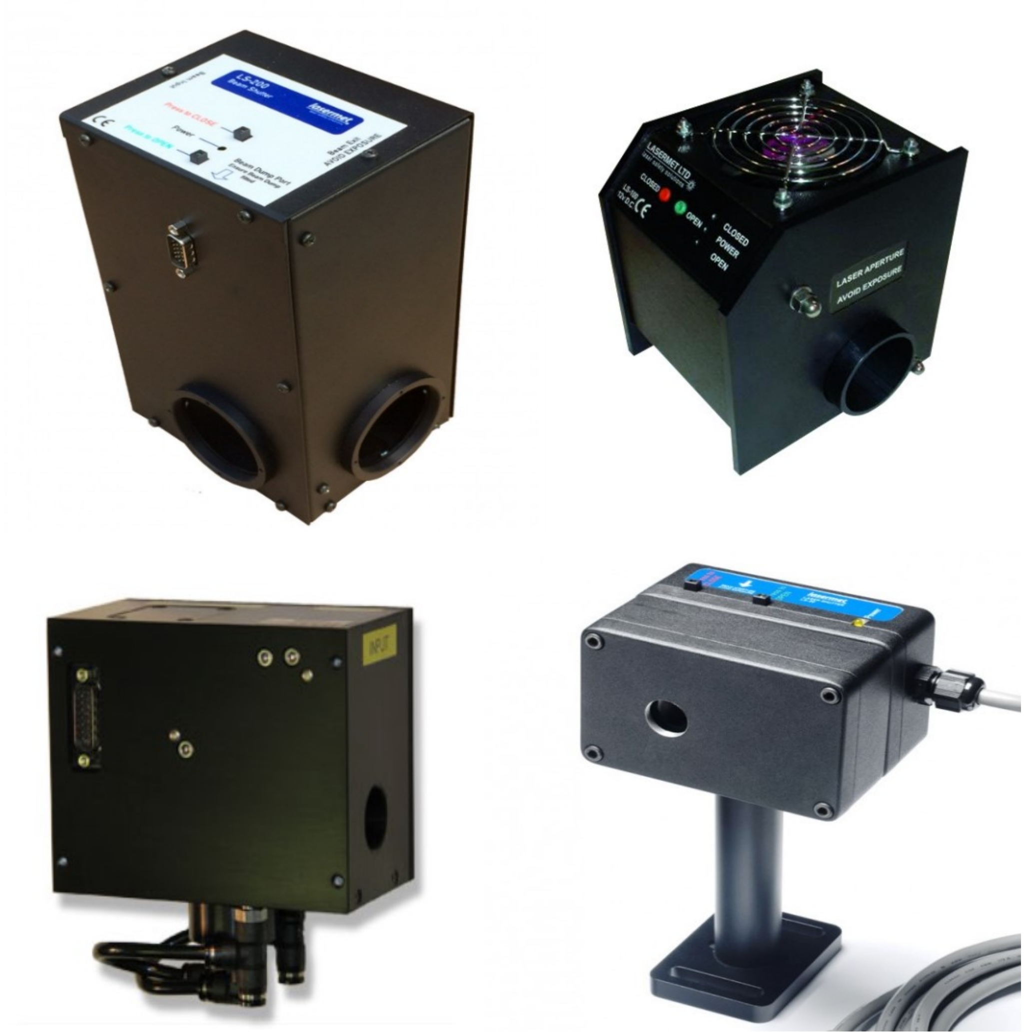

Fig. 1Examples of commercially available safety shutters for lasers [1] [2]

2. Starting Conditions and Limitations

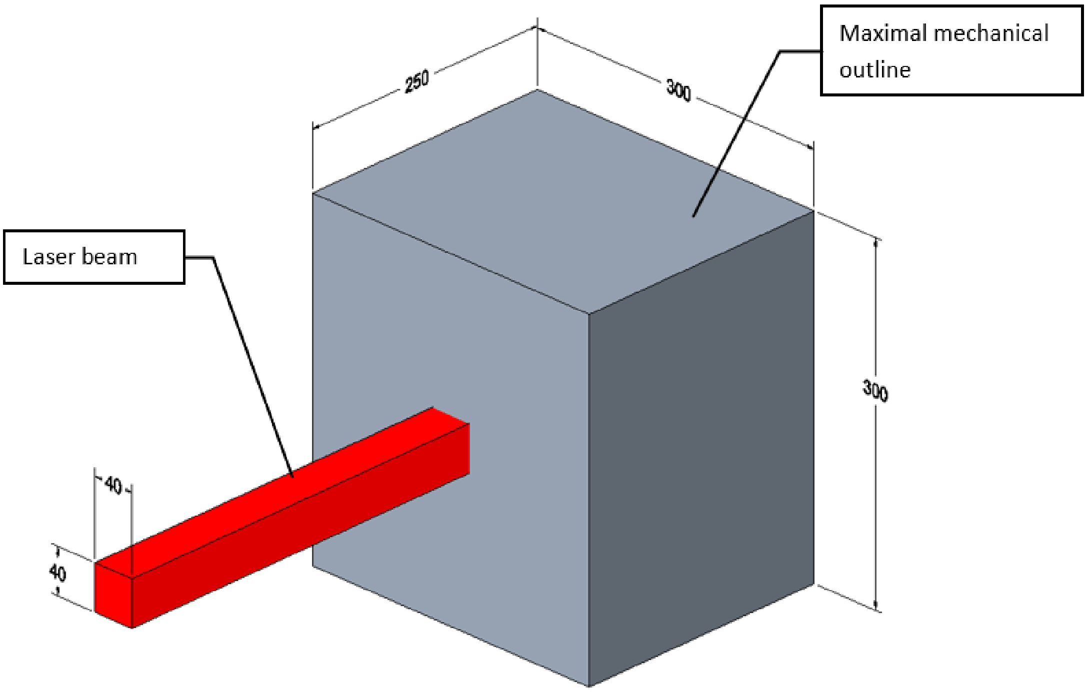

Fig.2 Shutter's maximum mechanical outline and laser beam shape

As seen in the figure above, the maximum volume we can create for the shutter is a rectangular prism of 300*300*250 mm. In addition, the shape of the laser is a square of 40*40 mm. Laser beam aperture has homogeneous energy distribution. A commonly used chiller in the market will be used to cool the safety shutter. The features of the product will be given in the analysis section of the thesis. Although there are no material restrictions for the product at the beginning, it is recommended to use aluminum alloy or steel. Other materials to be used in the safety shutter will be examined in the design section.

Other parameters related to laser beam and operation time are as follows :

Tab. 1 Parameters of Laser and Operation Time

Energy in pulse:	150 J
Pulse duration:	2 – 10 ns
Repetition frequency:	10 Hz
Wavelength:	1030 nm, 515 nm, 343 nm
Maximum operating time:	30 min

3. Design Theory

The design is generally based on reflecting and cooling the laser beam onto a cooling channel. During the operation period, it is ensured that the laser hits the cooling channel and is absorbed. During the time period without operating time, the laser enters the shutter and leaves the laser without any reflection.

It provides the operation time and the closed state of the shutter, a movement inside the shutter. What is meant by this mobility is that the laser beams come straight out of the shutter without hitting anything. To achieve this, some parts must move inside of shutter. There are 2 options for this. Firstly, it can be thought that the cooling channel is moved by an actuator to stop and start the operation time. And secondly, a mirror is moved with the help of the actuator to reflect the laser beam on a fixed cooling channel stopping or starting the operation time.

It preferred to use mirrors in the design because it is easier to install and lighter than the cooling channel, and it is also a better option in terms of mobility.

Another important aspect in the design is the angle of incidence of the laser beam into the cooling channel. The aim here is to increase the area covered by the laser beam on the cooling channel and to reduce the heat density that will occur on the surface. In other words, although the laser we will use here normally has an area of 40 * 40mm, we will have a wider area by changing the angle of reflection of the laser on the surface of the cooling channel.

These are the basic design considerations, now we will specifically examine all the parts that make up the design, their material and thermal properties, and their geometry.

3.1. Calculations

The equation for photon energy is

Where E is photon energy, h is the Planck constant, c is the speed of light in vacuum and λ is the photon's wavelength. As h and c are both constants, photon energy E changes in inverse relation to wavelength λ.

Planck's constant = 6.62607004 × 10-34 m2 kg / s

The speed of light = 299 792 458 m / s

What is the energy of a photon of (λ = 1030 nm) and of a photon of (λ = 515 nm) and of a photon of in units of (λ = 434 nm) eV = 1.6*10-19 J

Photon(λ = 1030 nm) : E = (6.626*10-34 Js)(3*108 m/s)/(1030*10-9 m) = 4.4*10-19 J = 6.31 eV = 1 * 10-18 J

Photon(λ = 515 nm) : E = (6.626*10-34 Js)(3*108 m/s)/(515*10-9 m) = 4.4*10-19 J = 3.15 eV = 5.048 * 10-19

Photon(λ = 343 nm) : E = (6.626*10-34 Js)(3*108 m/s)/(434*10-9 m) = 4.4*10-19 J = 2.66 eV = 4.25 *10-19 J

In the calculations here are that if the photon energy originating from the laser affects the object with the lowest wavelength during the operation period, we calculate the maximum operation time from 30 minutes * 60 seconds to 1800 seconds. By multiplying the operation time by 1 *10-18 J, we get 18 *10-16 J. This value is the total photon energy we will obtain during the maximum operation period.

Repetition frequency 10 Hz means 10 pulses per second. Energy in every pulse is 150 J so 10 * 150J=1500J per second = 1500W average input power.

We will use the 1500 W value as the heat power in the simulation in the next steps in report.

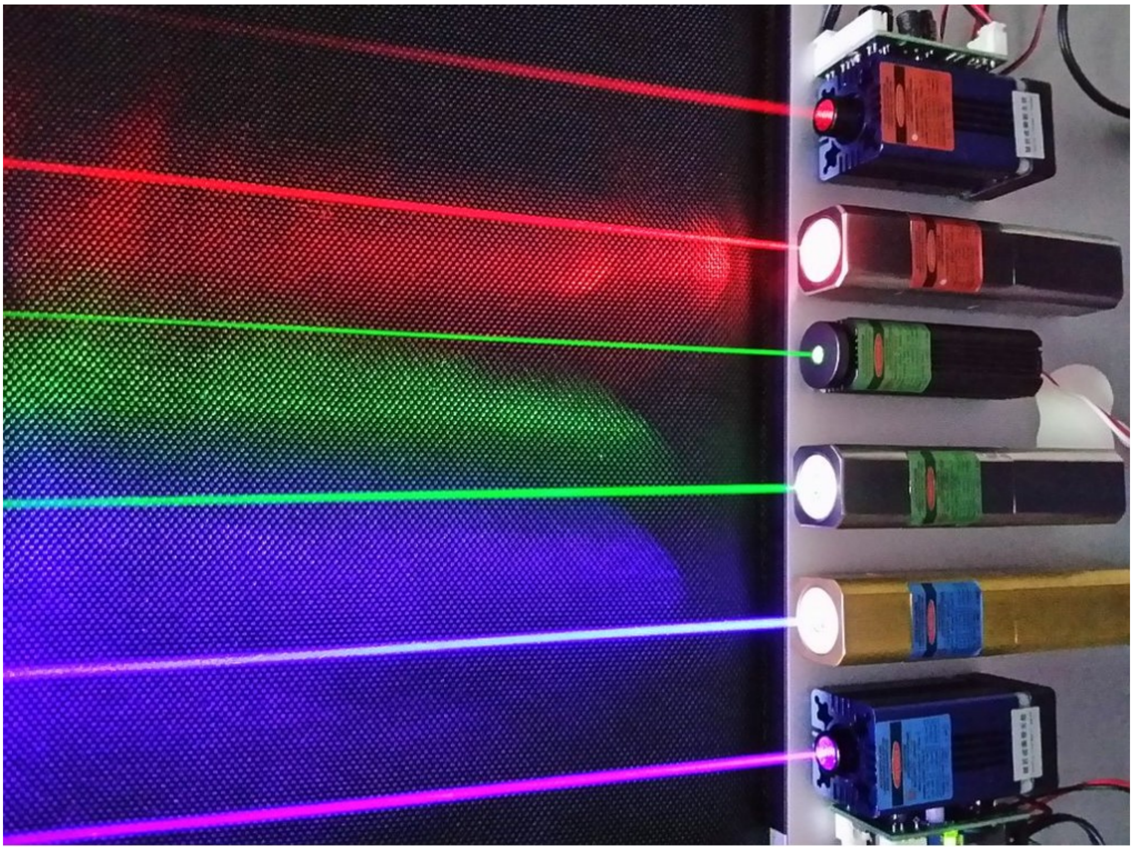

Fig. 3 Photons are emitted in a threaded laser beam [3]

3.2. Design overview and Tools names

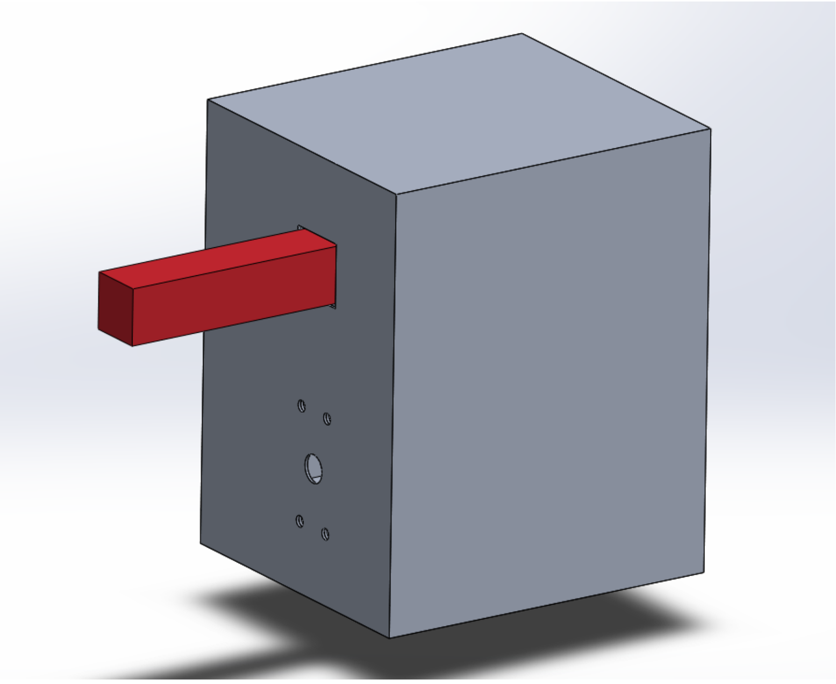

Fig. 4 Safety Shutter Overview

In the figure above, the outside view of the shutter and the entrance of the laser to the shutter are seen.

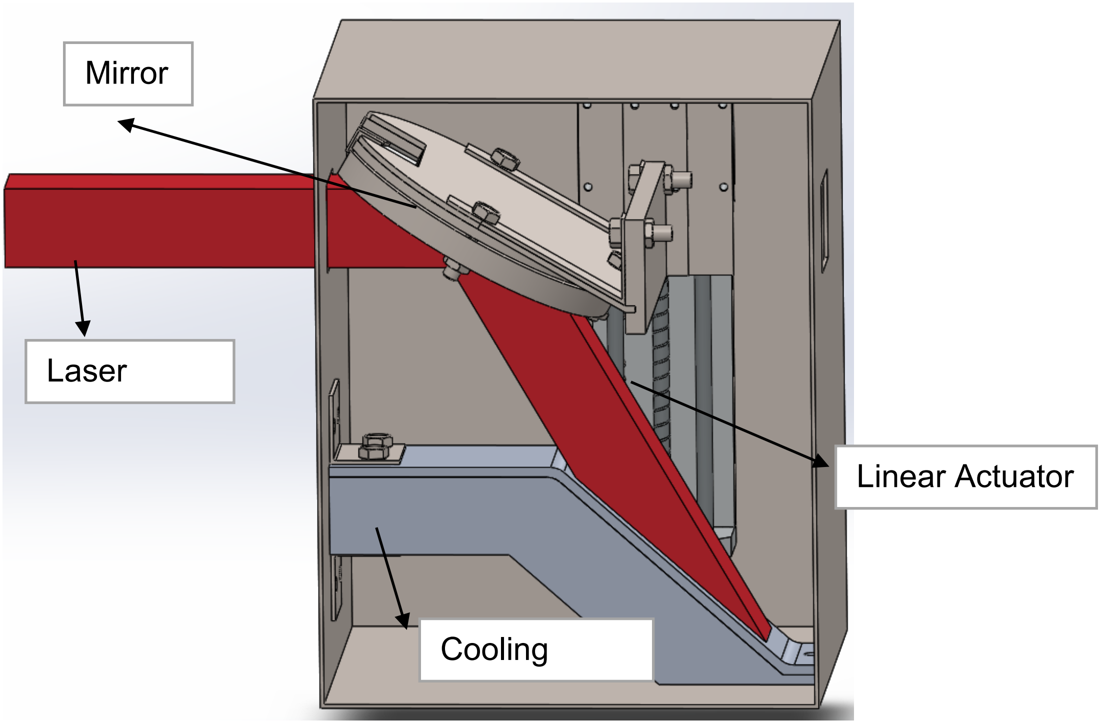

Fig. 5 Interior view of the shutter

3.3. Tools Details and Materials

a. Shutter Body : It is the part that holds the assembly together, in which the rest of the assembly is contained. There are holes on it for laser and water inlets and outlets, as well as for electrical connection of the actuator. AISI 316 stainless steel is used as material. The holes on it are suitable to be created with cnc milling.

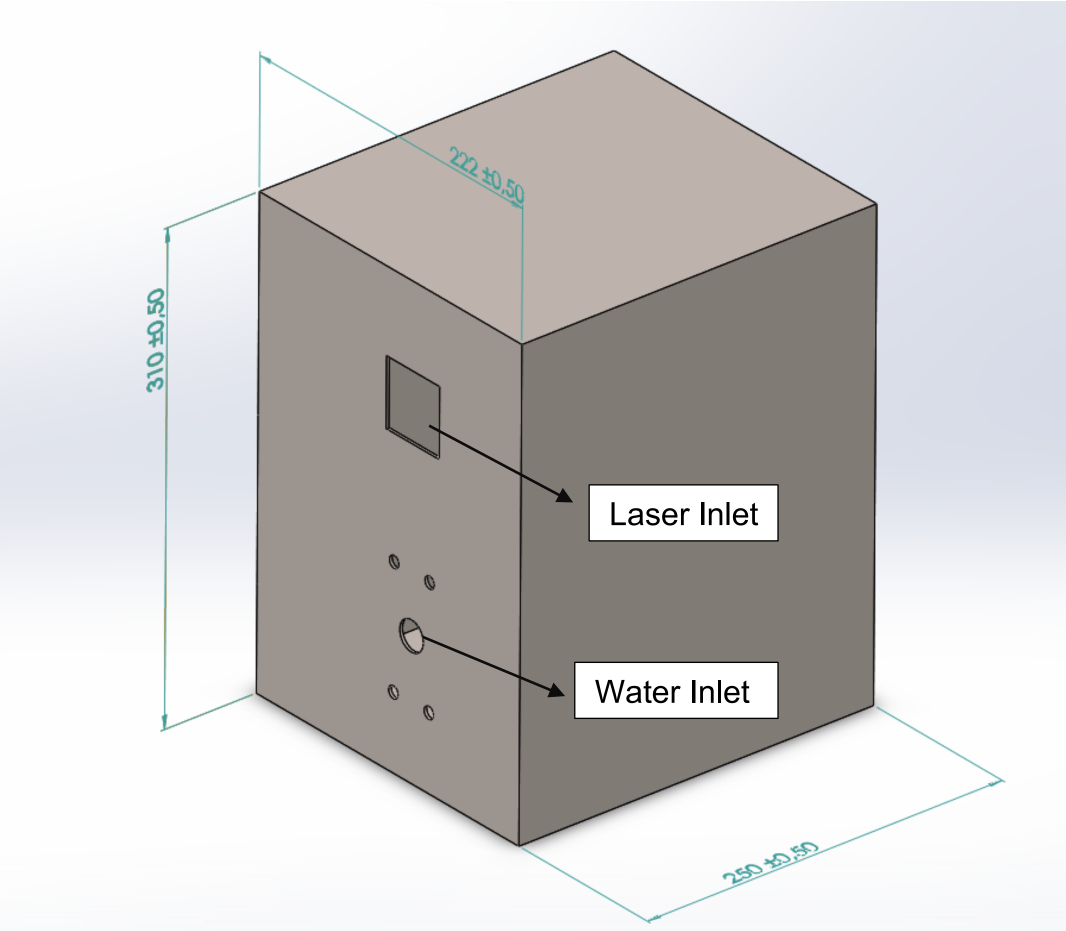

Fig. 6 Overview of Shutter Body

As seen in the figure above, the maximum outer dimension target for the shutter body is provided. The dimensions are 250*310*222 mm and the wall thickness of the object is 2 mm. Laser input is designed as 45*45 mm. Here, the area of the laser sent to the object is assumed to be 40*40, and it is desired to obtain a higher measurement than this measurement. The water inlet and outlet holes of the object are 20mm. This size is the same as the water output size of the chiller, which is the cooling source.

b. Mirror : In this section, the mirror and some parts used in its assembly will be examined. Mirror mounting consists of mirror, silicon rubber, thermal pad and some fixing elements. The mirror is a moving part and therefore some mounting and bearing elements have been designed for its fixation. This ensures a compact movement.

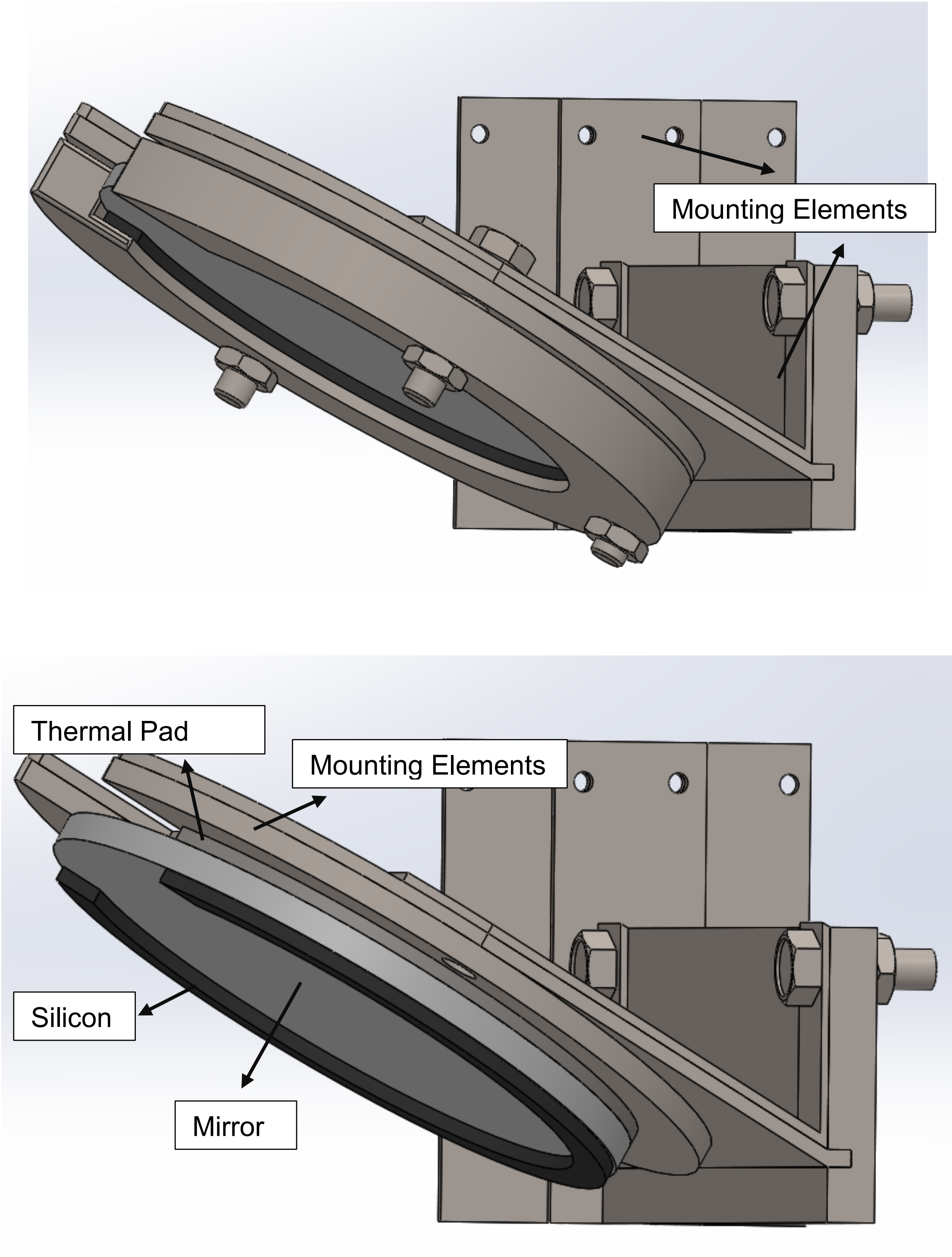

Fig. 7 Mirror Group

Mirror

Here we have to determine the mirror selection according to the laser parameters. The wavelengths we have are 1030nm, 515nm and 343nm. The mirror we choose should be suitable for operation in this wavelength range. Another factor in laser selection is the energy in the pulse. While trying to optimize the design, the ideal mirror diameter of 130mm was obtained. The thickness of laser mirrors is usually 20 times smaller of the diameter. We assign our mirror thickness as 6mm.

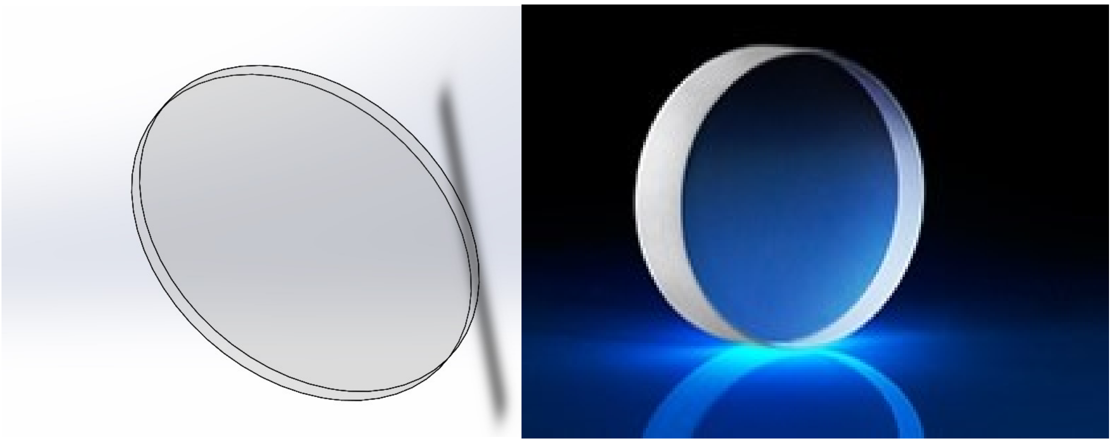

Fig. 8 Laser Mirror Solidworks Model - Laser Mirror [4]

Silicon Rubber Ring

Silicone rubber is an elastomer composed of silicone—itself a polymer—containing silicon together with carbon, hydrogen, and oxygen. They are used in industry commonly. Silicone rubbers are often one- or two-part polymers and may contain fillers to improve properties or reduce cost. Silicone rubber is generally stable, and resistant to extreme environments and temperatures from −55 to 300 °C while still maintaining its useful properties. The purpose of use in the project is to prevent heat conduction from the mirror to other parts of shutter. Its outer diameter is 129, its inner diameter is 114 and its thickness is 3mm.

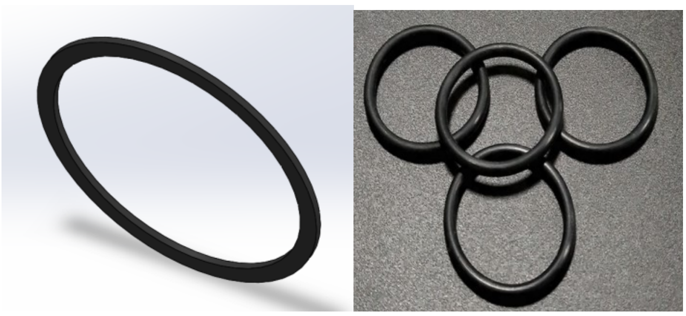

Fig. 9 Silicon Rubber Ring Solidworks Model - Silicon Rubber

Thermal Pad

In machining, computing and electronics, thermal pads are pre-formed rectangles of solid material (often paraffin wax or silicone based) commonly found on the underside of heatsinks to aid the conduction of heat away from the component being cooled (such as a CPU or another chip) and into the heatsink (usually made from aluminum or copper). Thermal pads and thermal compound are used to fill air gaps caused by imperfectly flat or smooth surfaces which should be in thermal contact. Thermal pads are relatively firm at room temperature but become soft and are able to fill gaps at higher temperatures. In the project, it was used between the mirror and the mounting element in accordance with these purposes. Its diameter is 130.5 mm and its thickness is 3mm.

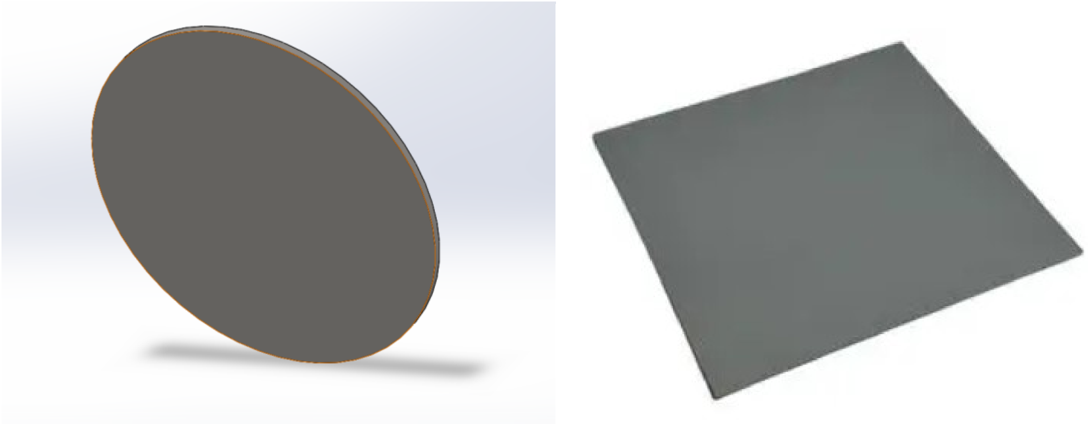

Fig. 10 Thermal Pad Solidworks Model - Thermal Pad

Mounting Elements

Some coupling and mounting elements have been used to assemble parts such as mirror, thermal pad, silicon rubber ring, and at the same time keep all these parts together and make them to move compactly with the actuator.

All parts used here are AISI 316 stainless steel. Their production can be done easily by cnc milling and sheet metal bending methods. And bolting will be used for their assembly. The aim is to achieve an extremely compact assembly. And the design was designed accordingly. No welding was used in production or assembly. The side of the mirror group that comes to the laser is designed with a mouth opening (except mirror). With this way, the heat effect of laser to metal mounting pieces can be minimized.

In the figures below, it is seen that each element used in mirror assembly is represented in different colors.

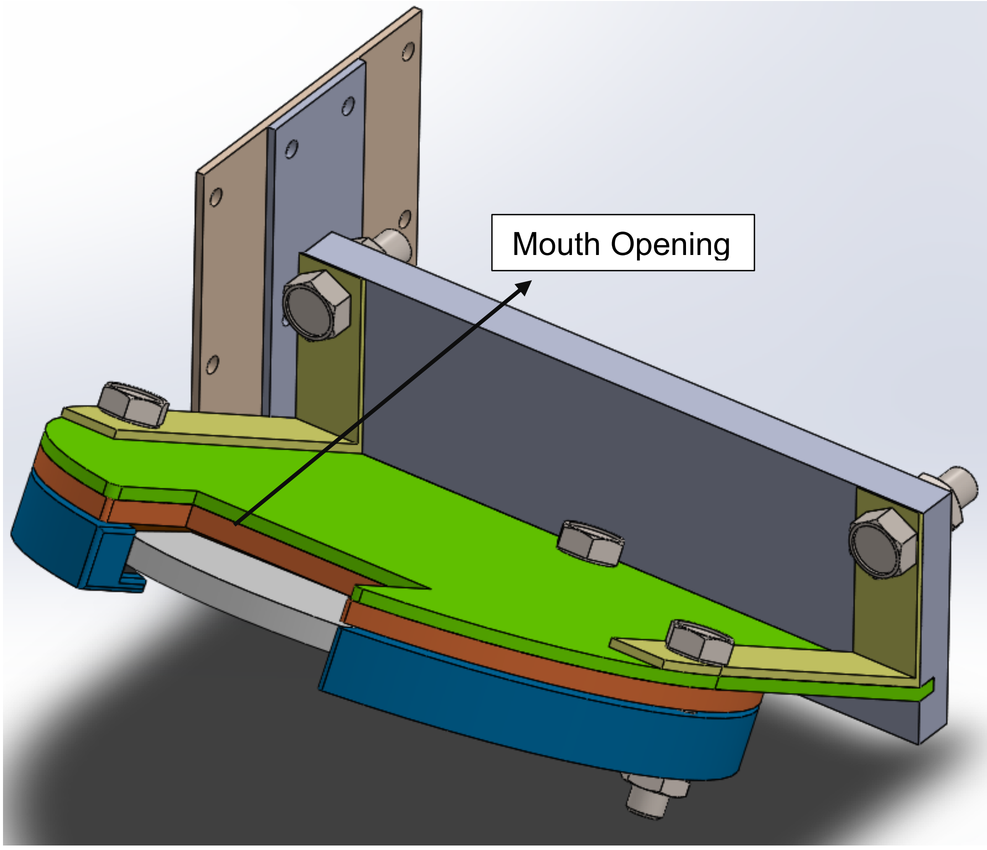

Fig. 11 Mirror Assembly Solidworks Model

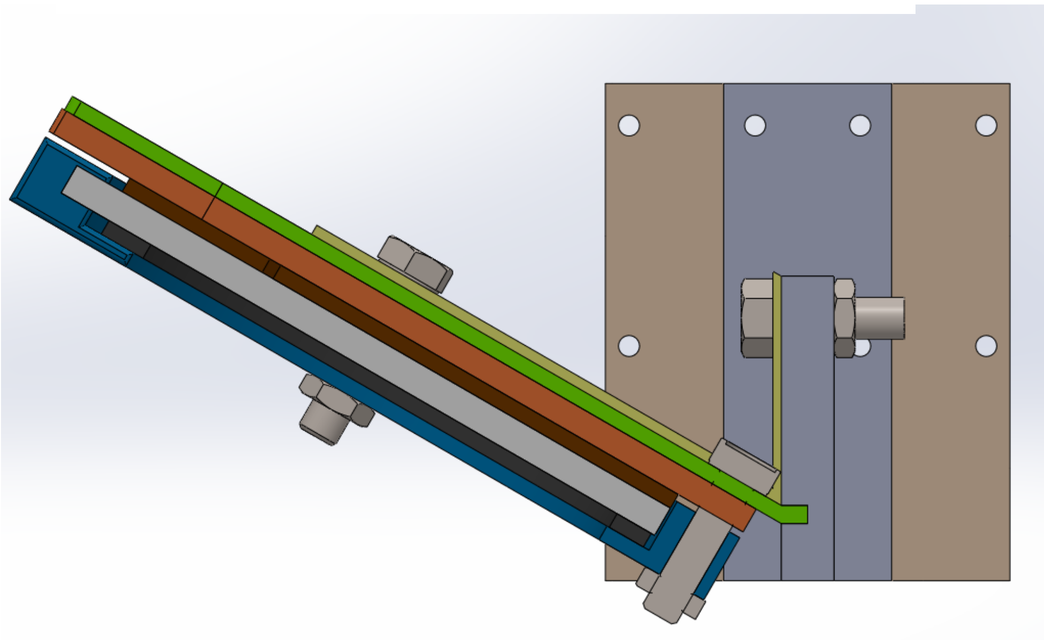

Fig. 12 Mirror Assembly Cross Section

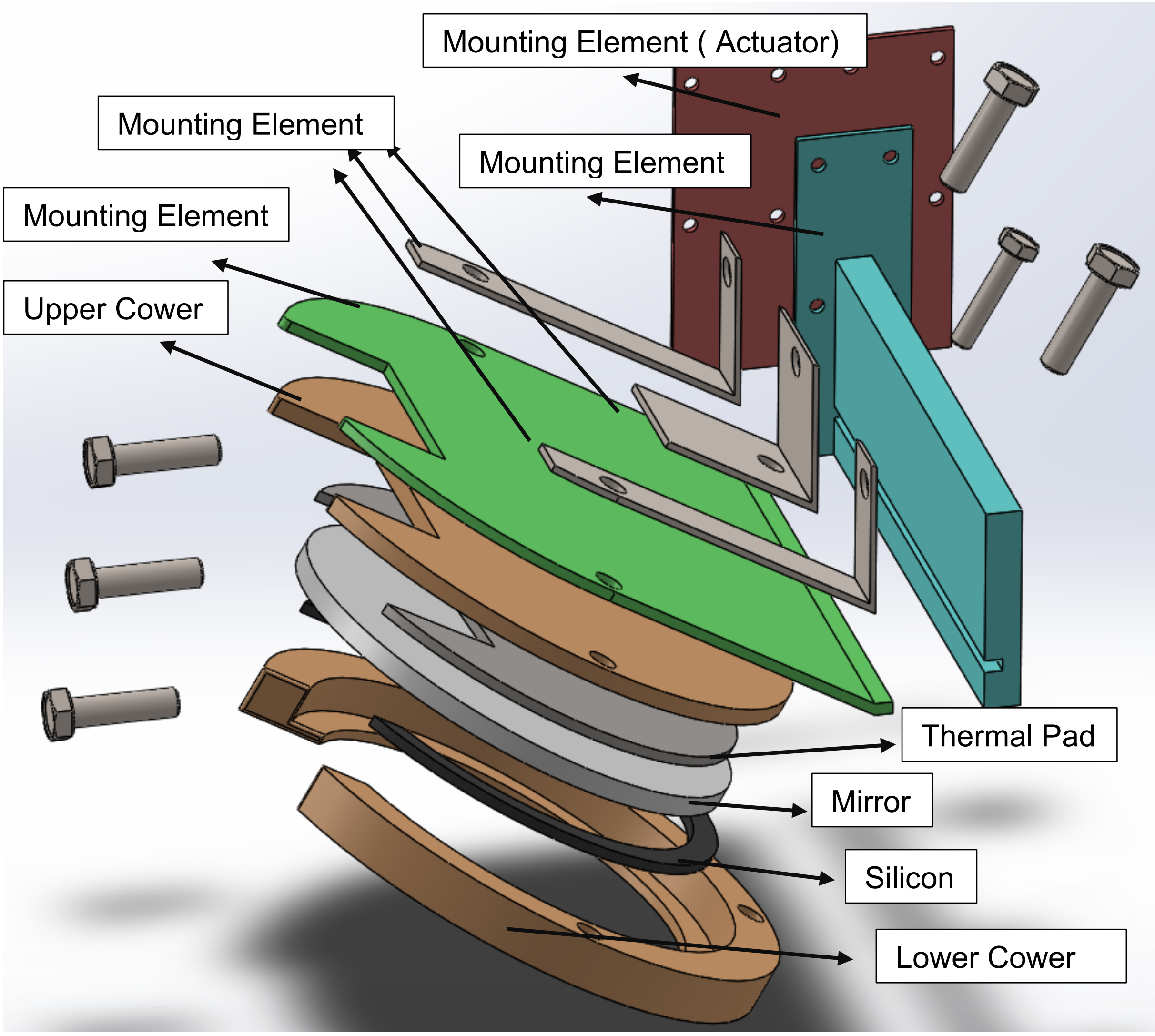

Fig. 13 Mirror Assembly Exploded View

The elements used in the assembly of the mirror were produced by cnc turning, milling and sheet bending methods. After the parts are made together, the bolts are tightened and the assembly is closed. In order to tighten the bolts, the silicon o-ring will be calculated as 1 mm thicker than it should be, and it will be compressed after the bolts are tightened.

Some elements are designed with mounting slots for ease of assembly. And the welding method was not used in the assembly construction.

c. Linear Actuator : In this section, the mirror and some parts used in its assembly will be examined. Mirror mounting consists of mirror, silicon rubber, thermal pad and some fixing elements. The mirror is a moving part and therefore some mounting and bearing elements have been designed for its fixation. This ensures a compact movement.

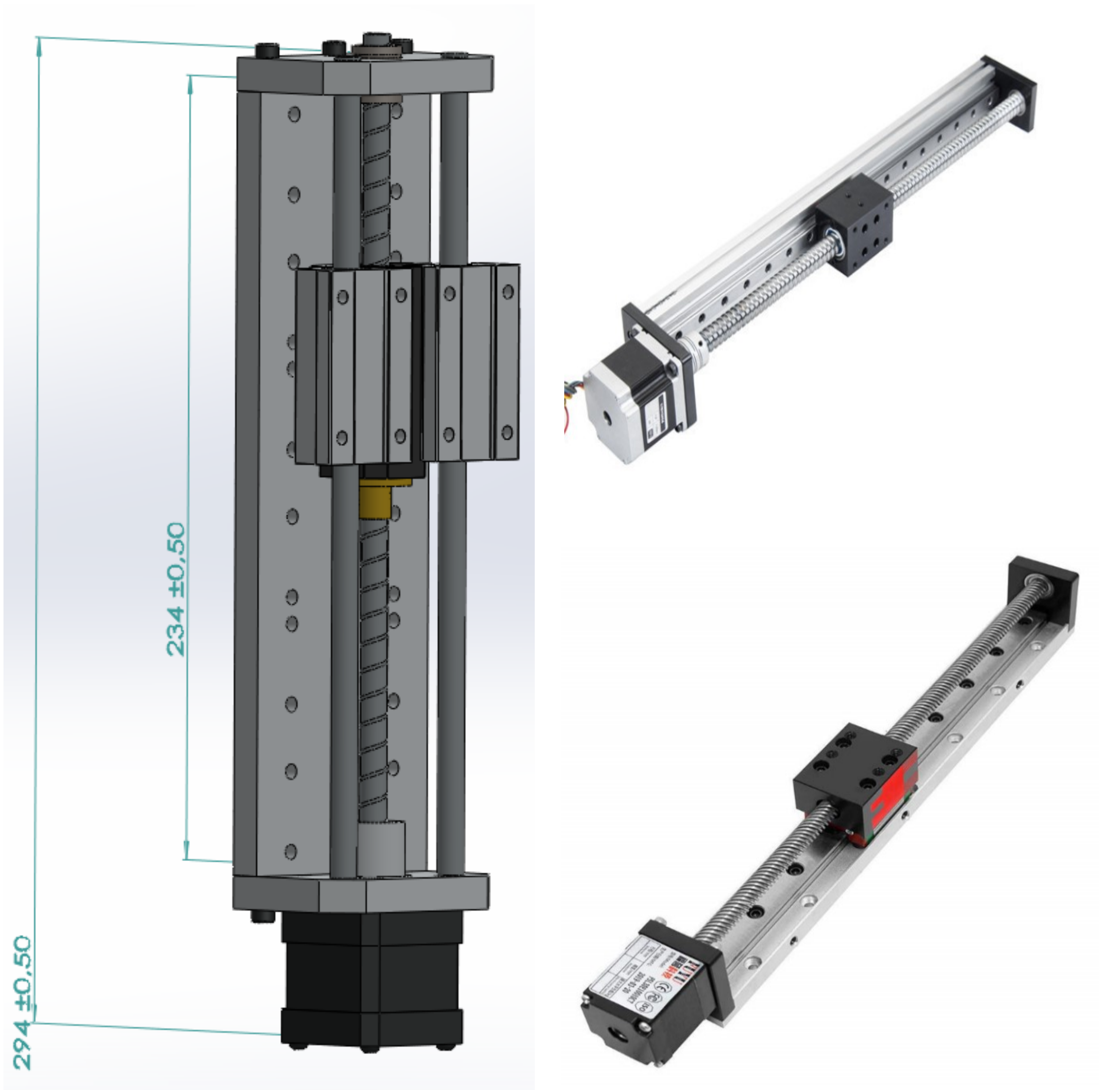

Fig. 14   Linear Actuator Solidworks Model – Linear Actuator [5]

Linear Actuator has a stepper motor and the circular motion produced by this motor is converted into linear motion on the actuator. The linear actuator used in the design can be found widely in the market and its table on it can move displacement of approximately 80 mm expected from the mirror due to design. There are many holes on it both for mounting to the body of the shutter and for mounting mirror elements to the actuator. Its material is aluminum alloy and stainless steel. Maximum speed of actuator is 50mm/s.

d. Cooling Circuit : This is the part where cooling will take place. The water inlet and outlet are here and the laser is reflected on the surface of this part. This is the part where the laser beam will be absorbed and cooled. In the design of the Cooling Circuit, the water changing speed is very important and the size of the contact surface where the laser is reflected is very important. Because of this increasing, cooling becomes easier. Also, as can be seen below, fins are placed inside the cooling circuit to dissipate the heat.

Alloy 1350, a special aluminum alloy, is used as the material of the cooling circuit. The 1xxx aluminum alloy series has very high electrical and thermal conductivity. Aluminum alloy 1350 has a higher specific heat than its counterparts in the 1 series of aluminum alloy. This means it will heat up more slowly than others. The surface of the cooling circuit is inclined 40 degrees relative to the ground, and thanks to this inclination, the area that the laser will contact has increased from 16 square centimeters to 51.2 square centimeters.

Cooling circuit consists of 2 separate parts. The bottom and upper parts are welded to each other. The fins to the upper part are welded to the upper part before upper part are welded to the lower part.

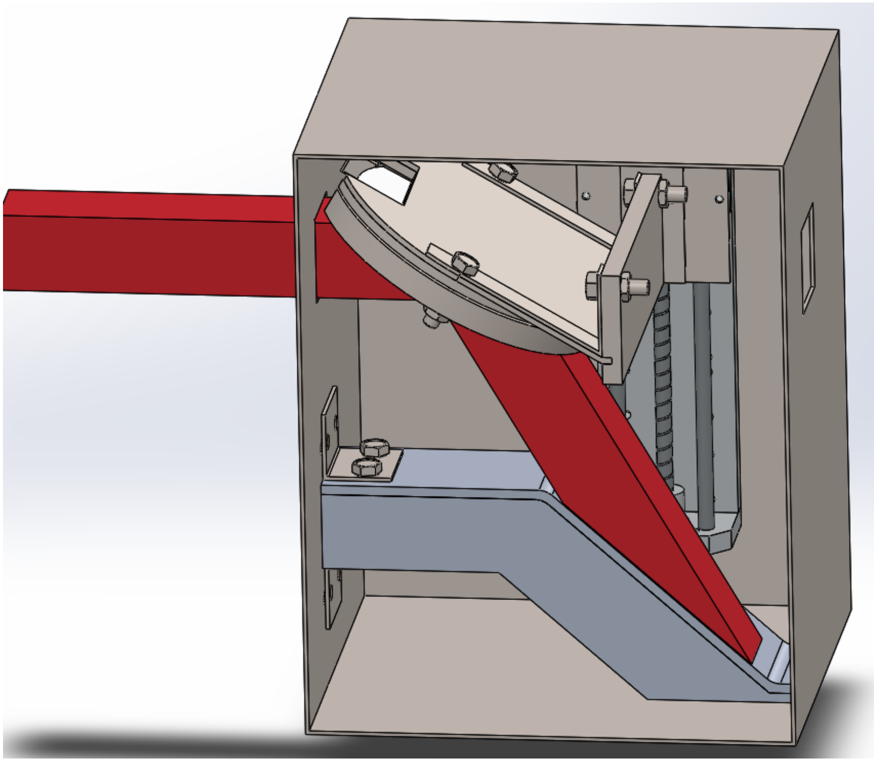

Fig. 15 Cooling Circuit Solidworks Model

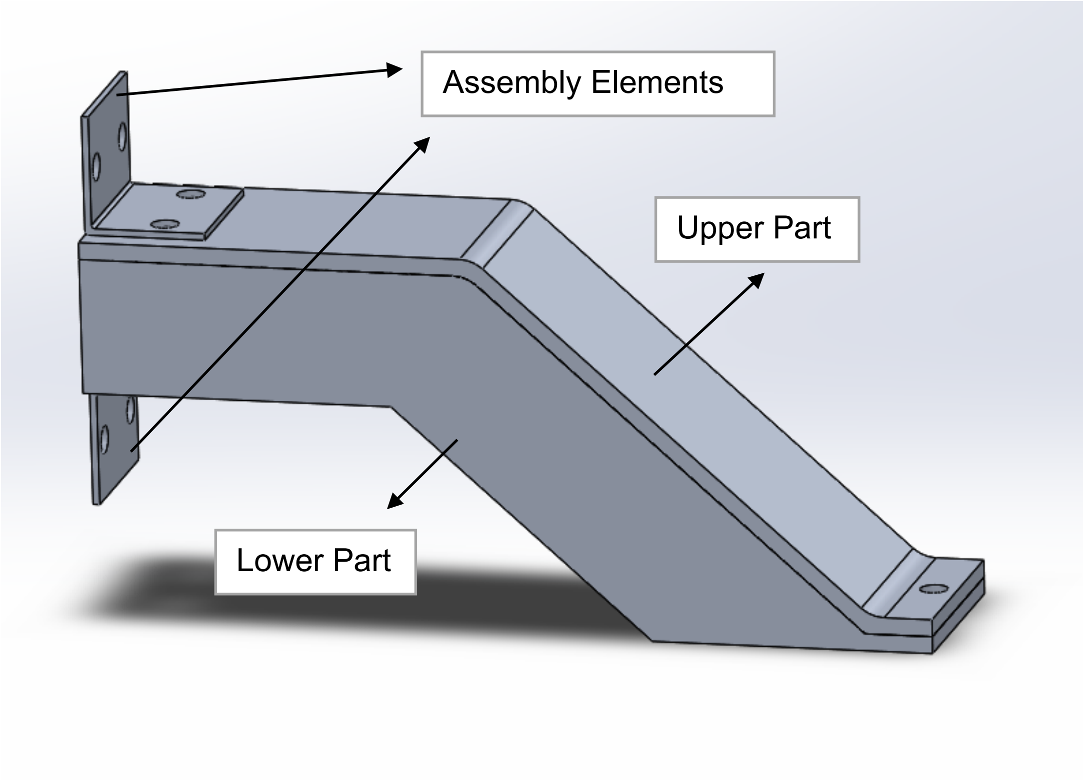

Fig. 16 Cooling Circuit Solidworks Model

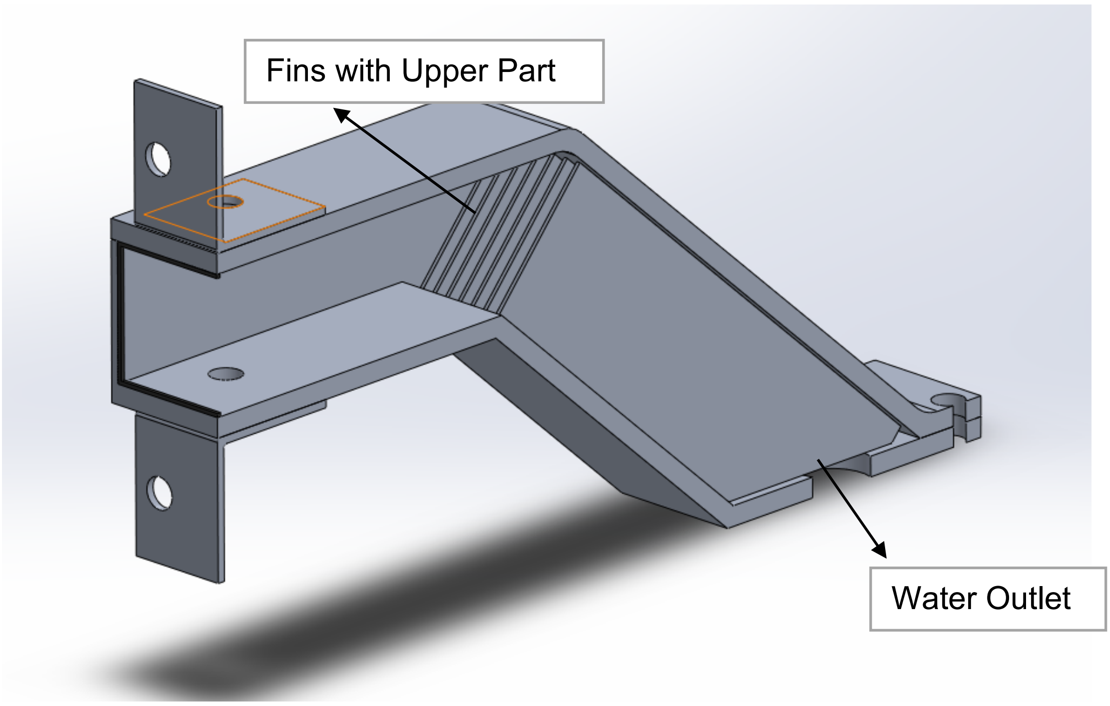

Fig. 17 Cooling Circuit Solidworks Model Cross Section

Tab. 2 Material Properties of Alloy 1350 [5]

Property	Value	Units
Elastic Modulus	69000	N/mm^2
Poisson's Ratio	0.33	N/A
Shear Modulus	27000	N/mm^2
Mass Density	2700	kg/m^3
Tensile Strength	827.227	N/mm^2
Yield Strength	275.742	N/mm^2
Thermal Expansion Coefficient	2.4e-005	/K
Thermal Conductivity	230	W/(m·K)
Specific Heat	1000	J/(kg·K)

3.4. Operation of Safety Shutter

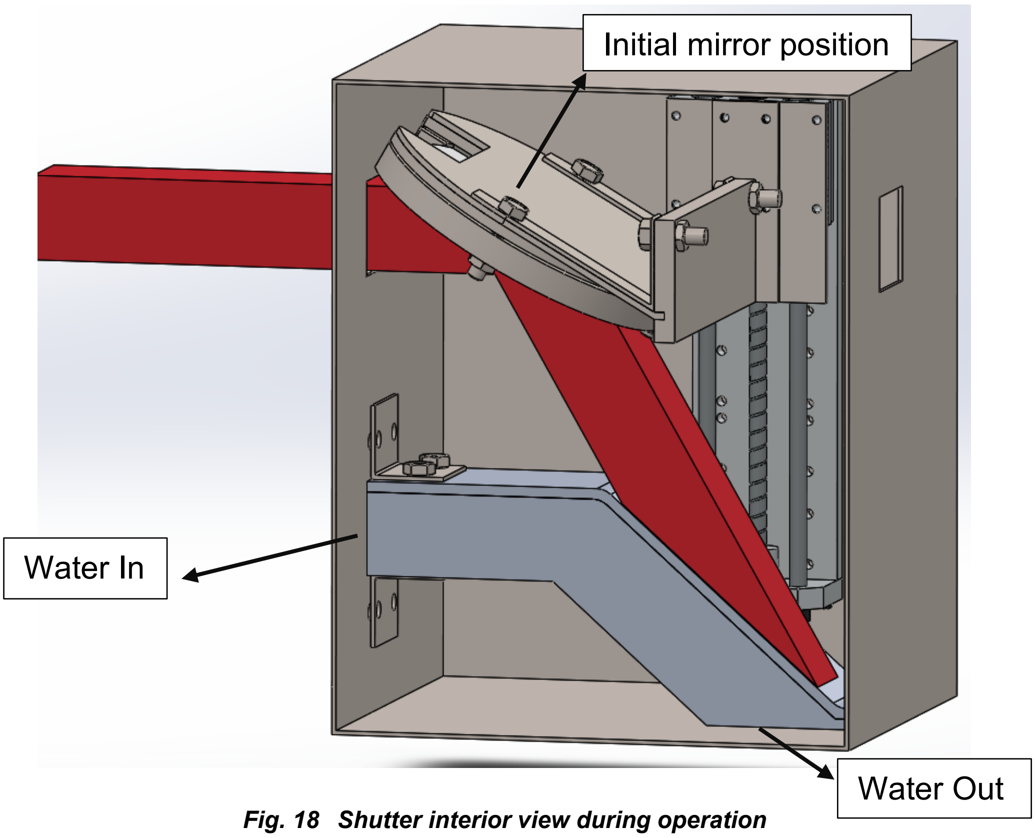

Fig. 18 Shutter interior view during operation

As seen in the figure above, during the operation period, the laser hits the mirror and is reflected and absorbed by the cooling circuit. After the operation period, the mirror group is lowered by 80 mm with the help of the actuator and allows the laser to exit the shutter. (Fig.18)

The maximum speed of the stepper motor is 50mm/s and the actuator move takes approximately 1.6 seconds. This is an acceptable time for this operation.

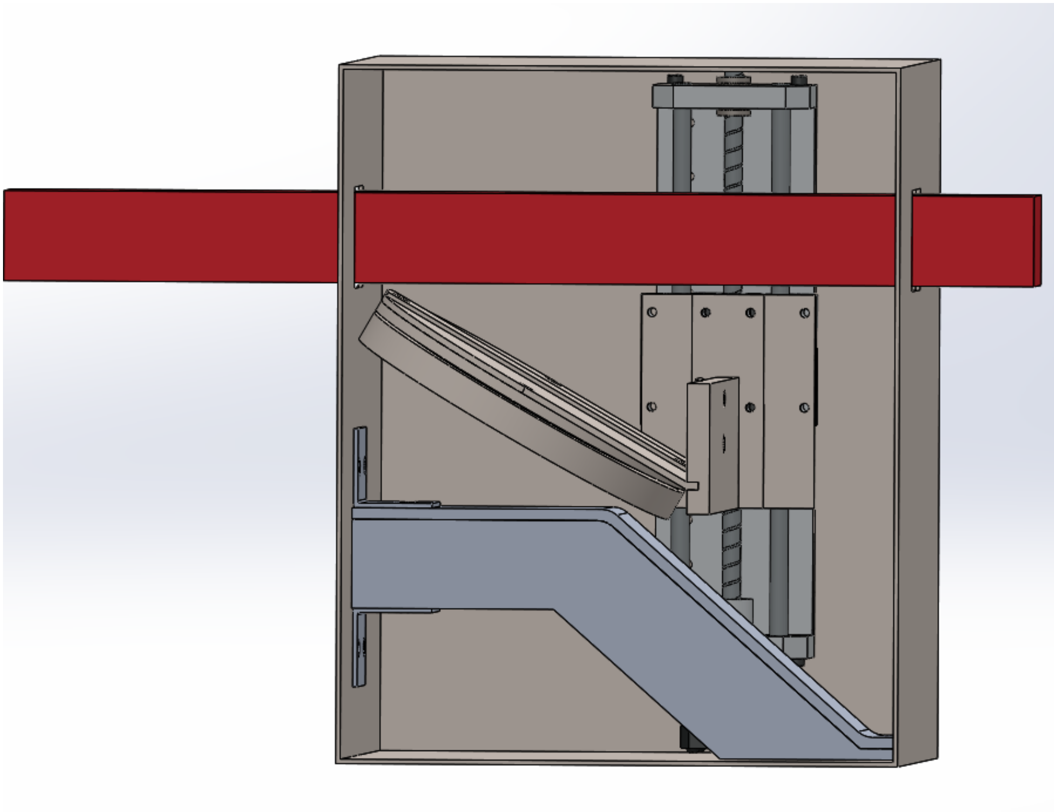

Fig. 19 Shutter interior view out of operation time

4. Thermal – Fluent Analysis

4.1. Thermal Analysis of a 100*100mm Simple Plate

Before choosing the material we will use in Dizayn, thermal analyzes were made on an simple plate to choose which material would be more suitable for working conditions. In order to make a choice between some types of aluminum alloys and stainless steel, the correct parameters were determined and the analyzes were compared.

Alloy 1350 : The properties of alloy 1350 can be seen in the table 2.

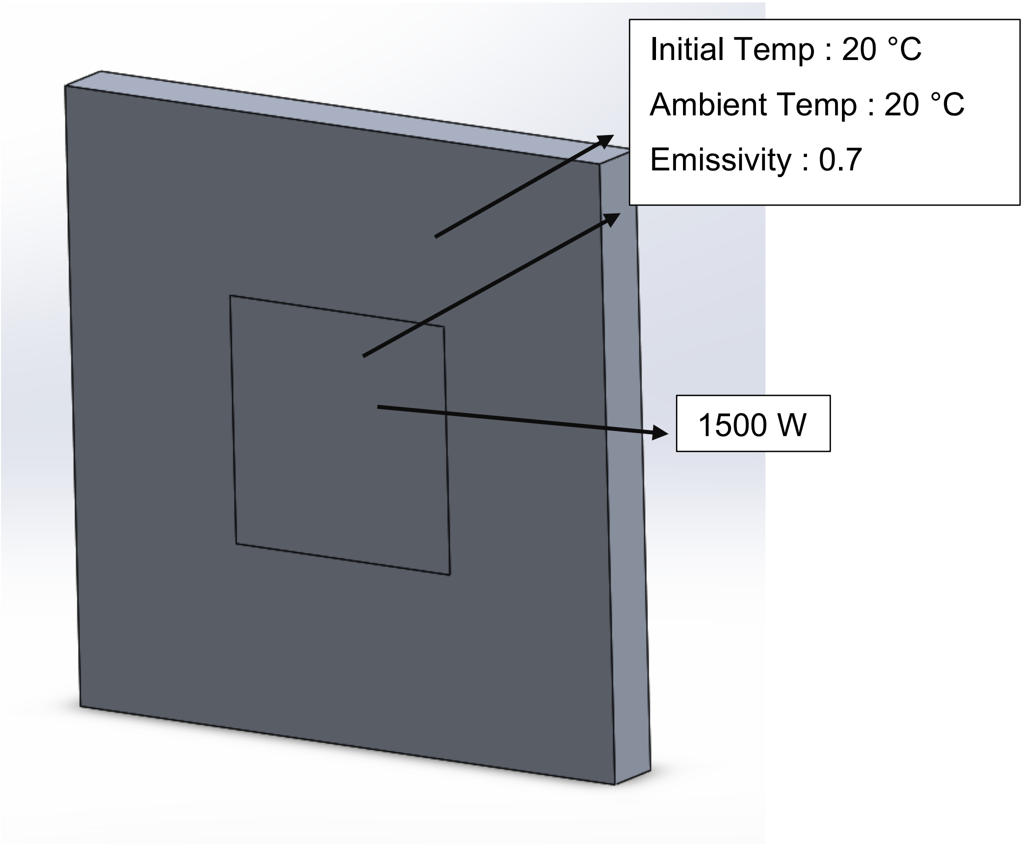

Fig. 20   100*100 Plate (Alloy 1350) [6]

A 40*40 square was drawn with the dividing line on the flat plate shown in the figure. The laser beam will contact this part. Each pulse has 150 J of energy and the frequency is 10 Hz. This means an energy of 1500 W, and this 1500 W is applied to a 40*40 square for a steady state analysis. Other parameters we use in the analysis are the initial temperature of the object (20), the initial temperature of the room (20) and the emissivity value of the material (0.7). These parameters were applied to all sides of the object.

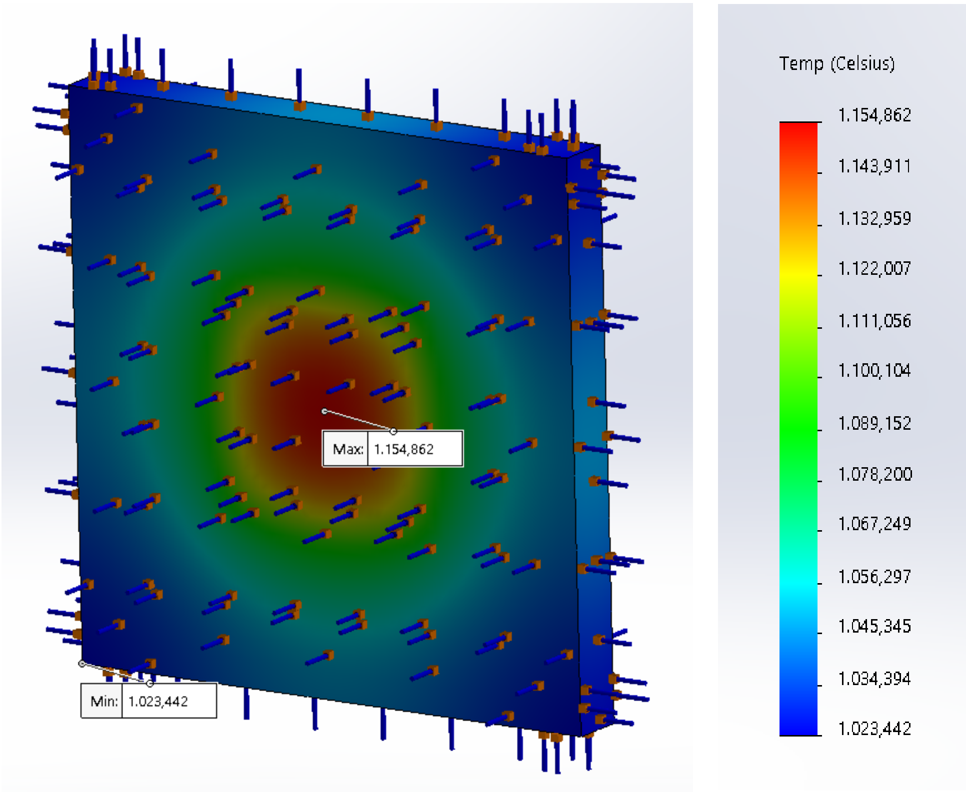

Fig. 21 Analysis Results of Alloy 1350

The same analysis was made for stainless steel and Alloy 1060 by changing only the material and emissivity properties without making any changes in the parameters and shape.

Stainless Steel : The emissivity value for stainless steel is accepted as 0.59 [6]. Other parameters can be seen in the table below.

Tab. 3 Material Properties of Stainless Steel [6]

Elastic Modulus	1.929.999.974	N/mm^2
Poisson's Ratio	0.27	N/A
Mass Density	8000	kg/m^3
Tensile Strength	5.800.000.008	N/mm^2
Yield Strength	1.723.689.323	N/mm^2
Thermal Expansion Coefficient	1.6e-005	/K
Thermal Conductivity	16,3	W/(m·K)
Specific Heat	500	J/(kg·K)

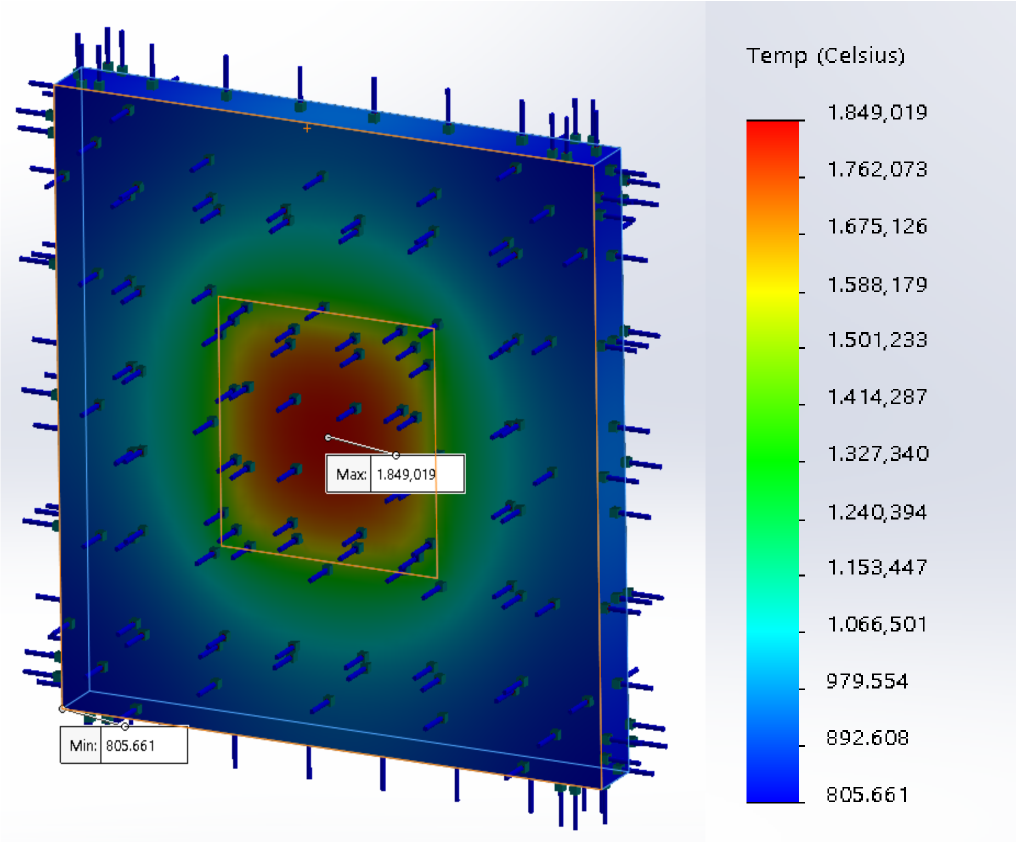

Fig. 22 Analysis Results of Stainless Steel

Alloy 1060 : The emissivity value for Alloy 1060 is accepted as 0.7 [6]. Other parameters can be seen in the table below.

Tab. 4 Material Properties of Alloy 1060 [6]

Elastic Modulus	69000	N/mm^2
Poisson's Ratio	0.33	N/A
Shear Modulus	27000	N/mm^2
Mass Density	2700	kg/m^3
Tensile Strength	689.356	N/mm^2
Yield Strength	275.742	N/mm^2
Thermal Expansion Coefficient	2.4e-005	/K
Thermal Conductivity	200	W/(m·K)
Specific Heat	900	J/(kg·K)

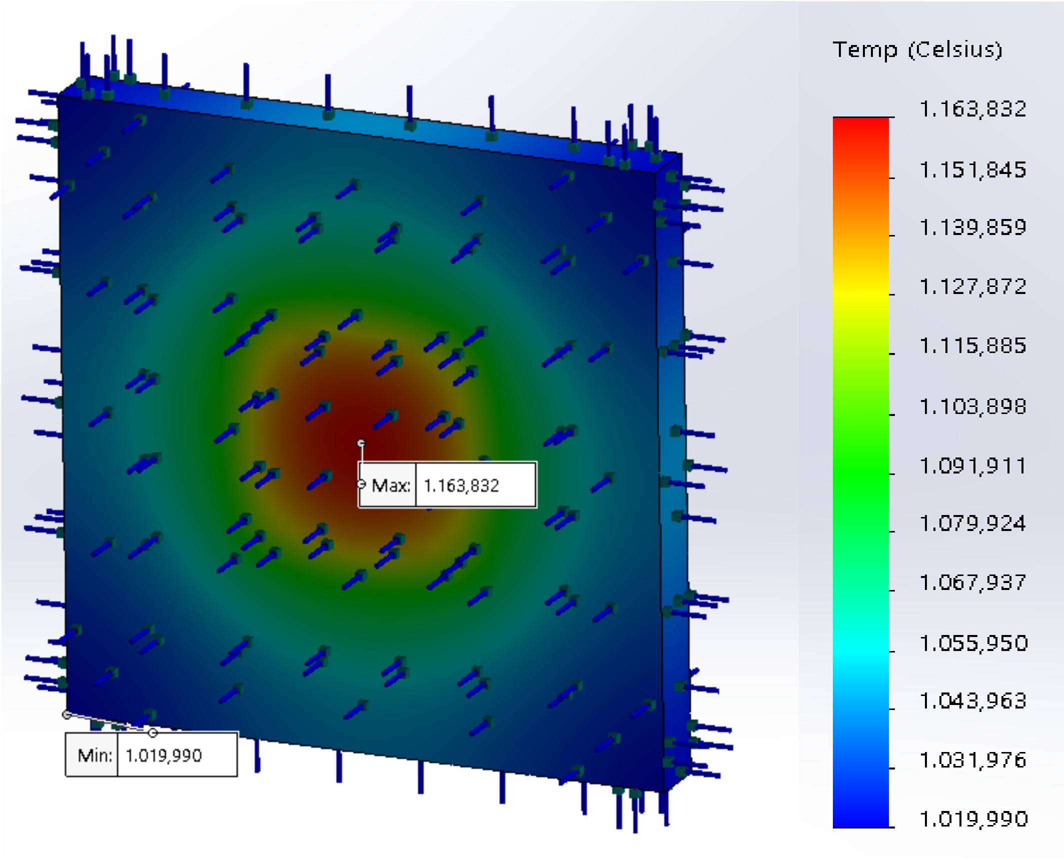

Fig. 23 Analysis Results of Alloy 1060

The important parameters here are thermal conductivity and specific heat. Alloy 1350 and Alloy 1060 have almost exactly the same parameters. However, Alloy 1350 has a higher specific heat than Alloy 1060, so it is less warm according to the analysis result. Stainless steel has much less specific heat than these two. That's why it's much warmer. Also, its emissivity value is lower than the other two. Emissivity is the radiation ability and it is important for us to be high here. In addition, it is important for us to have high thermal conductivity. In aluminum alloys, all 1xxx alloys have high thermal resistance and are therefore considered the most suitable material for such designs.

When all these factors come together, the most suitable material was found to be Alloy 1350. This material is more expensive than stainless steel and does not need to be applied for the entire design. Alloy 1350 will only be applied for the cooling circuit.

4.2. Thermal - Fluent Analysis of Safety Shutter

4.2.1. Thermal - Fluent Analysis of Safety Shutter

Thermal analysis will be done on the cooling circuit. Since other parts of the shutter will heat less than this part, calculating the highest temperature on the cooling circuit is sufficient to prove whether the design is successful or not. To achieve this, we will remove the other parts of the design from the analysis and activate the cooling circuit, which is sufficient so that we can define the water inlet, the water outlet and the heat that the laser will generate.

Analysis Parameters: We will perform an internal flow analysis. The fluid we will use is water and all the properties of water are defined in Solidworks. The solid in the analysis is Alloy 1350. The wall is assumed to be an adiabatic wall. Ambient temperature is 20 °C, ambient pressure is 101325 Pa and initial solid temperature is 20 °C.

We will apply an input parameter in flow analysis. We will show details about the chiller we use and find the inlet parameter from here.

CW-5300	CW-5300AH	CW-5300BH	CW-5300DH	CW-5300AI	CW-5300BI	CW-5300DI
Voltage	AC 1P 220V	AC 1P 220V	AC 1P 110V	AC 1P 220V	AC 1P 220V	AC 1P 110V
Frequency	50Hz	60Hz	60Hz	50Hz	60Hz	60Hz
Current	0.25~4.93A	0.25~5.03A	0.45~7.61A	0.7~5.38A	0.7~5.48A	0.45~8.16A
Machine power	0.90kW	0.93kW	0.72kW	0.95kW	0.98kW	0.77kW
Compressor power	0.80kW	0.83kW	0.62kW	0.80kW	0.83kW	0.62kW
	1.09HP	1.13HP	0.84HP	1.09HP	1.13HP	0.84HP
Nominal cooling capacity	7950Btu/h	8291Btu/h	6039Btu/h	7950Btu/h	8291Btu/h	6039Btu/h
	2.33kW	2.43kW	1.77kW	2.33kW	2.43kW	1.77kW
	2003Kcal/h	2089Kcal/h	1522Kcal/h	2003Kcal/h	2089Kcal/h	1522Kcal/h
Refrigerant charge	650g	750g	680g	650g	750g	680g
Pump power	0.05kW			0.1kW		
Max.lift	12M			25M		
Max.flow	13L/min			16L/min		
N.W.	44Kgs					
G.W.	50Kgs					
Refrigerant	R-410a					
Precision	±0.3℃					
Reducer	Capillary					
Tank capacity	10L					
Inlet and outlet	Rp1/2"					
Dimension	59 X 38 X 74 cm (L X W X H)					
Package dimension	68 X 53 X 90 cm (L X W X H)					

Fig. 24 Chiller CW-5300BI [7]

The main reason we chose this chiller is that it is easily available in the market and can compensate the energy input of 1500 W with 1.77KW. According to the figure, we see a pipe screw of Rp1/2". This means that there is a pipe diameter of approximately 20 mm. Since we don't want pressure or velocity loss or gain in the pipe, we made a suitable inlet hole for this outlet in our design. In the table, we see that the flow rate is 16L/min. We will apply it in the analysis as 0.85 m/s. We chose 20 °C as the inlet water temperature, the same as the ambient and solid temperature.

The water output will be to the ambient pressure, and we will apply a heat generation of 1500W to the surface where the laser reflects to the cooling circuit.

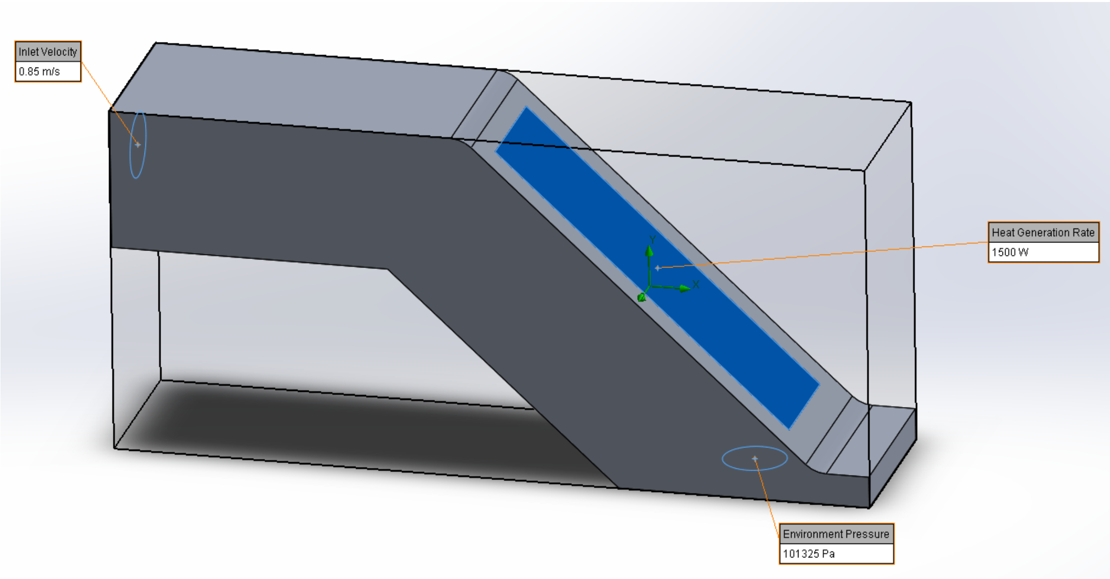

Fig. 25 Boundary Conditions of Al1350

As the analysis goal, we set the maximum solids temperature and run the analysis.

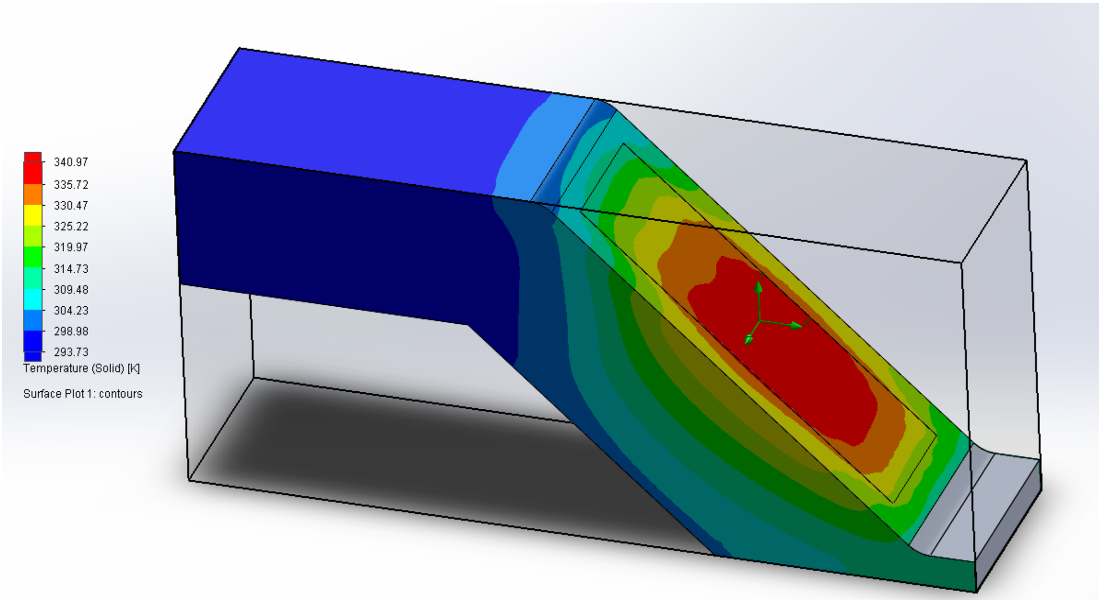

Fig. 26 Analysis Results of Al1350

As seen in the figure above, the highest temperature reached on the cooling circuit is 69°C. This temperature is acceptable as the highest temperature achieved. Thanks to the constant water flow, it is observed that the temperature rises in the areas where the laser does not come into direct contact is much less than in the areas where the laser is in direct contact. However, the temperature of the solid formed is reasonable under the conditions of a fluid inlet at constant temperature (20 °C).

4.2.2. Thermal - Fluent Analysis of Safety Shutter (Without Cooling)

We perform thermal analysis on the same solid, under exactly the same conditions, the same geometry and parameters, only removing the cooling.

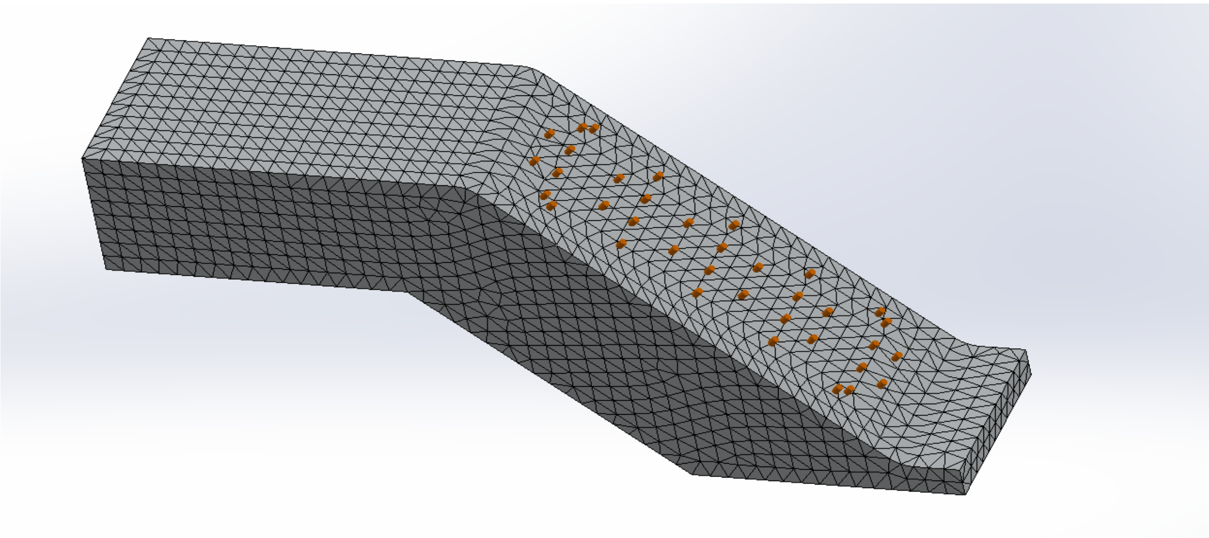

Fig. 27 Meshed Cooling Circuit

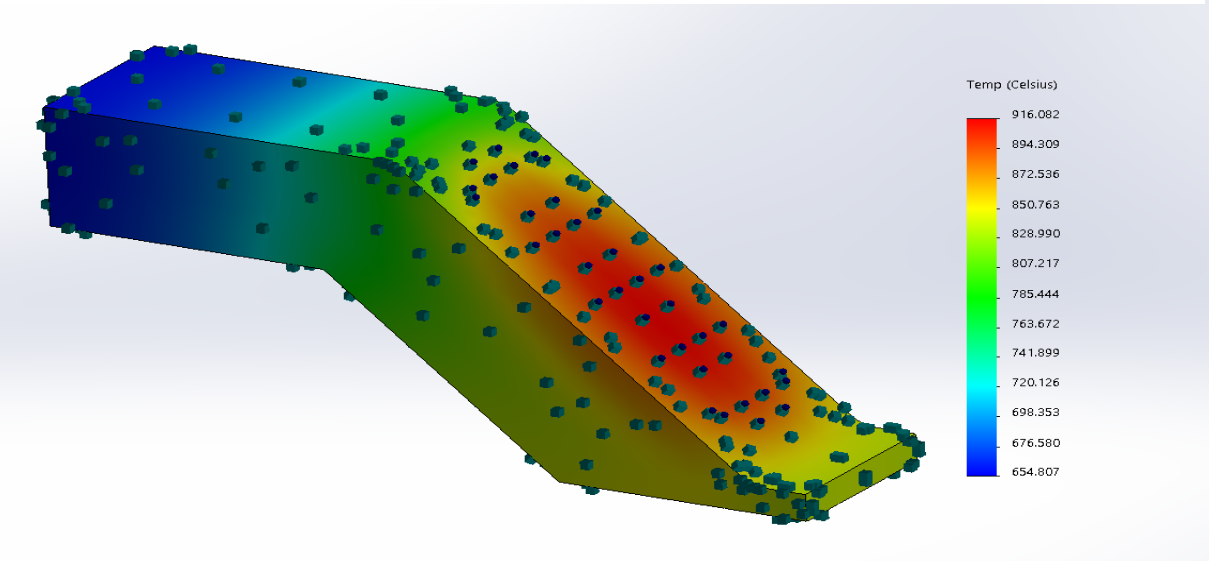

Fig. 28 Analysis Results of Al1350 (Without Cooling)

As can be seen in Figure 27, unreasonable temperatures occur on the cooling circuit when there is no water cooling. It was observed that the maximum temperature increased to approximately 920 °C.

4.2.3. Thermal - Fluent Analysis of Safety Shutter (Without Fins)

We will do a flow analysis again, but we will remove the fins we use in the cooling circuit from the design. All remaining parameters will be the same as in topic 4.1.1.

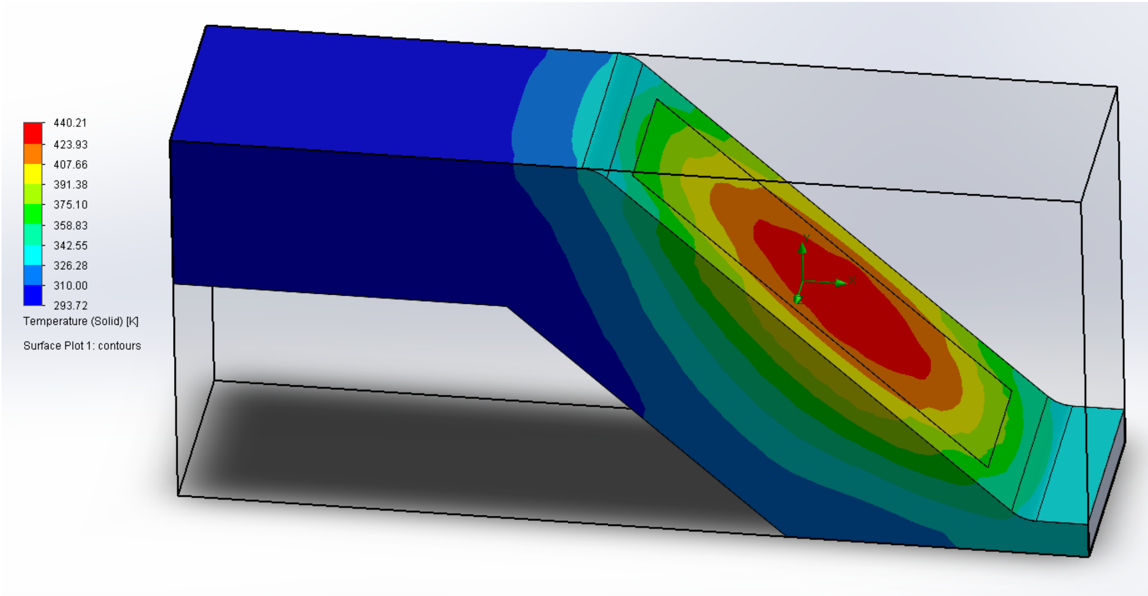

Fig. 29 Analysis Results of Al1350 (Without Fins)

As seen in Figure 28, when we remove the blades from the design, the maximum temperature goes up to 167 °C. Here we can see the importance of using wings. The reason for using fins is to increase the solid area and slow down the heating. Another benefit of increasing the solid area is that it enlarges the cooled area. Thus, the cooling becomes larger and faster. Fins are extensions on exterior surfaces of objects that increase the rate of heat transfer to or from the object by increasing convection. This is achieved by increasing the surface area of the body, which in turn increases the heat transfer rate by a sufficient degree.

4.2.4. Thermal - Fluent Analysis of Safety Shutter (Stainless Steel)

In this section, we will see what the maximum temperature would be we would get if we designed the cooling circuit with AISI 316 stainless steel.

All remaining parameters and boundary conditions are also the same as in geometry topic 4.2.1.

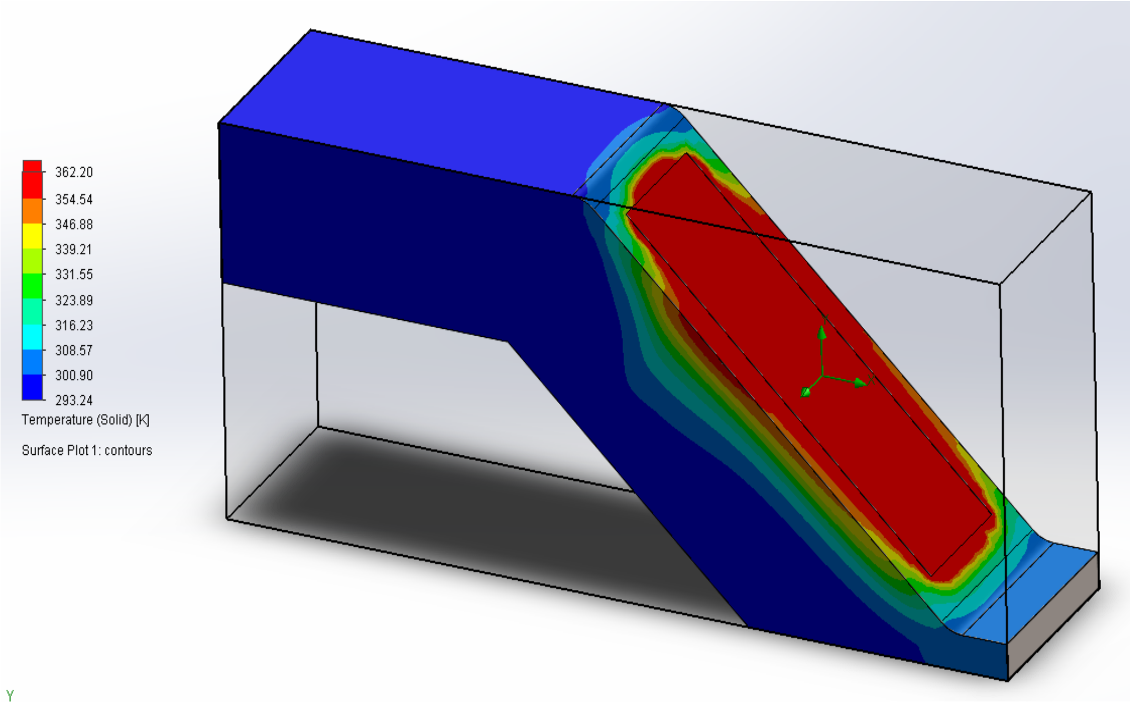

Fig. 30 Analysis Results of AISI 316 stainless steel

The material has been changed and assigned as AISI 316 stainless steel. On the other hand, a maximum temperature of 90 °C was obtained. From here, we can deduce that our material selection is better than AISI 316 stainless steel.

4.2.5. Thermal - Fluent Analysis of Safety Shutter (With Smaller Laser Area)

As a final benchmark parameter, we will reduce the zone of the laser on the cooling circuit. If we did not enlarge the area covered by the laser field with the help of a mirror and surface of cooling circuit, we will measure the maximum temperature we will achieve. Now we will reduce the area from 126*40 mm to 40*40 mm and apply flow and thermal analysis again.

The material will again be Alloy 1350. The assumption here is that the maximum temperature achieved will increase. Because the area covered by the laser will decrease also the cooling area will decrease, but the energy in the pulse will remain constant at 1500 W. Since we will try to cool practically the same energy with a smaller cooling area, the maximum temperature will increase.

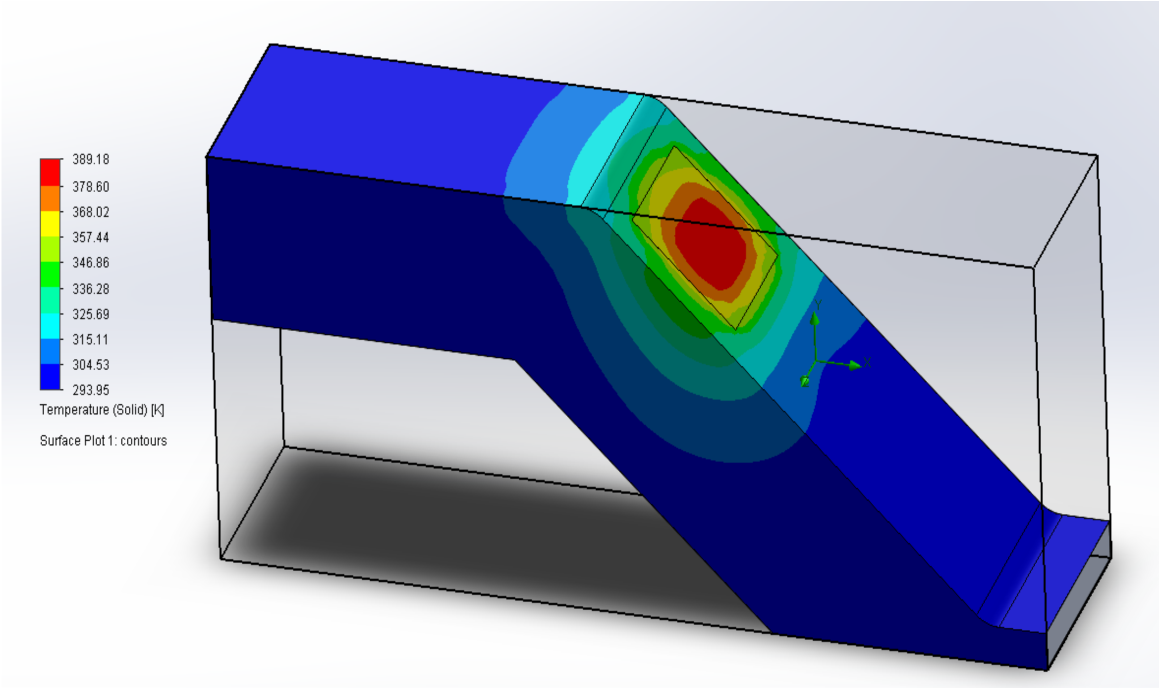

Fig. 31 Analysis Result of Safety Shutter (With Smaller Laser Area)

As can be seen in Figure 30, when the area covered by the laser is reduced to 40*40mm, the maximum temperature reached increases up to 117 °C. Here we can observe the contribution of the enlargement of the laser area to the cooling.

4.3. Comparison Of All Analyses

Tab. 5 Comparison of All Analyzes Scenarios

Design Type	Max °C
Default Design	69
Without Cooling	920
Without Fins	167
Stainless Steel (AISI 316)	90
With Smaller Laser Area	117

As can be seen in the table above, the minimum temperature we have obtained belongs to the design that has fins, cooling and enlarged laser zone , and that we also use Alloy 1350 as the material.

5. Other Possible Designs for Safety Shutter

For safety shutter design, more than one method or design can be considered. Contrary to what was considered for the default design, other design ideas can be developed without using mirrors or using pneumatic type instead of electric.

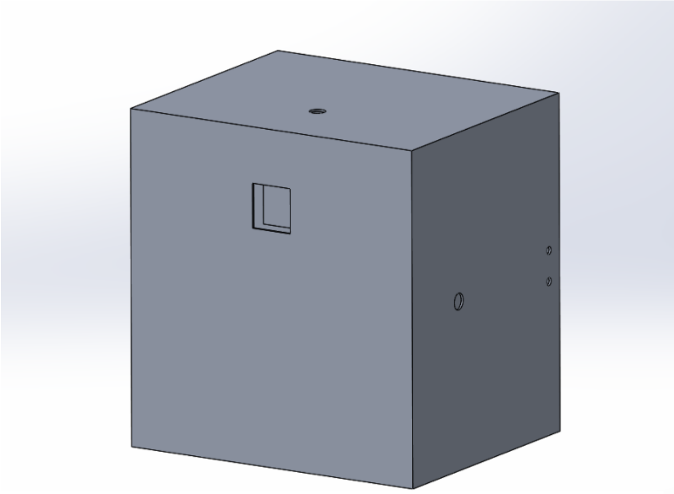

Fig. 32 Rotary Safety Shutter Out view

In models which does not have mirrors, the laser beam comes directly onto the cooling circuit. The part that needs to move when the operation period is completed is the cooling circuit. That is, the cooling circuit must be mounted to the actuator.

The actuation of the actuator can also vary. The actuator can be driven either circularly or linearly to the cooling circuit and the operation can be stopped.

5.1. Rotary Safety Shutter

The shutter is designed as a rotating cylinder. The laser beam (40*40) mm enters through the 45*45mm square space on the box surface and is reflected on the shutter. This continues for the duration of the operation. When the run time is up, the pneumatic actuator engages, drives the shaft, and the louver rotates at an angle to switch to the next laser path. Thus, the laser can come straight out of the box.

The shutter is completely filled with water and designed to be waterproof. There is no contact between the surface of the laser and water. The water inlet outlets on the box and the water inlet outlets on the shutter are in the same direction and a hose should be used for their connections. A chiller should be preferred for cooling. For the shutter material, it is reasonable to concentrate on an aluminum alloy of 1350 or another 1xxx class , as in the design. Both options will be better options than stainless steel.

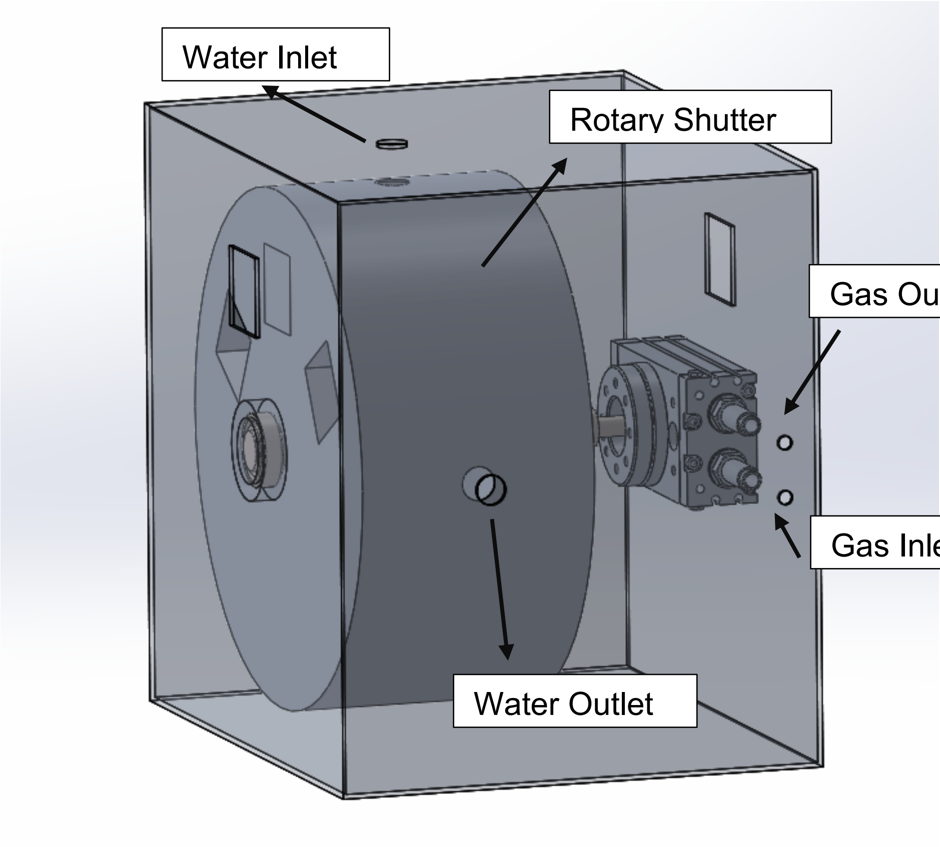

Fig. 33 Rotary Safety Shutter

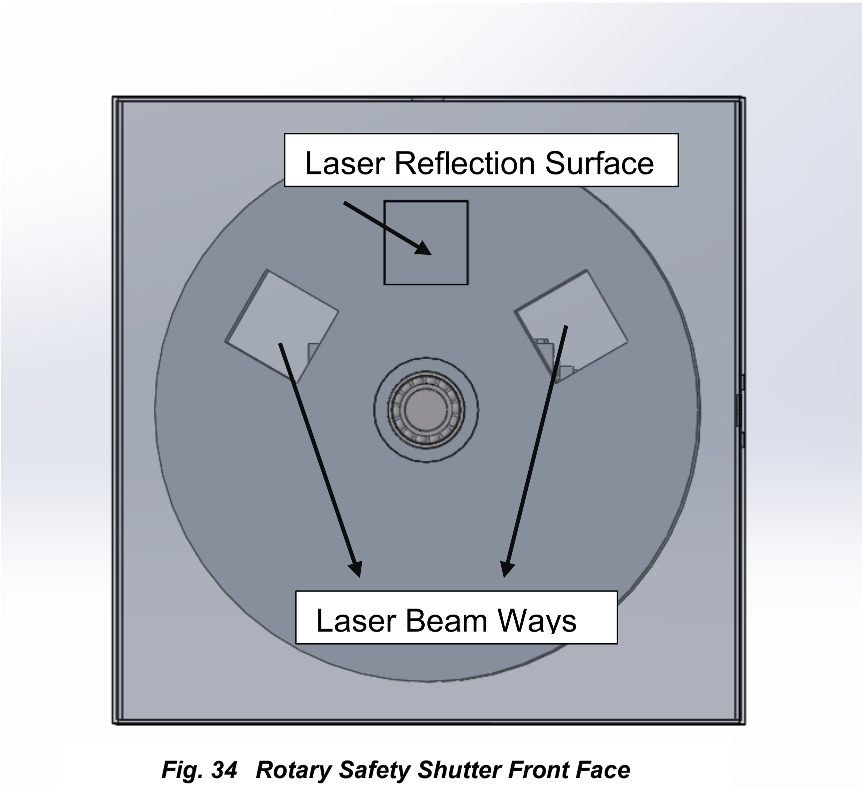

Fig. 34 Rotary Safety Shutter Front Face

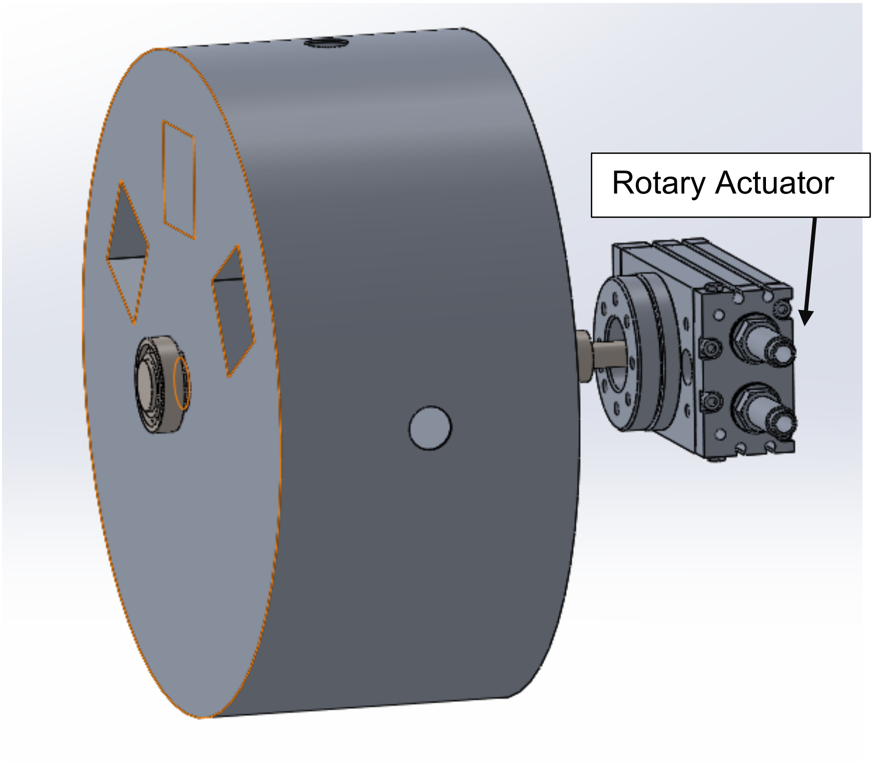

Fig. 35 Rotary Safety Shutter

The pneumatic actuator has been chosen as a rotary pneumatic actuator. Main shaft is screwed to the Pneumatic actuator and driven. Its material is aluminum and it is double acting. The working range is between 0 and 190 degrees.

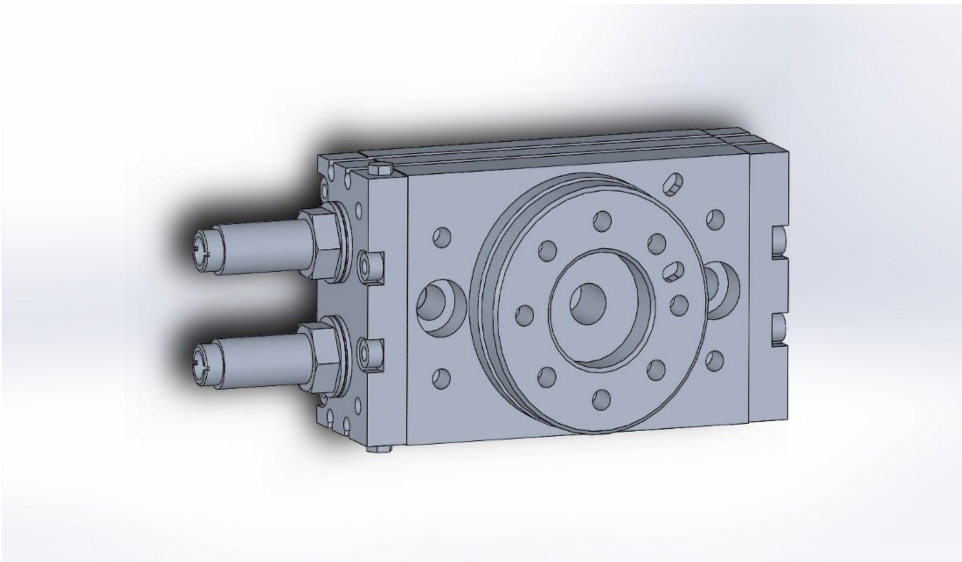

Fig. 36 Pneumatic Actuator [8]

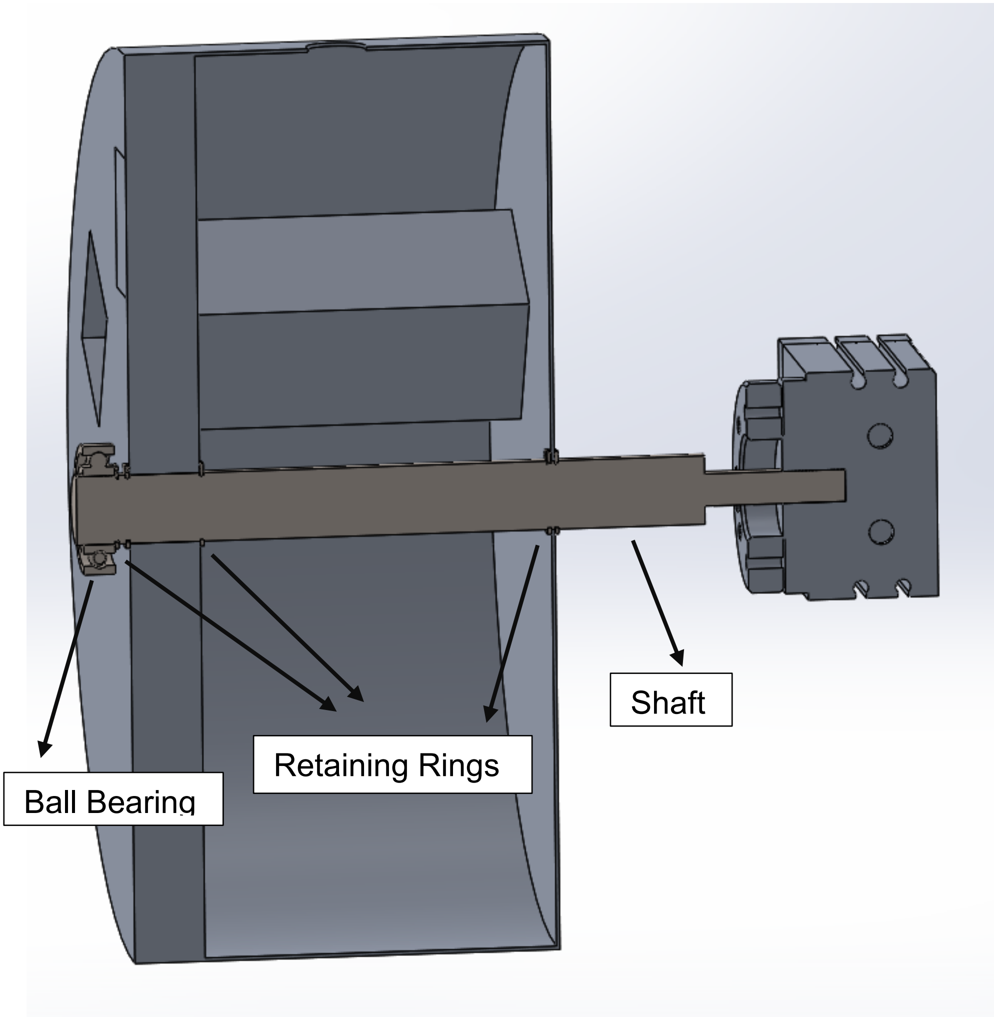

Fig. 37 Rotary Safety Shutter (Side Section)

5.2. Linear Safety Shutter

The safety shutter can also be designed with a linear moving cooling circuit instead of a rotary cooling circuit. In this design, pneumatic linear actuators, springs to dampen motion, and linear guides to manage motion are used.

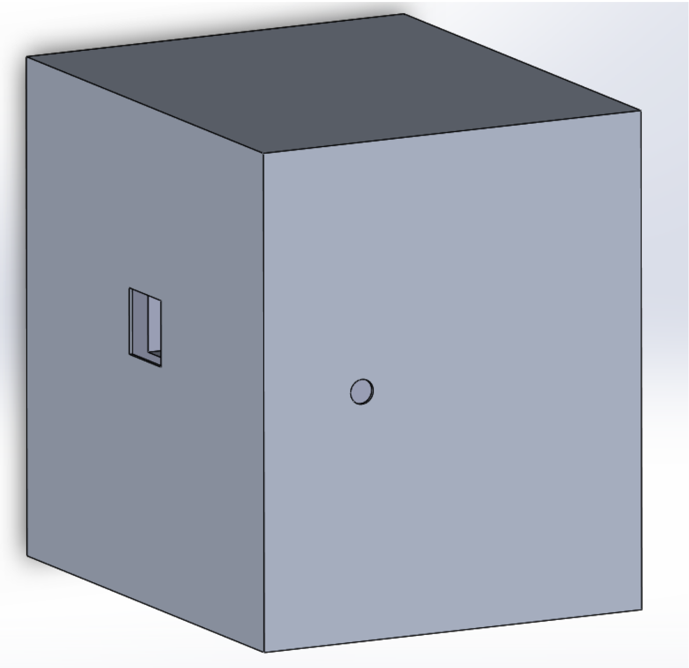

Fig. 38 Linear Safety Shutter (Out View)

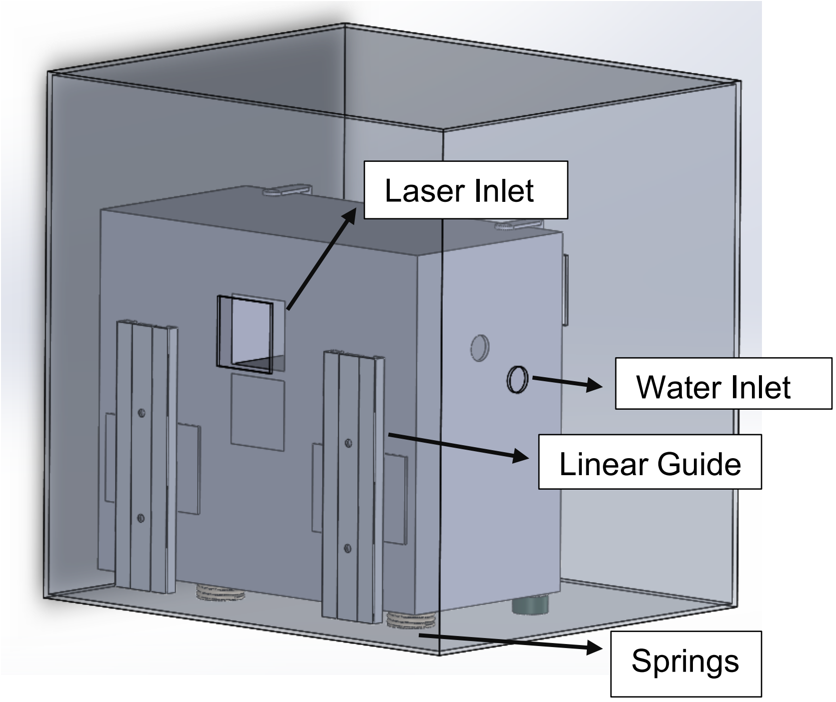

Fig. 39 Linear Safety Shutter

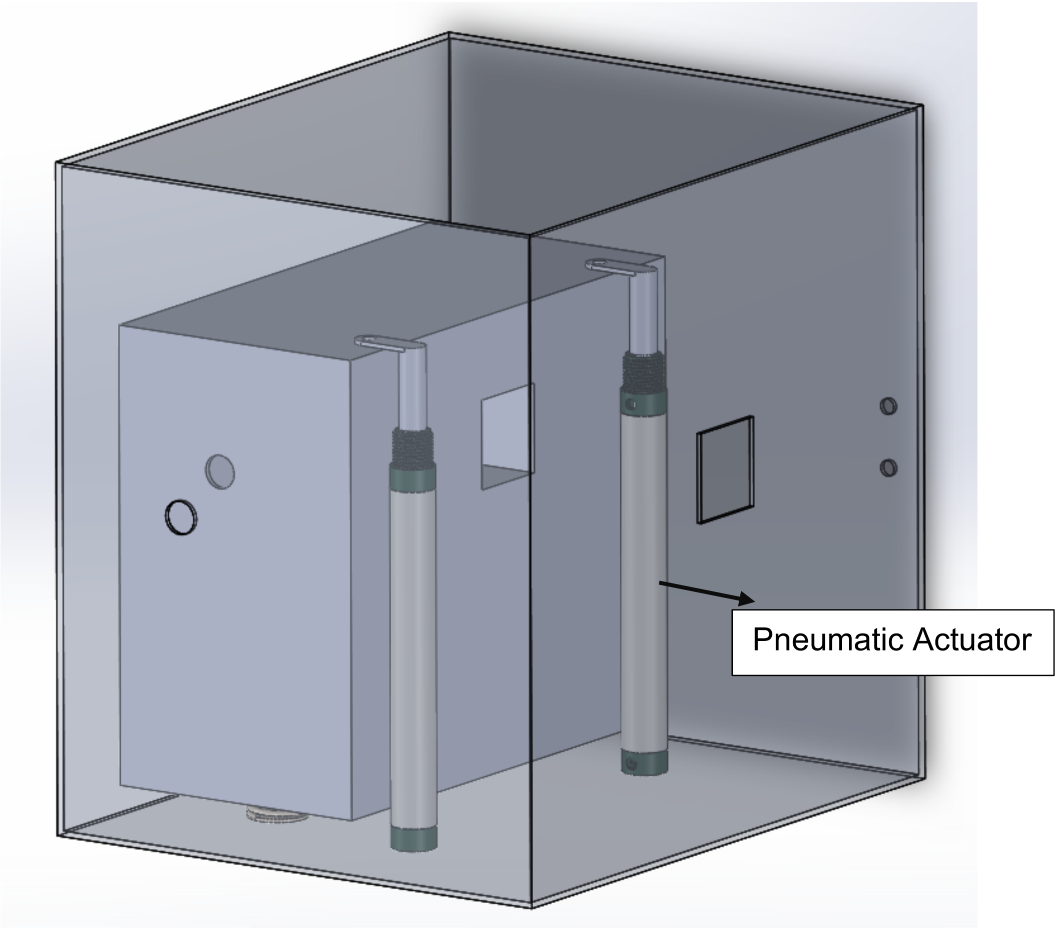

Fig. 40 Linear Safety Shutter

Thanks to the hole on the shutter, the laser can come out of the box without touching any point. The pneumatic actuator on both sides of the shutter is mounted on the safety shutter. When the operating time starts, gas is supplied to both pneumatic actuators at the same time and the shutter rises with the help of the linear guide. After this movement, the laser is reflected on the surface of the shutter and water cooling is activated. Reaction time is very important here. Due to the short reaction time, in the default design uses an electric actuator instead of a pneumatic actuator.

6. Safety Shutters in Industry

6.1. Lasermet LS-200 Laser Shutter

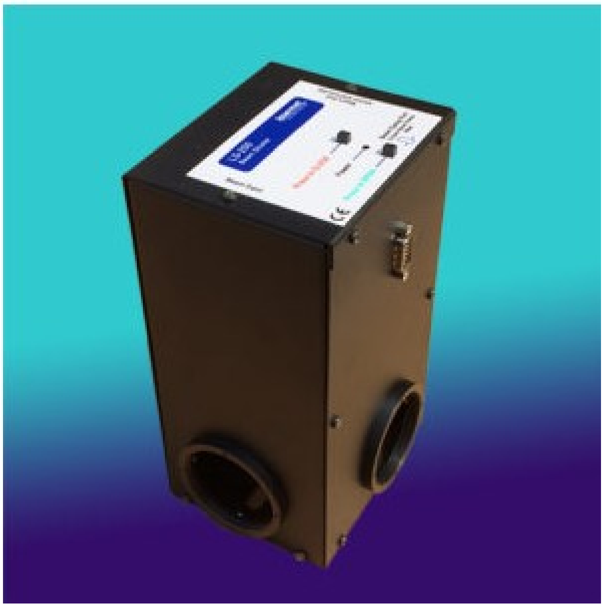

Fig. 41 Lasermet LS-200 [9]

The LS200 Laser Safety Shutter is designed to prevent accidental exposure to potentially harmful laser beams. When the shutter is open the laser beam passes in clear air through the shutter. When closed, the shutter deflects the incoming laser beam out of a separate port to an appropriate beam dump which must be fitted. The shutter uses a gravity close blade and force-disconnect proving contacts and is designed to form part of a high-integrity safety system.

6.2. LS-20 High Integrity Laser Shutters

It has been designed to form part of a high-integrity safety system and features a gravity-close blade and force-disconnect proving contacts. When closed, the shutter deflects the incoming laser beam onto an internal beam dump where the energy is converted to heat which is dissipated in the aluminum casing of the shutter. When the shutter is open, the laser beam passes through the shutter without interruption.

Standard operation is by means of the ‘Open’ and ‘Close’ buttons on top of the shutter case. A remote switching station (LS-RS20) is available for remote operation of the shutter. Alternatively the shutter can be set to open as soon as power is applied. In all cases the shutter will close when power is removed.

The LS-20 has 16 mm diameter entry and exit apertures. These are threaded and beam tubes can be supplied to fit to the shutter case and enclose the laser beam.

Fig. 42 Lasermet LS-20 [10]

The maximum average power for use with the internal beam dump is 20 W. However for higher powers the beam dump can be easily removed by unscrewing it from the side of the shutter case. Beam tubes can be fitted and the beam can be directed to a remote beam dump. This allows the shutter to be used for much higher powers, even for multi-kilowatt lasers.

Model No.	LS-20-24	LS-20SIL-24
Max Average Power Using Internal Beam Dump	20 W	20 W
Max Average Power Using Separate Beam Dump	Unlimited	Unlimited
Aperture Diameter	16 mm	16 mm
Operating Voltage	24 V DC	24 V DC
Current Closed	30 mA	60 mA
Current Open	250 mA	500 mA
Internal Beam Dump Cooling	Convection	Convection
Size (mm)	98 x 65 x 37	98 x 65 x 73
Mass	400 g	800 g
Safety Integrity Level (to EN 61508)	TBA	SIL 3
Certified to EN ISO 13849-1 Safety of machinery – Safety-related parts of control systems. Performance Level as shown	'c'	'e'
Lifetime	5×10^5 Operations	5×10^5 Operations

Fig. 43 Lasermet LS-20 Specifications [10]

6.3. Beam Shutter & Beam Dumps

The LS-10-12 and LS-100-12 shutters are designed to absorb all the laser beam power thus eliminating the need for an additional beam dump and avoiding hazardous reflections. The laser beam is converted to heat and radiated from the shutter case.

These shutters can be used with lasers up to the maximum average power specified as follows. The LS-10-12 is suitable for up to 20 W average power. The LS-100-12 is air cooled by a fan and suitable for up to 200 W average power.

The shutters will not open unless power is supplied. When power is supplied a yellow LED lights to indicate that power is present. A green LED will also light indicating that the shutter is fully closed. To open the shutter the green button must be pressed. The green LED will go out and an orange LED will light indicating that the shutter is fully open. The shutter can be closed by pressing the red button or by cutting the power.

MODEL	MAX LASER POWER (W)	APERTURE SIZE (MM)	DRIVE VOLTAGE (V DC)	DRIVE VOLTAGE WITH LS-VC-24.12 (V DC)	CURRENT CONSUMPTION (MA)	SIZE (MM)
LS-10-12	20	15	11 - 14	15 - 35	150	98 x 63.5 x 36*
LS-100-12	200	50	11 - 14	15 - 35	150	130 x 150 x 140 *

Fig. 44 Lasermet LS-10-12 Specifications [11]

Alternatively, the LS-10-12 and LS-100-12 laser shutters can be put into 'switch bypass mode' by changing some internal links on the PCB inside the shutter. In this mode the shutter will open immediately when the power is applied and close when the power is turned off.

Fig. 45 Lasermet LS-10-12 [11]

7. Conclusion

The aim of the thesis was to design a safety shutter with high cooling efficiency, using a standard chiller, under specified parameters and within limits.

Firstly, the determined parameters were defined, and the details related to them were given. Calculations were made in accordance with these parameters and preliminary preparation was made for the design. Research has been done on the tools that will be used or likely to be used in the design, information has been given about their materials and explanations have been made about their geometry. By arranging scenarios on the design, it is aimed to increase the size of the area reflected by the laser on the cooling circuit. For this, optimizations have been made on the design in order to increase the angle of the cooling circuit relative to the ground and at the same time not exceed the box limits. It is aimed to facilitate cooling by increasing the area where the laser is reflected, and to slow down the heating by choosing the right material. After deciding on the general design, thermal and flow analyses were made.

The analyses were compared with each other. Analyses were made for the normal (decided) design first, then the design where cooling does not exist, the design without fins in the cooling circuit, the design with different material (stainless steel) and the designs where the area reflected by the laser is smaller than the normal design. As a result of the analysis, the maximum temperature of 69°C for the design was obtained. This temperature is quite reasonable and feasible. Compared to other analysis scenarios, much lower temperatures were obtained. Thus, it can be assumed that the material and geometry used in the design are close to correct.

After the analysis, 2 more designs I designed were examined. The components of these designs are defined, and the idea of the designs is explained. The differences that distinguish these designs from the default design are the absence of mirrors and the reflection of the laser at vertical angle to the cooling circuits. In addition, pneumatic actuators are used instead of electric actuators. These factors make these designs more inefficient.

Finally, some safety shutters that are widely used in the market have been examined and their features have been defined and related images have been presented.

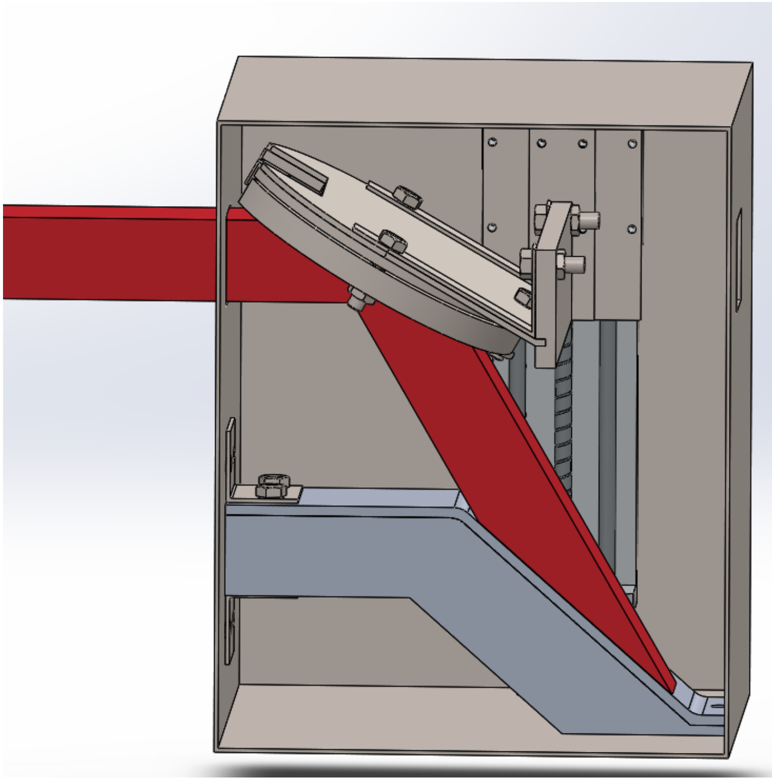

Fig. 46 Safety Shutter Interior View-1

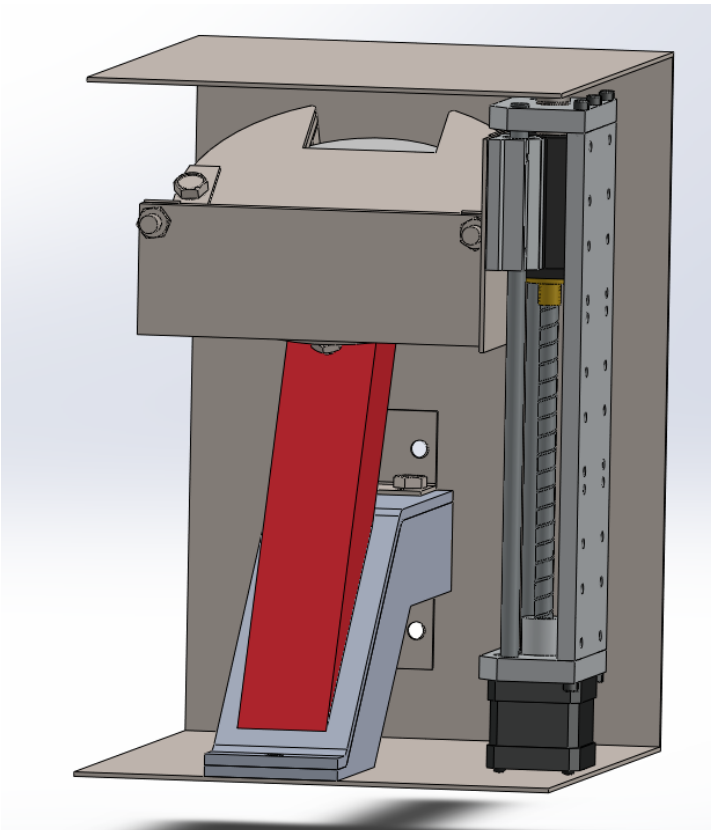

Fig. 47 Safety Shutter Interior View-2

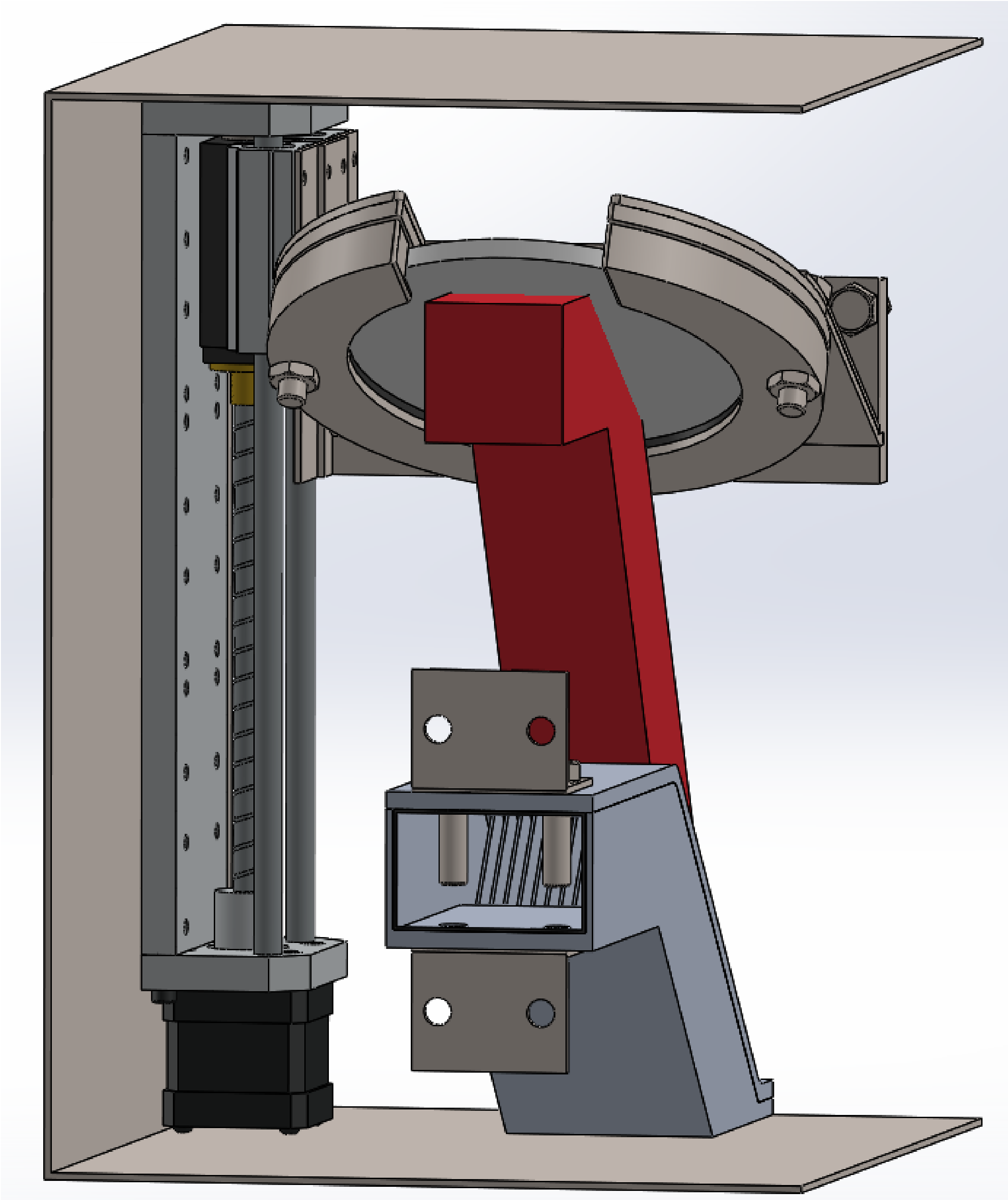

Fig. 48 Safety Shutter Interior View-3

8. References

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[9] Lasermet: https://www.lasermet.com/laser-safety-products/beam-shutters-beam-dumps/ls-20-high-integrity-laser-shutters/

[10] Lasermet: https://www.lasermet.com/laser-safety-products/beam-shutters-beam-dumps/

Attachments

1. CAD Model (Solidworks)
2. Solidworks Simulation Software Solutions
3. Electronic Version of the Thesis