Design, Simulation, and Fabrication of Steering Controlled Headlight Mechanism

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Abstract

Our design idea spawned from the increases in traffic accidents rate during nighttime driving on unlit roads. Most unexpansive cars have fixed headlights that have blind spots that the headlight does not cover. We took a look in the market to see what are the solutions that the manufacturers provide and concluded that most solutions are expensive to the average population. So, we had a brainstorming session and came up with a design project idea. Our project is based on a simple mechanism and it is low cost at the same time. Which is the 4-bar mechanism. Basically, we will weld a rod vertically on the steering arm that is connected to the tires. Then we will construct our 4-bar the crank and rocker must be parallel and has the same length to make sure that both headlights turn at the same angle as the tires. Then we will attach an extension pin to the headlight. We are aware of the tight spaces so we modeled our design on a specific pick-up car our mechanism should not alter any of the car`s functions or interfere with the under-carriage components of the vehicle. Our design aims to make it affordable, safe, and reliable at the same time. The methodology we followed is to first outline the components of the mechanism and set the maximum dimensions of each part. Second, we worked comprehensively on the design calculations needed such as Degrees of freedom, Stress analysis, and force analysis as well as choosing an appropriate material and an international standard. Finally, we will construct a 3D model and simulate it to check if the mechanism passes the engineering program's tests. If necessary, changes will be made after the simulation. After that, the mechanism will be manufactured to conduct real-world experiments and determine the practicality of our design.

Keywords: Headlight, Adaptive, Mechanism, Steering system.

1. Introduction

the majority of severe road accident occur at night. Many people have lost their lives while travelling, due to a road accident. To overcome this issue, we thought of a design that can be efficient, inexpensive and increase the safety of travelers on the highways and winding roads. Potholes are extremely dangerous and could cause a lot of damage to the vehicles especially at night. There are solutions regarding blind spots in the road as well as low visibility. But these solutions come at a very high cost and the cars that come with the solutions are mainly luxury cars for example: Mercedes and BMW. And it is not affordable to the middle to lower class people. Our goal is to make this project low cost but retain a high quality and affordable to the public. There are many roads in the kingdom of Saudi Arabia that are unlit and has sharp turns. For example: the southern part of the kingdom has a mountainous terrain. these mountain obstacles have sharp turns and dim visibility, and many people crash and could suffer fatal injuries due to the lack of perceptibility. In this project we are going to design a mechanism linked with the steering system and the headlight assembly so that the headlight will rotate simultaneously with the input of the steering column. the majority of severe road accident occur at night. Many people have lost their lives while travelling, due to a road accident. To overcome this issue, we thought of a design that can be efficient, inexpensive and increase the safety of travelers on the highways and winding roads. Some of the students in this project their motivation to do this project is because they were in a near fatal situation. Potholes are extremely dangerous and could cause a lot of damage to the vehicles especially at night. There are solutions regarding blind spots in the road as well as low visibility. But these solutions come at a very high cost and the cars that come with the solutions are mainly luxury cars for example: Mercedes and BMW. And it is not affordable to the middle to lower class people. Our goal is to make this project low cost but retain a high quality and affordable to the public. There are many roads in the kingdom of Saudi Arabia that are unlit and has sharp turns. For example: the southern part of the kingdom has a mountainous terrain. these mountain obstacles have sharp turns and dim visibility, and many people crash and could suffer fatal injuries due to the lack of perceptibility. In this project we are going to design a mechanism linked with the steering system and the headlight assembly so that the headlight will rotate simultaneously with the input of the steering column. The whole system involved in this mechanism and parts are headlight, steering column, and the tailored 4-bar mechanism.

2. Objectives

The objectives of the current paper is to enhance the ride comfort of the off-road and on-road middle class vehicles during night through improvement of the headlight covering area. The proposal is based on designing a simple mechanism to make the headlight movable with the same angle of the car-wheel yawing to enhance the vision of the driver during the night time and reduce or completely eliminate the poor-night-vision related accidents. The mechanism is selected such that it will be automatically driven with the rotation center of the steering arm as will be shown later in the paper. The proposed mechanism is a rocker-rocker inversion 4-bar mechanism and it is installed in the space behind the regular housing of the headlight in a way that does not affect the structural integrity of the car.

3. Literature Review

Despite that the concept of headlight controlled by the steering system is still considered to this day as being innovative, it is not new the first vehicle fitted with this system is way back in the 1920s. Pioneers in the automotive history featuring directional headlights were the 1928 Willys-Knight 70A touring. And the 1930 Czech Tatra. These cars were equipped with a third central headlight mechanically connected to the steering system. The most famous car that had the feature of directional headlights was the Citroen DS (1955-1975). It was introduced on the 1968 Paris motor show. This car had both headlights not only swiveling with the steering, but they were self-leveling as well, responding to inputs from the suspension. While it was a purely mechanical system operated by cables, the 1970 Citroen SM used a sealed hydraulic system with a glycerin based fluid.

Figure 1. 1928 Willys-Knight 70A touring

4. Methods

By taking a glance at the market and viewing the suggested alternatives we found that it is expensive for the majority of the buyers, so we decided to make an alternative that not only more affordable but has a great reliability. We discussed this with our supervisor, and he gave us the path to walk on to try and figure out how this design will look like and how it will be implemented in a consumer`s car. In this project we will propose some mechanisms that can be applied into the project. At the same time, we will keep some parameters in mind such as the cost of the parts needed, applicability, durability, and the most important safety.

The methodology starts with:

1-Outlining the different components of the mechanism. To create our mechanism based on these measurements, we will need a normal pickup truck spacing dimension. Moving on, we will begin by determining the mechanism's maximum dimensions, then proceed forward to get the dimensions of each individual component. The height of the mechanism should not be more than 40 cm and IV & II links which are parallel to each other have a maximum of 40

cm length and III link will be no longer than 30 cm which is perpendicular to II & IV links and connecting them. An extension of 10 cm is needed to hold the headlight with II link in front of the 3rd joint as shown in figure 2.10.
2-All calculations will be completed in a comprehensive manner, addressing all issues that may arise during design analysis. Starting with the degrees of freedom and force analysis, these calculations will be based on specific materials that will be in line with our design needs. Material selection will be accomplished by taking more than two material options and working through the steps below to determine which one best meets our criteria.
3-A stress analysis will be performed to determine if our mechanism has any weak places and to determine the design dimensions as well as the suitable material for the mechanism. To ensure that our design complies with the rules, we will base all of our calculations on international standards.
4-All of the calculations will be based on an appropriate failure theory.
5-This final step involves 3D modeling and simulation to check if the mechanism passes the engineering program's tests. If necessary, changes will be made after the simulation. Finally, the mechanism will be manufactured in order to conduct real-world experiments and determine the practicality of our design.

5. Results and Discussion

The values resulting from the from the Solidworks simulation analysis comparing with the theoretical calculations are acceptable and it indicates that the mechanism could hold the weight of the headlight. In the stress figure the most stressed point has yellow color which means it is around 70 MPa which is less than 90 Mpa (Sy =180) which is satisfactory. For the displacement the highest value occurs in the headlight's $F.O.S$ =2 holder, and we can solve this problem by designing fixed circular slot path as shown in the figure below. Our factor of safety is equal to 2 which is safe for the mechanism.
We have done manufacturing the mechanism without the headlight and the arm because they were not available in the market. The dimensions and parts schematics were given to the manufacturer, and they are available in the appendix. We had select all material AISI 1006 HR Steel for all components. It was work perfectly and smoothly.

Figure 2. Manufactured mechanism.

5.1 Numerical analysis

Degrees of freedom (DOF)
To best fit our constraints, we need our mechanism to have a DOF = 1 to be a mechanism that moves in one direction at a time. So, the headlight mechanism will move by one input and achieve our desire angle. Below are the calculations for the DOF:

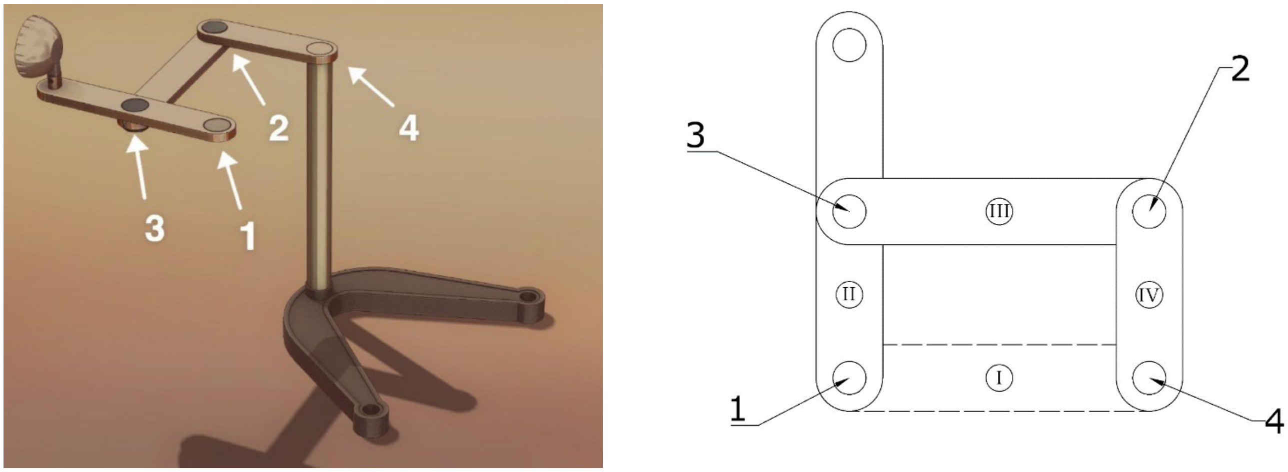


Figure 3. Schematic drawing of pairs on the mechanism to find DOF 2D and 3D.

Calculations for the DOF:
Links = 4 (3 bars, 1 ground link)
Lower pairs PL = 4 (revoulte joints)

$$\text{So DOF} = 3(n-1) - 2(PL) - PH = 3(4-1) - 2(4) - 0 = 1 \text{ (Constrained Mechanism)}$$

Force analysis:

We assumed the weight of the headlight is equal to 10 Kg. we also assumed the weight of the steel bar that holds the headlight to be 0.5 Kg. the values we assumed for the headlights are higher than the real weight of headlights on a real car.
We currently have been given the weight value and the friction due to the mechanism's motion is given by $F=\mu N$. And we have taken the worst-case scenario such that $\mu=1$ so, $F=N=W$.We included W*20 as a moment due to shifting the frictional force vertically by 20mm as shown in the figure below. Also, Mq was integrated to represent the moment which comes from the car`s steering input.

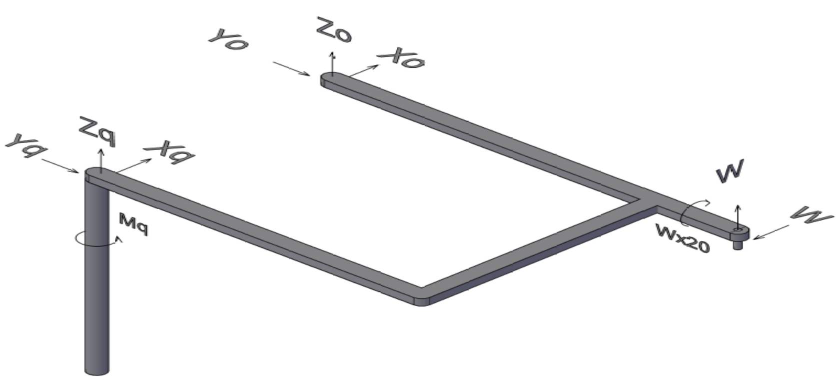


Figure 4. Model of the mechanism with force analysis.

All of the following force analysis are considered at the extreme right position which is at an angle of 30 degree from the y-axis. And the dimensions are taken in mm and were sketched by hand. The equilibrium conditions are applied in the 3D Cartesian coordinate system and the results of the force analysis are listed in the following table

Table 1. The values of the all reactions shown in Figure 4

Reaction	Value in Newton
X_O	35
X_Q	70
Y_Q	70
Y_O	70
X_A	70
Y_A	70
Y'_A	95.62
X'_A	25.62
Y'_C	95.62
X'_C	25.62
Y_C	70
X_C	70
Z_O	112
Z_Q	7
Z_A	7
Z_C	7

er completing the force analysis, this section of stress analysis we will determine the cross-sectional area. We have assumed the factor of safety to be = 2. And we have selected the materials of the mechanism that will be implemented.

First of all, we will analyze the shear stress on the pin at point A and determine the minimum diameter required for the pin.

$$\tau_{shear} = \frac{R_{total}}{\frac{\pi}{4} d_p^2} = \frac{S_{sy}}{F.O.S}$$

$$S_{sy} = 0.5 S_y = 0.5 \times 170 = 85 MPa$$

$$R_{total} = \sqrt{X_A^2 + Y_A^2} = \sqrt{70^2 + 70^2} = 98.995 N$$

$$\frac{85}{2} = \frac{98.995}{\frac{\pi}{4} d_p^2}$$

$$d_p = 1.722mm$$

Roundup the pin diameter to

$$d_{pin} = 4.5mm$$

$$d = d_{pin} + clearance = 4.5 + 0.5 = 5mm$$

We have calculated every stresses accruing on each link such as compression and bending stresses and calculated the cross sectional area by using the below formula

$$\tau_{x,y} = \sqrt{\tau_D^2 + \tau_t^2}$$

$$\sigma^{\sim} = \sqrt{\sigma_x^2 - \sigma_x \sigma_y + \sigma_y^2 + 3\tau_{x,y}^2}$$

- Buckling on the column

Due to the long length of the column, we will check the possibility of buckling occurring on the column.

$$P_{c,r} = \frac{\pi^2 \times E \times I}{L^2 * c}$$

- Sample of welding calculation

In this section we will analyze the weld between the arm and the weld.

Compression force and the bending moment and shear force and torsion will be incorporated for the analysis.

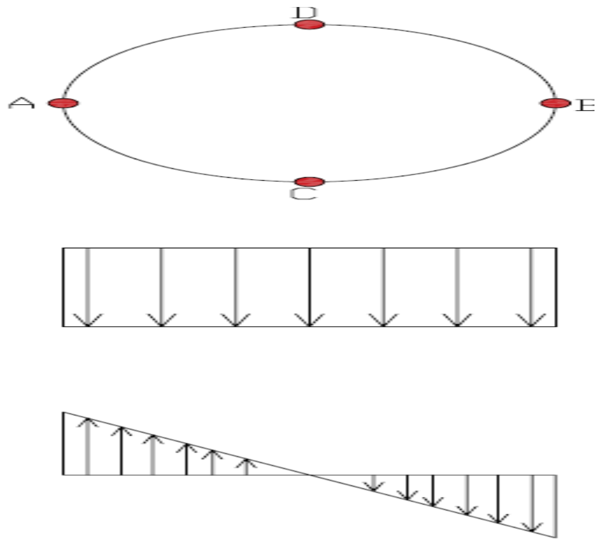
$$\sigma_c = \frac{F_v}{A_{Weld}} = \frac{7}{1.414\pi \times h(\frac{15}{2})} = \frac{0.2101}{h} Mpa$$

$$\sigma_c = \frac{0.2101}{h} \;, \sigma_b = \frac{M^v \times r}{I}, I = I_u * h$$

$$\sigma_b = \frac{98.995 \times 350 \left(\frac{15}{2}\right)}{0.707 \times \pi \times \left(\frac{15}{2}\right)^3} = \frac{277.33}{h} Mpa$$

$$\tau_D = \tau' = \frac{force}{A \times h} = \frac{98.995}{1.414\pi \times h \times r} = \frac{98.995}{1.414\pi \times h(7.5)} = \frac{2.971}{h} Mpa$$

$$\tau_t = \tau'' = \frac{M_D \times c}{J_u \times h} = \frac{23100 \left(\frac{15}{2}\right)}{2\pi \left(\frac{15}{2}\right)^3 h} = \frac{65.36}{h} Mpa$$



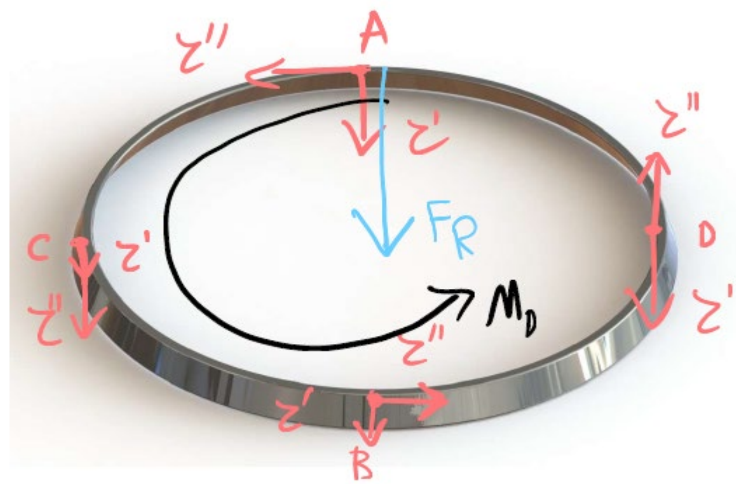


Figure 5 Compression force and the bending moment of the weld.

Figure 6. Cross section stresses.

-For the first worst case scenario will occur at point B as shown in the figure 5:

Table 1. Stresses permitted by the AISC code for weld metal

Type of Loading	Type of Weld	Permissible Stress	n*
Tension	Butt	$0.60S_y$	1.67
Bearing	Butt	$0.90S_y$	1.11
Bending	Butt	$0.60–0.66S_y$	1.52–1.67
Simple compression	Butt	$0.60S_y$	1.67
Shear	Butt or fillet	$0.30S_{ut}^{\dagger}$	

*The factor of safety n has been computed by using the distortion-energy theory.

†Shear stress on base metal should not exceed $0.40S_y$ of base metal.

$$\sigma_{tot} = \sigma_x = \sigma_c - \sigma_b = -\left(\frac{0.2101}{h}\right) - \left(\frac{277.33}{h}\right) = -\frac{277.5401}{h}$$

$$\tau_{tot} = \tau_{x,y} = \sqrt{(\tau')^2 + (\tau'')^2} = \sqrt{\left(\frac{2.971}{h}\right)^2 + \left(\frac{65.36}{h}\right)^2}$$

$$\sigma' = \sqrt{\sigma_x^2 - \sigma_{x,y} + \sigma_y^2 + 3\tau_{x,y}^2}\ ;\ \sigma' = 0.64S_y \text{ from table 1}$$

$$\sigma' = 0.64S_y = 0.64 \times 345 = 220.8\ Mpa\ ;\ S_y = 345\ Mpa$$

$$220.8 = \sqrt{\left(-\frac{277.5401}{h}\right)^2 + 3(\sqrt{\left(\frac{2.971}{h}\right)^2 + \left(\frac{65.36}{h}\right)^2}}$$

$$h = 1.357 \text{ mm} = 2 \text{ mm according to the standard}$$

- The final dimensions

We have taken the thickness (t) value for all the links as 10 mm since the largest value was 10 mm for manufacturing purposes. We have considered the heights of weld (h) to be 2 mm according to the standard. Also, the diameter of the rod is equal to 15 mm. Furthermore, the diameter of the headlight's holder equals to 10 mm. The following figures show the whole mechanism after finalizing the dimensions and assembling with the arm and wheel of the car:

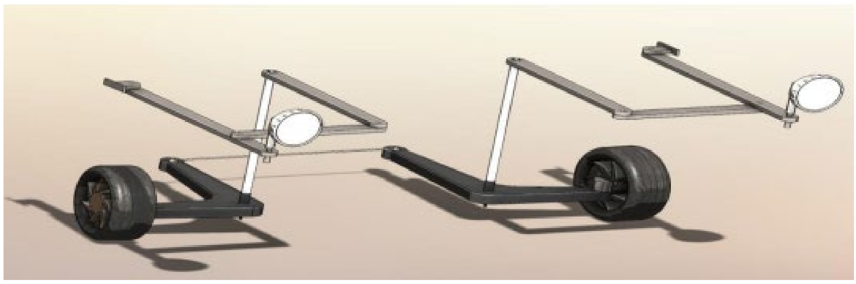
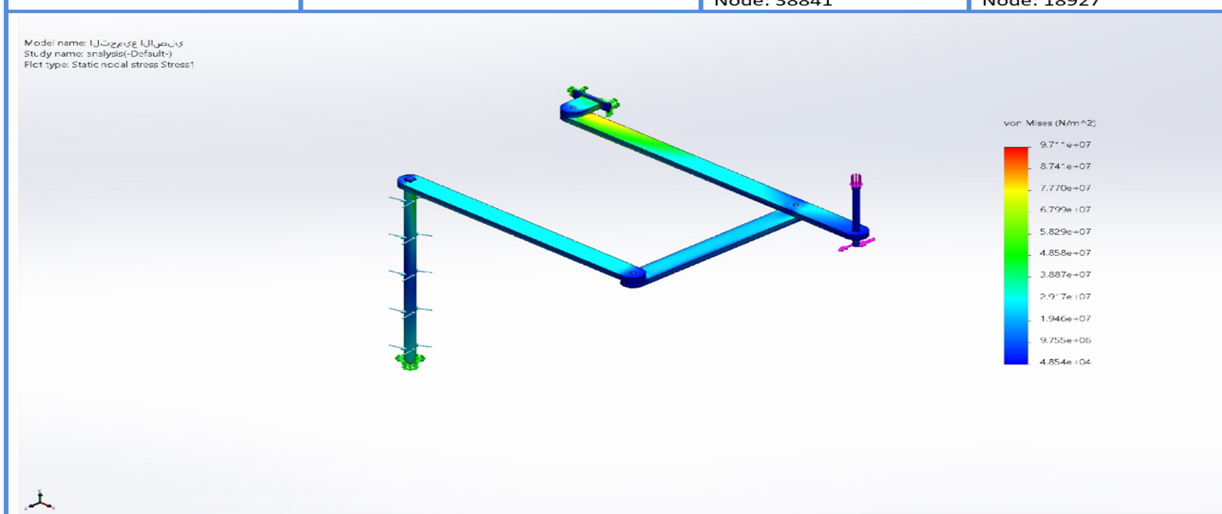


Figure 7 the mechanism at 0 degree tilt angle

5.2 Solidworks Simulation Results

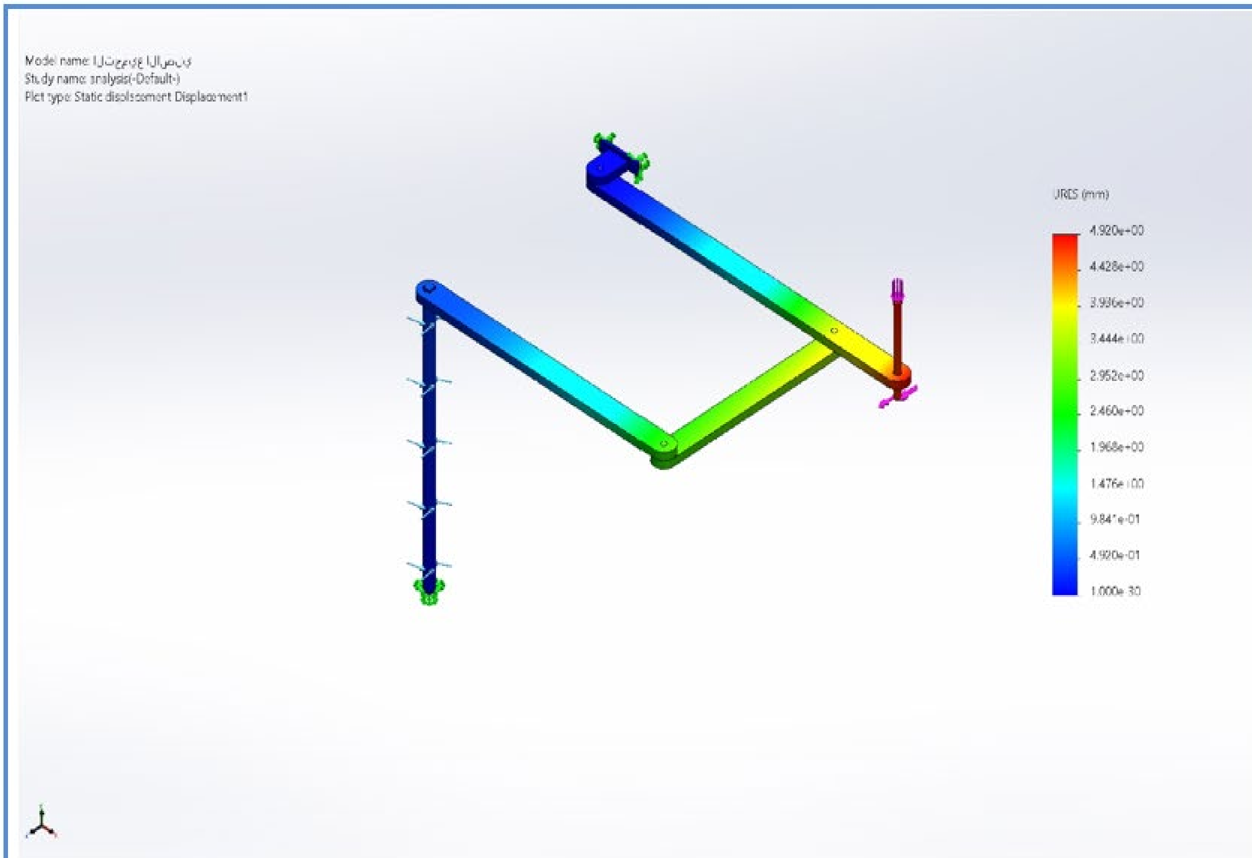
Now we will see the report results which contain the unit system, materials used and its properties, the fixed surfaces and loads information, mesh information, stresses analysis, displacement and factor of safety.

Name	Type	Min	Max
Stress1	VON: von Mises Stress	4.854e+04N/m^2 Node: 38841	9.711e+07N/m^2 Node: 18927



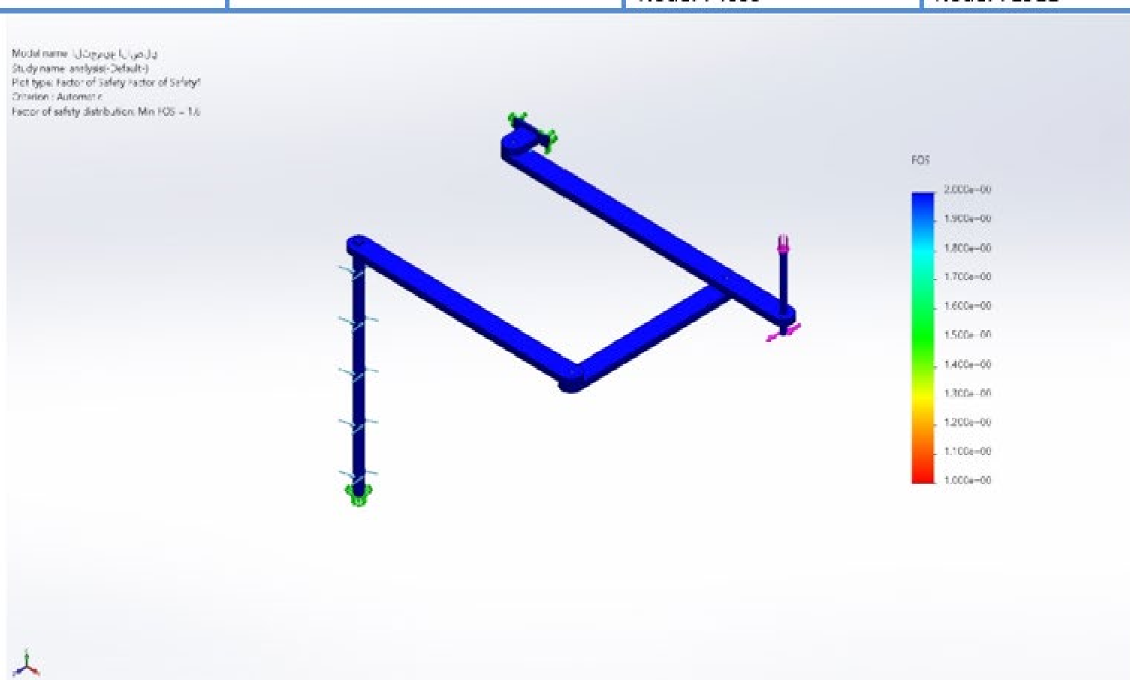
4-bar mechanism -analysis-Stress-Stress1

Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0.000e+00mm Node: 31329	4.920e+00mm Node: 38063



4-bar mechanism -analysis-Displacement-Displacement1

Name	Type	Min	Max
Factor of Safety1	Automatic	1.561e+00 Node: 74099	7.597e+03 Node: 71911



4-bar mechanism -analysis-Factor of Safety-Factor of Safety1

Our values from the analysis are acceptable and it indicates that the mechanism could hold the weight of the headlight. In the stress figure the most stressed point has yellow color which means it is around 70 MPa which is satisfactory. For the displacement the highest value occurs in the headlight's holder, and we can solve this problem by designing fixed circular slot path as shown in the figure below. Our factor of safety is equal to 2 which is safe for the mechanism.

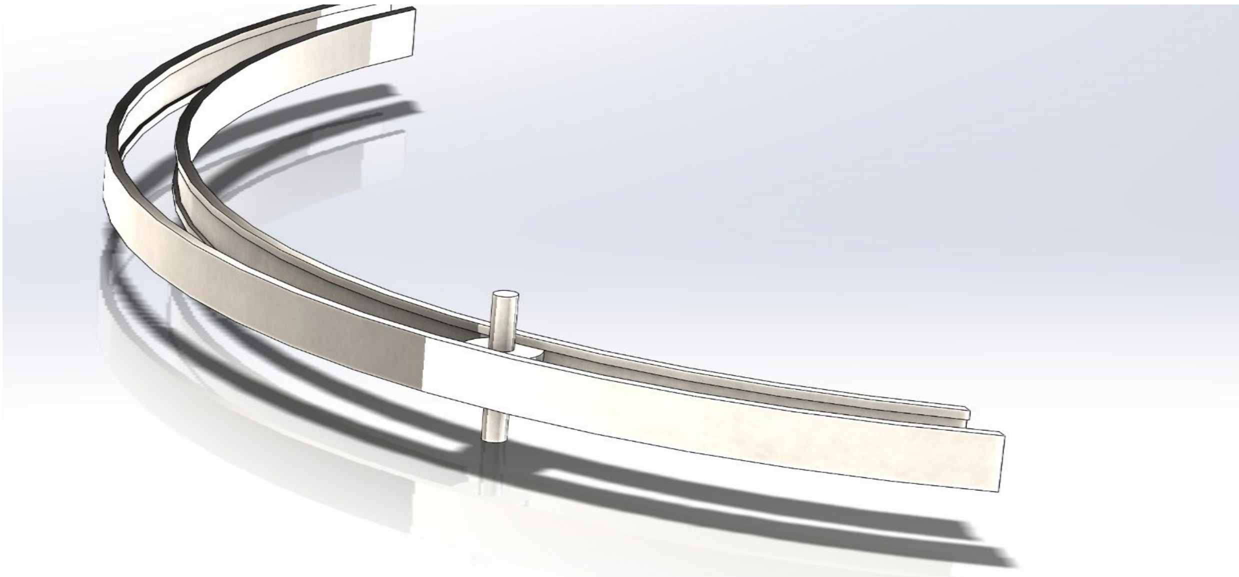


Figure 8 fixed circular slot

6. Conclusion

In conclusion, the full details of the project and standers are mention in the full project paper. We manage to design and simulate the 4-bar mechanism which tilt the headlight at an angle of 30^o. Also, AISI 1010 HR steel is the main material to fulfill the target design, such as great formability, durability, and good tensile and yield strength. In addition, the purpose of selecting this mechanism is accomplishing lower required maintenance and financial cost compared to the other alternatives. After simulating the model, the calculating dimensions, stresses and factor of safety values is validated by their simulated values.

References

classiccarweekly.net Available at: http://www.classiccarweekly.net/2017/04/20/1928-willys-knight-model-70a-saloon/. Accessed on July 5, 2021.
Budynas, R. Nisbett, K ., *Shigley's Mechanical Engineering Design*. 10th edition. McGraw-Hill 2014 Accessed Nov 7, 2021.
Pinterest., Available : https://www.pinterest.com/pin/279293614371078285/. Accessed on July 5, 2021.
Consumer guide., Available at: https://consumerguide.com/used/2003-07-porsche-cayenne/. Accessed on July 5, 2021.
Taneja,N Sharma, A., Development of an Adaptive Steering Controlled Headlight for Low-Cost Vehicles, Available: https://www.researchgate.net/publication/294260137_Development_of_an_Adaptive_Steering_Controlled_Headlight_for_Low_Cost_Vehicles. Accessed July5, 2021.
Dagne,A.Transmission angle & the preferred range, Available: https://www.slideshare.net/idanemariamtesera/lecture-2-linkages .Accessed Nov 7, 2021.
Falcon, C., Stepper Motors Assist Adaptive Headlights, Available: https://www.eetimes.com/stepper-motors-assist-adaptive-headlights/. Accessed July 5, 2021.
Kumar, A., Cam and Follower: Definition, Types, Working Principle, Terminology, Advantages, Applications, Available: https://themechanicalengineering.com/cam-and-follower/ . Accessed July 5, 2021.
Yadav, K., Design of mechanical components of Steering controlled headlights pdf, available: https://pdfcoffee.com/steering-controled-headlights-project-report-pdf-free.html. Accessed on July 5, 2021.

Types of Sprockets - A Thomas Buying Guide, Available: https://www.thomasnet.com/articles/machinery-tools-supplies/types-of-sprockets/ . Accessed July 5, 2021.
Parallel Motion Linkage, Available: http://wiki.dtonline.org/index.php/Parallel_Motion_Linkage. Accessed July 5, 2021.
Fine Tuning Steering System Design using MSC Adams Steering wheel explanation, Available: https://medium.com/pixmoving/fine-tuning-steering-system-design-using-msc-adams-bb64692f4895 Accessed July 5, 2021.
AISI 1010 HR steel, Available: http://www.matweb.com/search/DataSheet.aspx?MatGUID=7573afc5e06c4a518c01efba4690182c&ckck=1 .Accessed Nov 7, 2021.
AISI 1050 HR steel, Available: http://www.matweb.com/search/DataSheet.aspx?MatGUID=38f28349832c435ba35fecc1e6e3b360 .Accessed Nov 7, 2021.
Stainless steel A-4 316, Available: https://midlandbrightsteels.co.uk/portfolio/special-steels/a4-80/ .Accessed Dec 12, 2021.
Alexander, G. J. and Lunenfeld, H. (1990), *"A users' guide to positive guidance, third ed.,"* Report No. FHWA-SA-90-017, U.S. Department of Transportation, Federal Highway Administration, Washington, DC pp. 1–39.
D. Neunzig and R. Lachmayer, *"Lighting and Driver Assistances Systems for ImprovingVehicle Safety,"* ATZ Worldwide 6/2002, Vol. 104, pp 13-17.
Japanese Patent Application Laid-Open No. H8-192674.
US Patent No. 6,309,082, Inventor - Tien-Ching Wu.

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