DESIGN AND OPTIMIZATION OF SUSPENSION SYSTEM FOR SOLAR CAR

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ABSTRACT
Solar energy is becoming more applicable which aims to remove the dependency on traditional energy sources and replace them with more efficient ones. Solar cars are one of the main and most important applications of solar energy usage which can be demonstrated in reserving solar energy in car's battery with no pollutions. As the solar car has different designs than traditional cars, all its components need to be redesigned and refined to suit the new energy source. The main objective of this study is to design a suspension system for a solar car which is not only as light as possible but also strong enough to damp different forces while driving the vehicle. This paper covers step by step on the design of such a system to determine the possible solutions which will be the most appropriate design for solar cars. Several types of suspension systems have been studied and compared together using benchmarking to choose the best suspension system design. The modeling of different components of the suspension system is conducted using SolidWorks. Also, after the assembly step, static analysis based on the maximum load of the solar car is implemented to find the appropriate factor of safety. The calculated FOS for the designed assembly is 2.9 which is within the range of the target.

Keywords: solar car, suspension system, Factor of Safety.

INTRODUCTION
As the whole world is suffering from global warming and different kinds of pollutions such as air pollution, water pollution, and even noise pollutions which are mainly caused by cars due to the fact that they depend entirely on burning fossil fuel to operate. To eliminate such a problem, designing a car that can run using a clean energy source can lower the impact of the pollution on all the mentioned fields. Solar cars are a new type of cars which run using the solar energy gathered from the sun radiation which is absorbed using solar panels installed on the car body to provide the car with the sufficient power to run. This project focuses on the suspension system design and implementation for solar cars. A suspension system is one of the major components of the car and it plays a vital rule in the rider's comfort and safety. Suspension systems have three main types: passive, semi active, and active control, where each type must provide the following conditions: comfort ride, drivability, body leveling, and suspension deflection. Suspension systems also

contains several components such as the wheels which are connected to the suspension system and help in balancing the car. Other components of the suspension system are the rods, bushings and bearings. The bushings are either made from rubber which can break out, or tie roads which use lubricants as come in different types such as ball joints which use ball-like metal peace which is attached to the control arm and covered with lubricants for easy and safe movement. Finally, the steering rods are considered also a component of the suspension system. There also exists two main types of the suspension system steering which are hydraulic type, and electrical power type. The hydraulic type uses high-pressure fluids to help turning the wheels. This type has some limitation such as that the fluid may leak from the pipes which may cause the pump of the system to fail and the whole system will get into failure [1]. Also, in aviation industry, the application of shock absorbers in terms of safety is very critical and important. A typical aircraft landing gear was modeled in Matlab and different parameters such as the effect of damping coefficient, and the spring variation are the most significant parameters need to be considered in design [2].

The main motivation of this project is to lower the dependency on the traditional energy sources and aim to use renewable source in one of the most used aspects in life which is driving cars. Lowering the cars dependency on the traditional energy sources and using solar cars can vastly lower global problems and open the door for more applications using the solar power in Kuwait. Moreover, depending on a renewable energy source is both efficient and cost effective, and can contribute to improving the environment of Kuwait and the whole globe.

A new type of suspension system had been proposed which is called air suspension system. This type uses air bags to consume vibrations and allow the vehicle to be persistent. The proposed solution is to control the height of the chassis by inflating the airbag while the stiffness cannot be controlled, and it only depends on the volume and chassis load. The new solution contains two air champers which allow controlling chassis height and stiffness at the same time by controlling the air pressure in two champers. The advantages of this solution is that it uses a semi-active approach to design a suspension system which allows controlling the chassis height and the stiffness. The disadvantage of the proposed solution is that it relies on rubber airbags which may tear in their lifetime and need maintenance [3].

Another model had been proposed which is used to retrieve the stiffness parameters of a forklift Cabin suspension system. The model comes with three degrees of freedom which were tested and proved to be efficient. The stiffness parameters of the cabin suspension system are important in influencing the ride comfort. The proposed model is designed without dismantling the suspension system of the cabin vehicle. The model has the following assumptions:

1. The cabin has or supports 3 degrees of freedom
2. The driver’s seat is non-suspended and is connected directly to the body of the vehicle
3. The maximum deformation of each air spring is less than 16 mm

The main disadvantage of this model is that it has several assumptions to work which may not be suitable for general use. The efficiency of this model is high, and the stiffness of the given suspension system is also high [4].

Three different types of suspension systems had been analyzed which can achieve ride comfort and suppress vehicle vibration such as passive system, semi-active system, and active suspension system. Passive and semi-active suspension systems have limited vibration isolation under different conditions. The fully active suspension system in the other hand have actuators work with passive components to provide additional actuating forces to regulate the vehicle. Different studies of active suspension system such as optimal control, fuzzy control, neural network control, adaptive control, backstepping control, and sliding control have been applied. The efficiency of the solution shows that the curves of vertical displacement, role angle, and pitch angle are all consistent with the proposed solution [5-6].

One of the most important steps in design is the simulation step to ensure the model is safe for the fabricating process. The chassis of the current solar car has been modeled and simulated via SolidWorks. The static analysis has been conducted and the model has been fabricated in Kuwait [7]. Also, through the simulation process, applying different optimization method is necessary such as Design of Experiment (DOE) for different engineering problems to select the optimum design [8-9].

METHODOLOGY

2.1 Problem definition

The main challenge of this study is to design an effective suspension system for the solar car to make it useable and effective on road. The design of the suspension system is studied and designed using SolidWorks before being manufactured and tested. The design most adhere all the goals of a suspension system which are the driver's comfort, the drivability of the car, the suspension deflection, and active control of the car.

2.2 Concept Generation

Conceptual design is the first draft for different components of a suspension system that are modeled in SolidWorks. Each parts are designed separately using SolidWorks. Then the assembly of different components are conducted to form the suspension system. Two suspension system designs are taken into consideration as shown in Figure 1.

(a) First design

(b) second design

Figure 1: 3D Model of Suspension System for first and second Design

2.3 Benchmarking

In this section, several types of suspension systems are going to be compared based on the literature review, namely air suspension system, semi-active suspension system, active suspension system, passive suspension system as shown in Table 1.

Based on different rules and regulations of the competition, passive suspension system is chosen as the most suitable system in this study.

After the assembly of suspension system and the solar chassis, the length of the coil needed to be increased. Hence, the new coil is designed and replaced as shown in Figure 2.

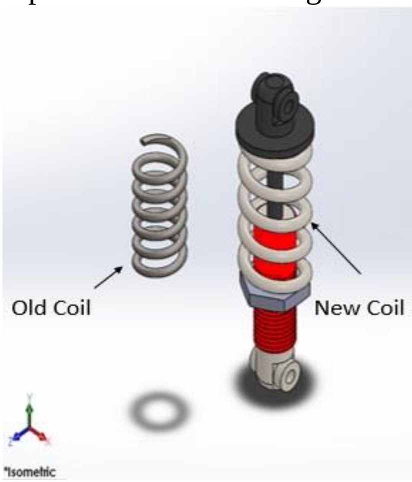


Figure 2: suspension system with the new coil

Table 1: The comparison of different suspension systems

Type	Advantages	Disadvantages
Air suspension system	1. Reduced vibration and noise effects. 2. less fuel consumption 3. Improves tire life	1. lower durability because the air bags can tear and wear 2. Costs more than other systems
Semi-active suspension system	1. Can be implemented using various controls 2. Allows for adaption of damping and spring stiffness on demand	1. Doesn't provide high efficiency when it comes to vibration and comfort 2. Has limited vibration isolation under different conditions
Active suspension system	1. Has actuators work with passive components to provide additional actuating forces to regulate the vehicle.	1. Complex to design and manufacture 2. Costly and may not be suitable for all types of traditional cars
Passive suspension system	1. Parts can be easily replaced and adjusted to suit the chassis of the car 2. Highly durable as all the parts are metallic parts 3. Low cast	1. Low vibration elimination 2. Low ride comfort 3. Lack of smart mechanisms to adapt with the road conditions

The next step is to conduct the static analysis using SolidWorks. For doing that, suspension system needs to be fixed from the lower part and the selected load needs to be applied to the upper part as shown in Figure 3.

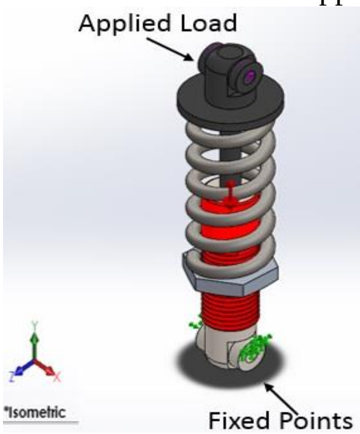


Figure 3: defining constraint and applying the static load

The first result based on the static analysis of suspension system is to determine the Von-Mises stress. As shown in Figure 4, suspension system is in safe zone (blue color) and the critical area of the model has Von Mises stress close to 6.4951 MPa.

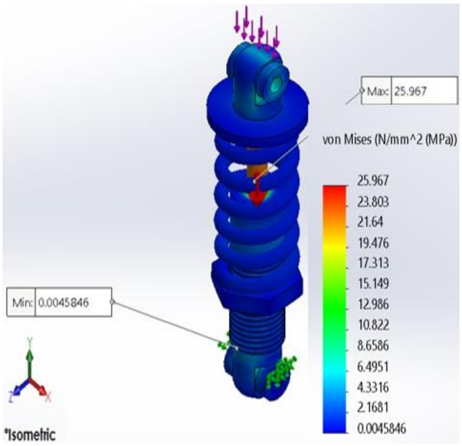


Figure 4: Von Mises stress analysis for the suspension system

The Next step is to determine the displacement of the assembly after applying the load in static mode. As shown in Figure 5, the maximum displacement for the upper part of the assembly is 0.027mm which is ignorable.

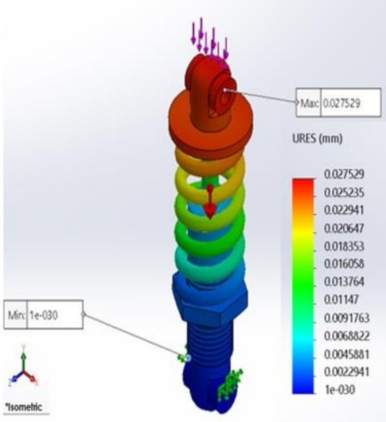


Figure 5: Displacement analysis for the suspension system

The Final Analysis is to determine the Factor of Safety (FOS) for the suspension system. Based on the literature survey, an acceptable FOS for vehicle components is between 2 to 3. As shown in Figure 6, FOS for the suspension system is 2.9 which is within the range. It means for any dynamic loads during driving if the maximum Von Mises stress is 2.9 times more than the maximum Von Mises stress in static mode, then the failure happens.

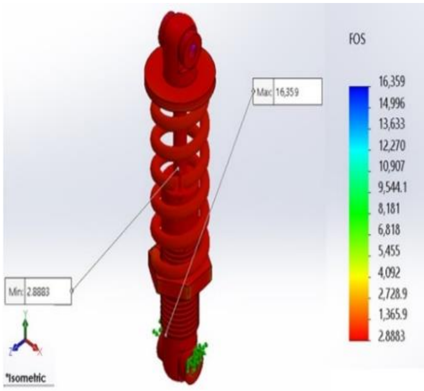
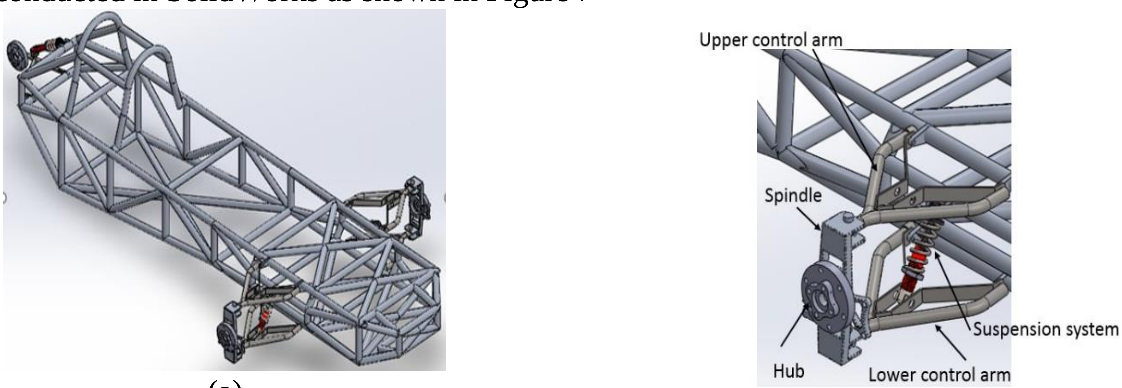


Figure 6: Factor of safety analysis for the suspension system

Finally the assembly for hub, spindle, upper and lower control arm including the suspension system and the chassis is conducted in SolidWorks as shown in Figure 7



(a) (b)

Figure 7: (a) Final assembly of solar car chassis and (b) suspension system assembly including hub, spindle, and upper and lower control arms.

CONCLUSION

Solar cars are becoming of great importance due to their ability to use clean energy, but they need to be developed to reach a certain point to be useable worldwide. The main objective of this study was to design a suspension system for a solar car with Factor of Safety (FOS) between 2 to 3 which is promising result toward making a safe and useable solar car. SolidWorks was applied to model the suspension system and conduct the static analysis, and the results were extracted from the system. Several types of suspension systems have been studied and compared together using benchmarking to choose the best suspension system design for a solar car. Other types of suspension systems exist but are not appropriate options for a solar car. Future work includes further improving the solar car design by focusing on other components such as the engine, the wheels, and the power reservation system in the car.

Compliance with ethical standards

Acknowledgments

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Disclosure of conflict of interest

The authors declare no conflict of interest.

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