بسم الله الرحمن الرحيم

"Air lift suspension system with passive control"

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الإهداء

إلى من تعهد الي بالتربية في الصغر وكانا لي نبراسا يضيء فكري بالنصح والتوجيه في الكبر أمي وأبي

حفظهما الله

إلى من شملوني بالعطف وأمدوني بالعون وحفزوني للتقدم، إخوتي وأخواتي

رعاهما الله

إلى كل الزملاء , زملاء المقعد الدراسي الذين ساهموا في انجاز هذا المشروع

إلى كل من قدم لي حرفا ، وأخذ بيدي في سبيل تحصيل العلم والمعرفة

إليهم جميعا أهدي ثمرة جهدي ونتاج بحثي المتواضع

كما ونتقدم بشكر خاص الى من ساندنا وحفزنا للتقدم الدكتور المهندس خالد طميزي المحترم

فريق المشروع

Abstract

Order has been increased rapidly for having efficient vehicles that is capable of to overcome the mountains and the rough roads. Since the available low structure vehicles will not face these obstacles; so in this project we will design a pneumatic system that is capable of to overcome the mountains, the rough roads problems and the low structure vehicles issue. So this project aims to rise the low structure vehicles when being on rough roads in what so called(air lift suspension system) with relatively low costs; using (level sensor, compressor,air tank,air bags ,flow control valve and micro-controller).

ملخص

الإنسان يحتاج ويستخدم المركبات بشكل متزايد أكثر من أي وقت مضى منذ وجوده على هذه الأرض مع زيادة المشاغل الحياتية وزيادة عدد السكان إضافة الى تباعد المسافات وتعدد المناطق الجغرافية المستوية منها والوعرة ،لذلك

من خلال هذا المشروع قمنا ببناء وتصميم نظام يقوم بشكل رئيسي على الانظمة الهوائية وهو (نظام التعليق الهوائي) بتقنية التحكم اليدوي، وهو نظام يمكن الاستفادة منه بشكل رئيسي في الطرق الوعرة وخصوصا عندما تكون المركبة ذات هيكل منخفض حيث ان النظم يحافظ على هيئة المركبة من الصدمات التي قد تنتج من السير على الطرق الوعرة، ويحافظ ايضا على راحة المسافرين والركاب.

مكونات هذا النظام غير مكلفة و بامكان الجميع تملكها، لذلك المركبات التي تعمل بهذا النظام سيرها على الطرق الوعرة لم يعد يسبب المشاكل لهيئتها اضافة الى راحة ركابها. حيث اننا استخدمنا في هذا النظام (طابات هواء، متحكم دقيق، حساسات لقياس الارتفاع، مضخة هواء, صمام يدوي للتحكم في كمية الهواء).

قمنا ببناء النظام على شكل نموذج يمكن الاستفادة منه كنموذج تعليمي كونه مثبت على هيكلية سيارة، مع تحديد قيمة الضغط اللازم للانظمة الهوائية بقيمة (6 بار).

1

Chapter one

1. Introduction

1.1 Overview.

1.2 Project Objectives.

1.3 Design limitations.

1.4 Previous studies.

1.5Time Schedule.

1.6 Budget.

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1.1 Project Overview

A car without a suspension would be about as comfortable as a horse and buggy ride. Even with your speed limited to a crawl, no amount of cushioning would save you from the bone shattering dips and cracks in the road. Passenger vehicles have since incorporated a suspension system to minimize the effects of uneven or worn-down roads and to support the ever-increasing weight of today's larger vehicles. The car's suspension system has to support the weight of the car, its passengers and cargo while allowing the tires and wheels to move up and down to compensate for uneven pavement. In addition, it has to prevent excessive body squat and dive while accelerating or braking. There are a number of systems used to achieve this which are (Air suspension, coil spring and leaf spring); but in spite of that suspension systems reduce the shocks and protects the vehicles body and offers physical comfortable to the passengers there's the unbalance conditions, the rough roads problems, and the low structure vehicles which the suspension system will not be able to deal with them. So in this project it’s wanted to design a system capable of to deal with these problems and make the required balance to the vehicles using a pneumatic system.

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1.2 Project objectives

1. Design a pneumatic system on the vehicle to protect its body from shocks and road strokes.

2. Its required to design this system for offering physical comfort to the passengers.

3. Implementation of the project in reality on any car.

1.3 Design limitations

1) The stroke length of the suspension in the vehicle must not be raised more than the allowable separation line.
2) The humidity that affect the lift system may cause system unstability.
3) It’s required that the new system won't prevent the original suspension system from functioning properly.
4) Reduction of oscillation in then vehicle.

1.4 Previous studies

1. In 1901, the American idea was to design a pneumatic spring vehicle The design consisted of a left and right air spring longitudinally channeled nearly the length of the vehicle.
2. In 1946, American studies reached to built a non-production prototype that featured numerous innovations, including a four-wheel independent air suspension system.
3. In 1954, Frenchman developed a functioning air/oil hydro-pneumatic suspension, incorporating the advantages of earlier air suspension concepts.
4. In 1960, the was the first German car with self-leveling air suspension.
5. In 1975, the German companies incorporated a hydro-pneumatic suspension on Mercedes vehicles.
6. In 1986, Toyota Japanese company introduced the first electronically controlled a semi-active full air suspension (spring constant, variable attenuation force).
7. In this current year Mercedes German company developed a very smart system that could discover the roads using global positioning system, cameras on the wheels, and proximity sensors then adjust and rise the vehicle based on the current road condition (adaption system)**.**

Note: In our project we will redesign a pneumatic air lift system with passive control

to solve rough roads problems like Citroen old systems.

1.5 Time Schedule

Table 1.1 shows the activities that done in the project, and the time for each one.

Week Task	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
The defined vehicle studying	■														
Define system location		■	■	■											
Preparing and buying the kits					■	■	■	■	■						
System installation										■	■				
Programming the system											■	■			
Documentation and results													■	■	
Presentation															■

1.6Budget.

As in any other problem, in selection of material the cost of material plays an important part and should not be ignored.

Sometimes factor like scrap utilization, appearance, and non-maintenance of the designed part are involved in the selection of proper materials.

a. Primary cost.
b. Manufacturing cost
   Lathe, drilling, welding, power hacksaw, gas-cutting cost.

   Manufacturing cost = primary cost +labor cost

= 2500+ 1000

= 3500 NIS

c. Overhead charges
   The overhead charges are arrived by "manufacturing cost"

   Overhead charges = 15% of the manufacturing cost

   = 450 NIS

d. Total cost = manufacturing cost + overhead charges

   = 3500 + 850
   Total cost of project = 4350 NIS

1.7 Chapters Contents

Chapter Two: Suspension background and vehicle geometry.

Chapter Three: Air control mechanism design and analysis**.**

Chapter Four: Conclusion and recommendation.

2

Chapter Two

2. Suspension background and vehicle geometry

2.1 Introduction

The suspension system must support the vehicle, provide directional control during handling maneuvers and provide effective isolation of passengers/payload from road disturbances. Good ride comfort requires a soft suspension, whereas insensitivity to applied loads requires stiff suspension. Good handling requires a suspension setting somewhere between the two. Due to these conflicting demands, suspension design has had to be something of a compromise, largely determined by the type of use for which the vehicle designed. Active suspensions is considered to a way of increasing the freedom one has to specify independently the characteristics of load carrying, handling and ride quality [1].

2.2 Principles of suspension operation.

The suspension system isolates the body from road shocks and vibrations which would otherwise be transferred to the passengers and load. It also must keep the tires in contact with the road. When a tire hits an obstruction, there is a reaction force. Suspension systems serve a dual purpose — contributing to the vehicle's handling and braking for good active safety and driving pleasure, and keeping vehicle occupants comfortable and a ride quality reasonably well isolated from road noise, pumps, and vibrations. The suspension also protects the vehicle itself and any cargo or luggage from damage and wears [2] .

1) Driving safety:

Wheel contact with the road surface, which is essential for braking and steering, is maintained.

2) Driving comfort:

Unpleasant and unhealthy stresses to vehicle passengers are minimized, and damage to fragile loads is avoided.

3) Operating safety:

The vehicle components are protected against excessive stresses.

2.3 Sprung and un-sprung weight:

Vehicle weight are divided into two parts, sprung and un-sprung weight. Sprung weight is weight carried by the springs. This includes the vehicles frame and body, passenger, the power train, and most major components.

The un-sprung weight is the mass of the suspension, wheels or tracks (as applicable), and other components directly connected to them, rather than supported by the suspension, and it is the mass not carried by the springs[2].

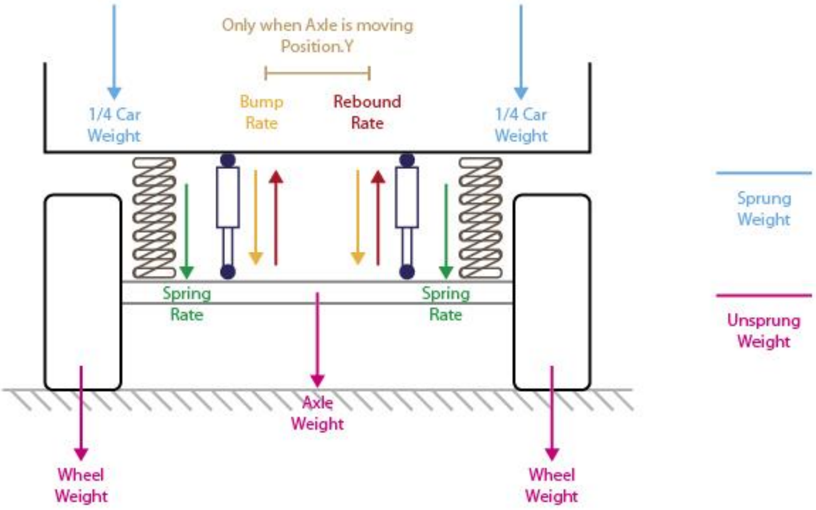

Figure 2.1: Sprung and un-sprung weight

Every time a car hits a pump, the wheel, tire, brakes, and other un-sprung parts have to move in response to the bump. This mass of parts has to accelerate upward, stop, and accelerate back down. The more mass that has to move, the slower it will react. By decreasing the un-sprung weight, the suspension will be able to respond more rapidly to bumps and road conditions. This means the tire can regain contact with the road sooner after encountering a bump. In addition, since the shocks and springs still have to respond to movement by the un-sprung weight, reducing this weight will allow the springs and shocks to better control the sprung weight of the vehicle, which is also responding to bumps, dips, potholes, and other road conditions .

2.4 Types of suspension system:

There are many types of suspension system in general use; we can describe it as following:

- *Dependent suspension system:*

Motion of a wheel on one side of the vehicle is dependent on the motion of its partner on the other side, because both wheels of a pair are mounted on a common axle that acts as a rigid beam, which is then connected by springs to the vehicle structure.

- *Semi-dependent suspension system:*

The rigid connection between pairs of wheels is replaced by a compliant link. Both wheels of a pair are again mounted on a sprung common axle, but in this case, it acts as a beam with limited flexibility.

- *Independent suspension system:*

Motion of wheel pairs is independent, so that a disturbance at one wheel is not directly transmitted to its partner. Each wheel of a pair is separately linked and sprung from the vehicle structure, so that its movement relative to the latter is the same in roll as it is for ride .

- *Interdependent suspension system:*

Both wheels on each side of the vehicle have their springs coupled together , either mechanically or hydraulically , so that single wheel bumps are shared between front and rear springs for softer ride, together with reduced pitching except during acceleration and braking.

2.5 Front and Rear suspension systems.

The front and Rear suspension system are extremely important to provide proper wheel position, steering control, ride quality, and tire life.

The impact of the tire striking road irregularities must be absorbed by the suspension system. The suspension system must supply proper ride quality to maintain customer satisfaction and reduce driver fatigue, as well as provide proper wheel and tire position to maintain directional stability when driving. Proper wheel positions also ensure normal tire tread life[3] .

2.5.1 Front suspension system

Multilink front-suspension systems use the strut -spring assemblies found in the Macpherson system but replace the lower control arm with a series of links. These links pivot slightly when the vehicle turns, allowing for increased control and stability during cornering.

This design also includes an upper link that attaches to the unitized body near the top of the strut/spring assembly, a lower link and a third link that connects the upper link to the steering knuckle. Unlike other front strut -suspension systems, the strut assembly does not rotate when the tires are steered.

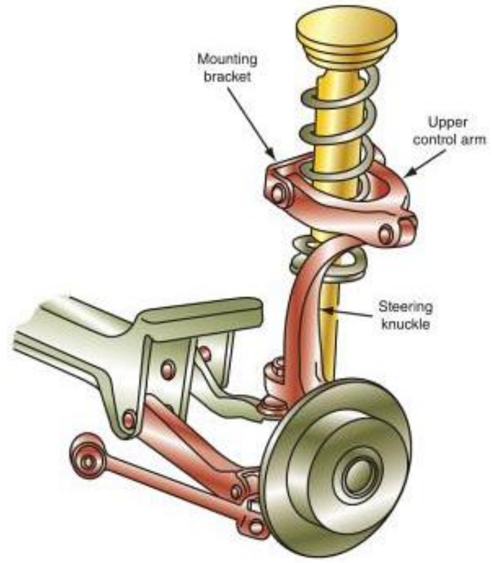

Figure 2.2: Multilink front-suspension systems [3]

Typically component in a short and long arm (SLA) front suspension system are illustrated in figure 2.2.The type in front suspension system has a long lower control arm and a shorter upper control arm. Upper and lower control arm serve the purpose of control lateral (side-to-side) wheel movement.

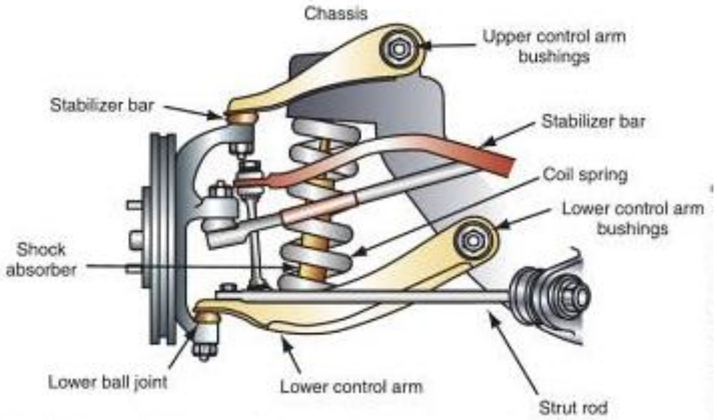

Figure2.3: Macpherson strut front suspension system

A Macpherson strut front suspension system has no upper control arm and ball mount bolted to the reinforced strut tower in the unitized body (figure 2.3). The strut supports the top of the knuckle and performs the same function as the shock absorber in an SLA suspension system. The coil spring is mounted in the lower support in the strut and the upper strut mount allow the strut and coil spring to rotate with the spindle when the front wheels is turned .

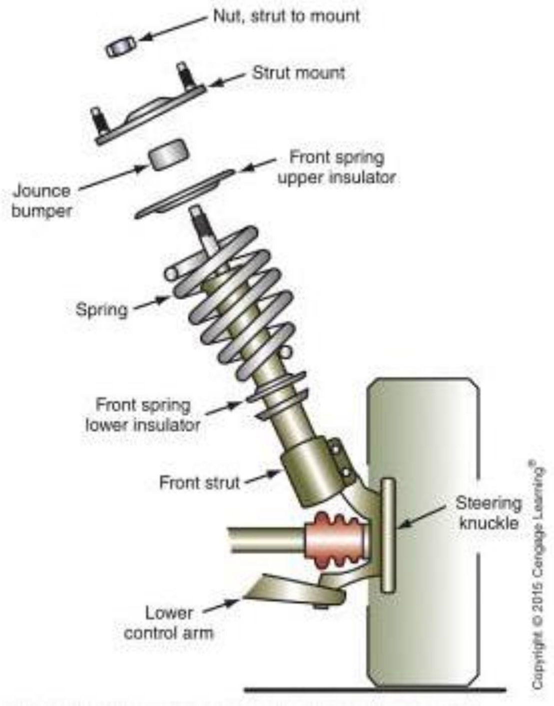

Figure 2.4: The coil spring

2.5.2 Rear Suspension System

Rear suspension system plays a very important part in ride quality and in the control of suspension and differential noise, vibration, and shock. Although the front wheel actually steer the vehicle, the rear suspension is also vital to steering control.

The rear suspension must also provide adequate tire life and maintain tire traction on the on the road surface. Rear suspension system includessliveraxle, Semi-dependent, independent. Live axle rear suspension systems are found on rear –wheel-drive (RWD) trucks and vans, a few rear RWD cars, and some four-drive wheel (4DW) cars. Front wheel drive (FWD) vehicle have semi-independent or independent rear suspension. Independent rear suspensions are also found on RWD and 4WD cars. See figure 2.5.

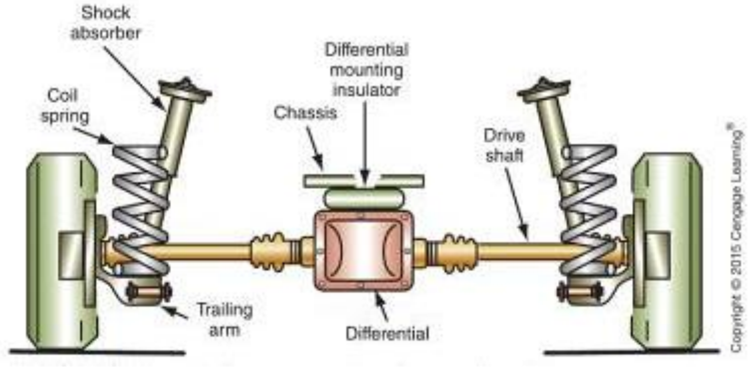

Figure2.5: Independent rear suspensions in RWD [5]

During hard acceleration, the entire power train twists in the opposite direction to engine crankshaft and drive shaft rotation. The engine and transmission mounts absorb this torque. However, the twisting action of the drive shaft and differential pinion shaft tend to leave the rear wheel on the passenger's side of the vehicle.

Extremely high acceleration may cause the rear wheel on the passenger's side to lift off the road surface. Once this rear wheel slip on the road surface, engine torque is reduced, and the leaf spring forces the wheel downward. When the rear tire contacts the road surface, engine torque increase and the cycle repeats. this repeated lifting of the differential housing is called axle tramp, and this action occur on live axle rear suspension system, axle tramp is more noticeable on live axle leaf spring rear suspension system in which the spring have to absorb all the differential torque. For this reason, only engine with moderate horsepower were used with this type of rear suspension. Rear suspension and other axle component such as spring mounts, shock absorbers, Independent rear suspensions and wheel bearing may be damaged by axle tramp. Mounting one rear shock absorber in front of the rear axle and the other rear shock behind the rear axle helps reduce axle tramp.

All rear suspension systems are designed to keep the rear axle and wheels in their proper position under the vehicle body. The rear wheels must always track exactly straight ahead. The rear suspension axle allows each of the rear wheels to move up and down somewhat independently from the frame. The spring assembly must also absorb a large amount of rear end torque from acceleration (on rear drive vehicles), side thrust from turning and road shock from bumps .

2.6 Classification of Suspension Systems.

Suspension system may be classified as following:

2.6.1 Passive suspension system

A passive suspension system is one in which the characteristics of the components (springs and dampers) are fixed. The designer of the suspension according to the design goals and the intended application determine these characteristics. Passive suspension design is a compromise between vehicle handling and ride comfort, as shown in Figure 2.6.[5]

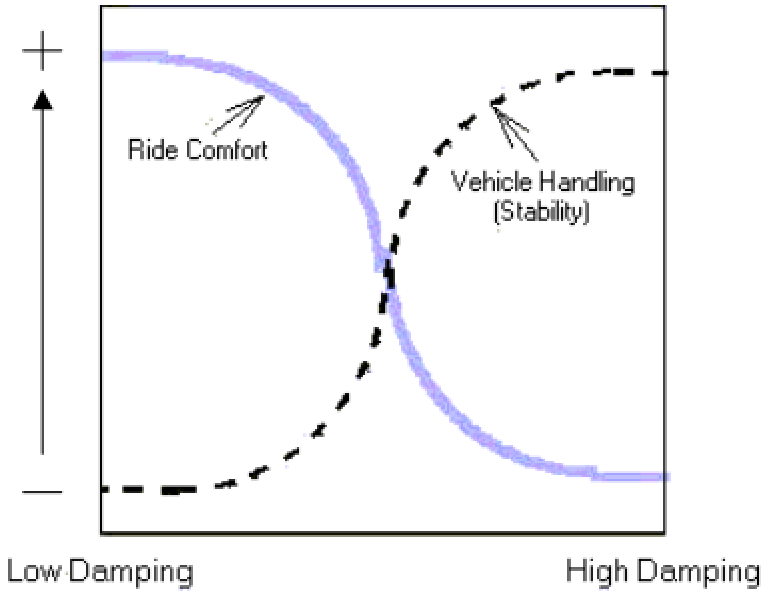

Figure2.6: A compromise between vehicle handling and ride comfort

A vehicle suspension with stiff spring and firm damper is referred as 'hard' suspension. This provides good control on the vehicle body motion and wheels vibration, and it creates optimal handling. However, this system is unable to offer effective body isolation. On the other hand, a suspension with low stiffness and soft damping, called'soft' suspension provides effective body isolation from road unevenness and creates good ride comfort. However, this system cannot control the motions of the vehicle body and wheels effectively .

2.6.2 Active Suspensionsystem

In an active suspension system, the passive force elements are replaced or assisted by active force elements. These elements are able to produce a force when required and act independent of the suspension condition. Therefore, the trade-off between ride comforts, suspension travel and wheel load variations can be better resolved. The passive damper or both the passive damper and spring are replaced with a force actuator, as illustrated in Figure 2.7**[5]**

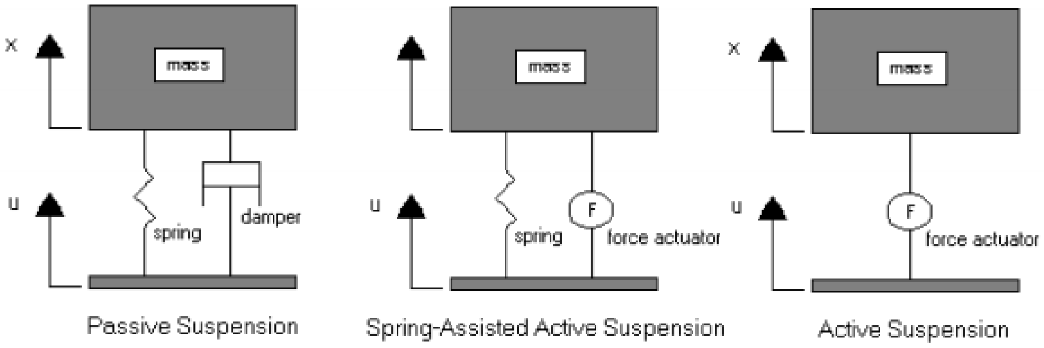

Figure2.7: The passive damper or both the passive damper

and spring are replaced with a force actuator.

The force actuator is able to both add and dissipate energy from the system, unlike a passive damper, which can only dissipate energy. With an active suspension, the force actuator can apply force independent of the relative displacement or velocity across the suspension. Given the correct control strategy, the results in this side is the better compromise between ride comfort and vehicle stability as compared to a passive system.

The force actuators necessary in an active suspension system typically have large power requirements. The power requirements decrease the overall performance of the vehicle, and are therefore often unacceptable. Detraction to active suspension systems is that they can have unacceptable failure modes. In the case of actuator failure, the vehicle would be left un-damped, and possibly un-sprung. This is a potentially dangerous situation for both the vehicle and operator .

2.6.3 Semi-active Suspension system

Semi-active suspension systems were first proposed in the early 1970’s. In this type of system, the conventional spring element is retained, but the damper is replaced with a controllable damper as shown in Figure (2.8).

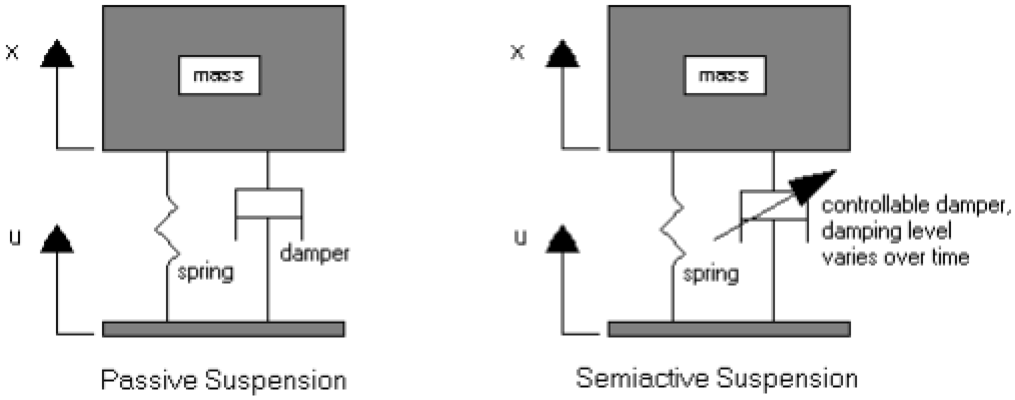

Figure 2.8: The damper is replaced with a controllable damper.

Whereas an active suspension system requires an external energy source to power an actuator that controls the vehicle, a semi-active system uses external power only to adjust the damping levels, and operate an embedded controller and a set of sensors. The controller determines the level of damping based on a control strategy, and automatically adjusts the damper to achieve that damping. Semi-active systems not only have a less dangerous failure mode, but are also less complex, less prone to mechanical failure, and have much lower power requirements compared to active systems .

2.7 Suspension system general components:

Suspension is the term given to the system of shock absorbers and linkages that connect a car to its wheels. A lot of the system's work is done by the springs. Under normal conditions, the springs support the body of the car evenly by compressing and rebounding with every up-and-down movement. This up-and-down movement, however, causes bouncing and swaying after each bump and is very uncomfortable to the passenger. These undesirable effects are reduced by the shock absorbers[5] .

2.7.1 Dampers

A damper is a device that dissipates energy in the form of heat. Energy is changed to heat by forcing a viscous fluid through an orifice. In a vehicle, energy from the road, rather than being transmitted to the vehicle, is changed into a temperature rise of the fluid inside of the damper. Two types of dampers are commonly used in vehicular applications, twin-tube and mono-tube dampers. Both twin-tube and mono-tube dampers typically have bilinear damping characteristics This means that the slope of the damper force vs. relative velocity is greater at low velocities than it is at high velocities, as shown in figure (2.9) .

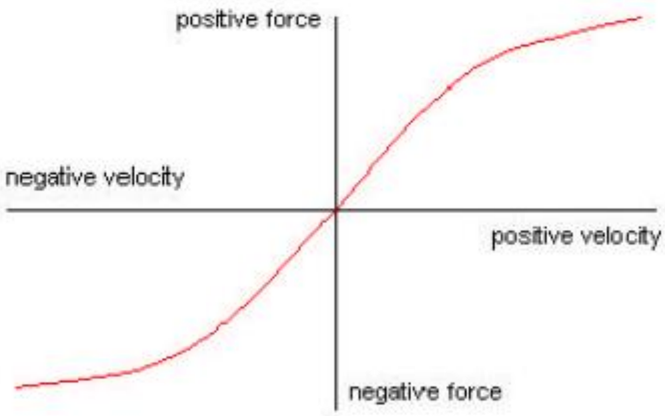

Figure2.9: The relation between the damper forcevs. relative velocity

Twin and mono-tube dampers have the same outward appearance and the same general structure, as shown in Figure 2.10.

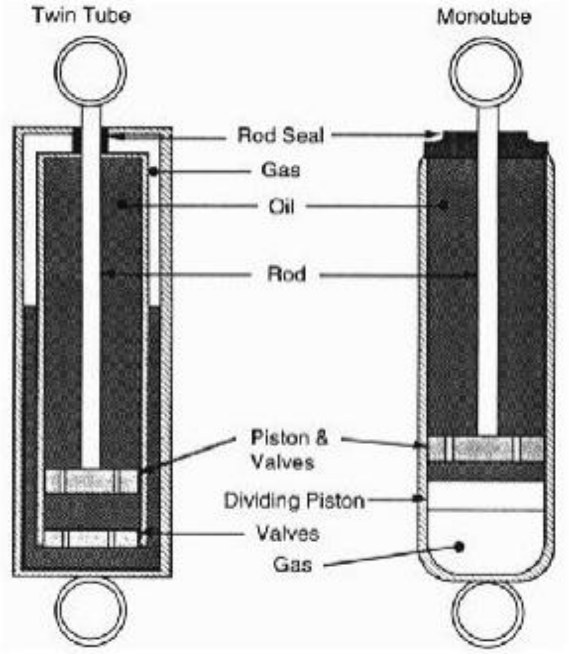

Figure 2.10: Twin and mono-tube dampers have the same outward appearance and the same general structure.

In both cases, the shock absorber has a piston that traverses back and forth inside a cylinder. In a mono-tube damper, the piston travels in a single cylinder that contains a fluid chamber and pressurized air chamber. A floating piston is used to separate the fluid and air chambers. The air chamber is used to accommodate the change in the fluid chamber volume, due to the volume of (13) the piston rod. As the piston rod pushes in, it reduces the fluid chamber volume, which is gained back by the floating piston moving down against the compressible air chamber. Conversely, when the rod is pushed out, the fluid chamber volume increases and the floating piston moves up to fill the excess volume, in order to avoid the creation of a vacuum in the fluid chamber.

The damping force is the result of viscous friction arising from the passage of the working fluid through an orifice. The level of the damping force that results is a function of properties of both the orifice and the fluid. The size and shape of the orifice as well as the viscosity of the fluid determine how easy it is for the fluid to pass through the orifice. A semi active suspension system uses a damper in which the level of damping force can be adjusted.

2.7.2 Springs:

The springs used on today's cars and trucks are constructed in a variety of types, shapes, sizes, rates and capacities. The most common types include coil springs, leaf springs and torsion bars. These are used in sets of four for each vehicle, or they may be paired off in various combinations and are attached by several different mounting techniques [6]:

1) Coil spring

Coil springs are generally installed between the upper and lower control arms with the shock absorber mounted inside the spring. In some cases, the coil spring is mounted on top of the upper control arm and a spring tower formed in the front-end sheet metal. Coil springs comer in many rates and can be used to change the handling and ride characteristics of a vehicle. Figure(2.11)

The most common variety of springs are coil springs, these are usually placed around the damper housing to form a spring-damper unit. A spring is an elastic device that resists movement in its direction of work. The force it exerts is proportional to the movement of one of its ends. Or to put this into a mathematical equation (2.1):

$$\text{Force}=K * X \quad (2.1)$$

[7].

Where K is the spring constant and X related to the Movement of the coil spring. A high value for the spring constant makes for a stiff spring. Moreover, a low value makes for a soft spring[7] .

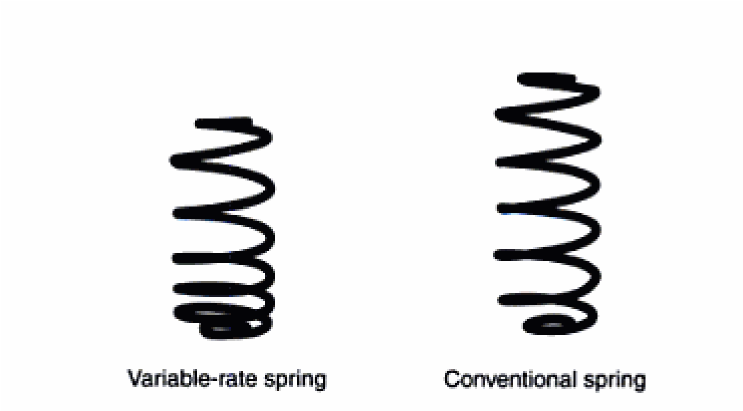

Figure2.11: Variable-rate and conventional spring

2) Leaf springs:

Leaf springs are made from layers of spring steel bolted together through the center of the leaf. This center bolt locates the spring to the axle housing and is attached to the housing with large U-bolts. The ends of the leaf spring are attached to the frame or body through a shackle that allows the spring to flex without tearing out. The leaf springs also act as control arms to keep the axle housing in proper position See figure(2.12)

Figure2.12: Leaf spring

3) Torsion bars:

The torsion bar provides its spring action by the twisting of a flexible steel bar. This twisting of a steel bar provides the resistance to the up-and-down movement of the front end. There are two torsion bars, one for each front wheel. The rear of the torsion bar is mounted on the frame of the car and the front is bolted to the lower control arms. The big advantage of a torsion bar is that it's easily adjustable. By turning the tensioning bolts, you can adjust the ride height very easily Figure(2.13)

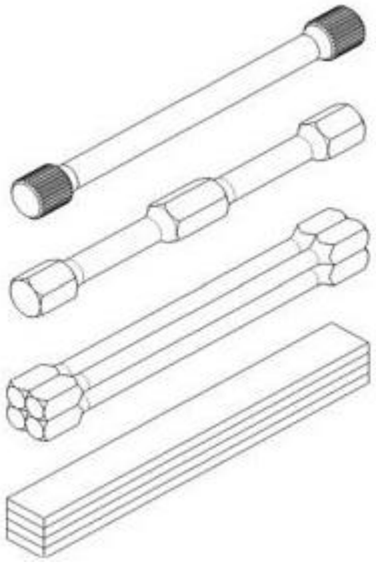

Figure2.13: Torsion bars

2.8 Basic Suspension Geometry

Suspension geometry is defined as "The angular relationship between the suspension, the steering linkage and the wheels - relative to the road surface". The suspension geometry for any given vehicle is a result of the design engineer's development of the vehicle and the design criteria for that particular vehicle.

The safety, stability, handling and performance of a vehicle depend on many factors. One of the most important aspects of these characteristics is the design of the suspension and steering systems.

There are several alignment geometry angles, which relate to the suspension components .we are going to be covering, negative camber, positive camber, caster angle, toe angle, and their effects [8].

2.8.1 Caster angle

The caster angle identifies the forward or backward slope of a line drawn through the upper and lower steering pivot points when viewed directly from the side of the vehicle. Caster is expressed in degrees and is measured by comparing a line running through the steering system's upper and lower pivot points (typically the upper and lower ball joints of an A-arm or wishbone suspension design, or the lower ball joint and the strut tower mount of a McPherson strut design) to a line drawn perpendicular to the ground[9].

If the steering axis is tilted rearward, it is called "Positive Caster". A forward tilt is called" Negative Caster". See fig(2.14).

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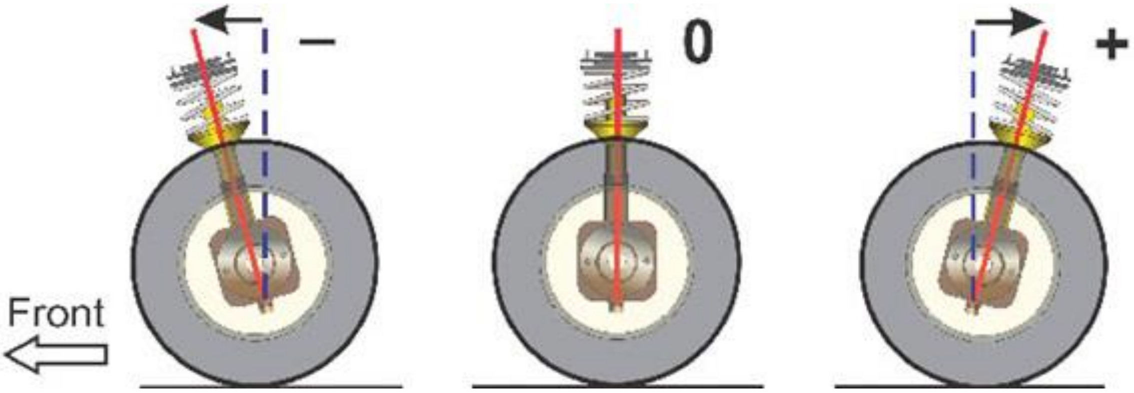


Figure2.14: Positive Caster and negative caster**.**

2.8.2 Camber

The camber angle identifies how far the tire slants away from vertical when viewed directly from the front or back of the vehicle. Camber is expressed in degrees. See figure (2.15).

If the wheel tilts out at the top, the camber angle is positive and if the wheel tilts in at the top, it is negative.

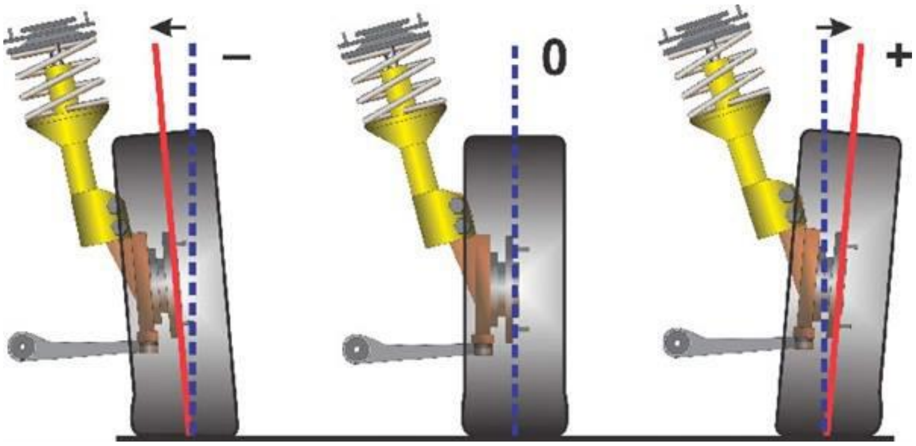


Figure 2.15:Positive and zero and negative camber

Excessive positive camber will cause abnormal wear on the outer edge of the tire. Moreover, excessive negative Camber will cause abnormal wear on the inner edge of the tire. Camber is measured in Degrees and Minutes and is measured at the front and rear of the vehicle.

2.8.3 Toe Angle – Toe Out and Toe In

Toe is the measure of how far inward or outward the leading edge of the tire is facing, when viewed from the top. Toe is measured in degrees and is generally a fraction of a whole degree. It has a large effect on how the car reacts to steering inputs as well as on tire wear. Aggressive toe angle will cause the tire to develop “feathering” across its surface, as show in figure(2.16).

1) Toe-in:

Toe-in is when the leading part of the tire is turned inwards towards the center of the car. This makes the tires want to push inward, which acts to improve straight-line stability of the car as it is traveling down the road, particularly at high speed (highway).

2) Toe-out

Toe-out is when the leading part of the tire is turned outwards away from the center of the car. This makes the tires want to separate from each other. This improves “turn-in” response considerably but again, at the cost of tire wear. Running toe-out in the rear is generally not recommended since it will make the car want to pivot (over steer) at all steering angles, but in the right setup it can help (auto-x / technical tracks).

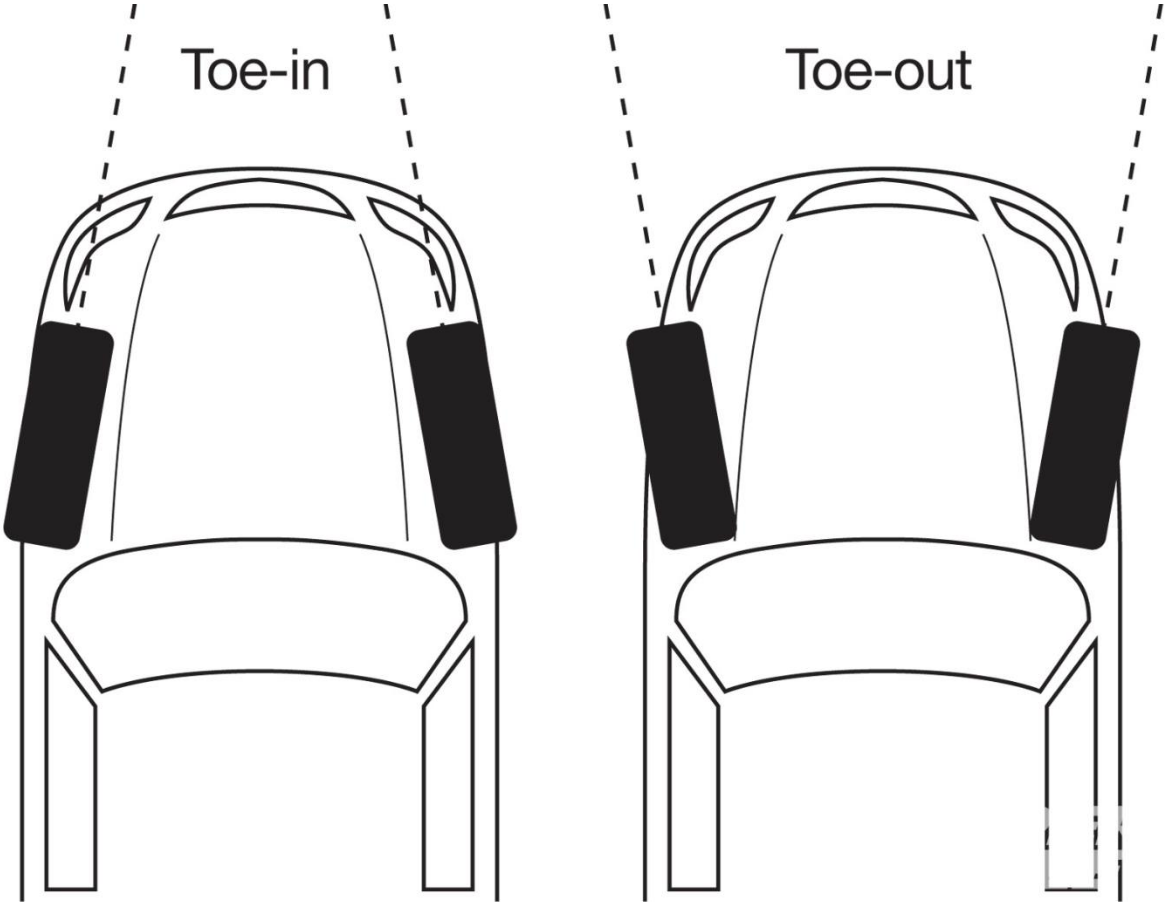


Figure 2.16: Toe out and neutral toe and toe in

2.9 Dynamics of suspension system

The primary functions of a vehicle’s suspension systems are to isolate the structure and the occupants from shocks and vibrations generated by the road surface. The suspension systems consist of all the elements that provide the connection between the tires and the vehicle body and are designed to meet the following requirements: (1) Ride comfort, (2) Handling.

It is obvious that a suspension system must be able to withstand the loads acting on it. These forces may be in the longitudinal direction such as acceleration and braking forces, in the lateral direction such as cornering forces, and in the vertical direction.

This chapter consists of two main sections. In the first section, vehicle dynamics are presented under different cases in order to obtain axial loads on the suspension system. In the second section, consists the kinetic analysis and the mobility of suspension system .

1) Vehicle Handling.

Handling is a characteristic of a vehicle that provides stable and safe driving that can be created via a steady contact between the tires and road surface. In some references, handling is called also with other names such as road holding, ride stability, and driving safety, implying the same meaning. The handling capability of a vehicle is important during maneuvers such as cornering, braking, or accelerating. In these extreme situations, weak handling reduces the control ability of the vehicle and can affect the safety of the passengers. Due to this fact, handling is considered as an important capability for vehicles and beside the ride comfort, it is considered as the main target of using the suspensions in vehicles[9] .

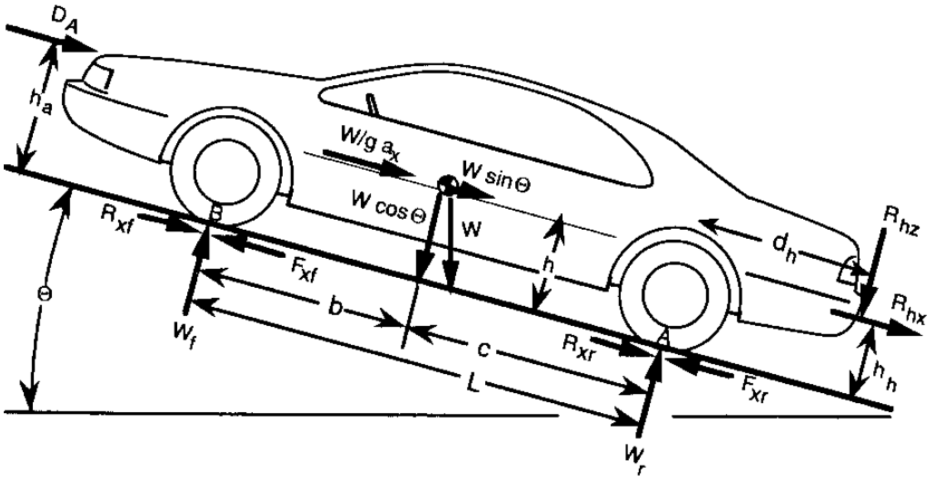
2) Ride Comfort

Ride comfort is considered as the first objective of the suspension systems of vehicles. Ride comfort is an important characteristic of vehicles that indicates how much riding is comfortable for passengers.

2.9.1 Dynamic axle loads:

Determining the axle loads on the vehicle by using Newton’s second low.

Consider the vehicle shown in figure below:



The forces acts on the vehicle:

: Aerodynamic force.D_A

& R_{xr}: Rolling resistance forces.R_{xf}

F_{xr}: Tractive forces.F_{xf} &

R_{hz}: The vertical and longitudinal forces acting at hitch point.R_{hx} &

W: The vehicle weight.

By take moment about point A, then

$= (wc\ \cos\Theta - D_A h_a - (w\frac{a_x}{g}h) - R_{hx}\,h_h - R_{hz}\,d_h - w\,h\sin\Theta) / LW_f$

And by take moment about point B, then

$= (w\,b\cos\Theta + D_A h_a + (w\frac{a_x}{g}h) + R_{hx}\,h_h + R_{hz}\,(d_h + L) + w\,h\sin\Theta) / LW_r$

Where, W_f and W_r is the weight on the front and rear axles respectively.

2.9.2 Static axle load:

When the vehicle on level ground and the velocity almost equal zero, then the transfer weight and aerodynamic force equal zero.

, then $\cos\Theta = 1$ & $\sin\Theta = 0\Theta = 0$

So the weight on the front and rear axle:

$$W_f = W\ \frac{c}{L}$$

$$W_r = W\ \frac{b}{L}$$

Based on our vehicle its estimated the fore acting on the front wheels to be $\frac{1}{3}W = 1328N$

And the force acting on the rear wheels to be $\frac{2}{3}W = 2655N$

Based on this weight we could choose air spring in chapter three.

2.10 Mobility of suspension system:

An automotive suspension supports the vehicle body on the axle. A "full car" model of a suspension with (7) rigid body degree of freedom is shown in figure. The vehicle body is represented by the "sprung mass" m while the mass due to the axle and tire is represented by the "un-sprung mass" masses mu1, mu2, mu3 and mu4. The spring and damper between the sprung and un-sprung mass represent the vehicle suspension. The vertical stiffness of each of the 4 tires is represented by the springs Kt1, Kt2, Kt3 and Kt4[10].

The seven degree of freedom of the full car model is the heave z, pitch Θ and roll Ø of the vehicle body and the vertical motion of each of the four un-sprung masses. The variables Zr1, Zr2, Zr3 and Zr4 are the road profile inputs that excite the system, see figure(2.23).

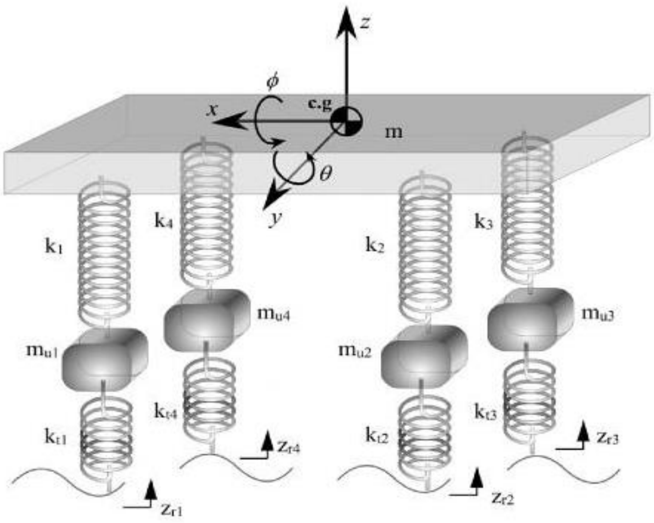


Figure 2.23: Mobility of suspension system

Suspension systems are in general three-dimensional mechanisms and as such are difficult to analyze fully without the aid of computer packages. Their analysis is complicated by the inclusion of many compliant bushes, which effectively result in links having variable lengths.

Most of the kinematic connections between the members of a suspension mechanism can be reduced down to the kinematic pairs. Each has an associated number of degrees of freedom and can be classified as lower pairs (connections having a SDOF) or higher pairs (more than one DOF). It has been shown that the mobility M, of a plane mechanism forming a closed kinematic chain, is related to the number of links n, the number of lower pair's jl and the number of higher pair's jh According to the Kutzbach criterion:

$M = 3(n - 1) - jh - 2jl$ [10] (2.24)

3

Chapter Three

3. Air control mechanism design and analysis.

3.1 Mechaniccal design

3.2 Project block diagram

3.3 Project pneumatic circuit

3.3.1 System air bag.

3.3.2 Non-return valve .

3.3.3 Pressure regulator .

3.3.4 Hoses & Connectors.

3.3.5 Air tank.

3.3.6 Pressure Gauge.

3.3.7 Relief valve.

3.3.8 Flow leveling valve.

3.3.9 Air compressor

3.4 System design and analysis

3.4. 1 Kinetic Analysis and calculation for Macpherson suspension system.

3.4.2 Piston stroke calculation for single acting cylinder.

3.4.3Pressure calculation for a single acting cylinder.

3.4.4 Calculation for the time needed to fill the tank in several condition.

3.4.5 Calculation for air receiver to go from upper to lower pressure.

3.5 **System electronic circuit**

3.5.1 Arduino Uno micro-controller.

3.5.2 Ultrasonic measurement sensor.

3.5.3 LCD(16x2) screen**.**

3.6 Mathematicla modeling.

3.7 The effect of the pneumatic system addition on the vehicle suspension and performance

3.1 Introductions

This chapter is talking about a prototype design of subsystems, air bag and the pneumatic system including hoses, connecter, valves and the air-compressed tank. The design includes the basic steps for developing the prototype, which includes the sketch of the pneumatic circuit and its connection. The second part will be how to move this project to practical. So we will make our calculations in order to install the air springs in series with the suspension system.

3.1.1 The stiffness's of the suspension system and the required air spring

$F = K * X$ ……………………………………………………………………………………………….3.1

$K=F/X$

1.) Stiffness calculation for a quarter car or for one wheel

K=Force acting on rear wheel/ Length of suspension

K_{sus} = 3600 N/M

2.) Stiffness calculation for air spring

From datasheet:

At (1 bar)….F=3 kN

At (5 bar)….F=16 KN

At (7.5 bar)….F=25 KN

Max deflection is (365mm) at full stroke.

So the stiffness's at these different values are:

$K1_{air}$= 3000/0.365

= 8220 N/M

$K2_{air}$= 16000/0.365

= 43835.65 N/M

$K3_{air}$= 25000/0.365

= 68493 N/M

Now based on these results we see that the added air spring stiffness is bigger than the stiffness of the suspension system. And this result ensure us to install the spring in series. Due to the parallel installation by these results will cancel the original suspension system.

Mechanical design and considerations

In this section we will discuss one way used for building an experimental one car quarter model for the passive control of the system.

Naturally the parameters from one car to another is differ; however the parameters for four passengers are approximately in the same range.

Parameter	**Value in reality for the used car**
ms	320 KG
mu	28 KG
Ksus	3600 N/M
bsus	8500 Ns/M
Kw	92000 N/M

Table 3.1. System parameters

We found that it is reasonable to put the air spring in series to the suspension system. This decision was made on the basis of the stiffness's of the suspension with air spring.

Road profile

As for the excitation coming from the road profile, it was found that testing such system is done as follows [3]:

1. For testing the comfort in low frequency:

Road profile= sine of magnitude 15mm, with frequency (0-5HZ).

2. For testing the road handling:

Road profile= sine of magnitude 1mm, with frequency (0-20HZ).

3. For testing the comfort in high frequency:

Road profile= sine of magnitude 1mm, with frequency (4-30HZ).

The mechanical system

The mechanical system that must be built, is suggested to be assembled as shown in the fig 3.3. There are two masses sprung and unsprung between them lies the suspension system and the air spring; and below them there's the spring that represents the stiffness of the tire or the wheel; which affected by the road profile

As shown below; we will separate the parallel connection by adding a cylinder cover the original suspension system. Then we will fix the air spring on the base of the cylinder as shown. Then the connection way became series.

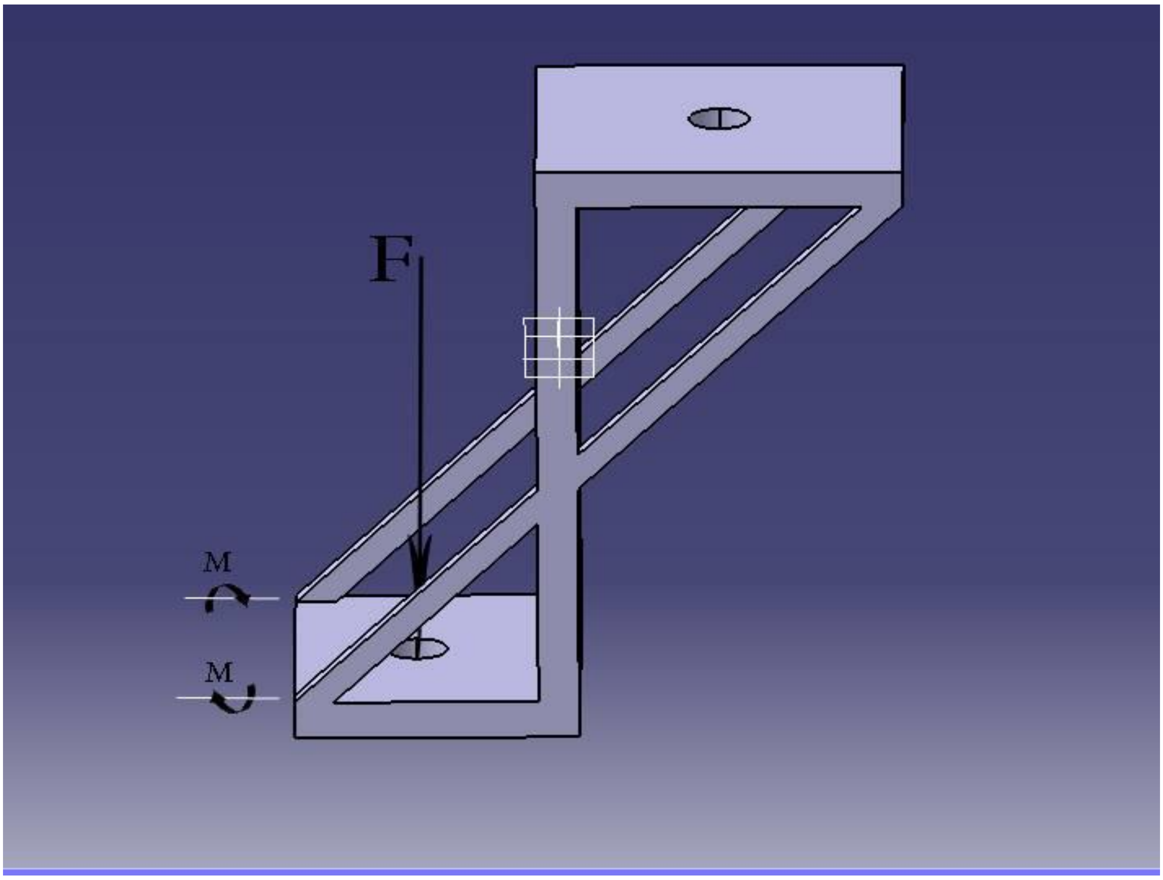


Figure 3.1 : Mechanical series system

The added base design

Because we did not found the required air spring to install; we have created an alternative solution to install our spring in series; so we will install the spring in parallel at the same we will convert the suspension system with a design of triangular base as follows. In this case the upper side of the spring is fixed to the sprung mass and the lower side is fixed to the designed, to do this we should make mechanical design for this base as follows:

The Welding Design

The welding is needed to connect the base with the beam (triangle). Figure 3.29 shows the welding joints. Filler metal rods and wires are designated by a system established by the American Welding Society (AWS). AWS designation is E60XX.

From the weld design tables the area of welding is:

$A= 1.414\ h\ d$……………………………………………………………………………….3.2

$= 1.414*h*0.01=0.01414\ h$

Where,
h: Height of welding.
d: Length of the part that the welding is on .
F: Force effect on the beam.
L: The length between the force and the beam.

M = F*L=
m*g*L……………………………………………………………………………………..3.3

Where;

$L = \sqrt{0.06^2 + 0.08^2}$ = 0.1 m

= 80*9.81*0. 1=78.48 N.m

The polar moment of area of the weld group per throat length (J_u) is selected from the weld design tables.

$J_u =$
……………………………………………………………………………………………3.4$\frac{bd^2}{2}$

This value needs to represent the value of (J)

$J = 0.707hJ_u = (0.707hbd^2)/2$

The leg weld (h) needs to be designed.
The primary shear is:

…………………………………………3.5$\tau' = \frac{F}{4A} = \frac{784.48}{4*(0.707h)b} = \frac{784.48}{4*0.707*h*0.01} = 27722.78/h$

The second shear is:

……………………………………………………………………………………..3.6$\tau'' = \frac{Mc}{J}$

$$= \frac{Md/2}{0.707hbd^2} = \frac{1.414M}{hbd} = \frac{1.414 * 78.48}{h * 0.01 * 0.01} = 1108576/h$$

= 1.12/h MPa $\tau = \sqrt{\tau'^2 + \tau''^2}$

Base: AISI 1018 HR steel → $S_y = 220\ MPa$

Beam: AISI 1018 HR steel→ $S_y = 220\ MPa$

Base: $\tau_{all} = 0.4\ S_y = 0.4 * 220 = 88\ MPa$

Beam: $\tau_{all} = 0.4\ S_y = 0.4 * 220 = 88\ MPa$

Note that the base is equal to the beam. Therefore, select an
Electrode not weaker than the attachment and the chosen electrode is E60XX .

3.2 Project block diagram

When the vehicle runs on the rough roads then the vehicle body. The cylinder arrangement is attached on the wheel axle; this motion is used to suck the air from the atmosphere. Thus, the piston inside the cylinder creates the internal pressure, which results in storage of air to the tank at certain pressure. Shown in figure (3.2)

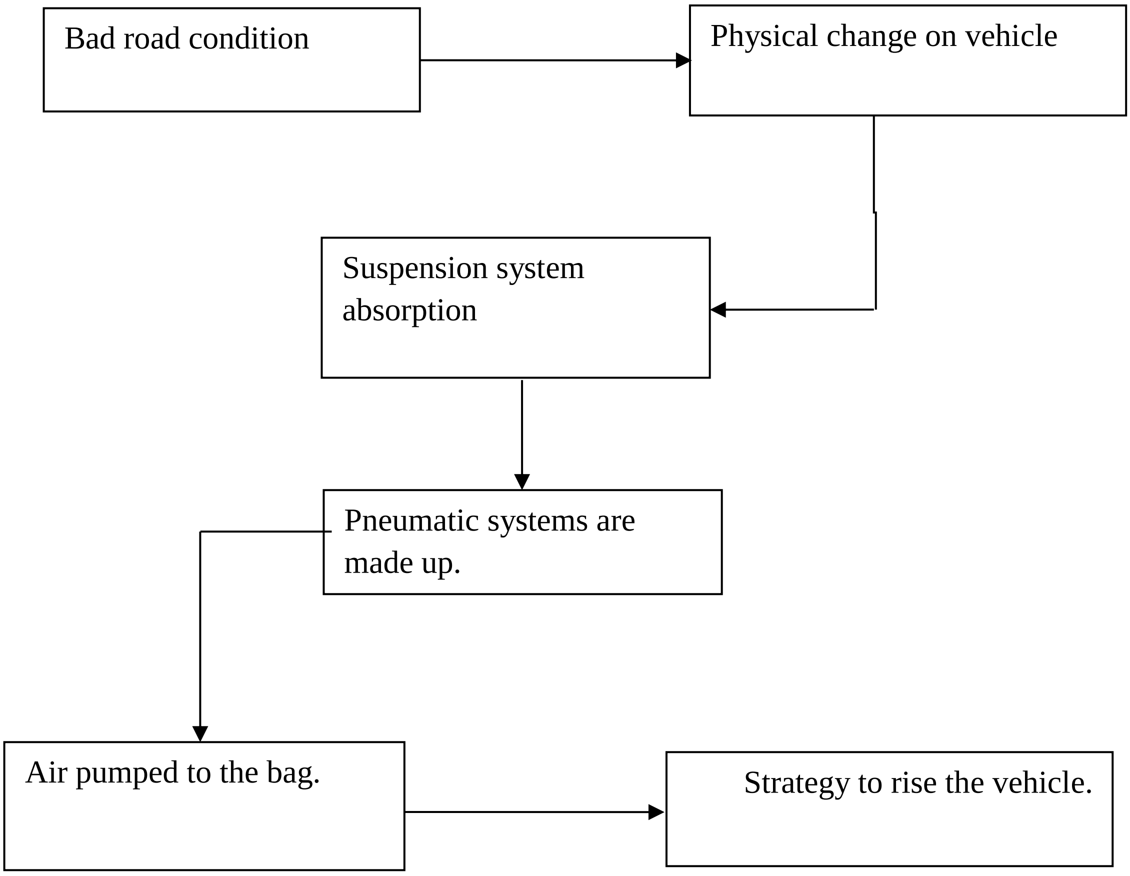


Figure 3.2: Project pneumatic block diagram.

3.3 Project pneumatic circuits

Figure (3.3) shows the pneumatic circuit of our project and illustrates the component of the system and its position. In this section, we will explain every part of this circuit and design the air bag that we will use.

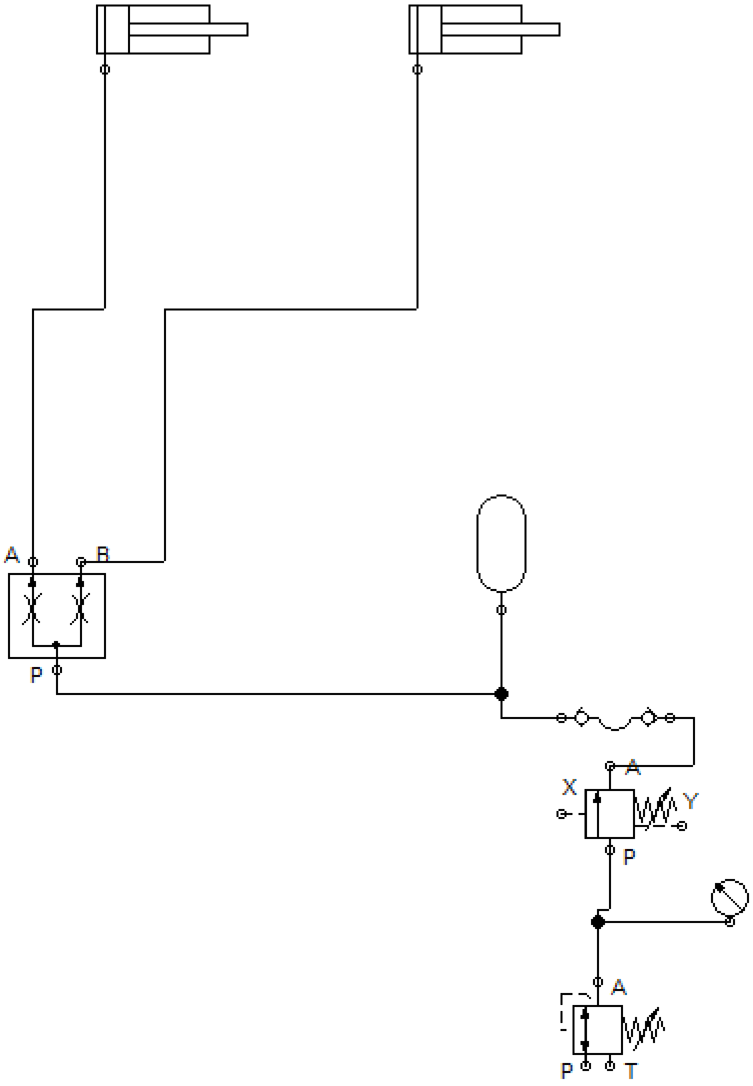


Figure3.3:Project pneumatic circuit

3.3.1Air spring :

Air suspension is a type of vehicle suspension powered by an electric or engine-driven air pump or compressor. This compressor pumps the air into a flexible bellows, usually made from extile-reinforced rubber. The air pressure inflates the bellows, and raises the chassis from the axle. See figure (3.4) catia 3D design for the used airbag.

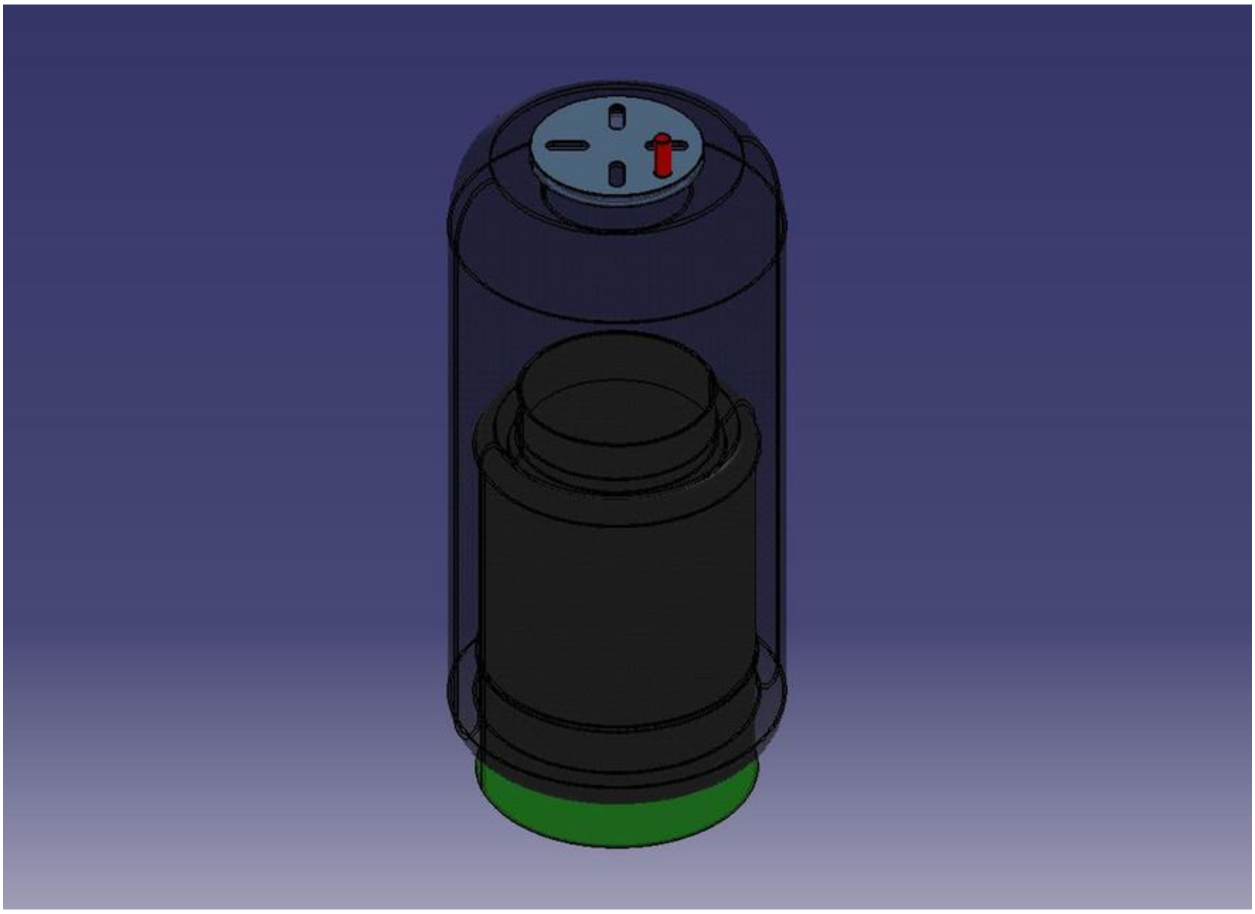


Figure3.4:Air spring

3.3.2 Non-return valve

Pneumatic non-return valve or called check valve, this valve is used to speed up the piston movement and also it acts as a one- way restriction valve which means that the air can pass through only one way and it cannot return back. By using this valve, the time consumption is reduced because of the faster movement of the piston.

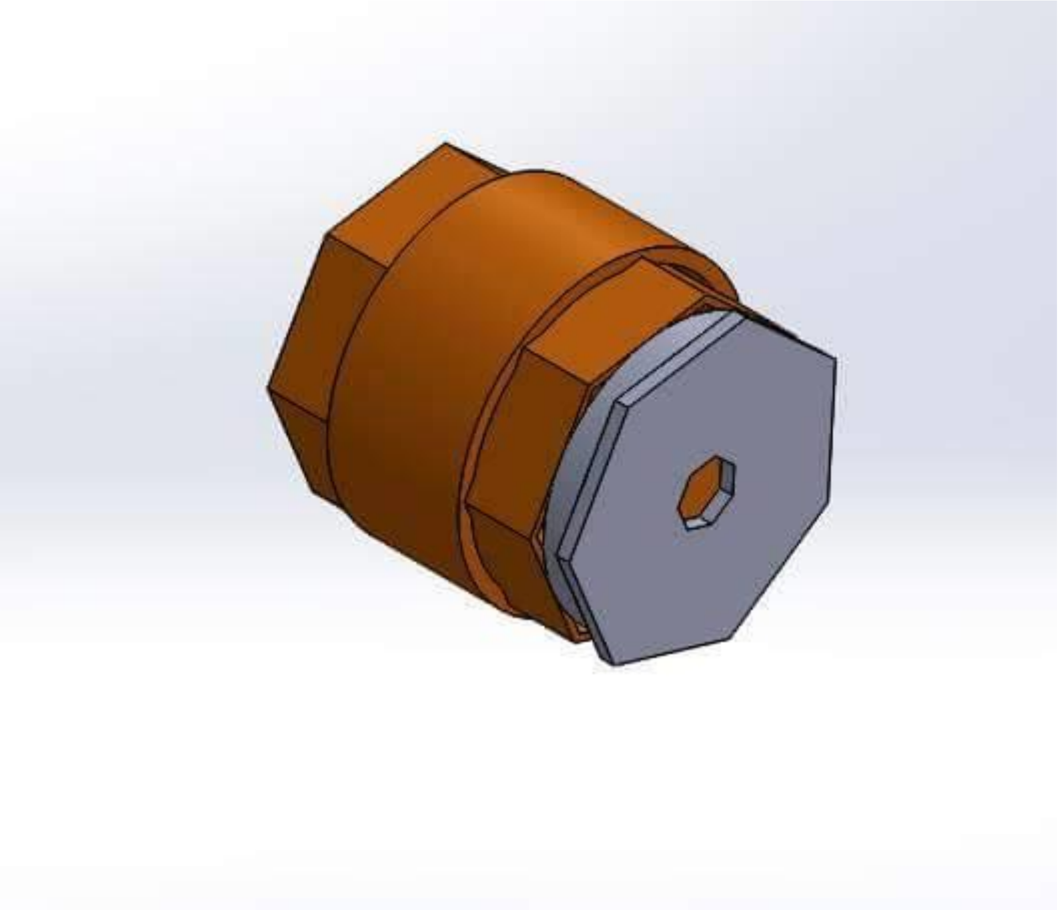


Figure3.5:Non-return valve

3.3.3 Pressure Regulator

A pressure regulator is a valve that automatically cuts off the flow at a certain pressure. Regulators are used to allow high-pressure fluid supply lines or tanks to be reduced to safe and/or usable pressures for various applications.

Air pressure regulators are used to regulate air pressure and are not used for measuring flow rates. Flow meters, Mass Flow Controllers are used to accurately regulate gas flow rates.

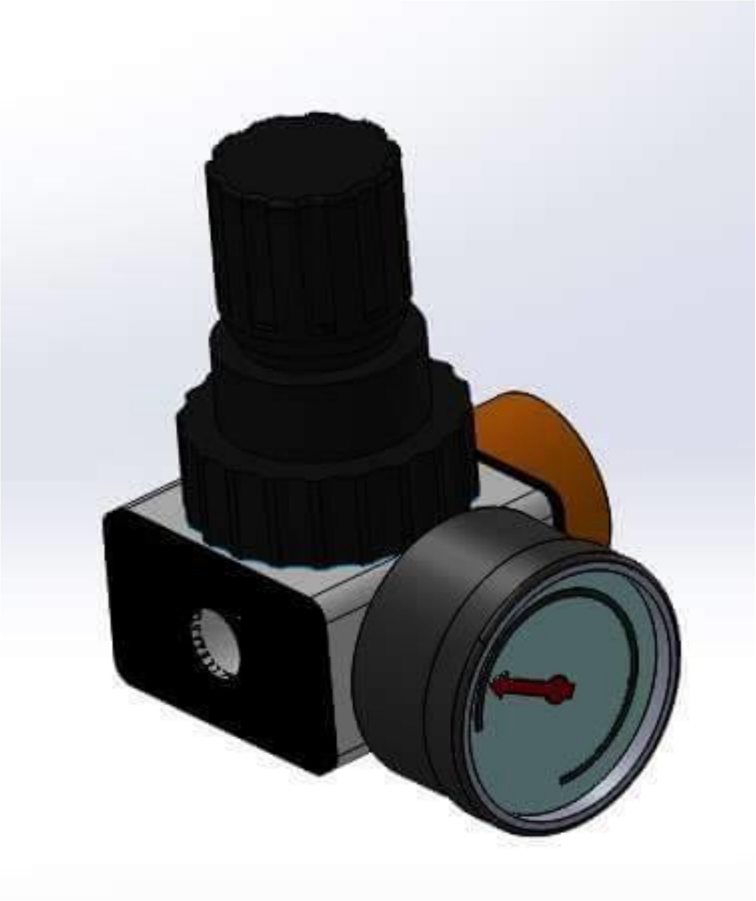
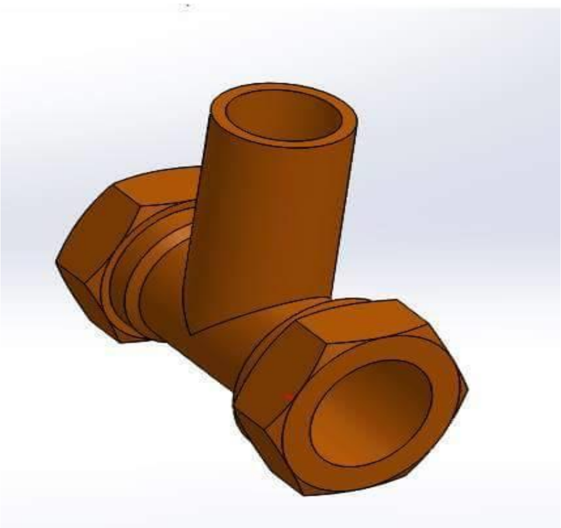


Figure 3.6: Pressure regulator

3.3.4 Hoses & Connectors

Hoses that used in this pneumatic system are made up of polyurethane. These hose can with stand at a maximum pressure level of 8 Bar. In our system there are two type of connectors used. One is the Hose connector and the other is the reducer and T-connector. Hose connectors normally comprise an adopt hose nipple and cap nut. These types of connectors are made up of bras or aluminum or hardened pneumatic steel.

(a)



(b)

Figure 3.7: Hoses & Connectors

3.3.5 Air tank

A pressure vessel or storage tank is a closed container designed to hold the air at a pressure different from the ambient pressure.

In our design, we use the air tank to collect and save the air that comes from the compressor, and the air tank must stand a high pressure and with capacity of 0.024 m^3. See figure (3.7)

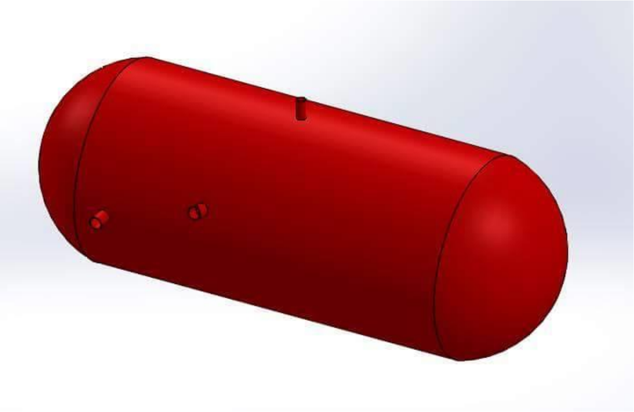


Figure3.7:Air tank

3.3.6 Pressure Gauge

Pressure Gauge is an instrument used to measure pressure, in this system we use it to measure the pressure in the air tank, and it can fit at the tank to see how much efficient this bag and to know the amount of air that can compress per on stroke. Look at figure(3.8)

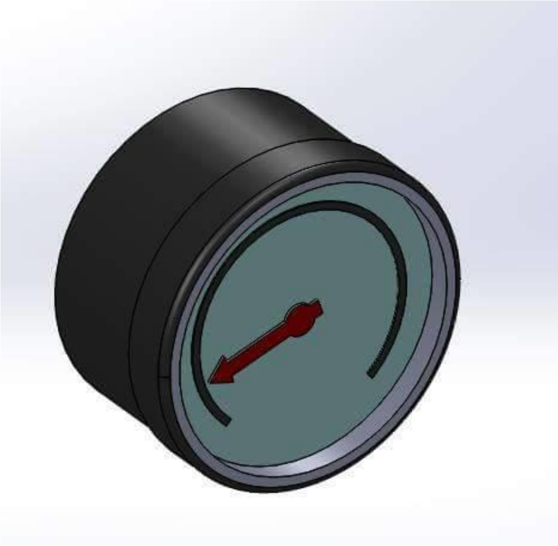


Figure3.8: Pressure Gauge

3.3.7 Relief valve

The relief valve (RV) is a type of valve used to control or limit the pressure in a system or vessel, which can build up for a process upset, instrument or equipment failure, or fire.

In our project relief valve used to keep the pressure in air-compressed tank in limitrangeUp to 30 bar. Figure (3.9) shown the relief valve.

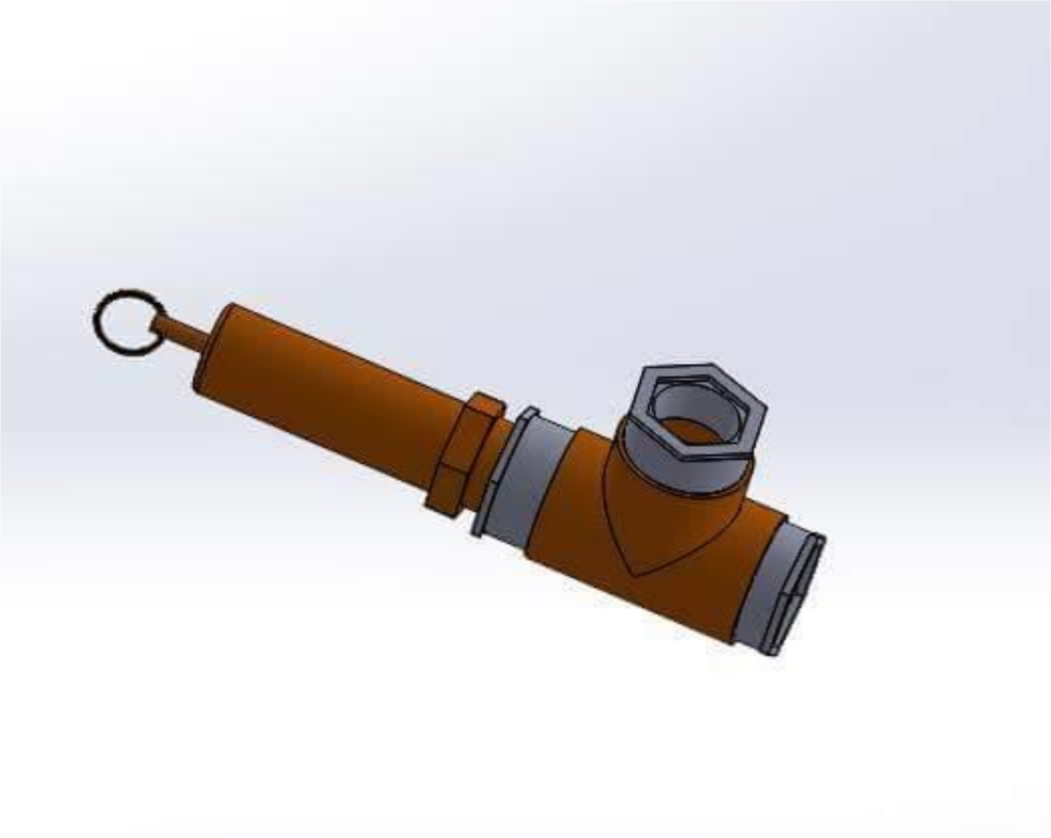


Figure 3.9: Relief valve

3.3.8 Flow leveling valve

Leveling valves, also called air suspension valves, are used to control the suspension in air-sprung vehicles. Their purpose is the sensitively graded control of the compressed air for the air suspension bellows as a ratio of the vehicle’s load. In this project its used also to control the air compressed to the air bags. Look at figure (3.10)

Fig 3.10: Flow levelling valve

3.3.9 Air compressor

The air compressor is an tank air supplier and it’s the main tool in this system, every pneumatic system requires an air compressor in order to supply air; the main component of the air-compressor is the piston that compresses the generated air from the surrounding area; the compressors in general are variable it could get one or two or more than. In this project its used portable air compressor with capacity of (18 bar) as seen in figure (3.11)

Fig 3.11: Portable air compressor

3.4System electronic circuit

This electronic circuit built in this system in order to measure the distance change in the vehicle suspension system and the shows how the pneumatic system could rise the vehicle; note that is the main reference value of the suspension system spring is known and defined in the arduino code as it will shown later. Here is the connection of the electronic circuit in figure (3.12)

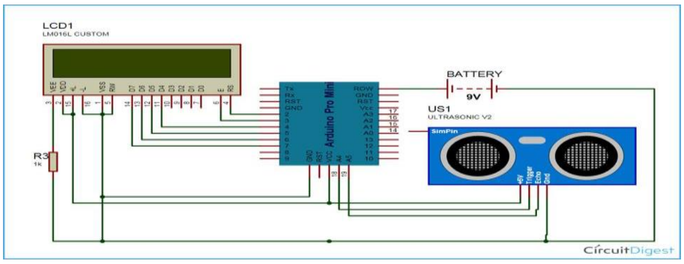


Fig (3.12): Electronic circuit of the system

3.4.1 Arduino Uno micro-controller

Arduino Uno is a microcontroller board based on the ATmega328P (datasheet). It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz quartz crystal, a USB connection, a power jack, an ICSP header and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with an AC-to-DC adapter or battery to get started. In this system the controller used to give the orders to the sensor to measure the changed distance and shows it on LCD screen. See figure (3.13)

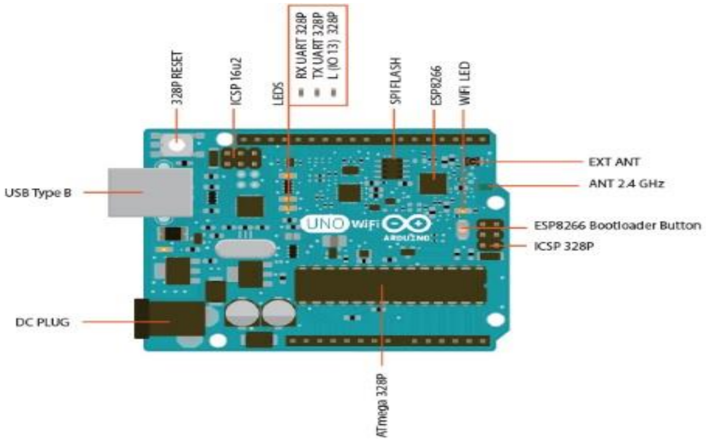


Figure 3.13: Arduino Uno micro-controller

3.4.2 Ultrasonic sensor

The ultrasonic sensor used in general to measure distances whether the distance vertically or horizontally, but it must be a clear object in the way of measuring distance in order to give an accurate result. In this project the sensor used to explain the change in suspension height when it compressed. Look at figure (3.14).

Figure 3.14: Ultrasonic sensor typed HC-sro4

3.4.3LCD (16×2) screen

LCD (Liquid Crystal Display) screen is an electronic display module and find a wide range of applications. A 16x2 LCD display is very basic module and is very commonly used in various devices and circuits. And it used in this system to show the reading from the ultrasonic sensor. See figure (3.15)

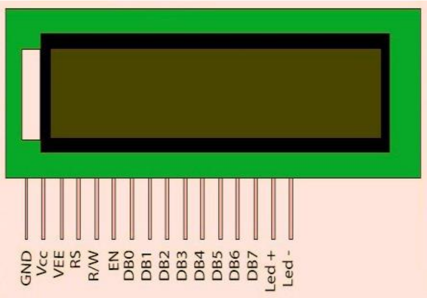


Figure 3.15: LCD (16×2) screen

3.5 Calculation for air receiver to go from upper to lower pressure:

An air receiver is essential to every compressed air system to act as buffer and a storage medium between the compressor and the consumption system.

The maximum capacity of the air receiver in any compressed air system must exceed the maximum mean air consumption of the system. In addition, the air consumption vary due to the process supported. In shorter period the demand may even exceed the maximum capacity of the air reservoir.

The volume of the air bag (V_c) can be calculated using eq.3.7.

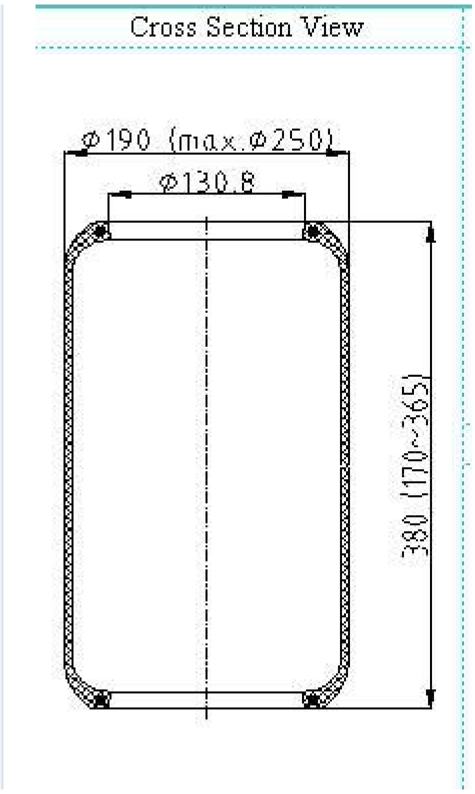


Figure 3.19: Sketch for airbag suspension with its dimension

As shown in the figure3.19

r: is the radius of the airbag.

h: is the stroke displacement

(3.7)$V_c = 3.14\, r^2\, h$

$V_c = 0.095^2 * 3.14 * 0.38 = 1.1 * 10^{-4} m^3$

The volume of reservoir tank (V_r) that we select in our prototype equal 24 liter, the reservoir of this size is widely available in the local market, due to that the system is a prototype we do not need to a certain size(there is no specific demand).

$V_r = 24\ liter = 0.024\ m^3$

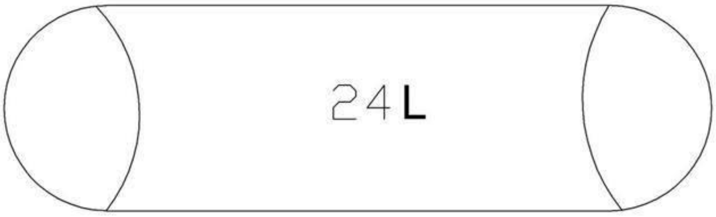


Figure 3.16: Sketch for air receiver with its volume

A commonly used formula to find a receiver size is:

…………………………………………………………(3.8)$Q_r = Vc * \frac{Vr}{Atmospheric\ pressure} / t$

Where;

t: is the time needed to fill the tank at specified pressure(min).

: Volume of the receiver tank (m^3).V_r

= maximum tank pressure (kPa).P_{max}

= minimum tank pressure (kPa).P_{min}

= Air flow throw the receiver (air demand).Q_r

= Air flow throw the air compressor.Q_c

From eq.3.14 the time equal:

$$t = 0.15\ sec$$

As the maximum pressure in the receiver equal:

$$P_{max} = 3000.00\ \text{kPa}$$

The minimum pressure in the receiver equal:

$$P_{min} = 200.0\ \text{kPa}$$

It is also common to size reservoirs that 1gallon for each ACFM (actual cubic feet per minute)

In addition, $\mathbf{Q_c}$ equal zero (there is no relative motion on the piston during discharge).

$$Q_r = Vc * \frac{Vr}{Atmospheric\ pressure} t$$

$$= 1.2\ m^3/min$$

3.6 Mathematical modeling

To analyze the dynamics and to design control system for the suspension system, a simplified model will be used. Thus it is required a quarter model car for representing the model of the vehicle with 2degree-of-freedom (DOF); in the fig below the natural suspension system and the adjustable suspension system.

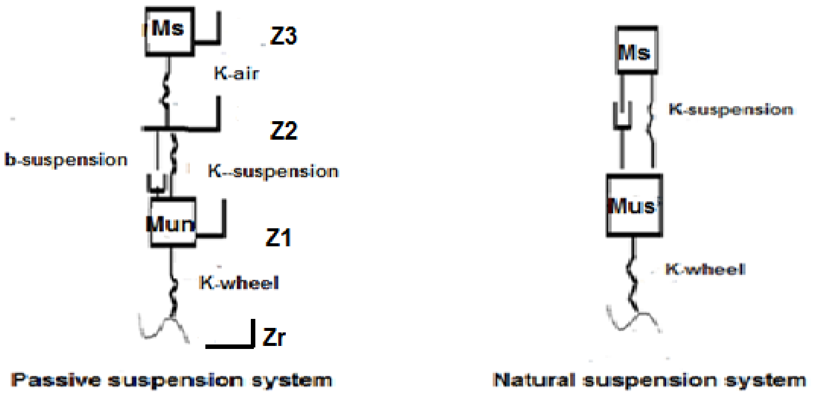


Figure (3.16) : Suspension system with/without the added system

Note that the subscript (s) is used with the parameters to represent the sprung mass, where the subscript (u) is used with the parameters to represent the unsprung mass. So that the dynamics of the system represented by the motion of the two masses are governed by analyzing the passive suspension system. We got the following equations:

……………………………………………………………………3.9$m_s\ddot{z}_3 + K_{air}(z_3 - Z_2) = 0$

$\mathrm{b_s}(\dot{\mathrm{z}}_1 - \dot{\mathrm{z}}_2) + k_s(z_1 - z_2) + k_{air}(z_3 - z_2) = 0$ ……………………………………………………3.10

$\mathrm{m_{us}}\ddot{\mathrm{z}}_1 + \mathrm{b_s}(\dot{\mathrm{z}}_1 - \dot{\mathrm{z}}_2) + k_s(z_1 - z_2) + k_{\mathrm{w}}z_1 = \mathrm{k_w}z_r$ ……………………………………………….3.11

$\mathrm{x}_1 = \mathrm{Z}_1$

$\mathrm{x}_2 = \mathrm{Z}_2$

$\mathrm{x}_3 = \mathrm{Z}_3$

$\mathrm{x}_4 = \dot{\mathrm{Z}}_1$

$\mathrm{x}_5 = \dot{\mathrm{Z}}_3$

$\dot{\mathrm{x}}_1 = \dot{\mathrm{Z}}_1 = x_4$

$\dot{\mathrm{x}}_3 = \dot{\mathrm{Z}}_3 = x_5$

$$\dot{\mathbf{x}}_{\mathbf{2}} = \dot{\boldsymbol{z}}_{\mathbf{2}} = \frac{1}{b_s}(k_s x_1 + (-k_{air} - k_s)x_2 + k_{air}x_3 + b_s x_4) \text{ ……………………………..…….3.12}$$

$$\dot{\mathbf{x}}_{\mathbf{4}} = \ddot{\boldsymbol{z}}_{\mathbf{1}} = ((-2k_s - k_w)x_1 + (2k_s + k_{air})x_2 - k_{air}x_3 - 2b_s x_4 \ \ldots + k_w z_r)/m_{us} \qquad 3.13$$

$$\ddot{\boldsymbol{z}}_{\mathbf{3}} = \frac{k_{air}}{ms}(x_2 - x_3) \text{ ……………………………………………………………………3.14}$$

$$\dot{\boldsymbol{x}} = \boldsymbol{Ax} + \boldsymbol{b}u \text{ ………………………………………………………………………………….3.15}$$

$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \\ \dot{x}_3 \\ \dot{x}_4 \\ \dot{x}_5 \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 1 & 0 \\ \dfrac{k_s}{b_s} & \dfrac{-\mathrm{k_{air}} - \mathrm{k_s}}{b_s} & \dfrac{k_{air}}{b_s} & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \\ \dfrac{-2k_s - k_w}{m_{us}} & \dfrac{2\mathrm{k_s} + \mathrm{k_{air}}}{\mathrm{m_{us}}} & -\dfrac{k_{air}}{m_{us}} & -\dfrac{2b_s}{m_{us}} & 0 \\ 0 & \dfrac{k_{air}}{m_s} & -\dfrac{k_{air}}{m_s} & 0 & 0 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \\ x_5 \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ 0 \\ \dfrac{k_w}{\mathrm{m_{us}}} \\ 0 \end{bmatrix} z_r$$

y= [0 0 0 k_w m_us]x

After getting the states of the system we will check out the simulation results on Matlab software before and after adding the air spring, and see the time difference of oscillation, also we will check out the amplitude for the cases.

Mathematical model of the system

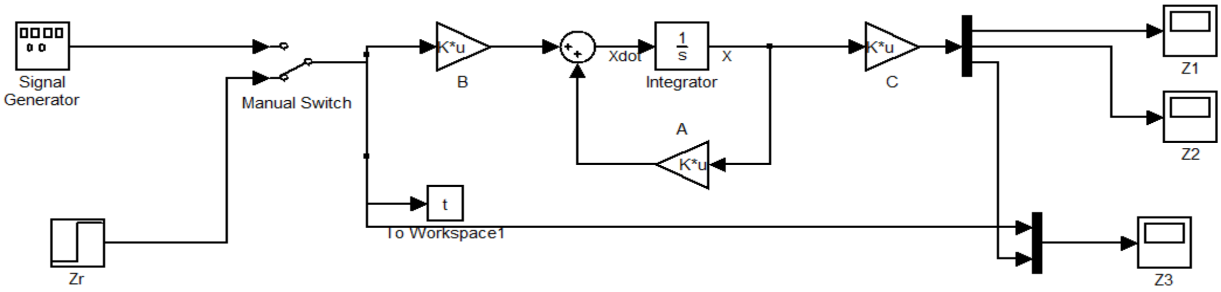
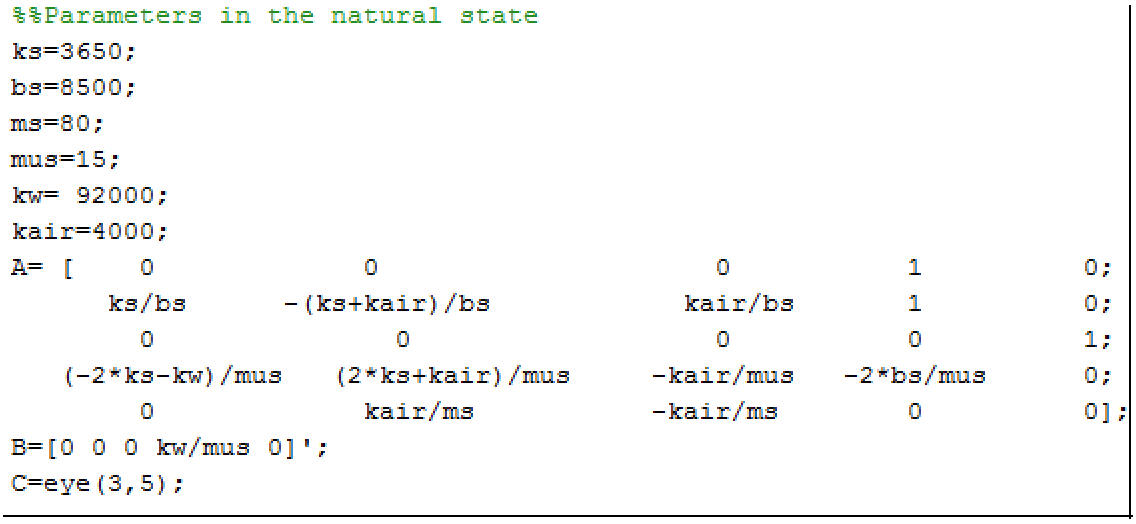


Figure 3. 17: Mathematical model

Case 1 :

We will check out the response of our system in the natural state and the air spring is approximately empty of air. So in this case the stiffness of air spring is 4000N/M.



```
%%Parameters in the natural state
ks=3650;
bs=8500;
ms=80;
mus=15;
kw= 92000;
kair=4000;
A= [     0               0                     0            1          0;
      ks/bs       -(ks+kair)/bs          kair/bs        1          0;
         0                 0                   0            0          1;
   (-2*ks-kw)/mus    (2*ks+kair)/mus      -kair/mus   -2*bs/mus      0;
         0             kair/ms            -kair/ms        0          0];
B=[0 0 0 kw/mus 0]';
C=eye(3,5);
```

Figure 3.18 : Matlab code in the natural state

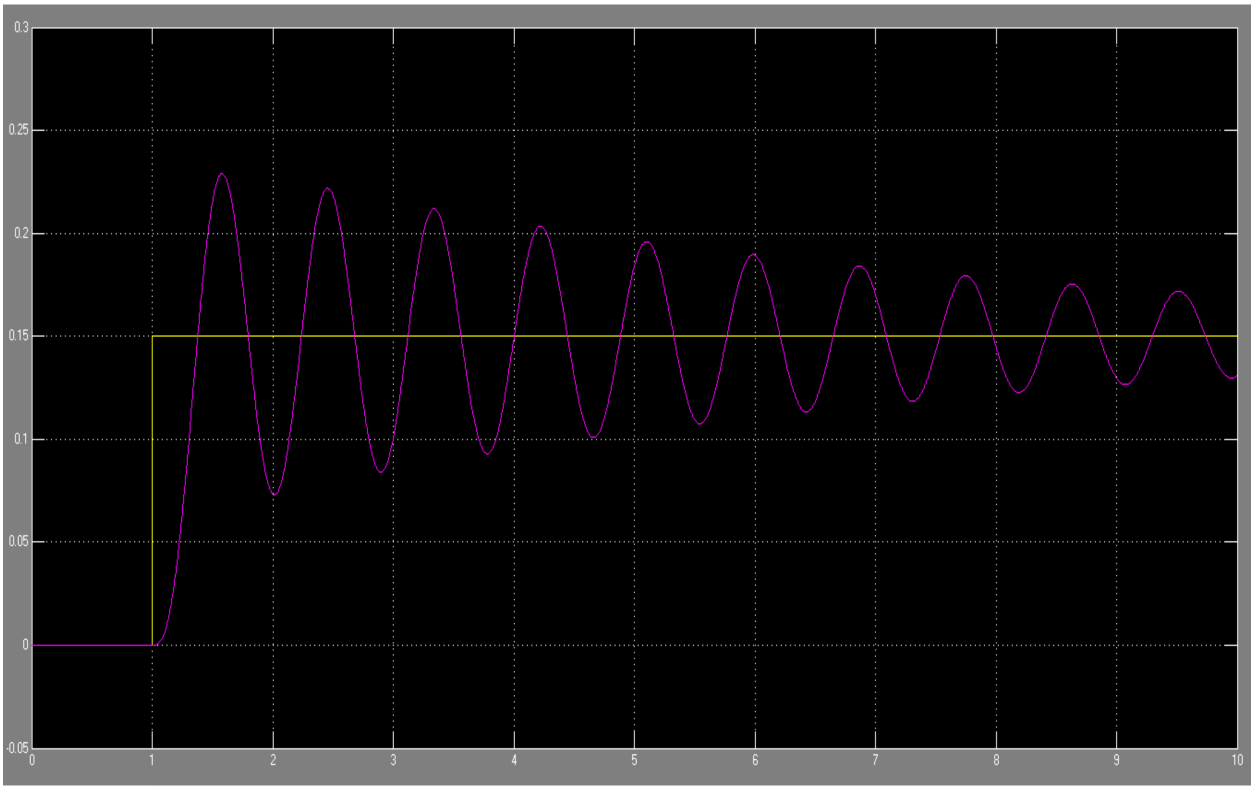
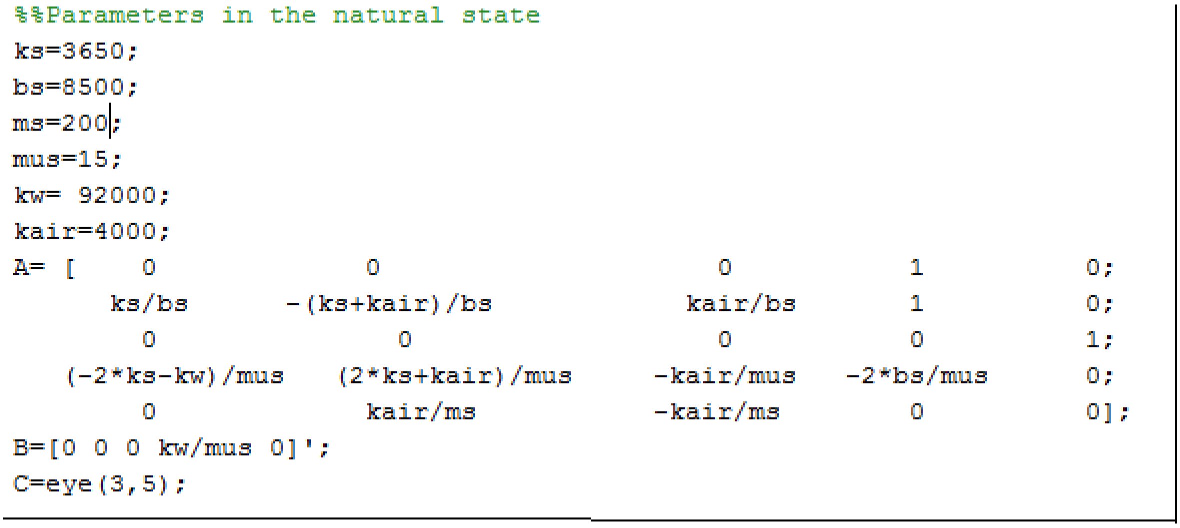


Figure 3. 20: Natural state response

Case 2 :

In this case we will check out the amplitude and time of oscillation with increasing the sprung mass at the same parameters.



```
%%Parameters in the natural state
ks=3650;
bs=8500;
ms=200;
mus=15;
kw= 92000;
kair=4000;
A= [     0             0                    0           1          0;
       ks/bs      -(ks+kair)/bs          kair/bs        1          0;
         0              0                   0           0          1;
    (-2*ks-kw)/mus   (2*ks+kair)/mus     -kair/mus    -2*bs/mus    0;
         0           kair/ms             -kair/ms       0          0];
B=[0 0 0 kw/mus 0]';
C=eye(3,5);
```

Figure 3.21 : matlab code after increasing the mass

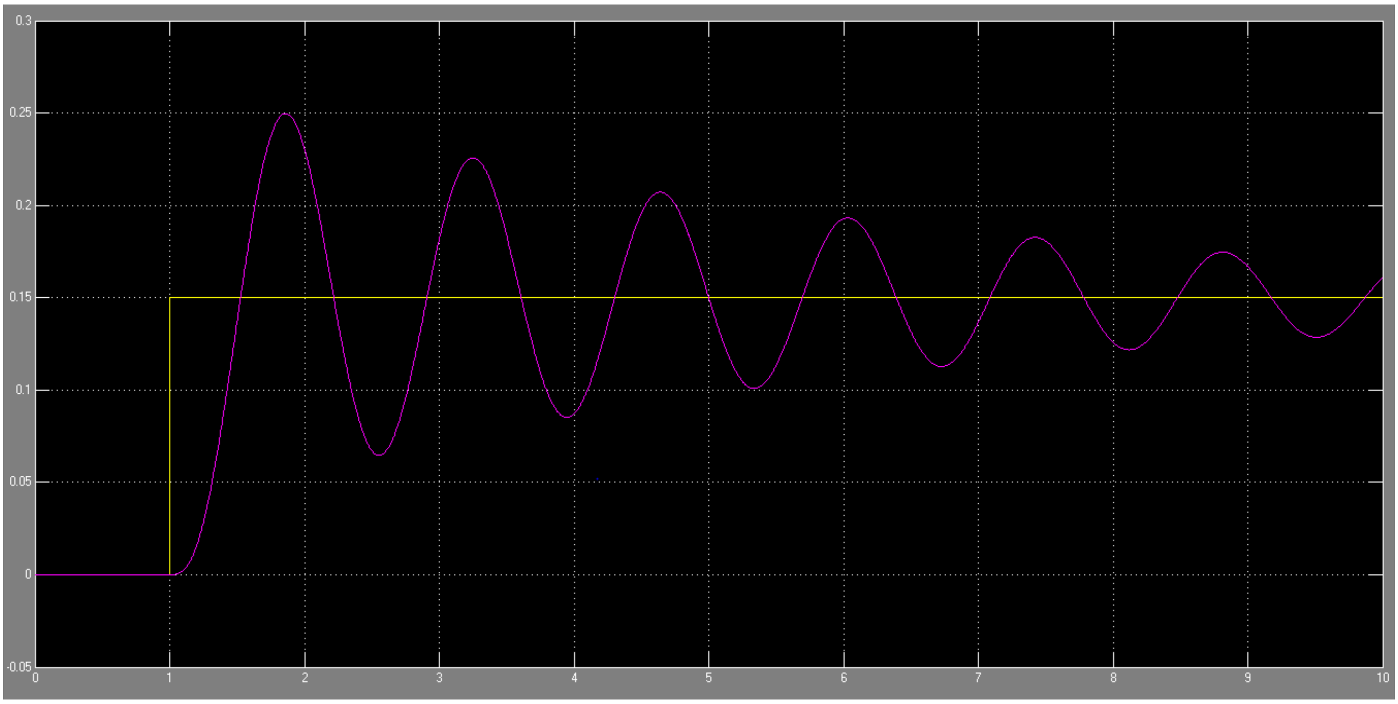
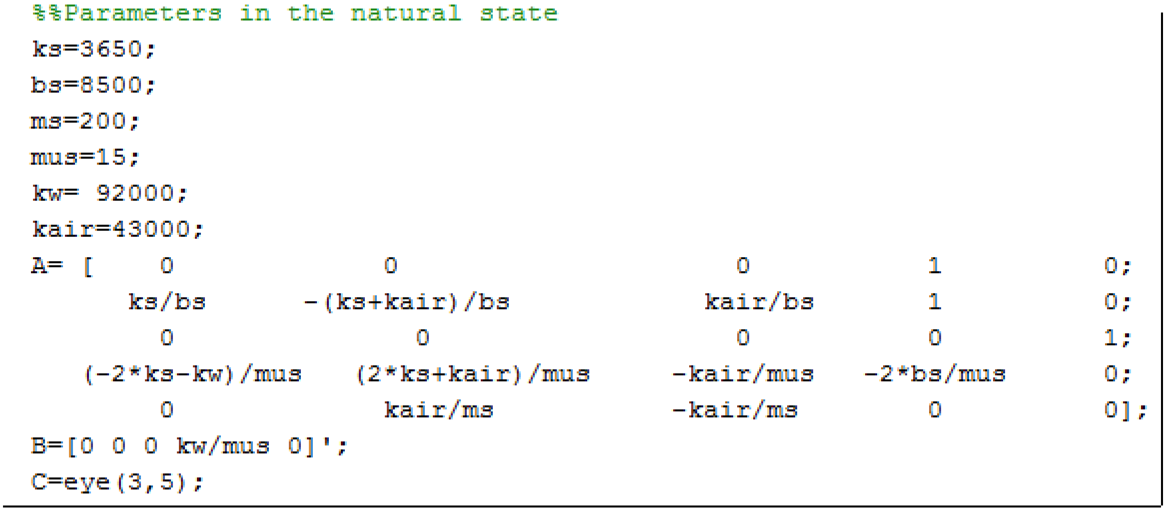


Figure 3.22 ; Response after increasing the mass

Case 3 :

In this case we will check out the amplitude and time of oscillation with increasing the sprung mass and the increasing the stiffness of the air spring .



```
%%Parameters in the natural state
ks=3650;
bs=8500;
ms=200;
mus=15;
kw= 92000;
kair=43000;
A= [    0              0                   0           1          0;
      ks/bs       -(ks+kair)/bs         kair/bs        1          0;
        0              0                   0           0          1;
   (-2*ks-kw)/mus   (2*ks+kair)/mus    -kair/mus   -2*bs/mus      0;
        0            kair/ms           -kair/ms        0          0];
B=[0 0 0 kw/mus 0]';
C=eye(3,5);
```

Figure 3.23 : Matlab code with increasing the stiffness of air spring

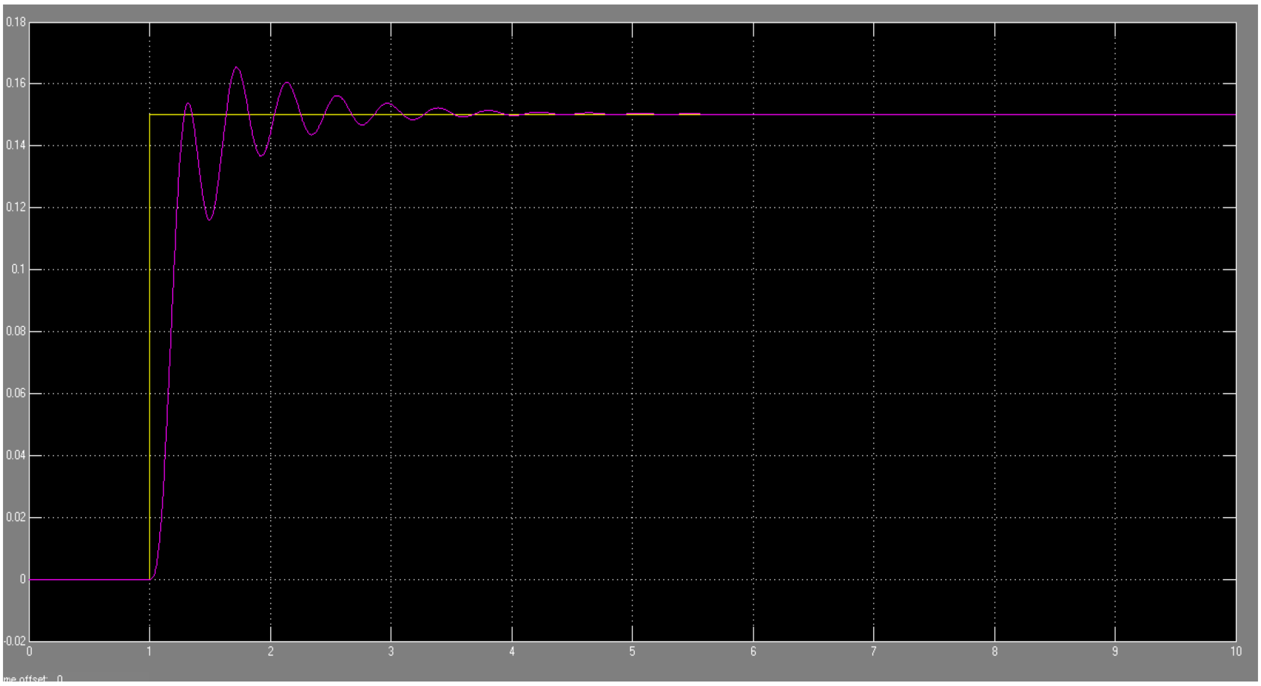


Figure 3.24 : Response with increasing the stiffness of air spring

Now we will compare these three results with each other in the following table:

Number of case	Amplitude (m)	Oscillation time (s)
1	0.22	7
2	0.25	8
3	0.17	3

Table 3.2 Comparing simulation results

The following table lists the notations used in describing the components suspension system:

Notation	Explanation
m_s	The mass of the chassis
m_u	The mass of the wheel
K_{sus}	The stiffness of the suspension system
K_w	The stiffness of the wheel
K_{air}	The stiffness of air spring
Z_r	The vertical displacement of road profile [m]
Z_1	The vertical displacement of the wheel
Z_2	The vertical displacement of the joint mass
Z_3	The vertical displacement of the chassis mass

Table 3.3 the notations used in the derivation of mathematical model

3.7 The effect of the pneumatic system addition on the vehicle suspension and performance.

There is two types of effect initiated during the system we must consider, effect on suspension vehicle performance and fuel consumption[3].

The effect of the mass addition on the vehicle performance and fuel consumption.

The total force on the car is in the "forward" direction, with magnitude:

$$F = mg\sin\theta - \mathrm{mg}\,\mathrm{c}_{\mathrm{rr}}\cos\theta - \frac{1}{2}\rho v^2 c_{\mathrm{d}} A \qquad (3.16)$$

M: is the car's mass.
G: is the acceleration due to gravity at Earth's surface.
Θ: is the angle from horizontal of the ramp.
Crr: is the rolling resistance coefficient.
P: is the density of air.
V: is the speed of the car.
CD: is the drag coefficient of the car.
A:is the car's cross section area.
(Crr) depends on many things rather than being a constant, but what is important here is that for rigid plastic tires, Crr should decrease with increasing m. CD is independent of m.

The first term in the above equation is the forward component of the force purely due to gravity, the second term accounts for rolling resistance, and the third term accounts for drag.

If you equate that equation with *(F=ma)* and divide both sides by (*m)*, you will get that the car's acceleration in the forward direction is:

$$a = g\sin\theta - \mathrm{g}\,\mathrm{c}_{\mathrm{rr}}\cos\theta - \frac{1}{2m}\rho v^2 c_{\mathrm{d}} A \qquad (3.17)$$

According to that equation, if (m) increases, the acceleration (a) will decreased.

Let us consider that there is two cases, one for the vehicle before any addition, and the other with adding the pneumatic system, and let us see the effect on the vehicle acceleration and fuel consumption.

Case 1: Acceleration of the vehicle without add the system:

Parameters: $m = 406kg, v = 50\,km/h\,, \rho = 1.2, c_d = 0.32, c_{rr} = 0.015\,, A = 1.83m^2, \theta = 4\,deg.$

By using eq.34, the vehicle acceleration should be:

$$a = 9.81 * 0.06975 - 9.81 * 0.015 * 0.997 - \frac{1}{2 * 406} * 1.2 * \left(\frac{50 * 1000}{3600}\right)^2 * 0.32 * 1.83$$

$$a = 0.381\mathrm{m}/s^2$$

Case 2: Acceleration of the vehicle with added the system:

By adding the mass of the pneumatic system (10.2 kg) to the mass of the vehicle (406 kg).the total mass becomes;

= 10.2+406 =416.2 kg$m_{\text{total}} = m_{system} + m_{vehicle}$

By using eq.3.4, the vehicle acceleration after adding the pneumatic system should be:

$$a = 9.81 * 0.06975 - 9.81 * 0.015 * 0.997 - \frac{1}{2 * 416.2} * 1.2 * \left(\frac{50 * 1000}{3600}\right)^2 * 0.32 * 1.83$$

$$a = 0.373\mathrm{m}/s^2$$

As we see in the two cases there are little different in the two accelerations before and after adding the system, therefore the additional weight from the system to the vehicle does not effect on acceleration. We need to calculate the distance that driven by the vehicle with and without additional mass to the vehicle to see the effect on fuel consumption.

Case 1: Without additional mass to the vehicle:

From the laws of motion, the traveled distance by the vehicle can expressed by the following equation:

$$\mathrm{x} = \mathrm{vt} + \frac{1}{2}at^2 \tag{3.18}$$

So the traveled distance by the vehicle without any increase in the total mass of the vehicle

Is:

$$\mathrm{x} = \left(\frac{50 * 1000}{3600}\right) * 1 + \frac{1}{2} * 0.49524 * 1^2 = 14.13650889\ m/\ \mathrm{sec}$$

Case 2: With additional mass to the total mass of the vehicle:

From eq. (3.22) the traveled distance by the vehicle with additional mass (mass of the pneumatic system) will be:

$$\mathrm{x} = \left(\frac{50 * 1000}{3600}\right) * 1 + \frac{1}{2} * 0.49523 * 1^2 = 14.13650389\ m/\mathrm{sec}$$

The traveled distance lightly decreased when we added the system, therefore there is a simple increase in fuel consumption in the same traveled distance.

4

Chapter four

4. Conclusion and recommendation.

4.1 Conclusion and results.

4.2 Recommendation for future work.

4.1 Conclusion and results.

Within our project**,**
we have built and design aprototype (as an educational form) for our pneumatic system and fixed it on a structure of a vehicle.

We can summarize the results obtained after the implementation of the project and making the necessary calculations for it as following:

1) The System depends directly on the suspension system in the vehicle. Therefore, any change in the suspension system displacement (goes up or down), the pneumatic system will behave the same as the suspension system does.

2)The pneumatic system addition has a very little effect on the vehicle suspension and performance as we see in ch.4, there is a little bit effect on the damping response (time and amplitude) for the suspension system.

3)The distance that the vehicle traveled during a certain period is lightly increase when we added the system to the vehicle. Therefore, there is a small simple increase in fuel consumption at the same traveled distance.

4.2 Recommendation for future work.

The essence of this project work is well encapsulated by the title of this work, namely, "**Air lift suspension system with passive control**". Indeed the title is emblematic of the broad range of topics covered in this project. These topics are critically important in the way they were interrelated for the overall success of this work. In this regard, the present section concludes this thesis by summarizing the recommending future work in this area.

Before any part added to the vehicle, we should know about the effect that associated with this change, both positive and negative. In our project, the mechanism associated with suspension system, so we do not want to make any change in the system, whether it is in system work or efficiency. The best choice when the air bag stands at the upper of the road that leads the suspension damper. Therefore, the same force that acts on the suspension will Reach and act directly at the top of the air bag. In this case, we must ensure that the air bag not affects the length of the suspension damper.

From another side, we select the air bag with respect to that our system design is a prototype, so when the system moved into and implement on the practical life, on a real vehicle for example. Keep in mind that the air bag must be designed in the way to bear the operating conditions (temperature and pressure), Based on air bag placement.

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