DESIGN AND DEVELOPMENT OF MOUNTAIN BIKE REAR SUSPENSION FOR ALL MOUNTAIN RIDING STYLE

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DESIGN AND DEVELOPMENT OF MOUNTAIN BIKE REAR SUSPENSION FOR ALL MOUNTAIN RIDING STYLE

MOHD AIMAN BIN MAHUSIN

Report submitted in partial fulfillment of the requirements
for the award of Bachelor of Mechanical Engineering with Automotive Engineering

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JUNE 2013

EXAMINERS APPROVAL DOCUMENT

UNIVERSITI MALAYSIA PAHANG
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I certify that report entitled 'Design and Development of Mountain Bike Rear Suspension for All-Mountain Riding Style' is written by Mohd Aiman Bin Mahusin with matric number MH09068. I have examined the final copy of this report and in my opinion, it is fully adequate in terms of language standard, and report formatting requirement for the award of the degree of Bachelor in Mechanical Engineering with Automotive Engineering. I herewith recommend that it be accepted in fulfillment of the requirements for the degree of Bachelor Engineering.

Assoc. Prof. Dr. Khairi Yusuf
Examiner

SUPERVISOR'S DECLARATION

I hereby declare I have checked this report, which written by Mohd Aiman Bin Mahusin, and in my opinion, this report project is adequate in terms of scopes and quality for the award of the degree of Bachelor of Mechanical Engineering with Automotive Engineering.

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STUDENT'S DECLARATION

I hereby declare that the work in this report is my own, except for quotations and summaries which have been duly acknowledged. The report has not been accepted for any other Degree and is not concurrently submitted for award of other degree.

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Date: 19 JUNE 2013

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ABSTRACT

This report discuss about the design and development of mountain bike rear suspension for all-mountain riding style. The objective of this study is to design and develop a proper geometry of rear suspension system for mountain bike, and to study the motion mechanisms of rear suspension system. This study deals with the path analysis (PA) of a wheel axle and pivot position determination for the crank set of mountain bike. The results show that the new developed rear suspension base on Monolink type have a suitable frame geometry that give a great horizontal and vertical travel for improvement of pedalling efficiency. In addition the crank set position for the Monolink rear suspension also helping for a smooth ride resulting from the less chain growth and chainstay lengthening. These research uses AutoCAD, Autodesk Sketch Pro and SolidWork to design and analyze the path analysis in terms of displacement of “x” and “y” axis of the developed rear suspension. The results are compared between another several types of rear suspension mechanisms.

ABSTRAK

Laporan ini membincangkan tentang merekabentuk dan pemajuan sistem suspensi belakang "Mountain Bike" untuk gaya tunggangan "All-Mountain". Objektif kajian ini adalah untuk merekabentuk dan memajukan system suspensi belakang yang baik untuk "Mountain Bike" dan mengkaji mekanisme pergerakkan system suspense belakang. Kajian ini berkaitan dengan analisis laluan gandar tayar dan penentuan kedudukan pangsi untuk set engkol "Mountain Bike". Keputusan menunjukkan suspense belakang baru yang telah dimajukan berdasarkan jenis "Monolink" mempunyai geometri bingkai yang menghasilkan pergerakan melintang dan menegak yang baik untuk penambaikkan kecekapan kayuhan. Tambahan lagi, kedudukan set engkol untuk suspense belakang "Monolink" juga membantu dalam penunggangan yang lancer hasil keputusan daripada pemanjangan rantai dan penyokong rantai. Kajian ini menggunakan perisian AutoCAD, Autodesk Sketch Pro dan SolidWork untuk mereka bentuk dan menganalisis laluan yang dilalui oleh gandar tayar suspense belakang yang telah dimajukan dari segi perubahan axis "x" dan "y".Keputusan analisis kemudiannya dibandingkan dengan beberapa jenis suspensi belakang yang lain.

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LIST OF ABBREVIATIONS

MTB	Mountain Bike
PA	Path analysis
WA	Wheel axle
OC	Outer circle
IC	Inner circle

CHAPTER 1

INTRODUCTION

1.1 Overview

Mountain bikes are also known as trail bikes that can be classified as the most extreme category of bikes. For all-mountain riding style the mountain bike is built to face almost everything a biker could run in a full day of riding. They are designed to climb hills efficiently,generally heavier and a bit stout or larger than the typical cross country mountain bike. With the futuristic design, they can handle a lot rougher terrain andobstacle as well. They are an excellent balance between efficiency, comfort, and control.Even the size is big, all mountain bikes are light and efficient enough to get biker to the top of the hill, it have soft enough suspension to keep bikerremain from rough terrain, and have enough travel to overcome the bigger hits.

The quality of mountain bikes depends on the decision of the rear suspension and a fork. As for an all-mountain riding style bike, it focus on its rear suspension that will help the movement to be smooth ride even in a rough terrain. Accordingly, this suspension help in many ways, it allows the bike rear body to move up when the wheel encounters a bump, and quickly move back down after the wheel passes the bump.The rear suspension consists of spring that can be a coil of steel, or it could be a cylinder containing pressurized air.In either case, the further the spring it is compressed, the more force it takes to compress it. This is the exact way in maintaining a good ride for all mountain bike journeys.

Available mountain bike rear suspension, however, are typically not working well since some of the manufacturers are trying to attract consumers nowadays with trick designs. Some product of rear suspensions that should give a good performances for all-mountain bike riding style do not work well, even decrease the effectiveness.

Basically, there are several types of suspension that can be developed or choose for all mountain riding style such as single pivot, virtual pivot, monolink, horstlink, soft tail, four-bar and unified rear triangle. Each of these suspensions has their own advantages and disadvantages.

1.2 Problem statement

During climbing up a hills or coasting through a rock garden, the poor suspension performance causes an unbalance to the biker,directly affect the pedalling power and finally slowing down the speed.Pedal kickback occurs when the rear axle moves further away from the bottom bracket. The top run of chain is getting longer which called chain growth, such that the tension of the chain decrease and make problem when it turns backward. Besides, the high-frequency trail vibrations and heavy-hitting compressions impact while riding have greatly influence to the suspension perfomance.

Certain positions can compress the suspension, such as brake squat or extend it, brake jack. Braking causes the biker weight to move forward, extending the shock. So, squat can be useful to maintain even geometry to counterbalance this effect, but it can also make the suspension feel harsh and lose traction, while a net extension may upset the geometry but increases the available traction. With well-constructed suspension may help to stabilize geometry of the rider even if the bike hit a big or small bump.

Besides that, all-mountain bike riding style countered bigger forces as it moving through many extreme terrains. A poor rear suspension may be defect. The stress and strain analysis has to be done to make sure the chassis and rear arm of the mountain able to withstand the forces.

1.3 Objectives

The objectives of this study are:

i) To design and develop a proper geometry of rear suspension system for mountain bike.
ii) To study the motion mechanisms of rear suspension system.

1.4 Project Scopes

This project will focus on design, develop and analysis of the rear suspension of all mountain bikes to optimize its uses. The parameters that would be studied in this project are:

i) Wheel path
ii) Chain growth

This project also focuses on the methods and software used which are AutoCADand Autodesk SketchBook Pro in order to sketch and construct the design of the rear suspension. All of the methods that used in this project were aimed to evaluate the best and optimum parameter stated above. Other than that, the material selection is also one of the project scopes, in order to analysis all mountain bike that can withstand the obstacle while riding.

Besides, SolidWork 2011/2012 is used in developing the rear suspension, in order to obtain the data of applied load. All of the methods that used in this project were aimed to evaluate the best and optimum parameter stated above. SolidWork, SketchBook Pro and AutoCAD could simultaneously satisfy requirementsofa good MTB rear suspension system both quality and as well as productivity with special emphasis on reduction of. Besides, the study of rear suspension vertical travel can be done using Solidwork motion application.

1.5 Thesis Organization

This thesis consists of five chapters that will explain about the design and development of mountain bike rear suspension for all mountain riding style. The first chapter is about the proposal of this study including of overview, problem statement, objectives and project scopes.

In chapter two, there is a literature review, discuss about the mountain bike rear suspension. The main propose of this literature review is to get the information about the project from the reference books, magazines, journals, technical papers and web sites.

Then in chapter three, it will describe about the overall process of methodology in this study from beginning until end. For chapter four, it is about the results and discussions. All the data and result from analysis is collected and then used for discussion.

Lastly, the conclusion and recommendation for this study is stated in chapter five.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Mountain Bike is a bicycle that is celebrates the challenges and spirit of technical riding through rough course or downhill where free rider have pushed the limits of what is possible on a bicycle (Blumenthal T, 2004). It is diverse riding style that demands the most from riders and equipment. This mountain bike is aimed at increasing durability and improving performance in rough terrain.

2.2 Full Suspension

An All-Mountain Bike usually consists of a full suspension system. Full suspension simply refers to a mountain bike with both front and rear suspension. It operated for many advantages such as increase pedal efficiency and rider comfort. Aside from improved comfort, other performance benefits include diminished rider fatigue, improved braking, cornering, line holding, and higher downhill speeds (Anon,1992).A full suspension system provides potential benefits of reduced fatigue, better traction for both up and downhill cycling and the ability to control the bicycle at faster downhillspeeds. Focus for the rear suspension, it is a rear joint with several part including swing arm, coil spring or damper. The accepted suspension components used on most production bicycle is a coil spring and oiled damper combination (Padilla,1996).While the mountain bike with a hardtail consist only a front suspension. **Figures 2.1** and **2.2** shown the different between hardtail and full suspension system.

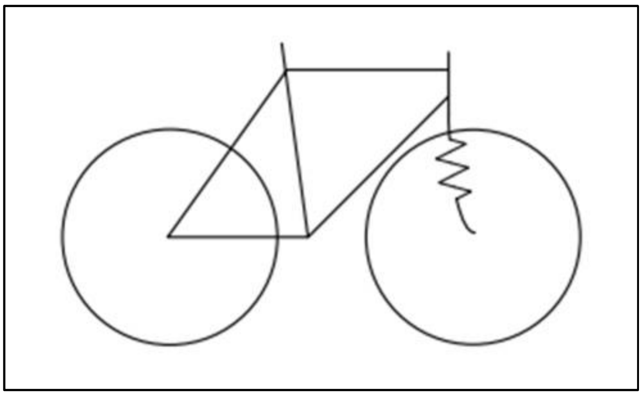

Figure 2.1: Hardtail suspension system

Rear suspension for MTB comprise of shock absorber system which is various type of spring/damper or any shock absorber devices and a pivot system that control the path of the rear wheel upon the impact that cause by the uneven ground surface. Usually a basic bicycle rear suspension, each design has a main pivot and some of it called rocker located at the main frame of the bicycle and with the other end connected to rear frame which is known as swing arm. This type of rear suspension pivotally moves in its circular path with a constant radius about a single axis of rotation which is fixed relatively to the main frame.

There are many type of rear suspension which show a complex linkage systems, such example are soft tail, unified rear triangle, single pivot, linkage driven single pivot, high single pivot, split pivot, horst link, short link four-bar, virtual pivot point, DW link, Giant Maestro, switch link, trek full floater, floating drive train, Equilink, Independent Drivetrain, Monolink, and Pendbox. For this project, the linkage system is more likely have an innovation based on the Monolink rear suspension system which provide a simple linkage system but give a maximum efficiency when pedaling through a garden of rock or bumps.

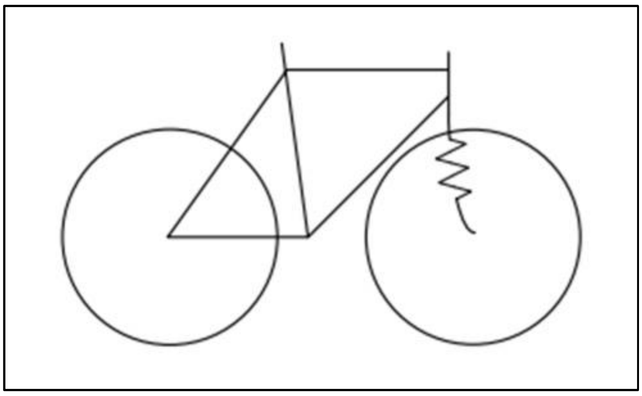

Figure 2.2: Full Suspension System

2.2.1 Design

To design is either to formulate a plan for the satisfaction of a specified need or to solve a problem. If the plan results in the creation of something having a physical reality, then the product must be functional, safe, reliable, competitive, usable, and marketable. Common to all MTB facilities should be sustainability, consideration and cohesion with its environment and technical features that are suited to the specific MTB discipline that the facility is catering for. For this design of the rear suspension, it is aim for development considering wheel path and chain growth effect.

2.3 Existing rear suspension

Nowadays, there are several type of mountain bike rear suspension been developed and each of the rear suspension has their own advantages and disadvantages. The types of suspension are Mono Link, Horst Link, Single pivot, Virtual Pivot, Four Bar and Unified Rear Triangle suspension system. In this section each of the suspension system is explained in simple way.

2.3.1 Mono Link Suspension

Mono Link is a clever new design that came out of the hands of engineers from Maverick Cycles. It is so unique and simple that it requires its own page. It is so proprietary that it must use a modified one a kind air shock that is mounted statically to the rear triangle. Usually the shocks used in suspension designs have two mount points that frame components may rotate on. Refer to Figure 2.3, the shock is permanently coaxial to the bar CG.

The program that was used to make these diagrams is incapable of calculating the wheel path, and has been edited in. As per a video released by Maverick Cycles, the wheel path is significantly more movement about up and back than every other design. This allows less energy to be lost in forcing the wheel out of the way by irregular terrain.

The bottom bracket is mounted roughly in the middle of the link FG, allowing minimal chain growth but just enough to limit pedal bob. Brake-induced lockout will be a very limited issue here because force vector from the brake caliper is perpendicular to the movement of the system's components.

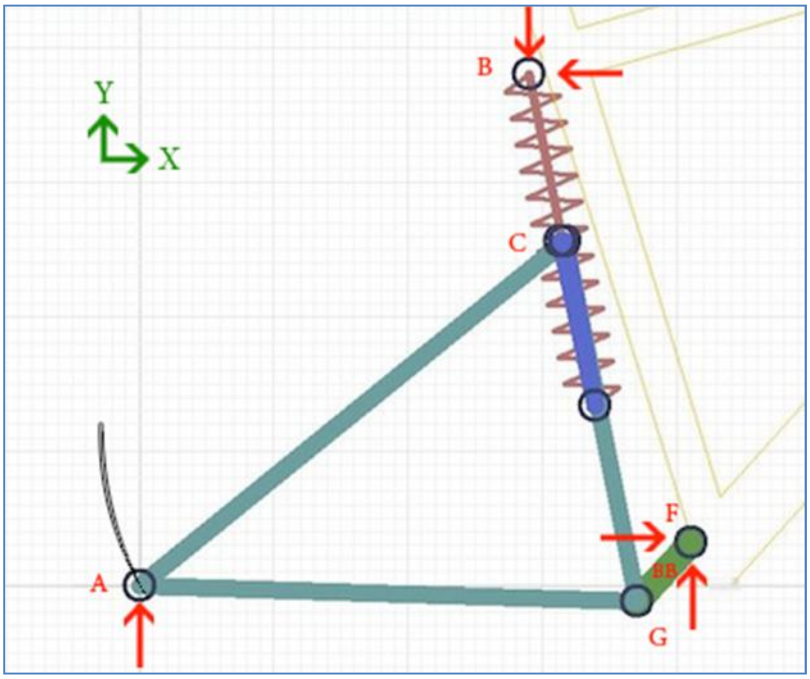

Figure 2.3: Mono Link Suspension System.

2.3.2 Horst Link Suspension

The design of the Horst link Suspension systems, is displayed in Figure 2.4. This is one of the oldest designs and is an attempt to veer from the traditional pivot-concentric wheel path. One could consider this having a 'virtual pivot point', which would be located just behind the point F, but it is more appropriate to categorize it as a four bar because of the linkage design. The advantage to this path is that the slope of the wheel path when there is no compression, which has a smaller slope, less vertical than a single pivot design, and allows for a more active suspension over small bumps.

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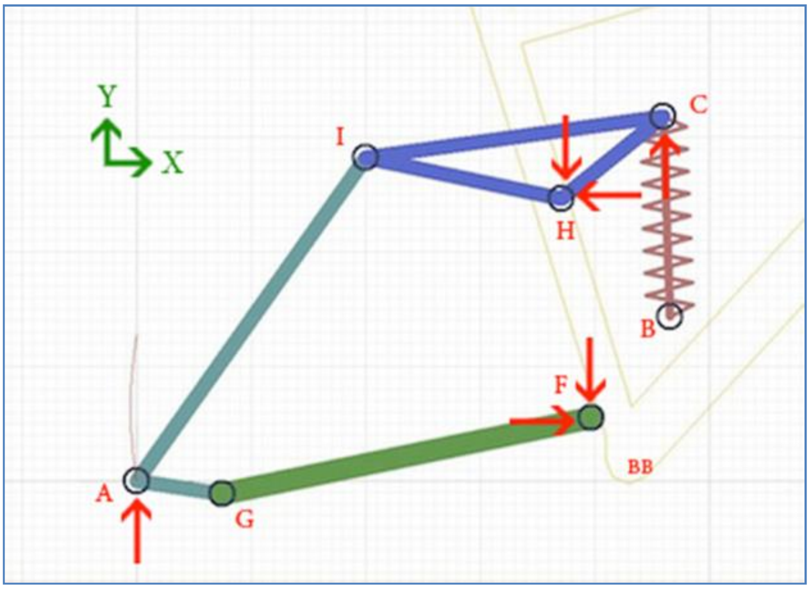

Figure 2.4: Horst Link Suspension System

From the figure it shown thatthere is difference between this system and a real virtual pivot setup on the virtual pivot system. Again, as the Split Pivot design does, the Horst Link has an issue with brake-induced lockout because the rear brake caliper is attached to the seat stay.

2.3.3 Single Pivot Suspension

The Single Pivot is the most widely used method to include rear suspension in bicycle frame design. If built correctly, this system will have the highest rigidity, durability, and versatility of any design currently on the market.

Single pivots were the first type of suspension to become widely available for a bicycle. It is simple, elegant, and requires very little maintenance, the epitome of an engineered solution. The only design parameters necessary besides building it strong enough is the location of the main pivot which is point D in Figure 2.5, both shock mount positions at points C and B, and the length of the swing arm.

As can be easily seen, the suspension works by using a large triangle which is the swing arm transfer upward forces from the wheel to lateral forces into the shock. The amount of travel, at-axle spring rate, wheel path, pedal-jack, and brake jack depend on the dimensions between all of the above points.

The forces on the swing arm are marked in red arrows at the points that make up the triangle. The wheel places a positive torque at length AD. The shock will provide an opposing negative torque. The forces from the main triangle on the pivot point at Point D will have a negative vertical component and a positive horizontal component.

The spring constant will be concave up, allowing for a buttery smooth ride regardless of where the suspension is at in its travel.The wheel path here is concentric to the pivot at Point D. Because the pivot is above the bottom bracket, marked BB in Figure 2.5, the wheel path will have an up and rearward path early in the suspension path, and will become vertical deep into the travel. Bump feedback is an issue here, and the rider will feel an ease in pedaling as the suspension absorbs a bump.

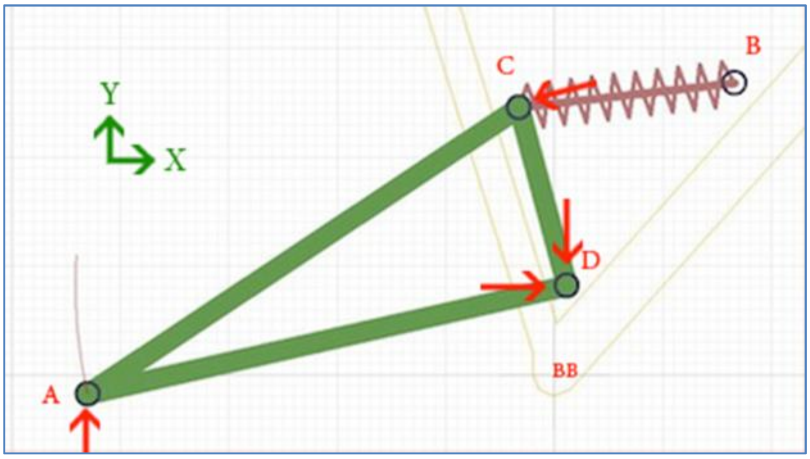

Figure 2.5: Single Pivot Suspension System

2.3.4 Virtual Pivot Suspension

Virtual Pivot Point technology has put into the hands of engineers endless possibilities to manipulate the wheel path of rear suspension. The most optimal path is the S-shaped curve. This is the technology that made this possible.

The design is called the DW-link, and is patented by the same person, Dave Weagle who designed the Split Pivot displayed on the Four Bar Suspension. It is hard to see, but there is an S-shaped curve here, as mentioned with this design. Unfortunately, there is a drawback to this method of suspension: High forces in a centralized region.

The area of the frame near the bottom bracket will be supporting the forces of the suspension at points F and H. This leads to an extremely high stress point. Because this design is more tailored to downhill cyclists and bikes, the extra material required is not a problem. Some of the bikes with this design are found will weigh over forty pounds.

Refers to Figure 2.6, the way it works is as the point A moves up, the triangle AGI will rotate clockwise about its own center, as well as rotating about a center up near the front wheel. The link IH will rotate clockwise with point H attached to the frame. Rocker GCF will rotate clockwise about the mounted point F.

The advantages of this technology are endless, and are often untapped. It is possible to adjust the wheel path to make whatever one whishes. The wheel path in the DW-link looks concentric around a point somewhere near the bottom bracket, or maybe about point I. But if it looks closely, noticed that its concavity becomes smaller, deeper into the suspension. Engineer chose this path so that the wheel travels up and back in the beginning of the travel, and will loop back and straighten out deep into the travel. This allows a more active suspension design while under both high and low compression.

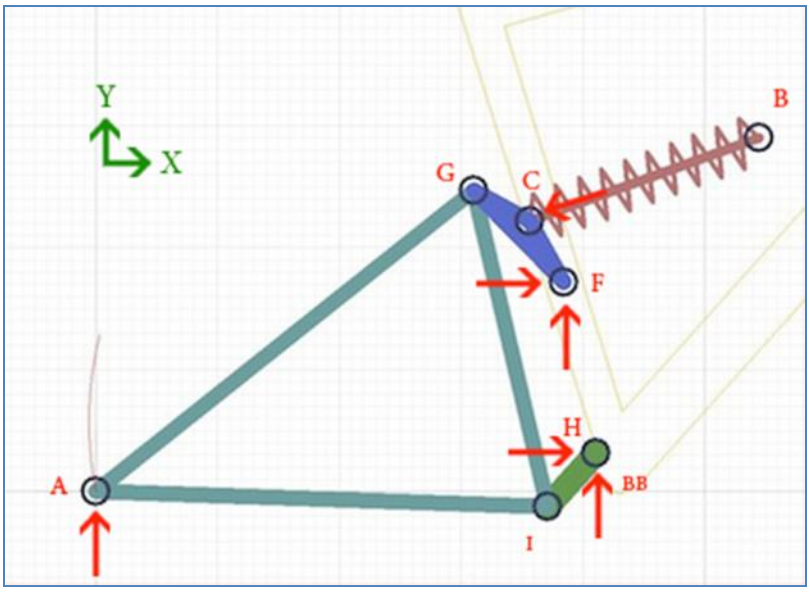

Figure 2.6: Virtual Pivot Suspension System.

2.3.5 Four-Bar Suspension

The Four-Bar design is a very widely used strategy that allows a large amount of adjustment of spring leverage ratios. The four-bar linkage design was the next step in the evolution of bicycle suspension. It was a lighter, more versatile design that, if built well, is a rock-solid choice for manufacturers. The main idea is the linkages and components represent a four-sided polygon: the chain stay, seat stay, rocker, and seat tube. The design is similar in principal to independent front suspension common in vehicles. There are different versions of this design, and each varies ever so slightly. But, each has their own patent filed with the US Patent Office.

The only difference is where the pivot is mounted near the axle. If the link is above or behind the axle, with the axle attached to the chain stay, it is considered a Bona Fide Single Pivot with cool linkages according to Figure 2.7. If the pivot combines the seat and chain stays at the axle, it is called the Split Pivot. If the pivot is directly in front of the rear axle, with the axle attached to the seat stay, it is called a Horst link. The way this design works is similar to most independent front suspension designs in a car. Referringto Figure 2.7, the wheel is mounted at Point A, and the chain stay pivots around point D. The rocker which is the triangle made up by points C, F and G is pivoted around point F. This is the device that transfers vertical movement by the rear axle to the shock.

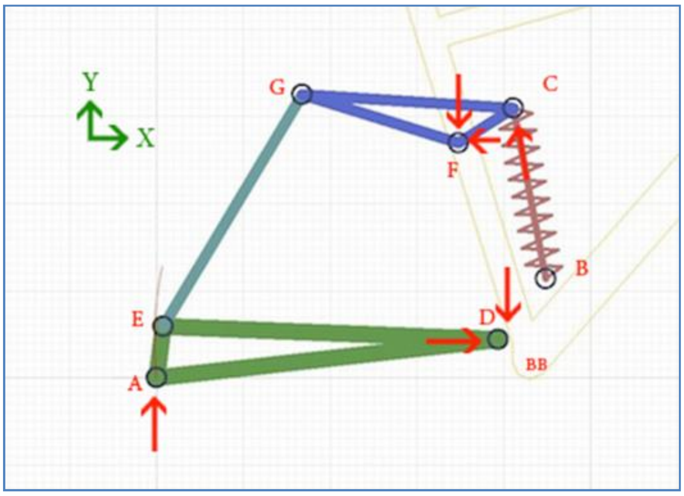

Figure 2.7: Four-Bar Suspension System.

This Four-Bar Suspension System is widely used and has a difference name. The first type is shown in Figure 2.7. The rear pivot is above the axle referring to Point E, with the axle attached to the chain stay Point A, and has the same exact wheel path as a single pivot design. The only difference is that it may be more reactive to bumps because it is lighter. Brake-induced lockout will be an issue if the rear caliper is attached to the seat stay instead of the chain stay.

The second design, called the Split Pivot, is where the pivot is coaxial with the wheel axle. It is in where the points A and E become the same. It is claimed by designers to eliminate brake-induced lockout because the braking forces are isolated from the suspension. This is a lie and is simply a marketing tool. Anyone with even a mild physics background is aware of Newton's third law about equal and opposite reactions. One cannot simply make a clever linkage design and have a braking force magically disappear. The energy must go somewhere, which happens to be in increasing the apparent spring rate at the wheel.

2.3.6 Unified Rear Triangle Suspension

Although this design has lost its appeal to the modern market, it remains a clever way to address the issue of chain growth. From the Figure 2.8, the only difference between the single pivot and the unified rear triangle is that the bottom bracket is attached to the swing arm here. This means that while the suspension compresses, the distance between the wheel axle and the bottom bracket will not change, resulting in no suspension activity from the chain tension, or vice-versa. Granted, pedal bob still exists due to the rider's bouncing up and down while pedaling, but there is no bump feedback at all because the chain remains the same length throughout travel.

Furthermore, the pedal bob will be increased because the bottom bracket is mounted on the swing arm. Any torque provided at a pedal, being on the end of a crank arm will be clockwise in the direction of suspension compression, thus further compacting of the suspension.The unified rear triangle design will have a similar wheel path and forces to the single pivot.

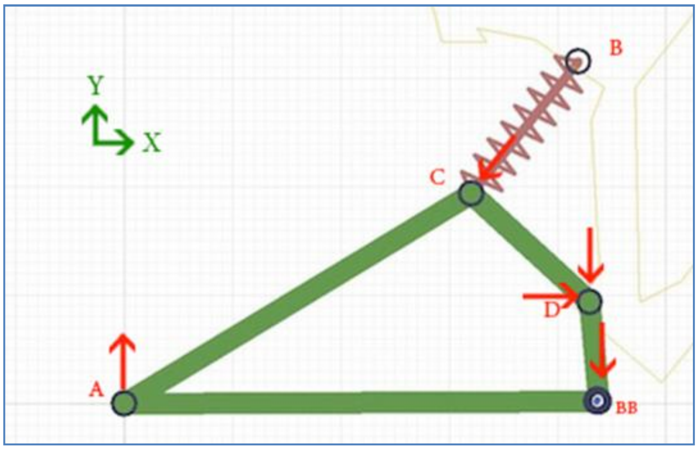

Figure 2.8: Unified Rear Triangle Suspension System.

2.3.7 Soft Tail Suspension

The target audience for this suspension design is mostly those who still want the weight benefits of a hard tail, but still want a cushioned ride to reduce vibrations and small bumps in their path. These kinds of frames usually have no moving parts, save for any shock and possible shock linkages in line with the seat stays. These frames are not designed for rough riding especially the newer versions, as the suspension system would not handle it at all, but more so cross country and sidewalk riding. In the past this type of frame has been hard to develop because of the limitation in materials.

The basic idea is that there are no pivots or moving parts in the chain stay. Point D and the frame component AD are fixed to the main frame. This provides excellent pedaling efficiency because there is no change in the chain stay length as which pedal-jack will be covered, and thus minimal pedaling energy is lost.

From Figure 2.9 the suspension works through the flexing of the component AD, and somewhere between points A and B there is a shock absorber. This design was difficult to make due to the necessary flexing of the AB component. Any metal would not be elastic enough to be able to bend and return to its original shape, and would become brittle enough to break over time.

Engineers then turned towards polymers. Polymers were the best material to be used at this point in time. The material was light, durable and would return to its original shape after being bent.As progress was made in material development, carbon fiber was introduced to replace the polymer chain stay. This was not only a more durable option, but lighter and more fine-tunable. With careful design to make the chain stay flattened so that it can be bent in the Y direction, but not the Z direction, lateral stiffness is achieved along with a greater flexibility in the Y direction.

The shock can be mounted in line coaxially with the seat stay or with a linkage up near the seat at point B. Having the former, it is possible to adjust the effective spring rate at the axle.The suspension travel is not significant enough here to account for changes frame geometry, pedal-jack or break-induced suspension lockout. All of the forces in this design are similar to the hard tail frame.

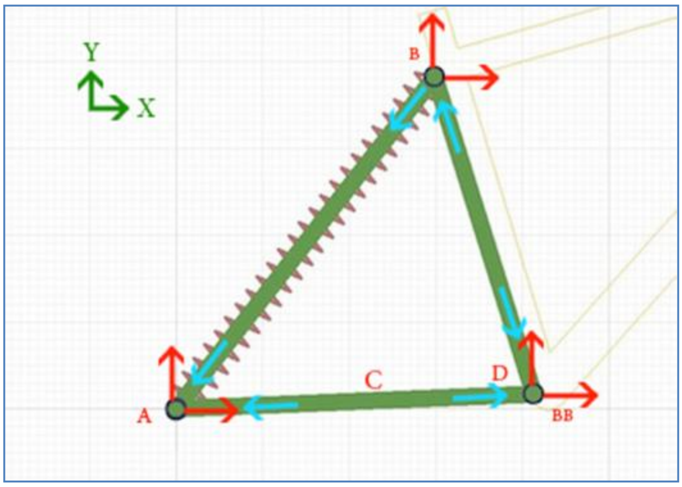

Figure 2.9: Soft Tail Suspension System.

2.4 Operation of rear suspension system

Briefly explain the operation of wheel path and chain growth in the rear suspension system as related to the objective of this project.

2.4.1 Wheel Path

A wheel path is the movement of the wheel as it hit a bump or rough surface. A mountain bike, it is design to facing all of this activity. For the front wheel path, universally agreed that the front wheel should move up and back as all suspension forks do. But for the rear suspension, the movement of the wheel path is either to be in horizontal and vertical travelled, logically it will be consider both of the path as the wheel is about to turn around the pivot. As the suspension compresses, the forward and rearward links of the bike rotate as indicated by arrows 188a and 189 in the figure 2.10.When the rear suspension tends to rotate about the pivot 180b, it can be assume that the wheel that attach at the other end point of the swing arm also tends to move in circular path which consider of horizontal and vertical movement.

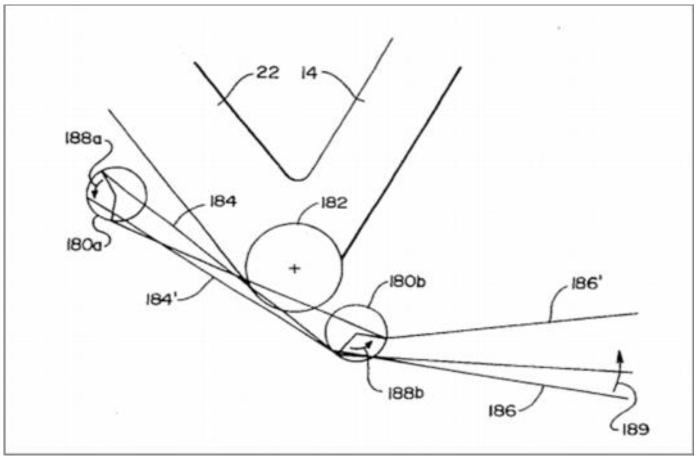

Figure 2.10: Rotation of wheel about the pivot,

Source: *Bicycle Rear Suspension System, B. Klassen*

Fact claimed that the more the wheel moves up and back throughout the wheel path, the more control and speed could be maintained by the rider. As shown earlier, there are many types of mountain bike rear suspension. Each of the suspension system performed a different result in horizontal and vertical travel when it hit a bump. So it is important to design a rear suspension that demonstrates the greatest amount of horizontal displacement throughout its vertical travel in order to improve or increase the pedal efficiency.

2.4.2 Chain Growth

Chain growth is the lengthening of the chain. Chain growth affect by the lengthening of the chain stay. Chain stay lengthening refers to the increase in distance between the bottom bracket and the wheel axle which occurs as a suspension is compressed. In a suspension system which causes the chain stay length to increase when the wheel is moved vertically, a downward force will develop on the wheel (B. Klassen, 1996). The chain growth gave a big impact on the pedaling efficiency. The less chain growth created, the better pedaling efficiency created. The well-constructed suspension exhibit a minimal chain growth while maximizing horizontal displacement. As a conclusion, by maximizing the rear wheel horizontal and vertical displacement and minimizing the chain growth it will give a good suspension system. The suspension that required both parameters, will maximizes both rider forward momentum and pedaling efficiency.

2.5 All-mountain bike rear suspension development

In this section the development of the rear suspension is detailed explained. Each of the explanation is described to achieve the objectives of this project. It is compose of improvement field, background, and summary of invention.

2.5.1 Field of Improvement

Presented improvement relates generally to bicycle, focus on all-mountain bike and more particularly to a rear suspension system which provides a good path wheel giving a high pedaling efficiency and producing a lower chainstay lengthening but still provides compliant suspension action that gave a comfort riding to the rider.

2.5.2 Background of Improvement

There is known that the previous design have a wide variety of mountain bike which include shock absorbing rear assemblies but somehow it is not properly functioning well. However, most of these have not proven entirely satisfactory in practice (B. Klassen, 1996). The shock absorbing rear assemblies of the prior art bicycles take on a wide variety of different configurations. In one commonly used configuration, the rear assemblies comprises a pair of chain stay, the front ends of which are pivotally connected to the main frame.

The back ends of the chain stays are attached to respective ones of a pair of drop-outs which accommodate the axle of the rear wheel. Also attached to respective ones of the drop-out are the bottom ends of a pair of seat stays or swing arms, the top ends of which are attached to respective ones end of a shock absorber. The end of the shock absorber opposite that attached to the swing arm is itself attached to portion of the main frame.

This bike is about to be have a dependent crank assembly which means it will be attachto the rear frame. Those prior art bicycles including shock absorbing rear assemblies possess certain deficiencies which detract from their overall utility. One such deficiency is attributable to the lack of efficiency in the transmission of energy from the rider to the wheel of the bicycle. This lack of efficiency occurs as a result of the crank assembly not being independently suspended relative to the main frame of the bicycle and rear assembly (J. S. Busby, 2000).

2.6 Shock absorber

Spring or damper is an essential element for rear suspension system which is known as shock absorber. The using of spring type, Figure 2.11, will allows the suspension to move up when the wheel encounters a bump and reacting quickly moving back down after the wheel passes the bump. But, if the suspension were equipped with just a spring, the MTB would have an uncontrollable handling, as it would bounce up and down for a several times after each bump. A suspension needs to dissipate the energy that stored in the spring when it compressed by a bump. So, it is good to use a device that is called damper that can dissipate the unwanted energy and keeps the suspension from bouncing out of control.

Figure 2.11: Spring type shock absorber

The most common type used is an oil-filled damper. Figure 2.12 shows the schematic diagram of the oil-filled damper. This type of damper usually used for car suspension as well as bike suspension. As the shock absorber is compressed, a piston inside it forces the oil to moving through a small hole, it is called an orifice (Horst, 1996). As energy applied it will be transferred to the fluid which passes through the orifice and by then this energy is converted to heat in the oil. These oil filled damper dissipate more energy and give more resistance to motion as it moving faster compressing the shock absorber.

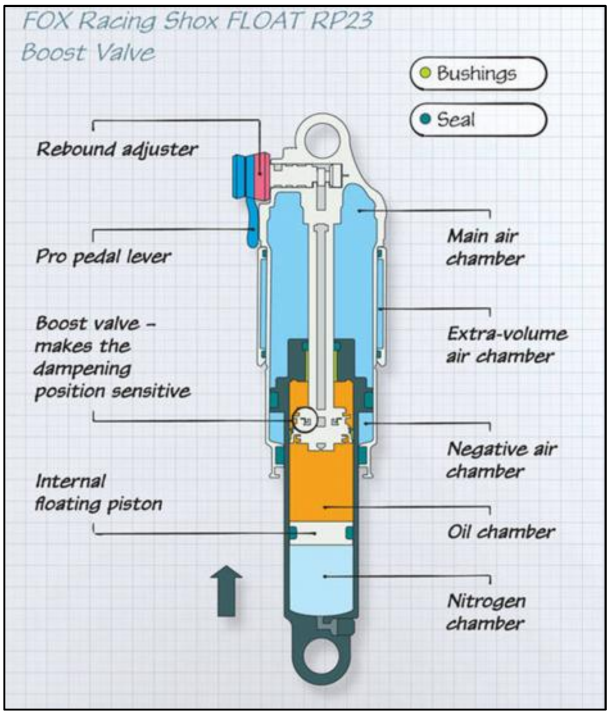

Figure 2.12: Schematic diagram of oil-filled damper

When the damper compresses faster, a greater volume of fluid has to flow through the orifice, so more pressure is required to force the fluid through. This increased flow does two things which are increases the stiffness of the suspension because the pressure resists the motion of the shock absorber and secondly it dissipates more energy.

2.7 Bearing

A bearing is one of the most important machine elements for mountain bike suspension system which constraint relative motion between some of moving parts to only desired motion. There many parts in mountain bike that using bearing such as bottom bracket, headset, pedals, pivot and hub. For this project bearing is considered important at bottom bracket and pivot only as the design is related to the main body frame and swing arm and pivot. A good choice bearing for rear suspension system will help the mechanism of movement being in fluent flow. The chosen bearing is considered three important element of its type of bearing, material and size.

Figure 2.13: Bearing sets

Figure 2.14: Bearings at upper pivot, GIANT Maestro MTB

Figure 2.15: Bearings at lower pivot, GIANT Maestro MTB

CHAPTER 3

METHODOLOGY

3.1 Flow Chart

Flow chart is an important method in order to make sure the project can be done on time with a proper project management. Based from the flow chart, Figure 3.0, the project started with the literature review on the project. Research was made throughout journals, webs, books and other related sources.

The design of the rear suspension is conducted after all the information about the project is gathered. The required parameters need to be defined as a design factor. Then, analyze the design using SolidWork, it based on the test that will be done. The fabrication start after design, analyze, materials selection and machine setup was prepared. After the fabrication is fully done, the suspension will run a test.

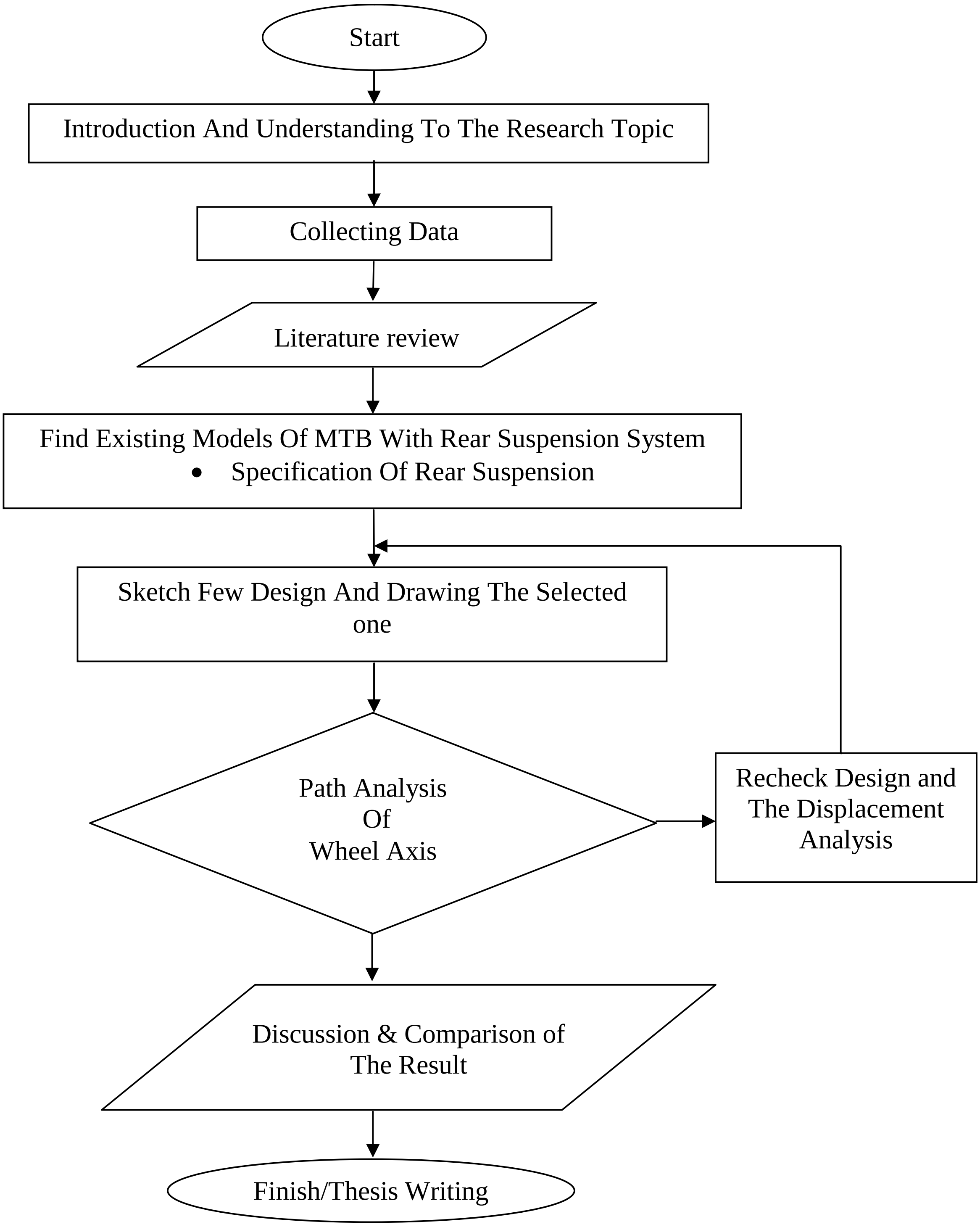

Figure 3.1: Flow chart that outlines the steps undertaken.

3.2 Flowchart Description

Figure 3.1 shows the research flow chart for every process that is needed to accomplish the project goals. At the early stage, the project starts with understanding the topic given then starts to determine the project scope and general background of the project. After that, the objective of the project is determined.

Next, the stages proceed by writing the literature review of the project. The sources of the information of the literature review came from the books, journal and research from the internet. By doing the literature review, it gives better understanding regarding to the project. Besides that, the data and the information from previous research and studies can be used to gain new idea and concept to be used in the project.

In this project, it starts with identifying the type of rear suspension. For this case, Malaysia is chosen for this research as the using of rear suspension for mountain bike among Malaysian cyclist is not well-popular. The model of the rear suspension system is chosen by considering about the following considerations such as the dimension, materials and the type of rear suspension. In this case, a monolink type rear suspension was chosen for development and geometry inovation.

After all the information regarding to the project already gathered, the presentation slide for Final Year Project 1 presentation is prepared. For instance, the residential building model, the climate data in tropical region, the buildings materials and other parameters that should be included for the analysis in this project.

Then, the next stage of methodology is continued with the Final Year Project 2 where the analysis of the rear suspension system for mountain bike by using the SolidWorks 2010 software. In this stage, the wheel axle path of the rear suspension will be analyzed then discuss and compared for further step.

3.3 Finding Current Design

According to the journal, book, article and some revision from the internet, there are various categories of rear suspension technology has been found, which are:

a) Mono link
b) Horst link
c) Soft tail
d) Hard tail
e) Single pivot
f) Virtual pivot
g) Four-bar
h) Unified rear triangle

These currently rear suspension finding is important as a revision to develop a new design that will achieve the objective of this project.

3.4 Draft/sketch New Design

A new develop design is sketch as a first step to identify and decide the shape, dimension and working mechanism of the new rear suspension. The sketch is either using a paper or simple drawing software which is Sketchbook Designer. The design consists of several type of MTB rear suspension system. After handling a survey among the cyclist enthusiastic around Malaysia, generating the concepts and make concepts evaluation, a Monolink type rear suspension is chosen for the development.

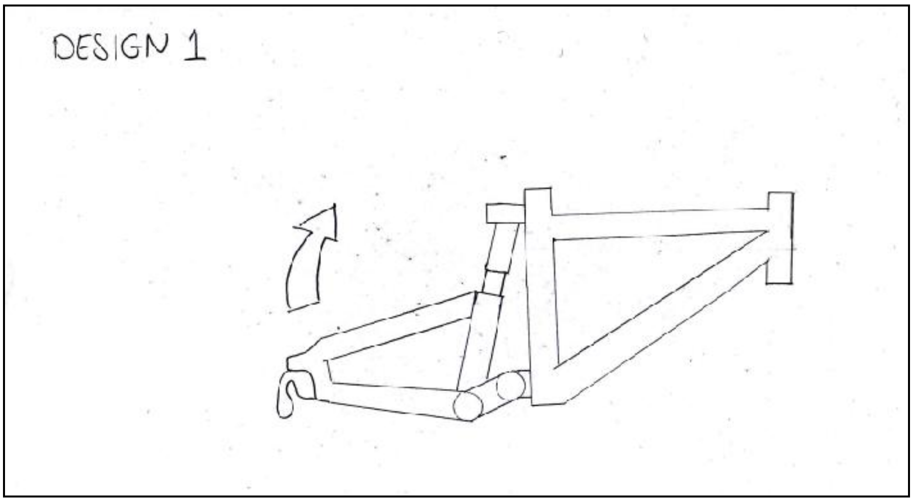

Figure 3.2: Sketch for design number one

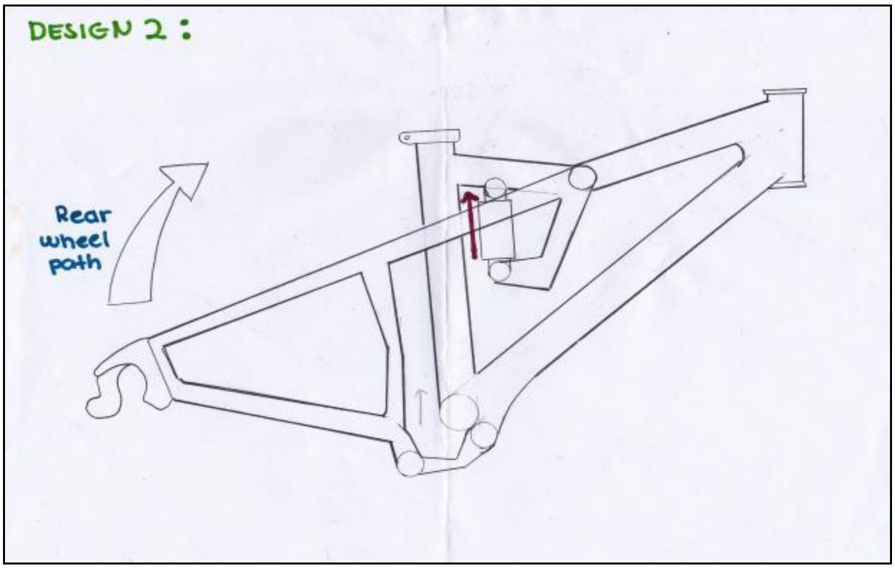

Figure 3.3: Sketch for design number two

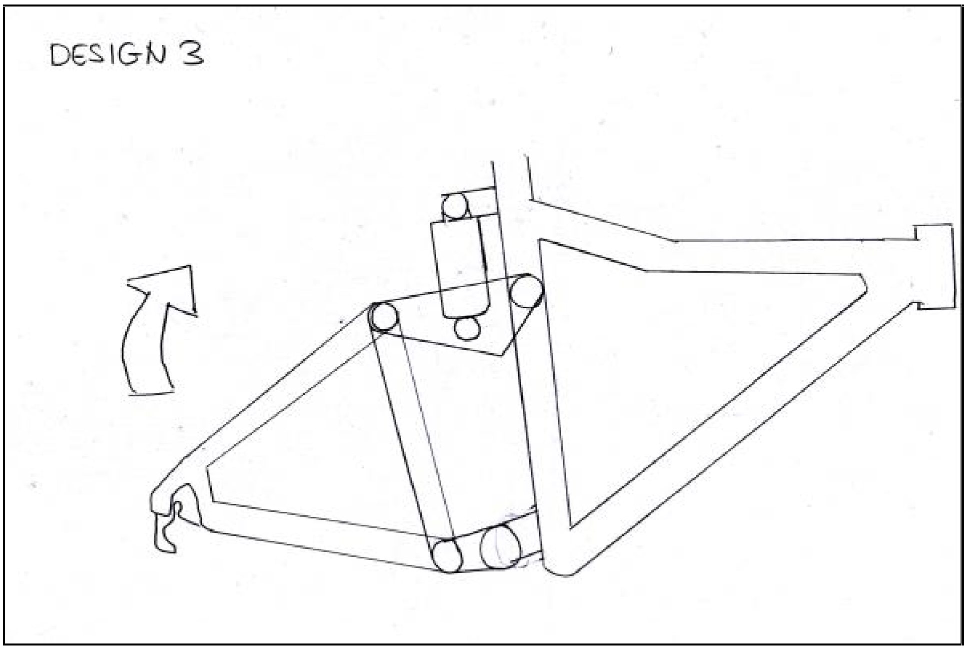

Figure 3.4: Sketch for design number three

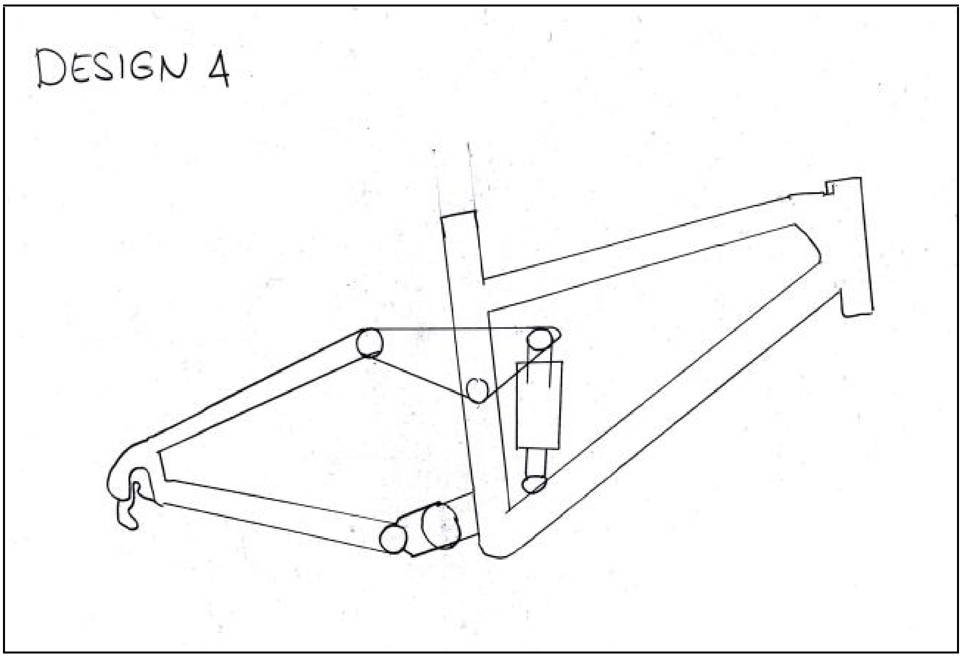

Figure 3.5: Sketch for design number four

3.5 Preparation of Rear Suspension System

The shape and dimension are decided, it is then proceed with the next step which is constructed the sketch into a rough 3D model. For this project, SolidWorks 2012 is used to accomplish the real shape of the rear suspension. Besides, by using SolidWorks 2012, it is able to applied simulation and then determine either the suspension is well functioning or not by using motion study application.

Figure 3.6: Side view

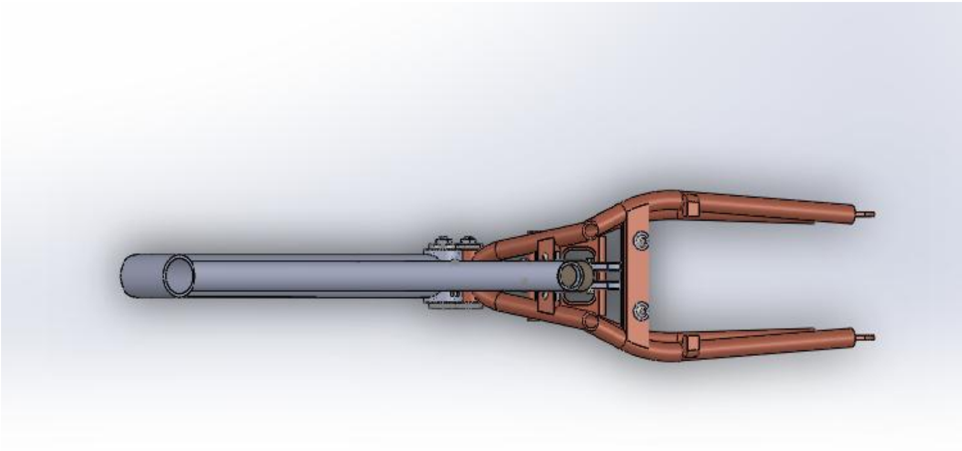

Figure 3.7: Plan view

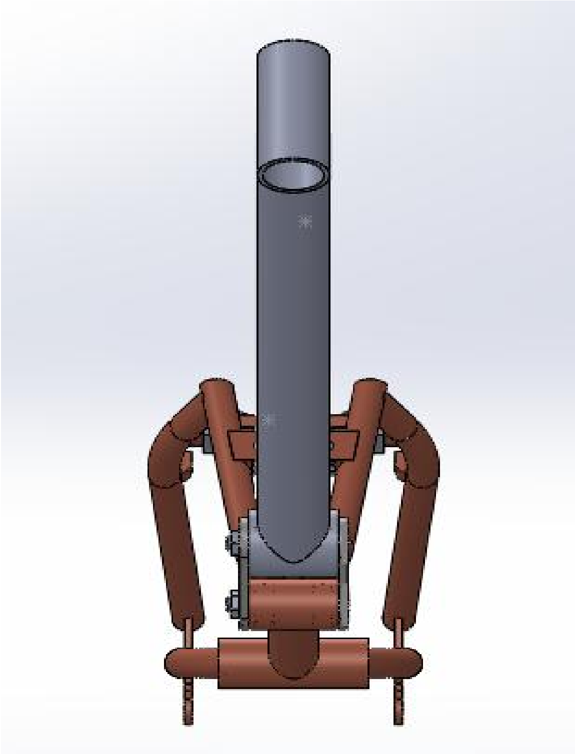

Figure 3.8: Front view

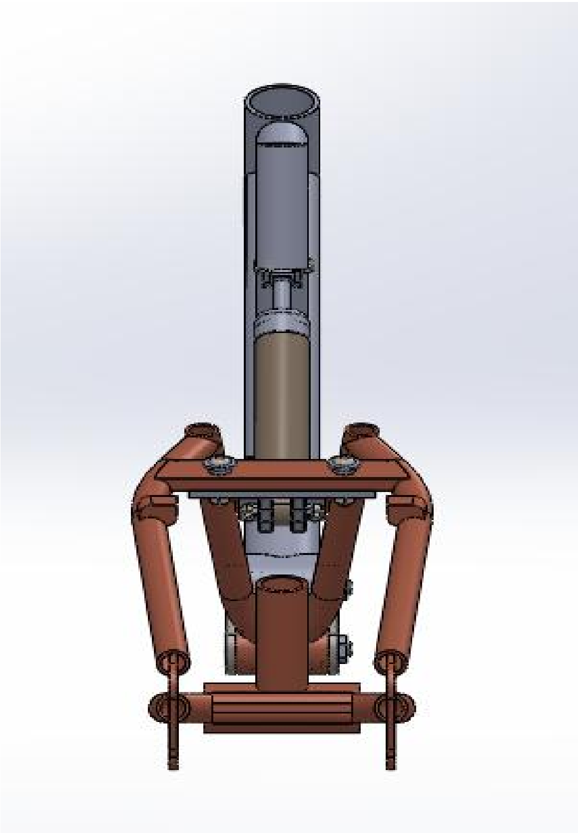

Figure 3.9: back view

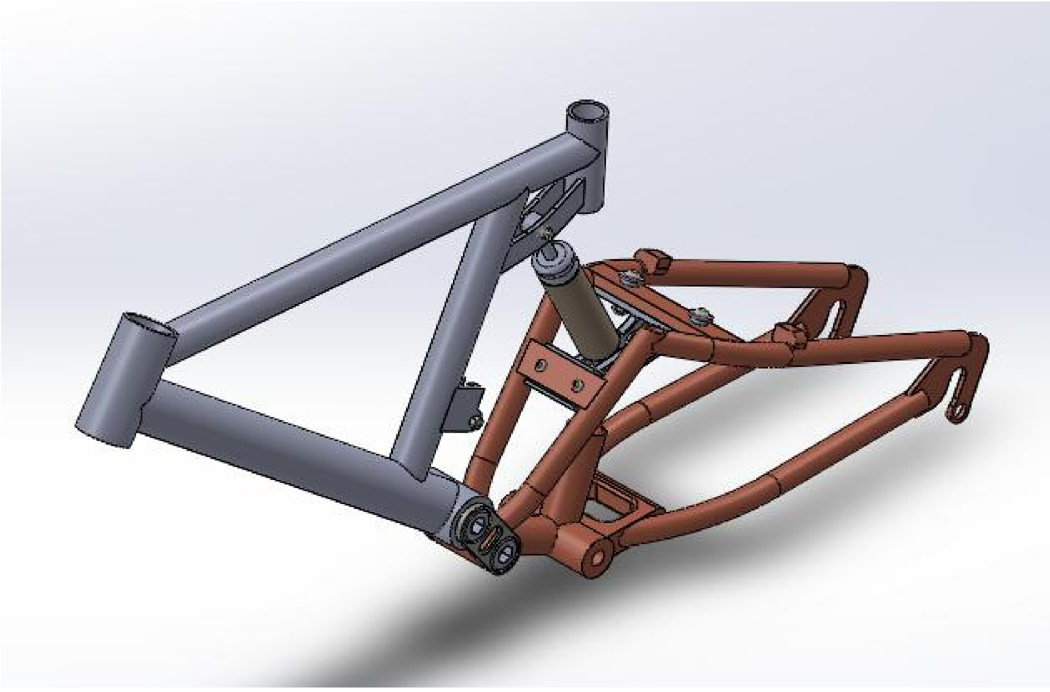

Figure 3.10: Trimetric view (front)

Figure 3.11: Trimetric view (back)

3.5.1 Developed Monolink Rear Suspension

This monolink rear suspension provides a system that is suitable to use for All mountain riding style bikes which allow a rear wheel to define a different trajectory according to the type of obstacles encountered by the rear wheel of the mountain bike. This bicycle composes of mainframe and a swing arm supporting a rear wheel axle about which a rear wheel may rotate. The rear wheel axle is allowed to move along various paths which have responded to vary shock forces exerted on the rear wheel. It will be placed in equilibrium position in the main frame.

There is provided a rear suspension system for a bicycle having a main frame and a swing arm, comprising a substantially rigid link which means it has first end portion pivotally connected to the main frame and a second opposite end portion pivotally connected to the swing arm. This part is also called as a Rocker which may be in any shape with the main function as the connector of the main frame and swing arm. For some full suspension MTB it have two part of rocker situated at lower and upper portion of the frame. While some others bike suspension do not have it as it pivotally connected directly to each other main frame and swing arm. Meanwhile there is a damper or spring that means adapted to cooperate those two parts for constricting the motions that occur between the main frame and swing arm to two independent directions as it travelling a bump or a garden of rock.

This design provided a rear suspension system for having a main frame and swing arm that is placed equilibrium position, enabling the rear suspension to have a two degree of freedom. Focus on the swing arm parts, for the first portion at the front it is connected to the rocker and the second portion at the back comprising a parts which a rear wheel may be mounted, it will supporting a rear wheel axle. This MTB frame also included a pedal crank set which assembly mounted to a lower portion of swing arm. This pedal crank set is situated behind the pivot that is connected to the Rocker.

This suspension system may have two degree of freedom. Moreover, it included a spring or damper extending between main frame and swing arm. The damper or spring adapted or deflection at least two partially independent directions. Specifically the first portion of the damper is set under the seat post while the other portion is connected to the upper parts of the swing arm.

3.5.2 Suspension

In general, most front and rear shock absorbing devices is composed of an elastic and a viscous element mounted in parallel as shown in figure 3.11. Mechanical properties of both elements are generally separately adjustable on most bicycles. The elastic element is made of a steel spring that can be pre-constrained at different levels or an air chamber that can be pre-inflated at varied pressures according to the nature of the terrain and the cyclist preference. The viscous element is generally made of a piston and cylinder chamber filled with oil. The oil travels through orifices made in the piston. The total size of the orifices may be adjusted to modify the damper viscosity. Some simpler and cheaper systems include an elastomer part that has both viscous and elastic properties. On some bicycles, the suspension system may be turned off through command in rigid mode.

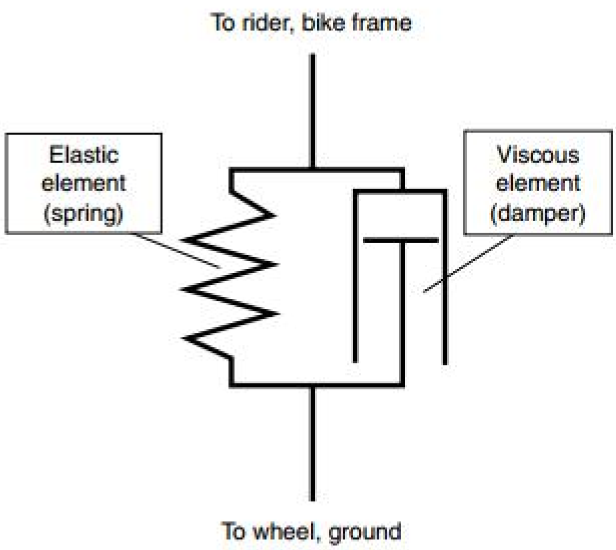

Figure 3.12: Components of shock absorbing device.

But usually most of the MTB that using have rear suspension system using oil-filled damper. So it is considered to use the oil filled damper in this new design of rear suspension.

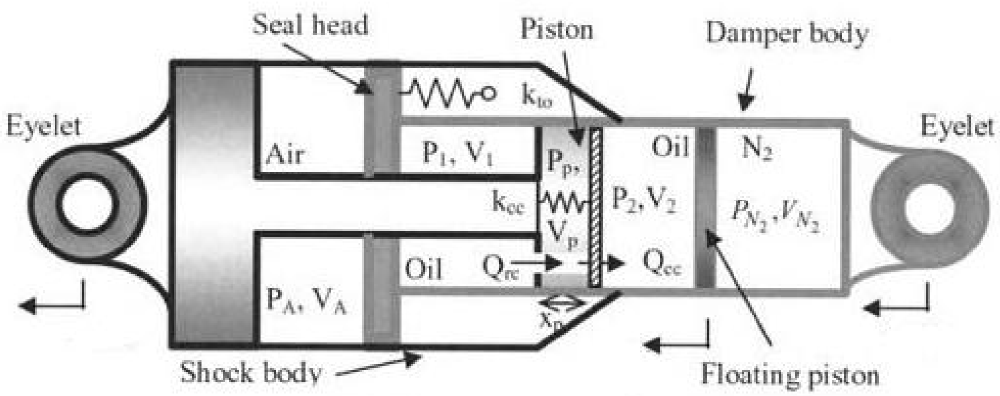

Figure 3.13: Cross section of oil filled damper

Based on figure 3.12, during compression, P_A increases as V_A is reduced, oil flows into the piston through the *cc* valve, Q_{cc} flows right to left. Q_{rc} also flows left as oil moves out of the piston through the parallel flow paths of the low speed compression port and the high speed relief valve. V_1 increases as V_2 and V_{N2} decrease. The pressurized nitrogen chamber is designed to prevent a vacuum from developing in Chamber 2, but the model does allow a vacuum to develop in chamber 1 under high compression speeds.

During rebound stroke, the motion of the damper body over the piston is reversed, and the speed is controlled by the oil flow rate through the rebound port, which then Q_{rc} flows to the right which is defined as positive. The rebound force is proportional to the square of Q_{rc}. Figure 3.13a shows the calculated rebound and low and high speed compression flow rates (Q_{rc}) through the piston resulting from various values of $P_1 - P_p$. Rebound flows are positive, while low and high speed compression flows are negative. Figure 3.13b shows the calculated value of Q_{cc} for various differences. This is flow through the compression initiation control valve. In this case $P_p - P_2$ of -4 atm is required before the *cc* valves opens, allowing significant relative motion between the damper body and the piston.

The force of the piston is related to the area of annulus, which is the difference between the piston and the rod area. The force from the base valve is related to the area of the rod only. Using the analysis of a free body diagram of a piston, the forces can be summed about the axial direction of the shock.

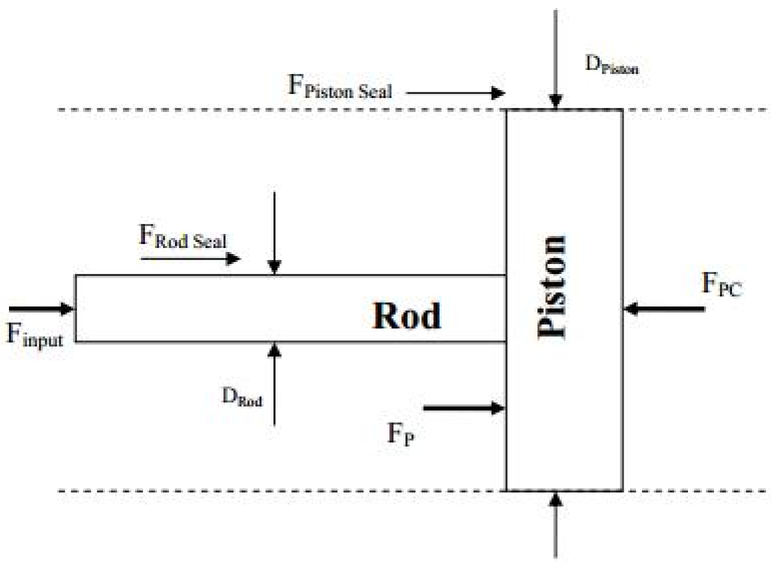

Figure 3.14: Free body diagram of piston and rod connection

$$\sum F_x = F_{input} + P_E(A_p - A_R) - P_c A_p - F_{gas} + F_{SF} = ma_x$$

From above equation, force that involved is the input force which is from the tire into the damper shaft, the pressure from the rebound and compression, P_E and P_C, and the combined force of friction from the sealing components. The mass of the piston is very small, so the acceleration component is unimportant. However as the input force changes, the extension and compression pressure change as well. Also note that there is a gas force due to the pressurization of the gas in the reservoir, leading the "gas spring force", $F = P_{gas} A_{R}$. The cross sectional areas of each piston and rod are calculated base on the dimension of FOX Suspension Float RP2 Rear Shock:

Figure 3.15: FOX Suspension Float RP2 Rear Shock

Piston: $A_p = (\pi D_p^2 / 4) = \pi(0.035)^2 / 4 = 9.621 \times 10^{-4}$ m

Rod: $A_R = (\pi D_R^2 / 4) = \pi(0.005)^2 / 4 = 1.963 \times 10^{-5}$ m

Annulus: $A_A = A_p - A_R = 9.424 \times 10^{-4}\ m^2$

Discussion on suspension rate, pairing a falling rate frame with a linear coil shock or an extremely rising rate frame with an air shock might not have acceptable results. Look at the most important considerations. All springs have "rates" and a suspension is just a type of spring. Define a coordinate x as the direction in which a spring compresses. The "spring rate" is a function of x, and describes the amount of force with which the spring will tend toward equilibrium at any point of compression or extension away from equilibrium. The steeper the rate function, the more a spring will resist additional movement the further it is moved from equilibrium. For a typical coil spring near equilibrium, the rate function is almost linear. If the rate function is concave up, then the spring has a rising rate, that is, the additional force needed to further compress the spring at each point will increase as the spring goes through its travel. If it is concave down, then the spring has a falling rate, with analogous results. Figure shows a graph with each type of rate.

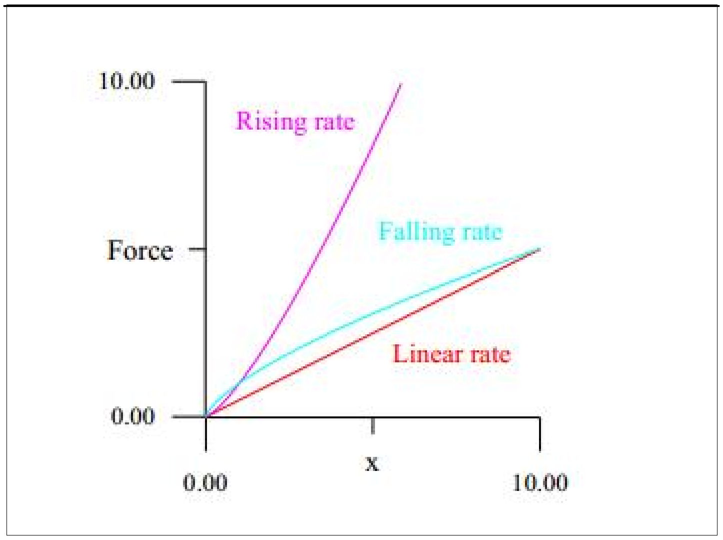

Figure 3.16: Suspension rate

The rate of a bicycle suspension is composed of the internal rate of the shock and the rate inherent in the suspension geometry. Internal shock rates range from near linear to rising. Coil springs tend to have more linear rates, while air springs tend to have rising rates. All frames may be fitted with a range of shocks, which these days generally have one of two lengths and standard mounts. Consideration on shocks will not be further, since it is not an inherent feature of frame geometry.

Establishing the main triangle as reference frame, the rear shock mount will travel a circular path around some pivot. The main pivot in the case of a mono-pivot and the upper frame pivot in the case of a 4-bar (our following statements will apply in both cases). If the tangent of the rear shock mount points near to the front shock mount as the suspension goes through its travel, then the relative movements of the shock mounts will have a neutral influence on suspension rate (by neutral its mean that, given a linear shock, the suspension rate will remain linear).

Figure shows a suspension member moving in the frame of the main triangle. As the suspension compresses, if the rear mount tangent is moving into alignment with the front mount, then the path will increase the rise (decrease the fall) in rate. If it is moving out of alignment with the front mount, then the path will decrease the rise (increase the fall) in rate. This is because for a given angle of rotation, the two shocks mount move towards each other the most when the rear mounts tangent is through the front mount.

If dealing with a mono-pivot, then the suspension member is the rear triangle and the rear connection will be to the rear axle. If there is a 4-bar, then the suspension member is the upper link and the rear connection will be to the rear link. In both cases, the larger the radius of the rear shock mount path, the larger will be the rate curvature due to geometry. Also, the longer the suspension member, the larger will be the magnification of the internal shock rate curvature, since the wheel will travel a greater distance for a given distance of rear shock travel.

This is most of the ballgame for a mono-pivot (minus only wheel path). For a 4-bar, one must do a similar analysis for the tangent of the upper rear pivot relative to the rear wheel axle. At any position in travel, if the tangent is pointing at the wheel axle, then the shock will compress least for a given amount of wheel travel. In most 4-bars this pivot has a path that will diminish the rate, and again, the larger the path radius of this pivot the larger will be the rate function curvature. The paths of the rear shock mount and upper rear pivot thus define the all over effect in a given 4-bar, minus wheel path.

3.7.3 Bearing

For most MTB that have rear suspension system may use a bearing at certain part. And it has been discuss in chapter 2. For this new design there are four points at the bike using bearing mostly at the lower rocker and shock absorber. The size, material and type of bearing are evaluated to ensure a suitable bearing is used in this mechanism of rear suspension movement. But for some reason, the used of bearing can be neglected as this project is about the development of geometry as main consideration that influence efficiency of pedalling. Below shows the calculation and evaluation of bearing should be choose at the crankset.

For the calculation of bearing, some parameter a made to be estimated that is a usual activity.

For estimations, when cyclist pedalling the value of each parameter would be as stated below;

Number of crankset rotate,	N_d = 200 rev/min
Life of crankset,	L_D = 50 000 hours
Radial load,	R_t = 5 KN
Axial load,	R_a = 2 KN

For the bearing,

Inner ring rotates,	v = 1
Commercial gearing,	a_f = 1.2

Then, choosing from the manufacturer that mostly use,

Rating life,	L_{10} = 1×10^6
	X_o = 0.02
	θ = 4.4599
	B = 1.48

From the drawing, it is scale 2, the actual diameter of bearing hole is 33mm, therefore the maximum diameter of the bearing hole is 66mm and the maximum wide is 20mm.

For a deep groove type bearing calculation:

- Choose, $F_a / C_o = 0.014$
- Calculate $F_a / VF_r = 2 / 1(5) = 0.4$
- $F_a / VF_r \leq e$

- From table 3.1, $X_1 = 1.00$

  $Y_1 = 0$

- $F_e = X_1 VF_r + Y_1 F_a = 5KN$
- $F_e = F_D$

Table 3.0: Calculation factor for single row deep groove ball bearings

Calculation factors for single row deep groove ball bearings

	Normal clearance			C3 clearance			C4 clearance		
$f_0 F_a/C_0$	e	X	Y	e	X	Y	e	X	Y
0,172	0,19	0,56	2,30	0,29	0,46	1,88	0,38	0,44	1,47
0,345	0,22	0,56	1,99	0,32	0,46	1,71	0,40	0,44	1,40
0,689	0,26	0,56	1,71	0,36	0,46	1,52	0,43	0,44	1,30
1,03	0,28	0,56	1,55	0,38	0,46	1,41	0,46	0,44	1,23
1,38	0,30	0,56	1,45	0,40	0,46	1,34	0,47	0,44	1,19
2,07	0,34	0,56	1,31	0,44	0,46	1,23	0,50	0,44	1,12
3,45	0,38	0,56	1,15	0,49	0,46	1,10	0,55	0,44	1,02
5,17	0,42	0,56	1,04	0,54	0,46	1,01	0,56	0,44	1,00
6,89	0,44	0,56	1,00	0,54	0,46	1,00	0,56	0,44	1,00

Intermediate values are obtained by linear interpolation

- $x_D = \frac{L}{L_{10}} = \frac{L_D n_D 60}{L_{10}} = \frac{50000(200)60}{1 \times 10^6} = 60$
- $C_{10} = a_f F_D [\frac{x_D}{xo+(\theta - x_o)(1-R_D)^{\frac{1}{b}}}]^{1/a}$
- a= 3 becouse of deep grove ball bearing
- C_{10} = 23.81
- Range OD = 72-62, B = 35 – 30
- The same for angular ball bearing

because $\frac{F_a}{VF_r} \leq e$

Than repeat for cylindrical and tapered roller,

- $C_{10} = a_f F_D [\frac{x_D}{xo+(\theta - x_o)(1-R_D)^{\frac{1}{b}}}]^{1/a}$
- a= 10/3 for cylindrical and tapered roller bearing
- C_{10} = 20.75

Compared the value of C_{10} between the four types of bearing:

Table 3.1: Value of C_{10}

Types of bearing	**C_{10}**
Deep Groove	23.81
Angular Bearing	23.81
02 Series	20.75
03 Series	20.75

Compared all bearing:

Table 3.2: Comparison of bearing

	Deep Groove	Angular Contact	02 Series	03 Series
OD	76-62	76-62	65-52	62
B	30-35	30-35	30-35	25
W	16-17	16-17	15-16	15

All bearing except 03 series met the specifications of the desired bearing size which is the maximum diameter of the bearing hole is 66mm, and the maximum width is 20mm and the applicable bore size is 30 to 35. Conclusion, the desired max OD has to be 66mm, max B = 36mm, max W = 20mm and C_{10} = 23.81. The desired bearing can be taken from SKF for angular contact ball bearing single row.

3.6 Aluminium Alloy

The material that has been selected for this project is aluminum alloy which is commonly used to make mountain bike. The properties of the aluminum alloy AA7005 are shown in Table 3.3. Aluminum alloy is a lighter material and suitable for the fabrication of this suspension. There will be two separate aluminum alloy which is the plate that used for the fabrication of the pivot estimated size 30 x 30 x 1 cm. The other aluminum alloy is in a rod shape that used for the fabrication of rear arm with estimated size 400 cm long and diameter of 3 cm.

Table 3.3: Aluminum Alloy AA7005 properties.

Chemical composition	
Aluminum Alloy	**Al: 93.3%, Mn: 0.45%, Mg: 1.4%, Cr: 0.13%, Zn: 4.5%, Ti: 0.04%, Zr: 0.14%**
Mechanical properties	
Density (Kg/m^3)	**2.6 – 2.8**
Elastic Modulus (GPa)	**70 – 80**
Tensile Strength (MPa)	**193**
Yield Strength (MPa)	**83**
Elongation (%)	**20**
Shear Strength(MPa)	**117**
Fatigue Strength (MPa)	**140**

3.7 Displacement of Rear Suspension

A qualitative method known as Path Analysis is used for analyzing the pedaling, braking, and shock absorption characteristics of full suspension frames. The main objective is to allow anyone to determine the true benefit or ability of the suspension design claims. From the research, most of the theories on bicycle suspension attempt to find the proper pivot points which make the frame shock non-reactive to pedaling at equilibrium or known as sag. A precise quantitative treatment of suspension geometries is a very involved process that requires significant assumptions, even in the most simple of cases. A number of simple theories purport to find correct geometries that eliminate rear shock activation at sag.

In order to have a better understanding about this analysis, once have to know first the terms that use to give an explanation such as reference frames, degree of freedom, center of mass, coaxial condition and instant center. In order to analyze any physical situation, a reference frame must be created. This is usually represented by of a set of coordinates in space, consisting of a mutually perpendicular set of lines, or axes, with common intersection. The place where the axes cross defines the origin, or zero point. It is usually give names to each axis, such as “x-axis” or “y-axis”. Depending on the sort of information in which are interested, coordinates could consist of one, two, three, or even more axes.

Each degree of freedom denotes an independent way in which a body can move. A completely free body has six degrees of freedom. Given standard rectangular coordinates, a free body can translate in any of the three coordinate directions and it can rotate around the three coordinate directions. For the present design of frame give two degree of freedom suspension system. The CM of a solid body, or system of bodies, is the weighted average, spatial distribution of all mass in the system. For example, the CM of a symmetric object, such as a wheel, is at the center or axle. For us, the most important fact regarding the center of mass is that a force applied to any part of the body will cause a parallel acceleration at the center of mass. For example, a force applied to a wheel somewhere along its radius, in the plane of the wheel, will cause acceleration at the axle parallel to the force. For a wheel in free space, this means that the wheel will start translating in the direction of the external force, as well as rotating.

If a wheel or a crank is mounted coaxially to a pivot in some mechanism, it does not matter how the object is mounted physically. In a bicycle, the rear wheel could be physically mounted to the seat stay or chain stay, and the crank could be mounted to the main triangle or the seat stay. The physical situation will be the same in all cases as long as the specified objects and pivots are coaxial or also can be called as equilibrium.

For understanding about IC, imagine a mechanism that has two rigid components. Two rigid arms, attached to the components by pivots, connect these two component sides. An example would be a 4-bar suspension linkage. In this case, one component could be the main triangle and the other the rear link. Next, fix a reference frame to the first component, which in our example is the main triangle. At any given time when the arms and the other component (rear link) move about the main triangle, the path tangents for is calculated all points in motion on these objects by constructing the IC. Draw lines through the two pivots on either side of each arm. If the arms are linear structures, then the axes will determine our lines. The point where the two lines cross is the IC. The path tangent of any point in motion is perpendicular to the line between the IC and the point.

Figures 3.17, 3.18, and 3.19 below are three examples from another research of rear wheel axle path for existing rear suspension consists of single pivot, virtual pivot and four bar link.

Figure 3.17: rear wheel path of single pivot suspension

Figure 3.18: rear wheel path of virtual pivot suspension

Figure 3.19: rear wheel path of four bar link suspension

Each of these types of rear suspension show the movement of the wheel path is either to be in horizontal and vertical travelled, logically it will be consider both of the path as the wheel is about to turn around the pivot. But each of it did not show a great amount of horizontal displacement throughout vertical travel. A good rear suspension system have to covered a great horizontal displacement as the more wheel moves up and back throughout the wheel path, the more control and speed could be maintained by the rider.

Next is the chain growth result for these three rear suspension. Chain growth is the lengthening of the chain. Chain growth affect by the lengthening of the chain stay. Chain stay lengthening refers to the increase in distance between the bottom bracket and the wheel axle which occurs as a suspension is compressed. In a suspension system which causes the chain stay length to increase when the wheel is moved vertically, a downward force will develop on the wheel (B. Klassen, 1996). Each of this suspension system show an excessive lengthening of chainstay causes its chain growth to elongate in a high value. By then, it will causes the bike controlled by the cyclist to be less and affected the speed while it moving through a rough surface.

In order to study this wheel path, the developed rear suspension is being analyzed using a SolidWork 2012. A motion study is applied to the complete drawing of the suspension system. A force is set up to know the result.

Figure 3.20: chain growth for single pivot rear suspension

Figure 3.21: chain growth for virtual pivot rear suspension

Figure 3.22: chain growth for four bar link rear suspension

CHAPTER 4

RESULT AND DISCUSSIONS

4.1 Rear suspension reaction

In mountain bike sport, there many kind of rear suspension system that consists various type of geometry. One of it is Monolink type rear suspension which direct connecting the swing arm and damper to the main frame with any upper pivot. This type of suspension directly transfer the force exerted from the uneven ground.

To develop the rear suspension, an analysis setup is very important to collect the data from the rear suspension response. Without this data, there will be no source a comparison for the mechanism obtained from the rear suspension actual motion.

That is why obtained result from the analysis is included to show the motion of the rear wheel axle development process. Even this data is not helping in fabrication process, but it will help so much in the validation process.

Result obtained by averaging the force exerted and wheel axle travelled and the result is for every 25 kN of force exerted the suspension will result of 6.25cm wheel travelled. This result was compared with simulation from previous study that obtained 11.6cm of wheel axle travelled from 40 kN of applied force (D. Lam, 2005). So the analysis result was validated.

Above diagram is a setup of simulation by using a GIANT maestro rear suspension system and in the simulation, the wheel axle shows a small travelled displacement. Same like the new developed rear suspension analysis. So this data is very useful to choose a right geometry to apply for the connection between rear suspension and main frame.

4.2 Damper reaction

For rear suspension displacement, this type of system have a motion of two degree freedom which mean it travels in two axis, *X* and *Y*. rear suspension damper has very stiff damper that could hold up a great force but it is depend on frequent of tire hitting a bump or rock. No size of bump or rock was recorded in this study.

So for best result of high activity damper motion, an analysis is done to show the mechanisms. Using 10 different value of force, it will show the displacement travelled by two different types of damper which is spring and oil-filled, to perform an uneven ground surface as it use for all-mountain bike riding style.

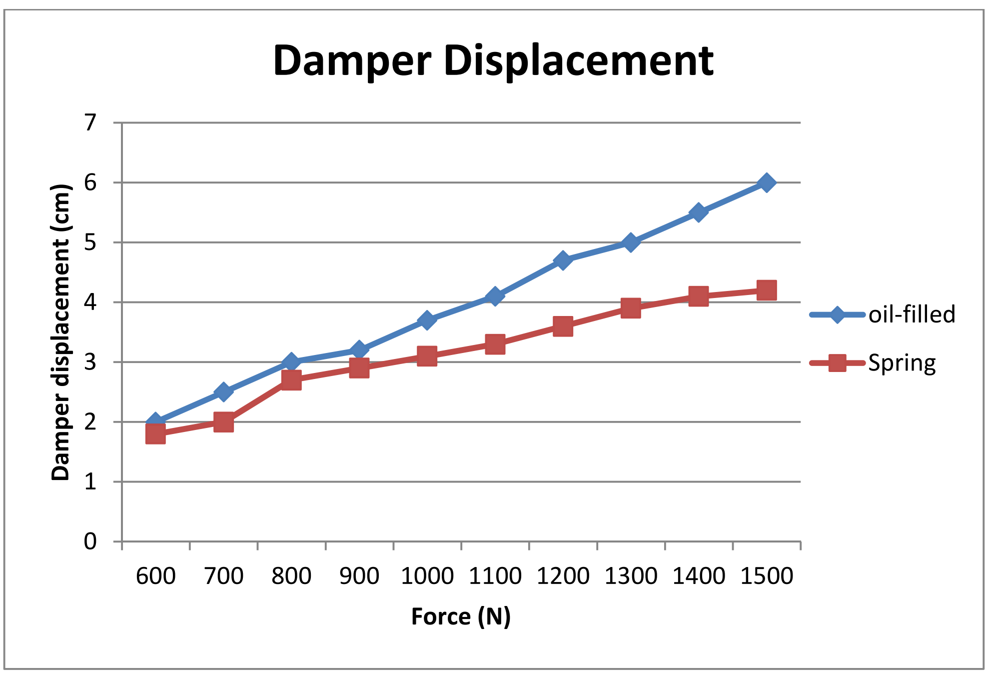

Figure 4.1: Damper displacement.

Figure 4.1 show the maximum displacement of the damper will be 6cm horizontal travelled which is the oil-filled type damper, with force from 600-1500 kN value of force applied. While a spring shock absorber maximum displacement is 4.2 cm, a total difference of 1.8 cm. This means when the oil-filled damper is used as it can absorb and support the force exerted. This data is helping to choose a suitable damper to imitate same reaction for Monolink rear suspension. Calculation for the horizontal travelled of damper has been shown in chapter three.

4.3 Rear suspension design

From the drawing the bicycle frame constructed to incorporate the two degree of freedom bicycle rear suspension. The main frame is formed of a cross bar or top tube and down tube joined at first ends by a head tube and at second end portion by a spring tube. A lower end of the spring tube is received within a substantially cylindrical sleeve extending upwardly at an angle from lower end portion of the down tube. A seat tube is provided at the rear end of the top tube for receiving a seat post.

The swing arm essentially comprises a pair of pivot front tubes having upper end. Extending from the lower ends of the pivot front tubes is a lower pivot mount which is provided at an apposed end with an axle receiving bracket defining a bore extending axially for receiving a bottom bracket axle of a pedal crank set assembly of the bicycle.

Extending from the rear side of the axle receiving bracket is a chain stay. A rear wheel axle dropout bracket connects the rear end of each spring stay member. The dropout brackets are adapted to receive between the axles of the rear wheel. The rear axle dropout brackets are disposed on opposed sides of the swing arm between the spring stay members and the chain stay members.

The lower ends of the pivot front tubes are rigidly connected to each other by are rigidly connected to one another by welded connection. The two degree of freedom bicycle rear suspension includes a pair of parallel rigid links which are pivotally mounted at respective first end to a lower end portion of the down tube for rotation about a first rotation axis and at a respective second end to opposed ends of the transversal member for rotation about a common second pivot axis. The swing arm is also connected to the main frame via damper or spring.

By having two independent pivots with one pivot being disposed on the main frame and the other pivot on the swing arm, a rear suspension having two degree of freedom is obtained. This connection between main frame and swing arm allows the rear wheel to reduce the component of the impact speed in the moving direction of the bicycle normally axis X, while allowing for the rear for the rear wheel to displaced in an independent direction perpendicular to the moving direction to the bicycle, basically axis Y when the rear wheel encounter a bump, a garden of rock or any other obstacles. As the rear wheel may be displaced in the plane X-Y, the rear suspension is not affected by the position of axis H of the bicycle relative to the direction of the force applied to the rear wheel. Therefore in the event that the principal axis H of the bicycle is not perpendicular to the shock force exerted on the rear wheel. The rear suspension will perform as well as when the axis H is perpendicular to the direction of the shock force.

The relative position of the two pivots is optimal when the axis extending through the center pivot at the main frame and pivot at swing arm is perpendicular to the axis extending through the center of the front and rear wheels of the bicycle. The efficiency of the bicycle rear suspension reduces as the axis extending through the center of the two pivots becomes parallel to the axis extending through the center of the rear and front wheels. According to the drawing, the two degrees of freedom rear suspension is provided with a damper provides a shock absorbing unit to absorb the various impact forces communicated to the rear wheel of the bicycle.

The damper comprises a cylinder having a reciprocating piston extending axially and outwardly from an upper end. The piston of the damper extends through a longitudinal slot. The upper end of the piston is pivotally connected to a mounting bracket extending between the lower end portion of the seat tube and the spring tube. While the lower end of the damper is pivotally connected to a mounting bracket secured at a center upper part of the swing arm. Accordingly, the damper is adapted to convert the energy of the shock force applied to the rear wheel of the bicycle into stresses within itself such as to significantly reduce the oscillation of the swing arm and to control the amplitude of the motion of the rear wheel.

It is understood that the other shock absorber systems may be used as long as they allow for displacement along two independent or partially independent or partially independent axes. Typically, a shock absorber system having two independent axes will include at least a spring unit, such as a coil spring and appropriate damping unit, whereas a shock absorber system having two partially independent axes.

Specifically referring to the drawing, it can be seen that the first pivot is located on the main frame, while the second pivot is located on the swing arm. The first and second pivots allow for the rear wheel axle WA to travel along two independent direction, for example according to two degrees of freedom, in an area or envelope delimited between a first circle OC having for center the first pivot and a radius R+1 and the second concentric circle of radius R-1, where R corresponds to the distance between the second pivot and the axle WA of the rear wheel and 1 to the distance between the first and second pivots. The second pivot may be displaced along a circular path 1 around the first pivot. The rear wheel axle WA may be displaced along a circular path around the second pivot.

The linear combination of the two rotational movement permit an infinite number of rear wheel axle WA trajectories within the area delimited by the difference between the inner surfaces OC and IC. Furthermore, the area accessible by the rear wheel WA will be limited by the maximal amplitude of the damper, as represented by the square area in the drawing. the intersection of the area OC-IC with the square area determines the accessible area within which the rear wheel axle WA may move. Figures show an example of a possible trajectory of the rear wheel WA when the rear wheel encounters an obstacle.

Although a plurality of pivot locations is possible to enable the rear wheel axle WA to be displaced in a plane in response to a shock force applied to the rear wheel, it is understood that some special configurations and locations are preferable to achieve the full benefit of the suspension and to provide increased torsion rigidity.

4.4 Simulation of rear suspension.

Force exerted to the rear suspension is greater than it should (4000 N compared to 2000 N). As weight is expected to be maximum of 200 Kg (2000N) for all-mountain cyclist, then addition of 200N for the force that exerted by the rear tire when hit a bump, travelling through a rock or fall from a high position. That is why the force applied is greater than it should be. Simulation proved that model analysis can imitate a real rear suspension response. Simulation was done using SolidWork 2012/2013 software. Analysis setting is shown in methodology.

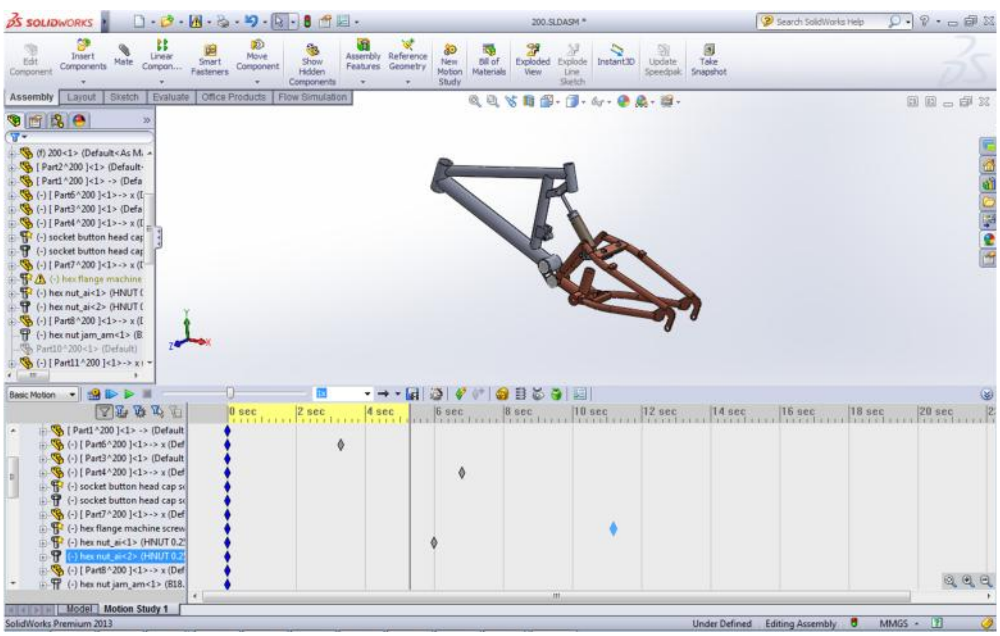

Figure 4.2 : method of displacement calculation

Figure 4.2 show method of displacement calculation by using SolidWork software. It is calculated from starting point, origin of wheel axle position until the maximum displacement it can travelled with the force that has been set. The force applied is shown in Figure 4.3. The blue arrow show a force that come from human body weight. While the green arrow show a force that come from uneven ground surfaces.

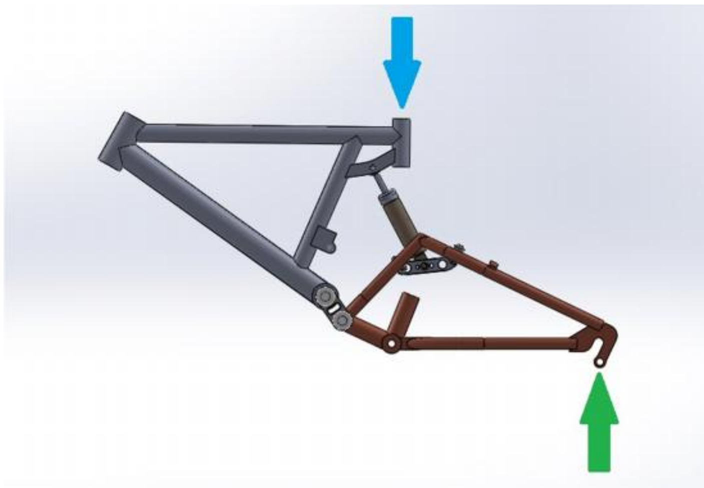

FIGURE 4.3: Force applied.

4.5 Path analysis result

This path analysis shown the different of WA travelled between developed and existing rear suspension. This path analysis gave the result of total x and y displacement of WA and the chain stay lengthening. Refer to the figure below from graph is shown the displacement of horizontal throughout vertical travel of WA.

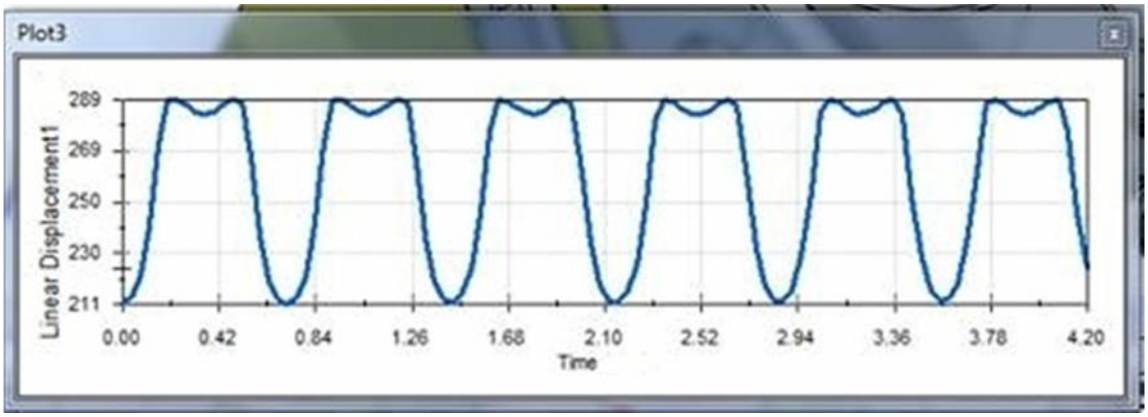

FIGURE 4.4: Displacement of developed rear suspension (mm/s)

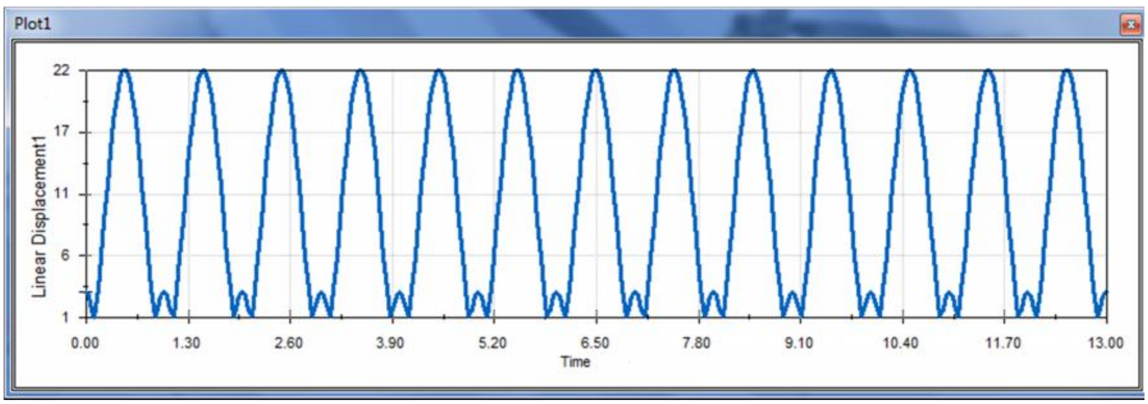

FIGURE 4.5: Displacement of existing rear suspension (cm/s)

From the graph it is shown that displacement of the WA of developed and existing (GIANT MAESTRO) rear suspension. Both suspensions were applied with same force.

Developed suspension show higher maximum horizontal travelled which is 289 mm, while for the existing suspension is 220 mm only. It is important to design a rear suspension that demonstrates the greatest amount of horizontal displacement throughout its vertical travel in order to improve or increase the pedal efficiency (B. Klassen, 1996).

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

This rear suspension will be able to perform a full complete suspension activity when the cyclist hit a bump or crossing through a garden of rock. The WA travelling path is a parameter that indicates whether the rear suspension has performs a good suspension or not.

WA travel from the starting point to maximum displacement was successfully recorded and analyzed. Without this data, the movement or reaction of the rear suspension resulting from the rough course travelled would not been known.

The existing rear suspension (GIANT Maestro) shown a small displacement value which is 220 mm. While the developed monolink rear suspension shown a bigger number of displacement, 289 mm. The monolink rear suspension give a great absorption of force applied compared to the existing rear suspension. It demonstrates the greatest amount of horizontal displacement throughout its vertical travel. By then it improve and increase the pedal efficiency.

5.2 Recommmendations

1. There were some recommendations for further studies in building a real complete model Rear suspension for stress, strain and fatigue experimental setup. First of all is the material selection. For all-mountain riding style bike, it usually travel a rough course so a right material should be choose as it have to takes many high impact. Aluminum 7000 or 6000 series would be a good choice.
2. A simulation result not always similar with the real experiment. If simulation is not helping, so trial and error method should be used.
3. About the damper, if it connected in a right way, it will be able to withstand a great force and can be used to record the data.
4. Overall dimension for this rear suspension system is not properly constructed. If the dimensions of each part are improved, it will be able to have great mechanisms.
5. The angle of connection between the main frame and damper should be test with different value, so that travelled path of WA can be chose either to have a horizontal or vertical priority.

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