TECHNICAL UNIVERSITY OF MOMBASA

SCHOOL OF ENGINEERING AND TECHNOLOGY

DEPARTMENT OF MECHANICAL AND AUTOMOTIVE ENGINEERING

BACHELOR OF SCIENCE IN MECHANICAL ENGINEERING

<u>PROJECT TITLE:</u>

DESIGN OF A COMPACT RETRACTABLE STAIRCASE FOR PUBLIC TRANSPORT BUSES

FINAL YEAR PROJECT

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DECLARATION

We, Mark Karugu and Oganda Brian, hereby declare that this project and the work presented within it is original. It was prepared from an engineering perspective acquired while pursuing our Bachelor of Science in Mechanical Engineering degree. Apart from the information gained from experience in the engineering field, the information was sourced from notes and relevant publications which we have appropriately referenced.

We can thus confirm that this project has not been presented in this or any other university or institution for examination.

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SUPERVISOR'S CONFIRMATION

This project has been submitted to the Department of Mechanical Engineering at the Technical University of Mombasa, with my approval as the supervisor.

Name: Gerald Mang'eni

Signature:

Date:

ACKNOWLEDGEMENTS

We extend our sincere thanks to our project supervisor, Mr. Gerald Mang'eni, for his belief and support during the development of this project. We also appreciate the entire Department of Mechanical and Automotive engineering and Technical University of Mombasa as a whole, for providing us with the facilities to carry out our research and development of the project as partial fulfillment of our Degree requirement.

We greatly recognize and thank the authors of the reference material we used to develop this project for offering a broad perspective of the project and its components.

We also thank our parents and families for their unconditional support financially, spiritually and morally throughout the project preparation period.

Last but definitely not least, we thank our esteemed panel and more so the project coordinator, Prof J.F. Kanyua for their selfless sacrifice of time to oversee and consider our project.

ABSTRACT

There are places where construction of fixed staircases to bridge vertical distances is impossible due to space limitation and varying elevation conditions. With this problem in mind, we took the challenge and proceeded to design a compact retractable scissor staircase. The design procedure took into account our area of application and the challenges present that should be considered. Here, we go through the process and requirements for the construction of the retractable staircase and also the mathematical analysis of the mechanism.

The force required for the translational actuation of the mechanism is provided by a double acting pneumatic cylinder by means of the slider and crank mechanism. We have designed an appropriate model for our case study and thus we have presented a practical solution that is simple and implementable.

LIST OF SYMBOLS

ϕ - Phi

π – Pi

E – Young's modulus of elasticity.

I – Moment of inertia

K – Radius of gyration

σ_c - Hoop stress

σ_l – Longitudinal stress

τ – Shear stress

Σ – Sigma

LIST OF ABBREVIATIONS

i.e. – id est.

DCV – Directional control valve.

IC – Internal combustion.

CFM – Cubic Feet per Minute.

FBD – Free Body Diagram.

SFD – Shear Force Diagram.

BMD – Bending Moments Diagram.

Contents

1.0 CHAPTER ONE: INTRODUCTION

1.1.0 STAIRCASE

A staircase is a construction designed to bridge a large vertical distance by dividing it into smaller vertical distances called steps.

Special types include; escalators, ladders, foldable stairs and retractable scissor stairs.

We have chosen to focus primarily on retractable scissor stairs.

1.1.1 Foldable Scissor Stairs

In places where there is not enough space for a fixed stair, a foldable stair mechanism can be used.

Scissor like elements formed by a four bar linkage form the foldable stair mechanism. The links are connected using revolute joints. A slider and crank mechanism is used as the load input mechanism, with the crank acting as the input link for the four bar mechanism. The motion of the connecting rod is transferred to the crank which pushes the coupler forward which causes the vertical links to move unfolding into a vertical and horizontal arrangement which makes up the staircase/steps.

1.2.0 THEORY

1.2.1 Scissor Stairs

Scissor stairs consist of linked folding supports in a crisscross pattern. Its extension is achieved by applying pressure to the outside on a set of supports located at one end of the mechanism elongating the crisscross pattern. This is achieved by either mechanical, hydraulic or pneumatic means. This folding scissor staircase depends on this knowledge on its operation.

1.2.2 Pneumatics.

Pneumatics dates back to the early 17th century from the Latin word *pneumaticus* meaning air or wind. Pneumatics involves the use of compressed air in an industrial setting to produce mechanical motion. This process is applied in a foldable scissor staircase with the use of air pressure action on a piston in a pneumatic cylinder to produce linear motion facilitating the folding and unfolding mechanism instead of manpower i.e. hand. This greatly reduces occupational risks. Since the air used is readily available in surplus amounts from our atmosphere, it is inexpensive and efficient. The compressed air is channeled through transmission lines(pipes) to the pneumatic cylinder's cavity to push the piston causing a mechanical motion to push open the scissor staircase. Retraction causes folding of the staircase back. This is achieved by the use of a double-acting cylinder.

1.2.3 Hydraulics

Hydraulics date back to the late 1700s, when a British mechanic and engineer Joseph Bramah began working on practical applications of Pascal's principle developed by a French mathematician Blaise Pascal. Hydraulic systems are made up of four main components; **the reservoir** where the liquid is held, **the pump** which applies mechanical energy into the system by moving the fluid in the reservoir, **valves** that are used to start and stop the system and direct where the fluid moves and **actuators** that takes the generated hydraulic energy and converts back to mechanical energy for use.

1.3.0 OVERALL OBJECTIVE

Develop a foldable scissor staircase that is efficient and safe in operation.

1.3.1 Specific Objectives

- Design a system that is simple and functional.
- Design a system with minimum operational cost.
- Design a system that will allow good maintenance practices.
- Develop a space efficient design.
- Develop an appropriate model.

1.4.0 PROBLEM STATEMENT

Moving a body or loads over large vertical elevations requires a lot of energy in terms of human power which is often insufficient. This archaic method of lifting poses a big risk of if dropped. In as much as fixed stairs may be suitable for such applications, specific places do not have enough space for the fixed staircase. In a field study done at Mwembe Tayari bus station, it was distressing to see old people, children and pregnant women struggle to board and alight from the buses due to the elevation of the floor platform. Truck drivers also have a hard time climbing to their cabins since they are greatly raised to accommodate the engine.

1.5.0 ASSUMPTIONS

- Fluids have no shape of their own and flow to acquire the shape of their container.
- Gases can be considered compressible at pressures used in pneumatic systems.

- Flow rate of compressed air depends on the pressure gauge reading.
- Any flow of the air through a transmission line is accompanied by a reduction in fluid pressure.

1.6.0 SIGNIFICANCE AND MOTIVATION OF STUDY

- Practical application of skills learnt in class in approaching a problem.
- Using pneumatics technology, this project will solve occupational hazards.
- It is a partial fulfillment of the requirements for Degree in Bachelor of Science in Mechanical and Automotive Engineering.

2.0 CHAPTER TWO: METHODOLOGY

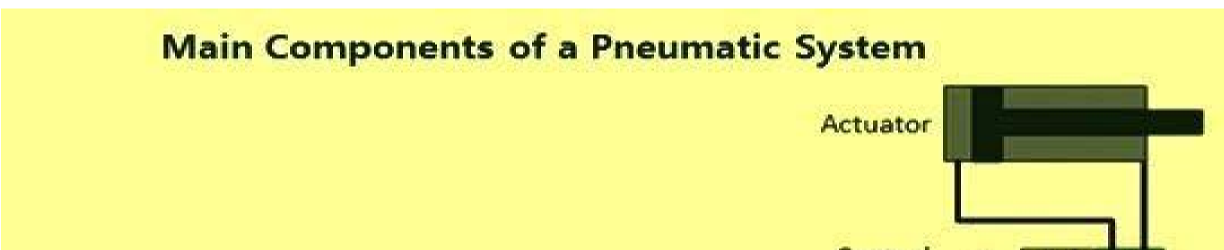
2.1.0 LITERATURE REVIEW OR SURVEY

Technological advancement has led to improvement in almost all spheres of life. The desire towards this technological and scientific advancement has come up with many world dynamics. Since past up to date, scientists and engineers have done a lot of work in line with retractable stairs. There are many constructions that have been used to achieve the desired results. A review of some work gives the design and construction of a retractable scissor staircase, commonly known as foldable stairs. Before looking at specific subjects of this project, a broader perspective of pneumatic and scissor mechanism should be considered.

2.2.0 PNEUMATIC CIRCUITS

The circuit composes of the following components;

- Active components(compressor).
- Transmission lines (pneumatic hoses, valves and air reservoir).
- Passive components (pneumatic cylinder, service unit).
- Filters, regulators and lubricator.



2.2.1 Pneumatic Cylinder

A pneumatic cylinder based on application is usually a single acting cylinder where there is a single port in the cylinder, and cylinder extension is done by compressed air and retraction by means of a coiled spring. Double acting cylinders have two ports that both extend and retract the piston by means of compressed air.

2.2.2 Flow Control Valve

A flow control valve regulates the flow or pressure of a fluid. They normally respond to signals from devices such as temperature gauges and flow meters. They are normally fitted with actuators and positioners which are pneumatically actuated for control purposes.

2.2.3 Relief Valve

These valves are used to protect components from excessive pressure. This is achieved by limiting the pressure system within a specific range. It is normally closed and opens when pressure exceeds a specific set value by diverting air flow to the atmosphere.

2.2.4 Directional Control Valve

DCV’s allow fluid to flow into different paths from one or more sources. DCV’s consist of a spool inside a cylinder which is electrically or mechanically actuated. On actuation, the spool which is specially grooved slides inside the cylinder either permitting flow or restricting flow, thus controlling air flow.

2.2.5 Pressure gauges

They are devices designed to measure the pressure of fluids in a system. To ensure consistency and safety, check to be aware of leaks or building pressure in a system. Pressure gauges' function by a principle of flexing elastically under application of pressure differential. The deformation of this element is then measured and converted to the rotation of a pointer on a scale display. They are calibrated in pounds per square inch(psi).

2.2.6 Hoses/Transmission Lines

These are tubes used to convey pressurized air to actuators, valves and other devices. They generally consist of an inner, one or more layers of reinforcing braided or spiral-wound fiber and an outer protective cover.

2.2.7 Reservoir/Air Storage Tank

This refers to a pressure vessel used to store pressurized air. They are used in pneumatic systems where the flow of air within the system needs to be controlled and to also compensate for pressure fluctuations.

2.3.0 FOLDABLE SCISSOR STAIRS

Foldable stair mechanism usually applies where there is not enough space for a fixed stair. A four bar mechanism is used to actuate the scissor like elements which form the foldable stair mechanism. Stiffness and the strength of the links play an important role in this mechanism. While the links are actuated, the structure of the mechanism changes and the mobility in the mechanism is analyzed. Scissor like platforms can be used in vertical lifting of objects in industries which can be modified to form a foldable stair mechanism. A new kind of scissor-hinge structure, planar in nature is used to produce translational and curvilinear scissor-hinge systems. Linear actuators are used in this case to actuate the mechanism. Circular and non-circular arches can be built using this mechanism. Spatial scissor-hinge structural mechanism is used to form arch-like, dome-like and double curved shapes using actuators which are stable in nature and carry loads. Scissor structures are suitable for making disaster relief shelters due to its light weight and high volume expansion ratio.

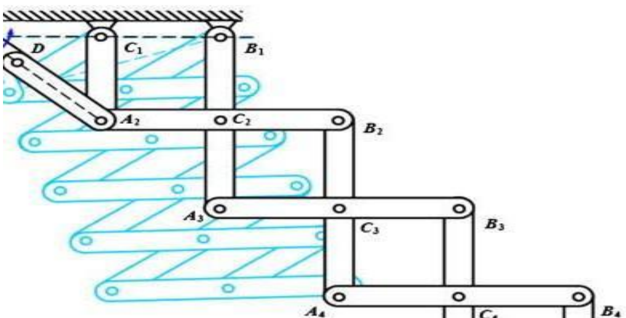
A non-linear vibration isolation system for the scissor-like structure was designed using linear springs and dumping components.

2.4.0 WORKING PRINCIPLE OF SCISSOR STAIRS

In this case we use a linear actuator to actuate the crank in the slider-crank mechanism instead of a rotary actuator. Here, a combination of slider and crank mechanism and a four bar mechanism are used along with the scissor-like elements to perform the foldable stair mechanism. By controlling a double acting cylinder using a direction control valve, stoppage of the foldable stair mechanism at intermediate levels can be obtained. By using a direction control valve, there is no external force required to hold the foldable stair mechanism when it is working.

2.5.0 MECHANISM OF THE FOLDABLE STAIRS.

The foldable stair mechanism consists of links arranged in a vertical and horizontal manner that make it the stair-like arrangement. These links are connected to each other using revolute joints. The crank in the crank and slider mechanism, which pulls the entire set of links up or down makes the stair-like arrangement. This crank also acts like an input link for the four bar mechanism. This folding and unfolding of the stair resembles the scissor-like structure. The crank is connected to the connecting rod through a revolute joint, which moves due to the actuation of the slider. The slider moves linearly due to the translatory motion exhibited by the linear actuator. The construction of the mechanism is as shown;



Where;

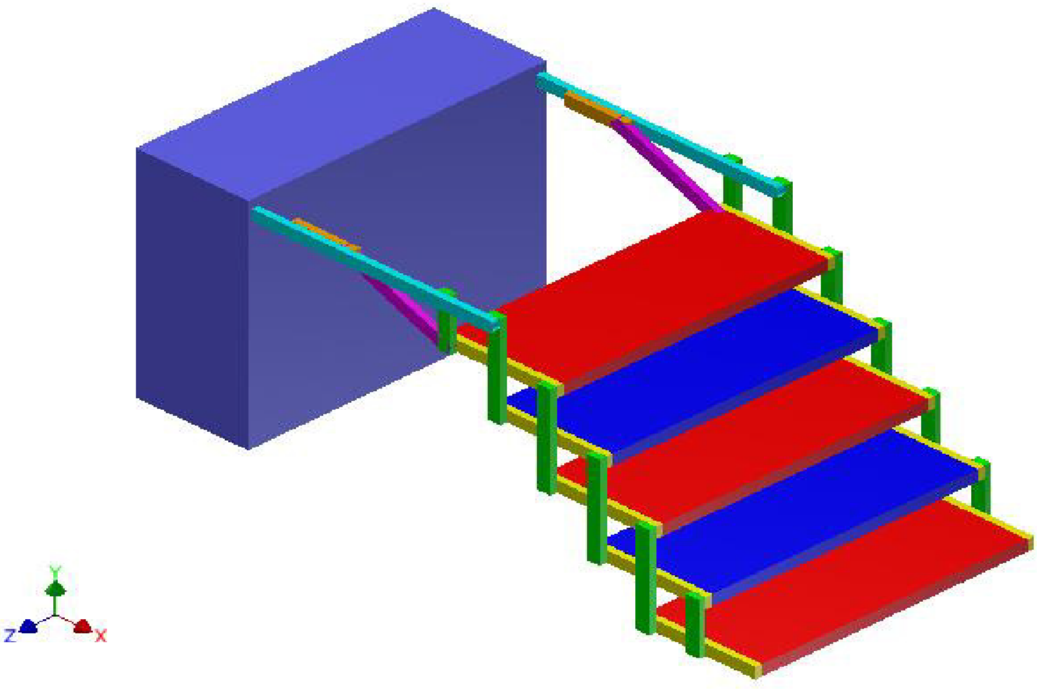
$A_1 - A_6$ are the inner revolute joints,

$B_1 - B_6$ are the outer revolute joints,

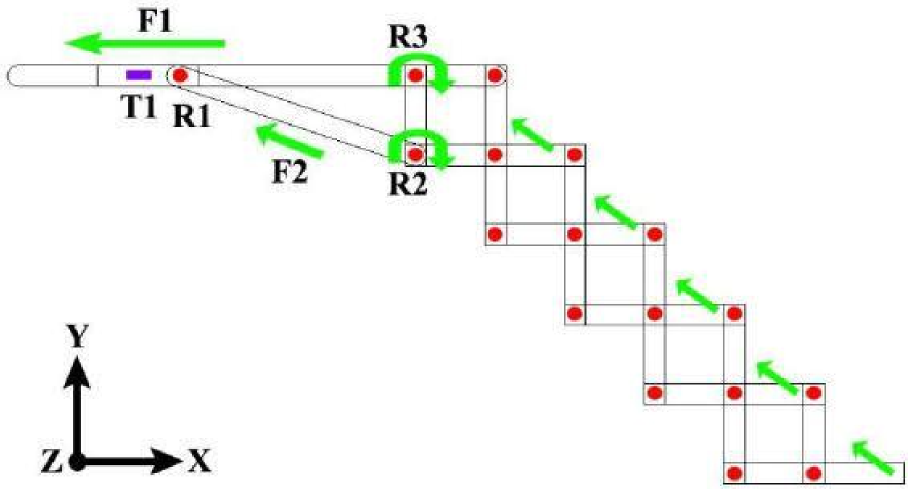
$C_1 - C_6$ are the scissor joints.

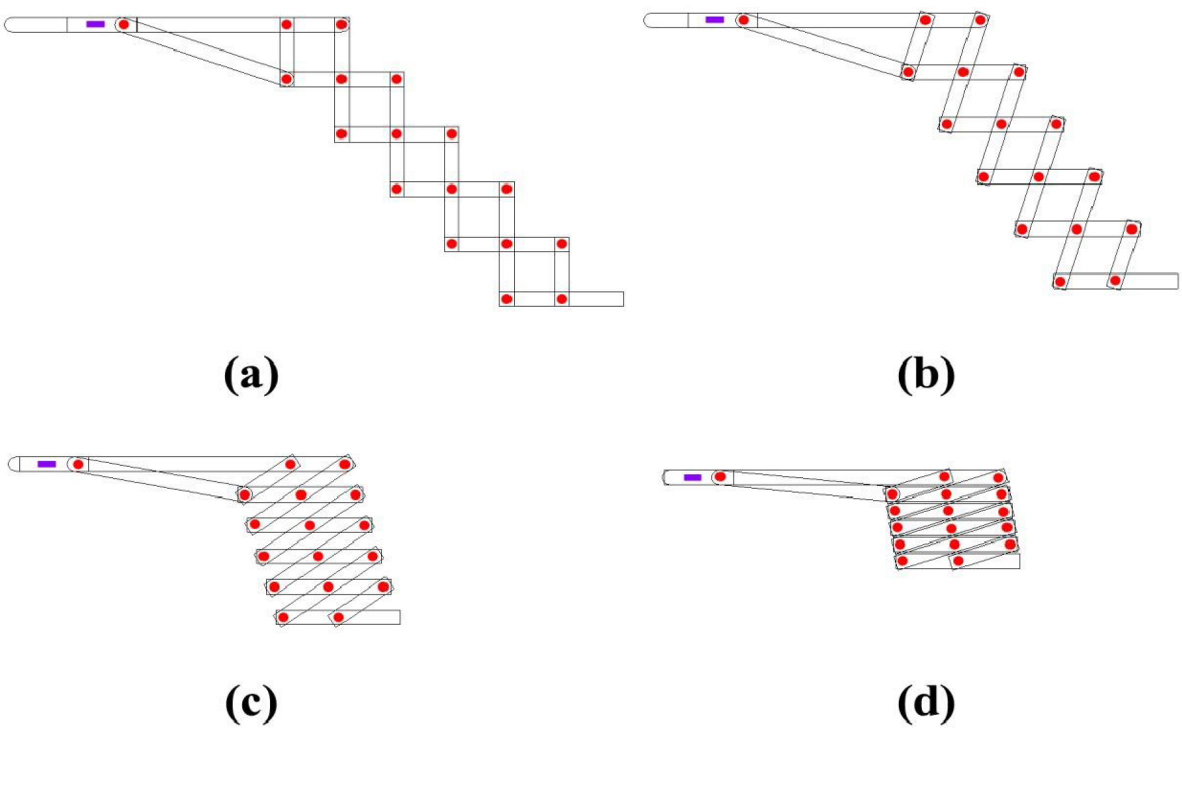
Two sets of this planar mechanism are placed parallel to each other at an offset distance. The horizontal links in the two sets are connected by using a bar/tread over which the foot of the user is placed.

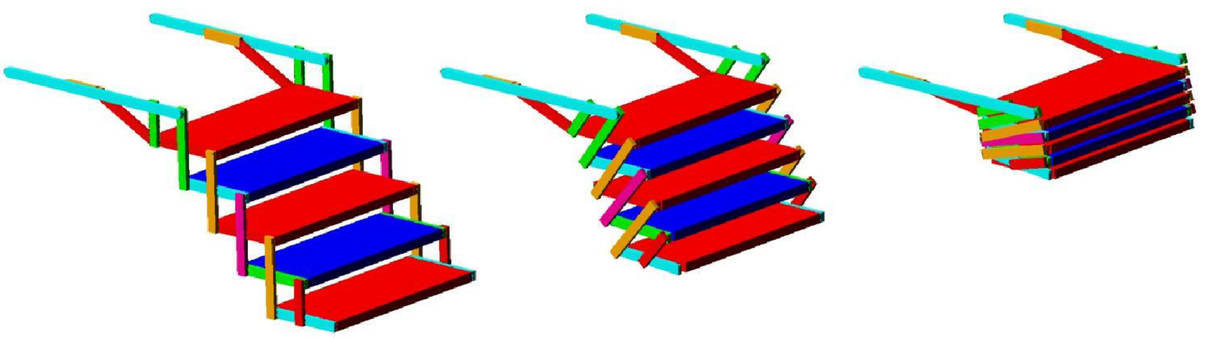
The staircase appears as shown



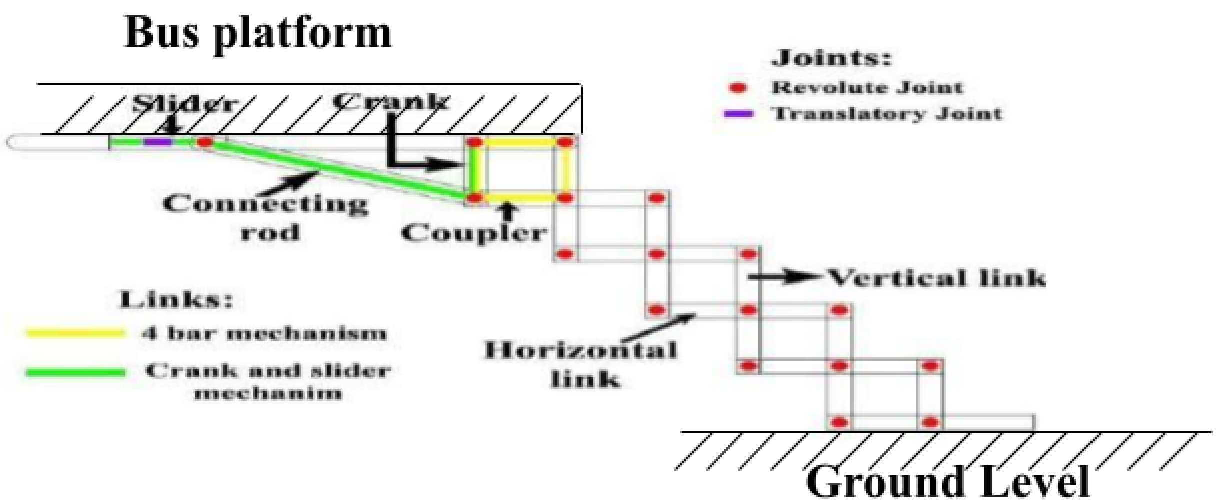
The folding process







2.6.0 PARTS OF THE FOLDABLE STAIR MECHANISM



2.6.1 Vertical Links

The vertical links are connected to the horizontal links at two or three points. They are used to fold or release the horizontal links when it is actuated by the crank. They decide the height of each step in the stair

2.6.2 Horizontal Links

They are connected to the vertical links at two or three points through revolute joints. They are used to provide a platform/tread where the foot of the user can be kept. It decides the length of each step in the stair.

2.6.3 Slider

The slider is used to actuate the mechanism due to its linear motion. It moves due its attachment to the rod of the double acting cylinder at one end. The other end is joined to the connecting rod through a revolute joint.

2.6.4 Connecting Rod

It is connected to the slider through a revolute joint at one end and the other end is connected to the crank and the coupler of the four bar mechanism through a pin joint. The connecting rod is utilized to transform the linear motion of the slider to the rotary motion of the crank. Through varying its length, the linear force needed for actuation, and the linear distance to be moved by the slider vary.

2.6.5 Crank

The crank is used to transfer the motion from the connecting rod to the coupler. When it rotates, the rotation is transferred to the horizontal link which further causes the folding and unfolding of the foldable scissor mechanism.

2.6.6 Revolute Joints

Foldable scissor stairs are pinned at all hinge points and each pin has a running clearance between the outside diameter of the pin and the inside diameter of the clearance hole. The more the scissor pairs stacked on top of each other, the more the pinned connections that are needed to accommodate movement, or deflection when folding and unfolding, or when under load.

2.7.0 ADVANTAGES AND DISADVANTAGES

2.7.1 Advantages

- It takes up little space in disassembled and foldable form.
- Mobility. The design makes it easy to move a folding ladder.
- It is a simple design.
- It is easy to operate, reach and secure in the desired position
- They can be used in a variety of applications.

2.7.2 Disadvantages

- They require more architectural support during construction.
- Moving large items is sometimes time-consuming.

2.8.0 MINIMIZING ERRORS

2.8.1 Minimizing Deflection

By using the specified pneumatic double acting cylinders, you are able to hold the weight of the staircase when loaded and unloaded. This can also be achieved by fixing supports to reinforce the scissor mechanism stability. Designing for strength is also an effective method to minimize unwanted deflection. Ensuring that the staircase is not loaded beyond the specified weight limit also minimizes deflection. Using the specified material for the construction of the scissor staircase ensures accurate weight limit hence preventing unwanted deflection.

2.8.2 Minimizing Air Leakage

If leaks are present along any stretch of hoses, you will lose pressure between the air compressor and your pneumatic tools. This probably due to significant distancing between a compressor and your end point processes and they occur mainly at the connecting points on either end or anywhere along the hose. Tubes leading outside the compressor could also leak at any point between the compressor unit and the end point application. This can be caused by rusting due to moisture and cracking as a result of brittleness of the metal hence forming holes in the tube which causes pressure drop in the transmission lines. If couplings become lose at any point in the transmission line, a pressure drop occurs due to loss of air at this point. If regulators such as pressure gauges, lubricators and moisture separators are faulty, they can also leak compressed air. Minimization of air leaks can be done by installing and maintaining seals and tightening couplings. Regulators, lubricators and separators should be properly installed and maintained to ensure the system is air-tight. Only proper hoses and tubes free of cracks and holes should be used for the pneumatic system. It can also be helpful to install pressure gauges at intermediate positions to allow detection of pressure drops which may indicate leakage.

2.8.3 Elimination of Hose Swell

Flexible hoses should be limited in length wherever possible and replaced with pipe or mechanical tubing as necessary to eliminate swell as the system pressure fluctuates.

2.8.4 Transferring Loads over Fixed End of the Platform

If possible, avoid exerting loads over the sides of the scissor staircase tread. It is more difficult to control the deflection when the load is not shared equally between the vertical links.

2.8.5 Supporting Base Frame

The base frame is the top-most horizontal link and offers a point for attachment to the point of application. The bottom-most horizontal link should be designed to properly rest on the ground to offer firm support.

Base frames that are not properly bolted, welded or otherwise attached to withstand downward forces due to gravity and loading contribute to deflection by bending. Base frames should be properly attached to the surface on which they are mounted in order to adequately withstand loading without deflection.

2.9.0 OTHER DESIGNS OF FOLDABLE STAIRS.

2.9.1 Telescoping Ladders

A telescoping ladder is operated under the principle of the telescope. It folds down to a compact size which makes it easy to store and transport. The can easily be height adjusted to meet the required need.

Disadvantages

1. High maintenance cost.
2. Only useable in light duty applications.

2.9.2 Klapster Stairs

Klapster foldable staircase optimizes space by swiveling through 90 degrees facilitating a vertical folding towards the wall when not needed. Once folded up, both stair stringers and steps are on one plane along the wall and extend out from the wall at around 3cm. where facilities are available to make adjustments on the wall, the wall surface can be indented in order for the outer stair plane to lie firmly along the wall level.

Disadvantages

1. Requires attachment on both platforms i.e. Upper and lower platform.
2. Only used for light duty applications.

Klapster stairs

2.9.3 Eclettica Spiral Staircase

It is a vertical stack of drawers that swivel to become a staircase. It looks like a large cabinet but can effortlessly unfold into a staircase with just a push of a button by mechanism of an electric motor. The steps can be utilized as storage compartments, shoe racks, bottle holders or practical drawers. The drawers in the steps help in maximizing space vertically while the closed position of the stair doesn't block much horizontal space.

Disadvantages

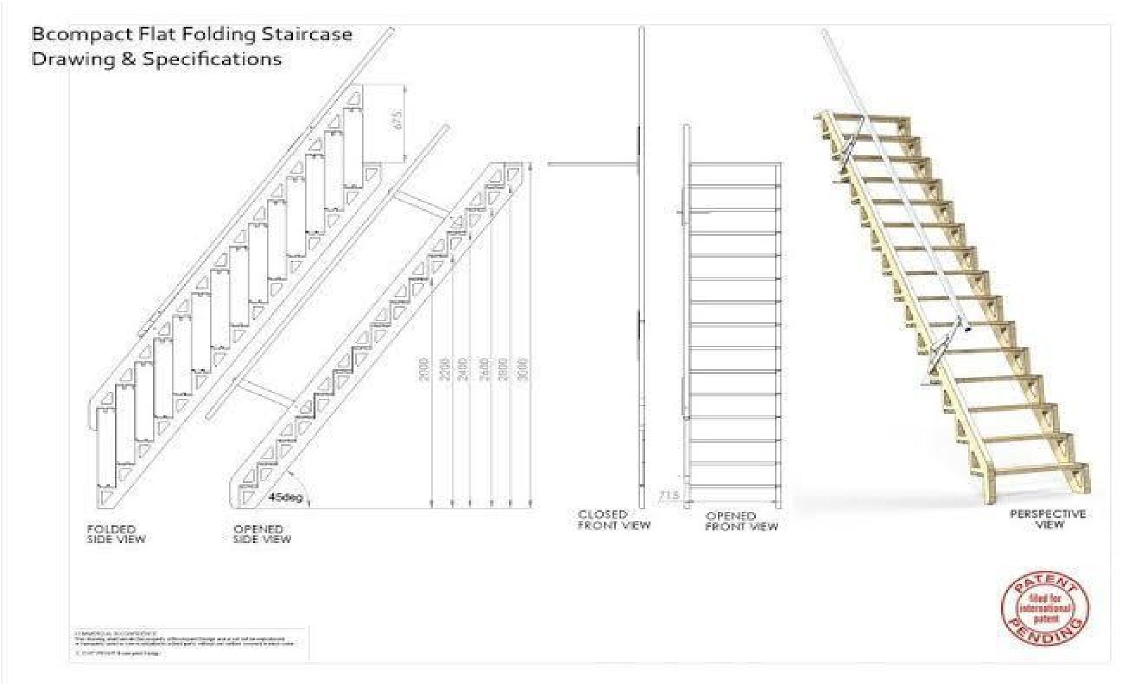
1. They are more difficult to navigate than other types of stairs.
2. It is difficult to carry large items up.
3. Only one person can go up or down at the same time.

2.9.4 Compact Hybrid Staircase

The compact hybrid staircase is designed to fold all its steps and stringers flat against the wall it is attached to. They uniquely fold sideways unlike other foldable stairs. Unlike the ladder that has an optional fixed handrail, the hybrid stair has a patent-pending bi-folding handrail that is safely and conveniently folded against the wall when the staircase is folded. It also enables the opening and closing from both the lower or upper floor.

Disadvantages

1. Requires attachment on both platforms i.e. Upper and lower platform.
2. Only useable in light duty applications.



2.10.0 PROPOSED DESIGN

We propose the scissor mechanism design as a model to design a foldable scissor staircase to solve the problem of this project. The design depends on the job specification. The advantages of scissor mechanism design will hold on this design.

2.11.0 FOLDABLE SCISSOR STAIRCASE LOADING

2.11.1 Pneumatic Cylinder Loading

The pneumatic cylinder is mounted parallel to the horizontal links. This therefore makes it experience total loading when the scissor foldable stairs are fully open and the double acting cylinder is fully extended to the right. The total load acting on the cylinder includes;

- Mass carried on our stairs = 100kg - 300kg.
- Mass of crank = 0.4 kg

- Mass of each horizontal link = 0.5 kg.
- Mass of each vertical link = 0.8 kg

Total mass = Total tread mass + 2[$\sum(hm + vn + cp)$**]**

Where h = horizontal link mass, m = number of horizontal links.

v = vertical link mass, n = number of vertical links.

c = mass of the crank, p = number of cranks.

Total load(F) = Total mass × 9.81(gravitational pull).

Load experienced by the cylinder(F_C) is calculated using the formula;

$$\mathbf{F_c} = \frac{\frac{F}{2}}{\tan tan\,\emptyset}$$

Where;

F_c = Load experienced by the cylinder

F = Total staircase weight when not loaded.

∅ =Angle between the scissor joints and the horizontal link.

Area of cylinder (mm^2) = $\frac{Fc}{pressure}$

2.11.2 Foldable Scissor Stair Calculations

For a foldable scissor stair, the weight it carries depends on;

Length of the links and angle of cylinder mounting to the horizontal link.

Formula used;

$$\mathbf{W} = \frac{w+wa}{2}$$

Where;

W = load experienced by a single planar mechanism.

w =load to be lifted(N).

w_a = the combined weight of the scissor arms and the tread platforms.

3.0 CHAPTER THREE: DESIGN THEORY AND CALCULATIONS

This chapter covers the research, strategy, method and analysis of the design in consideration.

The design theory as well as design is influenced by the problem to be solved.

3.1.0 DESIGN THEORY

Pneumatic systems are used to control and transmit power in a linear direction.

A compressor driven by a prime mover such as an IC engine or electric motor increases the pressure of air which is in turn stored in a reservoir. The direction and rate of flow of the compressed air is controlled by valves. An actuator (pneumatic cylinder) is used to convert the pressure energy to mechanical power. The amount of output power developed depends upon the flow rate, pressure, the pressure drop in the hoses and actuator and the cylinders' overall efficiency.

3.2.0 DESIGN CONSIDERATIONS

3.2.1 Safety Considerations

- Pressure and temperature ratings.
- Interlocks for sequence operations.
- Emergency shutdown features.
- Power failure locks.
- Operation speed.
- Environmental considerations.

3.2.2 Functional Considerations

- Life expectance.
- Facilitate good maintenance practice.
- Meet the required performance specifications.

- Ability to withstand operational hazards.
- Compatibility with electrical and mechanical components.

3.2.3 Efficiency of Operation

- Design to maintain minimum operational cost.
- Design to prevent and remove contamination.
- Access to spare parts for repair and adjustment.
- Keep the system simple, safe and functional.

3.3.0 CIRCUIT DESIGN APPROACH

3.3.1 Job Specifications.

- Minimum load – 100 kg
- Maximum load – 300kg
- Maximum height travel – 5 meters.
- Step width – 1 meter.

3.3.2 Stair Dimensions

- Overall staircase width=1m.
- Tread width=29 cm
- Riser height =18 cm

3.3.3 Link dimensions

- Horizontal link length = 29 cm.
- Horizontal link width = 4 cm.
- Horizontal link breadth = 2 cm.
- Vertical link length = 40 cm.

- Vertical link width = 4cm.
- Vertical link breadth = 2 cm.

3.3.4 Slider and Crank Specifications

- Slider length = 10 cm.
- Slider width = 4 cm.
- Slider breadth = 4 cm.
- Crank length = 22 cm.
- Crank width = 4 cm.
- Crank breadth = 2 cm.

3.3.5 Revolute Joint Specifications

- Pin diameter = 2cm.
- Pin length = 5 cm.
- Hole diameter = 2.05 cm.
- Clearance = 0.05 cm.

3.3.6 Size of the Cylinder Needed

This depends upon which side is to be lifted i.e. piston or rod side.

Selecting the working pressure depends on;

- Bore size
- Area of the cylinder

3.4.0 SPECIFICATIONS

3.4.1 Considerations when Selecting Cylinder Size

Large diameter cylinder

- Operates at low pressure.
- Requires a higher capacity compressor.

Small diameter cylinder

- Operates at high pressure.
- Requires a lower capacity compressor.

3.4.2 Capacity of the Compressor Needed.

The required capacity depends on;

- The size of the reservoir tank.
- The duty cycle time.
- The type of prime mover available.
- The required piping.
- Air treatment options.
- Whether regulation is required.

3.4.3 Capacity of Motor Needed.

- Shaft torque
- Shaft power
- Pneumatic power

3.4.5 Size of Reservoir Needed.

- The reservoir needed is calculated by taking the highest CFM (cubic feet per minute) requirement and multiply by **1.25** or **1.5**.

  $$\mathbf{CFM = A \times S \times C}$$

Where;

A=piston area

S=stroke length

C=number cycles per minute

- The length and width of the reservoir depends on the availability of space, mounting accessories such as filters and transmission lines and free heat dissipation allowance

3.4.6 Valve Selection

Relief valve

Relief valve selection depends on pressure range and flow handling capacity.

Directional control valve(DCV)

Selection is based on the area of application and flow handling capacity.

Pilot operated check valve

Choice depends on power failure conditions to ensure safety. Based on whether you want to avoid leakages through DCV or holding the cylinder at intermediate positions.

3.4.7 Pipe Selection

It depends on;

- Pressure line velocity.
- Suction line velocity.

- Area $=\pi d^2/4$
- The wall thickness is selected based on line pressure.

3.4.8 Pressure Supplied to the Pneumatic Cylinder.

pressure= $\frac{force}{area}$

where F=force applied by the compressed air on the cylinder.

A=cylinder cross section area

3.5.0 BUCKLING ACTION ON CYLINDER

In the selection of cylinders, two primary concerns are considered;

- The ability of the piston to support a specified load without undergoing unacceptable deformations.
- The strength of the rod and its ability to support a specified load without experiencing excessive stresses.

Buckling load (Euler)PE = $\frac{\pi^2 EI}{L^2}$

where;

E = Young's modulus of elasticity

I = Moment of inertia

L = Unsupported length

To prevent buckling, the compressive stress must not exceed the yield stress.

Because of large deflection caused by buckling, the least moment of inertia can be expressed as **$I = AK^2$**, where **A** is the cross-sectional area and K is the radius of gyration of the cross-sectional area.

K= $\sqrt{\frac{I}{A}}$

For the smallest radius of gyration of the links, the least moment of inertia must be taken in order of the critical of buckling stress not to be exceeded.

3.6.0 STRESSES IN CYLINDERS.

When cylinders are subjected to internal fluid pressure the following types of stresses are developed;

- Hoop/circumferential stress
- Longitudinal stress

3.6.1 Hoop Stress

Hoop stress is developed as a result of forces applied from inside the cylindrical pipe pushing against the pipe walls. This is a result of forces pushing against the circumferential cylinder walls.

3.6.2 Longitudinal Stress

Longitudinal stress is a result of forces pushing against the top end of the cylinder.

These forces are derived using newton's first law.

Let;

D = internal diameter of the cylinder.

T= thickness of the cylinder

P= internal pressure of the cylinder

σ_c = circumferential/hoop stress

σ_l = longitudinal stress

l= length of the cylinder

hoop stress (σ_c) = $\frac{Pd}{2t}$

longitudinal stress (σ_l) = $\frac{Pd}{4t}$

maximum shear stress $\tau_{max} = \frac{Pd}{8t} = \frac{\sigma c - \sigma l}{2}$

bursting force(pressure) = PdL

Resisting strength = $2Lt\sigma c$

Bursting force = resisting strength ($pdL = 2Lt\sigma c$)

Note: The maximum stress developed must not exceed the permissible tensile stress (σ_t) of the material.

3.7.0 MATERIAL SELECTION

A thorough survey has to be done in order to conclude on best material of any component.

Stages when material selection needs to be considered;

- New processes and process changes
- New applications and equipment
- Exchange of existing materials to minimize cost
- Exchange of material due to poor performance of existing materials.

To make an appropriate material selection, it is important to get a full picture of the surface conditions in order to specify the demands of the application.

The aspects to consider which are material related include;

- Mechanical strength
- Corrosive resistance
- Physical properties
- Surface aspects. Appearance and clean-ability.
- Fabricate-ability.

Other aspects to consider include;

- Cost
- Availability
- Previous experience standards and approvals.
- Recyclability.
- Possibility for weight reduction.

The most important mechanical properties of material which are necessary for the success of this project include;

Hardness

This refers to the different properties such as resistance to wear, machinability, deformation and resistance to scratching.

Ductility

Ductility is the ability of a material to be drawn into a wire with the application of a tensile force, making it both strong and plastic.

Strength

This is the ability of a material to resist external forces without breakage or yielding the internal resistance offered without break-down.

Malleability

This is the ability of a material to be hammered or rolled into a thin sheet. A malleable material is plastic but not essentially strong. Examples; copper, aluminium, lead-soft steel and wrought iron.

Plasticity

It is a property of a material to retain its shape after the deformation produced under load permanently.

Toughness

It is the property of a material to resist fracture due to high impact loads such as hammer blows.

Brittleness

The property of a material to break with little permanent deformation when subjected to tensile load. Brittle materials snap off without giving any sensible elongation. Example; cast iron.

Elasticity

The property of a material to regain its original shape after deformation when the external force is withdrawn.

Stiffness

The ability of a material to resist deformation under stress.

3.8.0 COMPONENT MATERIAL

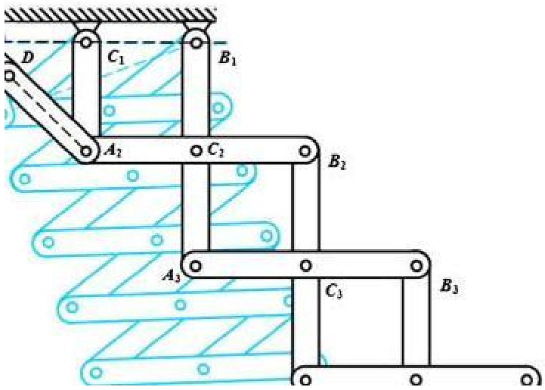
After taking into account the considerations to select the appropriate material for our model, we settled on the following choices for our components;

- Scissor arms – 2014 (T6) Copper aluminum alloy.
- Pneumatic cylinder – Stainless steel.
- Tread platform – Slip mat aluminum plate.
- Slider – Stainless steel.
- Crank – Chrome stainless steel.
- Base frame – Stainless steel.

4.0 MODELLING

4.1.0 MODEL SPECIFICATIONS

For our project model, we opted to use a staircase with the following specifications;



- Number of steps/treads = 3
- Number of vertical links needed = 4
  - ✔ Full length vertical links = 2
  - ✔ Cranks = 2
- Number of horizontal links needed = 3

4.2.0 MASS PROPERTIES

- Mass of the users (mass to be lifted) = 300kg.
- Mass of each tread platform = 2.5kg.

Mass properties of horizontal link

Configuration: Default

Coordinate system: -- default --

Density = 2.8×10^{-3} grams per cubic millimetre

Mass = 592.01 grams

Volume = 211433.63 cubic millimetres

Surface area = 37769.91 square millimetres

Centre of mass: (millimetres)

X = 65.95

Y = 36.21

Z = 10.00

Principal axes of inertia and principal moments of inertia: (grams * square millimetres)

Taken at the centre of mass.

Ix = (1.00, 0.00, 0.00) Px = 103493.45

Iy = (0.00, 1.00, 0.00) Py = 3878391.11

Iz = (0.00, 0.00, 1.00) Pz = 3942416.96

Moments of inertia: (grams * square millimetres)

Taken at the centre of mass and aligned with the output coordinate system.

Lxx = 103493.45 Lxy = 0.00 Lxz = 0.00

Lyx = 0.00 Lyy = 3878391.11 Lyz = 0.00

Lzx = 0.00 Lzy = 0.00 Lzz = 3942416.96

Moments of inertia: (grams * square millimetres)

Taken at the output coordinate system.

Ixx = 938988.13 Ixy = 1413751.57 Ixz = 390414.77

Iyx = 1413751.57 Iyy = 6512255.49 Iyz = 214377.38

Izx = 390414.77 Izy = 214377.38 Izz = 7293373.18

Mass properties of vertical link

Configuration: Default

Coordinate system: -- default --

Density = 2.8×10^{-3} grams per cubic millimetre

Mass = 838.41 grams

Volume = 299433.63 cubic millimetres

Surface area = 50969.91 square millimetres

Centre of mass: (millimetres)

X = 129.06

Y = 20.00

Z = 10.00

Principal axes of inertia and principal moments of inertia: (grams * square millimetres)

Taken at the centre of mass.

Ix = (1.00, 0.00, 0.00) Px = 144560.12

Iy = (0.00, 1.00, 0.00) Py = 10645244.05

Iz = (0.00, 0.00, 1.00) Pz = 10733909.90

Moments of inertia: (grams * square millimetres)

Taken at the centre of mass and aligned with the output coordinate system.

Lxx = 144560.12 Lxy = 0.00Lxz = 0.00

Lyx = 0.00 Lyy = 10645244.05 Lyz = 0.00

Lzx = 0.00Lzy = 0.00Lzz = 10733909.90

Moments of inertia: (grams * square millimetres)

Taken at the output coordinate system.

Ixx = 563767.20 Ixy = 2164032.47 Ixz = 1082016.24

Iyx = 2164032.47 Iyy = 24693056.81 Iyz = 167682.83

Izx = 1082016.24 Izy = 167682.83 Izz = 25033246.90

Mass properties of crank

Configuration: Default

Coordinate system: -- default --

Density = 7.8 × 10^{-3} grams per cubic millimetre

Mass = 1261.39 grams

Volume = 161716.74 cubic millimetres.

Surface area = 28737.92 square millimetres.

Centre of mass: (millimetres)

X = 24.35

Y = 46.59

Z = 10.00

Principal axes of inertia and prin cipal moments of inertia: (grams * square millimetres)

Taken at the centre of mass.

Ix = (1.00, 0.00, 0.00) Px = 218361.94

Iy = (0.00, 1.00, 0.00) Py = 4627041.25

Iz = (0.00, 0.00, 1.00) Pz = 4761310.57

Moments of inertia: (grams * square millimetres)

Taken at the centre of mass and aligned with the output coordinate system.

Lxx = 218361.94 Lxy = 0.00Lxz = 0.00

Lyx = 0.00 Lyy = 4627041.25 Lyz = 0.00

Lzx = 0.00Lzy = 0.00Lzz = 4761310.57

Moments of inertia: (grams * square millimetres)

Taken at the output coordinate system.

Ixx = 3082914.33 Ixy = 1431016.02 Ixz = 307128.26

Iyx = 1431016.02 Iyy = 5500988.10 Iyz = 587725.16

Izx = 307128.26 Izy = 587725.16 Izz = 8247531.70

4.3.0 CYLINDER LOADING CALCULATIONS

Total mass = Total tread mass + 2[$\sum(hm + vn + cp)$**]**

Total mass = (3 × 2.5) + 2[(0.592 × 3) + (0.838 ×2) +(1.261 ×2)]

= 7.5 + 11.948 = 19.448 kg.

Where h = horizontal link mass, m = number of horizontal links.

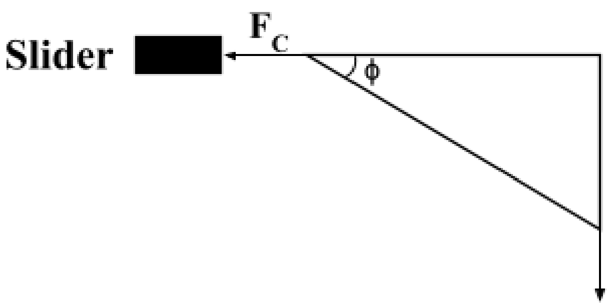
v = vertical link mass, n = number of vertical links.

c = mass of the crank, p = number of cranks.

Total load(F) = Total mass × 9.81(gravitational pull).

F = 19.448 × 9.81 = **190.785 N**

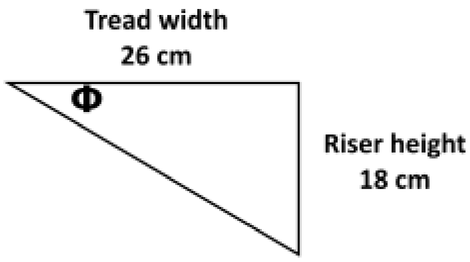
4.3.1 Load Experienced at the Pneumatic Cylinders



For each cylinder;

$$\tan \Phi = \frac{\frac{F}{2}}{Fc}$$

$$F_c = \frac{\frac{F}{2}}{\tan tan\ \Phi}$$



$\Phi = \left(\frac{18}{26}\right) = \mathbf{34.7^{0}}$

Taking our formula;

$$\mathbf{F_c} = \frac{\frac{F}{2}}{\tan tan\ \Phi}$$

$$F_c = \frac{\frac{190.785\ N}{2}}{\tan tan\ 34.7} = \mathbf{137.76\ N}$$

4.2.2 Calculation of the Cylinder Size

(A) Area of cylinder $(\mathbf{m^2}) = \frac{Fc}{pressure}$

By considering our area of application i.e. Buses and trucks, we decided to utilize the available compressed air used for brakes, for our actuation. The existing bus air brakes require ***830 kN/m²*** for stopping. To achieve the desired results, a pressure regulating valve is used to regulate our actuating pressure, not to exceed the above but practically applicable to our model.

We chose to use an estimate value **of 135 kN/m²** in our model.

Pressure = 135 kN/m²

Applying our formulae**;**

$A = \frac{137.76}{135 \times 1000} = \mathbf{1.02 \times 10^{-3}\ m^2.}$

Using the formula;

$$\textbf{Area(circle)} = \pi\frac{d^2}{4}$$

$$d = \sqrt{(\frac{4A}{\pi})}$$

$$= \sqrt{[\frac{(4\times1.02 \times 10^{-3})}{\pi}]}$$

$$= \mathbf{0.03605\ m}$$

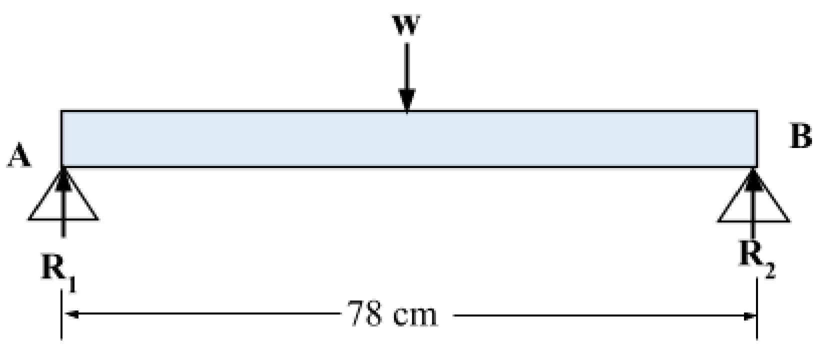
$$\mathbf{= 36.05\ mm}$$

Note: The cylinder size needs to be greater than the acquired value in order to lift the mechanism.

For our model, we recommend a cylinder of **40 mm** diameter.

4.3.3 Bending Moment Analysis

Our model is expressed as a simply supported beam with a point load acting at the center of the beam.



Taking a maximum user mass of 300 kg.

W = 300 × 9.81 = 2943 N

= 2.943 kN.

Taking our moment about point A;

$$\sum MA = \mathbf{0}$$

$[\ (39 \times 10^{-2})\ W] - [(78 \times 10^{-2})\ R_2] = 0$

$$\mathbf{R_2} = \frac{(0.39)\times 2.943}{(78 \times 10-2)}$$

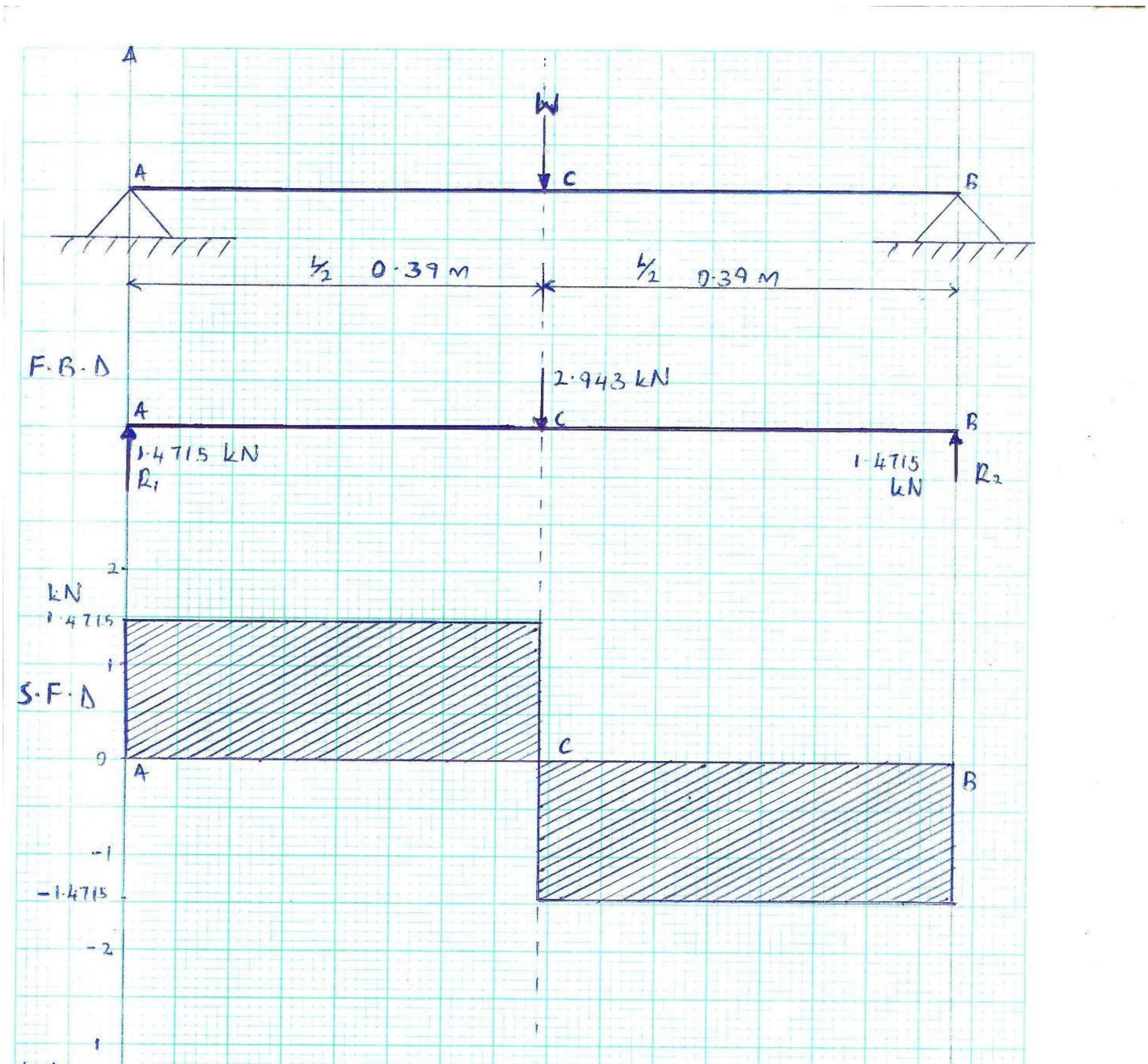
$$= \mathbf{1.4715\ N}$$

For a point load acting centrally;

$$\mathbf{R_1 = R_2} = \frac{W}{2}$$

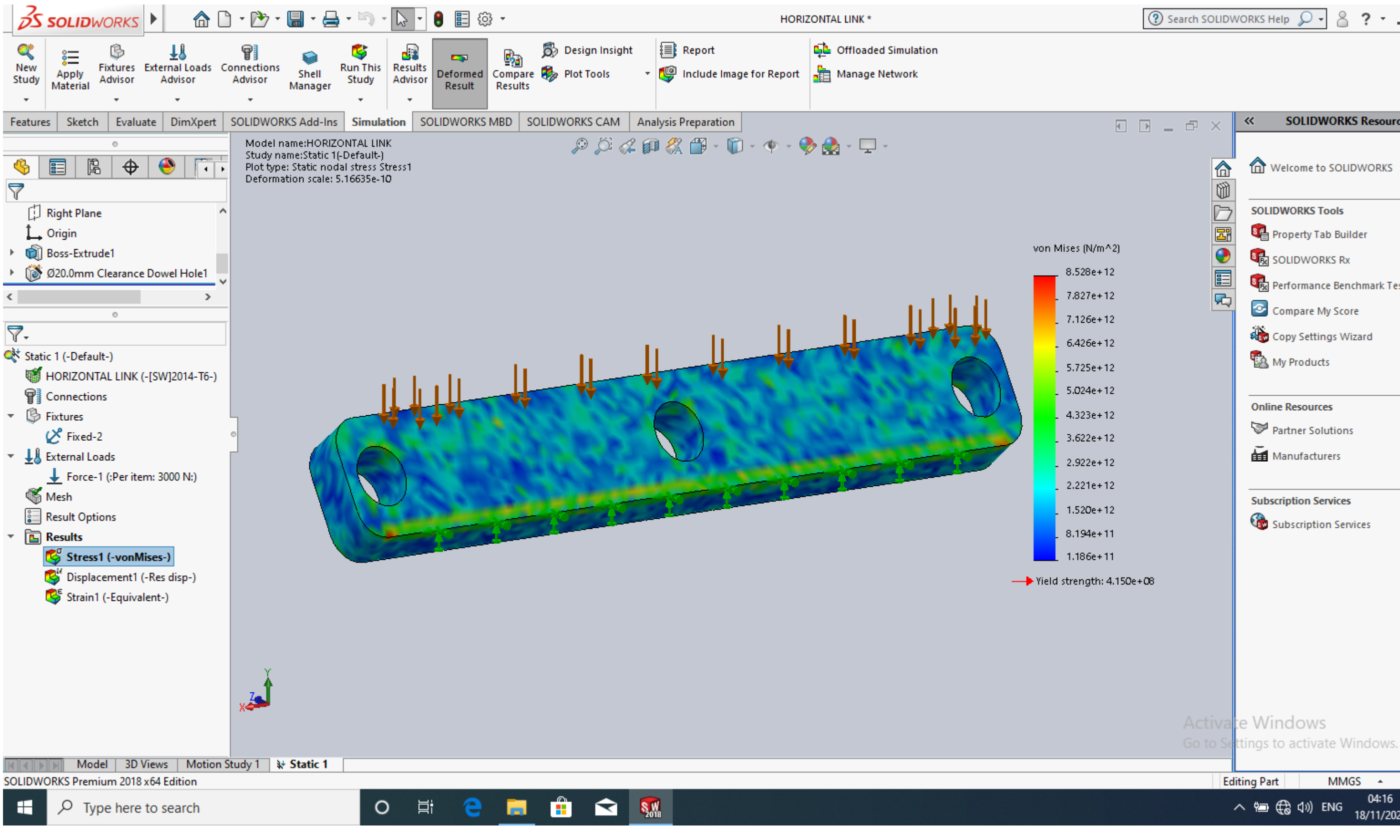
Therefore, **R1 = 1.4715 N**

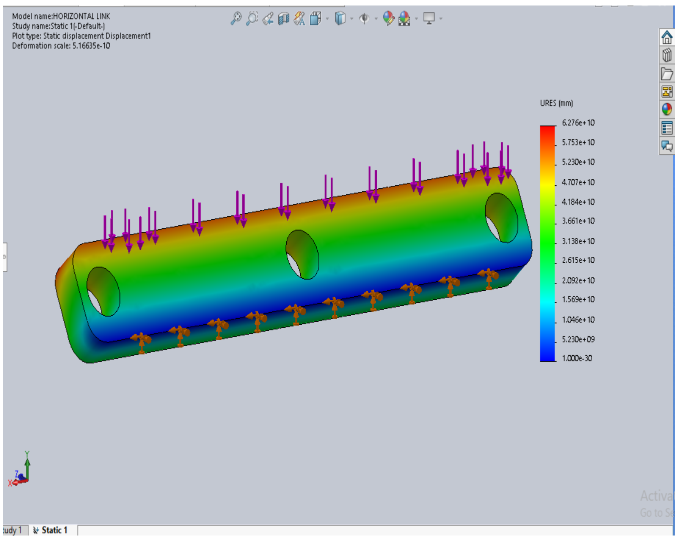
4.2.4 Free Body Diagram, Shear Stress Diagram and the Bending Moments Diagram

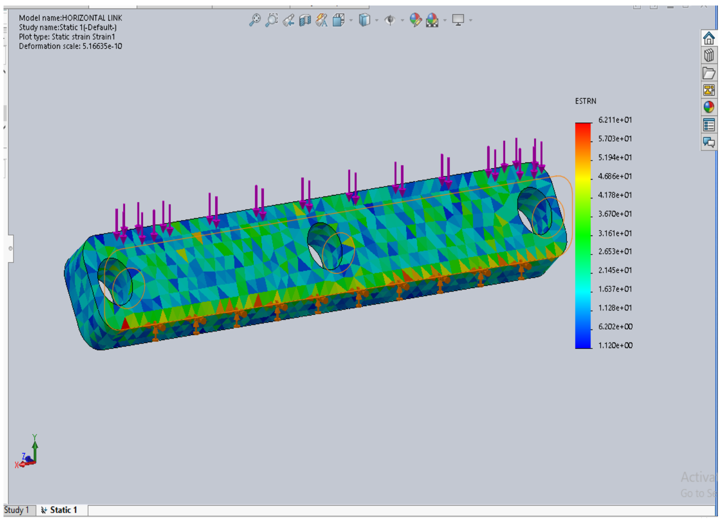


5.0 CHAPTER FIVE: SIMULATION

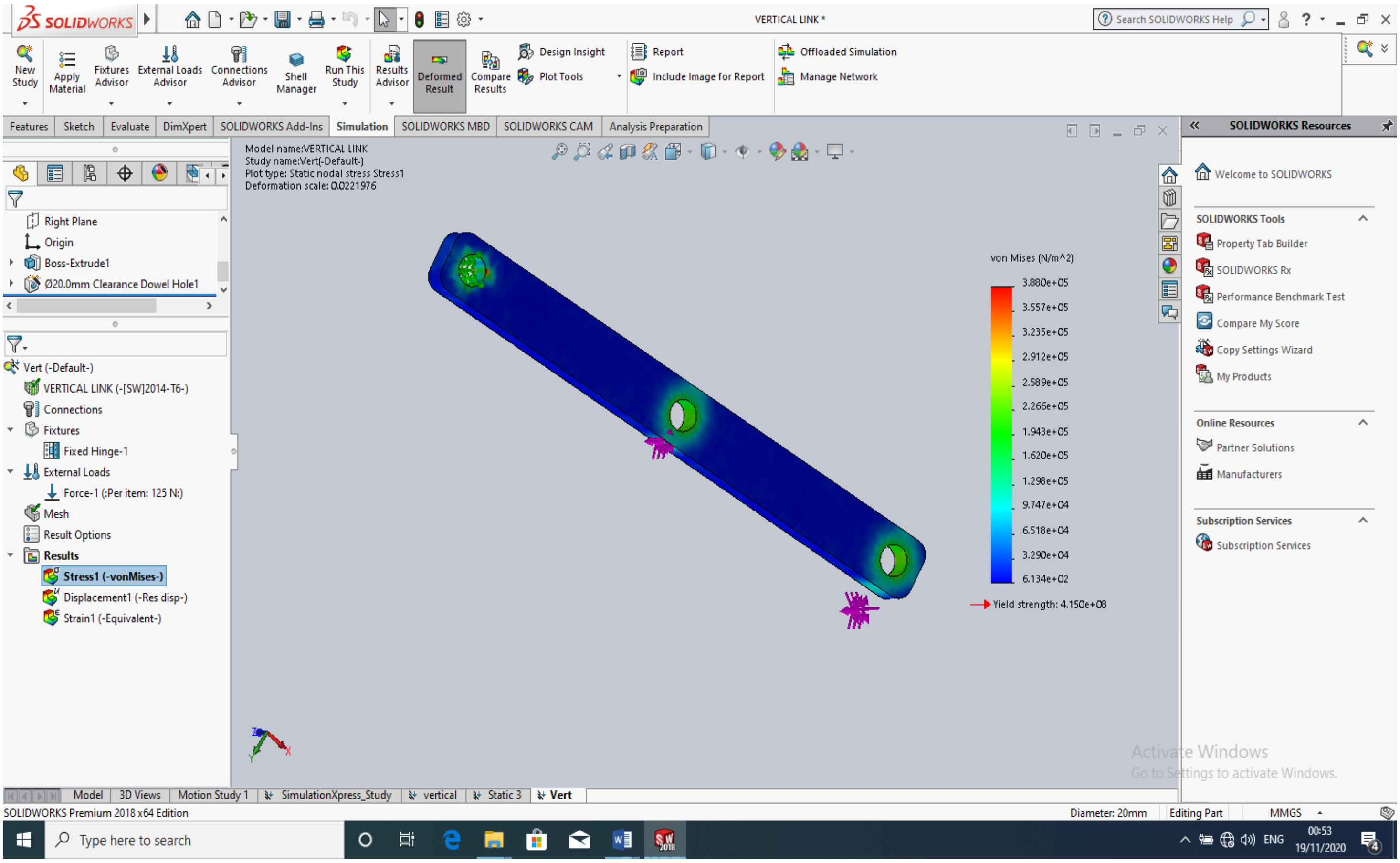
5.1.0 Horizontal Link

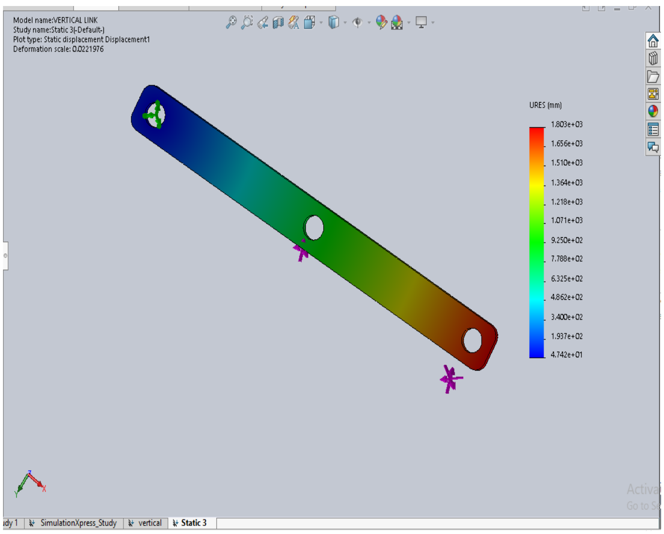


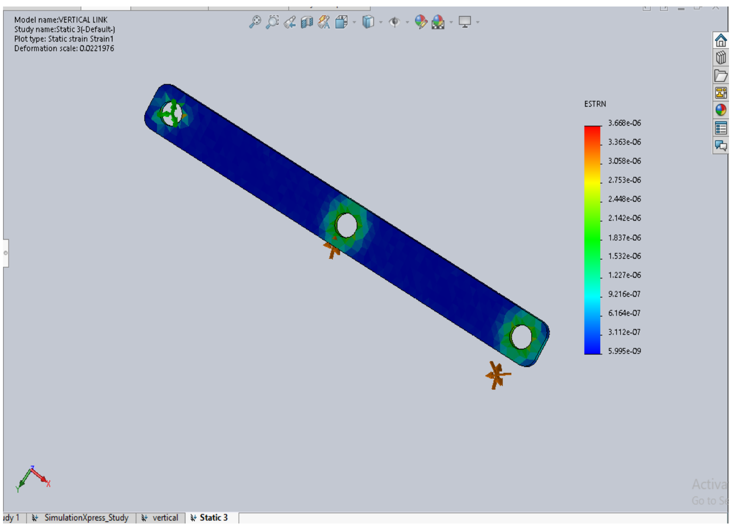




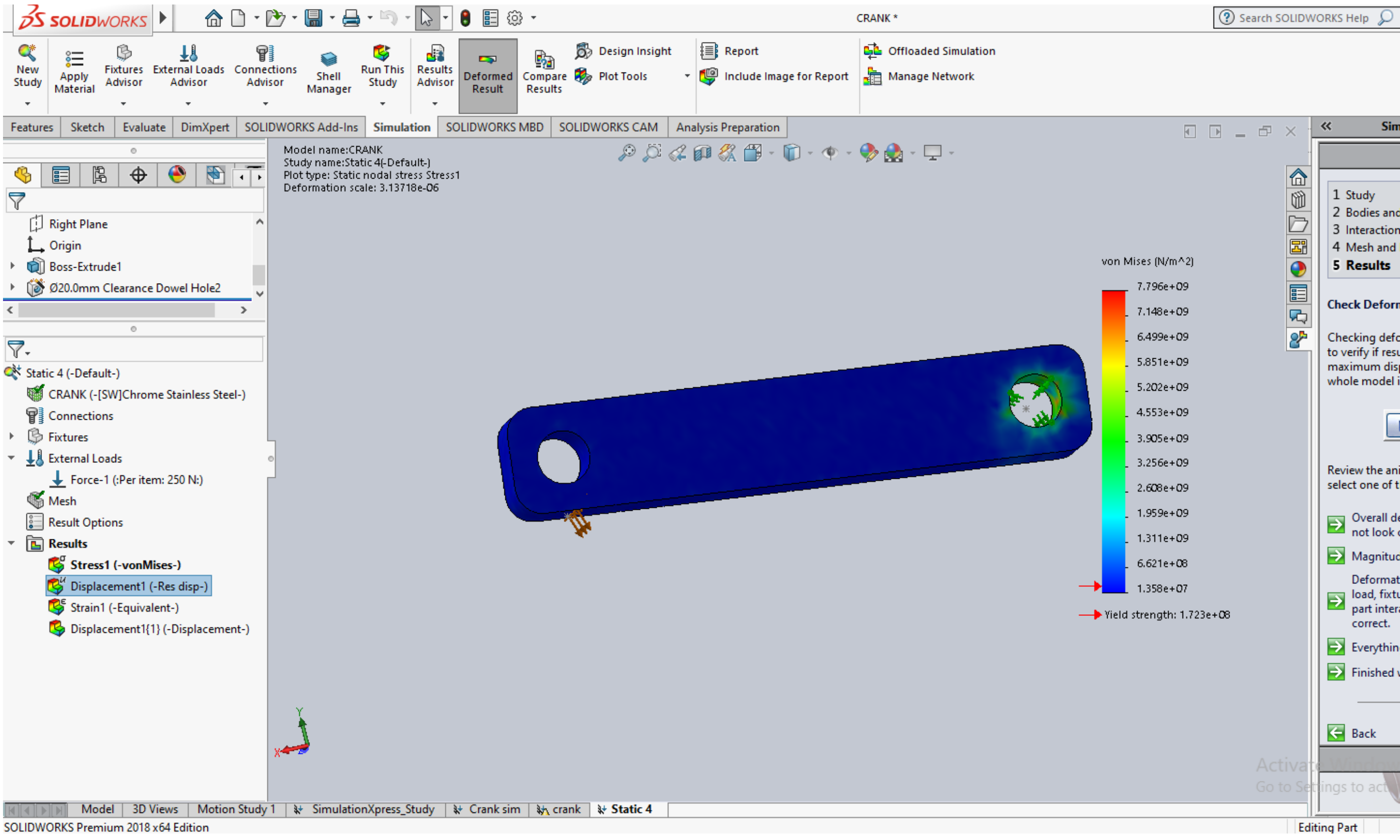
5.2.0 Vertical Link

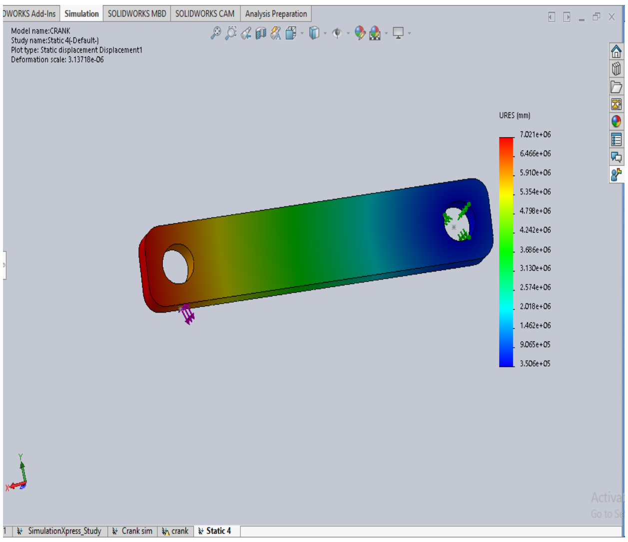


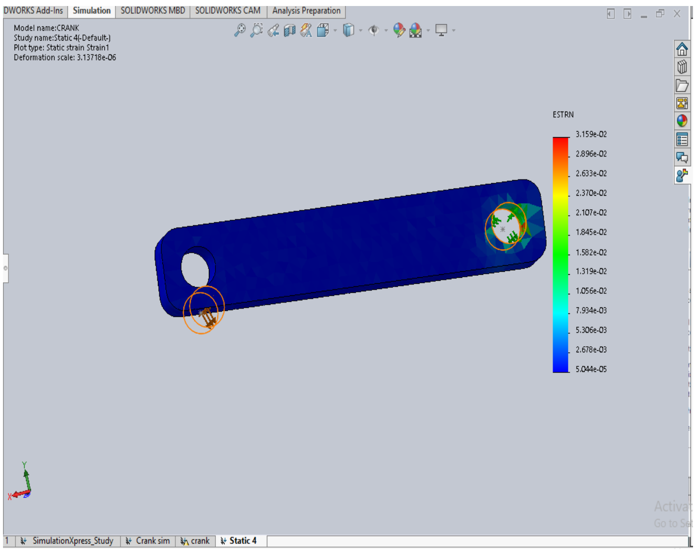




5.3.0 Crank


Model name:CRANK
Study name:Static 4(-Default-)
Plot type: Static nodal stress Stress1
Deformation scale: 3.13718e-06
von Mises (N/m^2)
7.796e+09
7.148e+09
6.499e+09
5.851e+09
5.202e+09
4.553e+09
3.905e+09
3.256e+09
2.608e+09
1.959e+09
1.311e+09
6.621e+08
1.358e+07
Yield strength: 1.723e+08





6.0 CHAPTER SIX: PROJECT COSTING

DESCRIPTION	COST
1. Data collection and research including soft copy books, journals, hardcopy books and internet	**3,000 Ksh.**
2. Printing the project	**4,500 Ksh.**
3. Binding the project	**200 Ksh.**
4. Miscellaneous expenses	**2,400 Ksh.**
TOTAL	**10,100 Ksh.**

7.0 CHAPTER SEVEN: PROJECT TIME MANAGEMENT

MONTH	JANUAR Y				FEBRUAR Y				MARCH				SEPTEMBE R				OCTOBE R				
WEEKS	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	
Concept paper																					
Literature Review																					
Writing the proposal																					
Proposal presentation																					
Improvement on proposal																					
Final presentation																					

8.0 CHAPTER EIGHT: CONCLUSIONS AND RECOMMENDATIONS

8.1.0 CONCLUSIONS

Having done a thorough study of our design, we arrived at the following conclusions;

This construction is safe for use in variable height conditions since the steps are always parallel to the ground ensuring maximum stability.

The design works perfectly when specifications and measurements in design components are done and selected carefully. This can be proved by our shear force-bending moment diagrams drawn from our calculations.

The choice of pneumatic cylinder size depends on the mass of the scissor staircase construction appropriate for the area of application and the load it is designed for.

8.2.0 SOURCES OF ERRORS

- Improper treatment of metal may cause mechanical defects.
- Ignoring the project design specifications.
- Improper loading.
- Using too many stacked links hence reducing rigidity and stability of the design.
- Poor fabrication techniques.

8.3.0 RECOMMENDATIONS

- Applied load should be within the specified range to prevent deflection and deformation.
- Loads should be applied centrally in the mechanism to ensure uniform distribution of stresses to minimize deflections.
- Proper selection of the specified material in construction of the design.
- Use of the specified pneumatic equipment in the construction of the machine.

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