Design and Analysis of Extended Handle Pneumatic Floor Jack for Light Vehicles

Abduljebar Mahmud Aliy

A Thesis Submitted to the Department of Mechanical Engineering

School of Mechanical, Chemical, and Materials Engineering

Presented in Partial Fulfillment of the Requirement for the Degree of Master's in Automotive Engineering

Office of Graduate Studies

Adama Science and Technology University

June 2023

Adama, Ethiopia

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Advisor: Ramesh Babu Nallamothu (PhD)

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DECLARATION

I declare that this master thesis entitled "**Design and Analysis of Extended Handle Pneumatic Floor Jack for Light Vehicles**" is my original work. That is, it has not been submitted for the award of any academic degree, diploma, or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation.

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RECOMMENDATION

I/we, the advisor(s) of this thesis, hereby certify that I/we have read the revised version of the thesis entitled "Design and Analysis of Extended Handle Pneumatic Floor Jack for Light Vehicles" prepared under my/our guidance by **Abduljebar Mahmud Aliy** submitted in partial fulfillment of the requirements for the degree of Mater's of Science in Automotive Engineering. Therefore, I/we recommend the submission of the revised version of the thesis to the department following the applicable procedures.

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APPROVAL PAGE

I/we, the advisors of the thesis entitled "Design and Analysis of Extended Handle Pneumatic Floor Jack for Light Vehicles" developed by **Abduljebar Mahmud Aliy**, hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

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Co-Advisor/Co-Supervisor	Signature	Date

We, the undersigned, members of the Board of Examiners of the thesis by **Abduljebar Mahmud Aliy** have read and evaluated the thesis entitled "Design and Analysis of Extended Handle Pneumatic Floor Jack for Light Vehicles" and examined the candidate during the open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Masters of Science in Automotive Engineering.

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NOMENCLATURE AND ACRONYMS

A	*Area*
ASTM	American Society for Testing and Materials
D	*Diameter*
CFD	*Computational Fluid Dynamic*
F	*Force exerted*
FEA	*Finite Element Analysis*
GVWR	Gross Vehicle Weight Rating
ISO	*International Standard Organization*
kPa	*Kilopascal*
LDV	*Light Duty Vehicle*
m^2	*Meter square*
Mm	*Millimeter*
MOGA	Multi-Objective Genetic Algorithm
N	*Newton*
NSGA-II	Non-dominated Sorted Genetic Algorithm-II
P	*Pressure*
PDF	*Partial Differential Equation*
PDF	*Portable Document Format*
PVC	*Polyvinyl Chloride*
RSM	Response surface methodology
SUV	*Sport Utility Vehicle*
t	*thickness*
USB	*Universal Serial Bus*

ABSTRACT

Drivers require a lifting device jack with a slot that fits in place under the car in the appropriate area while changing tires. Jacks are also necessary in workshops or maintenance centers for the maintenance and replacement of parts to make the process faster and easier. A pneumatic jack is a vital vehicle component that is employed in a variety of maintenance centers and/or by using shop truck vehicles for site maintenance purposes. When the pneumatic system is being adopted for the first time, however, it has to deal with the question of compressed air supply. The key part of any facility for the supply of compressed air is using a reciprocating compressor. The goal of this thesis is to design and analyze extended-handle pneumatic floor jacks for light-duty vehicles. Repairing more than two vehicles at a time by using a single compressor is economically effective. The designed pneumatic floor jack is used for a light-duty vehicle that has GVWR below 3860 kg only. The output of the research illustrates the effect of airbag thickness adding from 2.5mm to 3mm the load applied on the pneumatic floor jack to minimize the compression force. It will provide some guidelines to design and analyze extended handle pneumatic floor jacks for light vehicles from natural rubber and its static, and dynamic analysis using ANSYS 2022R1. There are different materials used to design and analyze extended handle pneumatic floor jacks for light vehicles; such as tire rubber, structural steel, stainless steel, air hose, pneumatic control valve, hollow shaft, PVC plastic, drive wheel, etc. were used. Depending on the analysis the result will be effectively utilized in modeling the extended handle pneumatic floor jack which is used to lift a vehicle's single tire at a time for performing maintenance and tire change. Finally, the thesis concluded the design of the extended handle pneumatic jack results in better performance than the four-wheeler cylindrical pneumatic jacks by saving workspace, time-consuming, and being easy to operate for elders, women, and everybody in the maintenance shops.

Keywords: *telescopic shaft, tire rubber, extended handle, control valve, air compressor, air hose*

CHAPTER ONE
INTRODUCTION

1.1 Background

1.1.1 Pneumatic System

The word ‘pneuma' comes from Greek and means wind. The word pneumatics is the study of air movement and its phenomena are derived from the word pneuma. Today pneumatics is mainly understood to mean the application of air as a working medium in the industry especially the driving and controlling of machines and equipment. Pneumatics has for some considerable time between used for carrying out the simplest mechanical tasks in more recent times and has played a more important role in the development of pneumatic technology for automation. Pneumatic systems operate on a supply of compressed air which must be made available in sufficient quantity and at a pressure to suit the capacity of the system (*S.Sathiyaraj, V.Selvakumar, 2015*).

When the pneumatic system is being adopted for the first time, however, it is necessary to deal with the question of compressed air supply. The key part of any facility for the supply of compressed air is means of using a reciprocating compressor. A compressor is a machine that takes in air, and gas at a certain pressure and delivered the air at high pressure. Compressor capacity is the actual quantity of air compressed and delivered and the volume expressed is that of the air at intake conditions namely at atmospheric pressure and normal ambient temperature. The compressibility of the air was first investigated by Robot Boyle in 1962 and which found the product of pressure and volume of a particular quantity of gas (*S.Sathiyaraj, V.Selvakumar, 2015*).

During the repair and maintenance of cars, it is necessary to lift a car (sometimes one tire or all the car) from the ground to change a tire or to repair the car, different types of jacks have been developed for this purpose, however, traditional manual jacks operate and it needs substantial and skilled effort from the user, in the same time traditional jacks are heavy, large and also difficult to carry or fix in the proper position under the car, also in commercial and maintenance centers services stations are commonly equipped with large and high adequate position car lifting required (*Timur Choban Khidir, et al. 2019).*

The design of a pneumatic triple airbag jack is tough and built to last for a long time. Triple pneumatic airbag jacks are the preferred jacking tool on frame racks which are necessary and highly effective in maintenance applications, construction, and car tire change (*Timur Choban Khidir, et al, 2019)*.

It is also used in aircraft construction and maintenance, shifting pipelines, and railroads. Physically weaker drivers (young drivers, women, and senior citizens,) may face Great difficulties in traditional jacking a vehicle (*Khurmi, R.S., et al., 2005).* In case of an emergency case or tire repair, also from time gaining the traditional vehicle jacks require the driver to retrieve the jack from the car. Fix it under the vehicle in the proper location, and then manually rotate the screw thread or start handling the hydraulic jack to lift the vehicle (*Timur Choban Khidir, et al, 2019)*. This process is time-consuming, while the pneumatic airbag jack can put in any location under the car frame, this invention is very easy and pretty helpful, and it uses the air from the exhaust of the car or external compressor to inflate an airbag that is strong enough to hold up the car (*Herkules Equipment Corporation, 2014)*. This lifting will take less than a minute. Once it lifts the car high enough the air source supply needs to turn off. The airbag will stay inflated. When the tire replaces or the maintenance finish has just released the valve, flatten it out and continue driving. The required lifting height of the car can be controlled by further inflating the airbag (*Eskandary, et al., 2016)*. The airbag is designed to be used in such lever-type applications and can sustain the shearing force.

Reconditioning, repairing, and replacing are the three virtual processes necessary for effective working, and traveling, and the tires due to continuous fatigue may even get punctured. And here to repair this problem and continue to travel, the pneumatic jack plays an outstanding and unavoidable role. Almost all four-wheelers have a pneumatic jack for usage in repairing and reconditioning, but light vehicles use only a manual pneumatic jack in which is laborious to use and requires manual impact force (*Vivek. J.V., et al., 2018*).

More powerful jacks employ pneumatic force to raise more objects over longer distances. Mechanical jacks are often certified for maximum lifting capacity, however, pneumatic jacks use regular power and may unexpectedly dislocate from the location where it is installed.

The main design limits of a mechanical hydraulic jack are that it functions on manual impact force, takes time, and energy consumption, and it can also be a difficult job for a worker working in garages. After considering all of these disadvantages, the quick-lifting hydraulic jack was created.

In light automobiles, a conventional mechanical jack is utilized as a part of the vehicle for tire maintenance and replacement when the need arises. As previously said, the impact force is required, and hence the pneumatic jack with gear arrangement is built inexpensively to handle these obstacles.

The four-wheelers regularly have to be maintained and reconditioned properly for the effective working of all the parts and also for smooth driving. But on a journey, a sudden puncture of the tires may arrive and if it has to be replaced by the driver or the worker in the garage through the mechanical floor jack it requires time and also impact the force again (*Vivek J.V, et al., 2018*).

This will most appropriately benefit senior citizens to provide a safe and simple automatic pneumatic jacking system without manual effort. To provide a novel jacking system that can be operated from within the vehicle through a valve control. There are certain mechanisms already available for the same purpose which has a definite capacity to lift the car wheels (*Gawade P.D, et al., 2017*).

Fabrication is based on pneumatics which deals with the study and application of pressurized air to produce mechanical motion. A pneumatic jack is a fabricated model which when installed in four-wheelers, will ease the problems arising in the conventional-operated jack. This fabricated model consists of a small-size reciprocating air compressor which is driven by the battery used four-wheelers, an air tank to store the compressed air, a pneumatic control valve that regulates the airflow, and a double-acting cylinder used as a jack that performs lifting. Thus the car is lifted using a jack and the problem related to tires such as punctured tires, tire replacement, and wheel balancing can be resolved with less effort and time. While driving four-wheelers in the way when we faced a problem related to tires there is a hectic manual procedure used to lift a vehicle i.e., the use of a manual or hydraulic operated jack which requires extra human effort and time i.e., to place a jack in a supportable position then applying muscular force to screw in the jack for a spherical and transitional motion to lift vehicle. To save this effort and time we propose a fabricated model based on Pneumatics *(Shubham Gumphalwar, et al., 2018*).

Due to the difficulty of operating automobile jacks, various forms of electric jacks have been proffered. With the development of such electric jacks has gradually come an understanding of some of the problems associated therewith. Due to the torque needed to lift something as heavy as most automobiles, a severe mechanical advantage must be utilized. Jacks that are built into an automobile have not been accepted due to expense and the need to at least lift each side of an auto if not all corners individually (*Gawade P.D, et al., 2017*).

1.2 Statement of the Problem

With the intention of increase productivity, saving time and money, space, and also environmentally friendly, and requiring less human effort pneumatic jack is necessary equipment for maintenance service. Drivers require a lifting device jack with a slot that fits in place under the car in the appropriate area while changing tires. Pneumatic jacks are necessary in workshops or maintenance centers for the maintenance and replacement of parts to make the process faster and easier. Currently, existing jacks are difficult to lift for the elderly and women in maintenance shops, and they are especially inconvenient in bad weather. The introduction of the design of pneumatic floor jacks can increase productivity, minimize the skilled labor force, save time and money, and space for industrial, maintenance, and construction applications is one of the potential components.

To solve the problem in this regard extended handle pneumatic floor jack is an important role. The significance of this study work is that it is simple to use for women, the elder, or anybody who has a problem with their vehicle's tires in the shop and on the road by using a shop truck for maintenance propose.

1.3 Objectives

1.3.1 General Objective

The general objective of the research is to design and analyze extended-handle pneumatic floor jacks for light-duty vehicles.

1.3.2 Specific Objectives

To achieve the general objective of the research the following specific objectives are carried out:

- To design and assemble tire bag, telescopic shaft, and extended handle of pneumatic floor jack for light-duty vehicles.
- To analysis the static and dynamic load of the pneumatic floor jacks by using a finite element analysis test.
- To validate the numerical results by considering three tire bag thicknesses and compare with a four-wheeler cylindrical pneumatic jack for light vehicles.

1.4 Scope of Thesis

The extended handle pneumatic jack designed is used for only light-duty vehicles with GVWRs less than 3860 kg. The pneumatic bag thickness design focused on three determined thicknesses 2.5mm, 2.75mm, and 3mm to get a pneumatic bag that met the design requirements of the extended handle pneumatic jack for light-duty vehicles. Due to the limitation of compressed air sources everywhere, the applicable area of usage for this thesis is at the vehicle maintenance shop where an air compressor is available.

1.5 Significance of the Study

The research findings illustrate the effect of airbag thickness adding from 2.5mm to 3mm the load applied on the pneumatic floor jack to minimize the compression force. It will provide some guidelines on how to design extended-handle pneumatic floor jacks for light-duty vehicles from pneumatic bags. It also gives a better understanding of the pneumatic jack advancement over cylindrical pneumatic jack for users and researchers.

1.6 Beneficiaries of the Study

If this thesis were fabricated; vehicle owners, maintenance centers, private garages, researchers, designers, and job seekers are benefit from this.

1.7 Structure of the Thesis

The paper is organized into five chapters:

Chapter One: Introduction part which includes background, statement of the problems, objectives, scopes, and the significance of the study.

Chapter Two: Literature review emphasizes the past studies which have information pertinent to the study**.**

Chapter Three: Materials and methods deals with the methodology to be followed to accomplish the thesis.

Chapter Four**:** Results and discussion found at the end of the research.

Chapter Five: Conclusions, recommendations, and future work that this thesis cannot reach due to economic and office work challenges to do the necessary procedures of the thesis.

CHAPTER TWO
LITERATURE REVIEW

The primary goal of the literature review is to clarify the research gaps and problems under examination, to describe the link of each work to the others under evaluation, and to identify new methods to interpret earlier research.

The design of a pneumatic-operated jack for four-wheelers came with the following results. They could lift the weight of 25 kg at 327kPa and the volume of the air that can be stored in the storage tank is 66.05m^3. The pneumatic working fluid is also widely available and most factories are pre-plumbed for compressed air distribution, hence pneumatic equipment is easier to set up than hydraulics. To control the system, only ON and OFF are used and the system consists only of standard cylinders and other components, making it simpler than hydraulics. The working fluid of the pneumatic system absorbs excessive force, leading to less frequent damage to equipment (P. S. Borkar, *et al.*, 2015).

2.1 Pneumatic System

Pneumatics is a branch of mechanics that deals with the mechanical properties of gases. It works with the study of pressurized gas that produces mechanical motion, and the application of such gases to produce motion. Systems based on pneumatics are found in factories that deal with compressed air and inert gases. The energy produced by pneumatic systems can be more flexible, less costly, more reliable, and less dangerous than some actuators and electric motors.

The pneumatic system used extensively in the industry is commonly powered by compressed air or compressed inert gases. A centrally located and electrically powered compressor powers cylinders, air motors, and other pneumatic devices. A pneumatic system controlled through manual or automatic solenoid valves is selected when it provides a lower-cost, more flexible, or safer alternative to electric motors and actuators. Most industrial pneumatic applications use pressures of about 550 to 690 kPa.

Pneumatic systems generally have long operating lives and require little maintenance. Because gas is compressible, equipment is less subject to shock damage. Gas absorbs excessive force, whereas fluid in hydraulics directly transfers force. Compressed gas can be stored, so machines still run for a while if electrical power is lost.

2.1.1 Components of Pneumatic System

Pneumatic technology deals with the study of behavior and applications of compressed air in our daily life in general and manufacturing automation in particular. Pneumatic systems use air as the medium which is abundantly available and can be exhausted into the atmosphere after the completion of the assigned task (C. Jagadeesh Vikram, D. Mohan Kumar, 2018).

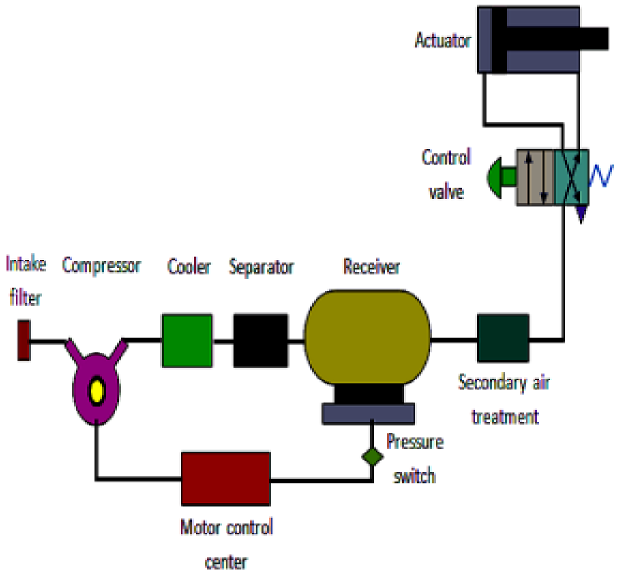


Figure 2. 1: Basic components of pneumatic systems (C. Jagadeesh Vikram, D. Mohan Kumar, 2018)

The Pneumatic working fluid is also widely available and most factories are pre-plumbed for compressed air distribution, hence pneumatic equipment is easier to set up than hydraulics. To control the system, only ON and OFF are used and the system consists only of standard cylinders and other components, making it simpler than hydraulics. The working fluid of the pneumatic system absorbs excessive force, leading to less frequent damage to equipment. We can lift a weight of 25 kg at a pressure of 200kPa (Gawade P.D *et al.*, 2017).

The inbuilt automatic pneumatic jack for a four-wheeler can lift the weight of 25 kg at 327 kPa. The volume of the air that can be stored in the storage tank is $66.05m^3$. Pneumatics working fluid is also widely available and most factories are pre-plumbed for compressed air distribution, hence pneumatic equipment is easier to set up than hydraulics. To control the system, only ON and OFF toggle switches are used and the system consists only of standard cylinders and other components, making it simpler than hydraulics. The working fluid of the pneumatic system absorbs excessive force, leading to less frequent damage to equipment. In case of excess pressure built-in, a pressure relief valve can be installed to release the excessive pressure when it crosses the required pressure limit (Manjesh BC, (2018).

The working medium adopted is compressed air. The compressed air is transmitted through tubes to a pneumatic cylinder where power is converted into reciprocating motion. The reciprocating motion is obtained by using an electrically controlled solenoid valve. The control unit provides the input to the solenoid valve. The jack receives reciprocating motion from the piston, which moves on the cylinder. The jack is placed under the vehicle chassis, where the vehicle is to be lifted. The vehicle can be lifted when the solenoid valve is switched. The vehicle over the jack gets the reciprocating motion through the piston which is connected to the jack (Shubham Gumphalwar, *et al.*, 2018).

The design was focused on all the processes of conception, visualization, calculation, refinement, and specification of details that determine the form of the product. Hence, the said electrically operated toggle jack for vehicles, specifically the scissors type has gone under force analysis so that its performance criterion will not fail in any sense. The main physical parameters of the design are determined through the appropriate calculations and practical considerations with reasonable assumptions. From the force and stress diagram in Figure 2.2, it was discovered that at the maximum raising height of 240mm of the horizontal tensile force in the opposite direction is the same. It is also the same for the minimum raising height of 115mm. Mild steel is used as the material for both gears due to its high strength, toughness, tooth hardness, and its economic effects.

Based on the Finite Element Analysis, it has been determined that the car jack system undergoes a peak nodal displacement of around 0.087974 mm (as shown in Figure 2.2) when exposed to a maximum load of 5000N. Furthermore, maximum Von Misses stress (a value used to assess if a given material will fracture), maximum principal stress, maximum shear stress, and shear stress values in safe point were noticed since tensor stress for all materials used was analyzed. (Gaurav Shashikant Udgirkar, *et al.*, 2014).

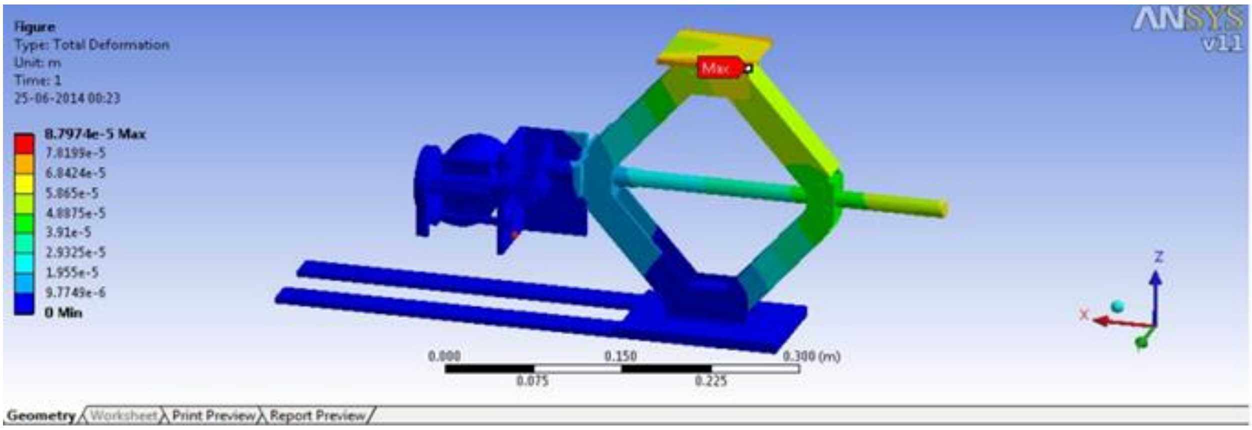


Figure 2. 2: Deformation pattern for jack (Gaurav Shashikant Udgirkar, *et al.*, 2014)

The following summary of results done by Finite Element Analysis test of the pneumatic bag jack [Von-Mises stress, and deformation] done by applying pressure P = 249809.6 N/m^2 for two different thicknesses of pneumatic airbag jack, t = 1 mm and t = 3 mm, (Timur Choban Khidir, *et al.*, 2019).

Table 2. 1: Summary of results (Timur Choban Khidir, *et al.*, 2019)

Item	Rubber Thickness (1mm)	Rubber Thickness (3mm)
Von-mises stress N/m^2	4.621e+007	1.566e+007
Max allowable stress N/m^2	20e+006	20e+006
Strain(mm)	4.107e+003	1.338e+003
Deformation(mm)	13.24e+005	3.756e+005
Deformation X-axis(mm)	2.907e+005	1.021e+005
Deformation Z-axis(mm)	12.91e+005	3.632005

A directional control valve that ensures the flow of air to airports by opening, closing, and switching their internal connections is described in Figures 2.3 and 2.4. Their classification is determined by the number of ports, the number of switching positions, the normal position of the valve, and its method of operation. Common types of directional control valves include 2/2, 3/2, 5/2, etc. The first number represents the number of ports; the second number represents the number of positions (Bobbili Seshagiri Rao, 2017).

i) 5/2 directional control valve

A directional control valve that has two ports and five positions can be represented by the drawing in Fig. 2.3, as well as its unique pneumatic symbol.

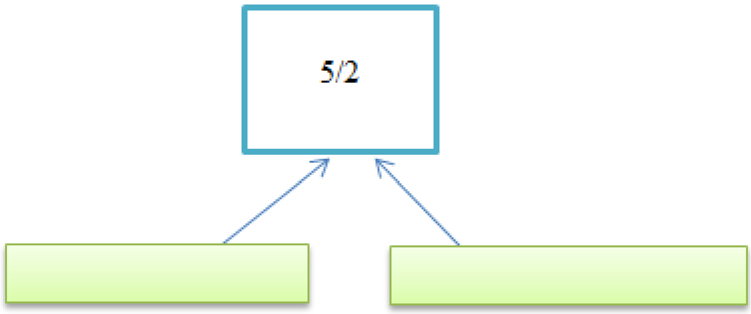


Figure 2. 3: Describing a 5/2 directional control valve (Bobbili Seshagiri Rao, 2017)

ii) 2/2 Directional control valve.

The structure of a 2/2 directional control valve is very simple. It uses the thrust from the spring to open and close the valve, stopping compressed air from flowing towards working tube "A" from air inlet "P". When a force is applied to the control axis, the valve will be pushed open, connecting "P" with "A" in Figure 2.4. The force applied to the control axis has to overcome both air pressure and the repulsive force of the spring. The control valve can be driven manually or mechanically and restored to its original position by the spring.

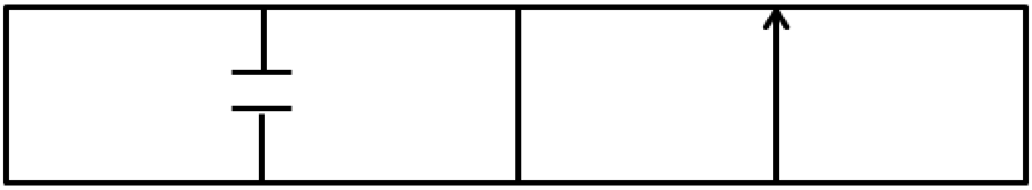


Figure 2. 4: Symbol of a 2/2 directional control valve (Bobbili Seshagiri Rao, 2017)

The actual working principle of a pneumatic system that lifts the car by using pressurized air. The cylinder is mounted centrally on the chassis. When the pressure valve is open then pressurized air flows in the direction of the pneumatic cylinder which can push the piston. This certain amount of pressure pushes the piston in the direction of the bell crank lever. The bell crank lever operates under the guidance of the c-channel. When the bell cranks liver forms a certain angle with the surface. These bells crank the liver touch the ground and lift the vehicle upward.

Once the car is lifted to a desired height the tires can be changed. It is the specialty of a simple jack that it possesses a self-locking system i.e. once the car is lifted to a certain height and even if the power to the jack is cut off the jack can still hold the entire part of the car that is lifted by it. And thus, the driver can easily change the tire.

Once the tire is changed, now the concern is to release the pressure in the jack which is in the form of pressurized air. Thus a relief valve is provided on the jack for this purpose. Once the relief valve is opened the air in the cylinder which has lost its pressure energy, starts returning to the control unit. Once the air starts returning the control unit then sends the accumulated air back to the cylinder. And in this way, the entire system was working, (Anal A Bangre, *et al.*, 2014).

The design load is important to calculate the amount of load that the pneumatic will be lifting when in operation on the test vehicle. The wheel-vehicle-airbag system works as a class 2 levers as shown in Figure 2.5. The mechanical advantage of this lever system is used to calculate the input force needed for a particular output force needed, which in this case is the 907.18kg design load. It is assumed that the center of gravity of the vehicle is on or very close to the center line of the vehicle along its length. Since the weight of the vehicle acts on its center of gravity and the input force of the airbag is located at the edge of the vehicle, the input distance is approximately twice that of the output distance. Figure 2.5 shows the relation between the load, lift point, and the fulcrum about which the vehicle is raised, (Faizan Nasir, 2009).

$$\text{Input Force} = \frac{\text{Output Force} \times \text{Output Distance}}{\text{Input Distance}} \tag{2.1}$$

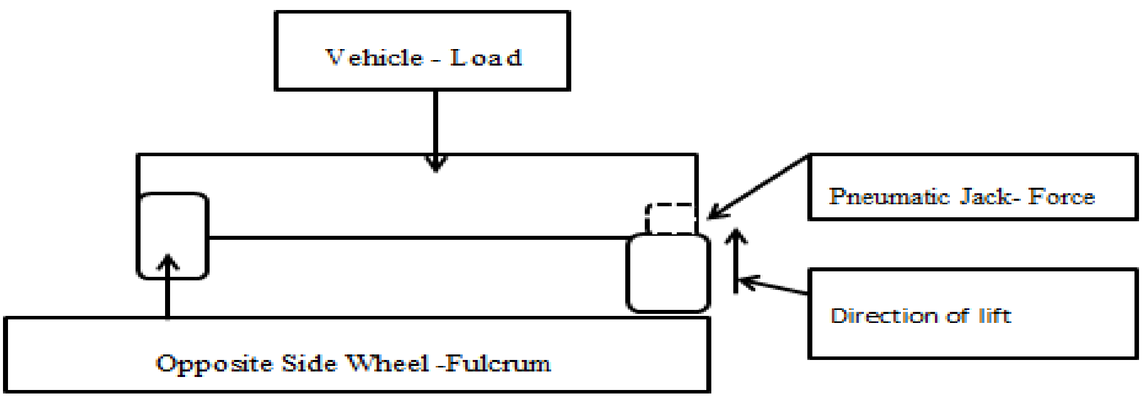


Figure 2. 5: Wheel vehicle jack lever design for 907.185Kg load (Faizan Nasir, 2009)

The operating systems of a pneumatic jack before using it must purge its pneumatics circuit to add any possible air to the system. To purge the system open the release valve, turning it anti-clockwise. Then with the aid of the lever operates the pump several times. Close the release valve with the lever in a clockwise direction until it is fully closed. The jack is now ready for use. To lower the jack, turn the release valve very slowly in an anti-clockwise direction. Always keep the jack in a vertical position, with the ram, extension screw, and pump retracted after use. If you require horizontally operating the jack the pump should be located on the jack's lower side (B. Babu, *et al.*, 2017).

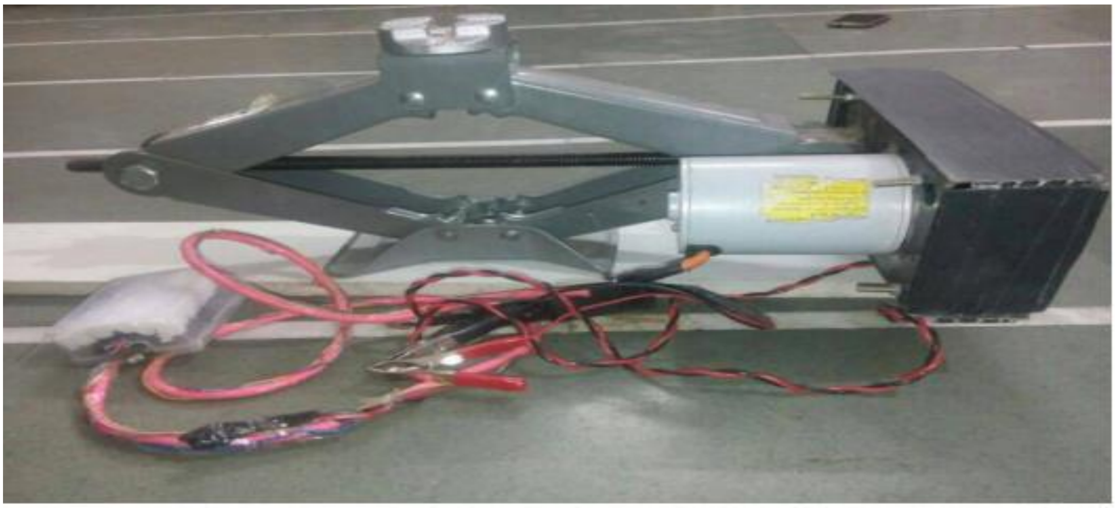


Figure 2. 6: Side view of the modified electric jack (B. Babu, *et al.*, 2017)

As shown in Figure 2.6 an electric jack is modified from a simple mechanical toggle jack. It shows an electric motor connected parallel with the power screw of the jack through the gearbox. The electric motor is connected to a remote which can use to lift and lower the jack, (Jayesh Vaghmash, *et al*. 2017).

Table 2. 2: Comparison of pneumatic jack and manual jack (J. Vaghmash, *et al*. 2017)

Pneumatic jack	Manual toggle jack
Can be done painlessly, saves time & energy	Consume a lot of time and energy
Durable and withstands high pressure/load	Durable and withstands high pressure/load
Automatic but still involves minor manual jobs	Everything needs manual work
The initial cost is slightly higher than the manual jack	Cheap and equipped in almost every vehicle
The compressor provides much more air per minute but provides less force per revolution and so less load-carrying capacity	Needs much fewer rotations per minute but produces higher force/torque per revolution and so high load-carrying capacity
High quality	High quality

The designed and developed integrated pneumatic car jack is a highly desirable jack to become available in vehicles that can be operated by compressed air. It is highly useful for pregnant ladies and old age people. Reduce human efforts, and utilize them for commercial business. Low-maintenance products designed (Kaushal H. Pandya, *et al.,* 2018).

Make an impressive task in the field of automobile and automobile workshops. It was very useful for women and old aged persons who drive cars. The project also reduced the cost involved in the corner. Their motto was to reduce human effort and increased safety (Akshay M. Rokde, *et al.*, 2018).

Designed and fabricated automatic pneumatic inbuilt jack system by using fifth wheel parking system was studied with a reduced size, pneumatic cylinder, and 0.07kgf/cm^2 compressor are used to operate. Various analyses were made on the jack. Before conducting the trial, the weight of the vehicle, and the analysis of each part were made. After the trial, it helps to evaluate whether the jack works properly and whether the fifth wheel helps to parallel parking (Atul A Dhawale, *et al.*, 2017)**.**

2.2 Tire Rubber

Rubber is an elastic substance that is obtained by coagulating the milky juice of any of various tropical plants (as of the general Hevea and Ficus) is essentially a polymer of isoprene, and is prepared as sheets and then dried Indian rubber. Rubber is an ideal material because it is strong, mostly unaffected by temperature changes, and is readily available. There is more to your standard tire than just the rubber we know it for. There is a surprising amount of engineering and design that goes into the tire industry.

2.2.1 Rubber Construction

There are two main types of rubber: natural rubber, which is made from latex extracted from plants (primarily the rubber trees and synthetic rubber (any artificial elastomer), which is manufactured from petroleum byproducts and includes some forms of styrene butadiene (SBR) and Polyacrylics polyvinyl acetate (PVA).

2.2.2 Natural Rubber (Polyisoprene)

Natural rubber is found as internal fluids of many plants & trees. It has excellent mechanical properties i.e. impact strength, resilience, tensile strength, abrasion resistance, tear resistance, and electrical insulation. Natural Rubber is usually used for applications where the highest physical properties are required, i.e. tires, gaskets, seals, Anti-vibration pads, electrical components, expansion bellows, conveyor belts, etc. Natural Rubber is not recommended for Chemical resistance, Fuels, Oils & Solvents (www.kurwarubber.com).

Table 2. 3: Natural rubber grade and specification (www.kurwarubber.com)

Specific Gravity	From 1.05 To 2.00	gm/cm^2
Hardness Range	From 10 To 100	Shore-A
Tensile Strength(265.5Kg/cm^2 taken as allowable)	Upto 300	Kg/cm^2
Elongation	Upto 800	%
Temp. Range	-25 To +75	deg. C

2.3 Literature Review Summary

The pneumatic working fluid is also widely available and most factories are pre-plumbed for compressed air distribution, hence pneumatic equipment easy to set up than hydraulic, and the working fluid of the pneumatic system absorbs excessive force, leading to less frequent damage to equipment. To control the system, only the ON and OFF toggle switches are used. To full fill, the requirements complete operation of the machine double acting pneumatic cylinder, solenoid valve, flow control valve, connectors, and hoses were used materials. The design considers the processes of conception, visualization, calculation, refinement, and specification of details that determine the form of the product. The literature reviewed the relationship between the load, lift point, and the fulcrum about which the vehicle is raised. Comparisons between electric jack and manual jack were conducted by consideration of different parameters and an integrated pneumatic car jack is a highly desirable jack to become available in vehicles that can be operated by compressed air. Comparisons natural rubber, which is made from latex extracted from plants (primarily the rubber trees and synthetic rubber (any artificial elastomer), which is manufactured from petroleum byproducts and includes some forms of styrene butadiene (SBR) and Polyacrylics polyvinyl acetate (PVA).

2.4 Research Gap

The main research gap of this review was the reviewed kinds of literature focused on four-wheelers or parking fifth wheelers pneumatic cylinder car lift that lifts the entire vehicle's body. But, the work done in some of the works of literature is too little to apply to our country's economic approach to designing and manufacturing cylindrical pneumatic jacks for job seekers. The existing pneumatic jacks lift the vehicle's entire body even if to change a single tire and/or to repair a single component. Conventional screw jacks take more time to lift than extended-handle pneumatic bag floor jacks. A pneumatic jack that is built into the chassis of the vehicle adds extra components to the vehicle and components are compactable which cause to maintenance difficult. The air source from the vehicle’s engine that needs the compressor or derived by the engine might expense to build the entire component on it. Existing jacks require more effort for the elderly and women and are especially disadvantageous under adverse weather conditions and economically more costly than pneumatic floor jacks.

More than two pneumatic floor jacks can use in the maintenance center but, even a well-organized shop may be not able to use one or two at a time four-wheeler jacks. A pneumatic floor jack needs less space area than a cylindrical pneumatic car jack and lifts the vehicle wheel at desired height selected. The study aims to consider two different thickness designs to validate appropriate thickness and provide an extended handle to prevent an accident that might happen during lying down under the vehicle lifted.

CHAPTER THREE
MATERIALS AND METHODS

This section includes the materials used and methods followed in designing and analysis of light-duty vehicle floor jacks with pneumatic and mechanical systems. The materials required for this design and the methodology to be followed are given below.

3.1 Methodology

The following procedures were utilized to meet the research objectives:

- A literature review was done to acquire relevant data and the experimental inquiry collected certain critical features of tire rubber and the analysis of jack components.
- Actual data was gathered by seeing and measuring the Toyota Land Cruiser HZJ79L and Hilux LAN25L-PRMDEN pickup four-wheeled light vehicle specifications.
- The telescopic stainless steel and tire rubber materials extended handle of a pneumatic jack for a light weight four-wheeled vehicle was theoretically calculated.
- Make a 3D model of the telescopic shaft, rubber bag, extension handle, and base parts by SOLIDWORKS 2020.
- Make an analysis of tire rubber materials, stainless steel, and structural steel materials used to design the pneumatic jack.
- Finally, state the results of the ANSYS 2022 R1 workbench.

Generally, the overall workflow of the study methodology looks like below:

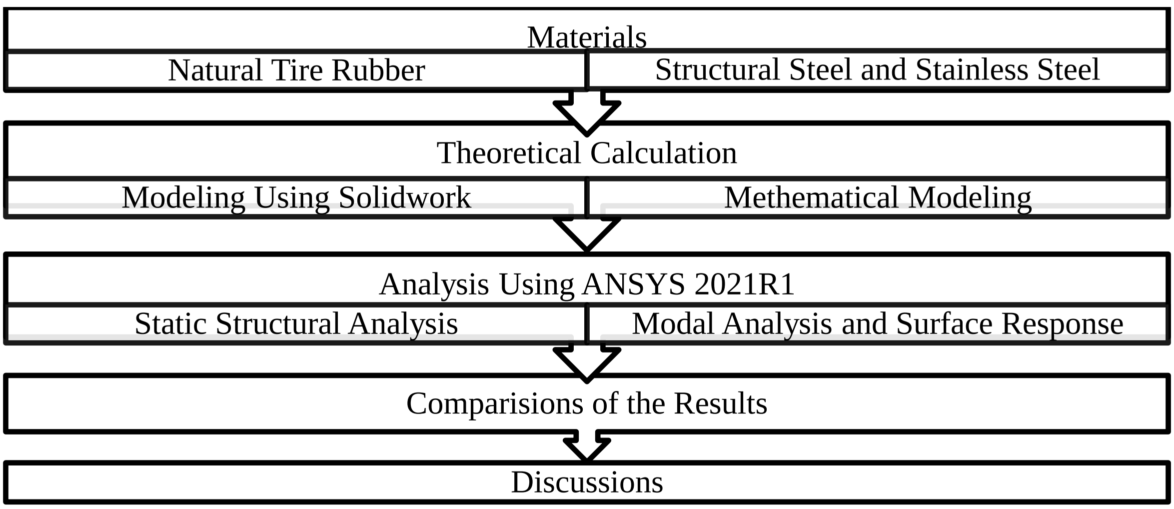


Figure 3. 1: Workflow of study methodology

3.2 Data Collection

Primary data were gathered by visiting commercial automotive sales and services shops and the governmental maintenance shops to identify what kind of jacks they are using and the problems are being faced. It is observed that electrically controlled hydraulically actuated car lifters in some private vehicles' sales and maintenance shops and Conventional jacks like scissor jacks, hydraulic jacks, and mechanical jacks are being used in governmental and private garages. The problems identified during their operation were identified as follows:

- ☞ Inability to raise weight: Overloading, trapped air, lack of lubrication, rust, and high/low oil levels are major causes of trouble lifting the load.
- ☞ Performance issues include water contamination, filter blockages, excessive fluid temperatures, and improper hydraulic fluids.
- ☞ Jack placement over uneven ground, load slipping off the jack, and attempts to lift more weight than the jack can support.
- ☞ A jack that has overflowed with fluid develops internal leaks, runs the risk of blowing out seals, and loses pressure.
- ☞ The friction in the screw threads increases as the load increases. A fine-pitch thread decreases the speed at which the jack can operate while increasing the advantage of the screw.

Secondary data were collected from various research papers, browse websites, manuals, textbooks, literature reviews, and media sources are:

- ☞ pneumatic bag jacks designed without extended handles which are not appropriate for use by everybody
- ☞ The designed cylindrical pneumatic jacks lift the entire vehicle's body for every task of maintenance
- ☞ Using hydraulic jacks difficulties are jammed or stalled wheels and frothy liquid spills.
- ☞ Four-wheeler pneumatic jacks, which are more expensive than pneumatic floor jacks, elevate the entire vehicle's body even if simply changing one tire or repairing the car.
- ☞ Even in a well-organized shop; more than two four-wheeler pneumatic jacks cannot be utilized at the same time because it takes more space

3.3 Components of Pneumatic Floor Jack

3.3.1 Control Valves

There are three valves on the triple pneumatic jack: air inlet valve, air outlet valve, and relief valve, which can help to operate the jack securely and quickly. First, keep the red valve closed, open the green valve, and input the compressed air; when inflating to the height, turn off the green valve. After use, open the red valve to bleed off the air. The relief valve in the middle ensures the injected gas is not excessive to ensure the security of the process.

3.3.2 Extended Handle and Pneumatic Bag

This pneumatic bag jack has a long handle, which makes the jack easy to move and use. And this handle can be disassembled from the middle, saving space and making it suitable to keep in the trunk. In addition, the long handle and the wheels make it easy to drag.

The pneumatic jack is a high-strength steel that makes the whole body secure and durable. Highly sealed airbags will not leak or be scratched. The quick jack car lift is suitable for the situation where a single wheel needs to be lifted in soft terrain for family-used cars, minivans, SUVs, and field vehicles. A pneumatic bag jack is designed to lift a vehicle, not off the ground. It is commonly used to lift a car enough to change a tire or perform maintenance underneath the vehicle.

3.3.3 Capacity

Because pneumatic bag jacks are used to lift vehicles with uneven weight distribution, they tend to be rated with a higher capacity than traditional floor jacks. If you need to lift a vehicle from the ground, the capacity of the pneumatic jack should be equal to or greater than the curb weight of the vehicle on which plan to use it. The vehicle's curb weight is its total weight, including the contents of its fuel tank and all of its standard equipment. It excludes the weight of any cargo, passengers, or extra equipment. Curb weight is considered the closest weight to the actual weight of the car.

The actual weight of a vehicle can be precisely determined by weighing the vehicle on a large scale. Scales for cars and trucks are often found at truck stops or where cargo is loaded onto trucks. By taking the Gross Vehicle Weight Rating (GVWR) and deducting the vehicle's payload or passenger/cargo capacity from GVWR, one can determine the curb weight. It is printed on the vehicle's compliance label (door jamb label). Payload or passenger/cargo weight capacity may be printed on the tire specification label located in a door jamb area. The capacity of extended handle pneumatic floor jack for light-duty vehicles is 3 tons.

3.3.4 Height

Height is important because it will determine whether or not one can use the jack for certain maintenance tasks on the vehicle. It should have enough height to allow for the removal of the old tires and the installation of new tires. To determine the appropriate lifting height of the pneumatic bag and to minimize width it is designed by triple balloons. So the minimum height is 140mm and the maximum height is 500mm.

3.3.5 Lifting Speed

The lifting speed of a pneumatic jack is an important consideration when making the selection. It refers to the time it takes from the start of inflation to full lift. The three main speed options are; slow, medium, and fast. Slow lifting speeds are usually between 4-6 seconds per centimeter of travel. This provides a smooth, controlled lift. Medium lifting speeds are usually between 2-4 seconds per centimeter of travel. Fast lifting speeds are usually between 1-2 seconds per centimeter of travel. The lifting speed of the telescopic shaft is controlled by selecting inlet valve graduate positions on the valve.

3.4 Design of Telescopic Shaft at Idle Position

When the pneumatic jack is at an idle position there is no air accumulated in the airbag and the telescopic shaft at the bottom level. The dimensions and the 3D model of the bottom section of the telescopic shaft are shown in Figure 3.2.

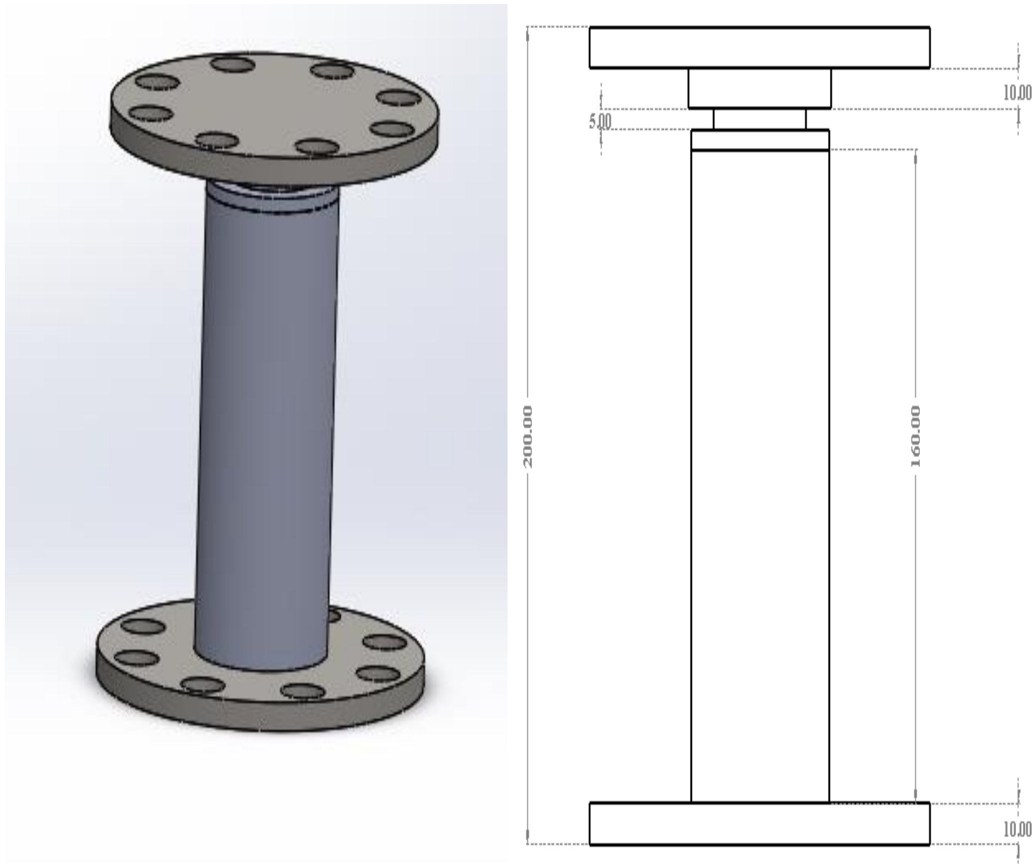


Figure 3. 2: Telescopic shaft 3D model and its dimension at idle position

Table 3.1 summarizes the dimensions of the telescopic shaft in the idle position.

Table 3. 1: Dimensions of telescopic shaft

I/No	Telescopic outer diameter(d) (mm)	Telescopic inner diameter(d_1) (mm)	Telescopic height(h) (mm)	Telescopic total height(h_T) (mm)	Telescopic base diameter(d) (mm)	Telescopic head diameter(d_2) (mm)
1	60.86	40.86	160	200	150	63

The cross-sectional areas of the telescopic shaft are as follows:

$$A = \frac{1}{4}\pi(d - d_i)^2 \tag{3.1}$$

The area of the Telescopic shaft at the idle position is equal to the bottom area (A_3) of the extended telescopic shaft is equal to 35,639mm^2. So the capacity of the compressor at the Ethiopian construction works Corporation Maintenance Center, and different Commercial Vehicle Sales and Service Companies is 8.5 bar (850kPa) and is taken as the reference in the case of this thesis study. At the idle position, the force is zero since the pressure was not applied to the airbag.

3.5 Design of Extended Telescopic Shaft

Most compressed air equipment is designed to operate at around 6-10 bar (500-1000kPa) (www.air-compressor-guide.com). So the capacity of the compressor at the Ethiopian Construction Works Corporation Maintenance Center is 8.5 bar (850kPa) is taken as the reference one.

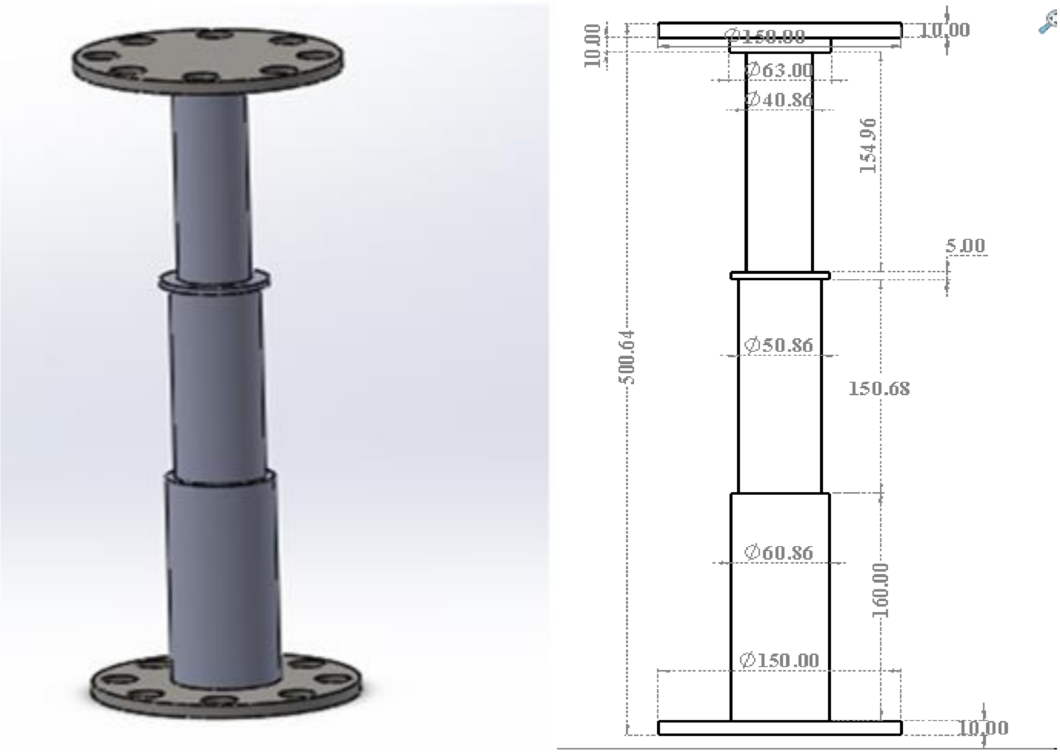


Figure 3. 3: Telescopic shaft 3D model and dimensions at extended position

The pneumatic jack with its internal stabilizer telescopic shaft specifications is given in Table 3.2.

Table 3. 2: Dimensions of extended telescopic shaft

Item No.	Telescopic diameter (mm)	Telescopic height (mm)	Total height of telescopic (mm)	Telescopic base diameter (mm)	Telescopic head diameter (mm)
1st	40.86	164.96	500.64	150	63
2nd	50.86	155.68			
3rd	60.86	160			

Where, A_1, A_2, and A_3 are the areas of the telescopic shaft, and h_1, h_2, and h_3 are the height of the telescopic shaft from top to bottom respectively.

Table 3. 3: Calculated values of telescopic shaft area, a moment of inertia, and other parameters are:

I/No	Parameter	1	2	3	4	5	6	7	Total
1	Area of telescopic (mm^2)	17662.5	1859.66	604	1750	706.5	863.5	17662.5	40402.16
2	Distance from neutrals axis (mm)	505	495	407.5	322.5	245	90	5	267.33
3	Moment of inertia (mm^4)	24837890.6	647279.65	97014.35	510250	181040.62	329209.4	24837890.6	2.64E-05
4	Section Modulus (mm^3)	331339.85	20548.56	4748.62	17008.33	7241.63	10973.65	331339.85	65310.11
5	The radius of gyration (mm^2)	37.5	18.66	12.67	18.03	16	19.53	37.5	

3.6 Design of Pressurized Pneumatic Bag

Figure 3. 4: Pneumatic air bag jack assembly

Toyota pickup vehicle is selected for pneumatic jack design and analysis the specification of the Toyota Land Cruiser 79 and Hilux double cabin are given in Table 3.4.

Table 3. 4: Specification of land cruiser 79 and hilux double cabin pick-up

Item No.	**Parameter**	**Detail Description**	
		Land Cruiser 79	**Hilux D/C**
1	Model code	HZJ79-DKMRS	LAN25L-PRMDEN
2	Drive	4x4	4×4
3	Transmission	5-speed & Manual	5-speed & Manual
4	Suspension	Front: Coil and Rear: Leaf	Front: double triangle and Rear: rigid axle with leaf spring
5	Brakes	Front: disc & rear: drum	Front: disc & rear: drum
6	Number of doors	4	4
7	Number of seats	6	6
8	Seat material	Vinyl	Vinyl
9	Engine model	1HZ	5L-E
10	Color	White, Silver Metallic, Grey, Blue	White, grey, black, blue

11	Displacement (mm)	4164	2986
12	Number of cylinders	6	4
13	Maximum power (km/rpm)	96/3800	70/4000
14	Maximum power(bhp/rpm)	129/3800	94/4000
15	Maximum torque (Nm/rpm)	285/2200	197/220
16	Electrics (volts)	12	12
17	Fuel type	Diesel	Diesel
18	Fuel tank capacity (liters)	130	80
19	**Curb weight(kg)**	2280	1870
20	Gross vehicle weight(kg)	3200	2710
21	Payload(kg)	920	840
22	**Dimensions (mm)**	L×W×H: 5240×1800×1980	L×W×H: 5255×1760×1810
23	Wheelbase(mm)	3180	3085
24	Ground clearance(mm)	235	265
25	Tires	Front & Rear :7.50R16-8 5.50F-Tubed	205R16
26	Tire type	Radial	Radial
27	Front and rear seating arrangement	1+2 and 3 forward facing	1 and 3 forward facing
28	Front & rear seating type	Bench	High adjustable & 3seats(40/60)
29	Owner's manual English	Tool kit & jack	Tool kit & jack
30	Air conditioning	Light reminder warning with buzzer	Manual

To determine the areas of the pneumatic bag jack shown in Figure 3.5 the cylindrical area calculation is used as shown in the equations below.

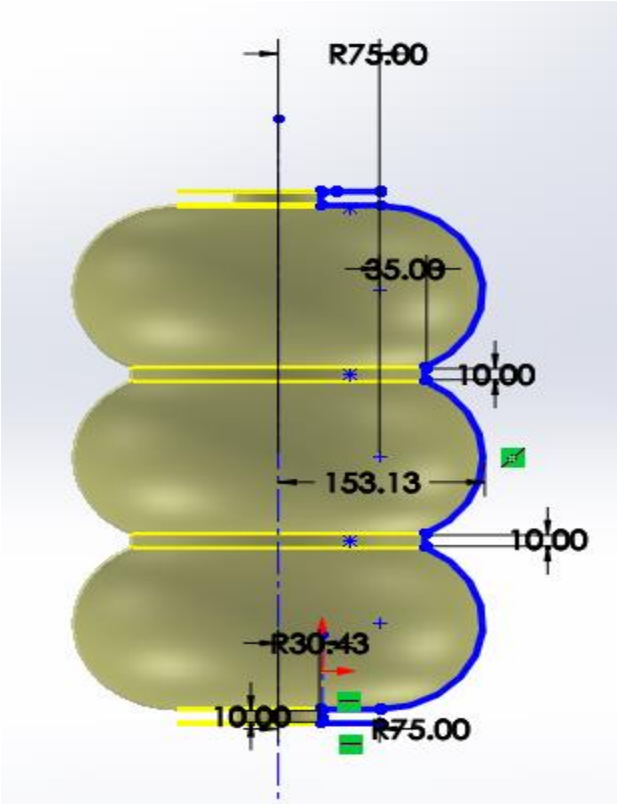


Figure 3. 5: Pneumatic floor jack dimensions

$$A_T = 2\pi r^2 + h(2\pi r) \quad (3.2)$$

As the specification gives in Table 3.4 the Curb weight is the weight of the vehicle including a full tank of fuel and all standard equipment. The weight of any passengers, cargo, or extra equipment is not included. Curb weight is considered the closest weight to the actual weight of the car.

The actual weight of a vehicle can be precisely determined by weighing the vehicle on a large scale. Scales for cars and trucks are often found at truck stops or where cargo is loaded onto trucks.

The curb weight can be calculated by taking the Gross Vehicle Weight Rating (GVWR) and subtracting the vehicle payload or passenger/cargo capacity from it. The vehicle's compliance label (door jamb label) displays the GVWR. Payload or passenger/cargo weight capacity may be printed on the tire specification label located in a door jamb area.

From Table 3.4 two large-weight vehicles (Toyota land cruiser HZJ79L and Toyota Hilux Double Cabin Pick-up) were selected as a sample to calculate the load of the payload of the vehicle =950 kg and 840 kg respectively.

The curb weight of both vehicles is 2280 kg and 1870 kg respectively.

The calculated total masses of the vehicles are the sum of payload + Curb weight =3200kg and 2710 kg and take acceleration due to gravity (g) = 9.81 m/s^2.

The value of the safety factor, according to (Rupesh N. Kalwaghe and K. R. Sontakke 2015), ranges from (1.3-2.25), and then take a factor of safety of 1.5.

Therefore, let's take the large weight to calculate a total weight (W_T) = $3200kg \times 10m/s^2 \times 1.5$

= 48,000N

Because the vehicle has four wheels, a pneumatic jack lifts one wheel from the ground at a time. So the weight of one wheel is one-fourth of the total weight is 8000 N.

3.7 Determination of Pressure, Force, and Area of Pneumatic Bag

As Pascal's law state, pressure is defined as the force applied per unit area. A force is a push or a pull on an object, resulting in a change in its initial state of motion or direction. Area, on the other hand, refers to how much space a two-dimensional shape or surface occupies. Since pressure is force per unit area, the expression for force in terms of mass can be used to solve pressure.

The analysis of stresses induced in a thin pneumatic bag is made on the following assumptions:

1. The impact of the rubber wall's curvature is neglected.
2. Over the section of the walls, the tensile stresses are distributed equally.
3. It is not taken into account how the pressure vessel's heads operate as a restraint.

3.8 Stress and Deflection Calculation of Pneumatic Bag Jack

When the telescopic shaft is loaded within the elastic limit, it changes its dimensions and on the removal of the load, it regains its original dimensions. This energy, which is absorbed in a body when strained within the elastic limit, is known as strain energy. It is held in the object while it is still under stress, and when the load is removed, the energy is released as in the case of a spring. The strain energy is always capable of doing some work. According to the R.S. Khurmi and J.K. Gupta (2005) textbook on machine design, the change in length of a pneumatic bag jack is calculated as follows.

$$E = \frac{\text{stress}}{\text{strain}} = \frac{\sigma}{\varepsilon} = \frac{\sigma}{\frac{\delta l}{l}} = \frac{\sigma \times l}{\delta l}$$

$$\delta l = \frac{\sigma \times l}{E} = \frac{11\text{MPa} \times 500.64\text{mm}}{1.93 \times 10^{11}\text{Pa}} = \frac{11 \times 10^{6}\text{Pa} \times 500.60\text{mm}}{1.93 \times 10^{11}\text{Pa}} = 2.85 \times 10^{-2}\text{mm}$$

3.9 Design Concept

As stated in the literature review synthetic tire rubber, stainless steel, and structural steel telescopic shafts are strong and compatible with the design, however, they are not the only option for optimizing the pneumatic floor bag jack application.

Structural steel is the material selected for designing the telescopic shaft and components of the pneumatic bag jack as; the upper and lower plate, base plate, rings, handles, and grooved pad on the top of the bag. Carbon steel is defined as steel that has its properties mainly due to its carbon content does not contain more than 0.5% of The plain carbon steels varying from 0.06% carbon to 1.5% carbon are divided into the following types depending upon the carbon content according to Indian standard [IS: 1762 (Part-I)–1974], a new system of designating the steel is recommended are:

1. Dead mild steel — up to 0.15% carbon
2. Low carbon or mild steel — 0.15% to 0.45% carbon
3. Medium carbon steel — 0.45% to 0.8% carbon
4. High carbon steel — 0.8% to 1.5% carbon.

Rubber is one of the most important natural plastics. It resists abrasion, heat, strong alkalis, and fairly strong acids. From two main types of rubber natural and synthetic rubbers, the artificial elastomer (synthetic) was the selected material for the designed pneumatic bag jack.

3.10 Dynamic Analysis of Pneumatic Bag Jack

Modal analysis helps to ascertain the vibration properties of (natural frequency and mode shapes) mechanical structures or components, showing the movement of different parts of the structure under dynamic loading conditions of the telescopic shaft, and the airbag's physical properties. It is the process of extracting modal parameters measured by frequency response, and a harmonic response or full transient dynamic analysis is a more detailed dynamic study. There are two theories reviewed to calculate the natural frequency of telescopic shaft and pneumatic bag.

a) The Euler-Bernoulli Beam Theory is a method for determining transferring loads and deflection characteristics of beams. It is a simplification of the linear theory of elasticity. It covers the case for small deflections of a beam that are subjected to lateral loads only. The Euler's equation for natural frequency is given as

$$\omega_n = \frac{n^2\pi^2}{L^2}\sqrt{\frac{EI}{\rho A}}\ ; f_n = \frac{\omega_n}{2\pi}$$

$$f_n = \frac{1}{2\pi}[n\pi/L]^2\sqrt{\frac{EI}{\rho}}, \qquad n = 1,2,3 \dots\dots\dots..$$

b) Another method proposed was derived from the dynamics of distributed property systems Humar, J.L. (2012). For this method, it is assumed that the modulus of elasticity and the mass are uniformly distributed, and the cross-section is constant throughout the length of the tree stem equation is:

$$\omega_n = \alpha_n^2\sqrt{\frac{EI}{mL^4}} \qquad \& \ \alpha_n = 1.875, 4.694,$$

Table 3. 5: Dynamic analysis of frequencies of telescopic shaft and airbag applied six different deformation forces summary

Item No.	Frequency values(Hz)	1	2	3	4	5	6
1	Telescopic	160.79	643.12	1447.03	2572.49	4019.52	5788.11
2	airbag	323.43	1293.85	2910.5	5174.22	8084.72	11642

3.11 Modeling of Pneumatic Bag Jack

Modeling and numerical simulation are critical components of today's automobile industry. They are required to minimize the time to market for new products as well as the expenditures involved with experimental testing. Good modeling and simulation in design and analysis provide numerous advantages, including reduced product manufacturing time, material scrap, and material cost. For a long time, the automobile industry has performed structural assessments (static, dynamic, safety, noise and vibration, handling, and so on) in vehicle structure design. Except for hydraulic jacks and a few pneumatic jacks, the precision and accuracy of models gradually rise in quality. There are several types of electric jacks available now because car jacks can be tricky to use. The evolution of these electric jacks has led to a progressive understanding of some of the issues they raise. Due to the torque needed to lift something as heavy as most automobiles, a severe mechanical advantage must be utilized. Pneumatic systems generally have long operating lives and require little maintenance. Because gas is compressible, equipment is less subject to shock damage. Gas absorbs excessive force, whereas fluid in hydraulics directly transfers force. Compressed gas can be stored, so machines still run for a while if electrical power is lost.

3.11.1 2D Dimensions and 3D Modeling of the Pneumatic Bag Jack

Ansys 3D design tools enable engineering teams to significantly boost productivity, spur innovation, and speed time to market. 3D design software allows your team to make smarter, faster decisions by reducing product development costs and improving workflows.

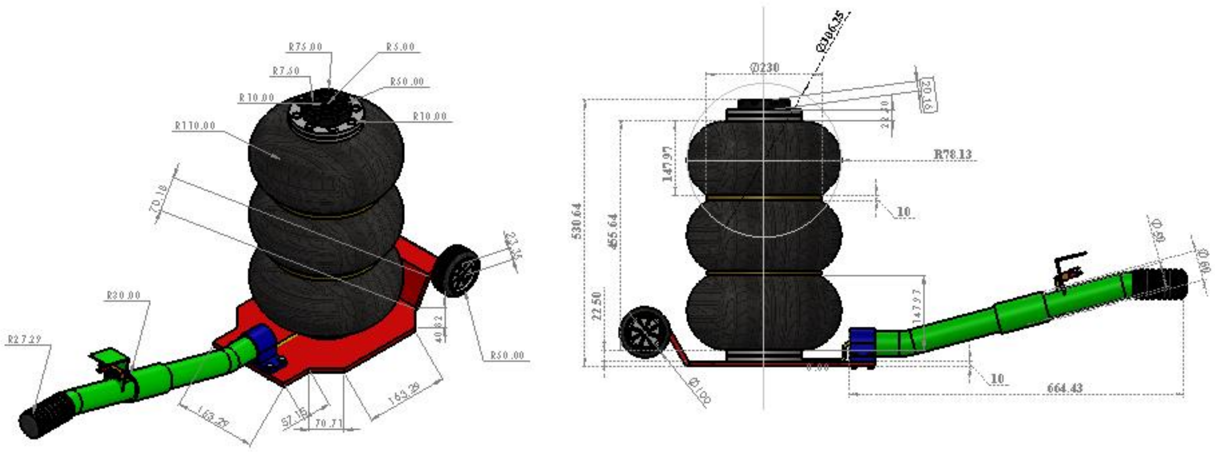


Figure 3. 6: 2D dimension and 3D models of pressurized pneumatic bag jack

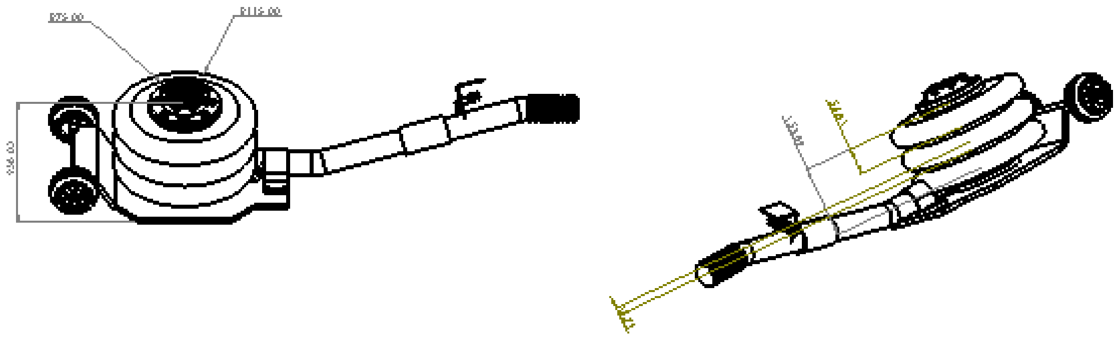


Figure 3. 7: 2D idle position of pneumatic bag jack

Modeling and numerical simulation are critical components of today's automobile industry. They are required to decrease the time to market for 3D. Modeling is a geometrical representation of a real item that retains all of the information that the original object possesses. Solid work is used to model various mechanical design and manufacturing activities.

3.12 Analysis of Pneumatic Bag Jack Using FEM

The Finite element Method (FEM) is a numerical approach for solving systems of partial differential equations (PDFs) encountered in engineering and mathematical modeling. Designers utilize ANSYS and simulation tools to monitor design performance on their desktops in a variety of industries, including aerospace, car, construction, nuclear, communications, biomedical, and many more. As a result, it allows for quick, dependable, and cost-effective product development from concept through validation. The ANSYS designers help to speed up and streamline the product development process by resolving challenges such as structural deformation, heat transfer, fluid flow, electromagnetic effects, and a combination of these phenomena working together (Wing Kam Li *et al*., 2022).

It is a software tool for finite element analysis (FEA) that can be used for a range of applications. It is a computational tool for disassembling a complex structure into small sections known as components. The program generates a complete description of how the system performs as a whole by implementing and solving equations regulating the operation of various elements. These findings can then be presented tabular or graphically.

This type of analysis is typically used to build and optimize systems that are too complicated to analyze manually. The geometry, scale, or governing equations of systems that fit into this category are too complex (Naghibi Beidokhti, Hamid, *et al.*, 2016).

3.12.1 Analysis of Static Structure

A static structural analysis identifies the displacements, stresses, strains, and forces induced by loads that do not cause substantial inertia and damping effects in structures or components. The assumption is for steady loading and response circumstances, which means that the loads and the structure's response will vary gently over time. The ANSYS solver can be used to calculate a static structural load. The following types of loading can be used in a static analysis:

- Externally applied forces and pressures
- Steady-state inertial forces (such as gravity or rotational velocity)
- Imposed (nonzero) displacements
- Temperatures (for thermal strain)

These features used more static loading conditions which do not change over time and location.

i. The load applied on the pad of the pneumatic bag jack is considered a part of the jack.

ii. The telescopic shaft automatically actuated when the compressed air was supplied to the pneumatic bag jack and the pressure was applied on the whole geometry of the pneumatic bag.

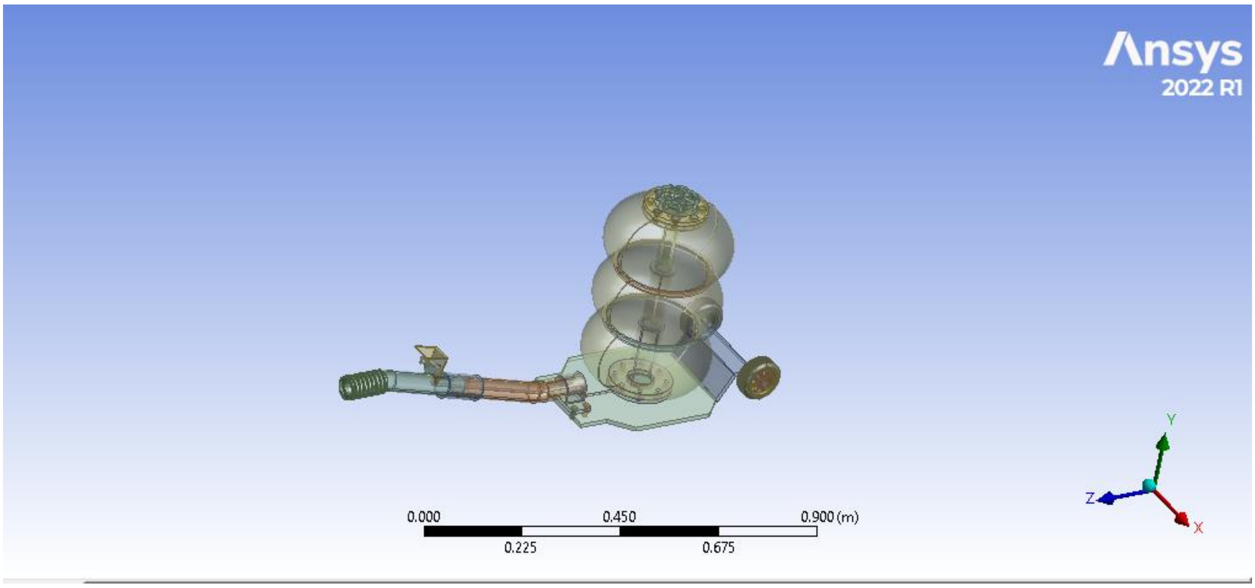


Figure 3. 8: The 3D model of the pneumatic bag floor jack

3.13 Static Analysis of Pneumatic Bag Jacks

To do static structural analysis on a structure or component, follow these steps:

3.13.1 Engineering Data

Tables 3.6, 3.7, and 3.8 show the particular material properties of structural steel, stainless steel, and tire rubber.

Table 3. 6: Isotropic elasticity engineering data of structural steel

Item No.	Structural steel Property	Value	Remark
1	Density(kg/m^3)	7850	
2	Young's Modulus(MPa)	2e+11	
3	Poisson's ratio	0.3	
4	Bulk modulus (MPa)	1.6667e+05	
5	Shear modulus (MPa)	7.6923e+04	
6	Tensile yield strength (MPa)	250	
7	compressive yield strength (MPa)	250	
8	Tensile ultimate strength (MPa)	460	
9	compressive ultimate strength (MPa)	0	
10	Structural steel coefficient of thermal expansion (1/°C)	1.2e-05	

Table 3. 7: Isotropic elasticity engineering data of stainless steel type 304

Item No.	Stainless steel Property	Value	Remark
1	Density(kg/m^3)	7750	
2	Young's Modulus(MPa)	1.93e+11	
3	Poisson's ratio	0.31	
4	Bulk modulus (MPa)	1.693e+05	
5	Shear modulus (MPa)	7.3664e+04	
6	Tensile yield strength (MPa)	205	
7	Compressive yield strength (MPa)	205	
8	Tensile ultimate strength (MPa)	586	
9	Compressive ultimate strength (MPa)	0	
10	Stainless steel coefficient of thermal expansion (1/°C)	1.7e-05	

Table 3. 8: Isotropic elasticity engineering data of tire rubber

Item No.	Tire rubber Property	Value	Remark
1	Density(kg/m^3)	1000	
2	Young's Modulus(MPa)	1e+06	
3	Poisson's ratio	0.3	
4	Bulk modulus (MPa)	8.3333e+05	
5	Shear modulus (MPa)	3.8462e+05	
6	Tensile yield strength (MPa)	22	
7	Compressive yield strength (MPa)	22	
8	Tensile ultimate strength (MPa)	5	
9	Compressive ultimate strength (MPa)	0	
10	Stainless steel coefficient of thermal expansion (1/°C)		

3.13.2 Geometry

Before attaching the geometry of the pneumatic bag jack rubber and telescopic shaft, specify numerous choices to set the qualities of the 3D model geometry to import from the supportable IGES file. These are the options: solid bodies, surface bodies, line bodies, parameters, attributes, named selections, and material properties; analysis type 2D or 3D, CAD associativity, importing coordinate systems, and importing work points are only available in the design modeler application, saving updated CAD file in reader mode, "smart" refreshing of models with unmodified components, and allowing parts of mixed dimension to be imported as assembly components that have parts of mixed dimension. The geometry of the extended pneumatic bag and the telescopic shaft is shown in Figure 3.9 (a) and (b).

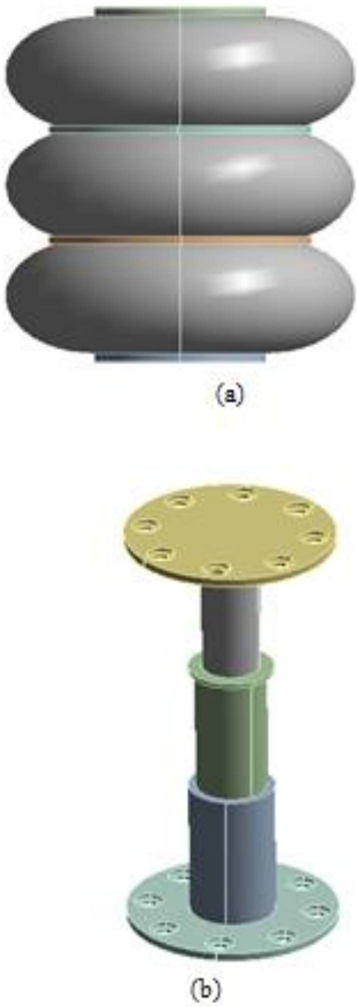


Figure 3. 9: The imported 3D model tire rubber and telescopic shaft

3.13.3 Meshing

Applying mesh, Allows for the smooth distribution of contact stresses by providing an appropriate mesh density on contact surfaces. Similarly, offer a mesh density sufficient for resolving stresses; areas of interest for stresses or strains require a comparatively fine mesh compared to those required for displacement or nonlinearity resolution. Figure 3.10 shows a meshed extended handle pneumatic bag floor jack.

Figure 3. 10: Meshed model of extended handle pneumatic bag floor jack

Table 3. 9: Pneumatic bag elements mesh number

Components	Element Numbers
Airbag	20,437
Telescopic shaft	12,394
Handle	49,829
Total	82,660

3.13.4 Applying Load and Boundary Conditions

Displacement constraint: the pneumatic bag jack stands by the base on the ground and the compressed air supply is through a control valve by an air hose. When the air is pressurized to the bag the telescopic shaft slides upward and lifts the vehicle one wheel at the desired height along the positive Y axis, and X and Z axes the airbag expanded by pressure at optimum bars. The boundary conditions of the telescopic shaft are shown in Figure 3.11.

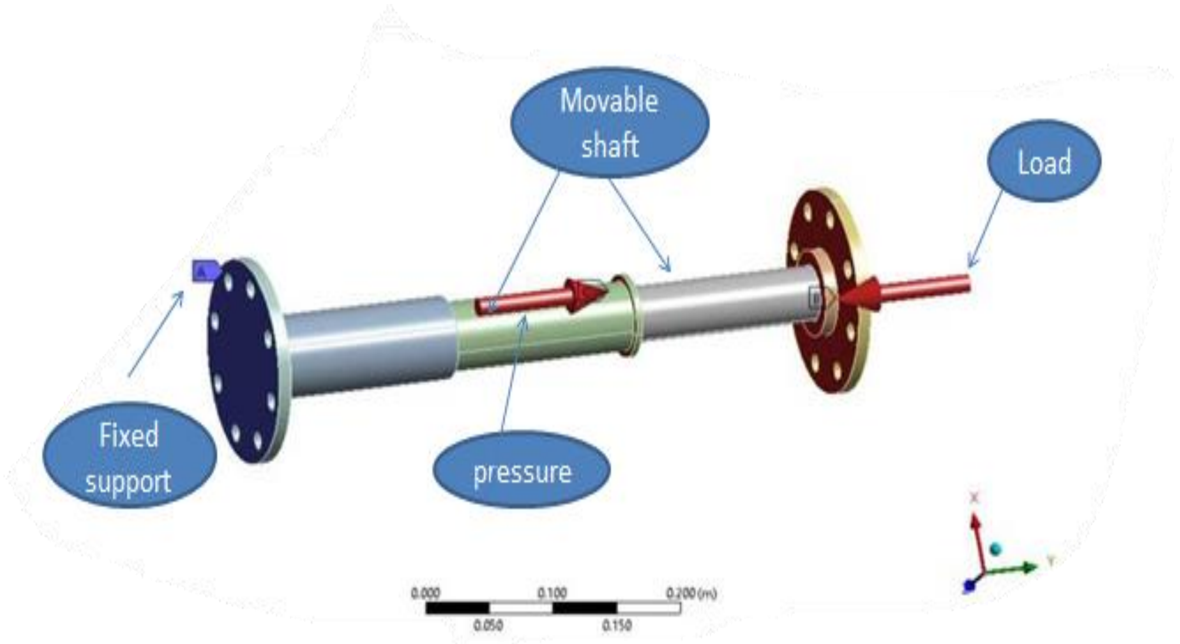


Figure 3. 11: Boundary condition and loaded telescopic shaft

3.13.5 Generate Solution

The project's input parameters are used to generate the solution. The essential variables to be addressed are total deformation, normal stress, strain, shear force, and equivalent (Von-Misses) stress. The solution output continuously updates any listing output from the solver and gives useful information on the structure's behavior during the analysis. The generated solutions of the telescopic shaft are shown in Figure 3.12.

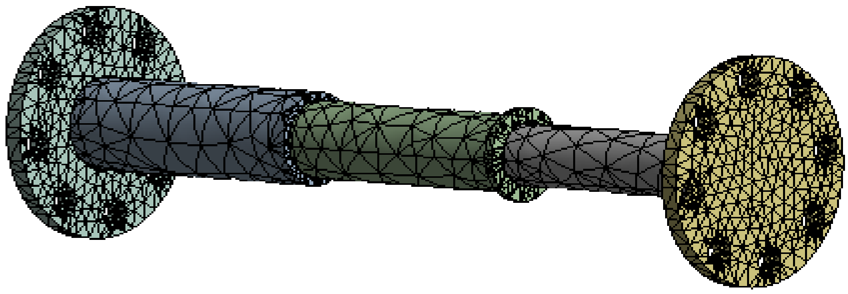


Figure 3. 12: Generating solution of telescopic shaft

CHAPTER FOUR
RESULT AND DISCUSSION

The static and dynamic structural evaluations performed on the telescopic shaft and airbag are reported in this chapter. The findings concentrate on three pneumatic jack components: total deformation, equivalent (Von-Misses) stress, and equivalent elastic strains. However, because total deformation and equivalent (Von-Misses) stress are the most important solutions for this design and analysis, they are the only ones presented. The study's conclusion is based on these findings, with the remaining findings shown in the appendix. The finite element analysis technique is vital in finding the maximum and least equivalent stress and displacement on the structural model; therefore it is critical to comprehend the considerable data output appropriately. The static and dynamic structural analysis determines the stress and deformation characteristics of the structure under static loading systems and boundary conditions. To solve the problem correctly, follow the ANSYS 2022R1 workbench's standard static structural analysis system step by step. Figure 4.1 shows the pneumatic floor jack subjected to static and dynamic structural evaluations.

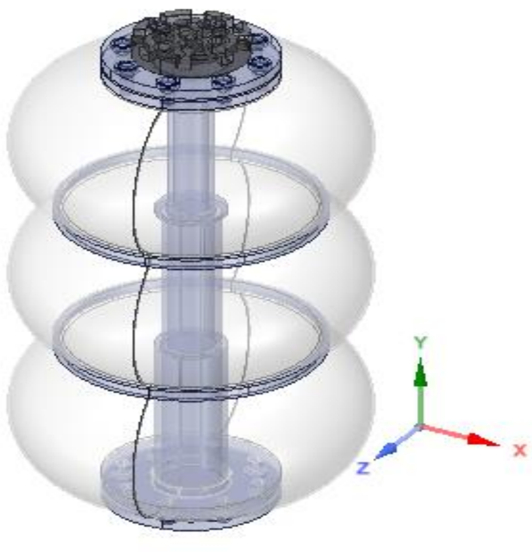
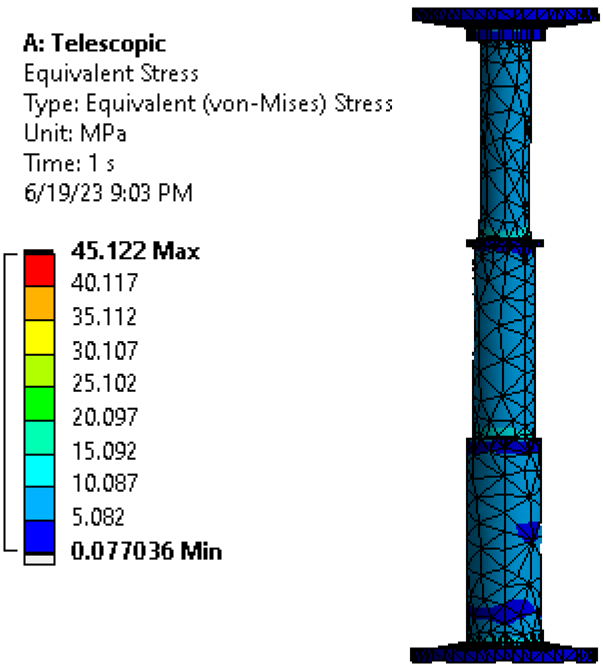


Figure 4. 1: The preview of the designed pneumatic floor jack

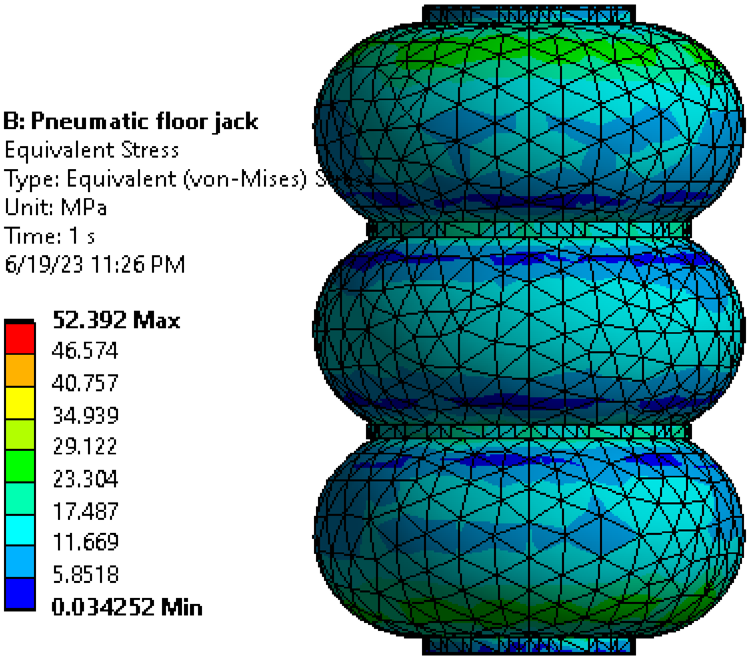
4.1 Results

4.1.1 Analysis of Static Structures

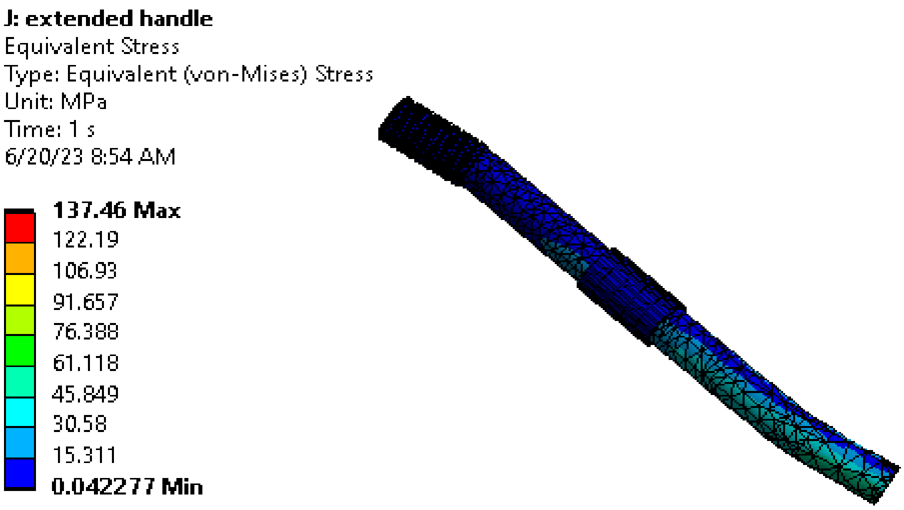
The FEA equivalent (Von-Misses) stress, total deformation, directional deformation (X-Axis), and maximum primary elastic strain values of the telescopic shaft and airbag are described below. The equivalent (von Mises) stresses of the telescopic shaft, airbag, and extended handle are shown in Figure 4.2. The equivalent (von Mises) stresses of the telescopic shaft, pneumatic bag, and extended handle are in the range of estimated values calculated in chapter three, as shown in Figure 4.2 below, and the values obtained are for the pneumatic bag 3mm thickness. The pneumatic bag with thicknesses of 2.5mm and 2.75mm does not reach the intended design outcome.



(a)



(b)



(c)

Figure 4. 2: Equivalent (Von-Mises) stress of telescopic shaft, airbag, and extended handle

The total deformation values of the telescopic shaft and airbag using FEA respectively are shown in Figures 4.3 and 4.4.

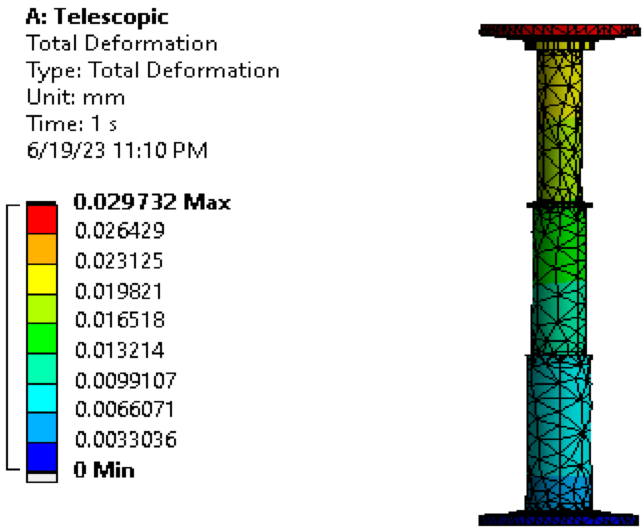


Figure 4. 3: Total deformation of telescopic shaft

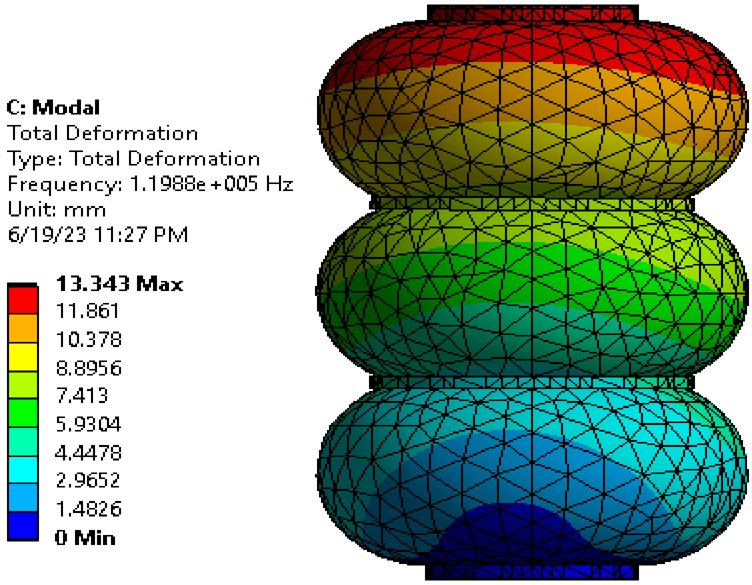


Figure 4. 4: Total deformation of the airbag

The directional deformation (X-Axis), values of the telescopic shaft and airbag using FEA respectively are shown in Figures 4.5 and 4.6.

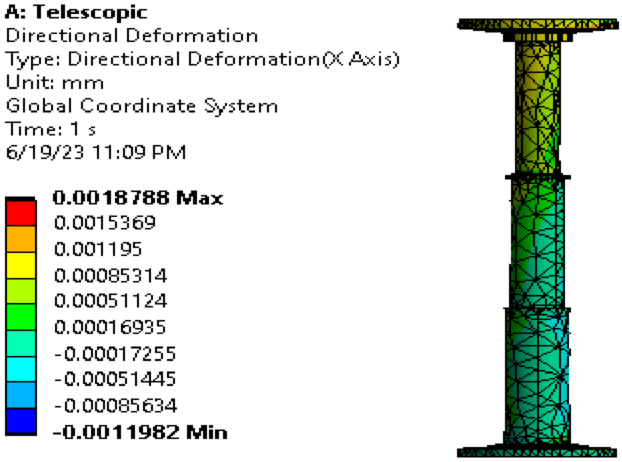


Figure 4. 5: Directional deformation (X-Axis) of telescopic shaft

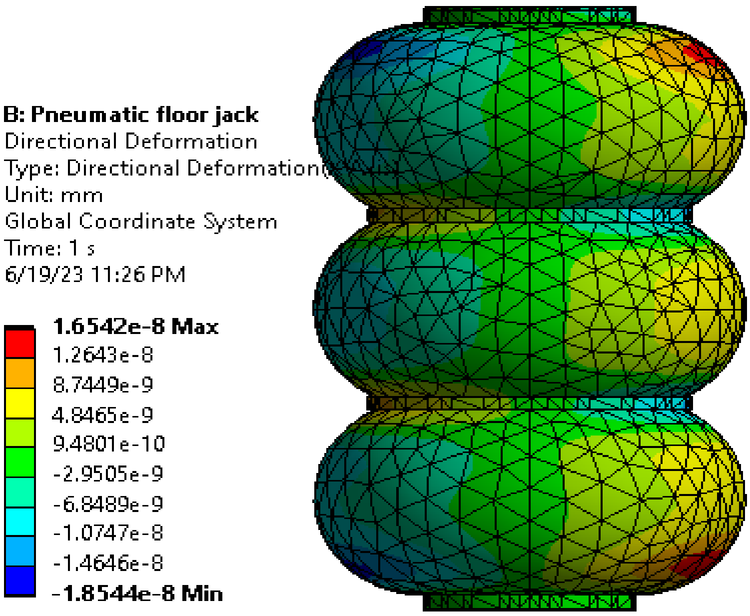


Figure 4. 6: Directional deformation (X-Axis) of the airbag

The maximum principal elastic strain values of the telescopic shaft and airbag using FEA respectively are shown in Figures 4.7 and 4.8.

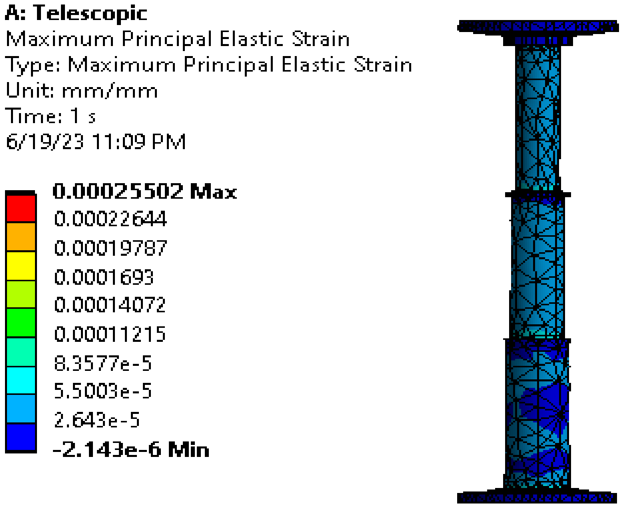


Figure 4. 7: Maximum principal elastic strain of telescopic shaft

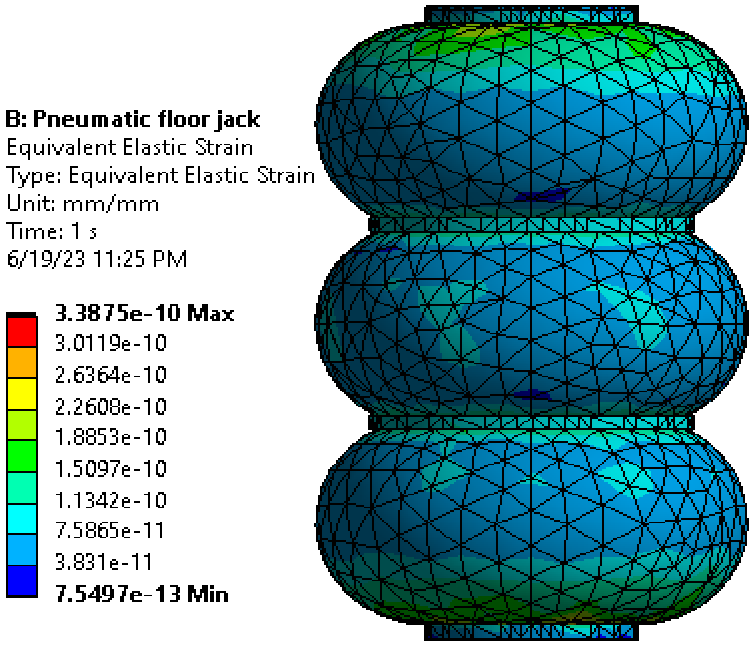


Figure 4. 8: Maximum principal elastic strain of airbag

4.1.2 Dynamic Analysis

The measurement of dynamic parameters of the pneumatic jack in the frequency domain at six distinct deformation analyses is known as the modal analysis of the telescopic shaft and airbag. Figures 4.9 - 4.20 consecutively list the dynamic analysis of telescopic shaft and pneumatic bag at different six frequency ranges.

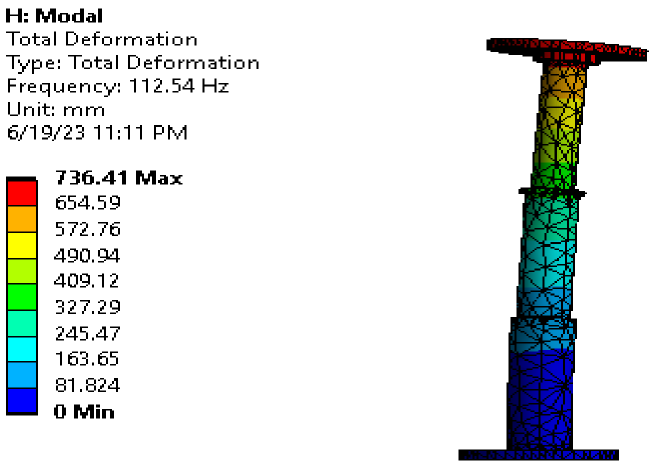


Figure 4. 9: Total deformation of the telescopic shaft at frequency 112.54 Hz

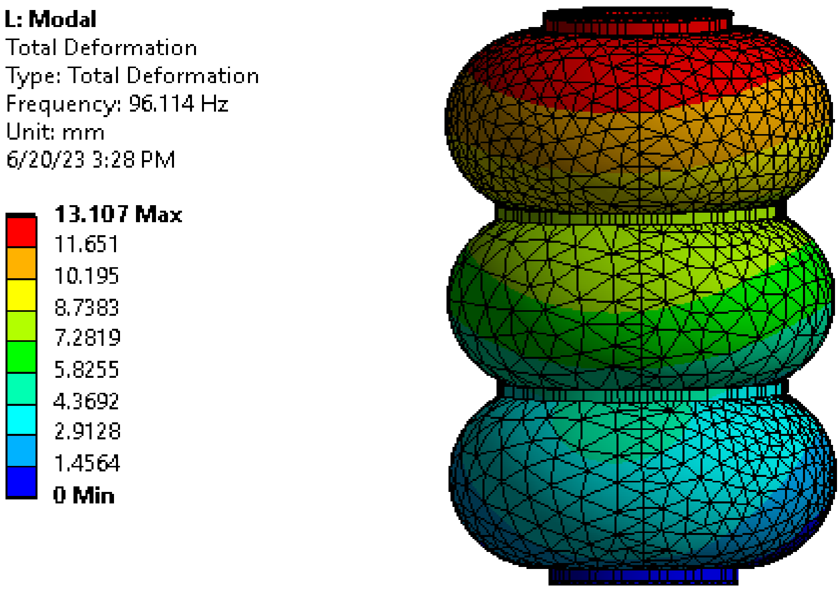


Figure 4. 10: Total deformation of the airbag at frequency 96.114 Hz

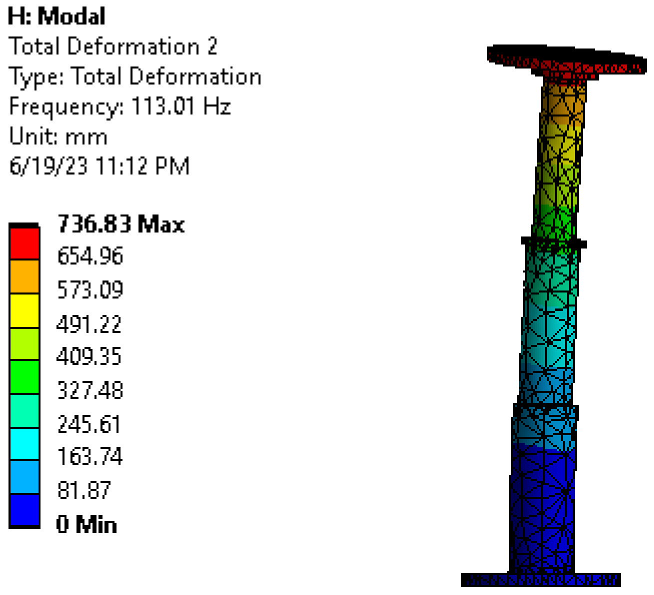


Figure 4. 11: Total deformation of the telescopic shaft at frequency 113.01 Hz

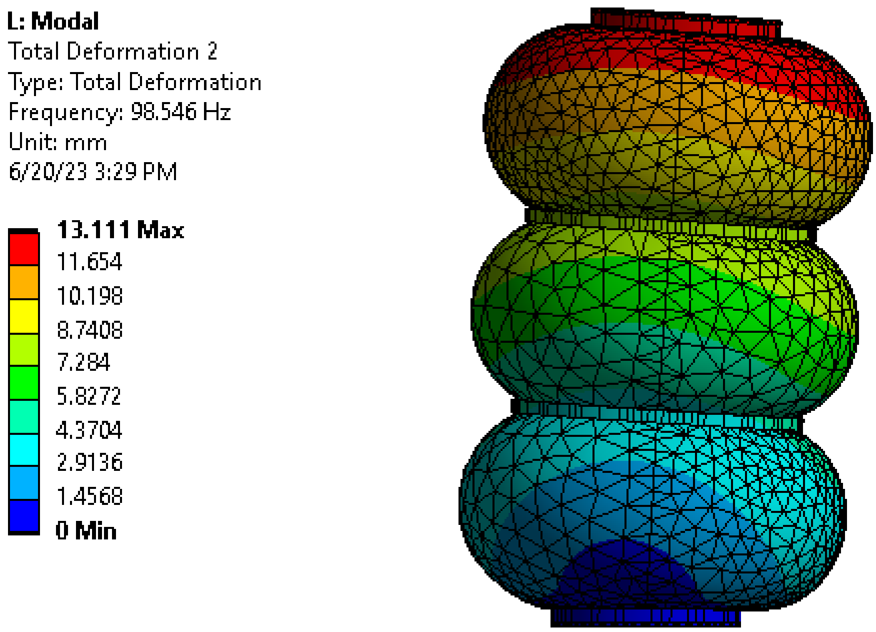


Figure 4. 12: Total deformation of the airbag at frequency 98.546Hz

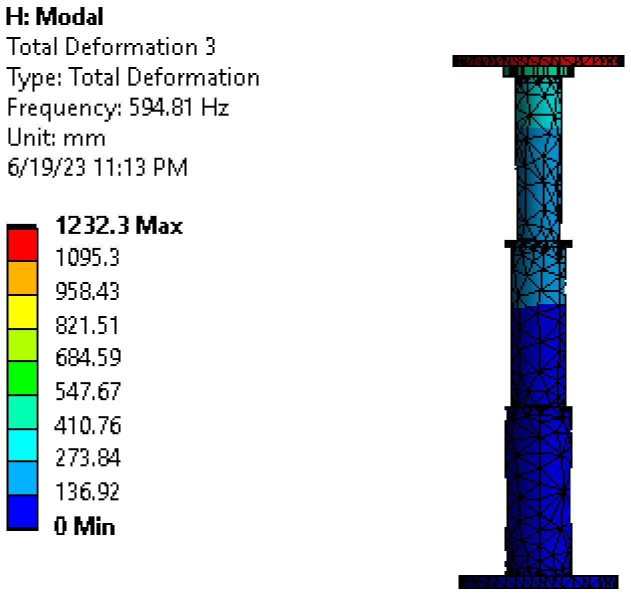


Figure 4. 13: Total deformation of the telescopic shaft at frequency 594.81 Hz

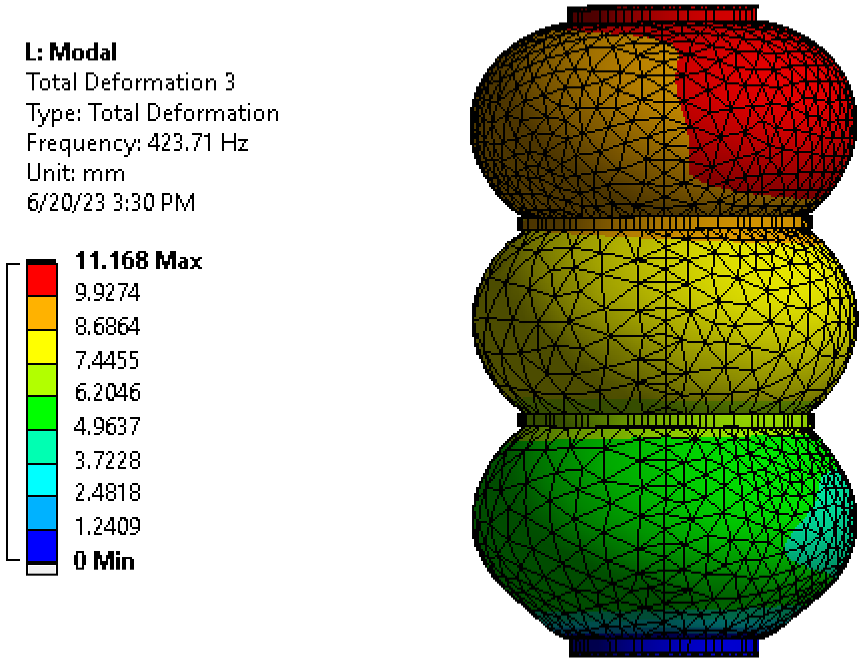


Figure 4. 14: Total deformation of the airbag at frequency 423.71 Hz

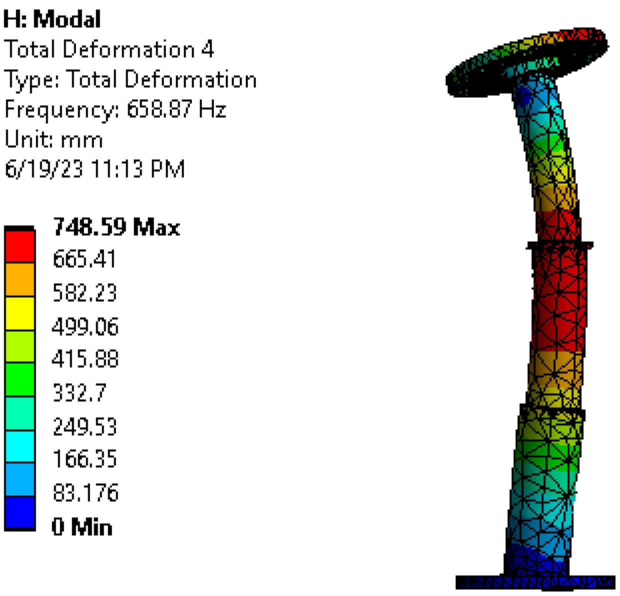


Figure 4. 15: Total deformation of the telescopic shaft at frequency 658.87 Hz

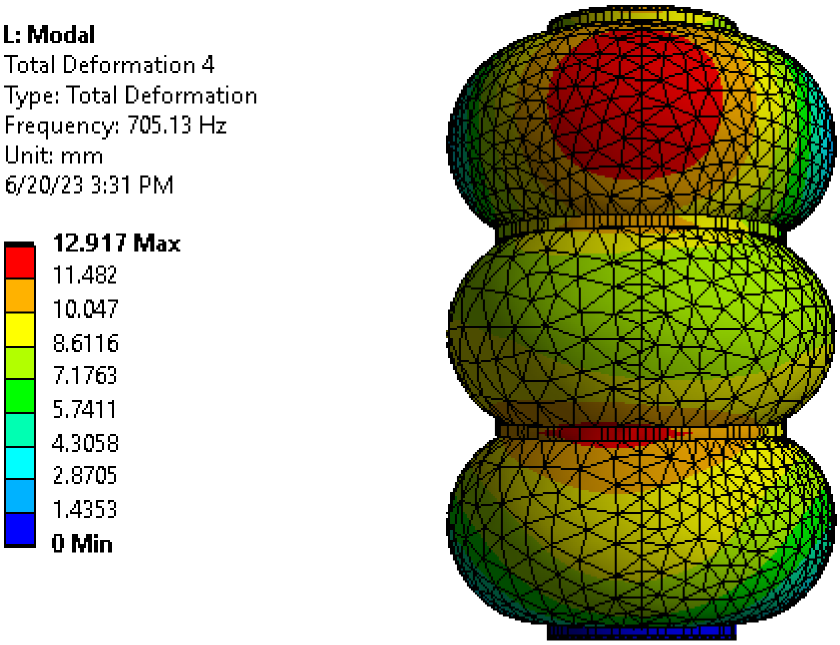


Figure 4. 16: Total deformation of the airbag at frequency 705.13 Hz

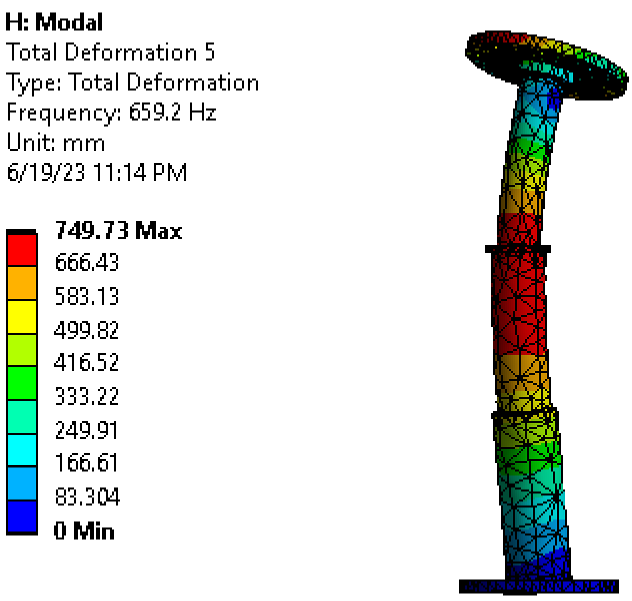


Figure 4. 17: Total deformation of the telescopic shaft at frequency 659.2 Hz

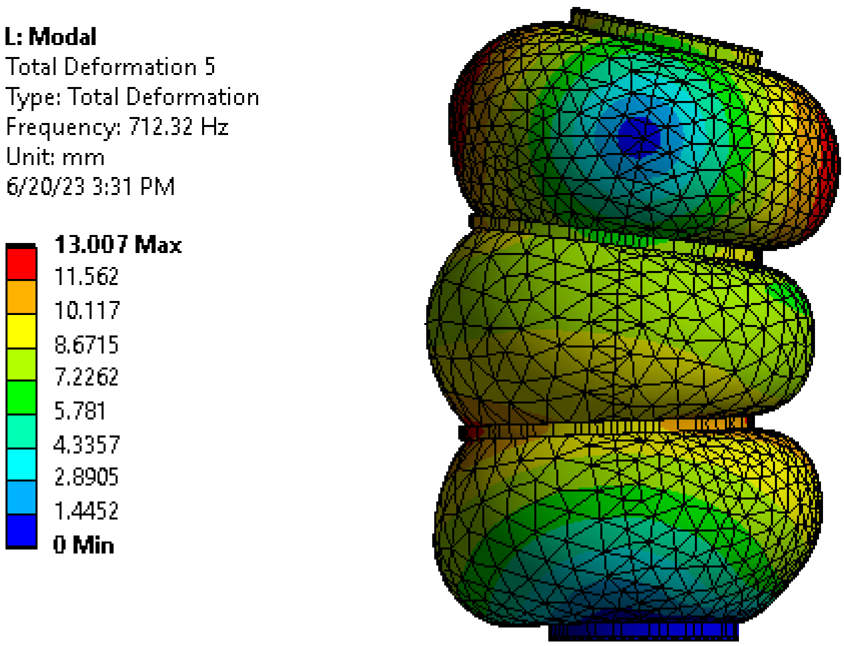


Figure 4. 18: Total deformation of the airbag at frequency 712.32 Hz

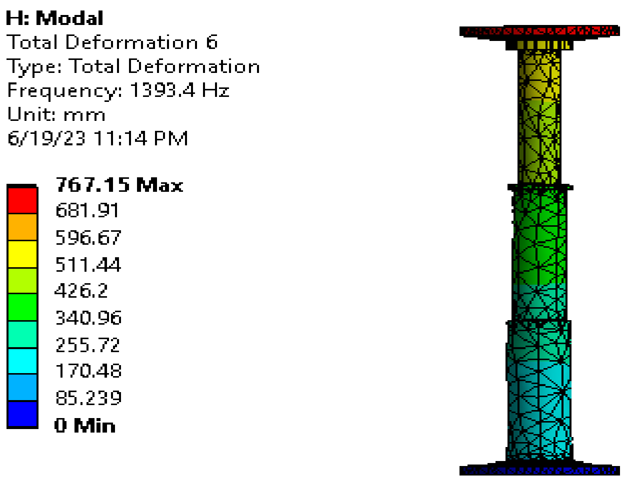


Figure 4. 19: Total deformation of the telescopic shaft at frequency 1393.4 Hz

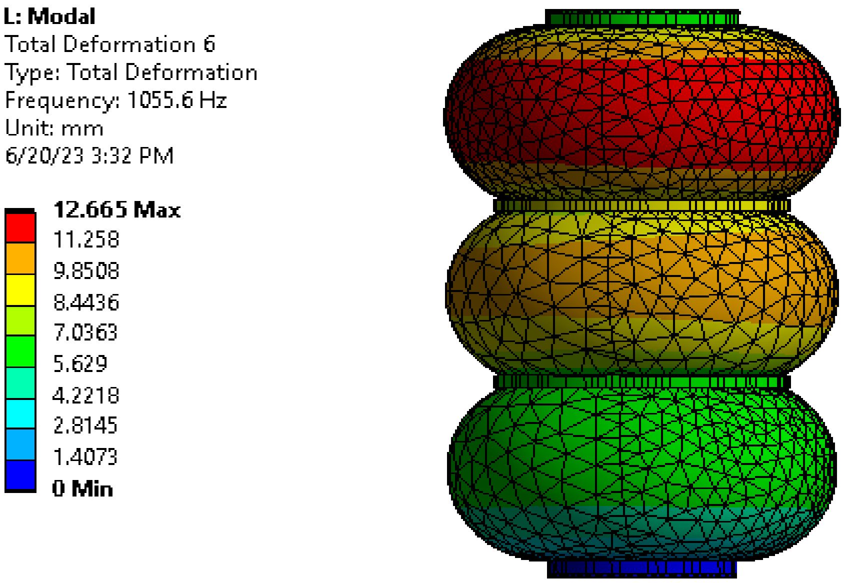


Figure 4. 20: Total deformation of the airbag at frequency 1055.6 Hz

The harmonic frequencies listed in Figures 4.9, 4.10, 4.11, and 4.12 are medium vibration frequencies determined from six different frequencies of the telescopic shaft and pneumatic bag to determine dynamic analysis. The harmonic frequencies shown in Figures 4.13, 4.14, 4.15, 4.16, 4.17, and 4.18 are not safe to design with, whereas the harmonic frequencies shown in Figures 4.19 and 4.20 are smoothly adjusted up and down. As a result, these two harmonic frequencies are optimal for the construction of a pneumatic floor jack.

4.2 Discussion

A static load of 4800N is applied to an extended handle pneumatic floor jack from a Toyota Land Cruiser 79 and HILUX Double Cabin in the static and dynamic structural analyses. The findings of this pneumatic bag floor jack and the four-wheeler are compared using FEA in this design comparison. The materials utilized for design and the mechanism are different. When an elastic body is subjected to external loads, it may deform or elongate based on the natural and harmonic frequencies of the imposed stress. Stress is defined as the average stress per unit area exerted by one particle of a body on another particle over an imaginary surface that separates them.

A pneumatic four-wheeler (Gawade P.D, *et al*., 2017) took up more room and was made of more materials, but it performed less efficiently than an extended-handle pneumatic bag jack. Increasing the rubber thickness has a positive effect on the performance of the pneumatic floor jack. The study applied 8.2MPa of pressure and found that using a 2.5mm thickness resulted in a maximum von Mises stress of 874.33MPa while using a 3mm thickness resulted in a stress level of 52.392MPa, as shown in Table 4.1. The stress levels for the 2.5mm and 2.75mm thicknesses exceeded the acceptable stress by 44% and 16% (608.65 MPa), while the 3mm thickness was 91% less than the allowable stress and could withstand the load. The 2.5 mm thickness exceeded 44% of this limit, while the 3 mm thickness was 92% less and could easily sustain the load. An increase in rubber thickness resulted in a decrease in total deformation so that the 3 mm airbag thickness jack exhibited significantly less deformation. Therefore, the optimum design among the three thicknesses is 3mm thickness. Figure 4.21 depicts the assembly of an extended handle pneumatic floor jack for light-duty vehicles.

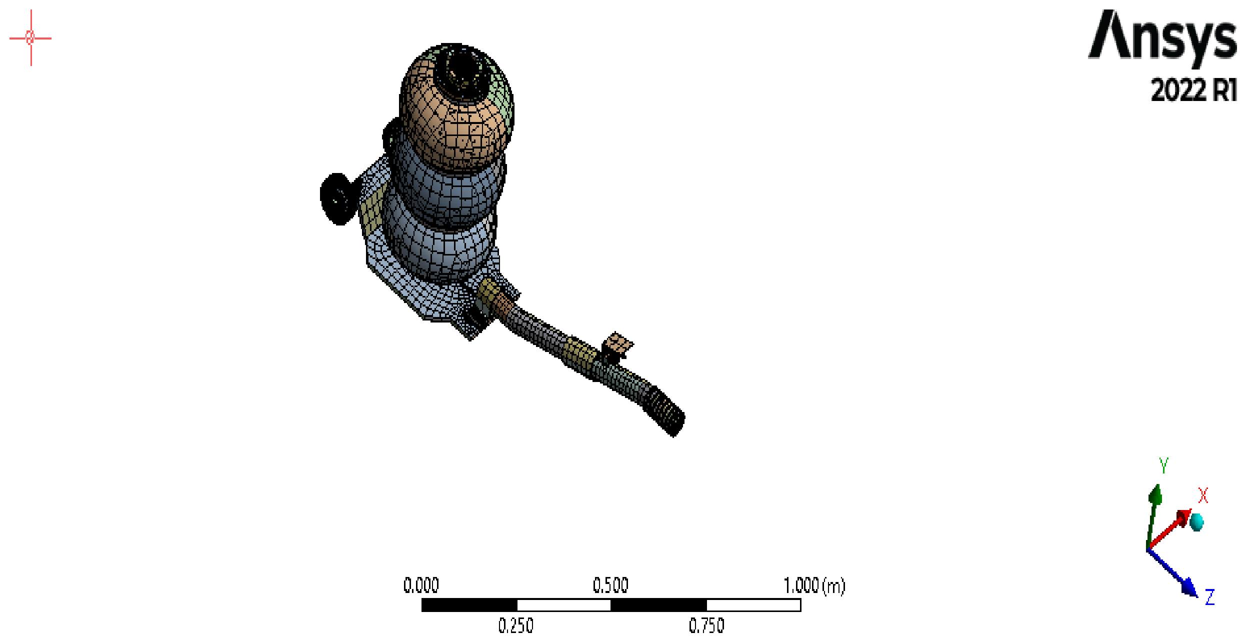


Figure 4. 21: Extended handle pneumatic bag jack for light-duty vehicles

The summary of von-misses stresses versus allowable stress comparisons is in Table 4.1

Table 4. 1: Summary of the Results of the Static Structure Pneumatic Jack

Comparisons of jacks	Max. Equivalent stress (MPa)	Max. allowable stress (MPa)	Max. Total deformation (mm)	Max. Principal deformation (mm)	Equivalent elastic strain (mm/mm)
Telescopic shaft	45.12	608.65	2.97e-2	1.88e-3	2.55e-4
Pneumatic bag T=3mm	52.39	608.65	2.40e-7	3.39e-10	1.77e-10
Pneumatic bag T=2.75mm	709.77	608.65	1.98	0.08	3.79e-3
Pneumatic bag T=2.5mm	874.33	608.65	3.36	0.41	4.49e-3

The summary of static structure in Table 4.1 is plotted in the chart below.

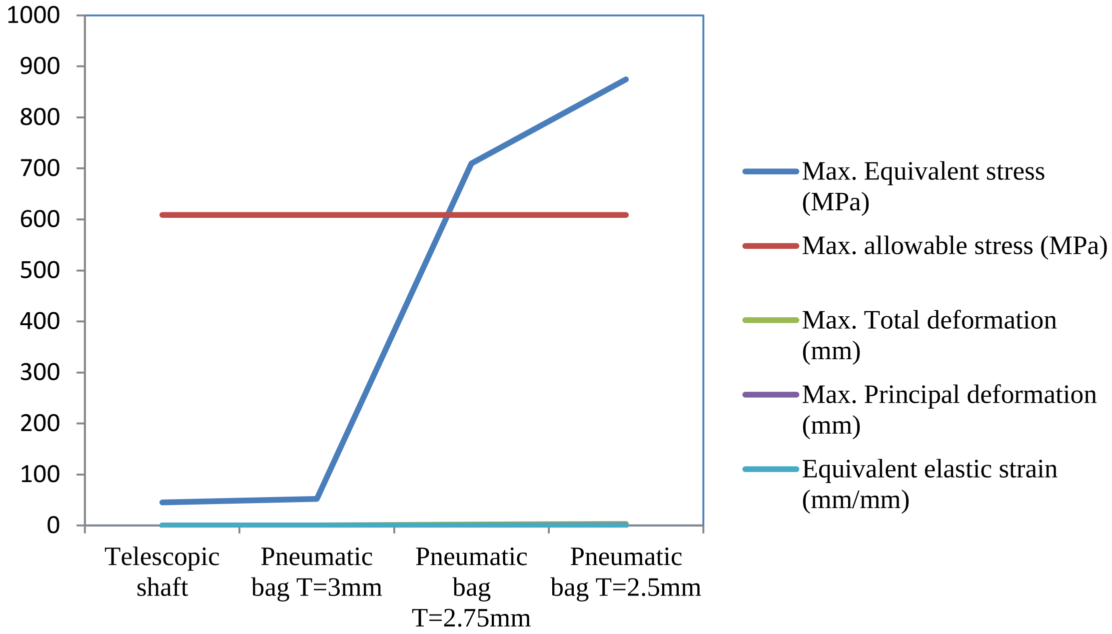


Figure 4. 22: Equivalent (Von misses stress) comparison graph in various pneumatic bag thicknesses

4.2.1 Response Surface Optimization

Response surface methodology (RSM) is a set of mathematical and statistical tools for developing empirical models. The objective is to optimize a response (output variables) which influenced by several independent variables (input variables). The common optimization methods are direct optimization and response surface optimization method. The direct optimization method obtains several experimental design points through the experimental design method, and solves the experimental design points one by one to find the optimal solution, so the calculation is large and the solution efficiency is low. Response surface optimization is to construct explicit constraints or objective functions in the original design problem which greatly improve the efficiency of optimization (Jin Xiangjie, *et al*., 2020).

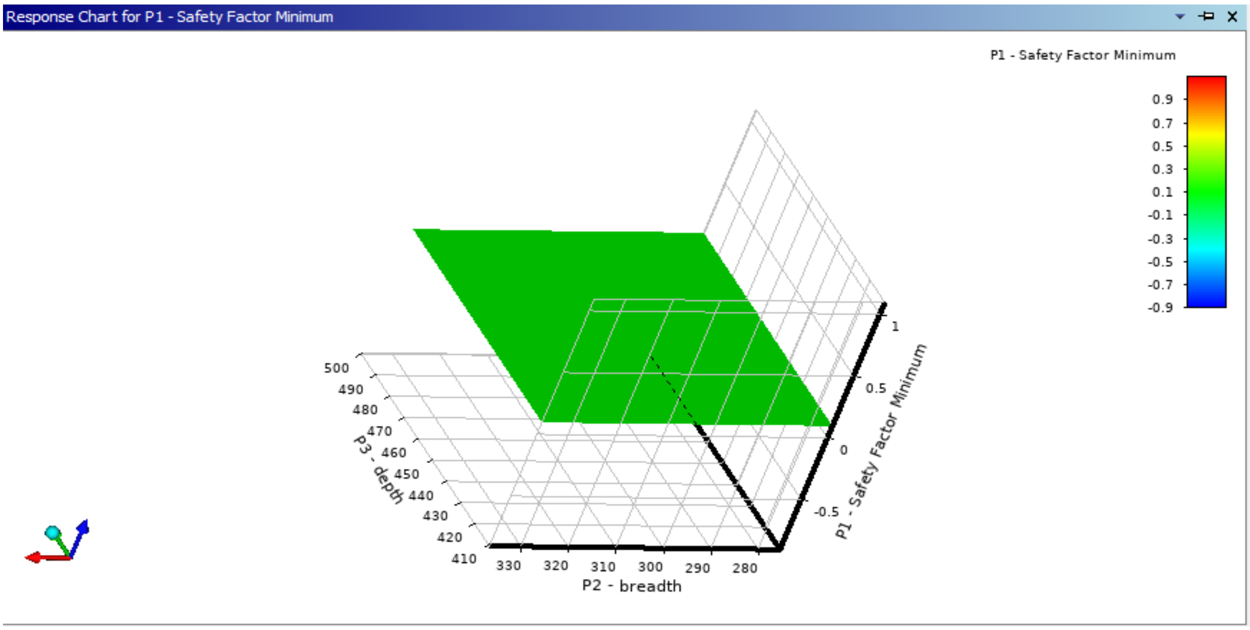


Figure 4. 23: Response surface optimization charts for P-1 safety factor minimum

The MOGA method (Multi-Objective Genetic Algorithm) is a controlled elitism variant of the popular NSGA-II (Non-dominated Sorted Genetic Algorithm-II). It accommodates numerous objectives and restrictions and seeks the global optimum. The configuration initially generated 2000 samples, 400 samples per iteration, and found 3 candidates in a maximum of 20 rounds, with status converged after 2289 assessments. As a result, the optimized point for this design is candidate point 1, as illustrated in Figure.4.24.

Item No.	Candidate points	Candidate point 1	Candidate point 2	Candidate point 3
1	P_1-safety factor minimun	0.095455	0.095455	0.095455
2	P_2-breadth	275.42	283.38	336.58
3	P_3-depth	409.52	421.08	496.21

Figure 4. 24: Candidate optimization points

4.2.2 Validation of the Von-Misses Stress

Table 4. 2: Comparisons of pneumatic floor jack with other pneumatic jacks

Types of pneumatic jack	**Weight Lifting capacity**	**Mechanism**
Design of Pneumatic Operated Jack for Four Wheelers	25 kg at pressure 3.27 bar	Four-wheeler
Design and Development of Automatic Pneumatic Jack for Four Wheeler	25 kg at a pressure of 2 bar	Four-wheeler
Design and Development of Integrated Pneumatic Car Jack	60kg at pressure 5 bar	Cylindrical piston
Design and Analysis of Pneumatic Bag Air Jack	1.25 ton at pressure 2.498 bar	Airbag jack
Design and analysis of extended handle pneumatic floor jack	3 tons at pressure 8.5 bar	Extended handle pneumatic jack

4.2.3 Deformation

From the analysis, and simulation the result of ASYSIS 2022R1 the values when the rubber thickness is 3mm the total deformation at the top of the extended handle pneumatic bag floor jack and pneumatic bag jack were obtained in Table 4.3.

4.3 Analysis of Harmonics

4.3.1 Frequency Response of Harmonic Analysis

Modal analysis for the airbag and telescopic shaft was done and frequency responses are shown in Table 4.3

Table 4. 3: Comparison frequency response of deformation at high amplitude

Comparisons of jacks	Max. Total deformation (mm)	Max. Total deformation 2 (mm)	Max. Total deformation 3 (mm)	Max. Total deformation 4 (mm)	Max. Total deformation 5 (mm)	Max. Total deformation 6 (mm)
Telescopic shaft	736.410	736.830	1232.300	748.59	749.730	767.150
Pneumatic bag t=2.5mm	421.95	423.130	367.310	426.230	430.07	415.870
Pneumatic bag t=2.75mm	13.343	13.380	11.615	13.470	13.600	13.151
Pneumatic bag t=3mm	13.107	13.111	11.168	12.917	13.007	12.665

The result of the maximum total deformation of the telescopic shaft and pneumatic bag at different six points is summarized in Figure 2.25.

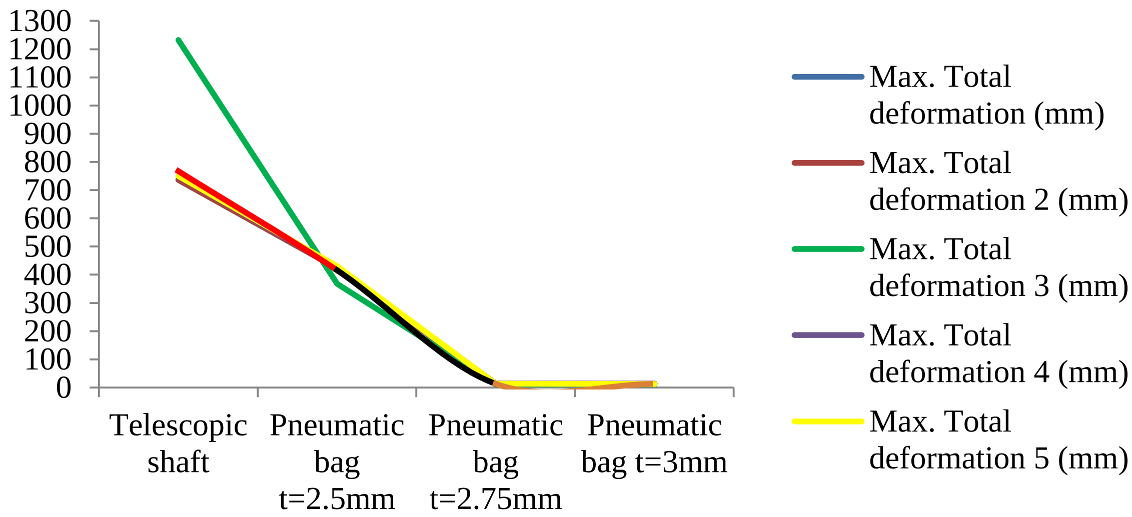


Figure 4. 25: The comparison chart of the maximum total deformation of the pneumatic bag and telescopic shaft at different points

A table 4.2 show the maximum total deformation at various points of the pneumatic bag, and this is further illustrated in the chart presented in Figure 4.26 It is evident that as the thickness increases, the deformation size decreases. Therefore, the optimized thickness is 3mm.

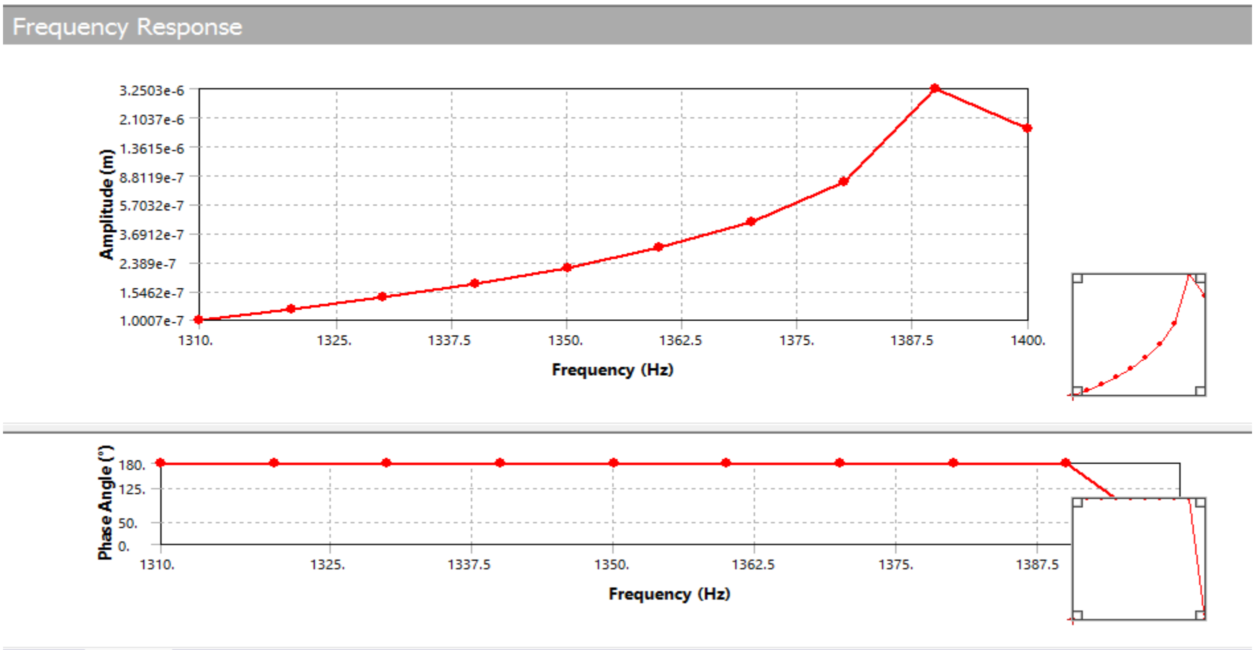


Figure 4. 26: The deformation of telescopic frequency response

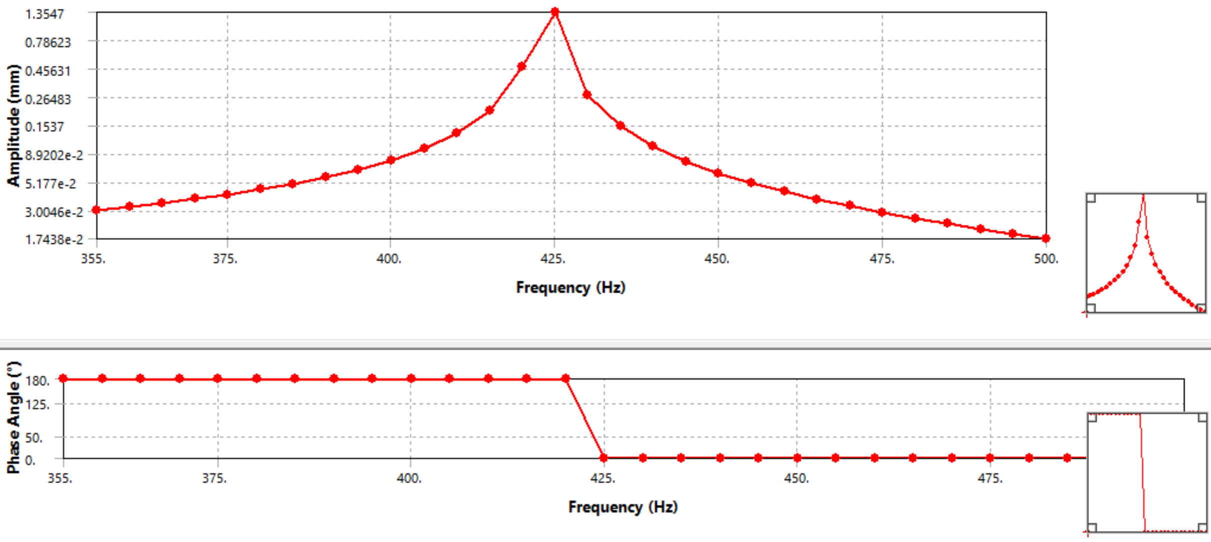


Figure 4. 27: The deformation of pneumatic bag frequency response

CHAPTER FIVE
CONCLUSIONS AND RECOMMENDATION

5.1 Summary

The pneumatic floor jack is extremely beneficial for workers in the vehicle workshop or service station. This thesis has also decreased the expense of the business. The thesis has been developed to complete the entire work that has also been provided.

5.2 Conclusions

We conducted a comparison study on pneumatic bag jacks made of natural tire rubber with thicknesses of 2.5 mm, 2.75 mm, and 3 mm. We analyzed the maximum von-misses stress after applying a pressure of 8.2MPa. The results showed that the maximum stress for 2.5 mm thickness was 874.33MPa and/or for 3 mm thickness, it was 52.39MPa. Unfortunately, both exceeded the allowable stress limit of the rubber, which is 608.65MPa. The 2.5 mm thickness exceeded 44% of this limit, while the 3 mm thickness was 92% less and could easily sustain the load.

The effect of rubber pressure was observed among models, with Table 4.3 depicting the deformation of the material. An increase in rubber thickness resulted in a decrease in total deformation and deformation in the x-axis. While the pneumatic bag air jack deformed by 2.5mm in all directions, the 3mm bag air jack exhibited significantly less deformation, as highlighted in Figures 4.6 to 4.12, Table 4.3, and Figure 4.25 plotted chart. Therefore, it concluded that the optimum thickness among the three options is 3 mm.

5.3 Recommendations

The researcher might conduct future research work on movable compressor technology to use pneumatic bag jack for light vehicles everywhere and /or might design the air source from exhaust gas for an inbuilt jack in the car body.

5.4 Future Work

Since an extended handle pneumatic floor, the jack has always been an integral part of any operation related to servicing the vehicle, it can be used for LDVs with some significant modifications, such as designing an inbuilt compressor in the vehicle's chassis, increasing the required torque, improving the material strength, and lifting capacity of the pneumatic bag jack. Some adjustments to the vehicle chassis design may also be necessary to accommodate the jack.

REFERENCES

Akshay M. Rokde, *et al.* (2018). *Design and Fabrication of Integrated Mechanical Jacks for Four Wheelers,* IJARIIE, Maharashtra: India, Vol.4, 73-80 pp.

Anal A Bangre, *et al*, (2014). *Design, Analysis, and Fabrication of Automatic Jacking System with Extension Arm,* International Journal of Mechanical Engineering & Robotics Research, Maharashtra: India, Vol. 3, 452 pp.

Atul A Dhawale, *et al.* (2017). *Design and Fabrication of Automatic Pneumatic Inbuilt Jack System by using Fifth Wheel Parking System*, International Journal for Scientific Research & Development. Nagpur: India, Vol. 5, 67-68 pp.

B. Babu, *et al*. (2017). *Design and Fabrication of Pneumatics Lifting System for Four Wheeler*, International Journal of Latest Engineering and Management Research, Rathinam Technical Campus: Coimbatore, Vol. 02, 12-15 pp.

Blevins, R.D. Formulas for Natural Frequency and Mode Shape; Van Nostrand Reinhold Co.: New York, NY, USA, 1979; ISBN 978-0-442-20710-6

Bobbili Seshagiri Rao, (2017). *Design and Fabrication of Pneumatic Jack Low Cost for Automobile,* International Journal of Innovative Research in Technology, Vol.4, 190 pp.

C. Jagadeesh Vikram, D. Mohan Kumar, (2018). *Design and Fabrication of a Vehicle with Inbuilt Pneumatic Jack,* International Journal of Pure and Applied Mathematics, Bist, Biher, Bharath University: Chennai, Vol. 119, 9901-9913 pp.

Faizan Nasir, (2009). *Vehicle Mounted Pneumatic Car Jack,* unpublished" BSc. A thesis submitted to the University of Cincinnati, 37 pp.

Gaurav Shashikant Udgirkar, *et al*, (2014). *Design, Development, and Analysis of electrically operated toggle jack using the Power of car battery,* International Journal of Computational Engineering Research, Panchavati: India, Vol. 04, 1 pp.

Gawade P.D, *et al*, (2017). *Design and Development of Automatic Pneumatic Jack for Four Wheeler*, IJARIIE. Ahmednagar, Vol.3, 1721 pp.

Herkules Equipment Corporation, (2014). *Pneumatic Air Jack*, Website:www.herkules.us. USA, 1-4 pp.

Humar, J.L. Dynamics of Structures, 3rd ed.; CRC Press-Taylor & Francis Croup: Boca Raton, FL, USA, 2012; ISBN 978-0-415-62086-4

Jayesh Vaghmashi, *et al.* (2017). *Design and Development of Electric Jack*, International Journal of Innovative Research in Science, Engineering, and Technology, Vadodara: India, Vol. 6, 7243-7249 pp.

Jin Xiangjie, *et al*. (2020). *Response Surface Optimization of Machine Tool Column Based on Ansys Workbench,* Academic Journal of Manufacturing Engineering, Zhengzhou, Henan: China Vol. 18, 162-170 pp.

Kaushal H. Pandya, *et al.* (2018). *Design and Development of Integrated Pneumatic Car Jack*, International Journal of Advanced Research in Science and Engineering, *Shivaji University Kolhapur: India, Vol.07, 19-23 pp.*

K.Sainath, *et al. (2014). Design of Mechanical Hydraulic Jack,* International Organization of Scientific Research Journal of Engineering (IOSRJEN). Vol. 04, 15-28 pp.

Manjesh B C. (2018). *Inbuilt Automatic Pneumatic Jack for Four-Wheeler*, International Journal for Research in Engineering Application & Management, Bangalore: India, Vol.03, 389-391 pp.

Mohd Bijarimi, *et al.* (2010). *Mechanical Properties of Industrial Tyres Rubber Compounds, Journal* of Applied Sciences. *Pahang: Malaysia, 1812:5654 pp.*

Naghibi Beidokhti, Hamid et al. (2016). A comparison between dynamic implicit finite element simulation of a native knee joint, medical engineering & physics, Nethreland:30(10): 1123-1130 pp.

P. S. Borkar, *et al*, (2015). *Design of Pneumatic Operated Jack for Four Wheelers,* International Journal for Scientific Research & Development, P.C.E.: Nagpur, Vol. 3, 3500 pp.

R.S. Khurmi & J.K. Gupta (2005). *Textbook of Machine Design*, A Textbook for the Students of B.E. / B.Tech., U.P.S.C. (Engg. Services); Section 'B' of A.M.I.E. (I) 1st multicolor edition.

Rupesh N. Kalwaghe and K. R. Sontakke,(2015) Design and Analysis of Composite Leaf Spring by Using FEA and ANSYS, International Journal of Scientific Engineering and Research (IJSER), Volume 3 Issue 5 pp.

SHAH KUSHAL, *et al.* (1016-2017*). Design and fabrication of pneumatic car jack*, Sal Institute of Technology and Engineering Research Mechanical Engineering. 8th semester of Gujarat Technological University, Ahmedabad

Shubham Gumphalwar, *et al.*, (2018). *Design and Fabrication of Pneumatic Car Lifter*, IJARIIE, Maharashtra: India, Vol.4, 3435 pp.

S.Sathiyaraj & V.Selvakumar (2015). *Design and Fabrication of Pneumatic Jack for Automobile*. International Conference on Information Engineering, Management, and Security. vol, 01, 272 pp.

Sutat Leelataviwat,*et al. Plastic versus Elastic Design of Steel Structures,* Structural Engineering and Geomechanics, Bangkok: Thailand, Vol.1, 29 pp.

Timur Choban Khidir, et al. (2019). Design and Analysis of Pneumatic Bag Air Jack, University of Kirkuk: Iraq, Journal of Mechanical Engineering Research and Developments, 61-64 pp.

Wing Kam Li *et al.* (2022). *Eighty years of the finite element method: birth, evolution and future*, archives of computational methods in engineering. 29(6): 4431-4453 pp.

Vivek.J.V, *et al*. (2018). *Design and Fabrication of Pneumatic Jack,* International Journal of Emerging Technology in Computer Science & Electronics. Chennai: India, Vol. 25, 603 pp.

APPENDIX

In this appendix the static analysis of extended handle pneumatic bag floor jack for light-duty vehicles

The directional deformation shear stress of a rubber tire and a stainless steel telescopic shaft in the X and Y directions is shown in Figure A1.

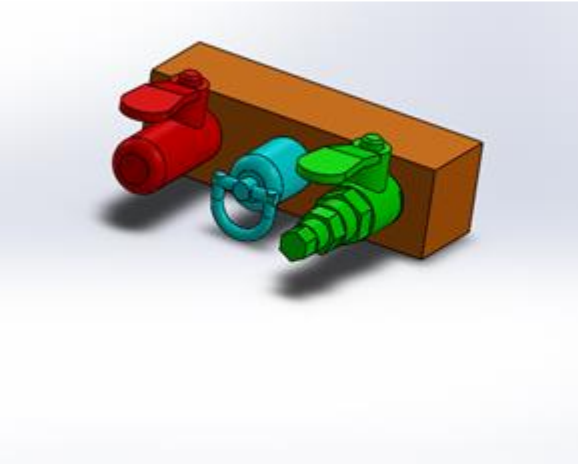


Figure A1: Control valves 3D model inlet, relief & outlet valves respectively

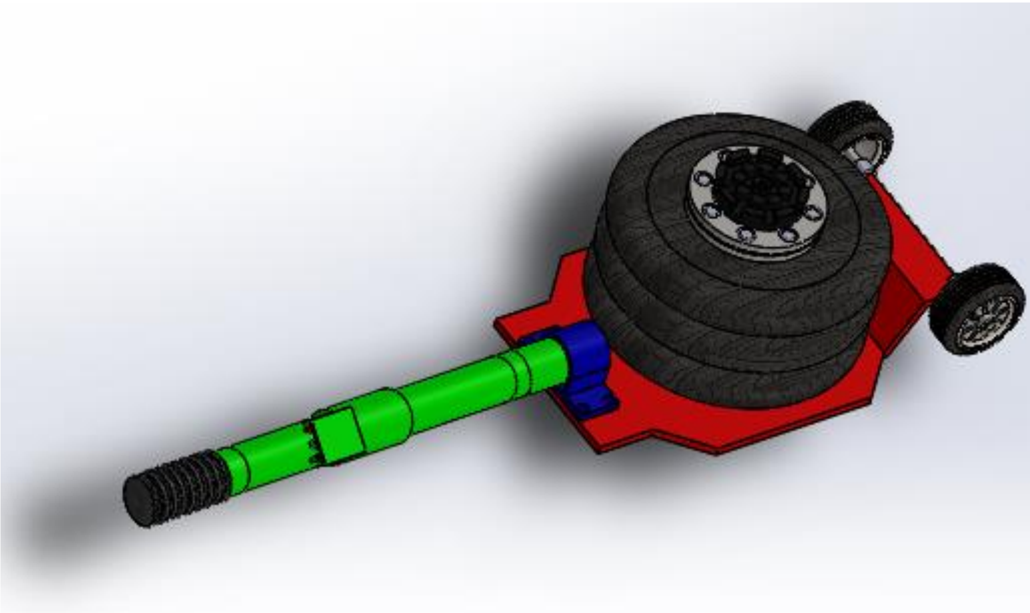


Figure A2: Extended handle pneumatic bag floor jack at the idle mode

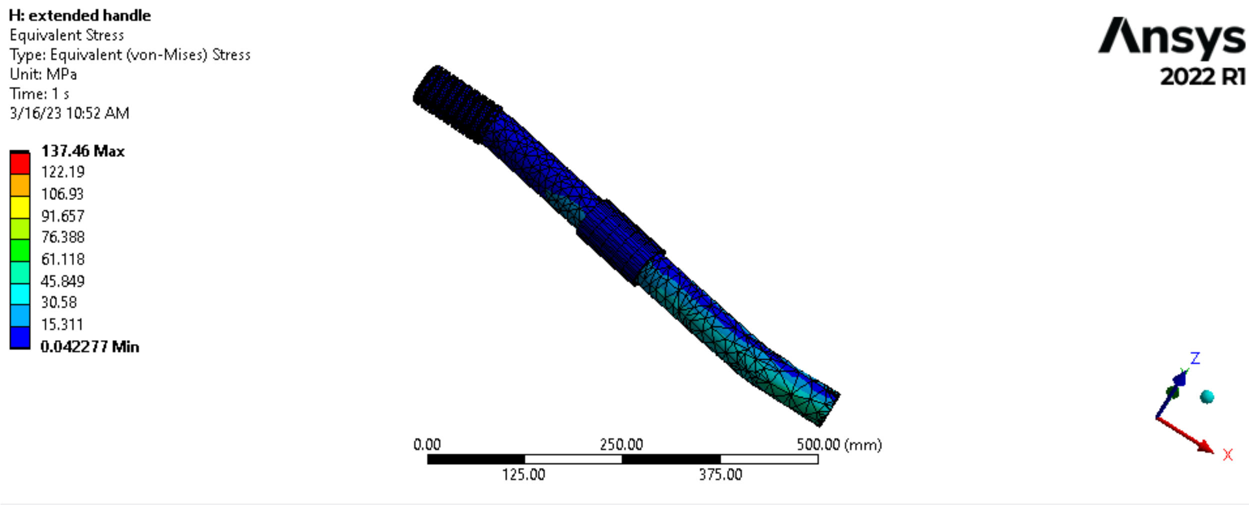


Figure A3: Extended handle von-misses stress

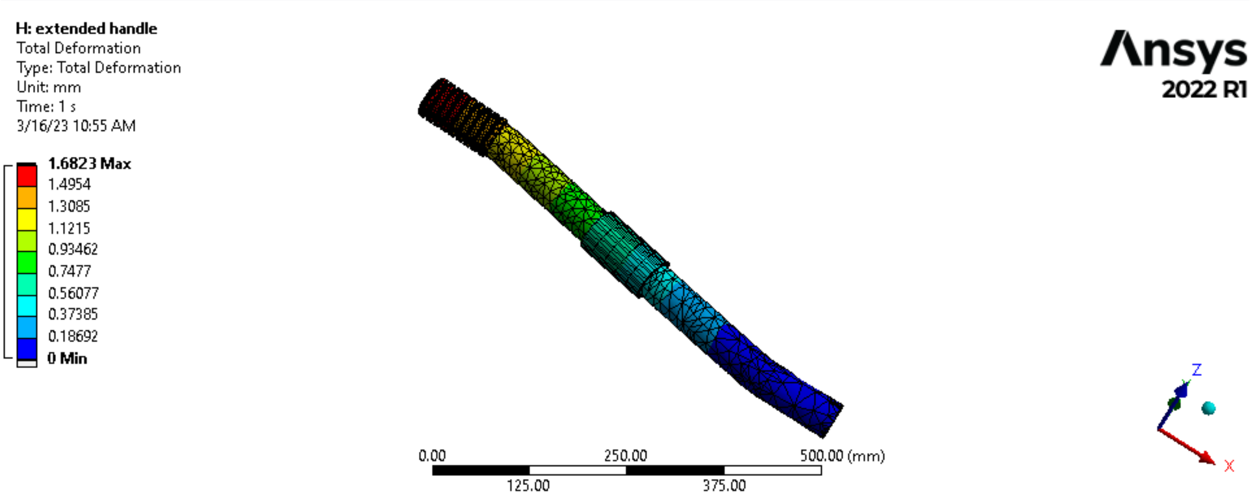


Figure A4: Extended handle total deformation

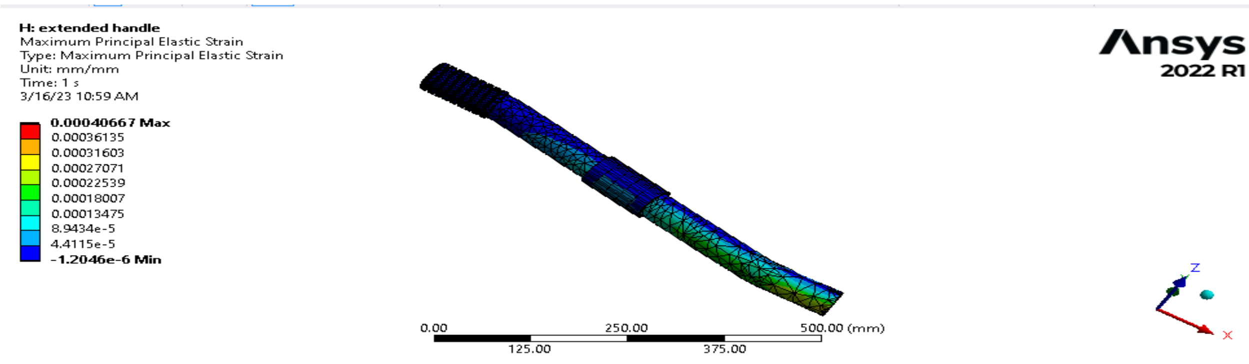


Figure A5: Extended handle the maximum principal elastic strain

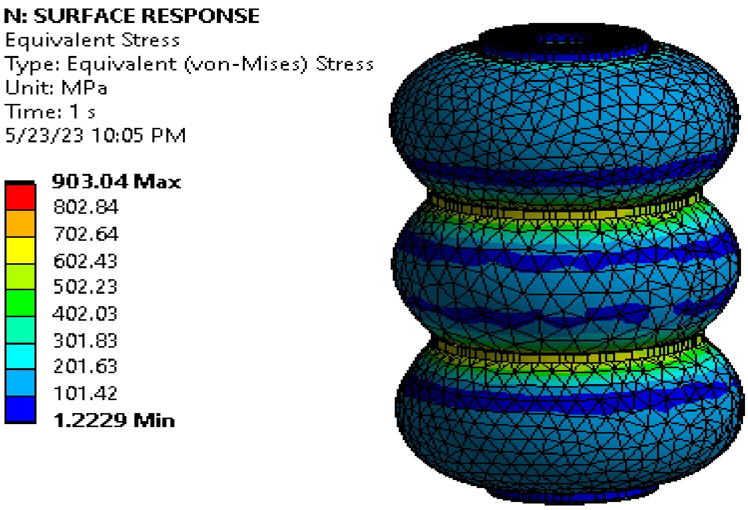


Figure A6: Surface response equivalent (von-mises) stress

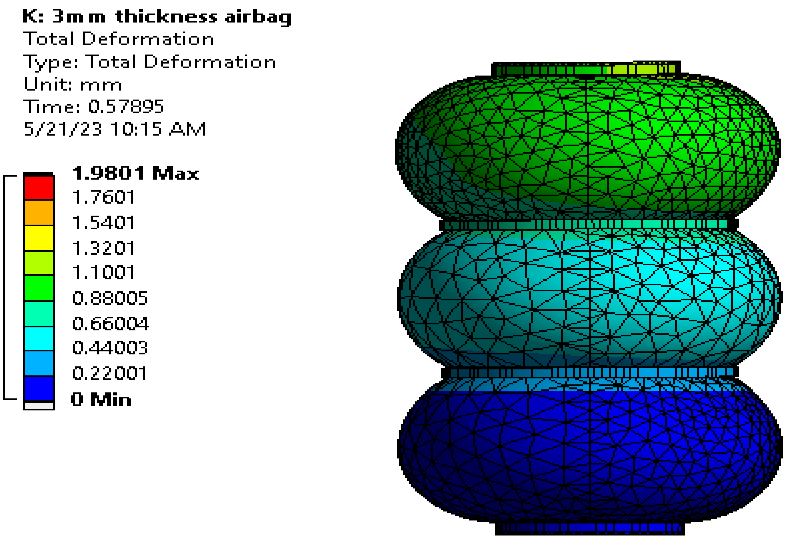
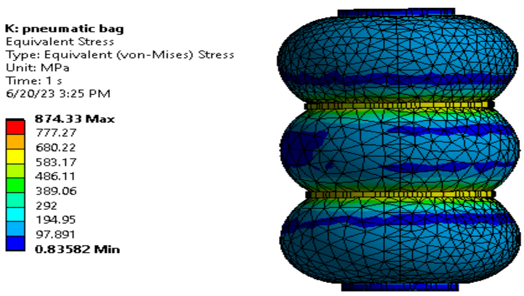


Figure A7: Modal and stress analysis at various frequencies and stresses of pneumatic jack



(a)

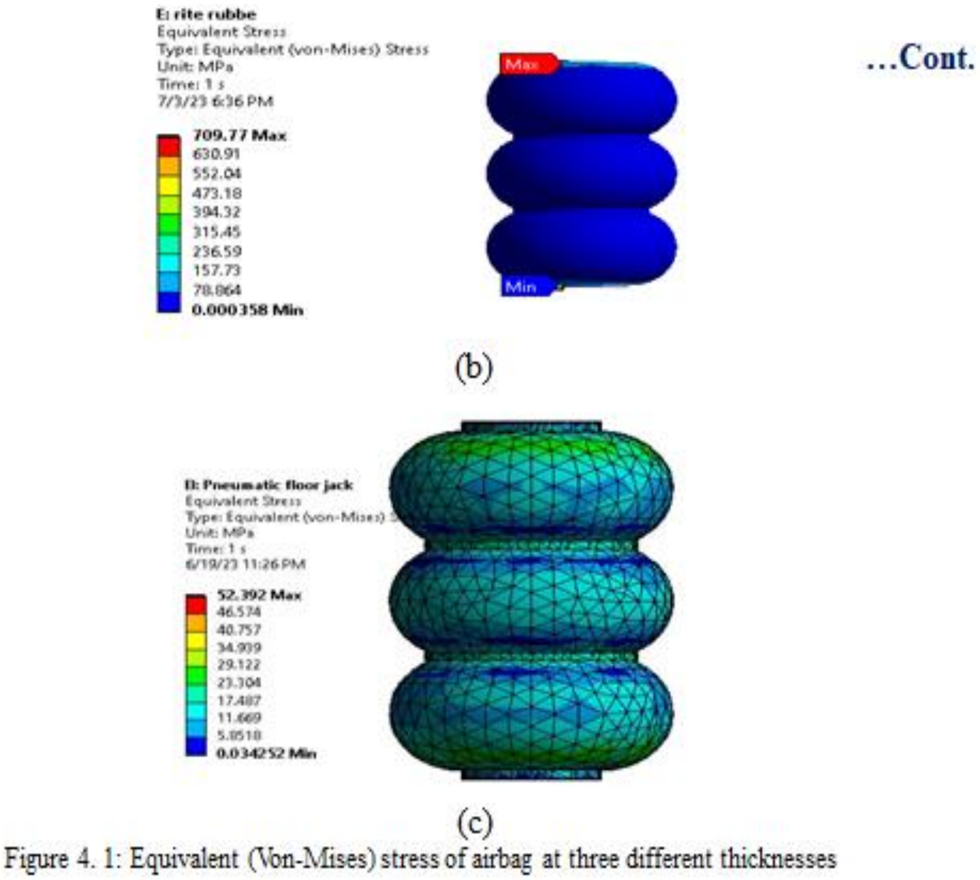


Figure A8: Equivalent (Von-Mises) stress of airbag at three different thicknesses

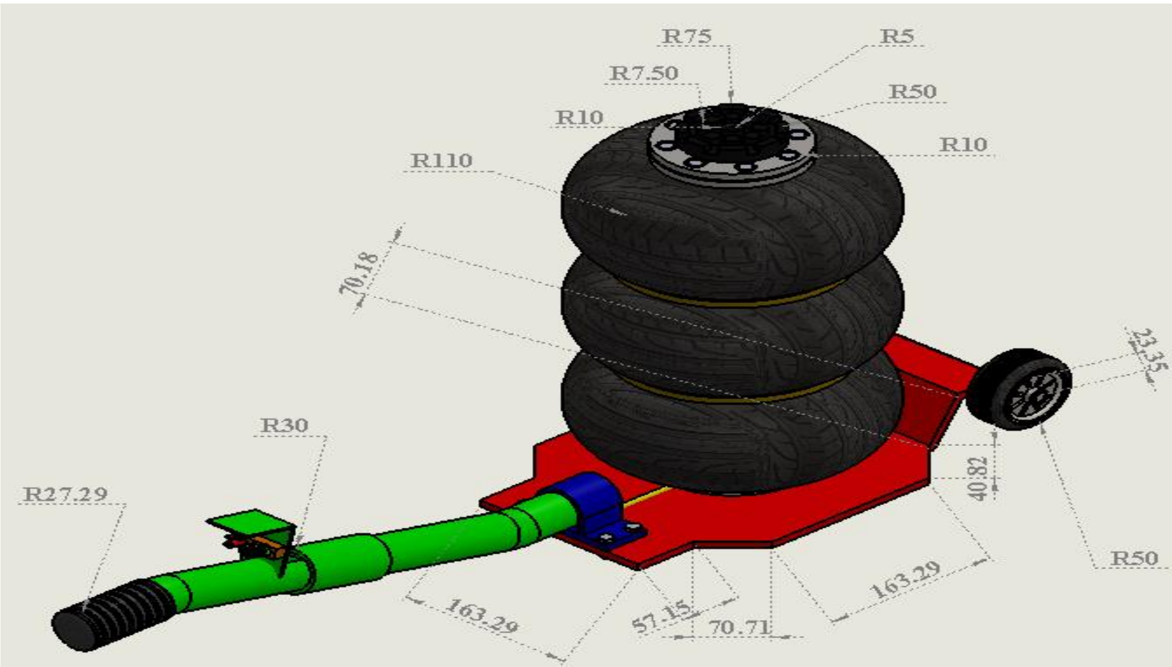


Figure A9: Assembly of extended handle pneumatic jack and its dimensions

Equation B1: the equations used for the design of extended handle pneumatic floor jacks

According to R.S. Khurmi and J.K. Gupta (2005) described in the textbook of machine design; the cross-section area, volume, cross-sectional moment of inertia about the neutral axis, applied pressure on the system, bending moment, and bending stress of hollow shaft and thin cylindrical bag are calculated as given in the following equations.

$$A = \frac{1}{4}\pi(d - d_i)^2 \tag{3.1}$$

Where,

A = Area of cross-section,

d_i = Internal diameter of the shaft, and

d = External diameter of the shaft.

i = 1, 2, 3….

$$V = \frac{1}{4}\pi(d - d_{i)})^2 h \tag{3.2}$$

Where

V = Volume of the telescopic,

d_i = Internal diameter of the shaft,

d = External diameter of the telescopic shaft, and

h = height of the telescopic

$$I = I_{xx} = I_{yy} = \frac{\pi}{64}(d^4 - d_i^4) \tag{3.3}$$

Where,

I = Moment of inertia of the cross-section about the neutral axis,

d_i = Internal diameter of the telescopic shaft, and

d = External diameter of the telescopic shaft.

$$K = \frac{\sqrt{I}}{A} = K_{xx} = K_{yy} = \frac{\sqrt{d^2 + d_i^2}}{4} \tag{3.4}$$

Where,

K = radius of gyration

I = Moment of inertia of the cross-section about the neutral axis,

A = Area of cross-section,

d = External diameter of the shaft, and

d_i = Internal diameter of the shaft.

$$Z = \frac{1}{Y} = Z_{XX} = Z_{yy} = \frac{\pi}{32}\frac{(d^4 - d_i^4)}{d} \tag{3.5}$$

Where,

Z = Section modulus,

y = Distance from the neutral axis to the extreme fiber,

d = External diameter of the shaft, and

d_i = Internal diameter of the shaft.

$$\frac{M}{I} = \frac{\sigma_{max}}{y};\ \sigma_{max} = M.\frac{y_c}{I} \tag{3.6}$$

Where,

σ_{max} = Maximum bending stress,

I = Moment of inertia of the cross-section about the neutral axis,

y_c = Distance from the neutral axis to the extreme fiber, and

M = Bending moment acting at the given section about the centroidal axis.

$$V = \pi r^2 h \tag{3.7}$$

Where,

V = volume of pneumatic jack,

r = radius of the airbag,

h = height of a single airbag, and

π = is constant.

The pressure exerted on the pneumatic bag jack is calculated by Pascal's law as follows:

$$\text{Pressure}(P) = \frac{\text{Force}(F)}{\text{Area}(A)} \tag{3.8}$$

Where,

P = pressure exerted on the system

F = force applied on the telescopic shaft, and

A = cross-section area load applied to the telescopic shaft.

$$E = \frac{\text{stress}}{\text{strain}} = \frac{\sigma}{\varepsilon} = \frac{\sigma}{\frac{\delta l}{l}} = \frac{\sigma * l}{\delta l} \tag{3.9}$$

Where,

A = Cross-sectional area of the telescopic,

E = Young's modulus of the material of the telescopic,

l = Length of the telescopic,

δl = Deformation/elongation of the telescopic,

P = Force at which the deflection δl is produced,

σ = Tensile or compressive stress,

V = Volume of the telescopic, and

ε = strain

$$t = \frac{P.d}{4\sigma_t.\eta} \tag{3.10}$$

Where,

t = Thickness of the airbag,

p = Intensity of internal pressure,

τ = Shear stress due to torsion.

L = Length of the airbag,

η = is the efficiency of the circumferential joints of the airbag,

d = Diameter of the airbag, and

σ_t = Tensile stress due to direct load and bending.

This equation is derived from the dynamics of distributed property systems Humar, J.L. (2012). For this method, it is assumed that the modulus of elasticity and the mass are uniformly distributed, and the cross-section is constant throughout the length of the tree stem.

$$\omega_n = \alpha_n^2 \sqrt{\frac{EI}{mL^4}} \quad \& \; \alpha_n = 1.875, 4.694, \tag{3.11}$$

ρ = Density of material,
L = Length of the telescopic shaft,
E = Modulus of Elasticity For stainless steel,
$\alpha_n =$ Solutions of the beam equation and depend on the vibration mode,
n = Mode Shape, and
I = Moment of inertia of the system.

Theoretical The Theory of Euler-Bernoulli Beams Beam theory is a simplified version of the linear theory of elasticity that allows you to calculate the load-carrying and deflection characteristics of beams. It only applies to humble deflections of a beam subjected to lateral loads. The natural frequency Euler's equation is stated as

$$\omega_n = \frac{n^2\pi^2}{L^2}\sqrt{\frac{EI}{\rho A}}; f_n = \frac{\omega_n}{2\pi} \tag{3.12}$$

$$f_n = \frac{1}{2\pi}[n\pi/L]^2\sqrt{\frac{EI}{\rho}}, \qquad n = 1,2,3 \tag{3.13}$$

n = Mode Shape,
ρ = Density of material,
I = Moment of inertia of the system,
ω_n = angular speed
L = Length of the telescopic shaft, and
E = Modulus of Elasticity For stainless steel.

Equation B2: solved equation extended handle of pneumatic bag jacks

$$A1 = \frac{\pi}{4}(d - d_i) = \frac{\pi}{4}(150^2 - 0) = 17{,}662.50\text{mm2}$$

$$A2 = \frac{\pi}{4}(d - d_i) = \frac{\pi}{4}(63^2 - 40^2) = 1{,}859.66\text{mm2}$$

$$A3 = \frac{\pi}{4}(d - d_i) = \frac{\pi}{4}(40.86^2 - 30^2) = 604\text{mm2}$$

$$A4 = \frac{\pi}{4}(d - d_i) = \frac{\pi}{4}(60^2 - 40^2) = 1{,}750\text{mm2}$$

$$A5 = \frac{\pi}{4}(d - d_i) = \frac{\pi}{4}(50^2 - 40^2) = 706.5\text{mm2}$$

$$A6 = \frac{\pi}{4}(d - d_i) = \frac{\pi}{4}(60^2 - 50^2) = 863.5\text{mm2}$$

$$A7 = \frac{\pi}{4}(d - d_i) = \frac{\pi}{4}(150^2) = 17{,}662.5\text{mm2}$$

$$A_T = (2 * 17{,}662.5 + 1{,}859.66 + 604 + 1{,}750 + 863.5)\text{mm}^2$$

$$A_T = 40{,}402.16\text{mm}^2 = 0.04\text{m}^2$$

$$Y_1 = 10 + 160 + 150 + 5 + 165 + 10 + 5 = 505mm$$

$$Y_2 = 10 + 160 + 150 + 5 + 165 + 5 = 495mm$$

$$Y_3 = 10 + 160 + 150 + 5 + 82.5 = 407.5mm$$

$$Y_4 = 10 + 160 + 150 + 2.5 = 322.5mm$$

$$Y_5 = 10 + 160 + 82.5 = 245mm$$

$$Y_6 = 10 + 80 = 90mm$$

$$Y_7 = \frac{10}{2} = 5mm$$

$$Y_c = \frac{505 * 17{,}662.50 + 495 * 1{,}859.66 + 407.5 * 604 + 322.5 * 1{,}750 + 245 * 706.5 + 90 * 863.5 + 5 * 17{,}662.5}{17{,}662.5 + 1{,}859.66 + 604 + 1{,}750 + 706.5 + 863.5}$$
$$= \frac{10{,}989{,}719.2}{41{,}108.66} = 267.33mm$$

A stainless steel telescopic subject to bending has a cross-section of circular form with an equal base has the same area at the top and the bottom (A_1=A_7=17,662.5mm^2) and moment of inertia calculated by using equation 3.3 described above.

$$\mathrm{I} = \mathrm{I_{xx}} = \mathrm{I_{yy}} = \frac{\pi}{64}(\mathrm{d}^4 - \mathrm{d_i^4})$$

$$\mathrm{I_1} = \mathrm{I_{xx}} = \mathrm{I_{yy}} = \frac{\pi}{64}(150^4 - 0^4) = 24{,}837{,}890.6\text{mm}^4$$

$$I_2 = I_{xx} = I_{yy} = \frac{\pi}{64}(63^4 - 40^4) = 647{,}279.65\text{mm}^4$$

$$I_3 = I_{xx} = I_{yy} = \frac{\pi}{64}(40.86^4 - 30^4) = 97{,}014.35\text{mm}^4$$

$$I_4 = I_{xx} = I_{yy} = \frac{\pi}{64}(60^4 - 40^4) = 510{,}250\text{mm}^4$$

$$I_5 = I_{xx} = I_{yy} = \frac{\pi}{64}(50^4 - 40^4) = 181{,}040.62\text{mm}^4$$

$$I_6 = I_{xx} = I_{yy} = \frac{\pi}{64}(60^4 - 50^4) = 329{,}209.38\text{mm}^4$$

$$I = I_{xx} = I_{yy}$$

$$\mathbf{I_T} = 24{,}837{,}890.6\text{mm}^4 + 647{,}279.65\text{mm}^4 + 97{,}014.35\text{mm}^4 + 510{,}250\text{mm}^4 + 329{,}209.38mm^4$$

$$I_T = 26{,}421{,}644\text{mm}^4 = 2.64\text{e}^{-5}\text{m}^4$$

The section modulus of the telescopic shaft was calculated by using equation 3.5

$$Z = \frac{1}{Y} = Z_{XX} = Z_{yy} = \frac{\pi}{32}\frac{(d^4 - d_i^4)}{d}$$

$$Z = \frac{1}{Y} = Z_{XX} = Z_{yy} = \frac{\pi}{32}\left[\frac{(63^4 - 40^4)}{63} + \frac{(40.86^4 - 30^4)}{40.86} + \frac{(60^4 - 40^4)}{60} + \frac{(50^4 - 40^4)}{50} + \frac{(60^4 - 50^4)}{60}\right] = \frac{\pi}{32} * 179 = 17.6mm^3$$

$$Z_1 = \frac{\pi}{32}\frac{(150^4 - 0^4)}{150} = 331{,}339.85mm^3$$

$$Z_2 = \frac{\pi}{32}\frac{(63^4 - 40^4)}{63} = 20{,}548.56mm^3$$

$$Z_3 = \frac{\pi}{32}\frac{(40.86^4 - 30^4)}{40.86} = 4{,}748.62mm^3$$

$$Z_4 = \frac{\pi}{32}\frac{(60^4 - 40^4)}{60} = 17{,}008.33mm^3$$

$$Z_5 = \frac{\pi}{32}\frac{(50^4 - 40^4)}{50} = 7{,}241.63mm^3$$

$$Z_6 = \frac{\pi}{32}\frac{(60^4 - 50^4)}{60} = 10{,}973.65mm^3$$

$$Z_7 = \frac{\pi}{32}\frac{(150^4 - 0^4)}{150} = 331{,}339.85mm^3$$

$$Z = \frac{(331{,}339.85 * 2 + 20{,}548.56 + 4{,}748.62 + 17{,}008.33 + 7{,}241.63 + 10{,}973.65)}{6}$$

$$= \frac{391{,}860.64}{6} = 65{,}310.11mm^3$$

The radius of gyration of the telescopic shaft was calculated by using equation 3.4

$$\mathrm{K} = \frac{\sqrt{\mathrm{I}}}{\mathrm{A}} = \mathrm{K_{xx}} = \mathrm{K_{yy}} = \frac{\sqrt{\mathrm{d}^2 + \mathrm{d_i^2}}}{4}$$

$$K_1 = K7 = \frac{\sqrt{I}}{A} = K_{xx} = K_{yy} = \frac{\sqrt{150^2 + 0^2}}{4} = 37.5mm^2$$

$$K_2 = \frac{\sqrt{I}}{A} = K_{xx} = K_{yy} = \frac{\sqrt{63^2 + 40^2}}{4} = 18.66mm^2$$

$$K_3 = \frac{\sqrt{I}}{A} = K_{xx} = K_{yy} = \frac{\sqrt{40.86^2 + 30^2}}{4} = 12.67mm^2$$

$$K_4 = \frac{\sqrt{I}}{A} = K_{xx} = K_{yy} = \frac{\sqrt{60^2 + 40^2}}{4} = 18.03mm^2$$

$$K_5 = \frac{\sqrt{\mathrm{I}}}{\mathrm{A}} = \mathrm{K_{xx}} = \mathrm{K_{yy}} = \frac{\sqrt{50^2 + 40^2}}{4} = 16\mathrm{mm}^2$$

$$K_6 = \frac{\sqrt{I}}{A} = K_{xx} = K_{yy} = \frac{\sqrt{60^2 + 50^2}}{4} = 19.53mm^2$$

$A_1 = \frac{1}{4}\pi(\mathrm{d} - d_1)^2 = \frac{1}{4} \times 3.14 \times (60.86mm - 40.86mm)^2 = 314mm^2$

$A_2 = 2 \times \left(\frac{1}{4}\pi(\mathrm{d} - d_2)^2\right) = 2 \times (\frac{1}{4} \times 3.14 \times (150mm - 0mm)^2) = 35{,}325mm^2$

$A_T = A_1 + A_2 = 314mm^2 + 35{,}325mm^2 = 35{,}639mm^2$

$$\begin{aligned} \mathrm{A_T} = \mathrm{A_1} + \mathrm{A_2} + \mathrm{A_3} &= 2\pi\mathrm{r}^2 + \mathrm{h}(2\pi\mathrm{r}) \\ &= [2 \times 3.14 \times 31.5^2 + 2 \times 12.5 \times 2 \times 3.14 \times 31.5] \\ &+ [3 \times 2 \times 3.14 \times 153^2 + 3 \times 148 \times 2 \times 3.14 \times 153] \\ &+ [2 \times 3.14 \times 115^2 + 2 \times 10 \times 2 \times 3.14 \times 115] \end{aligned}$$

$\mathrm{A_T} = 976{,}312.35\mathrm{mm}^2 = 0.976\mathrm{m}^2$

$$\mathrm{I} = \mathrm{I_{xx}} = \mathrm{I_{yy}} = \frac{\pi}{64}(\mathrm{d}^4 - \mathrm{d_i^4}) \tag{3.3}$$

$\mathrm{I} = \mathrm{I_{xx}} = \mathrm{I_{yy}} = \frac{\pi}{64}(306.25^4 - 303.25^4) = 339{,}643{,}189\mathrm{mm}^4$

$\mathrm{I_T} = 16{,}663{,}744\mathrm{mm}^4 + 11{,}555{,}169\mathrm{mm}^4$

$\mathrm{I_T} = 28{,}218{,}913.3\mathrm{mm}^4 = 2.82\mathrm{e}^{-5}\mathrm{m}^4$

$$W_1 = \frac{W_T}{4} = \frac{48{,}000N}{4} = 8000N$$

$\mathrm{P} = \mathrm{F}/\mathrm{A_1} = \left(\frac{8000\mathrm{N}}{0.018\mathrm{m}^2}\right) = 44.44\mathrm{MPa}$ The pressure applied on the telescopic shaft head from the vehicle weight

∴ Direct compressive stress due to axial thrust,

$$\sigma_0 = F/A_T = \frac{8000\mathrm{kN}}{0.04\mathrm{m}^2} = 200\mathrm{kN/m}^2 = 0.2\mathrm{MPa}$$

The bending moment at points A and B,

$\mathrm{M} = \mathrm{W} \times \mathrm{y_c} = 8000\mathrm{N} \times 267.33\mathrm{mm} = 2138.64 \times 10^3$ N-mm

∴ Bending stress due to bending moment,

$\sigma_b = \frac{\mathrm{M}}{\mathrm{Z}} = \frac{508.64 \times 10^3\ \mathrm{N.mm}}{65{,}310.11\mathrm{mm}^3} = 32.75\ \mathrm{N/mm}^2 = 32.75\mathrm{Mpa(compressive)}$ and resultant compressive stress,

$$\sigma_c = \sigma_b + \sigma_0 = 11\text{MPa} + 32.75\text{MPa} = 43.95\ \text{N/mm}^2 = 43.95\text{MPa}$$

$$\frac{M}{I} = \frac{\sigma_{max}}{y}\ ;\ \sigma_{max} = M.\frac{yc}{I} = 2138.64 \times 10^3\ \text{N.mm} \times \left(\frac{267.33\text{mm}}{26{,}421{,}644\text{mm}^4}\right)$$

$$\sigma_{max} = 21.64\text{N/mm}^2 = 21.64\text{MPa}$$

Putting all the values; we get

Since the hollow shaft is vertical, tensile stress at the topmost fiber is approximately zero, and compressive stress is at the bottom.

Distance of C.G. from upper extreme fiber y_t = 510 – 267.33 = 242.67 mm

Distance of C.G. from lower extreme fiber y_c = 267.33 mm

Therefore we will take the higher value of y i.e.; y_c = 267.33mm, and we get compressive stress.

$M/I = \sigma_{max}/y$; $\sigma_{max} = M.y_c/I$,

$\sigma_{max} = 2.14 \times 10^6 \times 267.33\text{mm}/\ 26{,}421{,}644\text{mm}^4 = 21.65\text{N/mm}^2$

$\sigma_{max} = 21.65\text{N/mm}^2$(Compressive) at the top of pneumatic jack

Maximum bending stresses are calculated by measuring the distance from the neutral axis to the top and bottom of the cross-section are:

$C_{top} = 510-\overline{Y} = 510-267.33 = 242.67\text{mm}$ and $C_{bot} = \overline{Y} = 267.33\text{mm}$

$\sigma_{top} = M\,\overline{Y}_{top}/I = (2.14\times10^6\text{kNmm}) \times (242.67)/\ 26{,}421{,}644\text{mm}^4$

$\sigma_{top} = 19.65\ \text{N/mm}^2$ (tensile)

Inspecting the above results, we conclude that the maximum tensile and compressive stresses in the hollow shaft are

$(\sigma_T)_{max} = 21.65\text{N/mm}^2$ (top of the section at $\bar{Y}$ =267.33mm)

$(\sigma_C)_{max} = 19.65\text{N/mm}^2$ (bottom of the section at $\bar{Y}$ = 242.67mm)

The volume of the pneumatic jack is

$$V_1 = 2(\pi \times 115^2 \times 12.5) = 77{,}891.625mm^3$$

$$V_2 = 3(\pi \times 153^2 \times 45) = 9{,}923{,}075mm^3$$

$$V_3 = 3(\pi \times 31.5^2 \times 10) = 830{,}530mm^3$$

$$V_T = (77891.625 + 9923075 + 830{,}530)mm^3 = 10{,}831{,}496.6mm^3$$

$$V_T = 10{,}831{,}496.6mm^3 = 10.8 \times 10^{-3}m^3$$

$P = \frac{F}{A} = \frac{mg}{A}$, where m is the mass of the object, the acceleration due to gravity is denoted by g, while the area is denoted by A. Since the vehicle is four wheels, a pneumatic jack lifts one wheel from the ground at a time. So the weight of one wheel is one-fourth of the total weight.

$$W_1 = \frac{W_T}{4} = \frac{48{,}000N}{4} = 8000N$$

$$\mathrm{P} = \frac{\mathrm{F}}{\mathrm{A}} = \frac{\mathrm{W_1}}{\mathrm{A_1}} = \frac{\mathrm{mg}}{\mathrm{A}} = \frac{8000\mathrm{N}}{0.976\mathrm{m}^2} = 8196.72\mathrm{Pa} = 8.20\mathrm{kPa}$$

The volume of the pneumatic jack is calculated as follows

$$\mathrm{V} = \pi\mathrm{r}^2\mathrm{h}$$

$$\mathrm{V_1} = 2 \times (3.14 \times 31.5^2 \times 12.5) = 77{,}891.625\mathrm{mm}^3$$

$$\mathrm{V_2} = 2 \times (3.14 \times 115^2 \times 10) = 830{,}530\mathrm{mm}^3$$

$$\mathrm{V_3} = 3 \times (3.14 \times 153^2 \times 148) = 32{,}635{,}891.44\mathrm{mm}^3$$

$$\mathrm{V_T} = (77{,}891.625 + 32{,}635{,}891.44 + 830{,}530)\mathrm{mm}^3 = 33{,}544{,}313.065\mathrm{mm}^3$$

$$\mathrm{V_T} = 33{,}544{,}313.065\mathrm{mm}^3 = 33.5 \times 10^{-3}\mathrm{m}^3$$

$$\mathrm{m} = \rho \times \mathrm{v}$$

Where,

m = mass of pneumatic jack

ρ =density of tire rubber

g = acceleration due to gravity and $V = \pi r^2 h$ where r = radius of airbag h = height of pneumatic jack and when the mass of air is negligible. Density of compressed air = 1000 kg/m^3 and density of tire rubber = 0.74 g/cm^3 and take acceleration due to gravity = 9.81 m/s^2

$$m = \rho \times v = 740\ kg.m^{-3} \times 33.5 \times 9.81^{-3} m^3 = 24.31\ kg \approx 24\ kg$$

Consider a pneumatic bag subjected to internal pressure as shown in Figure 3.5.

Let V = Storage capacity of the pneumatic bag jack

p = Internal pressure intensity,

d = Diameter of the pneumatic bag,

t = Thickness of the pneumatic bag,

σ_t = Permissible tensile stress for the pneumatic bag material.

In designing thin spherical tire airbags, we have to determine

1. Diameter of the pneumatic bag, and

We know that the storage capacity of the airbag,

$$V = \pi r^2 (h + h_i) = \frac{\pi}{2} d^2 = d = (2V/\pi)^{1/2}$$

2. Thickness of the pneumatic bag

As a result of the internal pressure, the pneumatic bag is likely to rupture along the center of the sphere. Therefore force tends to rupture the pneumatic bag along the center of the sphere or bursting force.

$$= \text{Pressure} \times \text{area} = P \times \frac{\pi}{4} \times d^2 \qquad (3.14)$$

And resistance force of the pneumatic bag

$$= \text{stress} \times \text{resisting area} = \sigma t \times \pi\, d.t \qquad (3.15)$$

Equating equations (3.14) and (3.15), we have $P \times \frac{\pi}{4} \times d^2 = \sigma t \times \pi\, d.t;\ t = \frac{P.d}{4\sigma t}$

If η is the efficiency of the circumferential joints of the cylindrical pneumatic bag, then

$$t = \frac{P \times d}{4\sigma t \times \eta} \tag{3.16}$$

$$V = \pi r^2 h = \frac{\pi}{2}(h + h_i)d^2 = d = (2V/\pi)^{1/2} = \frac{3.14}{2} \times 463.91 \times 306.25^2$$
$$= 68{,}310{,}204 mm^3$$

Assume η the efficiency of the circumferential joint is 75% (R.S. Khurmi and J.K. Gupta, 2005) and the designed pneumatic bag rubber thickness is 3mm the tensile stress of the pneumatic bag jack is calculated at $0.28\ \mathrm{N/mm^2}$

$$\mathrm{t} = \frac{\mathrm{P \times d}}{4\sigma\mathrm{t} \times \eta} \to \sigma\mathrm{t} = \frac{\mathrm{p \times d}}{4\mathrm{t} \times \eta} = \frac{8.2 \times 10^{-3}\mathrm{N/mm2} \times 306.25\mathrm{mm}}{4 \times 3\mathrm{mm} \times 0.75} = 0.28\ \mathrm{N/mm^2}$$
$$= 280\ \mathrm{kPa}$$

If the extended handle pneumatic bag jack thickness is designed to be 2.5mm the tensile stress is high and so the failures ratio is high

$$\sigma\mathrm{t} = \frac{\mathrm{p \times d}}{4\mathrm{t} \times \eta} = \frac{8.2 \times 10^{-3}\mathrm{N/mm^2} \times 306.25\mathrm{mm}}{4 \times 2.5\mathrm{mm} \times 0.75} = 0.3348\ \mathrm{N/mm^2} = 334.83\ \mathrm{kPa}$$

i) Calculating the dynamic frequency of the telescopic shaft by applying six different deformation forces on it and analyzing the results.

Where,

n = Mode Shape

f_n = natural frequency

ω_n = angular speed

$\alpha_n =$ Solutions of the beam equation and depend on the vibration mode

A = Area of cross-section

L = Length of telescopic shaft

ρ = Density of material

I = Moment of inertia of a system

E = Modulus of Elasticity For stainless steel

$E=1.93*10^{11}$ N/m^2

I=2.64 ×10-5 m^4

ρ =7750 kg/m^3

A=0.04m^2

L = 0.5m

Mode natural frequency of the telescopic shaft

E×I =1.93×10^{11}N/m^2×2.64×10^{-5}m^4 = 5,095,200 Nm^2

$$f_n = \frac{1}{2\pi}\left[\frac{n\pi}{L}\right]^2 \sqrt{\frac{EI}{\rho}}, \qquad n = 1,2,3$$

$$f_1 = \frac{1}{2\times 3.14}\times\left[\frac{1\times 3.14}{0.5}\right]^2\times\left[\frac{\sqrt{1.93\times 10^{11}\ \mathrm{N/m2}\times 2.64\times 10^{-5}\mathrm{m4}}}{7750\ \mathrm{kg}/m^3}\right]$$

$$= 0.159\times 39.44\times 25.64 = 160.787\mathrm{Hz}$$

ii) The dynamic frequency of a pneumatic bag is calculated by applying six different deformation forces to it and analyzing the results.

Where,

L = Length of pneumatic bag

E = Modulus of Elasticity For pneumatic bag

E =1×10^6 N/m^2

$I = 2.82e^{-5}\mathrm{m}^4$

ρ =740 kg/m^3

L = 0.15m

$$E\times I = 1\times 10^6\mathrm{N/m^2}\times 2.82\times 10^{-5}\mathrm{m^4} = 28.2\ \mathrm{Nm^2}$$

$$f_1 = \frac{1}{2\times 3.14}\times\left[\frac{1\times 3.14}{0.46}\right]^2\times\left[\frac{\sqrt{5\times 10^{10}\mathrm{N/m2}\times 2.82\times 10^{-5}\mathrm{m4}}}{740\ \mathrm{kg}/m^3}\right]$$

$$= 0.159\times 46.60\times 43.65 = 323.43\mathrm{Hz}$$