DESIGN OPTIMIZATION AND ANALYSIS OF SUPPORTLESS CHAIR FOR PROSTHETIC LEG PERSON

A Project report submitted in partial fulfilment of the requirements for

the award of Degree of

Bachelor of Technology
in
Mechanical Engineering

submitted by

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ABSTRACT

A worker finds it very challenging to stand for their entire shift at work, and persons who use prosthetic legs are unable to stand for lengthy periods of time. Some jobs make it challenging for workers to avoid the stress and exhaustion of having to stand, bend, and stoop for extended periods of time, adopting postures that could result in physical, muscular issues. Exoskeletons that are affordable and portable with an ergonomic design are the answer to this issue. The mechanical ergonomics device in this work has segments and joints that match those of the person it is externally associated with, and it is built to mimic the shape and function of the human body. Workers in the industrial sector can wear it on their legs like an exoskeleton. It locks into place and allows you to sit on it. The device never comes into contact with the ground, making it simpler to wear: a belt binds it to the hips, and straps wrap over the thighs. The user only needs to move into the appropriate stance. It will fit tightly to the lower part of the body as an external body part on which the greatest body forces will act. As a result, these forces must be carefully considered during structure design. The simplest strategy to forecast these forces during the pre-manufacturing stage is to perform a structure study using software. This aids in determining the stresses imposed on the structure, which is a critical criterion for model evaluation. With this being a skeleton for newer items, the exoskeletal support serves a number of different functions in addition to offering lower body comfort. The design's effectiveness and usability will be evaluated in context.

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CHAPTER-1

INTRODUCTION

Standing for a short period of time is beneficial to your health, but only provided you are not forced to do so for hours. Additionally risky is excessive sitting, which has a negative impact on the body's metabolic rate and increases the risk of diseases including high blood pressure, diabetes, cancer, and depression, among others. The fundamental goal of workstations is to increase productivity, yet the physical effects of work exhaustion on employees are given very little attention. Even though the workplace is ergonomically constructed, they are not effective in reducing worker fatigue since they must spend the majority of the time in one position for extended periods of time. There is currently no comfort-enhancing technology available for workstations in the rapidly evolving technological era. Workstations currently lack a device that can offer worker comfort in the age of rapidly advancing technology. It is clear that a sloping or kneeling chair preserves lordosis and sacral slope better than a level one in both an upright and slumped posture; this reduces tissue strain and, in turn, lessens back discomfort. Therefore, the reason why a sloping chair is preferred over a flat one is that a flexible wearable chair offers greater comfort than a flat one for the same working posture.

Exoskeletons have been developed to help people move more easily and for medical rehabilitation. Exoskeletons have been used particularly effectively in the field of medical rehabilitation, and a number of very small, powered exoskeletons for mobile applications have lately been demonstrated. However, the period of use is sometimes constrained by power limitations. To put it another way, the exoskeleton should safely and comfortably support the user's natural movements without compromising the user's agility. Researchers have integrated the user's purpose into the control of exoskeletons to meet this enormous challenge. Global population ageing is a problem, and physical decline and frailty among the elderly have emerged as socioeconomic issues in many nations. Exoskeletons are thought of as one of the most potential assistive devices for this enhancement. Improving and strengthening lower limb movement in old and dependent people has drawn particular interest due to the population's sharp increase.

Global population ageing is a problem, and physical decline and frailty among the elderly have emerged as socioeconomic issues in many nations. Exoskeletons are thought of as one of the most potential assistive devices for this enhancement. Improving and strengthening lower limb movement in old and dependent people has drawn particular interest due to the population's sharp increase. It is vital to determine principles of human motor adaptation and the characteristics that affect the rate of motor adaptation to powered assistance in order to drive robotic exoskeleton development. Aside from that, several advancements have been made, and Exo-Skeletons are now used in a variety of applications such as military, medical, and rescue operations.

The muscle effort needed to control the moving segments, the inertial forces generated by the moving segments, and the impulsive force given to the foot at ground contact all contribute to an increase in the lower extremity joint stresses during locomotion. It is true for the ankle angle when the individual is standing with the hip level with the ankle and when the length of the upper and lower leg is nearly identical. The entire lower extremity or limb of the human body, including the foot, thigh, and even the hip or gluteus region, is referred to as the human leg in the general sense; however, the definition of the term in human anatomy only refers to the portion of the lower limb that runs from the knee to the ankle. Legs are utilised for standing, walking, jumping, running, kicking, dancing, and other similar actions, and they account for a sizable amount of a person's bulk. Legs have two crucial functions: supporting the trunk during the grounding phase and stepping fast during the swing phase. The total of all muscle forces acting across a joint multiplied by the individual lever arms of each muscle results in an internal joint moment. The external moments produced by gravitational, inertial, and reaction forces are balanced and equalised by this internal joint movement. Calculating the external moments applied at each joint yields the internal joint moments. Humans have twin S-shaped spinal columns, which operate as shock absorbers to transfer weight from the trunk to the feet's load-bearing area. Due to their unique specialisation in support and mobility, human legs are extraordinarily long and strong. Numerous leg muscles, most notably the gluteal muscles, knee extensors, and calf muscles, are also adapted to walking on two legs. The solution to this challenge is to develop a portable gadget with an ergonomic design, as well as low-cost exoskeletons. A mechanical ergonomics device created around the shape and function of the human body, with segments and joints similar to those of the person it is externally associated with, is used in this work. It serves as a chair when needed and is known as the Supportless Chair. Workers in the industrial sector can wear it on their legs like an exoskeleton. It locks into place and allows you to sit on it. The device never comes into contact with the ground, making it simpler to wear: a belt binds it to the hips, and straps wrap over the thighs. These are carefully developed and are part of the mechanism, however another version may be worn with ordinary footwear and simply touches the ground when stationary. The user only needs to move into the appropriate stance. It will fit tightly to the lower part of the body as an external body part on which the greatest body forces will act. Because of its cost-effectiveness, any design flaw could cause the structure to collapse and cause a loss. Therefore, great consideration should be given to these forces while designing a structure. Making an analysis of the structure using software is the best technique to predict these forces during the pre-manufacturing stage. This assists in predicting the stresses imposed on the structure, which is one of the most essential criteria for model evaluation. The materials used and the load bearing capabilities of a leg define its use in any field of application. Before constructing these components, perform finite element analysis on the material properties and loads to appropriately determine the behaviour of these legs. Since the 1980s, there has been a substantial change in the types of materials used for exoskeletons including wood, leather, aluminium, and plastic. To make this product affordable for everyone, including employees and patients with leg injuries, we concentrated on simplifying the design and lowering the cost. The adoption of Support less chair should reduce the incidence of MSDs (Musculoskeletal Disorders), which occur in workers who engage in extended standing.

Support less chair also offers the possibility to:

- Assist wounded workers in getting back to work more quickly.
- Minimise, if not completely do away with, the necessity for microbreaks, worker switching, and other ineffective procedures.
- Provide a larger spectrum of personnel with the skills necessary to complete tasks safely, such as older or smaller workers. A prototype of this chair has been created in the current work. A good product that will ultimately increase efficiency at the workplace across numerous industries is a Supportless chair.

1.1 Problem Statement

The visual example is where our project's problem statement came from. It has been noted that people with prosthetic legs and regular workers have trouble standing for lengthy periods of time at work or in other public settings. A high-end prosthetic limb is also difficult for the average middle-class person to acquire, thus many with below-the-knee amputations use the Jaipur foot, a prosthetic leg made of rubber that is less expensive. Therefore, a mechanism must be created so the user can easily sit wherever in public locations.

1.2 Proposed Solution

The idea is to create an exoskeleton lower body mechanism that a person with a prosthetic leg can attach to both his artificial Jaipur foot and normal leg, allowing him to bend his knees to the level he wants to sit anywhere. To accomplish this, damper mechanisms will be used to direct the load towards the ground, and a proper structure will be created using lightweight materials to ensure that the wearer is not burdened.

1.3 Distinctive Features of This Mechanism

- Since it is based on exoskeleton technology, this device does not require the user to carry it externally.
- It will be constructed of lightweight materials to reduce the wearer's load.
- Material optimisation is carried out to lower the mechanism's cost.
- To investigate the dynamic properties of the system in the frequency domain, a modal analysis will be performed using Ansys.

1.4 How Is It Different from Similar Products?

Since there are many products on the market that are similar to this mechanism but are used for different purposes and there are also high-end prosthetic legs that are expensive and out of the reach of the average person, our design will be a great alternative for those using affordable prosthetic legs like the Jaipur foot. Our design makes it simple for the wearer to sit down and move the lightweight exoskeleton mechanism around.

1.5 Objective

In the workplace, the goal of this research is to assist employees in exercising more efficiently to lessen the negative effects of microgravity on bones and muscles. When we want to sit wherever or anytime, there are no seats available. In confined areas like warehouses, it is frequently difficult to provide seating equipment for every employee, and standing for extended periods of time is typically unhealthy. The energy efficiency of available robotic movement is a major problem.

People can sit anywhere due to the Portable Chair, which functions like an exoskeleton on mobility. To apply resistive forces to the muscle forces, the mechanism combines the dynamics of a hydraulic damper with a dynamic model of the lower leg's musculoskeletal system. The goal of this project is to create an exoskeleton-like assistive technology that will enable us to move normally while wearing it, including walking and running.

Numerous studies have demonstrated that spending the entire day seated can lead to a variety of health issues, such as diabetes and cancer. The goal of this research is to design and build a support-less chair technology, or a lower body exoskeleton. Additionally, this project can assist users sit anywhere without having to display a chair, improve their posture, and ease their leg muscles.

The control method is suggested for working out certain muscles in the lower body of a human being in this future, which is similar to a solution for the worker to continue working while standing. An exoskeleton that enforces passive force feedback control is used to do this. The suggested approach combines a dynamic model of the lower body's musculoskeletal system with the dynamics of hydraulic actuators. The exoskeleton is made to enable the subject to exercise bilateral specific muscles individually without restricting their range of motion.

The technique used is intended to counterbalance the motion of the human knee, yet it operates in a manner that is conceptually similar to an inverted four-bar chain mechanism. Without a chair or back support, a human can sit with the help of their two lower limbs. There will be Velcro strips available to clamp the assembly with human limbs.

1.6 Factors in Consideration Of Project

- Compatibility with the goal, strategy.
- Access to required scientific and engineering capabilities in R&D.
- Critical technological issues are likely to arise.
- The proposed new product's market prospects and possibilities.
- Production skills must be available.
- Expected financial return.

CHAPTER- 2
LITERATURE REVIEW

Before beginning the project, a brief review of publications on DESIGN OPTIMISATION AND ANALYSIS OF SUPPORTLESS CHAIR FOR PROSTHETIC LEG PERSON was completed. Many authors depicted various thoughts linked to their efforts on the design of exoskeleton and analysis of various mechanisms. The following are the papers that were reviewed:

S. T. MCCAW AND B. T. GATES [1] Much debate has been generated over the impact of modest leg length disparity on posture and gait. There have been many arguments made both in favour of and against the need for action to lessen the severity of the difference. Their study reviews the biomechanical effects of leg length inequality on the onset of stress fractures, low back pain, and osteoarthritis, and emphasises the need for accurate and reliable assessment of leg length differences using a clinically functional radiographic technique.

AYDIN TOZEREN [2] published a book on how human movement is governed by the same fundamental rules that apply to static and moving bodies, and this textbook approaches the science of human biomechanics quantitatively. A quantitative method of researching human biomechanics that illustrates classical mechanics concepts through case studies of human movement. The motion of objects is described using vector algebra and vector differentiation, and 3D motion mechanics is thoroughly discussed. It uses software-generated sequences and diagrams to depict human movement.

ROBERT PETER MATTHEW ET.AL [3] research helped us gain a general understanding of active and passive exoskeletons. For people with musculoskeletal disorders, assistive equipment like exoskeletons can improve rehabilitation and increase freedom. Standard devices either use active aid techniques like DC motors or passive support techniques like springs, orifice valves, or levers. While passive methods are constrained by user ability, active methods need a constant power input. This paper presents an Active/Passive Exoskeleton framework. This gadget can give continuous passive support, requiring just energy to change the dynamic features of the passive state. The first prototype

(APEX-) is introduced and tested on six healthy hammer curl individuals. It was discovered that variations in the APEX-'s passive state alter the number of curls performed by an individual. Increases in curl count of 65-92% were reported by modifying the inactive condition of the exoskeleton. This demonstrates the potential for such gadgets to aid an individual by utilising lightweight, energy efficient active/passive actuators.

PAUL DOMINICK E. BANIQUEDI AND NILO.T. BUGTAI [4] provided on how the clinical efficacy of robot-assisted rehabilitation systems in treating stroke patients is comparable to that of conventional approaches. Robotic exoskeletons for the upper limbs in particular are powered wearable gadgets made to match the user's joints and connections. The comfort and safety of the injured patient are compromised since current product design techniques simplify the complicated requirements of the human upper limb. In rehabilitation robots, it's crucial to take user requirements and needs into account at an early stage of design. In their work, they showed how the evaluation of user requirements is included into the creation of a wearable robot for the treatment of Filipino and Asian patients. Following the study and subsequent debate, a list of user specifications for wearable robots in neurorehabilitation was created. The final design priorities and device specifications are determined by a matrix that was created after the design engineers and their medical collaborators assigned equivalent importance ratings. They were able to successfully evaluate at least fifteen of the customer needs taken into account. The 7-degree-offreedom robotic exoskeleton for patients with Filipino and Asian body types was created using the findings of their investigation. With the use of this strategy, designers of medical devices can use their prior knowledge of design issues to incorporate user-centricity and compatibility into their current designs.

DAVIDOVITS. P [5] book addresses themes in physics as they apply to the life sciences, notably medicine, physiology, nursing, and other applied health professions. This is a brief introductory paperback that provides practical ways for applying physics knowledge to the study of biological systems. The content is presented in a basic manner that requires very little background in physics or biology.

DARCY ROBERT BONNER [6] In 1977, he designed a wearable chair that allowed users to sit on two legs, which was unusual at the time. However, the design proposed by them has some drawbacks, including the fact that it only enables one sitting position, regardless of the user's preference, and that there is significant stress on the lower leg as a result of the response force generated by the lower bar. The core notion is that incorporating internal hinges into the mechanism (structure when seated) releases joint moment, and making these hinges coherent with human lower body joints aids in the release of severe joint strains that occur when working. However, the concept presents significant ergonomic issues. The major issue with such a design is ensuring that workers may move freely and that it is in stable equilibrium after sitting. It is well demonstrated how a flexible wearable chair achieves static equilibrium and maintains a stable shape under stress.

ASHUTOSH BIJALWAN AND ANADI MISRA [7] Design of a flexible chair-like mechanism was examined. The flexible wearable chair functions similarly to a light weight mobile exoskeleton, allowing individuals to sit anywhere and in any working position. Because of their big dimensions, hefty weight (5 - 7 kg), and hard frame, traditional chairs are difficult to relocate to different working positions and are thus inappropriate for workplaces with limited space. Because it is made of lightweight aluminium alloy parts, the flexible wearable chair has a gross weight of 3 kg. Unlike ordinary chairs, it is made up of kinematic pairs that allow for pauses between continuous motions in every working posture, significantly lowering the risk of physical musculoskeletal disorder among workers. This paper's goal is to concentrate on the mechanical design and finite element analysis (FEA) of the mechanism using ANSYS software. In the current effort, all of the mechanism's components are designed under static load conditions. The analytical results show that a flexible wearable chair meets the balance and stability criteria and can reduce tiredness while working on an assembly line/factory.

H. ZURINA AND A. FATIN [8] The paper was interested in wearable devices that aid in boosting human efficiency and decreasing human weariness during work. The gadget under consideration here is the passive device. The equipment is known as a virtual Chair, and it allows the wearer to work successfully in any location while sitting. Zurina and A. Fatin collaborated on the Lower Body Exoskeleton Design and Development. In their article, they attempted to assess the feasibility of employing a virtual chair to improve energy economy and provide weight support when the user becomes fatigued, rather than continuously carrying the weight. Aside from that, in terms of ergonomics, the goals of providing comfort to users have been met by allowing users to select their comfort degree level from 45° to 90°. Apart from the benefits of their experiment, it is possible to infer that his design still has some flaws that must be addressed in the future in order to meet the goal of providing an ergonomic chair to users. Our version was tested in an experiment on a group member weighing 80kg and standing roughly 170cm tall. The results of the experiment testing show that for height and weight, the chair has no effect in terms of under or overmeasurement in its height dimension. It fits the user, demonstrating that this chair may be worn by persons of all heights. They experimented with using the chair while doing some work, and it was discovered that they had difficulty changing the degree level.

ADITYA BHALERAO ET.AL [9] worked on a pneumatic portable chair for employees to sit in while working. By reference to human seated and walking characteristics, a leg mechanism with kinematic structure has been conceived, the mechanical design of which can be employed by employees as a wearable exoskeleton. According to the Specified Design specifications, the body can hold roughly 100Kg of human body weight. Oil was eventually used into the weight sustaining mechanism to cut costs, resulting in improved outcomes. These types of devices with an ergonomic background can be simply upgraded by combining numerous facilities into a single body and being regularly modified. A rudimentary idea of how a Pneumatic or Hydraulic Cylinder exoskeleton might be utilised to minimise fatigue through simple kinematic processes. Due to specific constraints, not much progress has been done in this particular machine, and it is analogous to tailormade clothes that is only suitable for one person and may not fit adequately to other users. It has several key applications in real-time scenarios, such as wearing it in packed trains or public venues with limited space.

CYRIL VARGHESE [10] The Exoskeleton Based Hydraulic Support was successfully manufactured and proven to be sufficiently safe. Under fluctuating weight when walking, as well as when the user sits/rests on it. (Over a 43-day period, the Extra-Large Size Variant was tested on a user weighing 116 kg.) The total cost of manufacturing the EBHS is Rs. 8540 ($ 126.84), making it relatively affordable for the general population, industrial use, and military use. The EBHS will come in three sizes, small, regular, large, and extra-large, for those between the heights of 5'5" and 6'0". Due to the exoskeleton-based hydraulic support's incredibly low weight, it poses very little of a walking obstacle, and the user quickly gets acclimated to it.

ALEXANDER EGOYAN AND K. MOITSRAPISHVILI [11] developed an innovative parameterization to describe how the straight human body with its feet planted on the ground can lean forward and backward. The X and Y coordinates of the body's centre of gravity and the radius R of the base of support are two fundamental parameters that determine the stability of the static equilibrium of the upright human body during this motion. In order to compute the critical values of the angle between the vertical axis OY and the axis of the cylinder the body is placed inside, they added two coefficients, k1=Y CG /R and k2=X CG /R. They determined the crucial values "cr" and "cr" that indicate when the body becomes unstable during respective leanings backward and forward. It is demonstrated that the angle cr = |cr′ |+|cr″|, which strongly depends on k1 and weakly depends on k2, and the value of for the most stable position, in which the body's centre of gravity is exactly above the geometrical centre of base of support, can be used to describe the stability of an upright body. For bigger cr and smaller | opt |, stable equilibrium will be attained.

KEITH GUNARA ET.AL [12] had created a wearable mechatronic posture-assisting device that included a damper with connectors for pivotally attaching the damper to the support and an upper support for attaching to the person's thigh and a lower support for attaching to their shank. The damper's purpose is to linearly dampen the join's pivot. The damper has control mechanisms that permit it to be in both a locked and driven condition.

As a result, by looking at the articles that are related to our solution, we can see how different writers have approached the design of exoskeletons and the analysis of different systems from different perspectives. Using all the major insights we gained from examining the papers, we would then move on to designing a model.

CHAPTER-3

SELECTION OF MATERIALS

3.1 Aluminium 6061

Aluminium metal and its alloys are implemented in most of modern industrial processes due to its wide availability and the vast number of uses. An alloy is a metal made by combining two or more metallic elements to achieve improved material properties. Type 6061 aluminium is of the 6xxx aluminium alloys, which entails those mixtures which use magnesium and silicon as the primary alloying elements. The second digit indicates the degree of impurity control for the base aluminium. When this second digit is a “0”, it indicates that the bulk of the alloy is commercial aluminium containing its existing impurity levels, and no special care is needed to tighten controls. The nominal composition of type 6061 aluminium is 97.9% Al, 0.6% Si, 1.0%Mg, 0.2%Cr, and 0.28% Cu. 6061 aluminium alloy is heat treatable, easily formed, weld-able, and is good at resisting corrosion. Its weld-ability and formability make it suitable for many general-purpose applications.

Properties	**Values**
Density (kg/m^3)	2700
Poisson’s Ratio	0.33
Elastic Modulus (MPa)	6.89E+04
Ultimate Tensile strength (MPa)	2.76E+02
Bulk Modulus (MPa)	6.7549E+04
Shear Modulus (MPa)	2.5902E+04
Coefficient of Thermal expansion (10^-5/°C)	2.3

Table 3.1: Property table of Al 6061

3.2 Titanium Alloy

Titanium alloys are metals that contain a mixture of titanium and other chemical elements. Such alloys have very high tensile strength and toughness (even at extreme temperatures). They are light in weight, have extraordinary corrosion resistance and the ability to withstand extreme temperatures. Materials are frequently chosen for various applications because they have desirable combinations of mechanical characteristics. For structural applications, material properties are crucial and engineers must take them into account. They are light in weight, have extraordinary corrosion resistance and the ability to withstand extreme temperatures. However, the high cost of raw materials and processing limits to the use in military applications, aircrafts, bicycles, medical devices, sports cars, jewellery and etc.

Properties	**Values**
Density(kg/m^3)	4620
Poisson's Ratio	0.36
Elastic Modulus (MPa)	9.60E+04
Ultimate Tensile strength (MPa)	1070
Bulk Modulus (MPa)	1.14E+05
Shear Modulus (MPa)	35294
Coefficient of Thermal expansion (10^-5 /°C)	9.40E-01
Reference Temperature (°C)	22

Table 3.2: Property table of Titanium alloy

3.3 PVC Foam:

PVC foam offers many advantages, such as superior impact resistance, high strength, great durability, low water absorption, high corrosion resistance, and fire resistance to name a few. These benefits provide the perfect material to withstand all types of indoor and outdoor conditions, including harsh weather.

PVC foam is made up of PVC and Polyurea through an interpenetrating polymer network. Both substances are mixed, dispensed into a mould, sealed and heated. When it has expanded to its full density and cured, it is then ready to be cut for purchase.

Due to the structure of its component molecules, PVC foam boards are highly strong which ensures that they don't undergo any deformation. The boards can survive for as long as 4 decades without any damage

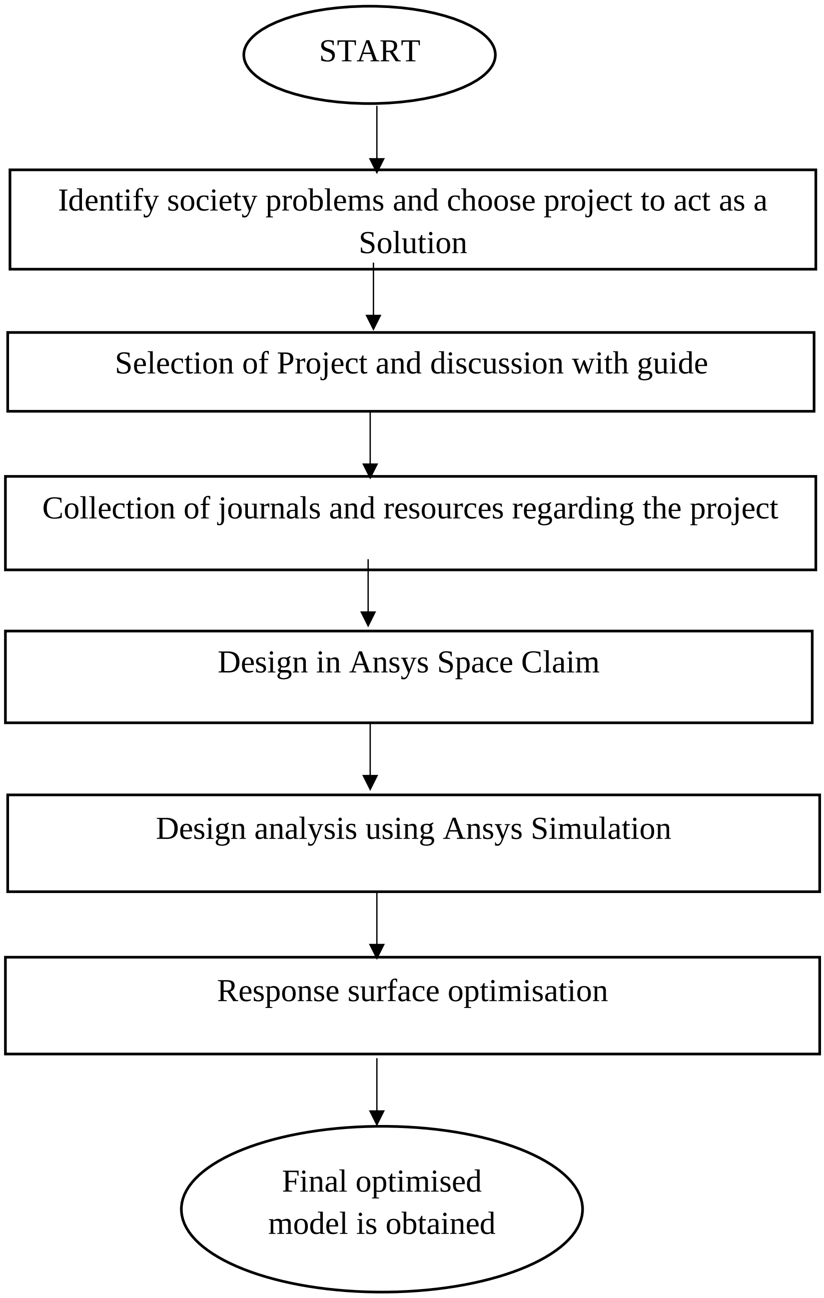
Properties	**values**
Density(kg/m^3)	60
Poisson’s Ratio	0.3
Elastic Modulus (MPa)	70
Ultimate Tensile strength (MPa)	52
Bulk Modulus (MPa)	50.8
Shear Modulus (MPa)	1.0
Coefficient of Thermal expansion (10^-5 /°C)	7×10^{-5}
Reference Temperature (°C)	3.2

Table 3.2: Property table of PVC foam

CHAPTER-4

DESIGN METHODOLOGY

A design is a strategy or specification for building a system, an object, or carrying out an activity or process. It can also be a specification for a prototype, a finished good, or a method.



To commence simulating a physical system or product, the initial phase involves generating a geometry of the system or product. This can be achieved by utilizing ANSYS Geometry tool or importing the geometry from a CAD software such as SolidWorks or CATIA.

Engineers and designers can utilize ANSYS Space Claim, a software for 3D CAD modelling, to swiftly and effortlessly create, modify, and fix 3D models. It offers a variety of tools and functionalities for generating and manipulating 3D models, which include solid modelling, direct modelling, and reverse engineering.

The interface of SpaceClaim is user-friendly and intuitive, making it easy for users to swiftly and effortlessly create and modify models. It is capable of handling various file formats such as STL, IGES, STEP, and SAT, enabling models to be imported and exported across different software packages with ease.

4.1 Design of Exoskeleton

To design the exoskeleton, a variety of tools such as line, circle, spline, and arc are used to create sketches in different planes. In ANSYS, feature tools like Pull, Fill, and several others are utilized to create a 3-dimensional body or structure. Some of the important tools and commands used in the design of the supportless chair are:

- In sketching, the line tool is used for creating straight lines within the design.
- The circle tool is utilized to create circles with precise dimensions.
- Other tools for sketching are available in the sketch tool bar, including but not limited to rectangle, polygon, ellipse, and many more.

4.1.1 Seat

The primary use of a seat is to provide a surface for a person to sit on. The Seat is designed to provide a comfortable and supportive surface for the body while in a seated position. The material set to the seat is ‘PVC foam’, as the foam material is soft and cushiony, which helps to reduce pressure points and distribute weight evenly across the seat and also are highly durable and resistant to wear and tear.

They can withstand frequent use without losing their shape or support. PVC foam seats are lightweight, which makes them easy to move and transport. They are also ideal for use in applications where weight is a concern, such as in our case.

Fig 4.1 Geometry design of seat

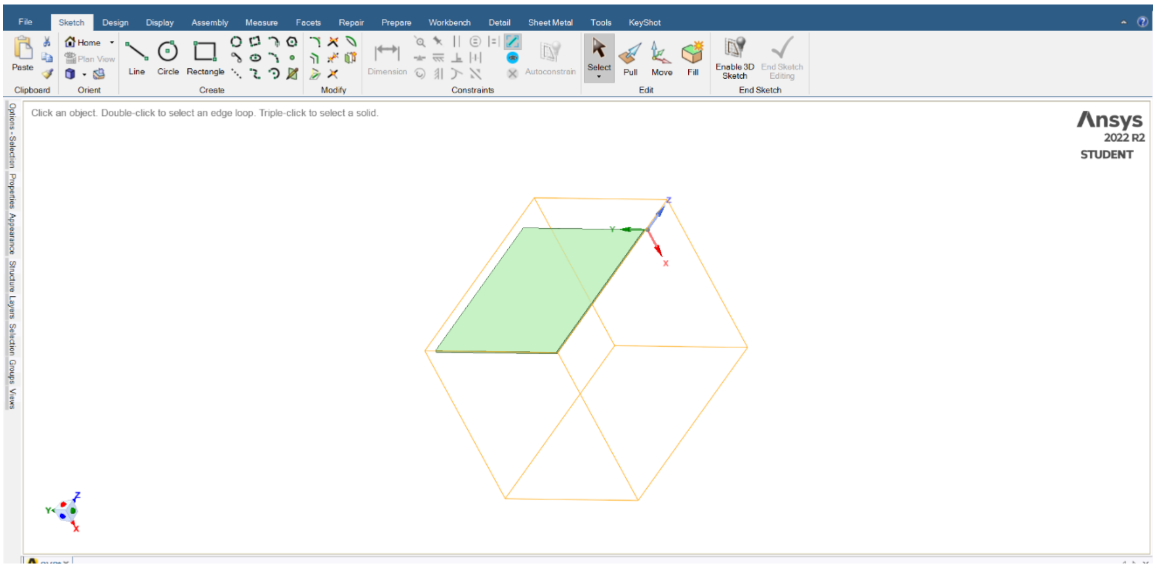


Fig 4.2 Dimensions of the seat

4.1.2 Upper and Lower Links

Upper links are the horizontal links which are joined to the lower link using Revolute joint. The material set to the links is Aluminium alloy (Al 6061). High-strength alloy 6061 aluminium can endure significant loads and strains. It can be easily moulded, cut, and drilled using standard machining techniques since it is well-machinable. This makes it a well-liked option for producing intricate parts and components. One of its best qualities is a good resistance to corrosion. In comparison to many other metals, aluminium 6061 is primarily lightweight.

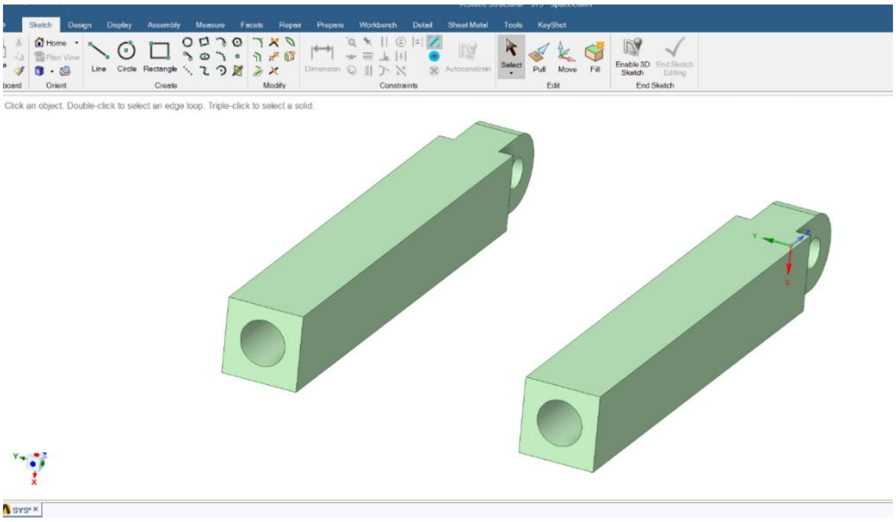


Fig 4.3 Upper Link

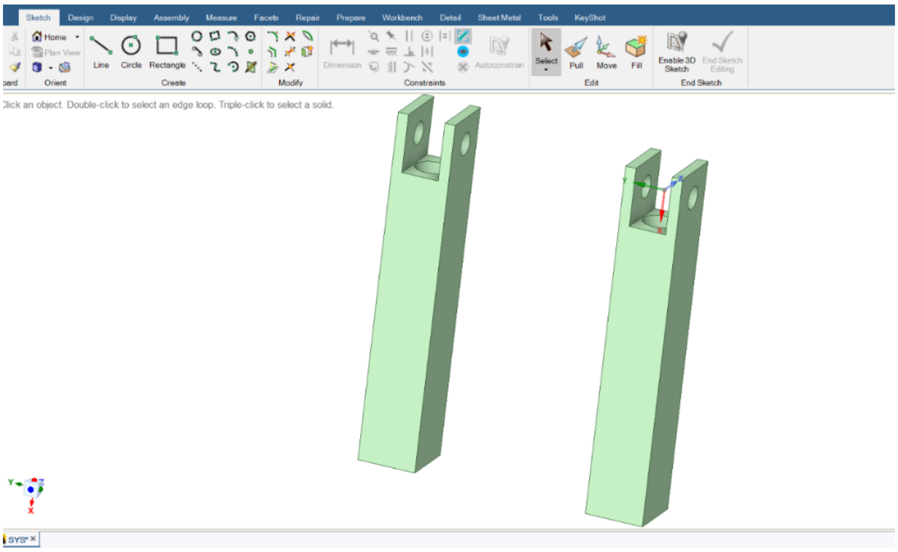


Fig 4.4 Lower Link

4.1.3 Pins

Pins are used in this design to join the upper and lower links together. The material set to the pins is titanium alloy. As titanium is known for its hardness and durability which are the key properties essential for the pins in a joint.

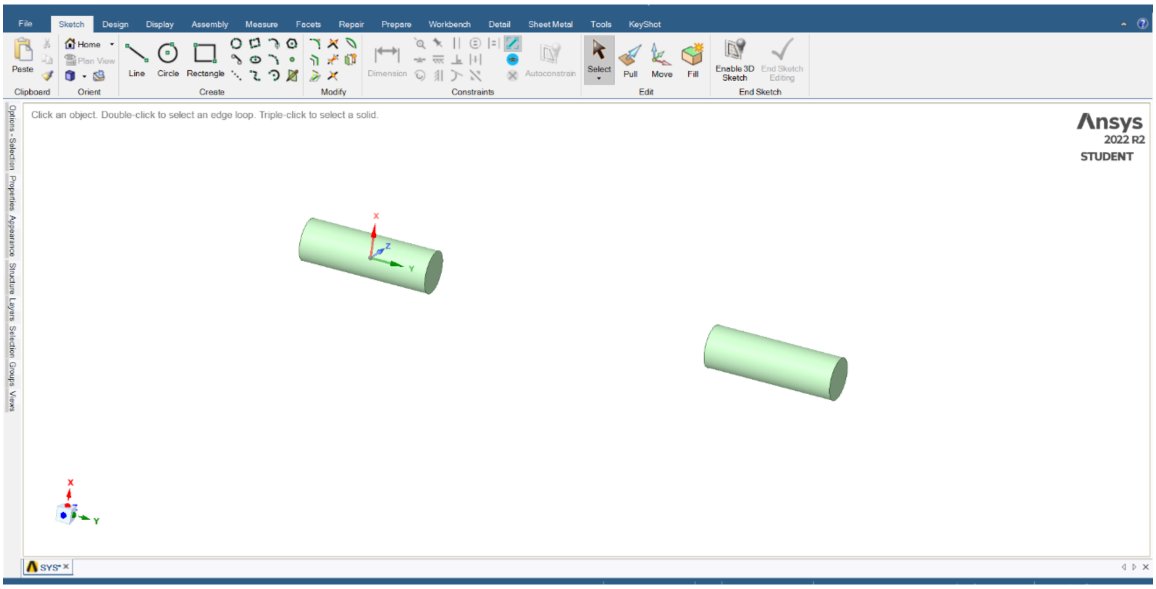


Fig 4.5 Pins

4.1.4 Final Assembly

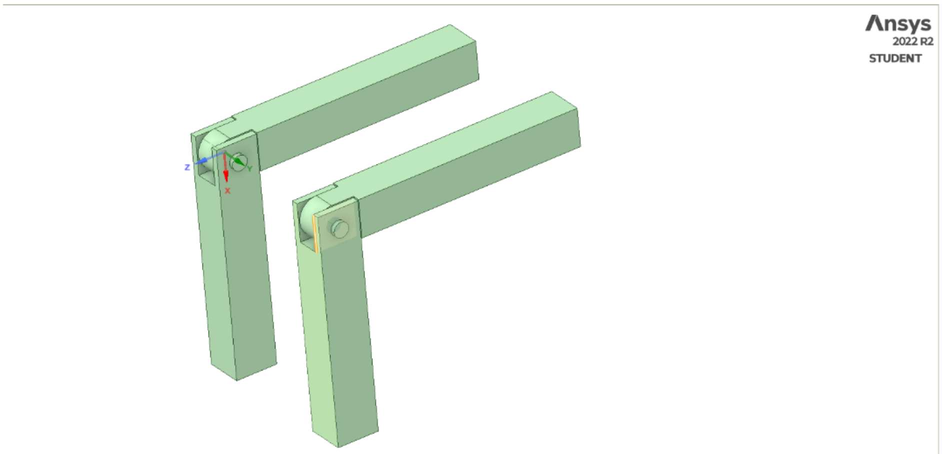


Fig 4.6 Joining all the links

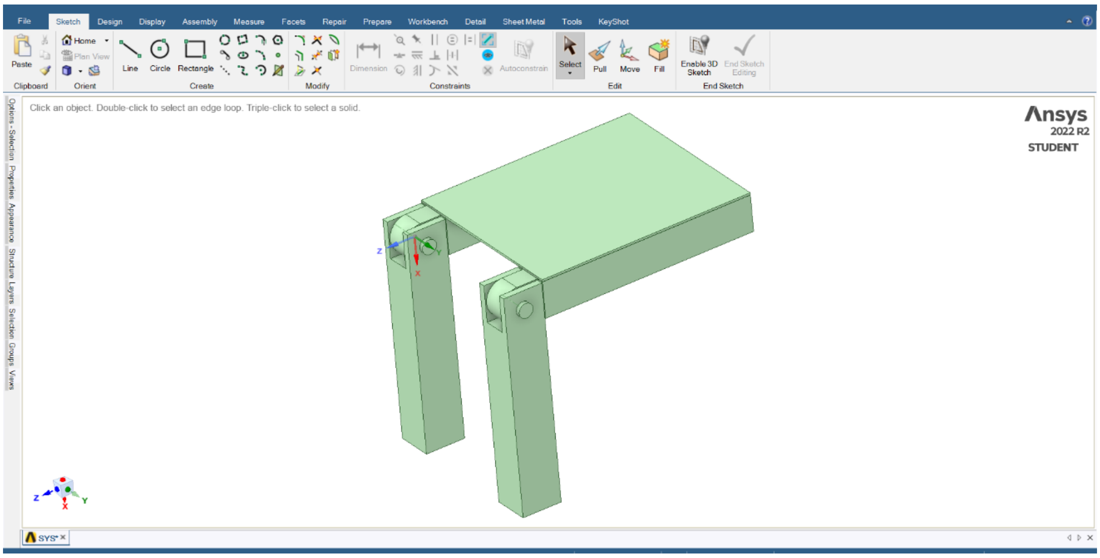


Fig 4.7 Arrangement of seat

4.1.5 Dampers

Dampers, also known as shock absorbers, are used in various machines and structures to absorb energy and reduce the impact of shocks, vibrations, or oscillations.

In the context of supportless chair, dampers are used to control the movement of the person using it. When the person begins to sit the dampers slow down the speed of motion by compressing and when the person tends to stands then rebounds. Dampers help to control the speed of the suspension movement and prevent it from bouncing excessively.

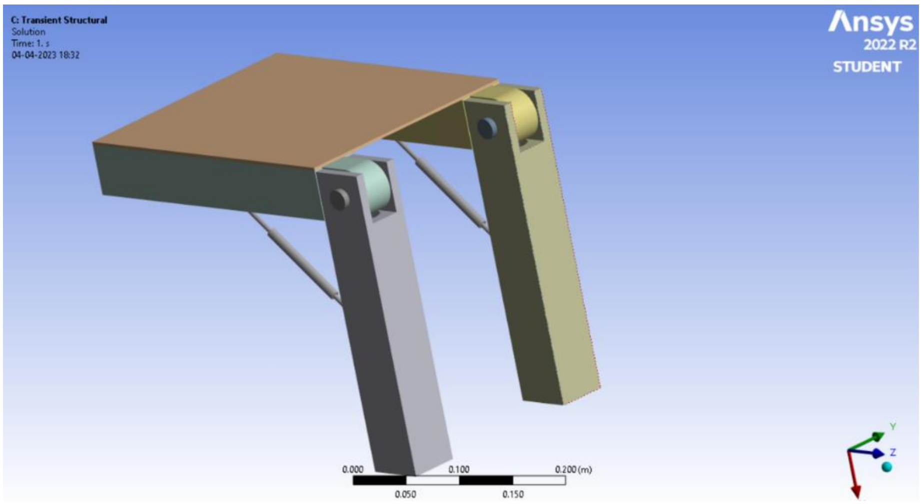


Fig 4.8 Final design with dampers

CHAPTER-5

ANALYSIS

The analysis model specifies a consistent set of essential system properties during development. The design criteria, including quality-of-service limitations, are often derived from the analysis. Additionally, there could be other criteria, such as reliability and safety level, reusability, maintainability, simplicity, time to market, among others. The process of systematically creating a design, involving the gathering of all necessary information, planning, and communication, is known as design analysis. This process can be applied to various forms of design, including physical structures such as buildings and intangible entities such as software, information, and processes.

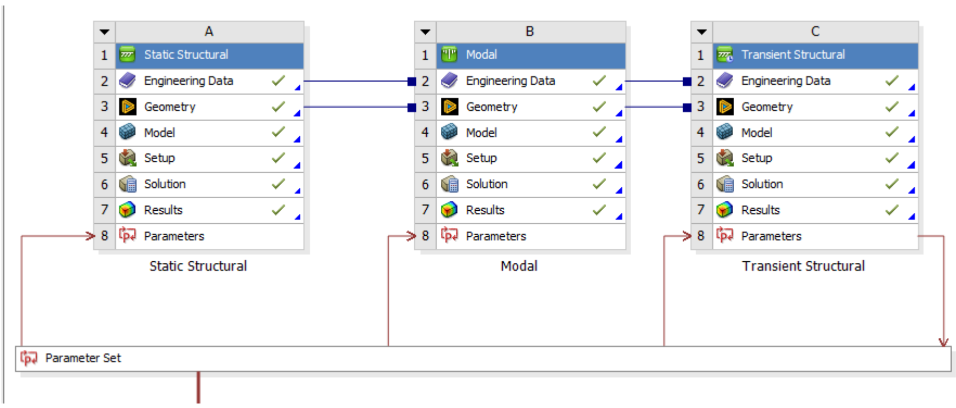
5.1 Engineering Data

For analysis purposes, materials are selected from engineering data that comes with pre-existing properties, or alternatively, materials with specific properties can be defined. In our project, we utilized aluminium metal for the mechanism, Titanium alloy for the pin, and PVC foam for the seat.

5.2 Geometry

The sketch produced in Space Claim is imported into the geometry selection process. Geometry modelling in the Ansys Workbench environment is largely automated while still allowing users to tailor it to fit their specific analysis or application requirements.

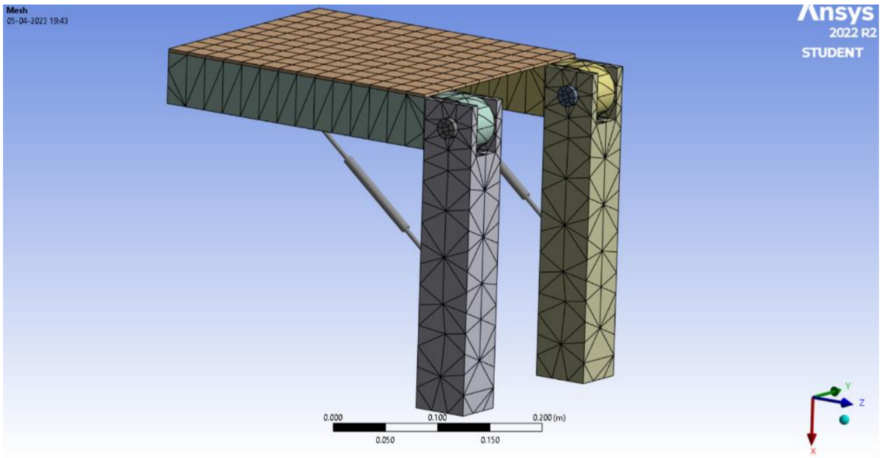
Fig 5.1 Geomety Imported Into Each Analysis



5.3 Meshing

Meshing refers to dividing the entire component into multiple elements so that, when subjected to a load, the load is evenly distributed throughout the meshed area. ANSYS offers meshing capabilities that can aid in obtaining accurate results while minimizing the time and effort required. More precisely meshing is the process of turning irregular shapes into more recognizable volumes called elements. Usually smaller mesh gives more accurate results.

Fig 5.2 Mesh generated



5.4 Static Analysis

- In a static structural analysis, the displacements, stresses, strains, and forces within a structure or component are calculated due to loads that do not create significant inertia and damping effects.
- The analysis assumes that the loading and response conditions are constant and do not change significantly over time.
- In contrast to dynamic analyses, damping and inertia effects can generally be disregarded in static structural analyses performed in Ansys Mechanical.

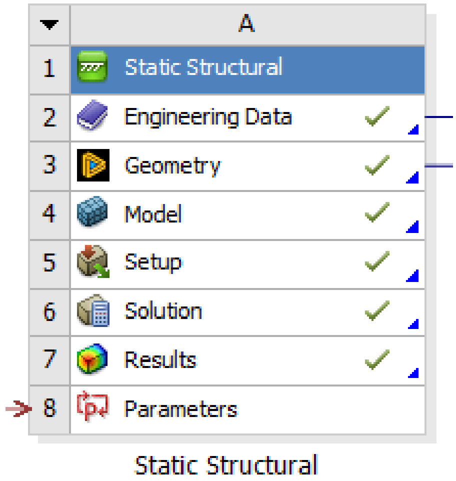


Fig 5.3 Schematic of Static Structural

5.5 Modal Analysis

- Modal analysis is the study of the dynamic properties of systems in the frequency domain.
- The purpose of modal analysis:
- Determining the specific frequencies and corresponding patterns of motion, or mode shapes, that a physical system will naturally exhibit.
- To verify the interconnections among the system's constituents for the presence of fixed modes .
- To determine whether the constraints are correct in the system.

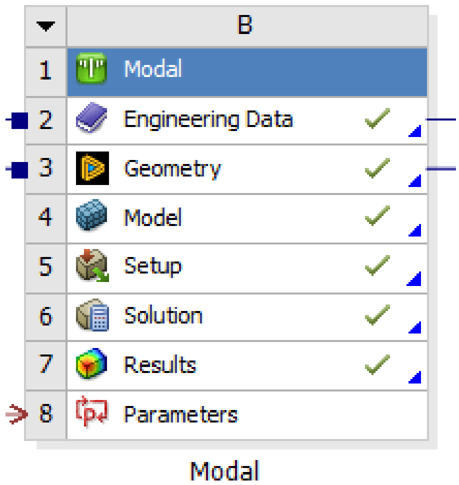


Fig 5.4 Schematic of Modal Analysis

5.6 Transient Analysis

• A transient analysis, by definition, involves loads that are a function of time.

• This type of analysis is used to determine the dynamic response of a structure under the action of any general time-dependent loads.

• When conducting transient structural analyses, our main interest lies in the way different components of the system respond dynamically. Therefore, it is crucial to take into account the effects of inertia and damping exhibited by the materials and parts under scrutiny.

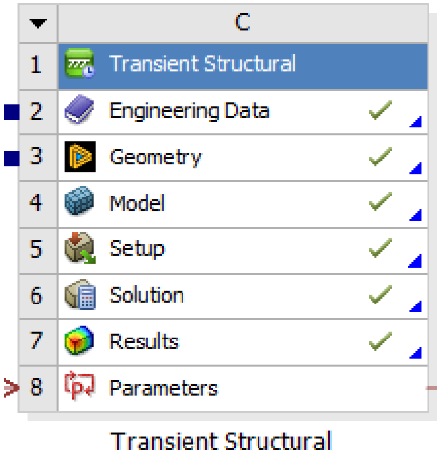
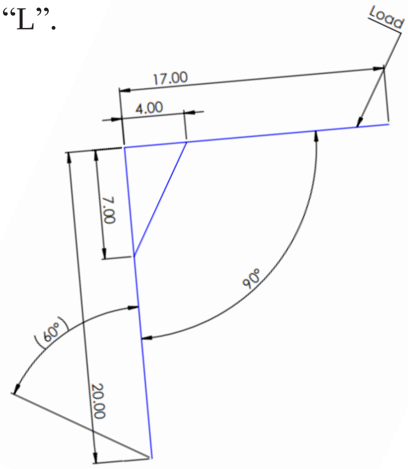


Fig 5.5 Schematic of transient analysis

5.7 Design Calculation:

At 90 Degrees: Let us consider the length of the link be “L”.



1. $L^2 = (0.17)^2 + (0.17)^2 - 2\,(0.17)\,(0.17)\,\text{Cos } 90$

$L^2 = 0.0289 + 0.0289 – 0$

$L^2 = 0.0578$ m

Link length = 240.4 mm

2) Force applied on the Seat: -

F= Mg = (160) (9.81) = 1569.6N

Area of the Cuboid is 2 [Lb + Bh + Hl]

Where L = 330 mm = 0.33 m

Breadth = 0.05 m

height = 0.05 m

Area of the Cuboid is 2 [(0.33) (0.05) + (0.05) (0.05) + (0.05) (0.33)]

= 2[0.0165 + 0.0025+0.0165]

= 2[0.0355] m^2

Area of the Cube is 0.071 m^2

Area of the 2 Channels is 0.071 x 2 = 0.142 m^2

Area of Cylinder is 23561.9449 mm^2 = 0.0235619449 m^2

Area of the Channel is 0.071 - 0.0235619449 = 0.0474 m^2

Area of the 2 Channels = 0.094876 m^2

Normal Stress:

$$\sigma = F/A = \frac{1569.6 \quad N}{0.094876\ m^2}$$

Normal Stress:

σ = 1.65437e4 Pa

CHAPTER-6

OPTIMIZATION

6.1 Background Knowledge for DOE and Optimization

The process of optimization involves a series of iterations aimed at discovering a design that either maximizes or minimizes a particular objective by exploring different possibilities within the design space.

We first need to define some terminologies for a design problem:

• "Parameters" refer to all the adjustable variables that can be manipulated in your design, such as geometry, topology, materials, and control gains. In other words, they are the various factors that can be tweaked or fine-tuned to achieve the desired outcome.

• "Variables" are a specific subset of design parameters that you aim to adjust during the design process, while keeping the remaining parameters constant. The complete range of possible settings for these variables is known as the design space.

• "objective" refers to a measure of how well a particular design performs. While it is often desirable to optimize for multiple objectives simultaneously, for simplicity, our discussion will concentrate on a single objective.

• "Constraints" are mathematical expressions involving the design variables that establish the range of feasible values for those variables. For instance, in the case of a bridge design, there must be a limit to the maximum stress that the structure can withstand, which is typically a multiple of the critical stress level factored by a safety factor.

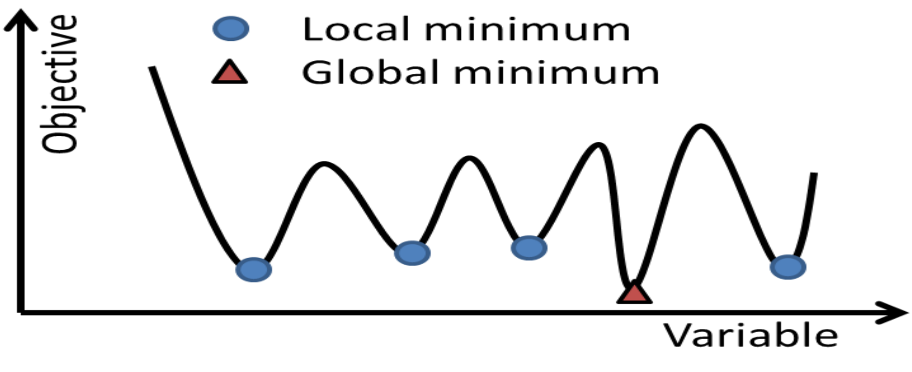


Fig 6.1 Chart Representation

6.2 Design of Experiments

The method of Design of Experiments (DOE) is employed to efficiently sample the design space, which encompasses all possible combinations of design parameters for a component, such as a brake disc. By doing so, a statistical model can be constructed to forecast the responses of a given design, such as the maximum stress, the first natural frequency, or the maximum temperature. DOE is particularly useful when there is a constraint on the number of simulations runs that can be executed, limiting the number of points that can be sampled. The fundamental concept underlying DOE is to distribute the sample points in a way that minimizes the uncertainty in the statistical model's estimation, resulting in a more precise prediction capability. In other words, the goal is to strategically place the samples across the design space to generate a model that has a low level of uncertainty and a high degree of accuracy when forecasting the responses of a given design.

Step 1: Define parameters and responses

The initial step in performing DOE for a particular model involves defining the collection of design variables and objectives of interest. These are commonly referred to as input and output parameters, respectively, in Ansys.

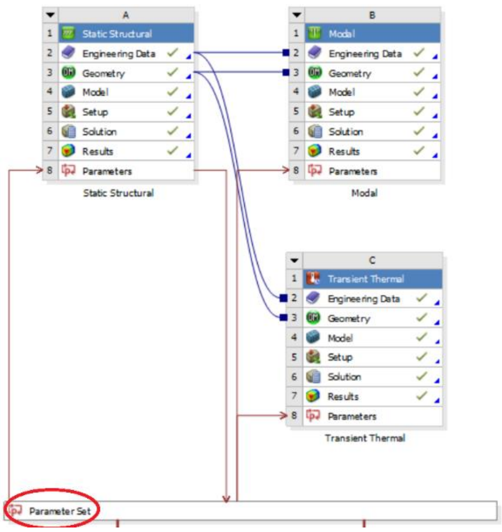


Fig 6.2 Parameters and Responses

Proceeding with the project, we took 3 input parameters which are Longitudinal stiffness, Longitudinal damping factor and diameter optimisation for the both lower and the upper links. Expected output parameters are Equivalent stress and total deformation of our design.

The below figures represent input and output parameters that have been used in the design optimisation of supportless chair.

3	Input Parameters
4	Transient Structural (C1)
5	P3 - Longitudinal - SYS\Upper-link To SYS\Lower-link Longitudinal Stiffness
6	P4 - Longitudinal - SYS\Upper-link To SYS\Lower-link Longitudinal Damping
7	Static Structural (A1)
8	P7 - Lower arm-opti
9	Output Parameters
10	Transient Structural (C1)
11	P8 - Equivalent Stress 3 Maximum
12	P9 - Total Deformation Maximum

Fig 6.3 input and output parameters

Step 2: Choose a design exploration method

The second step is to select a suitable Design Exploration method. By accessing the Design Exploration window, we can locate the "Response Surface" option, which enables us to execute DOE to generate a predictive model, also known as a response surface. We can then drag and drop the "Response Surface" tab from the Toolbox onto any of the available dashed boxes near the "Parameter Set" to proceed with the process.

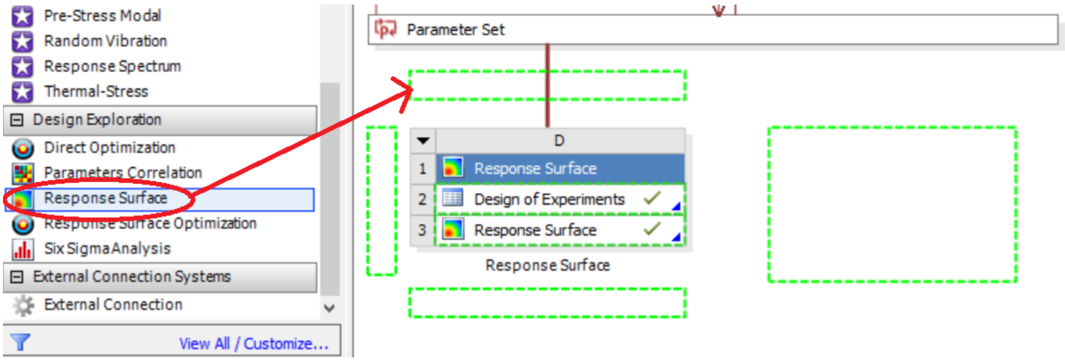


Fig 6.4 Response Surface

Step 3: Design points

In Ansys, there are several Design of Experiments (DOE) methods available. However, one of the primary benefits of using these methods is that the number of samples required is not dependent on the number of parameters being considered. As part of the design process, Ansys generates a set of 15 automated design points, which are used for the purpose of conducting the DOE.

Table of Outline A2: Design Points of Design of Experiments

	A	B	C	D	E	F
1	Name	P3 - Longitudinal - SYS\Upper-link To SYS \Lower-link Longitudinal Stiffness (N m^-1)	P4 - Longitudinal - SYS\Upper-link To SYS \Lower-link Longitudinal Damping (N s m^ -1)	P7 - Lower arm-opti (mm)	P8 - Equivalent Stress 3 Maximum (Pa)	P9 - Total Deformation Maximum (m)
2	1 DP 44	50000	2000	15	7.6584E+05	7.7178E-06
3	2 DP 10	45000	2000	15	7.6584E+05	7.7179E-06
4	3 DP 14	55000	2000	15	7.6584E+05	7.7178E-06
5	4 DP 11	50000	1800	15	7.6584E+05	7.7178E-06
6	5 DP 13	50000	2200	15	7.6584E+05	7.7178E-06
7	6 DP 34	50000	2000	13.5	8.1196E+05	7.7064E-06
8	7 DP 35	50000	2000	16.5	8.2549E+05	7.8368E-06
9	8	45935	1837.4	13.78	5.2312E+05	7.7969E-06
10	9	54065	1837.4	13.78	5.2312E+05	7.7969E-06
11	10	45935	2162.6	13.78	5.2312E+05	7.797E-06
12	11	54065	2162.6	13.78	5.2312E+05	7.7969E-06
13	12	45935	1837.4	16.22	8.3559E+05	7.8734E-06
14	13	54065	1837.4	16.22	8.3559E+05	7.8734E-06
15	14	45935	2162.6	16.22	8.3559E+05	7.8735E-06
16	15	54065	2162.6	16.22	8.3559E+05	7.8734E-06

Fig 6.5 design points of the experiment

Step 4: Create a response surface

In the context of Design of Experiments (DOE), it is common to use the results obtained to create a response surface that can be used for prediction purposes. ANSYS, a popular engineering simulation software, offers various response surface methods for this purpose. These methods aim to model the relationship between the input variables (factors) and the output variable (response) and can be used to make predictions for untested combinations of input variables.

- **Standard Response Surface**: The ANSYS software offers the Standard Response Surface method which involves fitting the experimental data using a polynomial surface. This method requires minimal computational resources for both fitting and prediction. However, the accuracy of the predictions heavily relies on selecting the appropriate polynomial bases. This approach is recommended when there is a substantial amount of data available and the objective function varies smoothly over the input space.

- **Kriging**: The Kriging method offered by ANSYS is non-parametric, which implies that the prediction will depend on all existing data points. This can result in slower prediction times when dealing with a large amount of data to fit. Additionally, the method can be slow in fitting the data due to the calculation of pair-wise distances between the data points. However, Kriging is capable of automatically fitting through all data points. This method is best suited for situations where the data is highly nonlinear and limited, and it is desirable to have the model fit through the available data, indicating a high level of confidence in the simulation results.

- **Non-parametric Regression**: The Non-parametric Regression method offered by ANSYS involves using Support Vector Regression. It is comparable to Kriging in that the prediction depends on the available data. However, instead of utilizing all the data points, this method selects the most significant ones to perform the prediction. Consequently, the computation cost for prediction is lower than that of Kriging, but the cost of fitting the data remains high. The resulting model may not fit through the data points. This method is best suited for situations where the available data is highly nonlinear, and it is not essential for the model to fit directly through the data.

- **Neural Network :** The Neural Network method provided by ANSYS involves using a feedforward neural network to create a nonlinear mapping between the input (a design) and the output (its objective value), mimicking the expensive simulation. The training of this method can be slow, especially when the network is deep, and it may result in different models each time, even when using the same data. However, the prediction phase is computationally efficient and involves simple matrix calculations. This method is ideal when dealing with highly nonlinear data that is abundant, and there is no need for the model to fit directly through the data.

- **Sparse Grid**: The Sparse Grid method offered by ANSYS is associated with the corresponding Design of Experiment (DOE) method. It is comparable to Kriging in that it can handle highly nonlinear objectives. This method achieves this by adaptively sampling in the most uncertain regions of the design space, potentially reducing the number of necessary samples. This approach is suitable when dealing with highly nonlinear objectives and the number of simulations that can be performed is limited.

To create a response surface, click on the "Response Surface" option in the Project Schematic window:

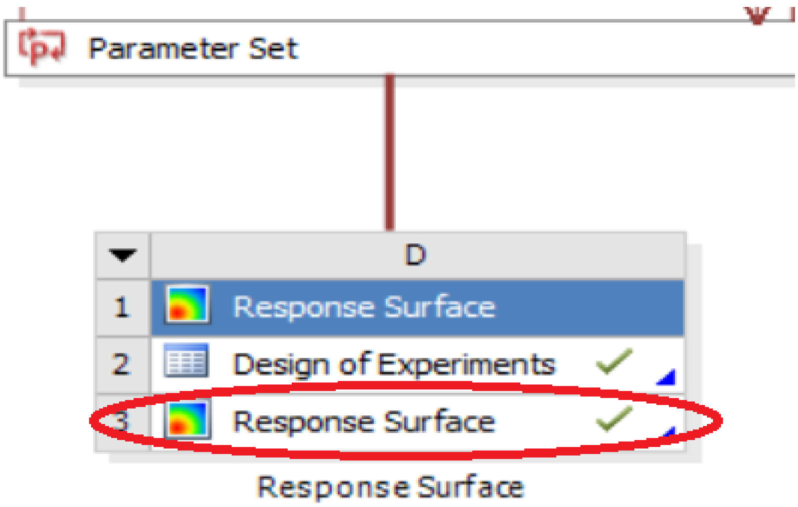


Fig 6.8 Parameter Set

Step 5: Boundary conditions:

In the context of mathematical modelling, boundary conditions are a crucial element that can serve as constraints to reduce computational memory usage and simulation time. These constraints define the behaviour of the model at its edges and are essential for accurate simulation results.

The following are the boundary conditions for the optimisation:

Properties of Outline A5: P3 - Longitudinal - SYS\Upper-link To SYS\Lower-link Longitudinal Stiffn

	A	B
1	Property	Value
2	General	
3	Units	N m^-1
4	Type	Design Variable
5	Classification	Continuous
6	Values	
7	Lower Bound	45000
8	Upper Bound	55000
9	Allowed Values	Any

Fig 6.9 Properties of Longitudinal Stiffness

The following figure consists of lower bound and upper bound of the longitudinal stiffness for the both upper link and lower link. The range should vary between 45000 to 55000Nm^{-1}

Properties of Outline A6: P4 - Longitudinal - SYS\Upper-link To SYS\Lower-link Longitudinal Damp

	A	B
1	Property	Value
2	General	
3	Units	N s m^-1
4	Type	Design Variable
5	Classification	Continuous
6	Values	
7	Lower Bound	1800
8	Upper Bound	2200
9	Allowed Values	Any

Fig 6.9 Properties of Longitudinal Damping

The following figure consists of lower bound and upper bound of the longitudinal Damping factor for the both upper link and lower link. The range should vary between 1800 to 2200 N s m^-1.

The following figure consists of lower bound and upper bound of the diameter of the links for the both upper link and lower link. The range should vary between 13.5 to 16.5 mm.

Properties of Outline A8: P7 - Lower arm-opti

	A	B
1	Property	Value
2	⊟ General	
3	Units	mm
4	Type	Design Variable
5	Classification	Continuous
6	⊟ Values	
7	Lower Bound	13.5
8	Upper Bound	16.5
9	Allowed Values	Any

Fig 6.10 Properties of parameter lower arm diameter

CHAPTER-7

RESULTS AND DISCUSSION

7.1 Static Structural

Initially, a basic structural analysis is conducted to determine the strength of the components. If a component fails due to the applied loads, further analysis is unnecessary, as it cannot be used in its current state. To analyse the various components of the differential, ANSYS 2022 R2 WORKBENCH was utilized for both meshing and solving.

7.1.1 Total Deformation

Total deformation refers to the overall deformation or displacement of a structure under an applied load or set of loads. It includes all deformations, including elastic and plastic, that occur in the material due to the applied load.

The total deformation of a structure is calculated by ANSYS based on the material properties, geometry, and boundary conditions specified in the simulation model. ANSYS uses finite element analysis (FEA) to discretize the structure into a mesh of small elements, and then solves the equations of motion to determine the deformation of each element under the applied load.

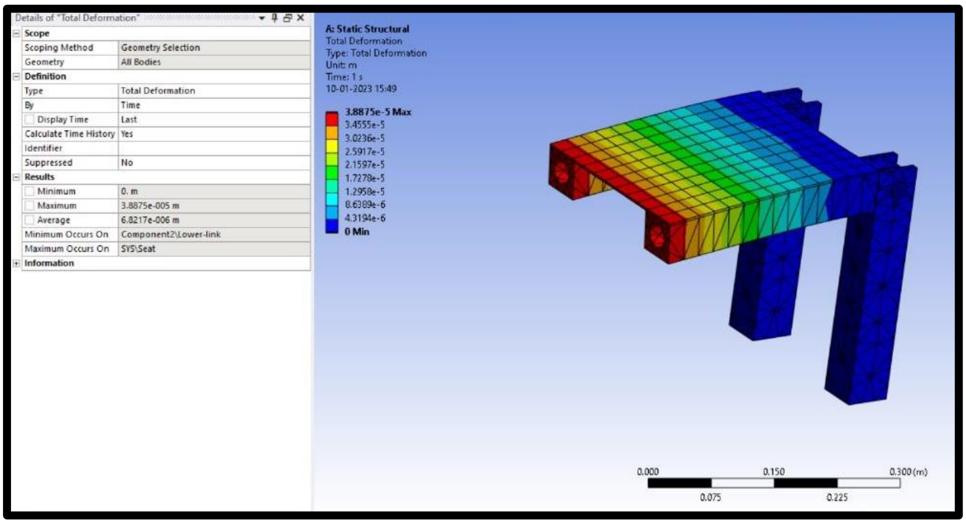


Fig 7.1 Total Deformation in Static Structural

Upon analysis of model, the maximum deformation occurs on seat in which the value is $3.8875e^{-5}$ m which is lesser than the ultimate deformation.

7.1.2 Equivalent (Von–Mises) Stress:

Equivalent von Mises stress is a measure of the combined stresses experienced by a material under a complex loading condition. It is a scalar quantity that represents the magnitude of the equivalent stress that would cause the same deformation and damage as the actual combination of stresses.

The equivalent von Mises stress is useful for comparing the strength of different materials or different designs under complex loading conditions, where the stresses are not easily separable into individual components. It is often used in engineering and materials science to design and evaluate structures, machines, and components that are subject to complex loading conditions.

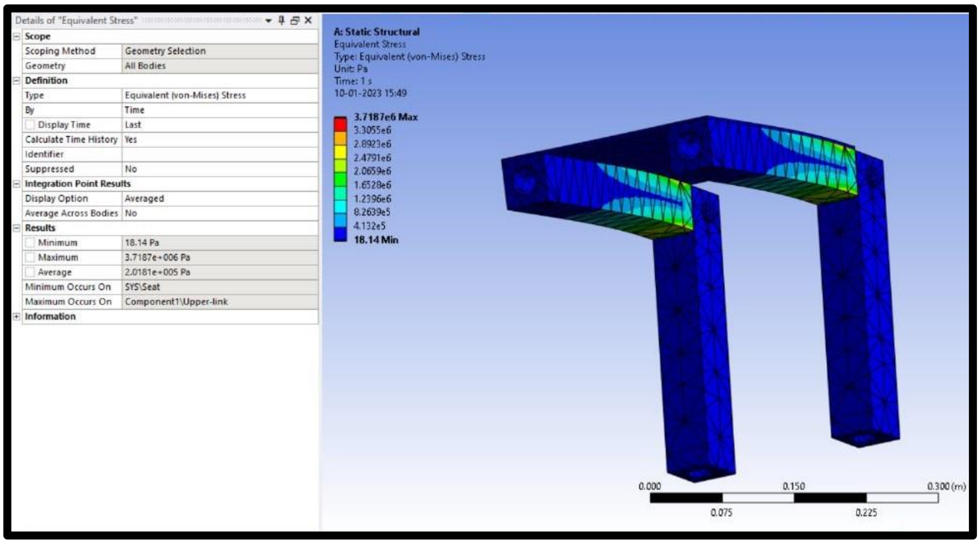


Fig 7.2 Equivalent Von Mises Stress in Static Structural

The maximum stress is observed on upper link which has value of 3.7187e6 pa

7.2 Modal Analysis

The modal analysis of the exoskeleton was executed and the first 6 mode shapes and their natural frequencies were computed.

7.2.1 Frequency

Frequency is a term used to describe the number of occurrences of a repeating event per unit of time. It is usually measured in Hertz (Hz), which represents the number of cycles or oscillations per second.

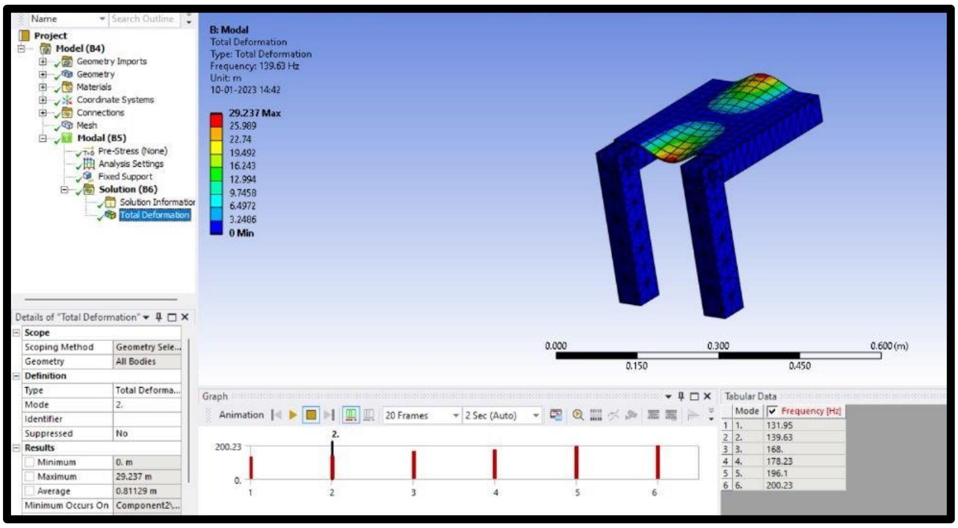


Fig 7.3 Frequency Representation

The following are the values computed by Ansys:

Tabular Data

	Mode	Frequency [Hz]
1	1.	131.95
2	2.	139.63
3	3.	168.
4	4.	178.23
5	5.	196.1
6	6.	200.23

Fig 7.4 Values of frequency

7.3 TRANSIENT ANALYSIS

Transient analysis is performed in ANSYS to study the dynamic behaviour of a system over time. In engineering, many systems exhibit time-dependent behaviour, such as mechanical systems subject to dynamic loads, or electrical circuits with time-varying signals. Transient analysis allows engineers to predict how a system will respond to these time-varying inputs and determine its performance under real-world conditions.

7.3.1 Equivalent (Von–Mises) Stress for Whole Design:

After attaching dampers, the maximum equivalent von-mises stress are 2.7274e6 pa which is less than 3.7187e6 pa observed without dampers.

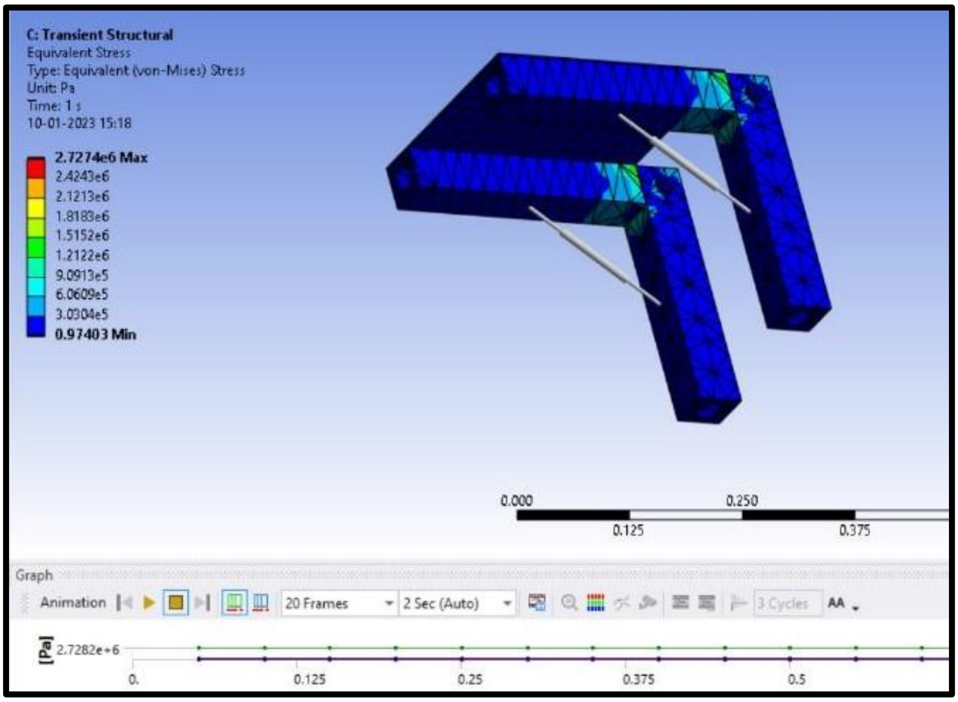


Fig 7.5 Equivalent von mises stress in transient module

	Time [s]	Minimum [Pa]	Maximum [Pa]	Average [Pa]
1	5.e-002	0.862	2.7262e+006	2.0838e+005
2	0.1	0.7992	2.7282e+006	2.0851e+005
3	0.15	0.75752	2.7263e+006	2.0839e+005
4	0.2	0.9184	2.7282e+006	2.0851e+005
5	0.25	0.7546	2.7263e+006	2.0839e+005
6	0.3	0.94233	2.7281e+006	2.0851e+005
7	0.35	0.75448	2.7264e+006	2.0839e+005
8	0.4	0.87903	2.728e+006	2.085e+005
9	0.45	0.7612	2.7266e+006	2.084e+005
10	0.5	0.83228	2.7278e+006	2.0849e+005
11	0.55	0.78067	2.7267e+006	2.0841e+005
12	0.6	0.84465	2.7277e+006	2.0848e+005
13	0.65	0.80892	2.7268e+006	2.0842e+005
14	0.7	0.90063	2.7276e+006	2.0847e+005
15	0.75	0.83903	2.7269e+006	2.0843e+005
16	0.8	0.96944	2.7275e+006	2.0847e+005
17	0.85	0.86604	2.727e+006	2.0843e+005
18	0.9	0.99718	2.7274e+006	2.0846e+005
19	0.95	0.88776	2.7271e+006	2.0844e+005
20	1.	0.97403	2.7274e+006	2.0846e+005

Fig 7.6 Details of equivalent stress

This table represents variation of equivalent stress with respect to time and the average stress is tabulated as shown in the figure.

7.3.2 Equivalent (Von–Mises) Stress for pins :

The equivalent von-mises stress for a titanium alloy pin used to join the upper and lower links are 7.6584e5 pa which is a optimum stress value.

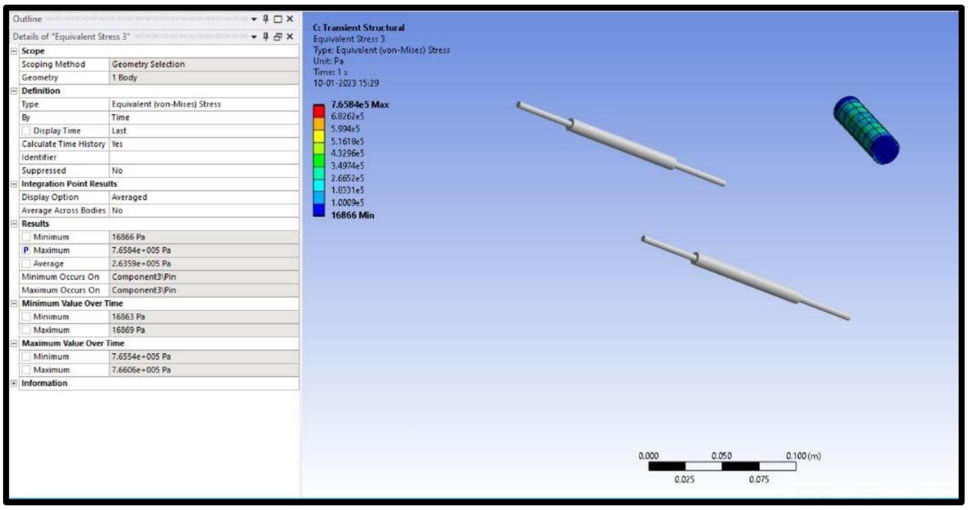


Fig 7.7 Equivalent von mises Stress for Pins

7.3.3 Total Deformation

Upon analysis of the final model with dampers the maximum deformation is 7.7421e-6 m which is lesser than 3.8875e-5 m observed without dampers.

Hence, dampers reduced the total deformation and equivalent von-mises stresses and helped to maintain stability for the mechanism.

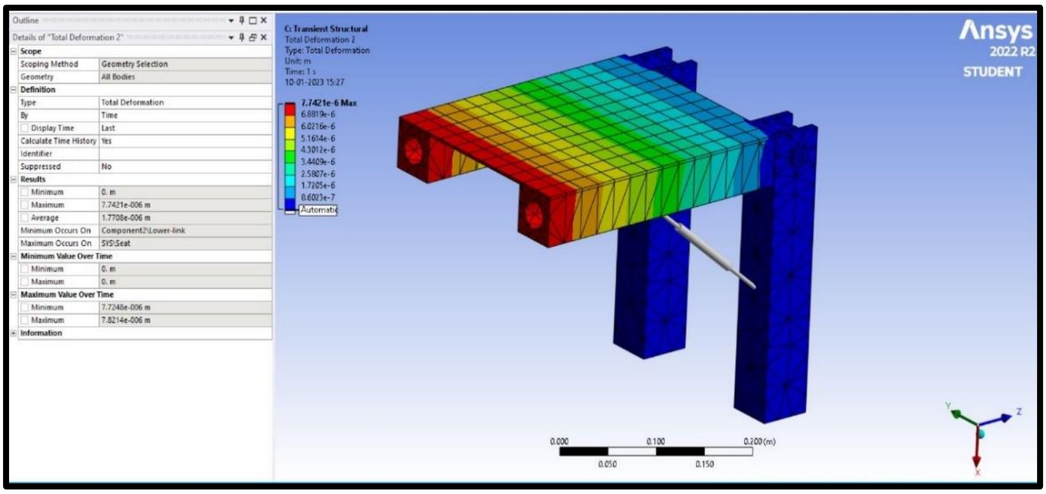


Fig 7.8 Total deformation of the supportless chair

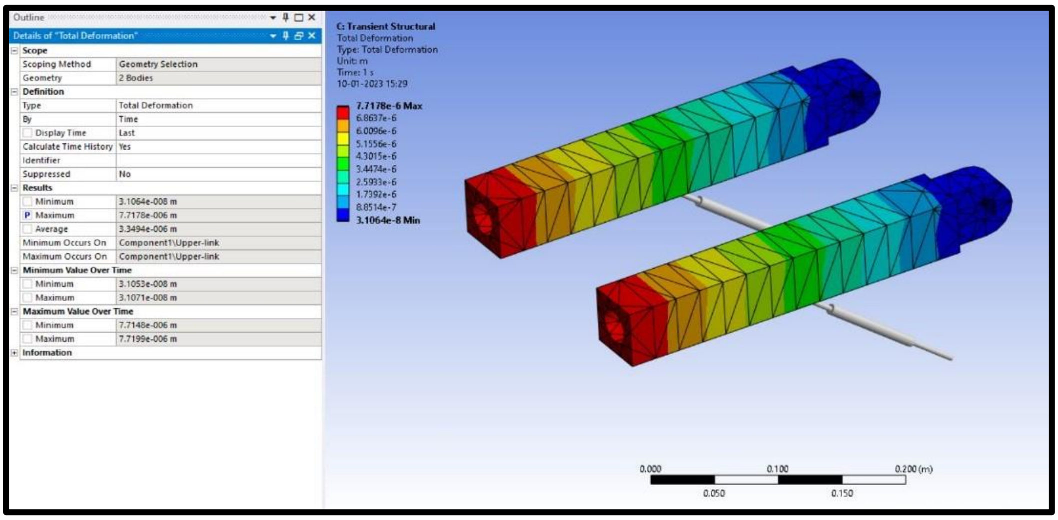


Fig 7.9 Total Deformation of The Upper Link

7.4 Multi Objective Genetic Algorithm Optimisation (MOGA)

Multi-Objective Genetic Algorithm Optimization (MOGA) is a type of optimization technique that uses a genetic algorithm to search for the optimal solutions to problems with multiple objectives.

The MOGA algorithm uses a fitness function that incorporates multiple objective functions, often conflicting with each other. The goal is to find a set of solutions that are Pareto optimal, which means that no solution in the set can be improved in one objective without degrading another objective. This set of solutions is called the Pareto front and represents the optimal trade-off between the multiple objectives.

After MOGA optimisation; the output results are as follows:

7.4.1 Equivalent stress :

Properties of Outline A11: P8 - Equivalent Stress 3 Maximum

	A	B
1	Property	Value
2	⊟ General	
3	Units	Pa
4	⊟ Values	
5	Calculated Minimum	5.2312E+05
6	Calculated Maximum	8.3559E+05

Fig 7.10 Properties of Parameter Equivalent Stress

The minimum equivalent stress in the design after optimisation is $5.2512e^{+0.5}$ pa.

The maximum equivalent stress in the design after optimisation is $8.3559e^{+0.5}$ pa.

7.4.2 Total Deformation:

Properties of Outline A12: P9 - Total Deformation Maximum

	A	B
1	Property	Value
2	General	
3	Units	m
4	Values	
5	Calculated Minimum	7.7064E-06
6	Calculated Maximum	7.8735E-06

Fig 7.11 Properties of Parameter Total Deformation

The minimum deformation of the design after optimisation is $7.7064e^{-0.6}$ m.

The maximum deformation of the design after optimisation is $7.8735e^{-0.6}$ m.

7.5 Response surface values :

Table of Schematic D3: Response Surface: Tolerances

	A	B	C	D	E	F
1	Name	Calculated Minimum	Calculated Maximum	Maximum Predicted Error	Refinement	Tolerance
2	P8 - Equivalent Stress 3 Maximum (Pa)	5.2312E+05	8.3559E+05	67543		
3	P9 - Total Deformation Maximum (m)	7.6972E-06	7.9324E-06	5.2961E-08		

	A	B	C	D	E
1	Name	P3 - Longitudinal - SYS\Upper-link To SYS \Lower-link Longitudinal Stiffness (N m^-1)	P4 - Longitudinal - SYS\Upper-link To SYS \Lower-link Longitudinal Damping (N s m^ -1)	P7 - Lower arm-opti (mm)	P8 - Equivalent Stress 3 Maximum (Pa)
2	Output Parameter Minimums				
3	P8 - Equivalent Stress 3 Maximum	54065	1837.4	13.78	5.2312E+05
4	P9 - Total Deformation Maximum	50151	2000	14.996	7.6569E+05
5	Output Parameter Maximums				
6	P8 - Equivalent Stress 3 Maximum	45936	1837.3	16.219	8.3559E+05
7	P9 - Total Deformation Maximum	55000	2200	16.5	7.9659E+05

Fig 7.12 Maximum and minimum values

This figure represents the values of longitudinal damping factor; longitudinal stiffness and lower arm diameter of the mechanism with the induced equivalent stresses at different readings.

7.6 Optimisation method

7.6.1 MOGA

The MOGA method, which stands for Multi-Objective Genetic Algorithm, is a modified version of the commonly used NSGA-II (Non-dominated Sorted Genetic Algorithm-II) that incorporates controlled elitism principles. This approach can accommodate multiple objectives and constraints and is designed to identify the global optimum.

Configuration:

To begin with, generate a total of 3000 samples. For each subsequent iteration, generate 600 additional samples. The goal is to identify 3 potential candidates within a maximum of 20 iterations.

Status:

Converged after 6609 evaluations.

7.6.2 Results

These are the final optimisation readings upon MOGA optimisation.

Output Parameter Minimums (Response Surface Optimization system)

Name	P3 - Longitudinal - SYS\Upper-link To SYS\Lower-link Longitudinal Stiffness (N m^-1)	P4 - Longitudinal - SYS\Upper-link To SYS\Lower-link Longitudinal Damping (N s m^-1)	P7 - Lower arm-opti (mm)	P8 - Equivalent Stress 3 Maximum (Pa)	P9 - Total Deformation Maximum (m)
P8 - Equivalent Stress 3 Maximum	54065	1837.4	13.78	5.2312E+05	7.7913E-06
P9 - Total Deformation Maximum	50151	2000	14.996	7.6569E+05	7.6972E-06

Output Parameter Maximums (Response Surface Optimization system)

Name	P3 - Longitudinal - SYS\Upper-link To SYS\Lower-link Longitudinal Stiffness (N m^-1)	P4 - Longitudinal - SYS\Upper-link To SYS\Lower-link Longitudinal Damping (N s m^-1)	P7 - Lower arm-opti (mm)	P8 - Equivalent Stress 3 Maximum (Pa)	P9 - Total Deformation Maximum (m)
P8 - Equivalent Stress 3 Maximum	45936	1837.3	16.219	8.3559E+05	7.8722E-06
P9 - Total Deformation Maximum	55000	2200	16.5	7.9659E+05	7.9324E-06

Fig 7.14 Max and Min of Output Parameters

The optimised diameter is 16.5mm with longitudinal stiffness value 55000 Nm^{-1}, longitudinal damping factor value 2200Nsm^{-1} with equivalent stress value $79659e^{+0.5}$ and total deformation value is $7.9324e^{-0.6}$ m .

CONCLUSION

Based on the results of the study, the Supportless chair's design optimisation and analysis met the goal by providing support for people with prosthetic legs as well as for regular workers. It also increases industry productivity by lowering worker fatigue.

- A lower body external skeletal system has been designed to accommodate sitting and partially standing posture.
- A successful design and analysis of the Supportless Chair Exoskeleton system has been achieved.
- The Supportless chair is subjected to static structural analysis, modal analysis, and transient analysis using Ansys workbench to determine total deformation.
- With a safe load of an average human weight and a factor of safety of 2, maximum displacement, maximum stresses, and deformations are determined.
- Design optimisation had been done to reduce the weight of the structure. and under safe loads, a weight decrease of around 10% is achieved.
- The design will be made lighter in the future, and high-quality materials will be used to achieve better strength at lower dimensions and weight.

The resulting design serves as a model for the creation of Supportless chair ideas that are better suited for workers, particularly in terms of the wearable chair's weight, mobility, safety, comfort, and affordability of its production.

FUTURE SCOPE

Due of its availability, the material selection was constrained. Future constructions may use carbon-fibre reinforced polymer (CFRP) to further reduce weight and boost structural strength. Different locking methods can be employed to provide better and smoother working of the chair because locking mechanism is not given full attention in the current job. Depending on the user's needs, the sensor can be fastened to the body to enable the mechanism to lock on its own. This chair needs to be modified further so that upper body parts are likewise free from MSD. It can relieve lower body tiredness. Making the chair into a folding, flexible wearable one will increase its portability. The chair can be converted into a multipurpose tool with additional kinematic linkages, allowing for the creation of numerous new goods. We can make it into a fully self-balancing chair by adding more links between the legs. It is a fully functional exoskeleton with add-ons including an audio jack, water bottle holder, and charging connections. It may be an assistance device if damper and electrical control are the main features. It could be modified for use in military applications as a load-distribution tool, a support for armament, and other things.

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