Sit to Stand Motion Assist System for Senior Citizens

THESIS REPORT

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Abstract

People suffer from various ailments like reduced range of joints motion, Parkinson’s diseases & osteoporosis etc. in later stage of life due to which Sit to Stand (STS) motion is difficult to achieve. To cater that, many hospital-oriented devices are there in the market, but they are not specifically oriented towards the daily users who are not patients rather need helping hand less often. Hence, there is a need of a STS Motion Assist System, a mechanism operatable without external assistance and energy source. Senior people tend to refrain from using modern equipment, so this device will be passive with least usage requirement and prior knowledge. One of the reasons for this idea is that it covers United Nations SDG - 3 (Good health and well-being). The idea is to transform miseries and discomfort of senior citizen into a comfortable journey with ease in sitting and standing. At present, some devices are available in the market with different roles, like active or passive, patients oriented, hospital usage and paralysis assistive devices etc. These devices are bulky and expensive, so this device would be relatively affordable and portable. The benefit of our device is that it will address this riddle from a different perspective using a simple mechanism and optimum design approach. Therefore, its practicality is decent and can serve a potential market gap.

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Chapter 1 : INTRODUCTION

1.1. Sit to Stand Motion

Sit-to-Stand (STS) is the one of the most important daily life functional activities & it is a pre-requisite for other daily life ambulatory functions. A healthy adult is expected to perform 60±22 STS motions every day. STS motion can be defined as the motion in which base of support is transfer from seat to feet, & also a movement from stable posture(sit) to a comparatively less stable posture(stand). However, the senior citizens have difficulty performing this motion due to reduced joint range of the motion, pain, stiffness of the joint and muscles weakness. The discovered factors that lead to the loss of joints mobility is due to chronic disease such as diabetes, Parkinson & arthritis. The muscles stiffness followed by the difficulty in performing STS motion is expected to start earlier in women comparative to men due to menopause & the most common diseases in the women i-e osteoporosis & osteoarthritis.

Sit-to-Stand motion is most mechanically demanding functional task for senior citizens to function independently and maintain daily life activities. At present Pakistan has 11.3 million people over the age of 60 year that constitutes the 7% of the total population of the country. STS assistant device help elderly to perform the sit-to-stand transfer motion successfully & provide the ease in the daily life activities. The development of STS assistive device for elderly people also complies with the United Nations Sustainable Development Goal (total 17 goals) SDG3, Good Health & Well-being. The agenda of SDG3 is good health for sustainable development & STS assistive device as the solution to the identified need of the senior citizens aligns with the SDG3.

There are various commercialized STS assistive devices in the market that help performing STS transfer movement, these already available devices are mostly patients oriented that have lost their muscular strength completely or have serious lower limb disorders. These devices help patients to perform STS motion & lifting, and most of them are driven by electric motors to support the body weight. And these electrically powered devices (active devices) can even lift the paraplegic patient that have zero control over the muscles. The malfunctioning of single electric component in these electrically operated devices can cause the serious damage to the patient. Besides, in case of assistance devices using electric motors the authentication standards are very strict for the medical devices. Also, these devices are mostly operated by the caregivers & not the user itself that limits the user independency & requires a person/assistant anytime the patient needs to perform the motion. And another factor that pertains to the current debate of active vs passive device is the social acceptance of an active STS assistive device. The elderly people are reluctant to use the robotic haul suits, exoskeletons & no of supporting belts that will help them to lift from sit to stand posture. So, to solve all these issues a passive non-electrically powered device needs to be developed.

A non-electrically powered device can also be further classified as self-powered and externally powered (any external human power/assistant). The aim of the project work is realization of STS assistive device for elderly people while at the same time ensuring the user independency to perform daily life activities. The focused group of the project work are senior citizens that find difficulty in performing STS motion both in office & home space. There are passive devices available that helps the user to perform this STS motion by sharing the load. However, they required an assistant to provide an external force. And it is practically unfeasible apparatus to engage the assistant to help performing the STS motion. So, a practical device is required that helps the user to perform the sit-to-stand motion at his own by sharing the load & ensures the independency to the user.

The focused age group people have partial loss of mobility & they required a little support to divide their path from sit to stand position so that there is no loss of extra energy. A self-powered STS assistive device that helps the user to perform this movement is the independent solution to the identified need. The mechanical mechanisms employed in the device that will ease STS & provides the stability at each point during the sit-to-stand transfer movement is to be developed.

There is various type of available assistance modalities for elderly based on seat, waist & arms that can be employed to provide an ease in the transfer movement. The previous studies have depicted that seat base modalities are most efficient in performing this specified motion. Firstly, an ergonomically designed assistive device based on the previous results that integrates into the daily life without any noticeable changes into the apparent life of user is the one of the aims of the project under progress. Secondly, the device must have easy control system because the users have very less dexterity to play the complex controls that will allow them to perform the STS motion.

The third factor is the economic factor & it is one of the important factors in commercialization of the products. The targeted demographic is not capable enough to afford the expensive devices available in the market that limit the functionality of their daily life activities. The goal of the project is to design the easily accessible STS assistive device aligning to the goal of SDG3, universal health coverage by reducing inequalities. The already available commercial devices include passive supports, such as grab bars and standing frames that provide stability as users rise, and active supports, such as lift cushions, lift chairs, and powered standing devices are quite expensive & thus used only for patients with severe lower limbs disorders in hospitals.

Converging to the point that a self-powered STS assistive passive device for daily life has a greater feasibility in terms of social & economical acceptance, design complexity, controls dexterity & muscles activity. The inactivity of muscles for a long span can result into muscles atrophy & can cause permanent immobility to the muscles. This concept design of a passive device is a tradeoff between an ease of use & percentage of muscles strength that is activated during the STS transfer movement.

1.2. Literature Review

The study “Force Assistance System for Standing-Up Motion” by D. Chugo, K. Kawabata, H. Kaetsu, H. Asama, N. Miyake, and K. Kosuge (2006) was done to design a 2 DOF system comprising of support bars and bed system which moves up and down. This system realizes the natural standing and sitting motion using the remaining strength of the patient. It basically had two major functions like, controlling of support bar and bed system coordination and combination of forces and positions. This study was somewhat different than other as it focused on remaining energy of the patients’ muscles.

This research is related to our study such that we can now understand the different assistance system for the patients with severe injuries and corresponding mechanisms for utilizing the stored potential and muscles energy.

Research done by J. Jeyasurya, H. F. M. Van der Loos, A. Hodgson, and E. A. Croft (2013) on “Comparison of seat, waist, and arm sit-to-stand assistance modalities in elderly population”- was done to design a fully automated STS system that can lead to atrophy of the leg muscles. For the fact finding, research was done with two groups assisted and non-assisted ones. STS rises with supports like grab bar, arm, seat, and waist assistance. Results proved that seat and waist assistance were medically stronger whereas after taking the feedback from the patients, seat assistance proved to be the best choice both in terms of usage and scientifically.

This research is related to our study such that we have now got the fair idea about the types of assistance possible in the STS devices and the suitable assistance i.e., seat assistance as it is medically and user friendly.

The research “Walking Assist Device with Bodyweight Support System” by Y. Ikeuchi, J. Ashihara, Y. Hiki, H. Kudoh and T. Nodan (2009) aimed at reducing the floor reaction force and ultimately reducing the load on the legs. This machine always maintains the assist vector force in the direction from the center of gravity of the floor reaction to the center of gravity of the user’s body. This is related to our study such that we can now understand the effects of reaction force on the standing force required by the muscles. Also, it helped us in reaching to the analogy that reaction force is the driving force in moving the user forward.

Research work by B. Chen, C.H. Zhong, H. Ma, X. Guan, L. Y. Qin, K. M. Chan, S. W. Law, L. Qin, and W. H. Liao (2017) naming “Sit-to-stand and stand-to-sit assistance for paraplegic patients with CUHK-EXO exoskeleton” was done to make a device for the patients who lost the motor and sensory functions of their lower limbs to perform the daily activities. This Exo-exoskeleton can provide normal reference patterns of proper assistive tongue. This device is used for patients with more upper body strength. This research paper was related to our study as it helped us know the importance of lower limbs (pelvic floor muscles) in sitting and standing and utilization of upper body strength in case required.

The research “Design of a Passive Gravity-Balanced Assistive Device for Sit-to-Stand Tasks” by A. Fattah, S. K. Agrawal, G. Catlin, and J. Hamnett (2016) was done to make STS passive gravity balancing assistive device. In this device, the contribute to the joint torque by the gravitational is dominant. Hence, identifying the center of gravity using parallelogram first and then connecting the appropriate springs to make up the total potential energy of the system due to gravity and spring constant. This research was helpful as it gave us the idea of using the potential energy stored due to gravity and spring in lifting the user's weight instead of applying the external active load like motor. Therefore, this proved to be passive and less energy intensive system.

Y. Chang, A. D. Singh, J. Girard, and Z. Wu (2010) did research on "Sit-to-Stand and Mobility Assistance Device" to design a device for the patients which require early mobility in the ICUs. It was users feedback device therefore it aimed at safety of the user, assistance in standing, support while walking, easy maneuverability, stability, rigidity, comfort, and adjustability. This research was related as it involved the usage of 4 bar linkages which follows the natural trajectory of the movement. The assistive force is greater than input force which helps the user guide to the certain position by releasing the pressure. Also, gathered the fair idea of the use of fully support harness and support in case of losing balance.

Research "Designing an Assistive Mobility Device for Geriatric Sit to Stand" by O. Bennett, S. R. Gabor, and S. Neeno (2016) was done to make a safer, reliable, and ergonomic device. This device was designed to cater for the forces required for the STS motion. This force was produces to the spring that extended when a person sits on it. We can relate to this research as we can make a device which can store the potential energy and release equal to the weight of the user. This way a controlled motion can be achieved. Moreover, this stored energy can also be used to generate the indirect response for the actuators.

Y. Hirata, J. Higuchi, T. Hatsukari and K. Kosuge (2008) did exceptional research on "Sit-to-Stand Assist System by Using Handrail and Electric Bed Moving Up and Down" for the patients with major injuries. The user assistive motion initiates from the bed whereas the handrail and electric bed are the supports which move up and down. Certain indexes like handrail position, height of the bed, foot position for stabilizing the posture of the user's posture and reducing the burden were considered. These indexes were determined using the body size and the disability of the user. This research is related to our work because we can implement same mechanism in out seat and can use wait as the assistive support. Moreover, we can also understand different parameters in terms of the safety of the patient and quick recovery.

Research "Design and Experiment of a Passive Sit-to-Stand and Walking (STSW) Assistance Device for the elderly" by S. W. Kim, J. Song, S. Suh, W. Lee, and S. Kang (2018) was done to predict the loosing of the muscular strength. The pneumatic and gas spring were used. Likewise, this device had two major functions: standing motion (extension of the actuators) and sitting motion (driven naturally with the gravitational force of the user's weight). This loosing of the muscle's strength led to the discomfort which is common over aging.

This study helpful in understanding the use of gas springs and pneumatic cylinders instead of conventional weight loadings and springs. Also, the use different mechanism opened wide range of related design for these sort of look-alike systems.

The research paper "Design and control of a sit-to-stand assistive device based on analysis of kinematics and dynamics" by B. Zhoua, Q. Xue, S. Yanga, H. Zhanga, and T. Wang (2021) aimed at patients with lower limb disorders, limb pain, muscles weakness, partial loss of the motor control function and physical defects in the joints. This 3 DOF series type STS assistive device used trajectory and velocity of each joint and its relationship with the law of plantar pressure during STS motion. Afterward, the kinematics and dynamic were used with end-effectors and linear actuators.

This research is related as we can now understand trajectory and velocity of each joint and their role in the muscle movement, and eventually user. The trajectory of joint is also very useful in determining the reaction forces and CG of the user while sitting and standing.

The research “Development of the Lift Assist Chair for the Elderly People “Rakutateru” done by A. Ahrary, W. S. Yangb, M. Inadac, and K. Nakamatsud (2018) to cater for the major highlighted by the Nurses of the weak legs and difficulties to stand from seat for most patients. Some reasons were weight of the user itself and some secondary diseases such as bedsores. It is related to our study because we came to know the areas of major weaknesses in muscles and joints. Moreover, the body movements after injuries can also be noted for narrowing down the muscle’s movements.

Some researchers A. Tsukahara, R. Kawanishi, Y. Hasegawa, and Y. Sankai (2009) worked on “Sit-to-Stand and Stand-to-Sit Transfer Support for Complete Paraplegic Patients with Robot Suit HAL” for designing the complete physical support of the lower limbs. This support was done with full fledge “robot suit HAL” which detects the wear’s motion synchronization his/her intentions. This is done just before sitting and standing to get the precise reading. Hence, HAL supports the weight and controls body posture. This research is bit broad and out of scope but still it is useful to understand the mechanism involving the sensors and material properties for the linkages and various other components.

The study “Compaction of Feature for Finger Motion Discrimination of Myoelectric Hand Using Principal Component Analysis” by TSUJIUCHI, N., ITO, A., & HISAMOTO, Y. (2018) highlights the usage of important limb functions i.e. finger. The study revolves around using the electrically operated motor-assisted device as an alternative to prosthetic limbs.

This research is related to our study such that we got a fair idea of the importance of body functions with interrelated motions. Although the study was focused on a finger, this can be replicated easily for legs and lower back muscles that are involved during the motion. This then can be further used to implement the constraints and make the model suffice.

In the research “Effects of a Dynamic Chair on Chair Seat Motion and Trunk Muscle Activity during Office Tasks and Task Transitions” by Nüesch, C., Kreppke, J., Mündermann, A., & Donath, L. (2018), the researchers interrelated the dynamics of chair like the lift motion and the forces involved during the process. It further relates this to the upward motion of the person to narrow down the limb movement with the external dynamics.

This research is related to our study such that it highlights all the important parameters which need to be considered to get bare minimum accuracy. Although it does involve complex manipulation of data, still working on basic design factors can lead to substantial results. Moreover, we have come across the idea of lift and down forces involved during the motion.

The study “Development of a sit-to-stand assistance chair for elderly people” by Aharari, A., & Yang, W. (2020) highlights the importance of sit-to-stand motion assist motion for elderly people. This shows the usage utility and requirements due to various health issues like knee-knocking and excess uric acid. Although the discussion of these ailments wasn’t part of the process, the remedies to get along with these challenges were discussed.

Our research relates to this study such that we can now implement our design for elderly citizens and improve the system in a way to makes it more convenient, less technical, and easier to understand. Since the motion involved old citizens, therefore making it more subtle and continuous (jerk-free) would be a challenging task for the designers.

In the research “Appropriate synthesis of the four-bar linkage” by Pickard, J., Carretero, J., & Merlet, J. (2020), they came across the best alternative solution for the synthesis four-bar linkage mechanism. This concept is vital for understanding the motion involving the rotation at two ends of a link. Although it did involve complex geometries, still it was very much related to our findings.

We used this research to understand our possible mechanism and methods to implement the design parameters. The major issue with the changing axis of the crank was corrected using the phenomenon called a pantograph. This four-bar analysis proved to be the governing breakthrough for our entire project.

The researchers Zhang, X., Zhang, Q., Li, Y., Liu, C., & Qiu, Y., (2021) in their research “Effect of the thickness of polyurethane foams at the seat pan and the backrest on fore-and-aft in-line and vertical cross-axis seat transmissibility when sitting with various contact conditions of the backrest during fore-and-aft vibration” came up with interesting results of the usage of polyurethane form for making the back support and seat of the chair. They wonderfully explained the health benefits of maintaining good posture with the aid of smooth support. This study helped us in the fabrication process where we used polyurethane in the best proportion to increase comfort while not compromising on the ergonomics and functions. The usage of polyurethane at the vital location also helped in the sub-conscious movement of elder citizens.

Chapter 2 : METHODOLGY

Methodology can be as defined as the no of steps taken from identifying the problem to giving the practical solution of the identified problem. Referring to Machine design "An integrated approach" by Robert L. Norton STS assistive device is also the machine because it also modifies the STS transfer motion. A design process of the machine consisted of 9 steps i-e identification of need, background research, goal statement, task specifications, synthesis, analysis, selection, detailed design, prototyping & testing, & production. The above description may give an erroneous impression that this process can be accomplished in a linear fashion as listed. On the contrary, iteration is required within the entire process, moving from any step back to any previous step, in all possible combinations, and doing this repeatedly. The four steps have been accomplished so far from problem identification to task specifications.

2.1. Problem Identification

A problem has been identified that most elderly people complain about the discomfort of movements caused by losing their muscular strength of lower extremity over aging. Especially in standing, sitting, and walking that are indispensable for the indoor activity of the daily life for the elderly, there is a limit to executing the action with the weakened muscular strength. The problem statement is usually vague at the initial point of the problem definition & it requires little background research to refine the problem definition.

2.2. Background Research

A literature review is done & it is observed that there are several assistive STS devices either available commercially or in development. Commercial devices include passive supports, such as grab bars and standing frames that provide stability as users rise, and active supports, such as lift cushions, lift chairs, and powered standing devices. However, all these available devices are patients oriented, required assistant & dexterity to operate. Hence, they are less feasible for daily use for senior citizens to perform STS. The kinematics of STS transfer motion are equally important to come up with the solution that fixes the problem in performing STS motion.

2.3. Biomechanics of STS Transfer Motion

The biomechanics of sit to stand transfer motion is important to understand to synthesize a solution that assist the senior citizens while performing their natural transfer motion. The sit to stand transfer motion of a body is the sequence of events that involves transfer of momentum that led to perform this motion. The joints can be moving or stationary depending upon the part of motion under process. Large moments are usually produced in both hip & knees during the sit to stand transfer motion. The STS motion is divided into four successive phases:

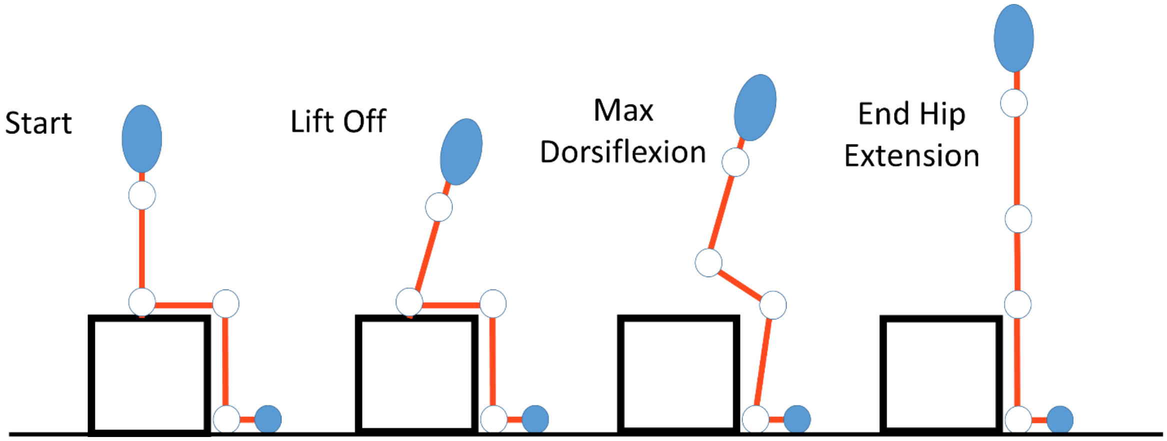


Figure 2-1: Phases of STS Transfer Motion

2.3.1. Flexion Momentum

The flexion momentum is the first phase in STS transfer motion. And this begins with the movement initiation when the person in sitting posture think of performing the STS transfer motion and ends just before the lift-off. Lift-off is the position when the person has just left the seat & the seat is no longer in contact with the person’s buttocks & thighs. There are two critical events involved in this phase. One is the trunk & pelvis rotation that generate the momentum at the trunk to be utilized in the next phases. And second is the initial foot placement backward 10cm behind the knees. These two events are also termed as Trunk Flexion & Ankle Dorsiflexion.

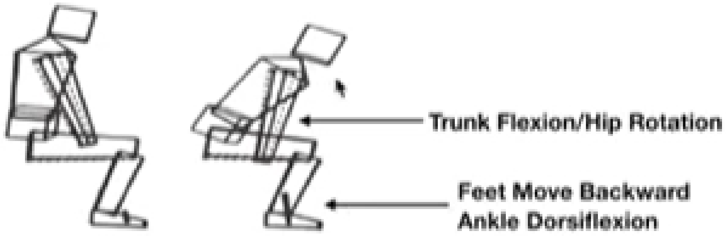


Figure 2-2: Flexion Momentum

2.3.2. Momentum Transfer

This phase starts from the lift-off and ends at maximum ankle dorsiflexion. The momentum generated in the previous phase is transfer to the whole body. And the person on the seat is no longer seated. Anterior movement of the thigh leads to the forward translation of the leg that resulted in the increase ankle dorsiflexion and the continued flexion of the hips while the quad muscles of thighs prevent the excessive knees deflection. The person is on the quadriceps & the quad muscle activity is removed the natural tendency would be to fall due to the gravity.

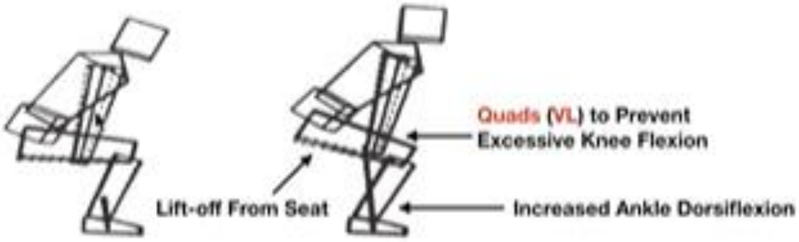


Figure 2-3: Momentum Transfer

2.3.3. Extension phase

This phase begins with the maximum ankle dorsiflexion left off in the previous phase & ends up at maximum hip extension. It involves three critical events of lower limb extension. The hip and knees are fully extended known as hip & knee deflection. The third important critical event is relative plantar deflection in which the position of foot doesn't changes yet the angle between tibial (lower portion of leg) and foot changes from 60 degrees in maximum ankle dorsiflexion to 90 degrees in relative plantar deflection. And thus, the point of maximum hip extensions terminates the extension phase.

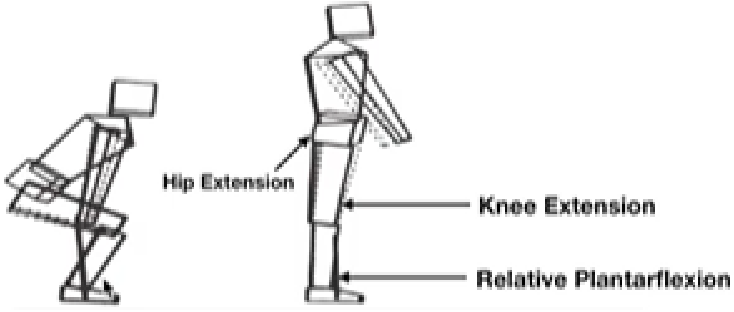


Figure 2-4: Extension Phase

2.3.4. Stability

This is the last & the most important phase of STS transfer motion. It begins with hip extension & ends with ankle flexion. It can be thought of as a phase after standing is complete & the now is the challenge of maintaining stability. The critical event in this phase is ankle strategy after the standing is complete to counter the unexpected perturbations & maintain balance. For example, if the body sways backward, muscles on the front of the ankle contracts to pull the COP forward. Conversely, if the sway is forward, muscles on the back of ankle contract and pull the COP backward.

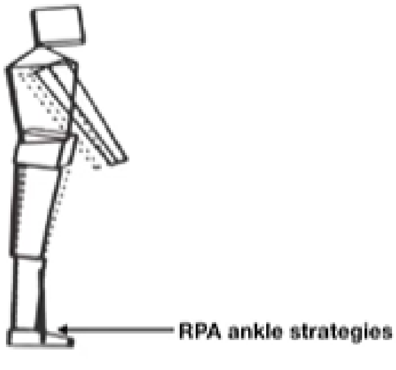


Figure 2-5: Stability after motion is achieved

2.4. Goal Statement

The development of passive STS assistive device that can help senior citizen weighing 60-70 kgs to perform sit-to-stand transfer movement.

2.5. Task Specifications

Task specifications are necessary to bound the problem & defined its scope so that deliverables of project can easily be achieved. After performing detailed background research, the decided specifications for STS assistive device are passive, self-powered (require no assistant), & for citizens with reasonable amount of muscular strength. Therefore, the development of the force assistance system for standing up motion which uses part of the remaining strength of the patient in order not to reduce their muscular strength.

2.6. Synthesis

The qualitative synthesis started off with the potential solutions that configures our desired solution to perform STS transfer motion.

2.6.1. Seat Assist Modality

The previous studies made on the different modalities seat, arm, waist assist favors the seat-assist STS modality due to better stability metrics & better usability in non-clinical applications. The current design concept also revolves around the seat-assist STS device & the goal is to assist the quadricep (thigh) muscles activity while performing the sit to stand movement. And there are chances that it will invariably be discovered to be flawed when later analyzed.

These kinds of chair-typed system/seat assisted system consist of actuator, transmission mechanism (or mechanical structures) and sensors, the power or the number of actuators is still the only thing that has been considered for executing the movement. The development has been made in the seat assisted modality using different transmission mechanisms.

2.6.2. Proposed Kinematics

At the grass-root level, a system needs to be designed that provides upward force to the person sitting on the chair by lifting the seat(base) adding momentum to the body while maintain the backrest straight throughout the complex motion generation to increase the stability of the system and avoid undesirable and non-effective sub-due motion.

Three position synthesis using fixed pivots

The proposed kinematics for seat assisted modality to perform STS motion can be breakdown into two. Firstly, seat base needs to be rotated while person performing the STS movement to assist the muscles activity. Secondly, the backrest should be straight relative to the rotation of seat during the motion generation. The first part can be achieved by fixing the one end of the link(2D) using a revolute joint. The complex motion of the backrest can be synthesized using the three-position synthesis with fixed pivots. The following figure shows the three-position synthesis of back support with fixed pivots.

Chapter 3 : Motion Synthesis

The three-position synthesis with fixed pivot is performed for the back support. The confronting challenge is to synchronize the motion of two links such that back support is always straight throughout the motion generation. This don’t give the optimal solution to the proposed kinematics. Different types of mechanism that exists is studied that best suited the problem at hand. After detailed research, a mechanism is identified that fulfills the desired requirements of performing one link a rotation while keeping one link straight throughout the motion. The mechanism is called pantograph. This mechanism has wide range of applications in milling machines, wood carving machine, drafting, E-highways, transmission of electricity on the train & force multiplier.

3.1. Pantograph

The Pantograph mechanism is a 4-bar link mechanism designed to adjust the supporting load at the rotation joint to perform the operation while being straight. This purely mechanical system uses little external effort for the maximum mechanical advantage. This upward and downward motion can be achieved using some piston rod or retainer springs, or any other restoring force device/mechanism. The perfect example of a pantograph is the electric trains, currently in use today in many subways across the world. This mechanism offers the best solution to the adequate flow of whopping 25,000 volts of current without little to no disruptions. It perfectly handles the aerodynamic drag and vortices at speeds above 150 km/h. Likewise, it also offers great solutions for height adjustment and efficient change in lanes at the stations.

3.3.1. Design Model

The two pantographs mechanism in XY plane connected through the links in Z-axis can form a 3D body that can resemble a seat assisted device that performed the required motion of rotation of seat about fixed pivot while keeping the back support straight throughout the complex motion generation. The pantograph mechanism is the combination of two four bar linkages that resulted in the required motion. The links highlighted with yellow color represents the first four bar linkages mechanism with link opposite to the shortest link grounded in fig 8 & links highlighted with blue color represents the second four bar linkage mechanism in fig 9. The red link & blue link resemble the back support & seat of the chair respectively.

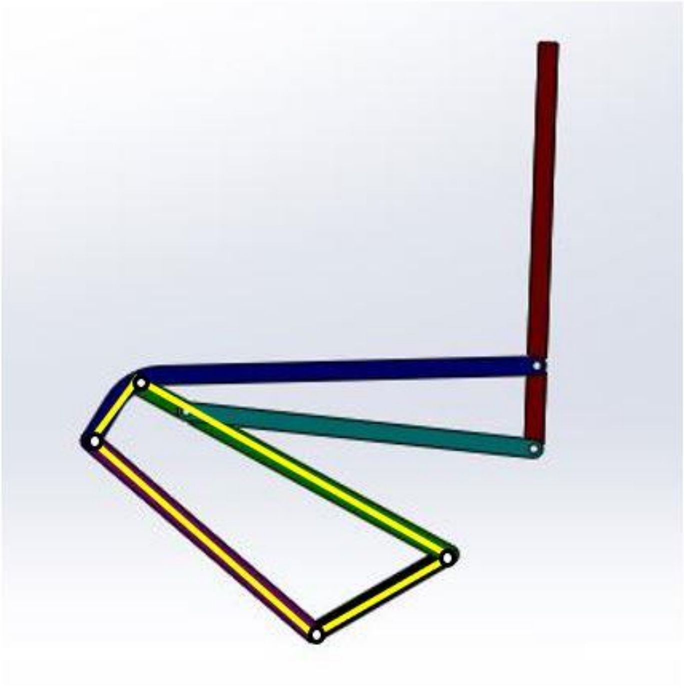


Figure 3-1: First Linkage (Highlighted in yellow)

Figure 3-2: Second Linkage (Highlighted in Blue)

3.1.2. Motion Generation

The motion started off with seat perfectly horizontal & ends up close to the vertical reference line with back support remain perfectly straight through out. The links changes their position throughout the motion & respective movements of links are shown at three instants during the motion generation.

Figure 3-3: Initial position of the links

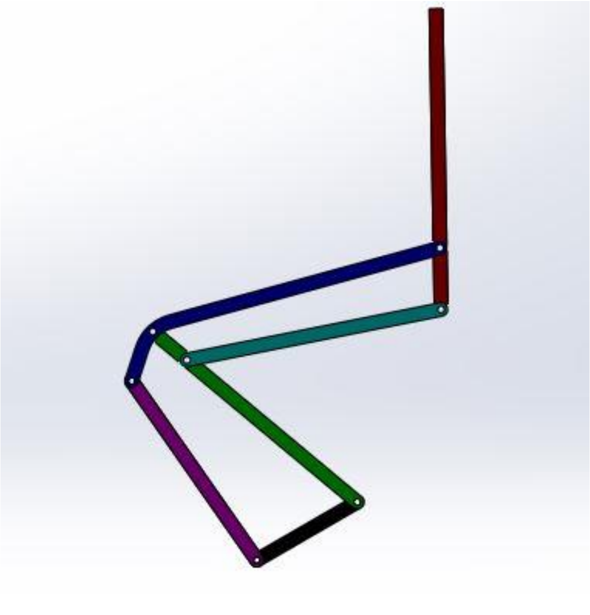


Figure 3-4: Position of links near middle

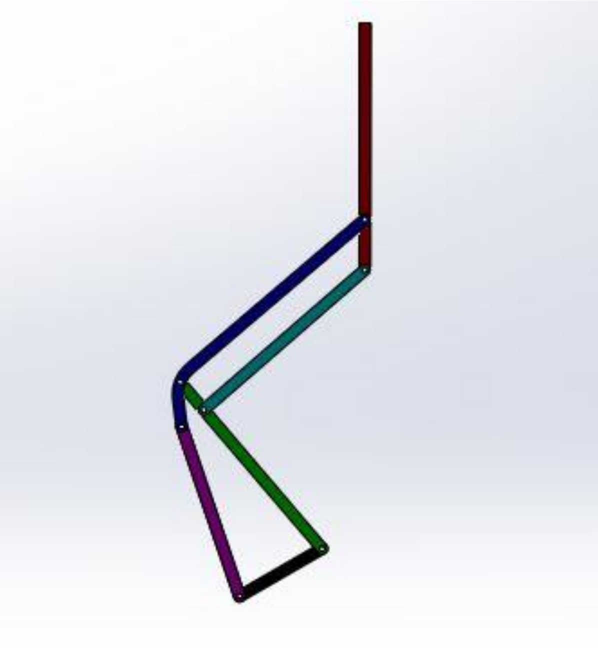


Figure 3-5: Close to the final position

3.1.3. Design Limitations:

The two pantographs mechanism in XY plane connected through the links in Z-axis can form a 3D body resembling a seat assistive device apparently look to meet the design requirements. The design limitations occur when a mannequin is placed on the model and the natural motion of STS is performed. It is observed that seat link in the pantograph mechanism slides backward laterally while knee joints coordinates do not change during the transfer motion. It is difficult to compromise the friction between the seat base and the human sitting on the chair as this adds to the comfortable sitting posture.

3.2. Second Design Iteration: Parallelogram Structure

Simplicity is one mark of good design. The fewest part that can get the job done are least expensive and most reliable. The challenge is still there to perform a seat a controlled rotation without the change in coordinates of knee joints and keeping the back straight throughout the STS transfer motion. The next derived mechanism is a four bar linkages mechanism. The grashof condition is used as a governing relation to describe the rotational behaviors of our mechanism. The governing relation is given as:

$$S + L \leq P + Q$$

Where:

S= length of shortest link

L= length of longest link

P= length of one remaining link

Q= length of other remaining link

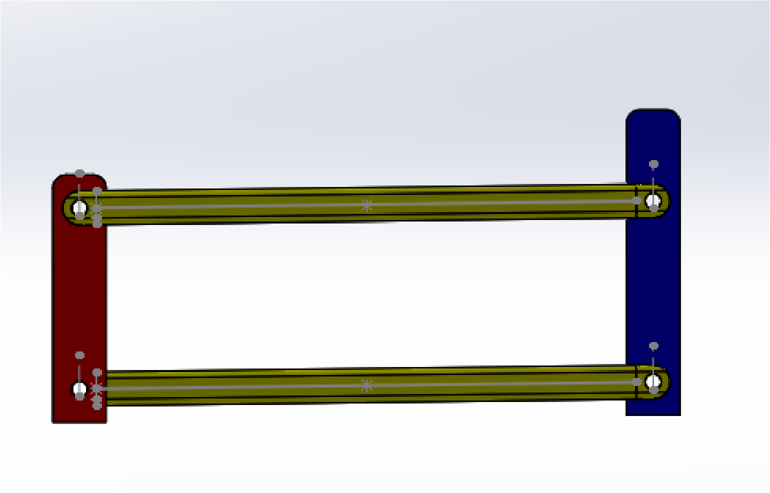


Figure 3-6: Chair frame structure

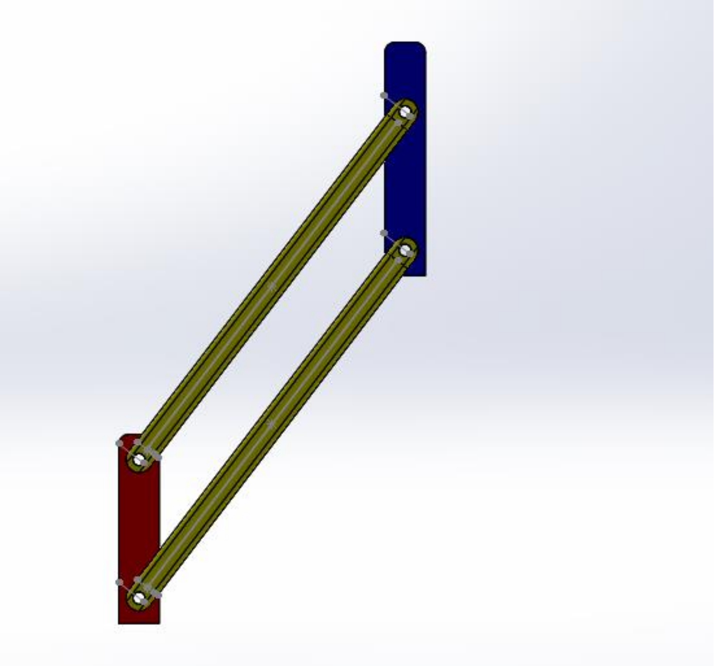


Figure 3-7: Side lift support linkages

In our design approach

$$S + L = P + Q$$

This condition is generally referred as special grashof and Class-III kinematic Chain. The link lengths are such that they form a parallelogram. The mechanism is likely to have change points twice when the links all become colinear. At these change points the output behavior is inderminate. At these colinear positions, the linkage behavior is unpredictable as it may assume either of two configurations. Its motion must be limited to avoid reaching the change points or an additional, out-of-phase link must be provided to guarantee a “carry through” of the change points. However, the colinear positions are avoided by providing a controlled rotation & placing the links of the parallelogram in a single plane.

3.2.1. Design validation

The two major challenges at hand while synthesizing the motion was performing the rotation of the seat that will provide the continuous push throughout the trajectory and keeping the back rest straight to reduce the tendency of the person sitting on the chair falling forward. Both of these requirements are expected to meet with this design model. The link acting as a seat base performs a revolute motion and the extended link opposite to the fixed link acting as a back support remain straight and the angle of the link remain zero throughout the motion.

Figure 3-8: Chair Structural Model

General chair model that will be further used for analysis and fabrication. It comprises the linkages and their particular positions to carry out the operation.

Chapter 4 : Chair Ergonomics

4.1. Design Guidelines for Healthy Citizens

Ergonomics refers to the design manifestation that helps and supports the user in doing daily tasks. Ergonomic seating should fully consider posture, pressure distribution, intuitiveness, and movement to create a comfortable experience for the user. Following are certain parameters which are taken into account using this approach (Chair Ergonomics and Seating, 2022).

4.1.1. Posture

Seating should be designed to properly support postures that promote health, which in turn encourages productivity and comfort. The workforce is made of individuals of difference shapes and sizes. In order to create products that support this diversity, adjustment and thoughtful design is key. Adjustment ranges are not arbitrary, but instead are intentional to meet the needs of the 5th-95th percentile. We use the latest anthropometric data to understand specific measurements that are related to ergonomic chair design, going beyond simply looking at overall height and weight.

4.1.2. Seat Height

Seat height can plan a huge role in making the user lethargic and unrest. Proper seat heigh has been proven to increase the productivity as it directly correlates with the Adjust seat height so that feet are firmly on the floor, knees are bent to 85-110 degrees, and hips are at or slightly above knee level.

4.1.3. Seat Depth

Seat depth help insures the usability of the chair for a larger user segment. Generally, when sitting for a longer duration, it is often convenient to release body or slouch on the chair. Therefore, seat should have enough space to allow such variation.

So, adjust seat depth so that there is about 2-3” of clearance between the front edge of the seat and the back of the knees. This will ensure that your legs are properly supported, without impinging blood supply to the lower legs. Hence, proper seat depth will also ensure that you can sit back far enough to utilize your backrest properly.

4.1.4. Lumbar Support and Recline Tension

Sitting for longer duration on study or computer chair can cause severe backbone issues. This can further lead to constant impairment in the lower back and hips joints. Therefore, ensure that chair offers proper lumbar support in upright and reclined postures. Check that the recline tension of your chair is at a level that is high enough to support your back, while still allowing for a comfortable recline. In some chairs, tension recline is manually adjustable, and in other chairs, the tension adjustment is engineered into the chair-meaning no adjustment is required.

4.1.5. Armrests

Arms rest not only support during the sitting position rather they are also used in standing motion in case user has weak knee joints.

So, Adjust armrest height and width to a position that:

1. support forearms
2. allows the shoulders to remain relaxed
3. allows for neutral postures of the wrists during typing and mousing tasks

Since, armrests are stretched at length, therefore their depth adjustments allow you to get closer to your worksurface, if desired.

4.2. Anthropometric Measurements

Anthropometrics refers to measuring humans, and the application of population size and weight in product design. In our design analysis, we have broadened our focus group from 5th-95th percentile to reduce the vague and incorrect assumptions and approximations.

Considerations of users on the small end of the spectrum (5th percentile) to the large end of the spectrum. We consider overall dimensions such as weight and height, but also more specific measurements in product development. No one is 50th percentile on all dimensions, some individuals have long torsos and shorter legs or vice versa. Therefore, it is important to have a more refined view of the data. For example, seat height adjustments are based on the measurement needed to support the 5th to 95th popliteal height.

4.2.1. Pressure Distribution

When designing seating, we utilize pressure mapping, as well as subjective feedback, to better understand the interaction between the user and the product. Properly considering pressure distribution will create a comfortable initial and long-term sit. To better process the pressure distribution, here are general breakdown based on applications:

1. What we want: Evenly distributed pressure
2. What we try to avoid: High pressure on buttocks and front of thighs
3. Seat curvature, material properties, and dimensions can all be engineered to optimize pressure distribution.

4.2.2. Intuitive Design

We are designing the product keeping the user in focus. The philosophy of designing products to align with user expectations. That is, users do not need to consciously think about how controls or adjustments are manipulated, but instead the design communicates appropriate interaction instinctively.

When you approach a door, the handle should communicate to you how the door operates. You can usually tell by the shape of the handle if you should push, pull, or slide the door handle. Intuitiveness is important because people need to understand how to use their seating without a manual. Adjustments are useless unless they are intuitive.

Miscellaneous Factors

Besides main factors which are discussed earlier, some miscellaneous factors like active sitting: reclining, changing postures, and fidgeting in your chair

Some addition frills which we can be considered are:

1. Adaptive Support: Moves with you as you change postures
2. Personalized Reclining: Assisted by proper tension adjustment and synchronized movement between the seat and the back (synchro-tilt)
3. Seating Options: Variety of chair styles made to meet work needs and encourage movement throughout the office

4.3. Dimensions

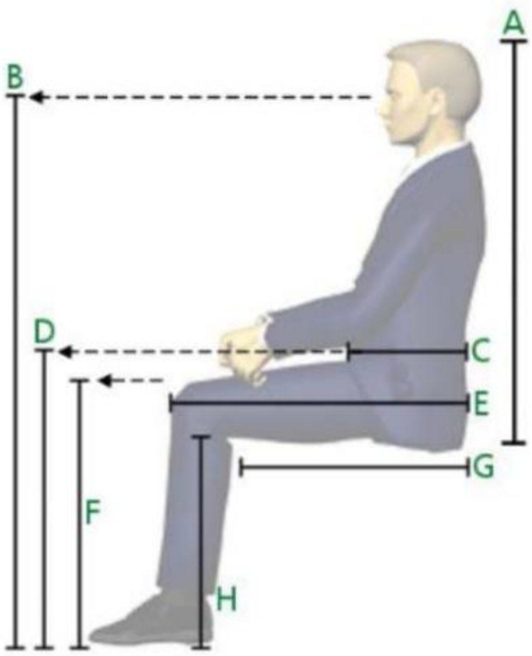


Figure 4-1: Dimensions definition

Measurement	**Letter**	**Female** **5th-95th %**	**Male** **5th-95th %**	**Overall** **Range** **5th-95th %**
Sitting Height	A	31.3”-35.8”	33.6”-38.3”	31.3”-38.3”
Sitting Eye height	B	42.6”-48.8”	46.3”-52.6”	42.6”-52.6”
Waist Depth	C	7.3”-10.7”	7.8”-11.4”	7.3”-11.4”
Thigh Clearance	D	21.0”-24.5”	23.0”-26.8”	21.0”-26.8”
Buttock-to-Knee	E	21.3”-25.2”	22.4”-26.3”	21.3”-26.3”
Knee Height	F	19.8”-23.2”	21.4”-25.0”	19.8”-28.0”
Seat Length/Depth	G	16.9”-20.4”	17.7”-21.1”	16.9”-21.1”

Popliteal Height	H	15.0”-18.1”	16.7”-19.9”	15.0”-19.9”
Seat Width	Not shown	14.5”-18.0”	13.9”-17.2”	13.9”-18.0”

Table 4-1: Chair Measurements

(Values for 5^{th}-95^{th} percentile males and females in the seated position used in designing seating.)

Dimensions	Females	Males	Overall Range
Popliteal Height	15.0”-18.1”	16.7”-19.9”	15.0-19.9
Seat Width	14.5”-18.0”	13.9”-17.2”	13.9-18
Seat Length/Depth	16.9”-20.4”	17.7”-21.1”	13.8-18.2
Seat Depth	14.5”-18.0”	13.9”-17.2”	16.9-21.1

Table 4-2: Data Extraction

The data for the dimension was taken from the research study by (Ergonomics and Design: A Reference Guide, 2018). The detailed breakdown is as follow:

4.3.1. Sitting Height

Sitting height plays crucial role for long hour sitting duration. It varies considerably across the users based on their height and sitting habits (slouching or reclination). The data of male and female (5^{th}-95^{th}) percentile was kept into consideration before coming up with suitable height. Many users’ category falls in this range, so the selection looked reasonable for common case usage (Popovic, 2019).

4.3.2. Sitting Eye Height

Sitting eye height has to be properly adjusted if aiming to use workstations. Anything above or below the optimal level can cause major eye impairments or in worse case leads to cataract. Since, we have taken into the sitting height. Therefore, sitting eye adjustment would be automatically done unless some have irregular torse/leg ration (in that case we can use height adjustment).

4.3.3. Waist Depth

Waist depth is the average depth of torse of a normal adult. Generally, the proportion is same in males and females (Rilling et al., 2009). To comprehend this into more logical reason, we can say that waist depth can be kept constant for a larger segment of audience.

4.3.4. Thigh Clearance

Thigh clearance is necessary to ensure comfort for more than average hours (around 3 hours) while doing your work. In most cases, thigh clearance helps maintain the comfort with reduce muscle cramp and hamstring issues. Thigh clearance angle directly corelates with the muscle movement and movements iterations (Miller et al., 1993).

4.3.4. Buttock-to-Knee

The buttock-to-knee is difficult to assume. Even when taking the average percentile, it varies considerably between different ages and genders. Therefore, the buttock-to-knee length was assumed to be average at 50th percentile. This came out to be the best possible solution to the pertaining problem.

4.3.5. Knee Height

As in the older age, the bone deformation occurs in senior citizen (Colon et al., 2018). Due to this the average knee height decrease. This isn't due to the bones becoming shortened, rather the muscles ligament and tendons becomes loose and flattens.

Hence, we took the average percentile of around 50th because our major proportion (around 50%) in the country is comprised of adults.

4.3.6. Seat Length/Depth

For the selection of seat length, we took the approximating by taking average being on the conservative side. The average depth is (16.9”-21.1”), hence to support anyone in this range, we made our selection of 17”. Being on the lesser side was to ensure that women can also use this chair with reasonable size as they share shorter seat depth range. The second reason was to cut down the material weight and cost.

4.3.7. Popliteal Height

In our normal computer chair, popliteal height is taken out of equation with the use of hydraulics. But since, in our case we have fixed popliteal height, therefore selection of appropriate size was necessary.

Less the normal height was increase muscle strain and fatigue while more than the normal height can hamper the blood flow in legs and puffed feets. Hence, to make the selection reasonable for both male and female, we took the overall range (5th to 95th percentile) for both genders (from 15” to 19.9”) and came down to 18”. This size is reasonable for both genders and also perfectly aligns with our other chair dimensions.

4.3.8. Seat Width

The overall average seat width range for 5th to 95th percentile adults it (13.9”-18”). Hence, keeping in view the maximum limit, we choose our seat width to be 18”. This was to ensure that everyone, irrespective to the age and gender, can comfortably sit on the chair.

Having size more than required don’t affect the ergonomics whereas the selection of similar size for width makes our chair dimensions in almost complete proportion.

Chapter 5 : Kinematic Analysis

5.1. Position Analysis

The position analysis was performed on solid works. For understanding, two coordinates were selected i.e., global coordinates and absolute coordinates. The position of a point in the plane can be defined using the position vector. Hence, the local and global coordinate system were defined using the same reference point.

Figure 5-1: Chair position analysis (rest)

Figure 5-2: Chair position analysis (motion)

Therefore, the displacement which is the change in position from one reference point to another. The governing equation which was used are:

$$Ra = Rx^2 + Ry^2$$

$$\theta = \frac{ry}{rx}$$

But the results were obtained using the CAD software i.e. solid works. Based on the assumptions, it is stated that system follows the complex motion as it possess both translation and rotational motion. It is worth noting that the order in which both are added are immaterial, which doesn't make any difference based on their occurrence.

Angular Displacements (deg)			
Time (sec)	Link 2	Link 3	Link 4
0	0	0	0
0.2	2.40	0	2.40
0.4	4.80	0	4.80
0.6	7.20	0	7.20
0.8	9.60	0	9.60
1	12	0	12
1.2	14.40	0	14.40
1.4	16.80	0	16.80
1.6	19.20	0	19.20
1.8	21.60	0	21.60
2	24.00	0	24
2.2	26.40	0	26.40
2.4	28.80	0	28.80
2.6	31.20	0	31.20
2.8	33.60	0	33.60
3	36	0	36
3.2	38.40	0	38.40
3.4	40.80	0	40.80
3.6	43.20	0	43.20
3.8	45.60	0	45.60
4	48	0	48
4.2	50.40	0	50.40
4.4	52.80	0	52.80
4.6	55.20	0	55.20
4.8	57.60	0	57.60
5	60	0	60

Table 5-1: Angular Displacement

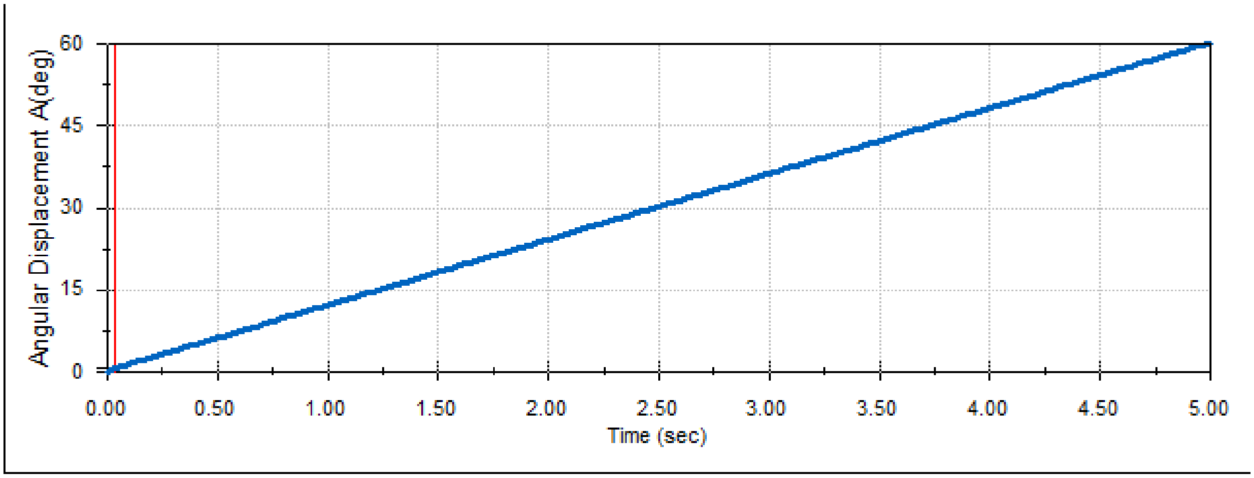


Figure 5-3: Angular displacement Link 2

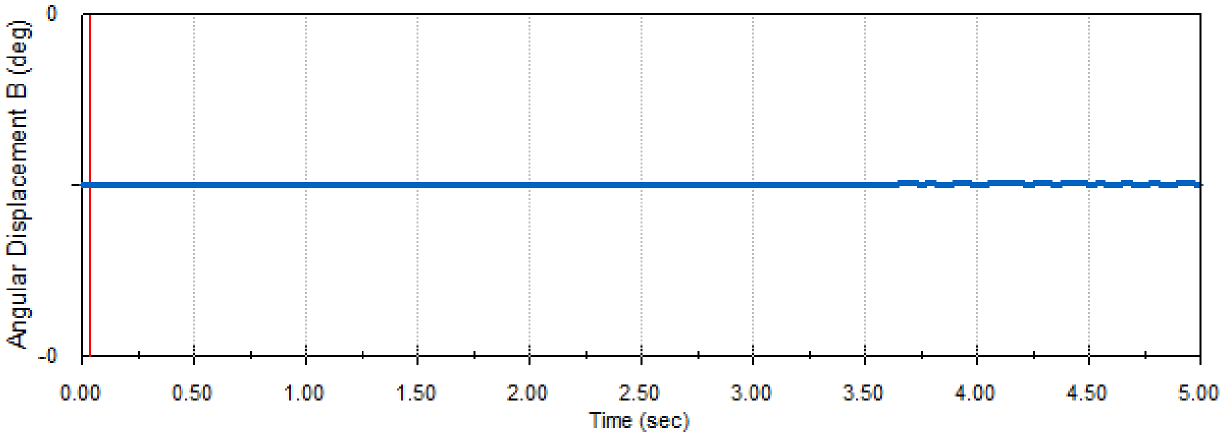


Figure 5-4: Angular displacement Link 3

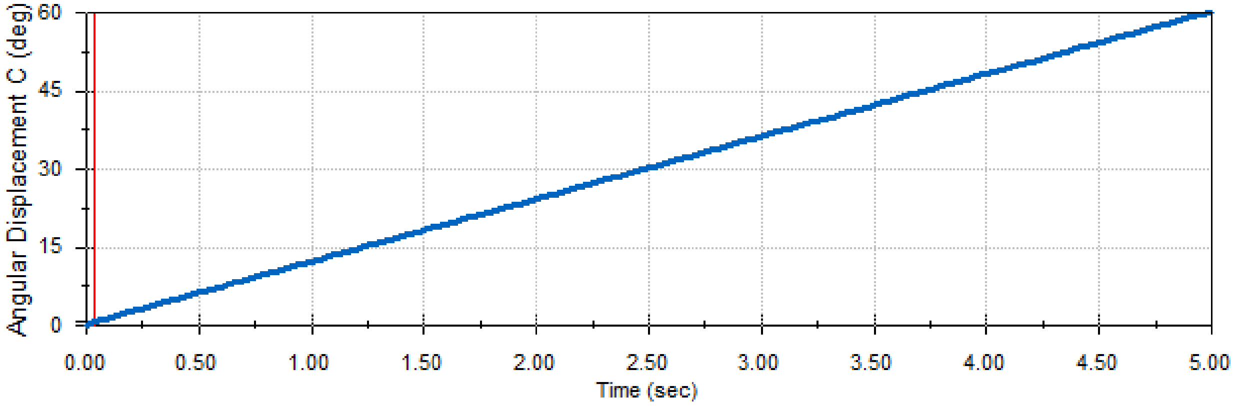


Figure 5-5: Angular displacement Link 3

5.2. Velocity Analysis

Once position analysis is done, next step is to find the velocity of all links and points of intersect of the mechanism. We need to know the velocities in our mechanism or machine, both to calculate the stored kinetic energy from mv^2/2 and also as a step on the way to the determination of the link's accelerations that are needed for the dynamic force calculations. Many methods and approaches exist to find velocities in mechanisms

We have used the CAD software i.e. solidworks to find the velocities. The governing equation for the velocity states:

$$Vpa = Vp - Va$$

Rearranging,

$Vp = Vpa + Va$; the relative velocities can be calculated using the same equation above.

Angular Velocity (deg/sec)			
Time (sec)	Link 2	Link 3	Link 4
0	12.00000007	0	12
0.2	12.00000007	0	12
0.4	12.00000007	0	12
0.6	12.00000006	0	12
0.8	12.00000006	0	12
1	12.00000006	0	12
1.2	12.00000006	0	12
1.4	12.00000006	0	12
1.6	12.00000005	0	12
1.8	12.00000005	0	12
2	12.00000004	0	12
2.2	12.00000004	0	12
2.4	12.00000004	0	12
2.6	12.00000003	0	12
2.8	12.00000003	0	12

3	12.00000002	0	12
3.2	12.00000002	0	12
3.4	12.00000001	0	12
3.6	12	0	12
3.8	12	0	12
4	11.99999999	0	12
4.2	11.99999999	0	12
4.4	11.99999998	0	12
4.6	11.99999998	0	12
4.8	11.99999997	0	12
5	11.99999997	0	12

Table 5-2: Angular Velocity

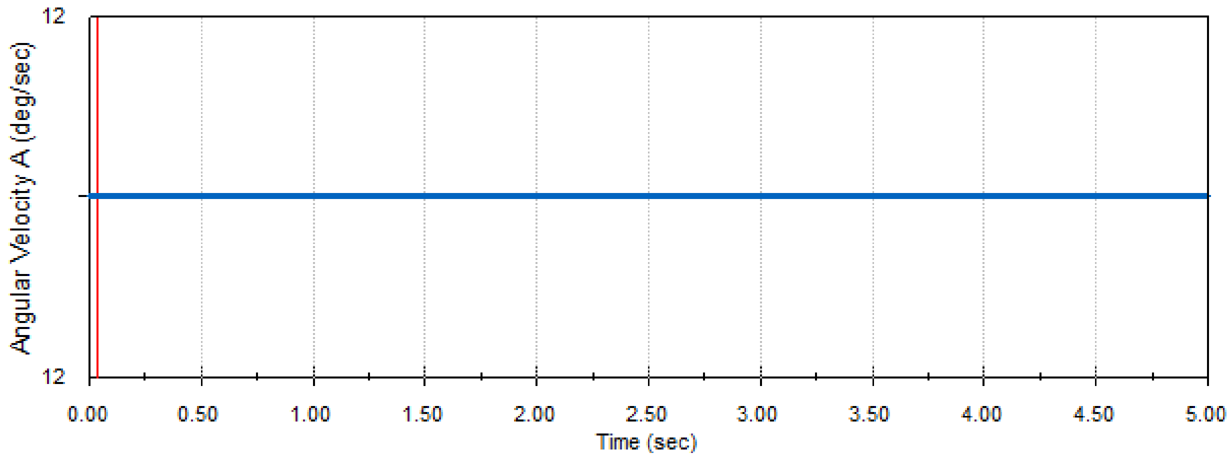


Figure 5-6: Angular velocity Link 2

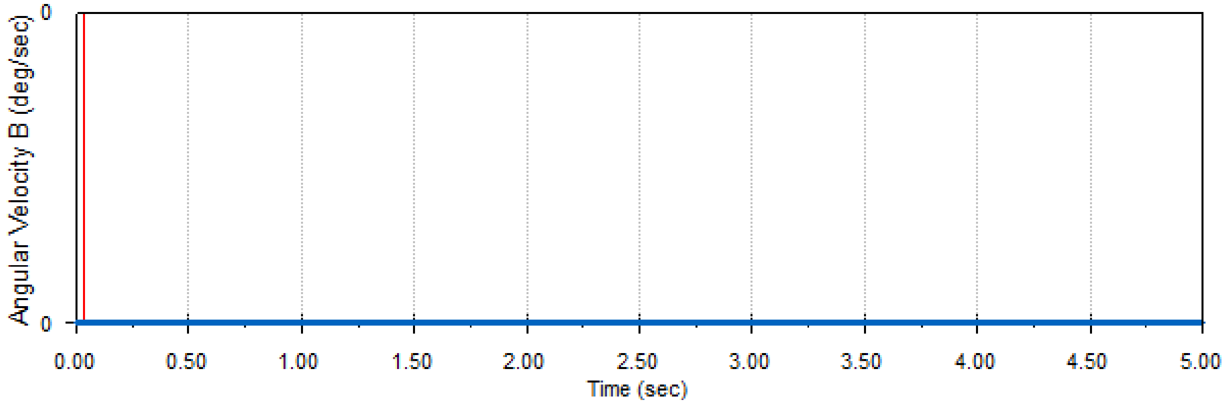


Figure 5-7: Angular velocity Link 3

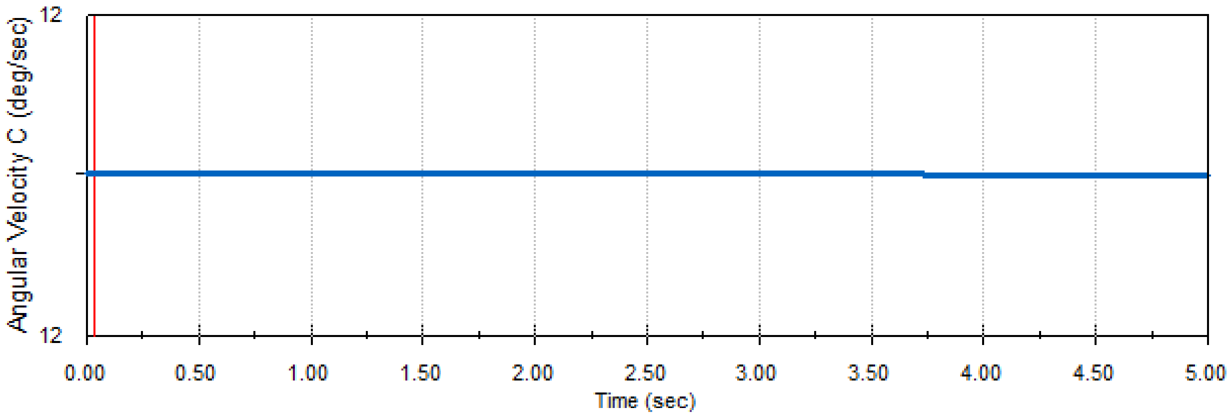


Figure 5-8: Angular velocity Link 4

5.3. Acceleration Analysis

Once a velocity analysis is done, the next step is to determine the accelerations of all links and points of interest in the mechanism or machine. We need to know the accelerations to calculate the dynamic forces from F = ma. The dynamic forces will contribute to the stresses in the links and other components. The angular acceleration at all the link came out to be zero.

5.3.1. Linear Acceleration for Link 2 at C.G

Time (sec)	x- component	y-component	Magnitude
0	-9.463853946	-0.001314627	9.463854
0.2	-9.455525142	-0.397619592	9.463882
0.4	-9.430580444	-0.793227323	9.463882
0.6	-9.389091311	-1.187443218	9.463882
0.8	-9.331130531	-1.579575885	9.463882
1	-9.256799766	-1.968937542	9.463882
1.2	-9.166229446	-2.354844911	9.463882
1.4	-9.05957837	-2.736621364	9.463882
1.6	-8.937033801	-3.11359655	9.463882
1.8	-8.798810605	-3.485109529	9.463882
2	-8.64515171	-3.850507533	9.463882
2.2	-8.476325439	-4.209152333	9.463882
2.4	-8.292629699	-4.560411033	9.463882
2.6	-8.094385369	-4.903670197	9.463882
2.8	-7.881940479	-5.238327035	9.463882
3	-7.655668526	-5.563793227	9.463882
3.2	-7.415965921	-5.879498696	9.463882

3.4	-7.163251089	-6.184892025	9.463882
3.6	-6.897972489	-6.47943136	9.463882
3.8	-6.620591196	-6.762605065	9.463882
4	-6.331596847	-7.033913291	9.463882
4.2	-6.031492034	-7.292884101	9.463882
4.4	-5.720807339	-7.539059361	9.463881
4.6	-5.40008689	-7.772008766	9.463882
4.8	-5.069890756	-7.991324024	9.463881
5	-4.730802189	-8.196618988	9.463881

Table 5-3: Linear Acceleration for Link 2

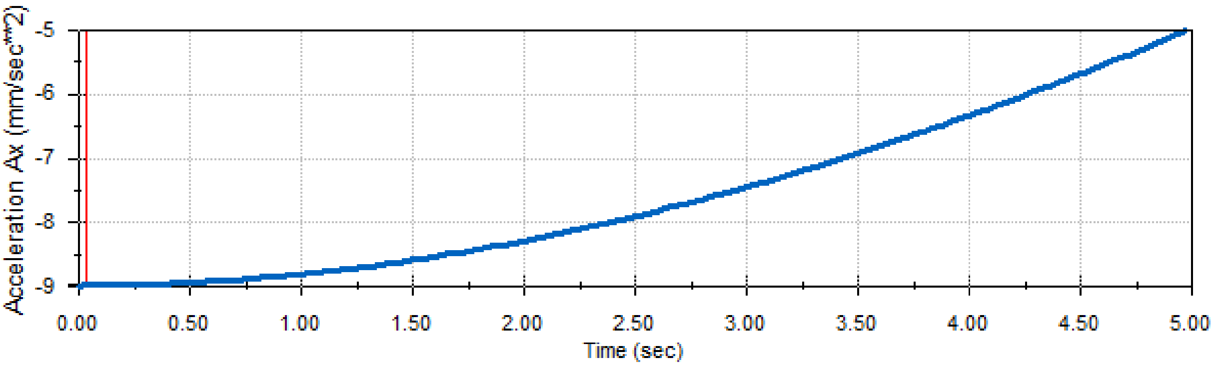


Figure 5-9: Link 2 Linear Acceleration x-axis

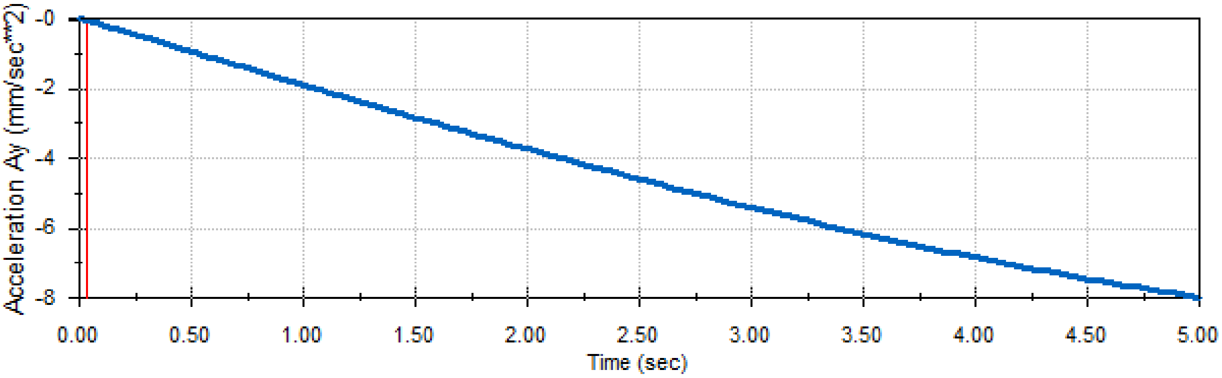


Figure 5-10: Link 2 Linear Acceleration y-axis

5.3.2. Linear Acceleration for Link 3 at C.G

Time (sec)	x- component	y-component	Magnitude
0	-18.9277	-0.00263	18.9277
0.2	-18.9111	-0.79524	18.92781

0.4	-18.8612	-1.58645	18.9278
0.6	-18.7782	-2.37489	18.92778
0.8	-18.6623	-3.15915	18.9278
1	-18.5136	-3.93788	18.92776
1.2	-18.3325	-4.70969	18.9278
1.4	-18.1192	-5.47324	18.9278
1.6	-17.8741	-6.22719	18.92779
1.8	-17.5976	-6.97022	18.92774
2	-17.2903	-7.70102	18.92776
2.2	-16.9527	-8.4183	18.92781
2.4	-16.5853	-9.12082	18.9278
2.6	-16.1888	-9.80733	18.92778
2.8	-15.7639	-10.4766	18.92775
3	-15.3113	-11.1276	18.92774
3.2	-14.8319	-11.759	18.92774
3.4	-14.3265	-12.3698	18.92777
3.6	-13.7959	-12.9588	18.92769
3.8	-13.2412	-13.5252	18.92777
4	-12.6632	-14.0678	18.92775
4.2	-12.063	-14.5858	18.9278
4.4	-11.4416	-15.0781	18.92774
4.6	-10.8002	-15.544	18.92776
4.8	-10.1398	-15.9826	18.92773
5	-9.4616	-16.3932	18.92773

Table 5-4: Linear Acceleration for Link 3

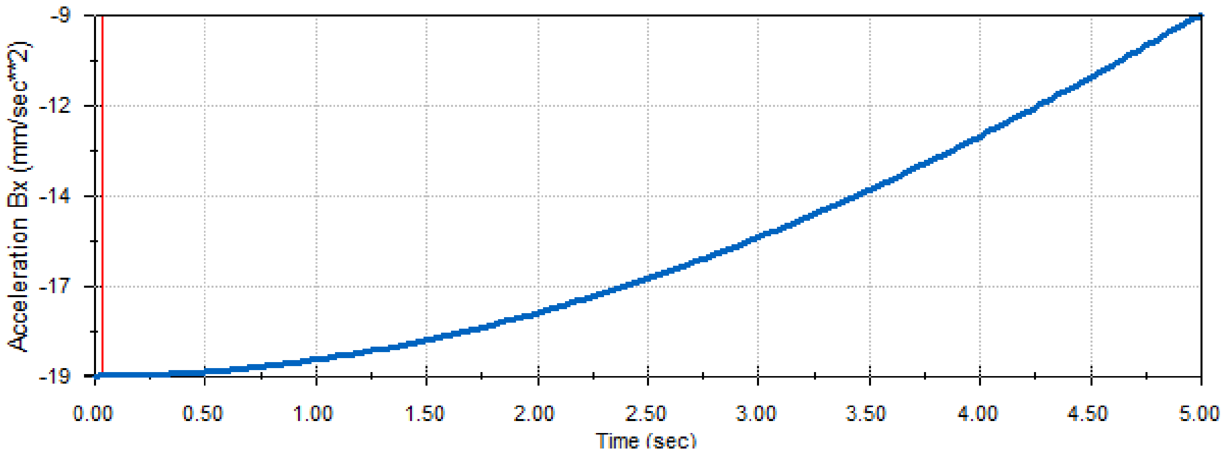


Figure 5-11: Link 3 Linear Acceleration x-axis

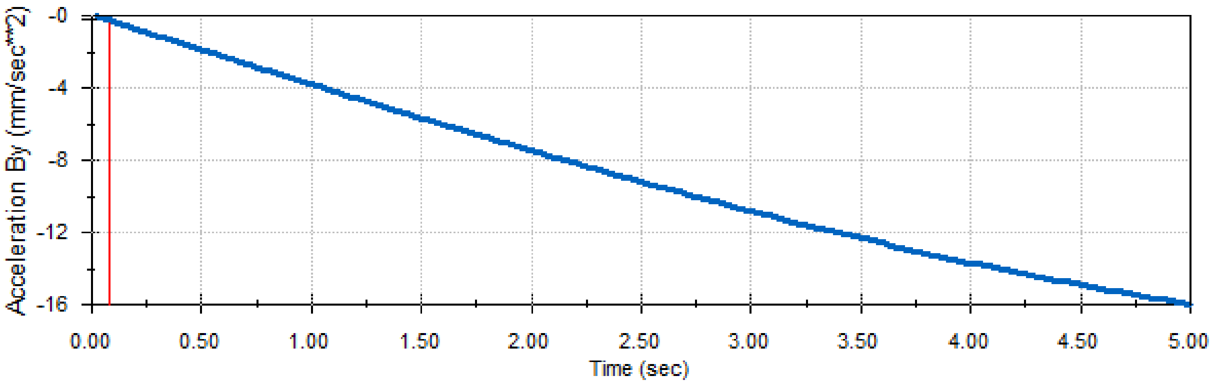


Figure 5-12: Link 3 Linear Acceleration y-axis

5.3.3. Linear Acceleration for Link 4 at C.G

Time (sec)	x- component	y-component	Magnitude
0	-9.46385	-0.00131	9.46385
0.2	-9.45553	-0.39762	9.463887
0.4	-9.43058	-0.79323	9.463881
0.6	-9.38909	-1.18744	9.46388
0.8	-9.33113	-1.57958	9.463882
1	-9.2568	-1.96894	9.463882
1.2	-9.16623	-2.35484	9.463881
1.4	-9.05958	-2.73662	9.463883
1.6	-8.93703	-3.1136	9.463879
1.8	-8.79881	-3.48511	9.463881
2	-8.64515	-3.85051	9.463881
2.2	-8.47633	-4.20915	9.463885
2.4	-8.29263	-4.56041	9.463881
2.6	-8.09439	-4.90367	9.463886
2.8	-7.88194	-5.23833	9.463883
3	-7.65567	-5.56379	9.463881
3.2	-7.41597	-5.8795	9.463886
3.4	-7.16325	-6.18489	9.463879
3.6	-6.89797	-6.47943	9.463879
3.8	-6.62059	-6.7626	9.463877
4	-6.3316	-7.03391	9.463881
4.2	-6.03149	-7.29288	9.463877
4.4	-5.72081	-7.53906	9.463884
4.6	-5.40009	-7.77201	9.463885
4.8	-5.06989	-7.99132	9.463878
5	-4.7308	-8.19662	9.463881

Table 5-5: Linear Acceleration for Link 4

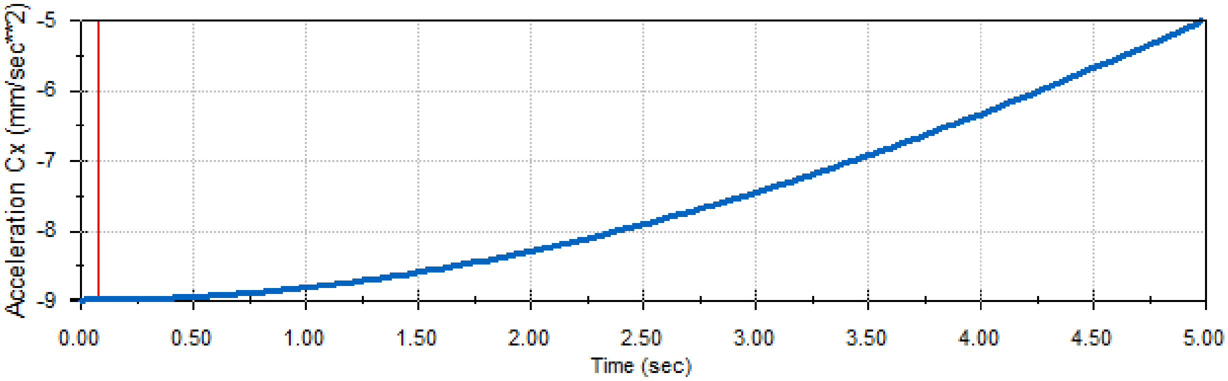


Figure 5-13: Link 4 Linear Acceleration x-axis

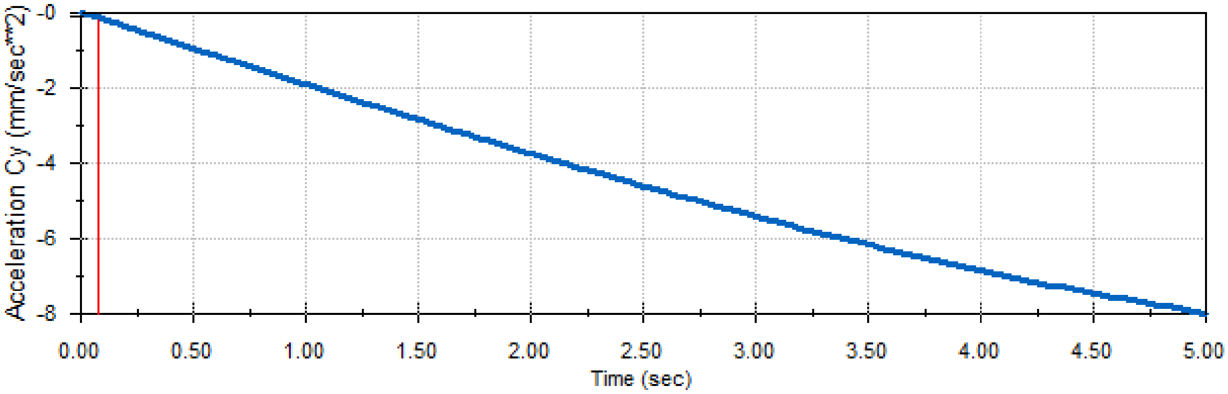


Figure 5-14: Link 4 Linear Acceleration y-axis

The graphs shows the liner acceleration at x-axis and y-axis. The counter relation is seen due the change in the applied force.

Chapter 6 : Dynamic Force Analysis

6.1. Material Selection

The material selection is an important parameter in machine design. The material should be selected such that it met the usage requirement without getting failed. The AISI 1018 Low mild steel is selected for the structure of the mechanism to create links, base holding the links, arm rests & back support. The prime reason for choosing this material is its ease of weldability. Mild steel can be easily welded by all the conventional welding processes. The welding plays a crucial role in defining the strength of our structure. The secondary reason for choosing the mild steel is that it is easily available in the market with different cross-sectional area & gauges required.

The second analysis is performed by distributing the load of the person sitting on the chair using the surface selection of the links. The results obtained shows that the deformation value is very small in millimeters and it is in the safe range of working of the chair. The kinematic synthesis and analysis have been used to define a geometry and set of motions for a particular design task. The kinetostatic solution is used to determine the forces acting on the joints and torque required by the system to drive power to the input link.

The design model is a combination of four linkages mechanism with one fixed link and three moving links. The bar has three moving links that resulted in nine equations with nine unknowns. The unknowns consist of eight reactions (x-y component) at all the four joints and the mobility torque at the input link. All dimensions of link lengths, link positions, locations of the links, CGs, linear accelerations of those CGs, and link angular accelerations and velocities have been previously determined from a kinematic analysis. The forces acting at all the pin joints of the linkages needs to be calculated for one or more position.

The external force Fp is acting at the point P that lies on the center of mass of link 4 at all the positions of the path trajectory as the function of input angle theta. This external force Fp resembles the human weight distribution during the STS transfer motion as the weight on the seat reduces with increase in angle of inclination (input angle).

$$F_{12,x} + F_{32,x} = m_2\, a_{G2,x}$$

$$F_{12,y} + F_{32,y} = m_2\, a_{G2,y}$$

$$T_{12} + F_{12,x}(d_2 sin\theta_2) - F_{12,y}(d_2 cos\theta_2) + F_{32,y}(f_2 cos\theta_2) - F_{32,x}(f_2 sin\theta_2) = m_2 {k_2}^2 \alpha_2$$

$$F_{43,x} - F_{32,x} = m_3\, a_{G3,x}$$

$$F_{43,y} - F_{32,y} = m_3\, a_{G3,y}$$

$$F_{43,x}(d_3) + F_{32,x}(f_3) = m_3 {k_3}^2 \alpha_3$$

$$F_{14,x} - F_{43,x} = m_4\, a_{G4,x}$$

$$F_{14,y} - F_{43,y} = m_4\, a_{G4,y}$$

$$-F_{14,y}(f_4 cos\theta_4) + F_{14,x}(f_4 sin\theta_4) - F_{43,y}(d_4 cos\theta_4) + F_{43,x}(d_4 sin\theta_4) = m_4 {k_4}^2 \alpha_4$$

In our case

$$f_4 = d_4 = d_2 = f_2 = r \qquad \&$$

$$f_3 = d_3 = r_3 \qquad \&$$

$$\theta_4 = \theta_2 = \theta$$

The simplified equations are

$$F_{12,x} + F_{32,x} = m_2\ a_{G2,x}$$

$$F_{12,y} + F_{32,y} = m_2\ a_{G2,y}$$

$$T_{12} + F_{12,x}(rsin\theta_2) - F_{12,y}(rcos\theta_2) + F_{32,y}(rcos\theta_2) - F_{32,x}(rsin\theta_2) = m_2 {k_2}^2 \alpha_2$$

$$F_{43,x} - F_{32,x} = m_3\ a_{G3,x}$$

$$F_{43,y} - F_{32,y} = m_3\ a_{G3,y}$$

$$F_{43,x}(r_3) + F_{32,x}(r_3) = m_3 {k_3}^2 \alpha_3$$

$$F_{14,x} - F_{43,x} = m_4\ a_{G4,x}$$

$$F_{14,y} - F_{43,y} = m_4\ a_{G4,y}$$

$$-F_{14,y}(rcos\theta_4) + F_{14,x}(rsin\theta_4) - F_{43,y}(rcos\theta_4) + F_{43,x}(rsin\theta_4) = m_4 {k_4}^2 \alpha_4$$

In matrix form,

$$\begin{bmatrix} 1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ rsin\theta & -rcos\theta & rsin\theta & rcos\theta & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & -1 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & -1 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & r_3 & 0 & r_3 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & -1 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & -1 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & rsin\theta & -rcos\theta & rsin\theta & -rcos\theta & 0 \end{bmatrix} \begin{bmatrix} F_{12,x} \\ F_{12,y} \\ F_{32,x} \\ F_{32,y} \\ F_{43,x} \\ F_{43,y} \\ F_{14,x} \\ F_{14,y} \\ T_{12} \end{bmatrix} = \begin{bmatrix} m_2 a_{G2,x} \\ m_2 a_{G2,y} \\ m_2 {k_2}^2 \alpha_2 \\ m_3 a_{G3,x} \\ m_3 a_{G3,y} \\ m_3 {k_3}^2 \alpha_3 \\ m_4 a_{G4,x} \\ m_4 a_{G4,y} + F_p \\ m_4 {k_4}^2 \alpha_4 \end{bmatrix}$$

All the components of linear accelerations of CGs are obtained using the Kinematic analysis in CAD software and values are stored in the data set at time intervals with corresponding values. The data set is read in the MATLAB to solve the matrix for all the values stored in the data set.

Chapter 7 : Results

7.1 Reaction forces at joints

The x and y component of the reaction forces at the joints and required torque at the input link is calculated for various angles of theta input. This result depicted the decreasing pattern in y direction forces acting at the joints as the theta angle increases during the sit to stand transfer motion.

Theta Input	**F12,x**	**F12,y**	**F32,x**	**F32,y**	**F43,x**	**F43,y**	**F14,x**	**F14,y**	**T12**
0.00795895	-0.01231	49.99565	0.005321	-49.9956	-0.00532	-49.9956	-0.01231	49.99551	6.8192
2.40795896	-0.0123	48.65342	0.005317	-48.6537	-0.00532	-48.6542	-0.0123	48.67004	-4.92832
4.80795898	-0.01227	47.2355	0.005303	-47.2361	-0.0053	-47.237	-0.01227	47.42026	0.613624
7.20795899	-0.01221	46.00453	0.005279	-46.0054	-0.00528	-46.0067	-0.01221	45.98354	3.778645
9.607959	-0.01214	44.66033	0.005247	-44.6615	-0.00525	-44.6633	-0.01214	44.66005	-5.99004
12.007959	-0.01204	43.31913	0.005205	-43.3206	-0.00521	-43.3228	-0.01204	43.33357	5.010641
14.407959	-0.01192	41.95956	0.005154	-41.9613	-0.00515	-41.964	-0.01192	42.02547	-1.52986
16.807959	-0.01178	40.67272	0.005094	-40.6747	-0.00509	-40.6778	-0.01178	40.64465	-2.51755
19.2079591	-0.01163	39.32508	0.005025	-39.3274	-0.00503	-39.3309	-0.01163	39.32464	5.023651
21.6079591	-0.01145	37.98449	0.004947	-37.9871	-0.00495	-37.991	-0.01145	37.9976	-4.80508
24.0079591	-0.01125	36.63681	0.004861	-36.6396	-0.00486	-36.644	-0.01125	36.67767	2.154776
26.4079591	-0.01103	35.34545	0.004766	-35.3486	-0.00477	-35.3533	-0.01103	35.30143	1.405452
28.8079591	-0.01079	33.98996	0.004663	-33.9933	-0.00466	-33.9985	-0.01079	33.98933	-3.99238
31.2079591	-0.01053	32.64971	0.004551	-32.6533	-0.00455	-32.6588	-0.01053	32.66203	4.35749
33.6079591	-0.01025	31.30696	0.004432	-31.3108	-0.00443	-31.3167	-0.01025	31.33724	-2.48481
36.0079591	-0.00996	30.04213	0.004305	-30.0462	-0.0043	-30.0525	-0.00996	29.93456	-0.493
38.4079591	-0.00965	28.65504	0.00417	-28.6594	-0.00417	-28.666	-0.00965	28.65415	2.967867
40.8079591	-0.00932	27.31489	0.004028	-27.3195	-0.00403	-27.3264	-0.00932	27.32685	-3.72403
43.2079591	-0.00897	25.97483	0.003879	-25.9796	-0.00388	-25.9869	-0.00897	25.99947	2.532431
45.6079591	-0.00861	24.53485	0.003723	-24.5398	-0.00372	-24.5475	-0.00861	24.77204	-0.1827
48.0079591	-0.00824	23.3204	0.00356	-23.3256	-0.00356	-23.3335	-0.00824	23.31912	-2.01757
50.4079591	-0.00785	21.9801	0.003391	-21.9855	-0.00339	-21.9937	-0.00785	21.99208	2.96818
52.8079591	-0.00744	20.64178	0.003217	-20.6473	-0.00322	-20.6558	-0.00744	20.6631	-2.32507
55.2079591	-0.00702	19.29009	0.003036	-19.2958	-0.00304	-19.3046	-0.00702	19.34752	0.599493
57.6079591	-0.0066	17.98615	0.002851	-17.9921	-0.00285	-18.001	-0.0066	17.98421	1.20163
60.0079591	-0.00615	16.6454	0.00266	-16.6514	-0.00266	-16.6607	-0.00615	16.65777	-2.15739

Table 7-1: Uniform Distribution

Theta Input	**F12,x**	**F12,y**	**F32,x**	**F32,y**	**F43,x**	**F43,y**	**F14,x**	**F14,y**	**T12**
0.00795895	-0.01231	24.99786	0.005321	-24.9979	-0.00532	-24.9979	-0.01231	24.99772	3.409609
2.40795896	-0.0123	24.32229	0.005317	-24.3226	-0.00532	-24.323	-0.0123	24.33892	-2.46332
4.80795898	-0.01227	23.57104	0.005303	-23.5716	-0.0053	-23.5725	-0.01227	23.75581	0.30561
7.20795899	-0.01221	23.00674	0.005279	-23.0076	-0.00528	-23.009	-0.01221	22.98575	1.890184
9.607959	-0.01214	22.32921	0.005247	-22.3304	-0.00525	-22.3321	-0.01214	22.32893	-2.99504
12.007959	-0.01204	21.65467	0.005205	-21.6561	-0.00521	-21.6583	-0.01204	21.66912	2.504485
14.407959	-0.01192	20.96177	0.005154	-20.9635	-0.00515	-20.9662	-0.01192	21.02768	-0.76373
16.807959	-0.01178	20.34159	0.005094	-20.3436	-0.00509	-20.3467	-0.01178	20.31353	-1.25964
19.2079591	-0.01163	19.66062	0.005025	-19.6629	-0.00503	-19.6664	-0.01163	19.66019	2.511854
21.6079591	-0.01145	18.9867	0.004947	-18.9893	-0.00495	-18.9932	-0.01145	18.99981	-2.40171
24.0079591	-0.01125	18.30568	0.004861	-18.3085	-0.00486	-18.3129	-0.01125	18.34654	1.076186
26.4079591	-0.01103	17.68099	0.004766	-17.6841	-0.00477	-17.6888	-0.01103	17.63697	0.7036
28.8079591	-0.01079	16.99217	0.004663	-16.9955	-0.00466	-17.0007	-0.01079	16.99154	-1.99623
31.2079591	-0.01053	16.31858	0.004551	-16.3222	-0.00455	-16.3277	-0.01053	16.3309	2.177923
33.6079591	-0.01025	15.6425	0.004432	-15.6464	-0.00443	-15.6523	-0.01025	15.67278	-1.2412
36.0079591	-0.00996	15.04434	0.004305	-15.0484	-0.0043	-15.0547	-0.00996	14.93677	-0.24738
38.4079591	-0.00965	14.32392	0.00417	-14.3283	-0.00417	-14.3349	-0.00965	14.32303	1.48398
40.8079591	-0.00932	13.65043	0.004028	-13.655	-0.00403	-13.662	-0.00932	13.66239	-1.8612
43.2079591	-0.00897	12.97704	0.003879	-12.9818	-0.00388	-12.9891	-0.00897	13.00168	1.265014
45.6079591	-0.00861	12.20373	0.003723	-12.2087	-0.00372	-12.2163	-0.00861	12.44092	-0.09046
48.0079591	-0.00824	11.65595	0.00356	-11.6611	-0.00356	-11.6691	-0.00824	11.65466	-1.00884
50.4079591	-0.00785	10.98231	0.003391	-10.9877	-0.00339	-10.9959	-0.00785	10.99429	1.483282
52.8079591	-0.00744	10.31065	0.003217	-10.3162	-0.00322	-10.3247	-0.00744	10.33198	-1.16134
55.2079591	-0.00702	9.62563	0.003036	-9.63137	-0.00304	-9.64011	-0.00702	9.683062	0.298853
57.6079591	-0.0066	8.988363	0.002851	-8.99426	-0.00285	-9.00325	-0.0066	8.986425	0.60088
60.0079591	-0.00615	8.314274	0.00266	-8.32033	-0.00266	-8.32954	-0.00615	8.326647	-1.07789

Table 7-2: Symmetrical Distribution on both sides

7.2 Stress & Deformation analysis

The 3D model of the assembly is placed in the static structural setting in the Ansys. The forces calculated at the joints in the dynamic force analysis at theta is equal to zero (sitting position) are applied at the joints. The maximum forces are acting during the sitting motion which are reducing from sit to stand transfer motion. So, the sitting point is critical position for calculating the total deformation and stress.

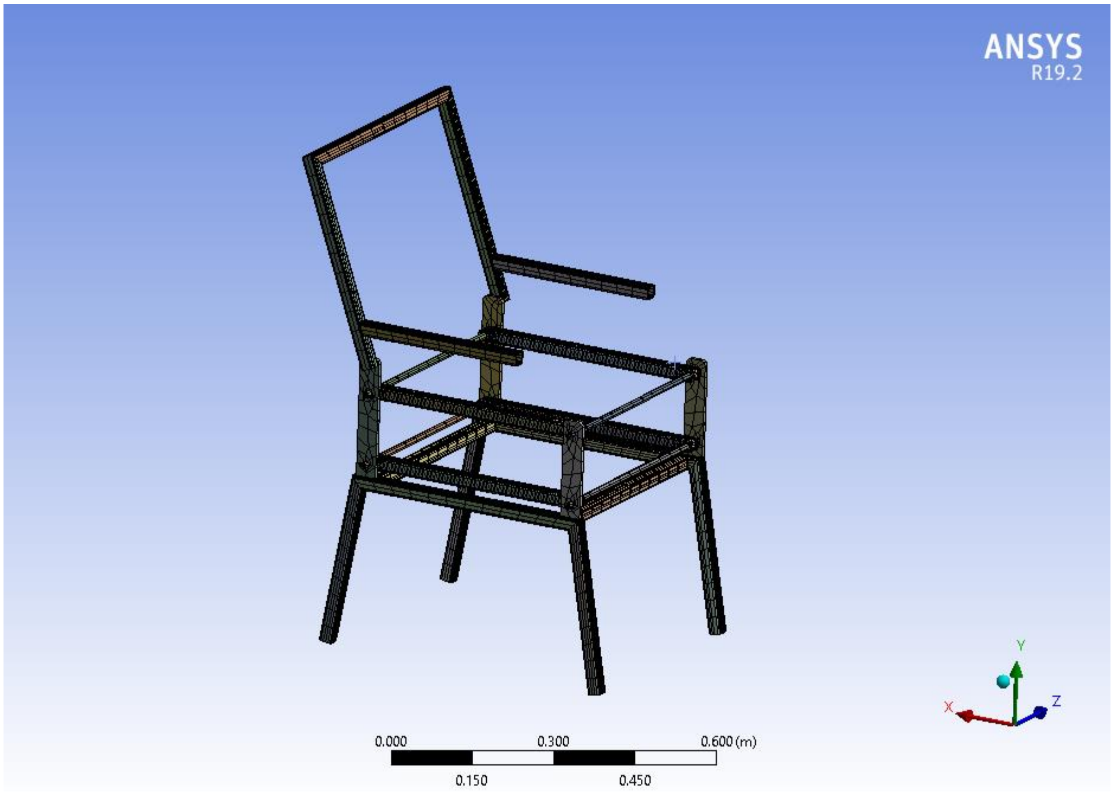


Figure 7-1: Ansys Mesh Model

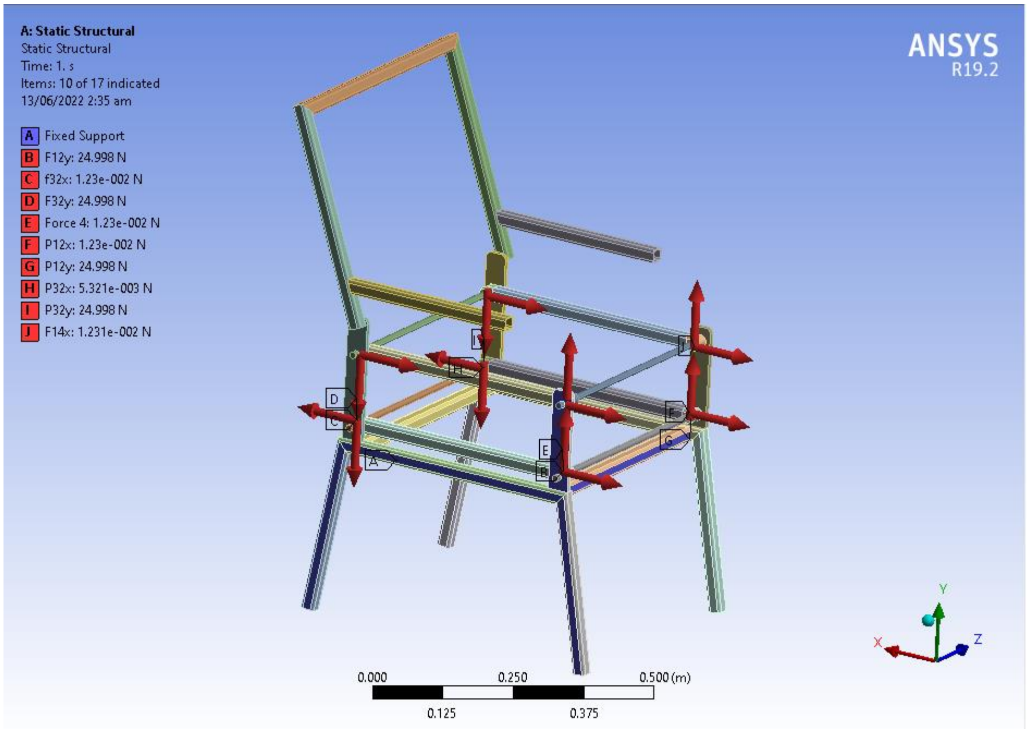


Figure 7-2: Joint Forces

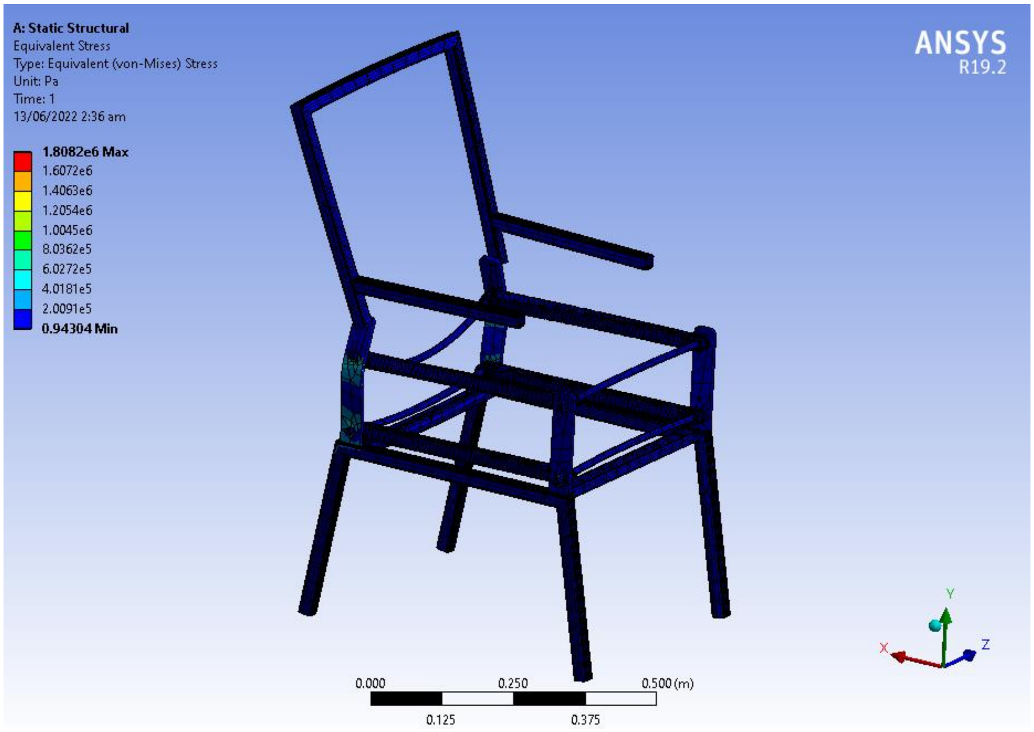


Figure 7-3: Von-Mises Stress

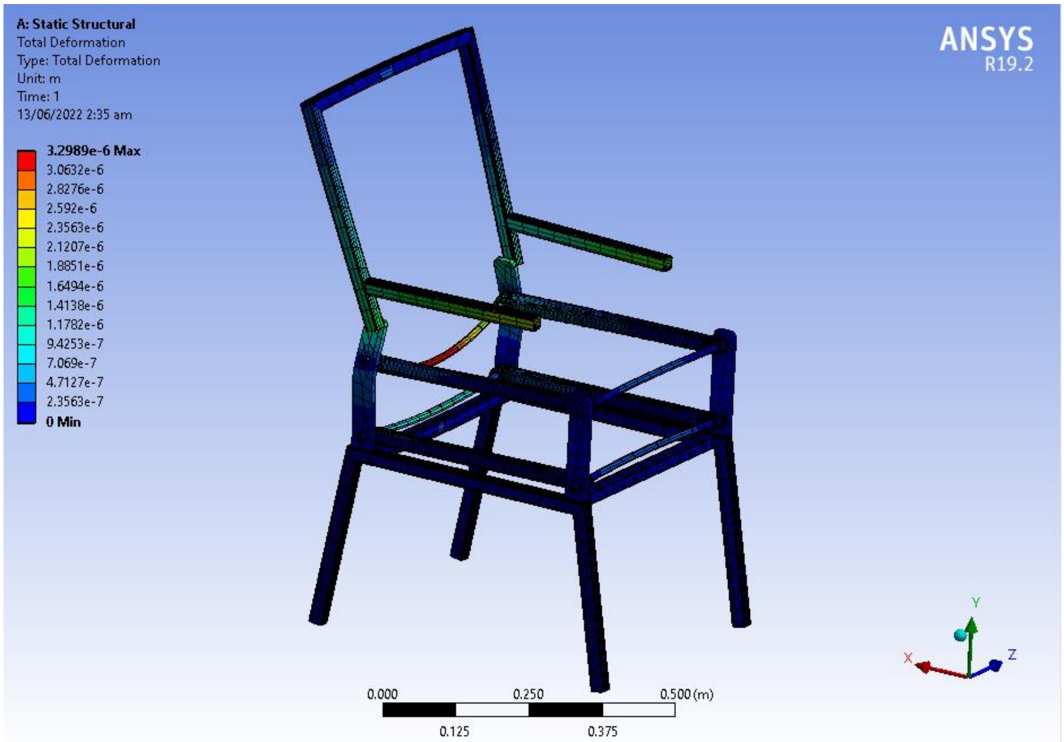


Figure 7-4: Total deformation in frame

The second analysis is performed by distributing the load of the person sitting on the chair using the surface selection of the links. The results obtained shows that the deformation value is very small in millimeters and it is in the safe range of working of the chair.

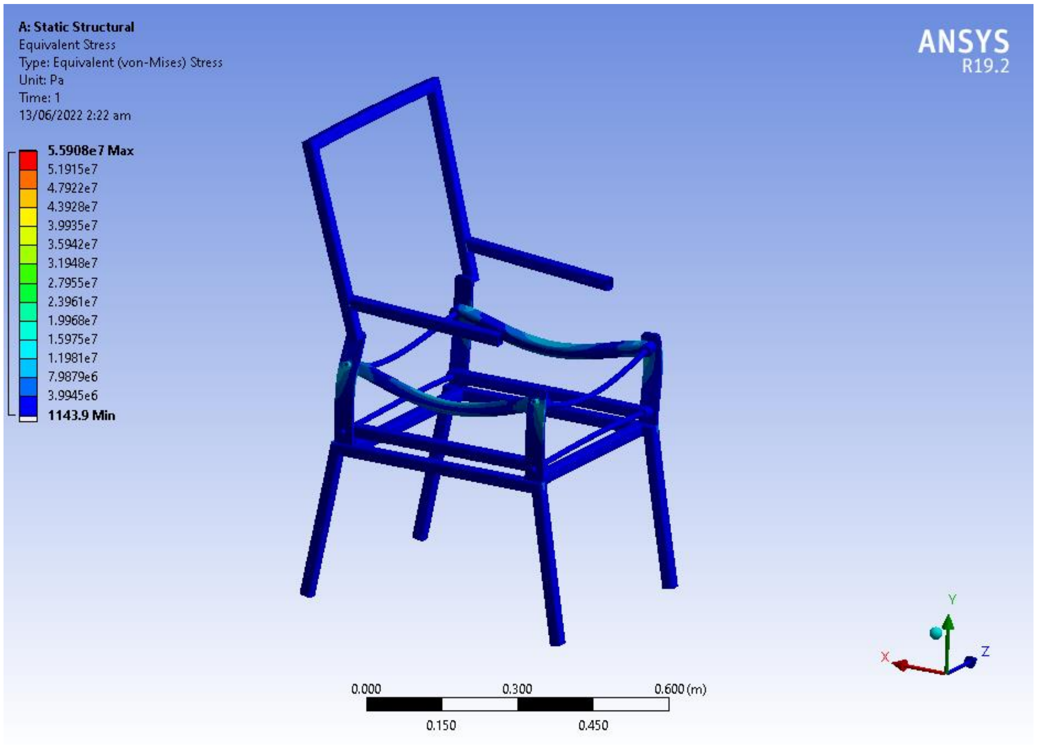


Figure 7-5: Von-mises stress on support

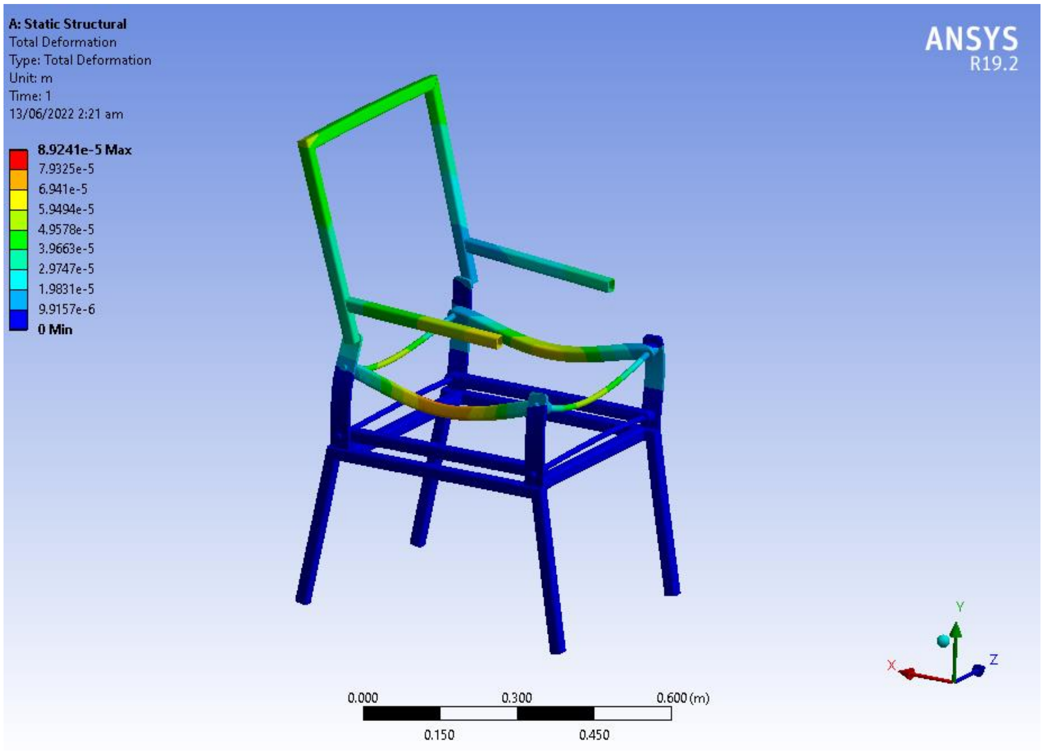


Figure 7-6: Total deformation of support

7.3. Factor of safety

Matters of uncertainty are ever present in engineering design and they are countered by design factor and factor of safety. The actual design factor was taken as 2 just to be on safer side as it is directly concerned with the health of senior citizens. The factor of safety differs a bit due to the standard sizes available in the market.

$$\eta_y = \frac{S}{\sigma}$$

The maximum allowable stress calculated with all the load applied comes out to be 55.9 MPa.

$$\eta_y = \frac{250}{55.9}$$

The factor of safety comes out to be 4.

References

1. D. Chugo, K. Kawabata, H. Kaetsu, H. Asama, N. Miyake, and K. Kosuge (2006). Force Assistance System for Standing-Up Motion

2. J. Jeyasurya, H. F. M. Van der Loos, A. Hodgson, and E. A. Croft (2013). Comparison of seat, waist, and arm sit-to-stand assistance modalities in elderly population

3. Y. Ikeuchi, J. Ashihara, Y. Hiki, H. Kudoh and T. Nodan (2009). Walking Assist Device with Bodyweight Support System

4. B. Chen, C.H. Zhong, H. Ma, X. Guan, L. Y. Qin, K. M. Chan, S. W. Law, L. Qin, and W. H. Liao (2017). Sit-to-stand and stand-to-sit assistance for paraplegic patients with CUHK-EXO exoskeleton

5. A. Fattah, S. K. Agrawal, G. Catlin, and J. Hamnett (2016). Design of a Passive Gravity-Balanced Assistive Device for Sit-to-Stand Tasks

6. Y. Chang, A. D. Singh, J. Girard, and Z. Wu (2010). Sit-to-Stand and Mobility Assistance Device

7. O. Bennett, S. R. Gabor, and S. Neeno (2016). Designing an Assistive Mobility Device for Geriatric Sit to Stand

8. Y. Hirata, J. Higuchi, T. Hatsukari and K. Kosuge (2008). Sit-to-Stand Assist System by Using Handrail and Electric Bed Moving Up and Down

9. S. W. Kim, J. Song, S. Suh, W. Lee, and S. Kang (2018). Design and Experiment of a Passive Sit-to-Stand and Walking (STSW) Assistance Device for the elderly

10. B. Zhoua, Q. Xue, S. Yanga, H. Zhanga, and T. Wang (2021). Design and control of a sit-to-stand assistive device based on analysis of kinematics and dynamics

11. A. Ahrary, W. S. Yangb, M. Inadac, and K. Nakamatsud (2018). Development of the Lift Assist Chair for the Elderly People "Rakutateru"

12. A. Tsukahara, R. Kawanishi, Y. Hasegawa, and Y. Sankai (2009). Sit-to-Stand and Stand-to-Sit Transfer Support for Complete Paraplegic Patients with Robot Suit HAL

13. TSUJIUCHI, N., ITO, A., & HISAMOTO, Y. (2018). Compaction of Feature for Finger Motion Discrimination of Myoelectric Hand Using Principal Component Analysis. *The Proceedings Of JSME Annual Conference On Robotics And Mechatronics (Robomec)*, *2018*(0), 2P1-D03. doi: 10.1299/jsmermd.2018.2p1-d03

14. Nüesch, C., Kreppke, J., Mündermann, A., & Donath, L. (2018). Effects of a Dynamic Chair on Chair Seat Motion and Trunk Muscle Activity during Office Tasks and Task Transitions. *International Journal Of Environmental Research And Public Health*, *15*(12), 2723. doi: 10.3390/ijerph15122723

15. Pickard, J., Carretero, J., & Merlet, J. (2020). Appropriate synthesis of the four-bar linkage. *Mechanism And Machine Theory*, *153*, 103965. doi: 10.1016/j.mechmachtheory.2020.103965

16. Aharari, A., & Yang, W. (2020). Development of a sit-to-stand assistance chair for elderly people. *International Journal Of Reasoning-Based Intelligent Systems*, *12*(2), 149. doi: 10.1504/ijris.2020.106808

17. Zhang, X., Zhang, Q., Li, Y., Liu, C., & Qiu, Y. (2021). Effect of the thickness of polyurethane foams at the seat pan and the backrest on fore-and-aft in-line and vertical cross-axis seat

transmissibility when sitting with various contact conditions of backrest during fore-and-aft vibration. *Applied Ergonomics*, *93*, 103354. doi: 10.1016/j.apergo.2021.103354

18. Allsteel. (2018). Ergonomics and Design A Reference Guide [Ebook] (p. 66). Retrieved from https://ehs.oregonstate.edu/sites/ehs.oregonstate.edu/files/pdf/ergo/ergonomicsanddesignreferenceguidewhitepaper.pdf

19. Ergo.human.cornell.edu. 2022. *Ergonomics of sitting*. [online] Available at: <https://ergo.human.cornell.edu/DEA3250Flipbook/DEA3250notes/sitting.html> [Accessed 9 June 2022].

20. Allsteeloffice.com. 2022. *Chair Ergonomics and Seating*. [online] Available at: <https://www.allsteeloffice.com/insights/wellness-ergonomics/ergonomics> [Accessed 10 June 2022].

21. Popovic, S. (2019). Nationwide Stature Estimation from Sitting Height Measurements in Kosovan Adolescents. *International Journal Of Morphology*, *37*(2), 504-508. https://doi.org/10.4067/s0717-95022019000200504

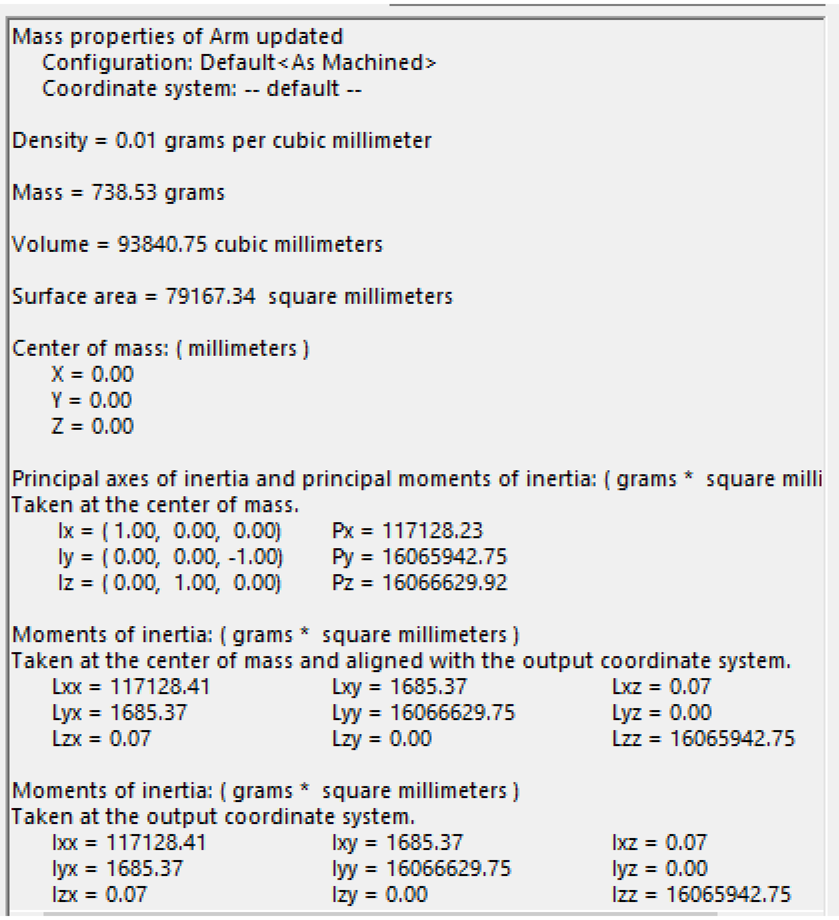
22. Rilling, J., Kaufman, T., Smith, E., Patel, R., & Worthman, C. (2009). Abdominal depth and waist circumference as influential determinants of human female attractiveness. *Evolution And Human Behavior*, *30*(1), 21-31. https://doi.org/10.1016/j.evolhumbehav.2008.08.007

23. Miller, A., MacDougall, J., Tarnopolsky, M., & Sale, D. (1993). Gender differences in strength and muscle fiber characteristics. *European Journal Of Applied Physiology And Occupational Physiology*, *66*(3), 254-262. https://doi.org/10.1007/bf00235103

24. Colón, C., Molina-Vicenty, I., Frontera-Rodríguez, M., García-Ferré, A., Rivera, B., Cintrón-Vélez, G., & Frontera-Rodríguez, S. (2018). Muscle and Bone Mass Loss in the Elderly Population: Advances in diagnosis and treatment. *Journal Of Biomedicine*, *3*, 40-49. https://doi.org/10.7150/jbm.23390

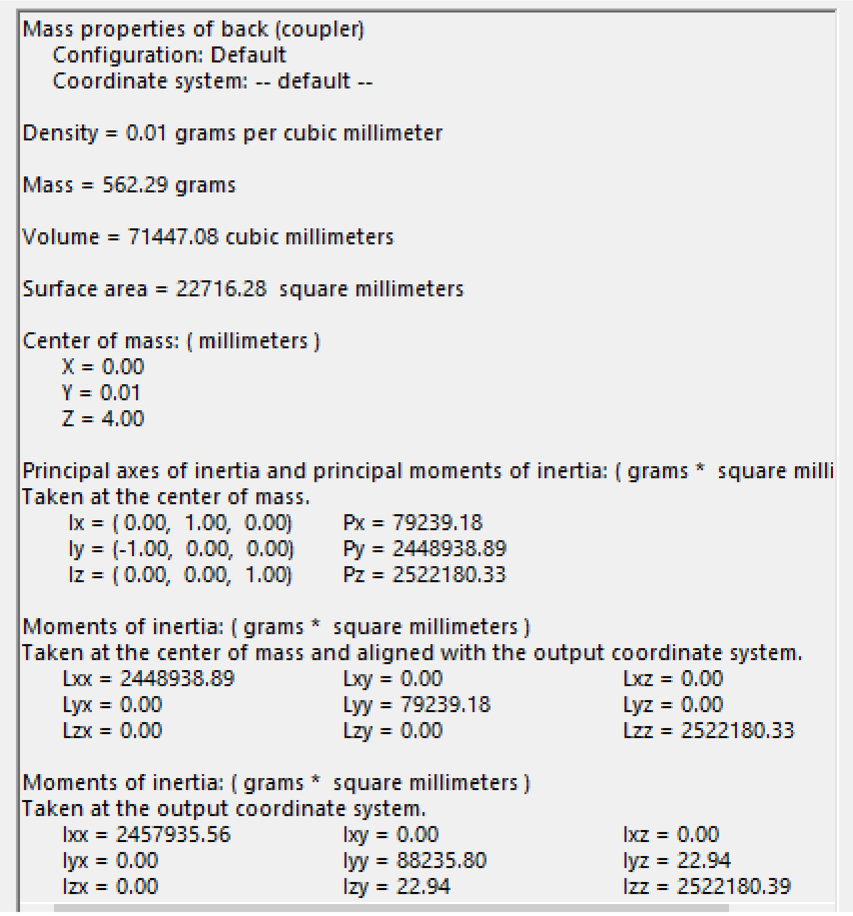
Appendix

Input Data for Matlab



```
Mass properties of Arm updated
    Configuration: Default<As Machined>
    Coordinate system: -- default --

Density = 0.01 grams per cubic millimeter

Mass = 738.53 grams

Volume = 93840.75 cubic millimeters

Surface area = 79167.34  square millimeters

Center of mass: ( millimeters )
     X = 0.00
     Y = 0.00
     Z = 0.00

Principal axes of inertia and principal moments of inertia: ( grams *  square milli
Taken at the center of mass.
      Ix = ( 1.00,  0.00,  0.00)       Px = 117128.23
      Iy = ( 0.00,  0.00, -1.00)       Py = 16065942.75
      Iz = ( 0.00,  1.00,  0.00)       Pz = 16066629.92

Moments of inertia: ( grams *  square millimeters )
Taken at the center of mass and aligned with the output coordinate system.
     Lxx = 117128.41                   Lxy = 1685.37                   Lxz = 0.07
     Lyx = 1685.37                     Lyy = 16066629.75               Lyz = 0.00
     Lzx = 0.07                        Lzy = 0.00                      Lzz = 16065942.75

Moments of inertia: ( grams *  square millimeters )
Taken at the output coordinate system.
     Ixx = 117128.41                   Ixy = 1685.37                   Ixz = 0.07
     Iyx = 1685.37                     Iyy = 16066629.75               Iyz = 0.00
     Izx = 0.07                        Izy = 0.00                      Izz = 16065942.75
```

Figure 01: Horizontal Links



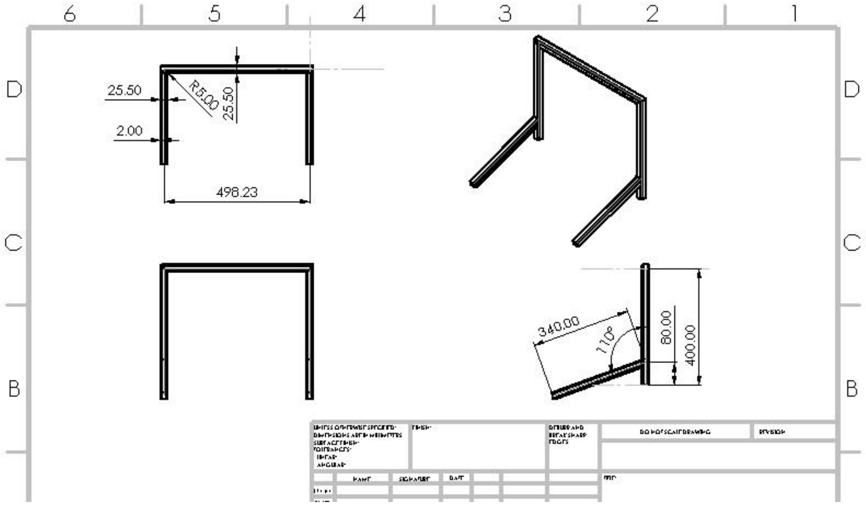
```
Mass properties of back (coupler)
    Configuration: Default
    Coordinate system: -- default --

Density = 0.01 grams per cubic millimeter

Mass = 562.29 grams

Volume = 71447.08 cubic millimeters

Surface area = 22716.28  square millimeters

Center of mass: ( millimeters )
     X = 0.00
     Y = 0.01
     Z = 4.00

Principal axes of inertia and principal moments of inertia: ( grams *  square milli
Taken at the center of mass.
      Ix = ( 0.00,  1.00,  0.00)      Px = 79239.18
      Iy = (-1.00,  0.00,  0.00)      Py = 2448938.89
      Iz = ( 0.00,  0.00,  1.00)      Pz = 2522180.33

Moments of inertia: ( grams *  square millimeters )
Taken at the center of mass and aligned with the output coordinate system.
     Lxx = 2448938.89              Lxy = 0.00                Lxz = 0.00
     Lyx = 0.00                    Lyy = 79239.18            Lyz = 0.00
     Lzx = 0.00                    Lzy = 0.00                Lzz = 2522180.33

Moments of inertia: ( grams *  square millimeters )
Taken at the output coordinate system.
     Ixx = 2457935.56              Ixy = 0.00                Ixz = 0.00
     Iyx = 0.00                    Iyy = 88235.80            Iyz = 22.94
     Izx = 0.00                    Izy = 22.94               Izz = 2522180.39
```

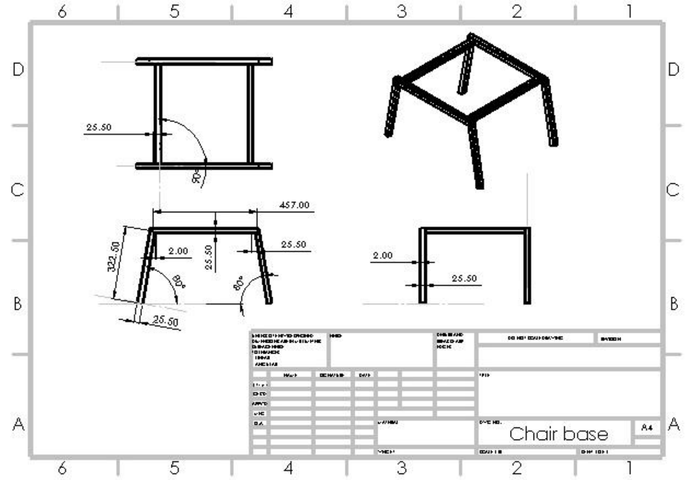
Figure 02: Middle Link

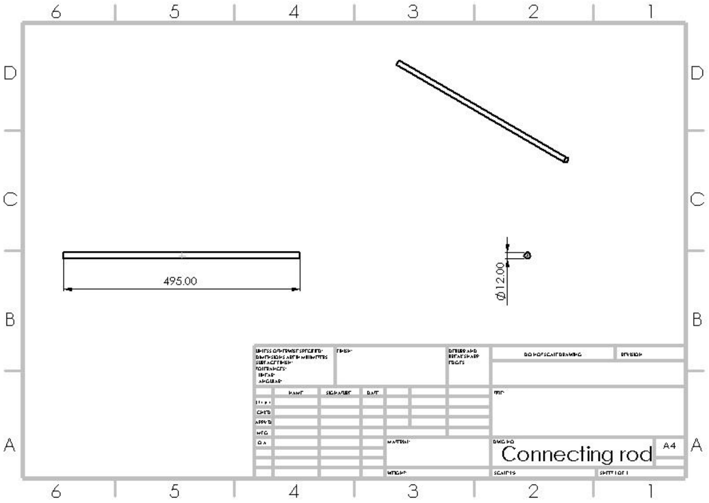
Matlab Code to Solve the Matrix:

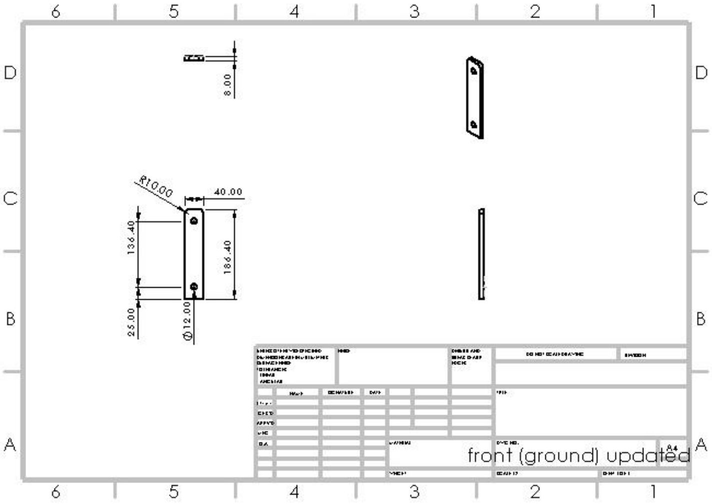
```
clc
clear
%DYNAMIC FORCE ANALYSIS OF FOUR-BAR MECHANISM
%TAKING INPUTS FROM THE USER FOR THE FOUR-BAR MECHANISM
Length_link1 = 0.1364; % lenght of the fixed link_1 (in meters)
Length_link2 = 0.4315; % length of Input link_2
Length_link3 = 0.1364; % length of coupler link_3
Length_link4 = 0.4315; % length of Output link_4
m2 =0.73853; % mass of link 2 (in kilogram)
m3 =0.56229; % mass of link 3
m4 =0.73853; % mass of link 4
alpha2 = 0; %constant angular velocity to the input link
alpha3 = 0; %constant angular velocity (no change in angular displacement & so angular velocity)
alpha4 = 0; %constant angular velocity
%{
acc2x = input('enter the CG_2x acceleration of the link 2 : '); % x_component
acc2y = input('enter the CG_2y acceleration of the link 2 : ');
acc3x = input('enter the CG_3x acceleration of the link 3 : ');
acc3y = input('enter the CG_3y acceleration of the link 3 : ');
acc4x = input('enter the CG_4x acceleration of the link 4 : ');
acc4y = input('enter the CG_4y acceleration of the link 4 : ');
Fp = input('enter the external load acting on the link 4: ');
theta = input('enter the input angle(in degrees): ');
%}
solution = zeros(9,26);
T = xlsread('C:/Users/BAZIF SALEEM/Downloads/Motion Analysis/dataset');
theta = T(:,2); % reading the value of theta from dataset
acc2x = T(:,11); % reading the value of acc2x from dataset
acc2y = T(:,12); % reading the value of acc2y from dataset
acc3x = T(:,13); % reading the value of acc3x from dataset
acc3y = T(:,14); % reading the value of acc3y from dataset
acc4x = T(:,15); % reading the value of acc4x from dataset
acc4y = T(:,16); % reading the value of acc4y from dataset


r3= Length_link3/2; % taking the center of gravity of the link
r= Length_link1/2; %taking the center of gravity of the link
%Build the matrix and right


%righthand vector
% running the loop for all the values in datasetS
for i = 1:26
    Fp = ((900-10*theta(i,1))/9)/2 ;
Vectorright=[ m2* acc2x(i,1)*(10^-3)  ; % acceleration is obtained in milliseconds
    m2* acc2y(i,1)*(10^-3) ;
    I2* alpha2;
    m3* acc3x(i,1)*(10^-3)  ;
    m3* acc3y(i,1)*(10^-3)  ;
    I3* alpha3;
    m4* acc4x(i,1)*(10^-3)  ;
   (m4* acc4y(i,1)*(10^-3))+ Fp ;
    I4* alpha4;
   ];
Matrix= [1, 0, 1, 0, 0, 0, 0, 0, 0;
        0, 1, 0, 1, 0, 0, 0, 0, 0;
        r*sin(theta(i,1)), -r*cos(theta(i,1)), -r*sin(theta(i,1)), r*cos(theta(i,1)), 0, 0, 0, 0,  1;
        0, 0, -1, 0, 1, 0, 0, 0, 0;
```

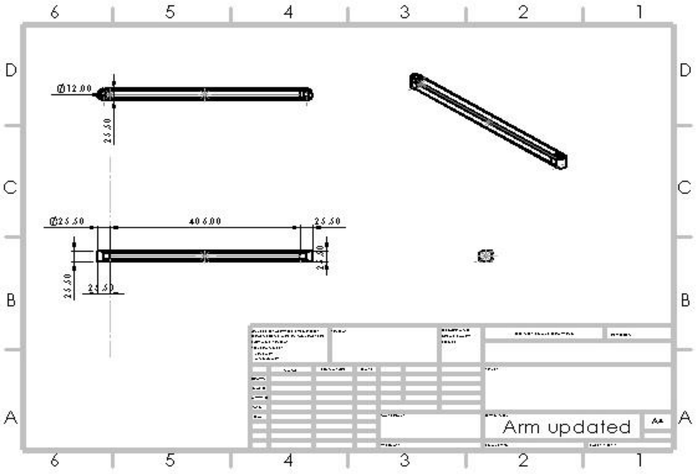
2D Drawings

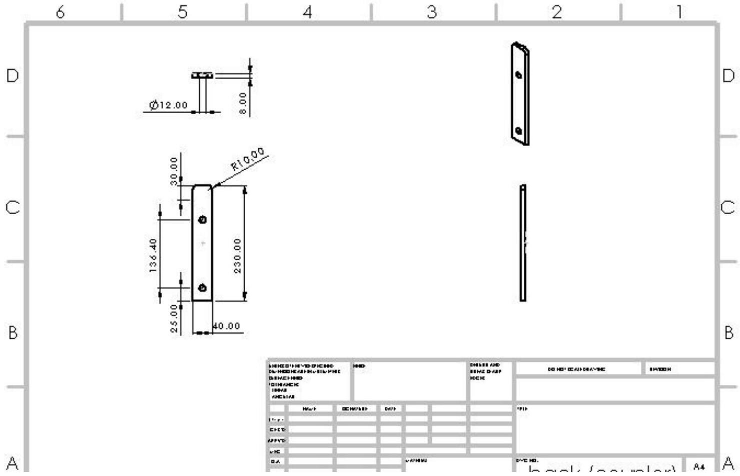

6
5
4
3
2
1
D
C
B
25.50
R5.00
25.50
2.00
498.23
340.00
110°
80.00
400.00


6
5
4
3
2
1
D
C
B
A
25.50
90°
457.00
322.50
2.00
25.50
80°
80°
25.50
25.50
2.00
25.50
Chair base
A4

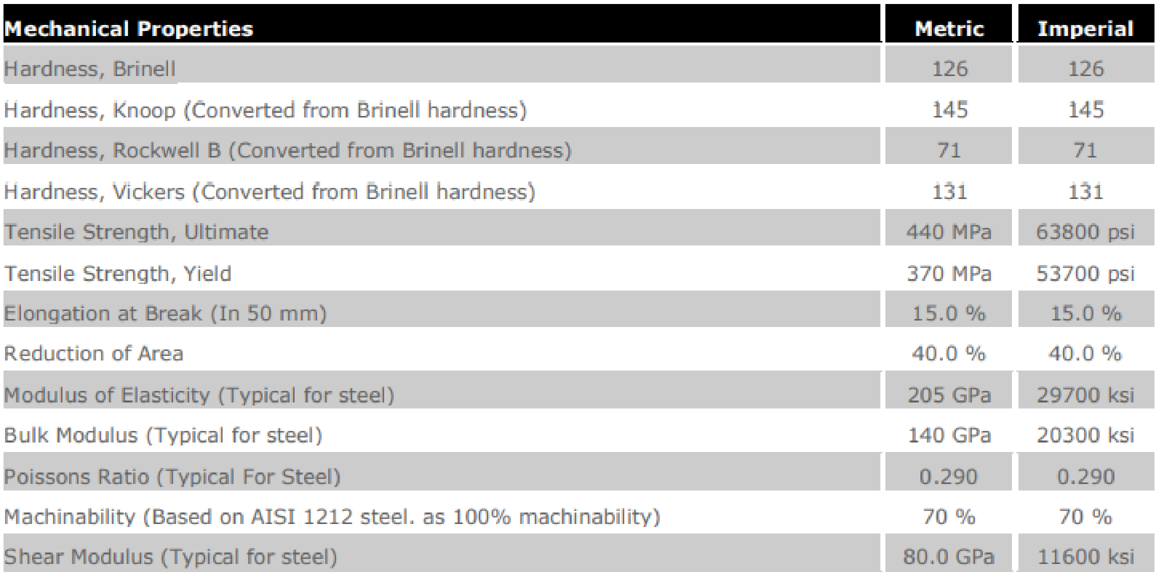

495.00
Ø12.00
Connecting rod
A4


8.00
R10.00
40.00
136.40
186.40
25.00
Ø12.00
front (ground) updated
A4


Ø12.00
25.50
Ø25.50
406.00
25.50
25.50
25.50
25.50
Arm updated
A4



Material Selection



Mechanical Properties	Metric	Imperial
Hardness, Brinell	126	126
Hardness, Knoop (Converted from Brinell hardness)	145	145
Hardness, Rockwell B (Converted from Brinell hardness)	71	71
Hardness, Vickers (Converted from Brinell hardness)	131	131
Tensile Strength, Ultimate	440 MPa	63800 psi
Tensile Strength, Yield	370 MPa	53700 psi
Elongation at Break (In 50 mm)	15.0 %	15.0 %
Reduction of Area	40.0 %	40.0 %
Modulus of Elasticity (Typical for steel)	205 GPa	29700 ksi
Bulk Modulus (Typical for steel)	140 GPa	20300 ksi
Poissons Ratio (Typical For Steel)	0.290	0.290
Machinability (Based on AISI 1212 steel. as 100% machinability)	70 %	70 %
Shear Modulus (Typical for steel)	80.0 GPa	11600 ksi