DESIGN AND SIMULATION OF A ROWING MACHINE

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AN INDIVIDUAL PROJECT REPORT SUBMITTED TO THE FACULTY OF ENGINEERING, TECHNOLOGY, APPLIED DESIGN, AND FINE ART, KABALE UNIVERSITY (KAB) IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF BACHELOR OF MECHANICAL ENGINEERING IN THE DEPARTMENT OF MECHANICAL ENGINEERING

APRIL, 2021

DECLARATION

I hereby declare to the best of my knowledge that this piece of work is my own and has never been submitted to any higher institution of learning for the award of a degree or any other academic qualification and thus describes my involvement as a student of Bachelor of Mechanical Engineering.

Signature:……..

DATE. 26/04/2022

17/AIBME/0533/G/F

APPROVAL

This is to certify that this work was carried out under strict supervision and has been approved for submission to the Department of Mechanical Engineering of Kabale University in partial fulfillment of the requirement of the award of a Bachelor of Mechanical Engineering.

SIGNATURE…………………………… DATE 25th/04/2022

MR. ISAAC NDA WULA
SUPERVISOR

ABSTRACT

Excessive and repeated sitting without enough body physical exercise can lead to heavy body complications. A lot of calories accumulate in the body when a person spends many hours seated as compared to exercising. The main objective of this project is to design a Rowing Machine to enable people to fully exercise their bodies to reduce their sitting time for better health and this will be achieved through conceptualizing the design, modeling, and simulation of the virtual prototype of the Rowing Machine.

The methods to be used involve developing a 3D model of the *rowing* machine using SOLID WORKS software, carrying out Finite Element Analysis. by ANSYS 2021 R2 software, and then motion analysis by MSC ADAMS/VIEW.

The simulation results indicated that the proposed system/machine is safe under different loadings and the proposed machine will operate with good performance.

ACKNOWLEDGEMENT

I wish to express heartfelt gratitude to several people for their steadfast support, guidance, and assistance. My first word of gratitude goes to the Almighty God; the creator of this universe for granting me divine favor, strength, knowledge, wisdom, understanding, and direction during the entire duration of my Bachelor's program.

I extend my appreciation to Kabale **university more so the teaching and non-teaching staff for the faculty of engineering but mainly the lecturers** at the mechanical engineering departments who have taught us engineering concepts and design procedures, thanks for guidance and concern towards my training plus my fellow trainees with whom we have shared a lot of ideas and knowledge regarding mechanical engineering field

I extend my special thanks to my supervisor **Mr. Isaac Ndawula** who never got tired to correct and guide me throughout this project work. His invaluable and unwavering support, advice, and guidance made this research work a success.

I would like to express my sincerest gratitude to my family, friends, and loved ones, my mother Mrs. Sarah Birungi, my great grandmother Mrs. Alice Babiyre, my beloved uncle Mr. Steven Busingye and Mr. Denis Kabonge as well as my aunt Mrs. Birungi Mary, who have contributed in one way or other as far as my academic are concerned in terms of finance, moral and emotional support and above all for their love and guidance

I would also like to acknowledge the Undergraduate Mechanical Class of (2017-2022) for the valuable support. Thank you, my colleagues, for the support you gave me, without you this work would never have been a success.

I wish I could acknowledge all the people who contributed to the success of this project. To the people whose names I could not mention specifically, I will always remain grateful to you for all your love and support.

DEDICATION

I dedicate this design project to all scientists who have championed to do projects and market ideas that promote health and fitness amongst people. In particular, I dedicate it to the researchers and designers who have prioritized designing rowing machines.

Furthermore, I would like to dedicate this industrial training report to my grandmother Mrs. Alice Babiyre, my beloved uncle Mr. Steven Busingye who have done all they can within their means to ensure my success in education, brothers, sisters, uncles, aunts, and all my relatives, friends, course mates, my university and company supervisor during the training and I thank u all of them for the financial, economic, spiritual, social, material, academic support granted to me until this level of my education and also during the training period.

To u all am grateful, may the almighty God reward you with blessing.

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	Cylinder outer diameter
	Internal pressure
	External pressure
	External radius
	Internal radius
	Hoop stress
	Longitudinal stress
	Maximum allowable stress
	Buckling load
d	Piston rod diameter
D	Piston diameter
L	Stroke length
p	Oil pressure
t	Cylinder wall thickness
E	Young's Modulus of Elasticity of piston rod material
I	Moment of inertia
K	Effective length factor
L	Piston rod length
l	Link length
0	Joint angle
T	Joint torque

ABBREVIATIONS

ADAMS	Automated Dynamic Analysis of Mechanical Systems
ANSYS	Analysis of Systems
DOF	Degree of freedom
FEA	Finite Element Analysis

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INTRODUCTION

1.1 Background

A 2016 Bureau of Labor Statistics survey involving workers across all civilian jobs revealed that most people employed in corporate jobs, including librarians, lawyers, accountants, and web designers spend more than 75% of their time sitting in their offices than either standing walking, causing serious health complications to them [1]. Many strategies have been developed at the workplace to reduce prolonged sitting, for example, standing up and stretching every hour, walking while you talk. There are very many health risks due to oversitting such as heart diseases, type 2 diabetes, and obesity. Effective and high body exercise are major contributors to overcoming these diseases [2].

A rowing exercise on a rowing machine is an effective way of fully exercising the body to stay in good health. A rowing machine is a machine with a few dynamic basic components that enable it to mimic the biomechanics of watercraft rowing. It enables a full-body workout with expansion and contraction of the Musculoskeletal system of the body in every rowing stroke, exercising the shoulders, arms, lower back, biceps, abdomen, thighs, buttocks, and legs, in four stages namely; catch, drive, finish and return phases [3]. It burns calories at a very fast rate to stay in a good health and the rate of burning calories depends on the speed and the resistance during rowing. The mechanism of the rowing machine will be discussed in detail in the section on modeling.

Rowing machines have also been developed to improve the physical condition of many people including those with paralyzed body systems[4][5]. The main factors affecting the effectiveness of rowing are the speed of rowing exercise and the kind of resistance used in the machine[6][7]. The most commonly used rowing machines use aerodynamic resistance while a few may be of either hydrodynamic, magnetic, or a combination of aerodynamic and magnetic resistances. Aerodynamic resistance rowing machine varies their resistance using the damper and their resistance also vary as the rowing speed increases. The resistance in the hydrodynamic rowing machine is offered by the viscosity of the used hydraulic. Magnetic resistance rowing machines obtain their resistance from the adjustable magnetic fields that occur between the metallic flywheel and the magnets.

In this project research, a rowing machine is proposed that will use a slider-crank mechanism. The mechanism will be made of two slides and a hydraulic resistance cylinder.

1.2 Problem Statement

Excessive and repeated sitting without enough body physical exercise is a danger to the body as it exposes the body to health risks of cardiovascular diseases, obesity, and type 2 diabetes causing a very high mortality rate and morbidity in people. To improve on health and immortality rate, people have to continuously and fully exercise their bodies. There are various machines used for exercising namely; stationary bikes, treadmills, step mills, and leg press machines.

1.3 Objectives 1.3.1

Main Objective

To design a rowing machine.

1.3.2 Specific Objectives

(a) To conceptualize the design.

(b) To design the components for the rowing machine.

(c) To perform finite element analysis by ANSYS.

1.4 Project Report Outline

Chapter 2 introduces the stationary and mobile categories of Rowing Machines, slider-crank applications, and hydraulic cylinder applications.

Chapter 3 presents the conceptual design and describes the working principle of the proposed rowing Machine. Furthermore, it describes the kinematic analysis, dynamic analysis, and design of the hydraulic resistance cylinder.

Chapter 5 discusses the modeling and simulation results of the study.

Chapter 6 provides the conclusion of this project report and discusses possible future works.

LITERATURE REVIEW

2.1 Rowing Machines

Research for the development of rowing machines started way back in 1981 [8]. There are mainly two types of rowing machines presented in previous developments and studies, namely; stationary and mobile rowing machines. Each type is presented in detail as follows.

2.1.1 Stationary Rowing Machines

In [9] a rowing machine was developed that consists of two adjustable hydraulic devices as shown in Fig. 2.1. It uses magnetorheological technology to control the hydrodynamic resistance of the hydraulic devices during a stroke. The lever kinematics are similar to those of the boat oars that enable the rower to mimic the biomechanics of watercraft rowing. The resistance force of the magnetorheological fluid device is varied by controlling the viscosity of the fluid circulating using the magnetic field. The base of the rowing machine is so close to the ground making it ergonomically unsafe. This in the long run can cause injury and fatigue to the muscular-skeletal system. The sliding of the seat is also limited which reduces the length of the stroke during the rowing exercise.

Figure 2.1: Lever type rowing machine [9]

In [4][10] a rowing machine was developed depicted in Fig.2.2. The proposed rowing machine uses Functional Electrical Stimulation to assist victims with paralyzed lower body parts to fully exercise. Its seat is fixed with a backrest to provide extra support to the rower. The rowing machine consists of a flip-up armrest to prevent side falling and a switch on the handle to control the simulation timing. It has dimensions of 2492 x 303 mm with a seat height of approximately 300 mm and a weight of 80kg. The simulation on the lower part of the body is obtained from a twochannel electrically powered simulator. This rowing machine uses an aerodynamic resistance in which the resistance increases with the increase in the rowing speed and it will reduce when the rowing speed decreases causing a sponge feeling. This rowing machine provides single direction resistance during the drive phase contrary to the recovery phase which hinders its effectiveness. Most of the components of the machine are electronic consuming electricity.

Figure 2.2: Finite Electrical Simulation type rowing machine [4][10]

In [11] an aerodynamic resistance rowing machine that consists of an air damper that protects the flywheel inside it was developed as depicted in Fig. 2.3. The handle is attached to the flywheel by a rolled cable. The nature of the rowing cable does not enable it to provide resistance in both directions. The resistance to be overcome is only provided during the drive phase. The components of this rowing machine are also heavy approximately weighing 120 kg.

Figure 2.3: An Air rower [11]

2.1.2 Mobile Rowing Machines

In [12] a rowing machine was developed as shown in Fig 2.4 that consists of two rear wheels and a single front wheel exercising the body. It consists of a row cable attached to the handle that transfers the rowing mechanisms to the three wheels. It consists of a return mechanism that brings the sliding seat and T handle back to the start position. It has specifications 2184.4mm x 990.6mm x 863.6mm. The nature of the rowing cable does not enable it to provide resistance in both directions. The resistance to be overcome is only provided during the drive phase. A tilted seat for the upper parts of the body and raised footrest make it ergonomically disastrous.

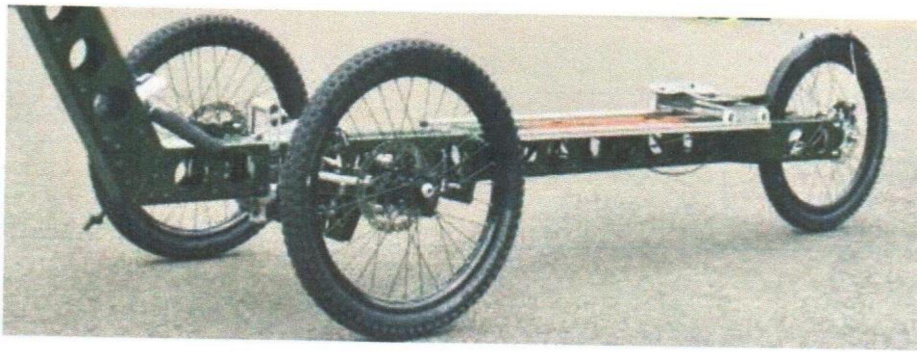

Figure 2.4: Row bike machine [12]

In [l3] a rowing machine was developed as shown in Fig.2.5 that consists of four wheels and four rowing positions attached to the frame. The machine is manually powered by four rowers positioned on sliding seats. The operation of the rowing machine mimics the biomechanics of watercraft rowing. It consists of various rowing linkages, crankshaft, connecting rod, and drive mechanism. The machine consists of basically the rowing mechanism and the steering mechanism. In the rowing mechanism, the sliding motion of the seat is converted to the rotary motion of the wheels by a crankshaft and connecting rods. The steering linkages provide direct control of the rowing machine. The translational motion of the seat is small limiting the length of the stroke for individual exercising. There is no maximum stretching of the muscles and also according to its design the machine is ergonomically unsafe because it is so low to the ground. It can cause muscleskeletal disorders.

8].

Figure 2.5: Rowing Human Powered car [13]

2.2 Slider Crank Mechanism Application

The slider-crank mechanism is a four-bar linkage configuration used to convert rotational motion to reciprocating motion. The crank rotational motion is converted into the slide translational motion and vice versa [14].

The slider-crank mechanism can be used to perform various tasks in many machines. One of the machines that use this mechanism is a multifunction robot based on a crank slider mechanism for energy harvesting. In this machine, the reciprocating and rotating subsystems are connected to the slider-crank mechanism [15].

A reciprocating cassava sieving machine [16] uses the crank slider mechanism in separating coarse particles, lumps, and unwanted materials from gains. On this machine, v belts from an electric moto transmit the rotational motion to the od and sieve tray.

The slider-crank mechanism is used in internal combustion engines of moto vehicles to convert the reciprocating motion of the piston to a rotary motion of the crank [17].

Servo press machines use a slider-crank mechanism during metal forming processes. In the conventional mechanical presses, the rotary motion of the moto is transmitted to the clutch brake via the flywheel. A set of gears is then connected to the clutch brake that transmits the motion to a crank slider mechanism. In a servo press, the rotary motion of a servo moto is transmitted to a crank slider mechanism via a set of gears[l 8].

2.3 Hydraulic Cylinder Application

Hydraulic cylinders can be used to perform various tasks in many machines. Hydraulic cylinders are mechanical devices that convert fluid power to mechanical power by Pascal's principle[19]. The brick molding machine uses a hydraulic cylinder to provide an adjustable position for the brick mold. High-pressure hydraulic fluid is transmitted throughout the machine to hydraulic motors and cylinders [20].

Hydraulic cylinders are used in a shield tunneling machine to push the shield forward during tunneling. The shield thrust system needs a large force that can be transmitted by the hydraulic cylinder system[21].

Hydraulic cylinders ae used in a manually operated hydraulic press and pull machine to transmit very large nominal forces. This machine is used in the defamation of materials such as in metal forming processes and strength material testing[22]. Hydraulic cylinder systems are used in hydraulic excavators to transmit large forces[23].

A hydraulic cylinder is used in a sheet metal bending machine to bend plates. The hydraulic cylinder converts fluid power to mechanical power needed to bend the plates[l9].

CONCEPTUAL DESIGN

3.1 System Description

The proposed conceptual design of the rowing machine is implemented using Solid Works software as shown in Fig 3.1. The system consists of mainly two parts; the moving platform and the slider-crank mechanism fixed to the grounded frame.

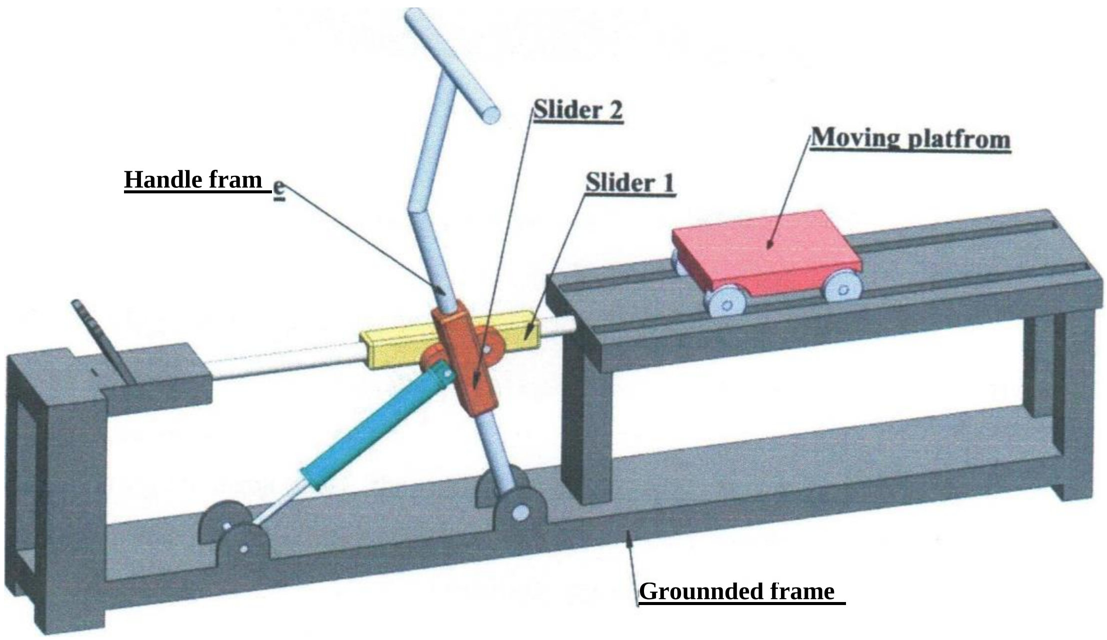

Figure 3.1: The proposed rowing machine

The moving platform is a 2 DOF translational seat with wheels so that it can move along the guides of the proposed machine.

The second part of the proposed rowing machine consists of a 2 DOF crank slider mechanism as shown in Fig 3.2. The crank slider mechanism converts rotational motion to translational motion. The mechanism consists of the resistance cylinder, two sliders, and the handle frame. The bottom ends of the resistance cylinder and the handle frame are fixed to the grounded frame by revolute joints. The first slider 1 oscillates along a rod fixed into the grounded frame in a position parallel to the base. The second slider 2 is connected to both the resistance cylinder and the slider l by revolute joints in an offset position from the rod of slider 1 and it oscillates along with the handle frame.

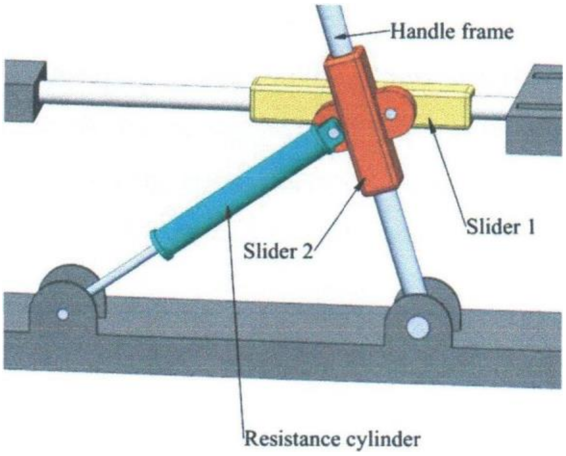

Figure 3.2: Slider crank mechanism

3.1 Working Principle

Exercising on the proposed· rowing machine involves four stages namely, the catch, drive, finish, and recovery phases in every stroke.

Basically, during the catch phase, the rower is prepared with the legs placed on the footrest and the hand on the handle at the initial positions Ho and Mo of the handle frame and moving platform respectively as depicted in Fig 3.3. With the drive phase, the rower applies the force to overcome the resistance as he slides backward away from the footrest, first with the legs, hips, and back and finally with the arms enabling body stretch of the legs, hips, and back and the arms towards the finishing phase.

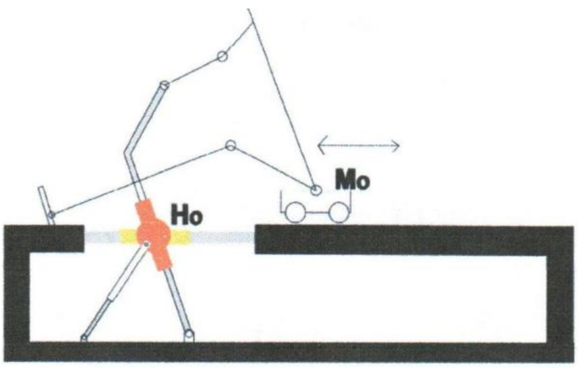

Figure 3.3: Rowing catch phase

The finish phase is the end of the stroke and it is during this phase that the body experiences maximum and full stretch of the muscles and tendons at positions HI and Mo of the handle frame and moving platform respectively. It is during the recovery phase rower moves towards the footrest as the handle frame and the moving platforms return to their original positions Ho and Mo respectively. This cyclic process is repeated over and over again until a time or distance is completed.

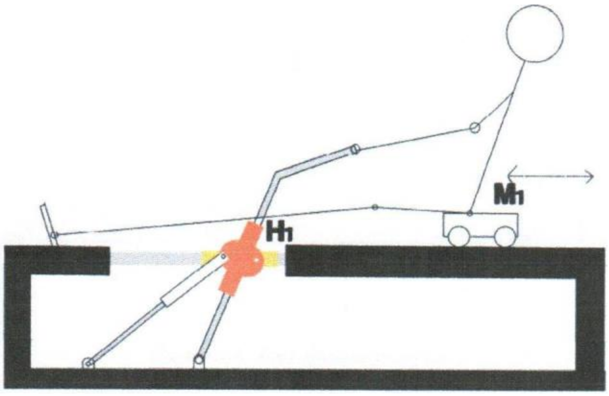

Figure 3.4: Rowingjinishphase

3.2 Kinematic Analysis

The main component of the proposed rowing machine to be kinematically analyzed is the 2DOF slider-crank mechanism that consists of four links, three revolute joints (A, B, and C), and two prismatic joints (P and T) as shown in Fig 4.1. Links l_2 and l are attached to the slider S2 (end effector). Link 1 makes a joint angle 0, and link 2 makes a joint angle 0, with the base link *l*.

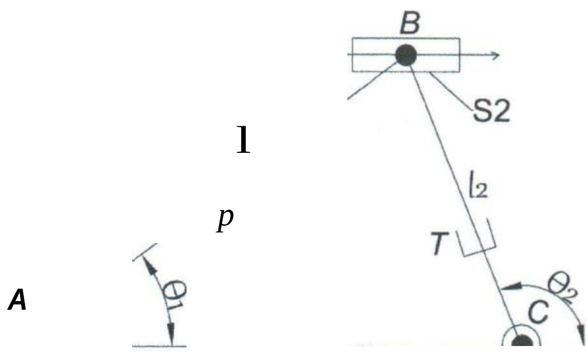

Figure 3.5: Closed loop slider crank mechanism chain

3.2.1 Forward Kinematics

The forward kinematics of the slider-crank mechanism is to obtain the end effector positions l $a,y)$ and 2 (O,y) at the finish and catchphrases of the rowing exercise respectively.

The end effector position 1 (a,y) for revolute joint, A via link L, is given as follows.

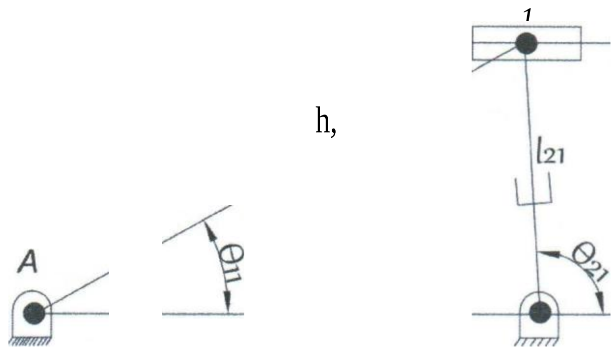

Figure 3.6: End effector position I

$$4= \text{lcos}0,, \; ya=$$

$$\text{l,sin}0,4$$

The end effector position 1 $a,y)$ with respect to revolute joint, A via link **l** is given as follows. x_{12} =

$$l + l_{21} \cos 0_{21}$$

$$Y12 = l_{21} \sin 0_{21}$$

The end effector position 2 $a,y)$ with respect to revolute joint, A via link I is given as follows.

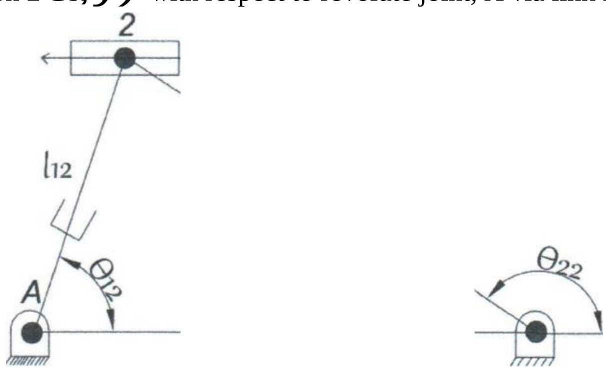

Figure 3. 7: End effector position 2

$$+= \text{lcos}0$$

$Y12 = l_{12} \sin 0_{12}$

The end effector position 2 O,y) to the revolute joint, A via link 2 is given as follows.

$22 - l + l22 \cos 022$

$Y22 = l22 \sin0,,$

3.2.2 Inverse Kinematics

The inverse kinematics of the slider-crank mechanism is to obtain the joint angle variables 0_{11} and 0_{21} at end-effector position *1* and 0_{12} and 0_{22} at end-effector position 2 respectively. The joint variables can be obtained in terms of the end-effector position as follows.

At end-effector position 1 O,y) :

8a,2) = (a42,32) $l_{11} \cos 0,, = l + l21 \cos 021$ $[_{11} \sin 0_{11} = l_{21}$ sin6,, Squaring both sides of the equations and simplifying;

$lf_1 \cos^2 0_{11} = l,\ \cos° 0_{21} + 2ll_{21} \cos 0_{21} + l^2\ lf_1 \sin^2 0_{11} =$

$l?_1 \sin^2 0_{21}$

Adding equations;

$lf_1 \cos^2 0_{11} + lf_1 \sin^2 0_{11} = l?_1 \cos^2 0_{21} + l,\ \sin 0_{21} + 2ll_{21} \cos 0_{21} + l^2\ l, = l,$

$+2ll,, \cos O, +$

$2ll_{21} \cos0,, = lf_1 - l\sim_1 - l^2$

$\cos 0,, = \frac{Z\text{-}zi}{(lf_1 - l, - l^2)}$

$0_{21} = \arccos \quad Z\text{-}ll_{21}$

At end effector position 2; $0_{11} = \text{arcsm} \cdot \left(\frac{as\%}{111}\right)$

082,)) = (a2,2) $l_{12} \cos 0_{12}$

$= l + l_{22} \cos 0_{22}\ [_{12} \sin$

$O, = l_{22} \sin0,,$

Squaring both sides of the equations and simplifying;

$$lf_2 \cos^2 0_{12} = l\sim_2 \cos^2 0_{22} + 2ll_{22} \cos 0_{22} + l^2 \; \mathbf{l}, \; \sin 0,,$$

$$= l si \; 0,a$$

Adding equations;

$$lf_2 \cos^2 0_{12} + lf_2 \sin^2 0_{12} = l\sim_2 \cos^2 0_{22} + l \sin 0_{22} + 2ll_{22} \cos 0_{22} + l^2 \; lf_2 = l\sim_2 + 2ll_{22} \cos 0_{22} + l2$$

$$2ll_{22} \cos 0_{22} = 2lf_2 - 2l\sim_2 - l2$$

$$\cos 022 = \frac{lf2 - l\sim 2 - l2).}{2\,ll22}$$

(

$$0_{22} = \text{arcco.s} \quad Zll_{22}$$

$$0,= \text{arcsm} \quad .,(5 \; l_{12}$$

3.3 Dynamic Analysis

The dynamic analysis of the slider-crank mechanism of the rowing machine is to obtain the joint torques τ_1 and $\mathbf{t},$ of links l_1 and $\mathbf{l}$ respectively. The center of mass of each link is right at the middle of the links. The Lagrangian method is used to achieve dynamic equations of the slidercrank mechanism.

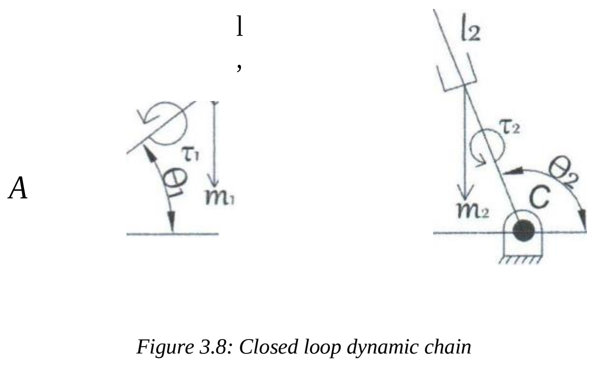

Figure 3.8: Closed loop dynamic chain

Joint torq_ue $\tau_i;$

$$\tau_i = \text{---}. \; -dt \; \frac{d\,dL}{d0,} \; \frac{dL}{d0,}$$

$$L(\theta,\dot\theta) = K(\theta,\dot\theta) - P(\theta)$$

Link l_1 analysis is as follows;

$$\begin{bmatrix} x_1 \\ y_1 \end{bmatrix} = \begin{bmatrix} l_1 \cos\theta_1 \\ l_1 \sin\theta_1 \end{bmatrix}$$

X1 ⌊- ⌊-l1 sin 01} 0

[

y. l,cos0, '

Kinetic energy K;

1, ==3mi 2

1

K1 = 2m1(xf + yf)

1 2 2

1=5ml401 2

Potential energy P;

$$P_1 = m_1 g \frac{l_1}{2} \sin\theta_1$$

Link l_2 analysis is as follows;

X2] = [l2 c~s 02]

[

~2]Y2 = ⌊-l2 sin 02⌋ 82

[

Y2 l2 cos 02

Kinetic energy K2;

=57772 1 2 1.

1

K2 = zm2Cx? + YD

1 2 2

+=7ml505

Potential energy P2;

l1 .

P =mg5sin0,

L(0,0) = K1 +K2 -Pi -P2

(·) 1 2 · 2 1 2 · 2 l1 . l1 .

L 0, 0 = K2 = 2m1l101 + 2m2l202 - m1g 2sm 01 - m2g2sm 02

Joint torque r 1;

$$\tau_1 = \frac{d}{dt}\frac{dL}{d\dot{0}_1} - \frac{dL}{d0_1}$$

$$\frac{dL}{d0_1} = -m_1 \frac{g}{2} \cos 0_1$$

$$\frac{dL}{d\dot{0}_1} = m_1 l \dot{0}_1^{2}$$

$$\frac{d}{dt}\frac{dL}{d\dot{0}_1} = m l \ddot{0}_1^{2}$$

$$\tau_1 = m l \ddot{6}_1^{2} + m_1 5 \frac{g}{} \cos 0_1$$

Joint torque τ_2;

$$\tau_2 = \frac{d}{dt}\frac{dL}{d\dot{0}_2} - \frac{dL}{d0_2}$$

$$\frac{dL}{d0_2} = -m_2 \frac{g}{2} \cos b0_2$$

$$\frac{dL}{d\dot{0}_2} = m_2 l b \dot{0}_2^{2}$$

$$\frac{d}{dt}\frac{dL}{d\dot{0}_2} = m l 5 \ddot{o}_2^{2}$$

$$\tau_2 = m l 5 \ddot{0}_2^{2} + m 5 \frac{g}{} \cos 0_2$$

3.4 Hydraulic Cylinder Resistance Design

3.4.1 Design of the piston rod

In the operation, the hydraulic cylinder is highly stressed by bending, compressive and tensile stresses. The piston rod most likely fails by buckling under compressive load than by bending. Therefore, the critical load;

$$P_{cr} = \frac{\pi^2 EI}{L^2 K^2}$$

3.4.2 Design of the piston

The main failure points are the edges and the kind of seals used at tolerance between the piston and cylinder walls.

F= P(A-- a) (D?- d)

A-a=----
4

$$D = \sqrt{\frac{4F}{\pi P} + d^2}$$

3.4.3 Design of the cylinder

The maximum working stress;

m- Tensile strength of the material *a* -
FOS

3.4.4 The outer diameter of the cylinder

Applying Jame's equation to obtain the outer diameter of the cylinder.

D?(o,+ P) b);; =
O,- P

3.4.5 Thickness of the cylinder

Thickness,

t=D- d

2

3.4.6 Bursting stress

This is the amount of hoop stress and longitudinal stress produced within the walls due to the external and internal pressures. This happens when the hoop's strength exceeds the tensile strength of the material.

Barlow formula to obtain,

Hoop stress

$$\sigma_H = P \frac{d_o^2 + d_i^2}{d_o^2 - d_i^2}$$

Longitudinal stress

$$\sigma_l = \frac{PR_i^2 - PR_o^2}{R_o^2 - R_i^2}$$

MODELLING AND SIMULATION

4.1 Rowing Machine Finite Element Analysis By ANSYS

ANSYS is a general-purpose finite element package software that deconstructs complex mechanical systems into very small pieces called elements. The steps for performing the finite element analysis of the proposed rowing machine are as follows.

4.1.1 Selecting the Analysis Type

The type of analysis carried out on the machine was selected as Static Structural Analysis to determine displacements, strains, and forces. in the proposed Rowing Machine.

4.1.2 Importing the 3D model

The 3D model of the rowing machine in IGS format is imported into Ansys 2021 R2 workbench in the design Modeler environment with 145 parts as shown in Fig 4.5.

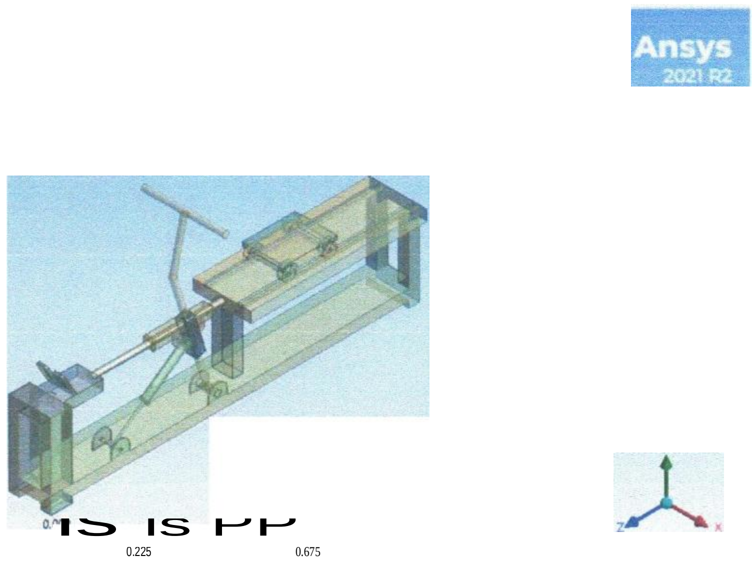

Figure 4.1: A virtual prototype of the rowing machine in Ansys 2021 R2 workbench

4.1.3 Selecting the Material

The material structural steel is selected and assigned to all parts of the rowing machine as illustrated in table 1.

Table 1: Material properties of the model in ANSYS

Material	Young's Modulus	Poisson's ratio	Density
Structural steel	200 GPa	0.3	*7850kg*/m

4.1.4 Generating a mesh for the model

Meshing for the virtual prototype is carried out as shown in Fig.4.6. A mesh size of 9mm is used to give a better-meshed structure with less computational time than those values greater or less than 9mm. The total number 77292 and 23919 nodes and elements created are and respectively.

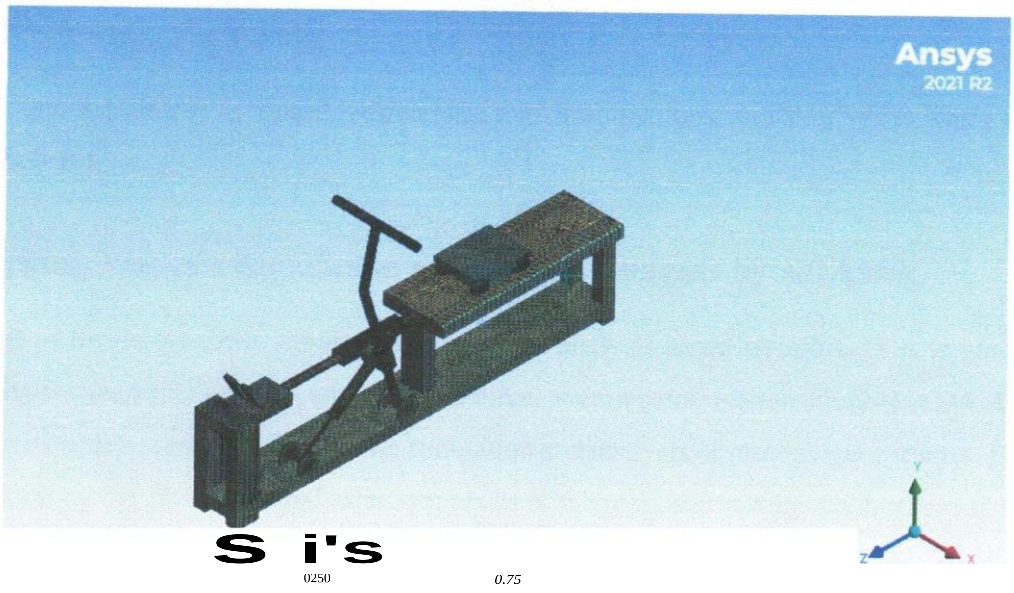

Figure 4.2: ANSYS meshing of the proposed rowing machine

4.1.5 Applying Boundary Conditions

The boundary and loading conditions under which the analysis is performed are set as follows; The grounded frame is fixed. A force of 376N is applied on the moving platform in the negative Y direction and a force of 11 OKN in the positive Z direction is applied on the handle as shown in Fig. 4.7

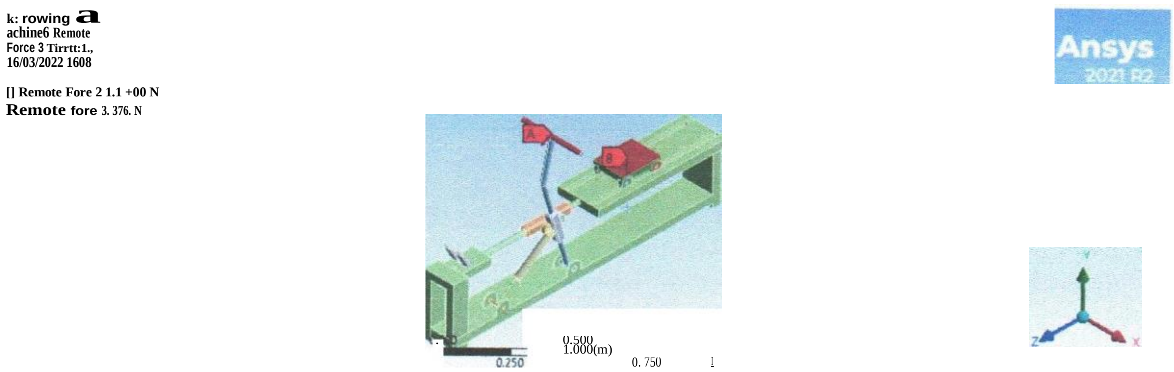

Figure 4.3: ANSYS boundary conditions

4.1.6 Evaluating the results

The deformations in the **X, Y,** and Z directions, total deformations, and Von Mises Stress analyses are carried out.

4.2 Rowing Machine Simulation and Motion Analysis by ADAMS

The goal of rowing machine simulation and motion analysis based on ADAMS is to analyze the machine displacement, velocity, acceleration, force, and moment relationship[24]. ADAMS is one of the most widely used software for the simulation and analysis of mechanical systems. The steps for performing the simulation and motion. analysis. of the proposed rowing machine are as follows.

4.2.1 Importing the 3D model

The 3D model of the rowing machine in PARASOLID format is imported into MSC AdamsNiew virtual environment directly as shown in Fig.4.8 and then the extra body parts created by Adams are removed.

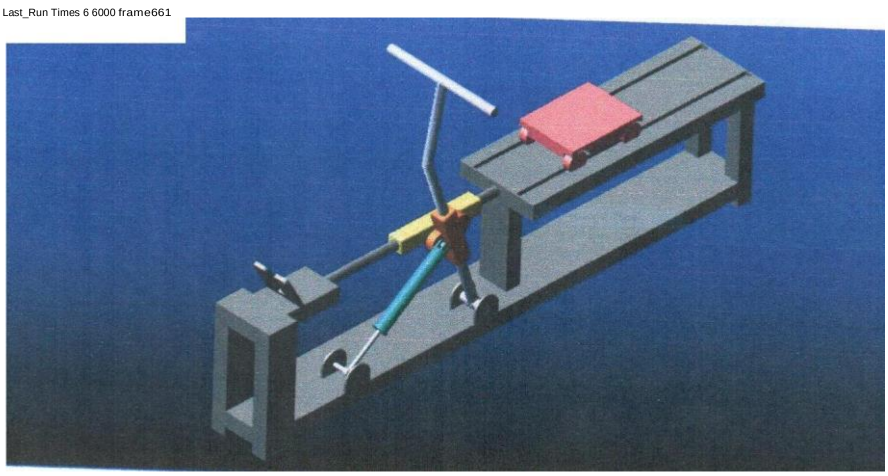

Figure 4.4: The JD model in the MSC Adams/View

4.2.2 Defining the Material

The material from which the rowing machine components are made is selected providing the mass and inertia properties of the machine parts as illustrated in table 2.

Table 2: Material properties of the model in MSC Adams/View

Material	Young's Modulus	Poisson's ratio	Density
Steel	200 GPa	0.29	$7850 kg/m^3$

4.2.3 Defining the joints

The kinematic elements of the slider-crank mechanism are joined to the fixed frame by two revolute joints and three prismatic joints to ensure rotation and translation of the hydraulic cylinder and the handle frame. The moving platform is joined to the fixed frame by two prismatic joints as shown in Fig.4.9.

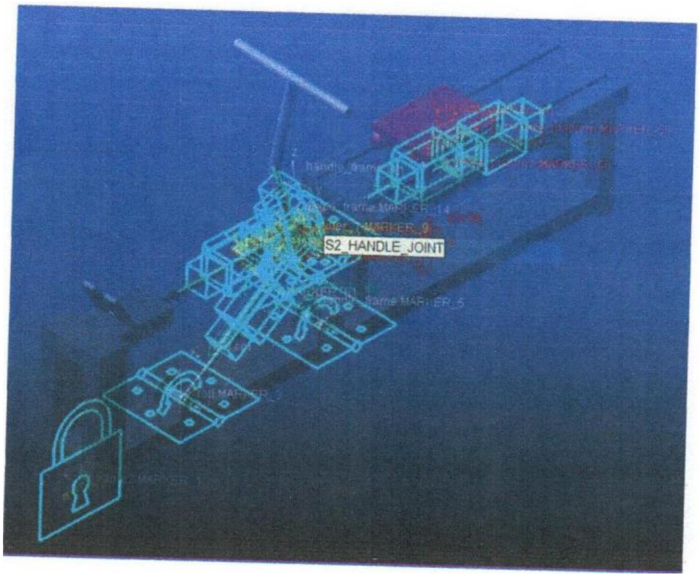

Figure 4.5: The defined joints of the Rowing Machine in MSC Adams/View

4.2.3 Defining the motion

Then translational joint motions are imposed on the ROD_ CL YINDER_JOINT and PLATFORM_FRAME_JOINT as shown in Fig.4.10.

The ADAMS equations of motion for the ROD_ CL YINDER_JOINT is,

$$step = \begin{cases} 0, & t = 0 \\ 5000d, & t = 1 \\ 0, & t = 2 \\ -5000d, & t = 3 \\ 0, & t = 4 \\ 5000d, & t = 5 \\ 0, & t = 6 \end{cases}$$

The ADAMS equations of motion for the PLATFORM_FRAME_JOINT is,

$$step = \begin{cases} 0, & t = 0 \\ 9000d, & t = 1 \\ 0, & t = 2 \\ -9000d, & t = 3 \\ 0, & t = 4 \\ 9000d, & t = 5 \\ 0, & t = 6 \end{cases}$$

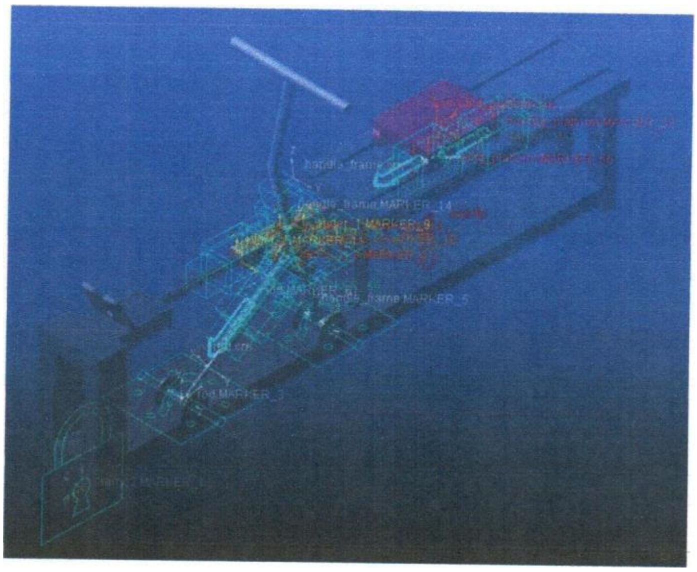

Figure 4.6: The defined motions of the Rowing Machine in MSC Adams/View

DISCUSSION AND RESULTS

The optimal dimension synthesis stage is carried out using a MEASURE tool of Solid Works and yields link dimensions are *l* = 370mm, *l* = 381mm, I = 217mm, l4 = 216mm, I = 295mm. Additionally, the joint angles oflinks l_1 andl_2 are obtained using inverse kinematics and yield the minimum and maximum joint angles of link L, as 60,, = 34°and 8, = 53° respectively. The minimum and maximum joint angles of the link 1 are b0,, = 144 and 0,, = 1040.

For safety operation, the diameter of the piston rod *d,* is 12 mm and that of the piston *D,* is 48mm. The maximum working stress of the cylinder crm is 143.3MPa. Using Lame's equation, the outer diameter of the cylinder D, is 56mm with a thickness t, of 4mm. Additionally using Barlow's formula, the Hoop and Longitudinal stresses are 137.3MPa and 57. 8MPa respectively. The 3D model of the proposed rowing machine is developed in Solid Works to be imported into ANSYS 2021 Rl software for static structural analysis. The 3D model is imported in MSC Adams/ View for motion analysis.

The FEA of the proposed rowing machine is carried out using ANSYS 2021 Rl and the results of maximum and minimum deformation are presented here. The meshing of the constrained virtual prototype of the proposed rowing machine is illustrated in Fig.4.6. The total deformation is depicted in Fig. 5.1, the maximum total deformation of 0.57606m occurs at the handle as illustrated in Fig.5.1.

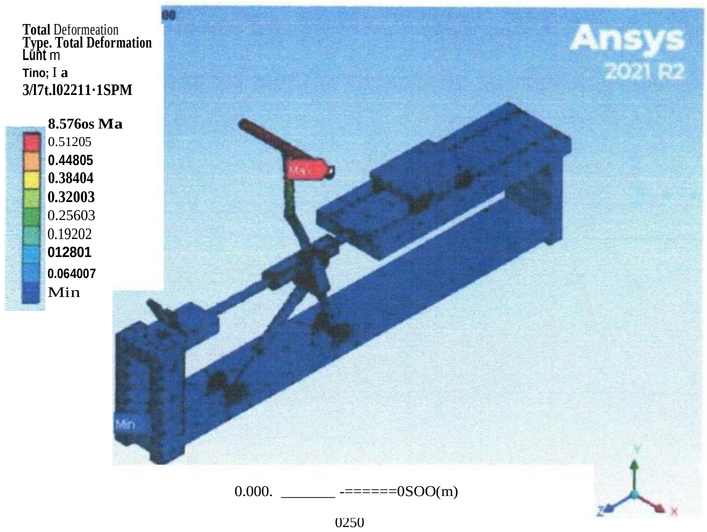

Figure 5.1: Maximum and minimum total deformation

Von Mises Stress checks for the safety ofthe proposed· Rowing Machine under worst-case roadTng conditions as shown in Fig.5.2. The maximum Von Mises Stress is 2.96961 Pa and it occurs in the middle of the handle frame. Since the maximum allowable stress of Steel materials considered for the Rowing Machine parts is 460MPa, then the factor of safety of the machine is 0.01549.

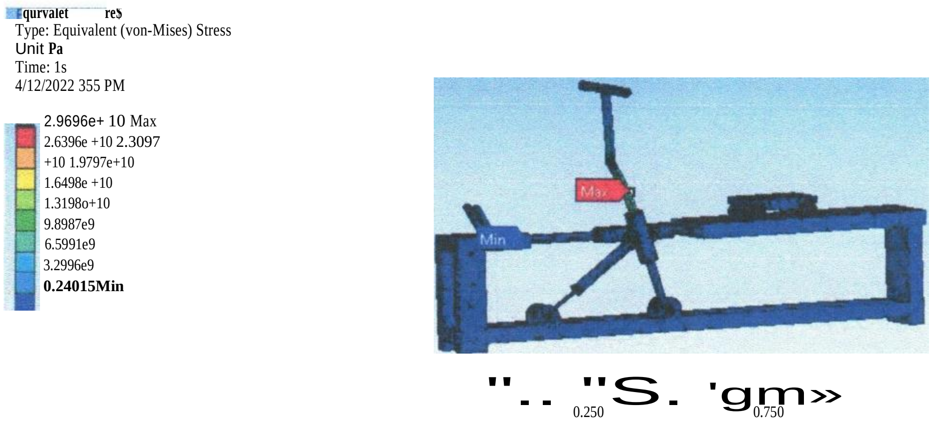

Figure 5.2: Von-Mises Stress

The-motion ana.J.ysi-s of the-end effector is carried out using MSC Adams/ View and the simulation graphs for the position, velocity, and acceleration are shown in Fig.5.2. The maximum and minimum positions of the end effector are 1656.0277mm and 1577.9651mm respectively while the maximum velocity is 160.986mm/s and the maximum acceleration is 717.458mm / s^2•

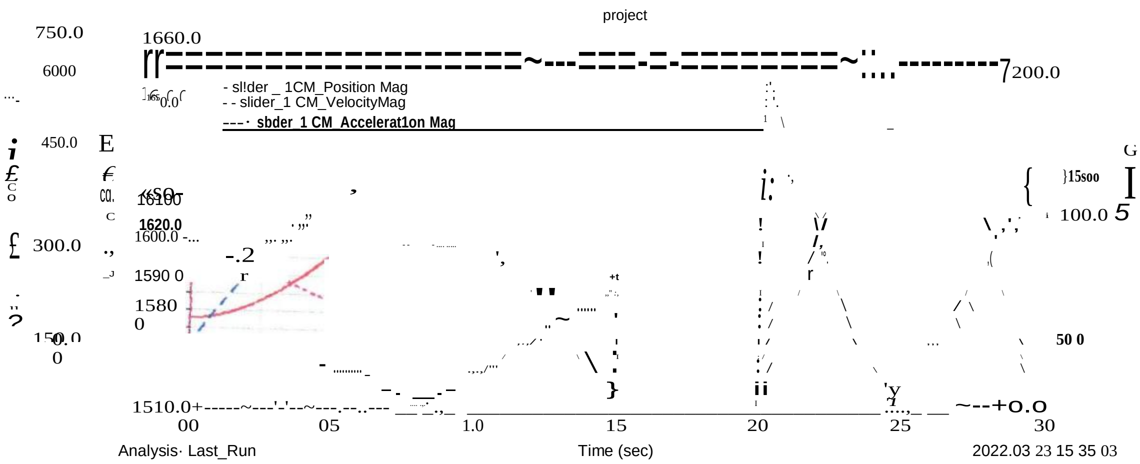

Figure 5.3: Simulation graphs of the position, velocity and acceleration of the end effector

Furthermore, the Adams simulation graphs of the joint torques r_1 and t, of the links l_1 and *l* are illustrated in Fig 5.3. The maximum and minimum torque of joint torque r_1 of link the l, are 456. 8097 N-mm and 179. 8721 N-mm respectively. The maximum and minimum torq_ue of joint torque t, of link the *[*$_2$ are 437.5732 N-mm and 302 · 7931 N-mm respectively.

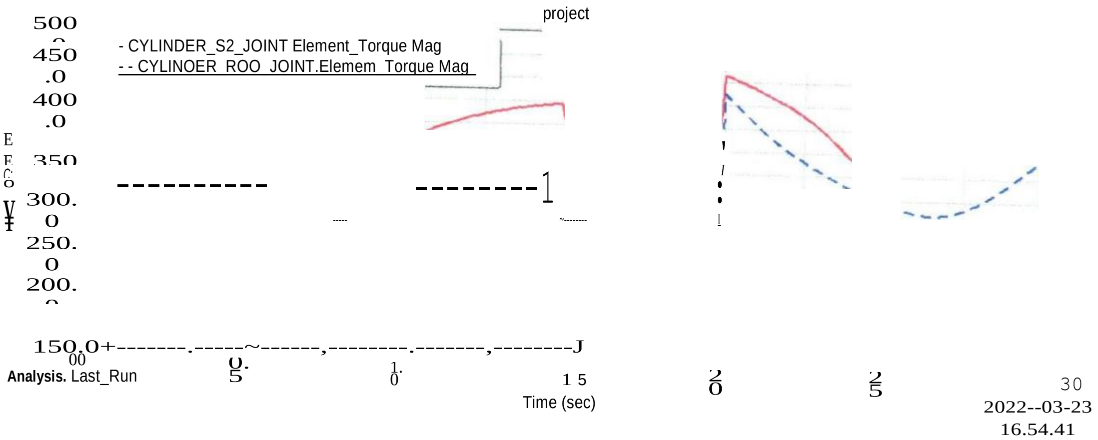

Figure 5. 4: Simulation graphs of the Joint torques

CONCLUSION AND FUTURE WORK

6.1 Conclusion

A design of an ergonomically safe Rowing Machine that uses a 2 DOF slider-crank for safe and full-body exercising is introduced. Force analysis, as well as motion analysis of the proposed Rowing Machine, is carried out. The FEA results confirm that the proposed is safe in terms of deformation.

6.2 Future work

Prototype fabrication of the ergonomically safe rowing Machine is the future extension of this work.

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